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ASME HANDBOOK

Metals Properties

ASME HANDBOOK

Metals Properties

Engineering Tables

Metals Engineering—Design

Metals Engineering—Processes

A S M E   H A N D B O O K

Metals Properties

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Sponsored by

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ASME Handbook

METALS PROPERTIES

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FOREWORD

The ASME Handbook of Metals Properties is one of the many services of the Society. It came into being as a result of a survey in 1941 by the Metals Engineering Division which revealed the need of the mechanical engineer and designer for a ready reference to the properties and characteristics of metals A preliminary study was instituted, and as a result, in August, 1945, the Executive Committee of the Council authorized the publication of a Metals Engineering Handbook and appointed a Handbook Board. This Board was set up as a continuing body, the members to be selected upon the recommendation of the Metals Engineering Division with the approval of the standing Committee on Professional Divisions and the concurrence of the Publications Committee. The personnel of the Board has changed from time to time.

The Society is grateful to the members of the Board and to the many others who have made valuable contributions to the text of the Handbook.

The Society is particularly happy to recognize the active cooperation of the American Society for Metals, which has permanent representation on the Board through a nominee of its own choice.

FREDERICK S. BLACKALL, JR., *President*, 1953
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

This Handbook has been prepared to fill the urgent need for a reference manual related to the design engineer's point of view. A wealth of information of direct interest to him has been compiled from many authentic sources and is presented in a form which, it is hoped, will prove most useful to the experienced engineer and the embryo designer alike

This volume tabulates the *properties of metals* about which a design engineer needs information. A volume has already been published dealing primarily with the *design* function in metals engineering. Another volume, in preparation, deals with the *processes* by which metals are converted to finished product. A fourth volume, also in preparation, collects in one place many *engineering tables* to supplement the designer's knowledge of standards for shape, dimension, gears, and the like.

The Advisory Committee, consisting of Messrs. H. B. Lewis, O J. Horger, C. L. Tutt, Jr., and J. F Young, has reviewed under the Board's direction matters relating to content, quality, format, and courses of action on the Handbook, and has reported findings and recommendations to the Board The work of this committee will continue as it will have the responsibility of recommending to the Board necessary revisions to keep this Handbook abreast of the ever-changing need for current design data.

Contributions have been made by members of The American Society of Mechanical Engineers and other societies. Industrial organizations have been most generous in furnishing data and in permitting the use of material already in print. In each case, proper recognition is given to these sources.

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PREFACE

PURPOSE. This Handbook is the direct outgrowth of a survey conducted in 1941 by the Metals Engineering Division. Disclosure that a need for it existed was somewhat startling because of the many reference books already available, and the excellent coverage of some of them. The survey explained, however, that other references were not written for the design engineer nor exclusively from his viewpoint, and that the existing handbooks did not contain the scope of metals engineering information needed by the design engineer. In practice he looked through many references to find related information on a single material, if, indeed, that information were available at all. This Handbook has been written to satisfy that need, to compile in one place engineering data on metallurgical, physical, fabrication, and mechanical properties of typical metals.

SCOPE. A word of caution, however, is in order at the outset. The design engineer is accustomed to using specification values of the properties with which he is concerned, since it is on such values that the engineer purchases material and supplies a product, usually under contract For these, he should refer to the applicable specification, and not to this volume. There are several reasons for this. First, specifications are continually being revised and the engineer would want to use the one that is currently in effect Second, this volume is not intended to be a collection of specifications and was not so designed. Third, while specification values are limiting values, or maximum or minimum values for acceptance, the values included are either actual test values for a single specimen or average values obtained in production practice.

Specifications by no means give all the data on a material that the engineer needs. It has therefore been the aim of the present volume to furnish comprehensive data with comments necessary to characterize the material and typify its uses for the guidance of the designer.

The data presented are organized according to the following plan:

1. Metals of like kind are grouped together. An ascending numerical sequence of designation is followed, with occasional exceptions necessitated by publication limitations.
2. All data for each metal are reproduced under the designation for that metal.
3. Metals have been identified, in most instances, by the designation commonly used by the fabricating industries. A cross index is provided for further identification by other systems.
4. A skeleton format has been employed to obtain continuity in presentation.
5. Properties reported cover sizes, forms, and conditions (cold work, heat-treatments, etc.) in which the metal is usually used. This has resulted in omissions from the skeleton format where specific data were not of importance to the typical applications for the metal.
6. The English system of units has been employed except where metric units are conventional, or where conversion would bias interpretation of data from the published source.

This plan was adopted with the hope that it would (1) facilitate reference, (2) aid the user to write in new information of special interest as it becomes available, and (3) provide research groups and suppliers some indication of omissions in available data.

CHOICE OF DATA. The constant change in the field of engineering materials can result in the inclusion of some items that will become less significant. Recent and future developments will be covered in revisions of this volume.

The large number of metallic engineering materials has created a selection problem that was met with arbitrary decisions. An outstanding example is that of the steels. While a large number are represented in this volume, they constitute only a minor fraction of the steels produced or even of those covered by the American Iron and Steel Institute. The same is true in the selection of typical nonferrous alloys. The necessary data for a material which is not included can often be approximated by interpolating between two close materials.

PROPERTY VALUES. The ideal way to present the values of the properties would be by scatter bands, by distribution curves, or by indicating the standard statistical deviation for an average value. It cannot be correctly said that the tensile strength of a certain steel at a certain size, heat-treated in a certain way, always has a singular value. Variations in composition, structure, and manufacturing practice produce corresponding variations in the properties obtained with a given material—made, let us say, to meet a commercial specification. A figure might be given for the most probable value and the expected variation above and below that value. With these facts, a reasonable minimum value could be approximated below which the property may seldom be expected to fall. The latter is the procedure of specification-writing bodies after they have sufficient evidence on which to base a finding. Unhappily the ideal is seldom achieved, though there is a trend in that direction.

The data presented in this Handbook come in one or the other of two categories. They are either average values representative of good practice or actual test values on single individual specimens. A typical case of reporting average values is that of the "physical property charts" of the SAE (Society of Automotive Engineers) steels. They give what is expected, on the average, for the middle of the range of composition. They offer a good compromise, since a producer will not care to cite minimum values that would stamp his steels as of inferior quality; and he will not care to cite the very best values, for, in that case, the user would experience too many cases of failing to get the published values. With this as a guide, the engineer should be able to determine the properties he can rely upon and the metallurgist should be able to decide on compositions and treatments to produce those properties.

UTILIZATION OF DATA. Where average expected values are not available, actual values are given, along with specific compositions and treatments. If another heat of metal of *exactly* the same composition were made, treated, and tested in the same way, the properties would be the same, within the experimental error of determination. In practice, conditions cannot be precisely reproduced, and successive lots of metal will vary by somewhat more than the error of testing variations. The actual variation will represent the summation of the effects of all the variables on the property. This indicates the significance to be attached to the properties of the individual metal, at least of that metal as a representative of a type or class. This cannot be expressed quantitatively unless the distribution curve for that type or class of metal is known. That is seldom the case in published or tabulated data; therefore, reasonable latitude, based on good experience and sound judgment, must be allowed in interpreting and using such data. It should also be clear that such data on individual metals or alloys are not proper for use in specifications.

The data selected for inclusion represent, in so far as I am able to judge, good data. Much of them I have been able to check against more than one reliable source, or to select from sources that are held to be reliable. Even so, there may be some inconsistencies, inherent in the subject matter. A good example is the high-temperature properties and behavior of the heat-resistant alloys. A few of these alloys have been quite well investigated, but others cannot yet be described adequately. In instances where the data seemed to call for such a procedure, I have not hesitated to include several sources.

PHYSICAL PROPERTIES. Data on the various physical properties of the pure metals are relatively accurate in determination and simple to use. Reasonably high purity of the test samples is usually guaranteed; and most investigators know that the metal must be soft-annealed to avoid vitiating the determinations by extraneous effects of cold work and its accompanying structural characteristics. While physical measurements always involve an "error," or uncertainty, the results are usually quite accurate with respect to purity, structure, and measurement. Within the experimental error there is little likelihood that most of the data are far wrong, and accordingly, there is little likelihood of making improper use of such data.

MECHANICAL PROPERTIES. Data on many mechanical properties of commercial metals and alloys require somewhat different treatment and interpretation. These are the data subject to the significant variations as described previously. Data for the heat-treating steels call for special comment. Until recently the carbon and alloy steels (SAE steels) have been treated largely on an individual basis, and indeed, they do have individual characteristics. But it is now clear that steels, almost regardless of composition and alloying elements, have surprisingly uniform tensile properties at the same hardness level, provided they are "fully hardened" when quenched.

The magnitude of the effect of producing an incompletely hardened condition by quenching is due principally to the "mass effect," and is shown by data on the mass effect of certain steels that appear in many of the tables of properties on wrought steels. This effect is also brought out by the inclusion of end-quench hardenability test data. Such data show the relative depths to which various carbon and alloy steels harden and at about what depths the incompletely hardened structures begin. They also show that little or no alloy is needed to harden small sections to produce optimum properties, but as the section size increases, the need for "hardening" elements increases to produce similar results. These generalizations were developed at a recent date but have been found to be a guide for the selection of steel compositions and treatments. Now that this information is available, it should be applied when using or interpreting data on the properties of heat-treated steels, at least for the ordinary tensile properties.

For data covering properties other than the simple static and tensile properties, the situation changes for all types of metals and alloys. This group includes such properties as notch toughness, notch fatigue, impact behavior or high-velocity loadings, fatigue, corrosion fatigue, low-temperature properties, high-temperature properties, corrosion, magnetic properties, and damping. These are controlled by composition, manufacturing variables, treatment, and structure. In so far as was possible, data have been included on these points but no correlations have appeared here except a few generalizations. Notch-toughness and creep properties have been studied elsewhere in some detail and a fair amount of information is available. Considerable discussion of the significance of these properties will be found in Parts I and II of the companion volume, "Metals Engineering—Design."

It is hoped that the data of this volume, or similar data in any book, will be used or applied with these qualifications clearly in mind. Until unequivocal metal data are available, the exercise of understanding and judgment is vital to the successful use of such data.

ACKNOWLEDGMENTS. The compilation of the material for the Properties and Data Section has been partly a task done at Battelle Memorial Institute and partly a labor of love. The editor wishes to express his appreciation for the excellent support furnished him by his company and for the assistance and encouragement given by the members of the Metals Engineering Handbook Board. One of their functions was to secure informed criticism of the treatment and coverage of many of the subdivisions. Those reviews were competent and thorough and I feel that the value of the data has been substantially increased by this backstage work Work on the manuscript was no sinecure for the office staff, and I want to thank them for the care and attention they have given to the proper handling of the many processing details. My special thanks are due to Mrs. Gene M. Weeks, for it was the happy way in which she combined skill with persistence that the original manuscript was converted into the uniform and readable pages of the final product. That was no simple task.

From past experience in compiling data in large numbers, it is practically certain that errors will be present, in spite of checking and rechecking So that steps can be taken to correct them in future editions, it will be appreciated if errors are called to the attention of Miss Jean Meyer, Secretary to the ASME Metals Engineering Handbook Board, 29 West 39th Street, New York 18, N.Y.

SAMUEL L. HOYT

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FERROUS

AISI STEELS

Steels, AISI

NON-FERROUS

COPPER AND COPPER BASE ALLOYS

Copper Alloys, Wrought

Copper Alloys, Cast

Wrought Iron

Chemical Composition[1]

	C %	Mn %	Si %	P %	S %	Slag %
Byers No. 1 Iron	.08	.015	.158	.062	.010	1.20
Mechanical Iron	.08	.029	.183	.115	.015	2.85
Hand puddled Iron	.06	.045	.101	.068	.009	1.97
Typical analysis, total	.02	.03	.15	.12	.02	3.0
Typical analysis, in metal	.02	.01	.01	.10	.02	–
Typical analysis, in slag	–	.02	.14	.02	–	–

[1]Several typical analyses are given of wrought iron

Physical Properties[1]
Density 0.28 lb/cu in. (7.7 S.G.)
[1]ASM Metals Handbook

Coef. of Thermal Expansion

Temp Range	
18-100C	$11.40 \times 10^{-6}/°C$
64-212F	$6.35 \times 10^{-6}/°F$

Characteristics. When properly made and inspected, wrought iron is a reliable, low strength, ferrous material which resists corrosive attack under normal atmospheric conditions and at moderately elevated temperatures. It is popular for chains because it is resistant to bruising and can be readily reconditioned by annealing. It loses useful strength and becomes notch brittle at low temperatures.

Commercial Forms. Pipe, plate, bars, shapes, sheet – coated and uncoated, rivets, staybolts, chain.

Thermal Conductivity[1]

Temp Range Deg C	Temp Range Deg F	$Cal/cm^2/cm/°C$	$Btu/ft^2/sec/in/°F$
100	212	0.141	0.114
200	392	0.129	0.104
300	572	0.120	0.097
400	752	0.108	0.087
500	932	0.098	0.079

[1]Bureau of Standards. Composition 04C, .046Mn, .265Si, 136P, 025S

Technological Properties
Machinability. Wrought iron in the cold drawn condition at 101-131 BHN is rated at 50% of the standard cold drawn B1112 steel.

Mechanical Properties[4]

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 8" %	Red Area %	Hard BHN	End Limit R B M psi	End Limit Axial M psi	NBT[2] Ft Lbs
Longitudinal test	46.9	–	–	–	105	23[1]	16	17.5
Transverse test	34.4	–	–	–	105	19[1]	11	4.8
Minimum ASTM Requirements								
Pipe, ASTM, A72-33	40	24	12	–	–	–	–	–
Plate, Longitudinal, ASTM, A42-37T	48	27	14	–	–	–	–	–
Shapes, bars ASTM, A207-38T								
Under $1\frac{5}{8}$ in.	48	.60TS	25	40	–	–	–	–
$1\frac{5}{8}$–$2\frac{1}{2}$ in. excl.	47	.55TS	22	35	–	–	–	–
$2\frac{1}{2}$ in. and over	46	.50TS	20	30	–	–	–	–
Bars, single refined, ASTM, A189-37T								
Under $1\frac{5}{8}$ in.	48	.60TS	25	40	–	–	–	–
$1\frac{5}{8}$–$2\frac{1}{2}$ in. excl.	47	.55TS	22	35	–	–	–	–
$2\frac{1}{2}$ in. and over	46	.50TS	20	30	–	–	–	–
Bars, double refined, ASTM, A189-37T								
Under $1\frac{5}{8}$ in.	48-54	.60TS	28	45	–	–	–	–
$1\frac{5}{8}$–$2\frac{1}{2}$ in. excl.	47-54	.55TS	25	40	–	–	–	–
$2\frac{1}{2}$ in. and over	46-54	.50TS	22	35	–	–	–	–
Rivets, ASTM, A152-37T								
$\frac{1}{4}$ – $\frac{7}{16}$ in. incl.	47	.60TS	22	–	–	–	–	–
Over $\frac{7}{16}$ – $\frac{3}{4}$ in. incl.	47	.60TS	24	–	–	–	–	–
Over $\frac{3}{4}$ – 2 in. incl.	47	.60TS	28	–	–	–	–	–
Staybolts, ASTM, A84-36	47-52	.60TS	30	48	–	–	–	–
Blooms ASTM, A73-36	45	.50TS	22[3]	30	–	–	–	–
Forgings ASTM, A73-36	45	.50TS	24[3]	33	–	–	–	–

[1]Rotating Beam
[2]Charpy test with keyhole notch. Typical Izod values for the Vee notch test specimen run from 45-60 Ft Lbs. These values drop off materially at low temperatures.
[3]4 in.
[4]ASM Metals Handbook.

IRON

Wrought Iron Chains

Chemical Composition

C <.06% Mn <.06%

Characteristics. Values given are for forge welded wrought iron chains. Values for a 3.5% Ni wrought iron are included for comparison.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 8" %	Red Area %
Typical properties[1]	47	28	25	40
Range	42-52	26-35	25-40	40-55
3.5% Ni	55-60	45-60	25-30	35-45
Elevated temp properties (See Fig 1, p 504, Met. Hnbk.)				

[1]Treatment – Chains are annealed at 1350-1375F to remove the work hardened layer and restore the initial ductility. The chains may be air cooled. At 32F the useful strength falls to 50% and at -4F to 20% of that at 70F.

Pure Iron

ADDITIONAL MECHANICAL PROPERTIES

Compression Properties[1]
Compressive strength of annealed ingot iron

Elastic limit	19,400 psi
Proportional limit	19,200 psi
Yield strength	20,600 psi

[1]Data from P. W. Bridgman

Mean compressability at 30C, up to 10M kg/cm² = 0.566×10^{-6} kg/cm²
Mean compressability at 75C, up to 10M kg/cm² = 0.572×10^{-6} kg/cm²
Pressure coefficient up to 10M kg/cm² = 7.0×10^{-6}/kg/cm²
Temperature coefficient between 30 and 75C = 2.3×10^{-4}/°C

Creep Strength. Data from Tapsell and Clenshaw, see Fig. 22, p 433 Met. Hdbk.

Hardness at Elevated Temperatures
Values obtained by Tapsell and Clenshaw by both static and impact methods are reproduced in Fig. 23, p 433 Met Hdbk. For effect of cold work on hardness, strength and ductility of ingot iron, see Figs 2 and 4, p 437.

Torsional Properties

Torsional PL, hot rolled ingot iron	12-15M psi
Torsional YS, hot rolled ingot iron	14-23M psi

Torsional Modulus.
Values for the torsional or shear modulus have been determined as follows:

Ingot iron	11.77×10^6 psi 11.78×10^6 psi
Electrolytic iron	11.45×10^6 psi 11.81×10^6 psi 11.66×10^6 psi

Fatigue Strength

				End Limit M psi
Ingot iron	annealed, reversed bending			26
	quenched, reversed bending			33[1]
	annealed, axial bending			26.7
	annealed, reversed torsion			12.8
		Temp Range Deg C	Deg F	
Axial loading between equal tensile and compressive stresses, 10^7 cycles, 2400 cycles per min. Tests on Haigh pulsating testing machine.		16	60	26.7
		100	212	24
		200	392	25.5
		300	572	33.4
		400	752	28.9
		500	932	12.3

[1]Water quenched from 1500F.

Poisson's Ratio
Values for Poisson's Ratio have been given from 0.25 to 0.33 but is usually taken as 0.28.

Low Temperature or Notch Brittleness
Test results of Epstein on ingot iron and other low carbon materials are reproduced in Fig. 5, p 440. The non-aging steel shows less effects of cold compression and low temperatures.

Aging and Mechanical Properties
Aging cold worked iron at room temp or at moderately elevated temp results in increased strength. For data on this effect, see Steel C1008.

Mechanical Properties (ASM Metals Handbook)

Form or Condition	Test Temp Deg C	Test Temp Deg F	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Red Area %	Hard BHN	Mod. of Elast. 10⁶ psi[4]	Mod. of Rupt. M psi[6]	Mod of Rigid. 10⁶ psi[6]	Angle of Twist[6 7]
Ingot iron											
Hot rolled rods and plates	–	–	42-48	26-32	22-28[1]	65-78	82-100	–	–	–	–
Rolled, finished hot	–	–	42.2	19.1	44.7	77.3	90	–	–	–	–
Rolled, finished cold	–	–	43.8	26.9	41.8	75.6	101	–	–	–	–
Rolled, ann. 24hr at 1650F	–	–	41	18.3	47	70.6	82	–	–	–	–
Rolled, WQ, 1725F	–	–	47	30.3	36.2	70.0	110	–	–	–	–
Cold rolled	–	–	100	–	–	65-70	220	–	–	–	–
Electrolytic											
As deposited	–	–	55-113.5	–	25-30	–	140-350	–	–	–	–
Fused and annealed	–	–	35-40	10-20	40-60[2]	70-90	45-90	–	–	–	–
Carbonyl	–	–	28-40	15-24	30-40[3]	70-80	–	–	–	–	–
Nat'l. Bur. of Stds.	–	–	28-30	6-8	36-46	>90	50	–	–	–	–
Effect of Temp[5]											
	16	60	49.5	–	45	69	–	29.8	63.2	11.6	778
	100	212	57.8	–	27	61.5	–	29.25	66.1	11.5	632
	150	302	59.8	–	26.5	60	–	28.4	70.3	11.4	628
	200	392	65.6	–	26.5	54	–	27.8	68.3	11.2	479
	250	482	64.7	–	30.0	54	–	27.2	68.3	11.1	447
	300	572	62.5	–	38.5	56	–	26.5	69	11.0	406
	350	662	56.7	–	44.5	61	–	25.8	65.9	10.7	297
	400	752	44.8	–	51	67.5	–	25.0	51.7	10.5	335
	450	842	37	–	51	67.5	–	24.0	41	10.3	326
	500	932	27.1	–	49	63.5	–	(23.0)	25.1	–	249
	600	1112	15.2	–	34	49.5	–	–	15	–	285
	700	1292	9.2	–	53.5	55.5	–	–	–	–	–
		70[8]	45.7	–	27.9	73.2	–	–	–	–	–
		-4[8]	53.8	30.7	42	75	–	–	–	–	–
		-58[8]	59.4	42.2	43	74	–	–	–	–	–
		-94[8]	61.7	43.4	37.5	72	–	–	–	–	–
		-148[8]	66.8	57.2	26.5	70	–	–	–	–	–
		-184[8]	77	66.7	17	68	–	–	–	–	–
		-292[8]	112	–	0	0	–	–	–	–	–

[1]On 8 in.
[2]On 1.5 in.
[3]Gage length = 10 × diameter
[4]The modulus, E, for polycrystaline iron is usual accepted as 30,000M psi but reported values vary from 27.2 to 30.6×10^6 psi. For the single crystal, E varies considerably or from E parallel to the (100) direction = 19×10^6 psi to E parallel to the (111) direction = 41×10^6 psi.
[5]The values obtained at elevated temperatures are materially affected by the test conditions, especially the speed of loading. The values from 16-700C are from Tapsell and Clenshaw and are for normalized ingot iron. The test bars were ½ in. × 2 in. and the elapsed time to reach the PL was 20 min. The increase in TS is held to be due to the presence of impurity elements, rather than to the iron proper, and can be materially modified by the addition of "stabilizing" elements such as Al, Ti or Zr.
[6]Test time· 20 min to the PL and to fracture.
[7]Deg/in. length
[8]Ingot iron, as rolled. Source: E. W. Colbeck, W. E. MacGillivray and X. X. Manning, Trans. Inst. Chem. Eng. (London), 1933. For additional data on ingot iron, by Lee, see Fig. 21, p 433 Met. Hdbk.

(Continued on page 4)

Pure Iron

(Continued from page 3)

Specific Heat. See Fig 4, p 424, Met. Hdbk.

Density[1]

	lb/cu in	S.G
Ingot iron	0.2842	7.866
Carbonyl iron	0.2840	7.860
Electrolytic iron	0.2845	7.874
Bur. of Stds. iron	0.2845	7.874
Calculated X-ray[2]	0.2842	7.865

[1]ASM Metals Handbook
[2]This value is calculated from a good value of the lattice parameter and the weight of an atom of iron.

Note: For effect of cold work see Fig 3, p 424 Met. Hdbk.

Chemical Composition[5]

	C %	Mn %	P %	S %	Si %	Cu %	Ni %	O_2 %	N_2 %
Ingot iron	<.020	<.020	.005 ±	.020 ±	tr	.04 ±	–	present	.004 ±
Electrolytic	.006	–	.005	.004	.005	–	–	present	–
Carbonyl	.0004±	–[1]	–[1]	–[1]	–[1]	–[1]	–[1]	<.01	–
Bur. Standards	<.001	–[2]	<.0005	.002	.002	<.002	–[2]	.003	.0002
H_2 purified[3]	.005	.028	.004	.003	.001	–	–	.003	.0001
Westinghouse[4]	<.005	<.003	<.003	<.005	<.01	<.001	–	<.01	<.004

[1]Unable to identify, also Cr, Co, Mo and Zn
[2]Unable to identify, also Ag, As, Au, B, Ba, Bi, Ca, Cb, Cd, Ce, Co, Cr, Ga, Ge, Hf, Hg, In, Ir, K, Li, Mg, Mn, Mo, Na, Ni, Os, Pb, Pd, Pt, Rh, Ru, Sb, Sc, Sn, Sr, Ta, Th, Ti, Tl, U, V, W, Y, Zn, Zr Total impurities <0 010% See Research Paper, RP 1472, Ntl Bur. Stds, May 1942
[3]Total impurities 0 024%
[4]Zn<.002%, Mo< 001%, Pb< 0004%, Sn< 0002%, others < 0001%, Fe=99 99%
[5]Commercial Grades

Characteristics. Pure iron is relatively soft and ductile and is strongly magnetic. It rusts and corrodes easily, and dissolves many elements and impurities rather easily.

Typical Uses. Ingot iron is used as sheet, plain and galvanized, for good resistance to corrosion in inside and outside applications, for deep drawn parts, enamelling stock, for third rails, etc. Iron powder is used for magnetic cores and in the pressed and sintered state for iron parts. Westinghouse iron is used as a spectroscopic standard.

Commercial Forms. Ingot iron is the only pure iron that is made on a tonnage basis. It is produced as sheet, strip, wire, galvanized sheet, rail sections for good conductivity, etc. Electrolytic iron is produced as cathodes for remelting or use in powder form. Carbonyl and hydrogen reduced and purified iron are powders for use in powder metallurgy. Other forms are for experimental work.

Technological Properties

Relative Machinability—The ASM machinability rating of ingot iron, cold drawn to 101-131 BHN, is 50% of the B1112 standard.

Thermal Conductivity[1]

The thermal conductivity of iron decreases with rise in temperature though, upon transforming into the gamma phase at A_3, it appears to increase. Data for ingot iron are shown in Fig 5, p 425 Met. Hdbk.

[1]ASM Metals Handbook, data from Cleaves and Thompson

Coef. of Thermal Expansion[4]

Temp Range Deg C	Deg F	Coefficient[3] per Deg C[1]	per Deg C[2]	Coefficient[3] per Deg F[1]	per Deg F[2]
-100	-148	–	9.1×10^{-6}	–	5.1×10^{-6}
-50	-58	–	10.5×10^{-6}	–	5.8×10^{-6}
0	32	–	11.5×10^{-6}	–	6.4×10^{-6}
20	68	–	11.7×10^{-6}	–	6.5×10^{-6}
100	212	12.6×10^{-6}	12.7×10^{-6}	7.0×10^{-6}	7.0×10^{-6}
200	392	13.8×10^{-6}	13.9×10^{-6}	7.6×10^{-6}	7.7×10^{-6}
300	572	14.6×10^{-6}	15.0×10^{-6}	8.1×10^{-6}	8.3×10^{-6}
400	752	16.6×10^{-6}	15.9×10^{-6}	8.8×10^{-6}	8.8×10^{-6}
500	932	16.8×10^{-6}	16.2×10^{-6}	9.3×10^{-6}	9.0×10^{-6}
600	1112	16.0×10^{-6}	16.0×10^{-6}	8.9×10^{-6}	8.9×10^{-6}

[1]Data by Austin and Pierce.
[2]Data by Hidnert on National Bureau of Standards iron
[3]Increase in length in parts per million at the indicated temp for a change in temp of 1°C. The coefficient for 1°F is 5/9 of the values given. Experimental difficulties make determinations above 600C uncertain, though it is known that gamma iron has a larger coefficient than alpha iron.
[4]ASM Metals Handbook

Electrical Resistivity[1]

	Temp Range Deg C	Deg F	
Bur. of Stds.	20	68	9.71 microhm/cm[3]
Temp Coef.	0	32	0.00651 ohm/ohm/°C

Note: Coldwork increases the resistivity of iron by a few per cent depending on the amount. Annealing the cold worked metal restores the original value. The effects of both cold work and annealing are shown in Fig 8, p 428 Met Hdbk. Electrical resistance at high and at low temp is shown in Fig 7, p 425.

[1]ASM Metals Handbook, data by Tammann and Moritz

Magnetic Properties[1]

Yensen gives the following values for ingot iron. Corresponding values are given for the 4% Si iron for comparison.

	Initial Permeability	Maximum Permeability	Hysteresis[2]	Residual Induction gausses	Coercive Force oersteds	Saturation gausses[3]	Resistivity micr-cm
Ingot iron	250	7,000	5,000	13,000	1.0	21,600	11
4% Si iron	600	6,000	3,500	12,000	0.5	20,000	50

[1]ASM Metals Handbook. See also Figs 9 thru 19, pp 429-31.
[2]Loss in ergs per cu cm per cycle for the saturation value of the flux density.
[3]Saturation value of the intrinsic induction.

Heats of Transformation and Fusion[1]

	Cal/gm	
At A_2	zero	
At A_3	4.9	Calculated by Ralston
At A_4	1.7	Calculated by Ralston
At M.P.	65	As heat of fusion. Ralston

[1]ASM Metals Handbook

Critical Points or Transformation Temperatures[4]

	On Heating	On Cooling
A_1	(not present)	(not present)
A_2 Curie point[1]	Ac_2 = 1414F	Ar_2 = 1414F
A_3[2]	Ac_3 = 1670F ($\alpha = \gamma$)	Ar_3 = 1659F ($\gamma = \alpha$)
A_4[3]	Ac_4 = – ($\gamma = \delta$)	Ar_4 = 2530±9F ($\delta = \gamma$)

[1]Magnetic iron loses its strong magnetism above A_2, the Curie point
[2]At A_3 iron changes from body centered cubic α iron to face centered cubic γ iron
[3]At A_4 γ iron changes to δ iron, which is body centered cubic.
[4]ASM Metals Handbook.

IRON GRAY, CAST

Class 20
MEDIUM SECTIONS

Chemical Composition [1] – Typical

Total C %	Graphitic C %	Combined C %	Si %	Mn %
3.50	2.90	0.60	2.25	0.50

P %	S %	Alloys %	C Equivalent [2] %
0.40	0.10	not used	4.3

[1] Irons of this class are commonly supplied with different analyses depending on the application. Compositions are not usually specified.
[2] CE = % Total C + 0.3 (% Si + % P)

Characteristics: A soft grade of gray iron, commonly melted in the cupola. It has very good fluidity and castability and is very easily machinable. It is particularly valuable in medium and thin-sectioned castings, and generally advisable where only moderate strength is required and it is desirable to avoid high casting stresses even in complicated sections.

Uses: Typical castings – machine bases, ornamental castings, grates, housings, frames, manhole covers, andirons, traffic signs, etc.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Imp S ft lb	Hard BHN	Shear S M psi	End Lt M psi
Cast 1.2 in. diam	0.51-1.00	1.2	20 min.	—	—	—	—	—	—	—
Typical	—	—	20 [1]	2 [2]	.25	53	55 [4]	180	32 [3]	10
Typical Range	—	—	20-24 [1]	—	—	—	—	—	—	—

	Comp S M psi	Mod of Elast E M psi	Trans Resil in. lb
Typical	95	12,000 [5]	350
Typical Range	80-105	—	—

[1] 0.750 in. diam machined from test bar (2)
[2] 1.2 in. diam. × 18 in. between supports
[3] 0.505 in. diam
[4] Charpy test bar 1.20 diam × 18 in. supports
[5] At ¼ transverse load

IRON GRAY, CAST

Class 20
LIGHT SECTIONS

Chemical Composition [1]

	Total C %	Graphitic C %	Combined C %	Si %	Mn %
Typical	3.50	–	–	2.25	0.50
Typical Range	3.40-3.60	–	–	1.75-2.50	0.40-0.60

	P %	S %	Alloys %	C Equivalent [2] %
Typical	0.40	0.10	not used	4.3
Typical Range	0.30-0.90	0.07-0.14	–	–

[1] Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2] CE = % Total C + 0.3 (% Si + % P)

Uses: Sanitary ware, cooking utensils, mail boxes, piston rings and similar thin-walled castings. Also – See Class 20, Medium Sections.[1]

[1] Typical castings – machine bases, ornamental castings, grates, housings, frames, manhole covers, andirons, traffic signs, etc.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Hard BHN	Comp S M psi	Mod of Elast E M psi	Trans Resil in. lb
Cast 1.2 in. diam	≦.50	0.875	20 min.	—	—	—	—	—	—	—
Typical	—	—	27 [1]	1 [2]	0.14	50	200	100	13,000 [3]	100
Typical Range	—	—	24-29 [1]	.8-1.2 [2]	0.13-0.17	43-56	180-220	95-130	—	—

[1] .505 in. diam machined from test bar (2)
[2] .875 in. diam × 12 in. between supports
[3] At ¼ transverse load

IRON GRAY, CAST

Class 20
HEAVY SECTIONS

Chemical Composition[1]

	Total C %	Graphitic C %	Combined C %	Si %	Mn %
Typical	3.50	–	–	2.25	0.50
Typical Range	3.30-3.60	–	–	2.20-2.40	0.40-0.60

	P %	S %	Alloys %	C Equivalent[2] %
Typical	0.40	0.10	not used	4.3
Typical Range	0.30-0.60	0.07-0.14	–	–

[1]Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2]CE = % Total C + 0.3 (% Si + % P)

Uses: Certain types of pipe, fittings, castings resistant to thermal shock, heavy machine bases, bed plates, weights etc. Also, see Class 20, Medium Sections.[1]

[1]Typical castings – machine bases, ornamental castings, grates, housings, frames, manhole covers, andirons, traffic signs, etc.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Hard BHN	Comp S M psi	Mod of Elast E M psi	Trans Resil M psi
Cast 1.2 in. diam	1.01-2.00	2.0	20 min.	–	–	–	–	–	–	–
Typical	–	–	16[1]	5.2[2]	0.25	40	170	90	9,000[3]	750
Typical Range	–	–	15-19[1]	4.5-5.5[2]	0.24-0.30	35-45	155-180	–	–	–

[1]1.25 in. diam machined from test bar (2)
[2]2.0 in. diam X 24 in. between supports
[3]At ¼ transverse load

IRON GRAY, CAST

Class 25
MEDIUM SECTIONS

Chemical Composition[1] **– Typical**

Total C %	Graphitic C %	Combined C %	Si %	Mn %
3.40	–	–	2.20	0.50

P %	S %	Alloys %	C Equivalent[2] %
0.30	0.10	not used	4.15

[1]Irons of this class are commonly supplied with different analyses depending on the application. Compositions are usually specified.
[2]CE = % Total C +0.3 (% Si +% P)

Uses. Use similar to Class 20 when higher strength required.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Imp S ft lb	Hard BHN	Shear S M psi
Cast 1.2 in. diam	0.51-1.00	1.2	25 min.	–	–	–	–	–	–
Typical	–	–	27.5[1]	2.1[2]	0.27	55.7	55[3]	190	37
Typical Range	–	–	25-30[1]	1.7-2.5[2]	0.25-0.35	45-65	–	175-210	32-45

	End Lt M psi	Comp S M psi	Mod of Elast E M psi	Trans Resil in. lb
Typical	12.5	100	13,000[4]	400
Typical Range	12-15	95-110	–	300-500

[1]0.750 in. diam machined from test bar (2)
[2]1.2 in. X 18 in. supports
[3]1.20 in. diam X 18 in. supports
[4]At ¼ transverse load

IRON GRAY, CAST

Class 25
LIGHT SECTIONS

Chemical Composition[1]

	Total C %	Graphitic C %	Combined C %	Si %	Mn %
Typical	3.40	–	–	2.20	0.50
Typical Range	3.25-3.55	–	–	2.00-2.40	0.40-0.75

	P %	S %	Alloys %	C Equivalent[2] %
Typical	0.30	0.10	not used	4.15
Typical Range	0.15-0.50	0.07-0.14	–	–

[1]Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2]CE = % Total C + 0.3 (% Si + % P)

Uses: Use similar to Class 20 when higher strength required.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Hard BHN	Mod of Elast E M psi	Trans Resil in. lb
Cast 1.2 in. diam	0.50	0.875	25 min.	–	–	–	–	–	–
Typical	–	–	31.5[1]	1.25[2]	0.17	57	205	14.000[3]	150
Typical Range	–	–	27-33[1]	.8-1.5[2]	–	52-65	190-225	–	–

[1]0.505 in. diam bar machined from test bar (2)
[2]0.875 in. diam X 12 in. between supports
[3]At ¼ transverse load

IRON GRAY, CAST

Class 25
HEAVY SECTIONS

Chemical Composition[1]

	Total C %	Graphitic C %	Combined C %	Si %	Mn %
Typical	3.40	–	–	2.20	0.50
Typical Range	3.00-3.55	–	–	2.00-2.30	–

	P %	S %	Alloys %	C Equivalent[2] %
Typical	0.30	0.10	not used	4.15
Typical Range	0.15-0.50	0.07-0.14	–	–

[1]Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2]CE = % Total C + 0.3 (% Si + % P)

Uses: Use similar to Class 20 when higher strength required.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Hard BHN	Mod of Elast E M psi	Trans Resil in. lb
Cast 1.2 in. diam	1.01-2.00	2.0	25 min.	–	–	–	–	–	–
Typical	–	–	23[1]	5.5[2]	0.30	42	175	11,500[3]	1,000
Typical Range	–	–	20-24[1]	5-7[2]	–	39-52	155-190	–	–

[1]1.25 in. diam machined from (2)
[2]2.0 in. diam X 24 in. between supports
[3]At ¼ transverse load

IRON GRAY, CAST

Class 30
MEDIUM SECTIONS

Chemical Composition [1]

	Total C %	Graphitic C %	Combined C %	Si %	Mn %
Typical	3.35	2 65	0 70	2.20	0.50
Typical Range	3.00-3 50	2.50-2 80	0 60-0.80	1.50-2 70	0 40-0 80

	P %	S %	Alloys %	C Equivalent [2] %
Typical	0 20	0.10	A small alloy content may be used	4.05
Typical Range	0.15-0.60	0.07-0.14		–

[1] Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2] CE = % Total C + 0 3 (% Si + % P)

Characteristics. This class together with Class 35 (35 M psi min.) represents a great number of gray iron castings. Class 30 and 35 irons are readily castable in thin sections, possess the high machinability characteristic of gray iron, and are close grained enough to be sound in relatively heavy sections

Uses Typical uses include light brake drums, clutch plates, crankcases, cylinder blocks, liners, sleeves, filter grids, impellers, compressor frames, pipe and fittings, rams, grate bars and numerous automotive, electrical and machine components.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Imp S ft lb	Hard BHN	Shear S M psi	End Lt M psi
Cast 1.2 in. diam	0.51-1.00	1.2	30 min.	–	–	–	–	–	–	–
Typical	–	–	32 5 [1]	2.2 [2]	0.28	58 4	60 [4]	200	44 [3]	14.5
Typical Range	–	–	30-34 [1]	2-2.5 [2]	0.24-0.30	54-68	–	175-215	–	–

	Comp S M psi	Mod of Elast E M psi	Trans Resil in. lb
Typical	115	15,000 [5]	430
Typical Range	–	–	350-500

[1] 0 750 in. diam machined from test bar (2)
[2] 1 2 in. diam × 18 in. between supports
[3] 0.505 in.
[4] 1.20 in. diam × 18 in. supports
[5] At ¼ transverse load

IRON GRAY, CAST

Class 30
LIGHT SECTIONS

Characteristics· This class together with Class 35 (35 M psi min.) represents a great number of gray iron castings. Class 30 and 35 irons are readily castable in thin sections, possess the high machinability characteristic of gray iron, and are close grained enough to be sound in relatively heavy sections.

Chemical Composition [1]

	Total C %	Graphitic C %	Combined C %	Si %	Mn %
Typical	3 35	–	–	2 20	0.50
Typical Range	3.30-3.50	–	–	1.70-2.50	0.40-0.80

	P %	S %	Alloys %	C Equivalent [2] %
Typical	0.20	0.10	not used	4.05
Typical Range	0 10-0 25	0 07-0.14	–	–

[1] Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2] CE = % Total C + 0.3 (% Si + % P)

Uses· Typical uses include light brake drums, clutch plates, crankcases, cylinder blocks, liners, sleeves, filter grids, impellers, compressor frames, pipe and fittings, rams, grate bars and numerous automotive, electrical and machine components.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Hard BHN	Mod of Elast E M psi	Trans Resil in. lb
Cast 1.2 in. diam	0.500	0.875	30 min.	–	–	–	–	–	–
Typical	–	–	37 [1]	1.375 [2]	0.16	63	210	16,000 [3]	140
Typical Range	–	–	35-40 [1]	–	–	–	–	–	–

[1] 0.505 in. diam machined from test bar (2)
[2] 0.875 in. diam × 12 in. between supports
[3] At ¼ transverse load

IRON GRAY, CAST

Class 30
HEAVY SECTIONS

Chemical Composition[1] – Typical

Total C %	Graphitic C %	Combined C %	Si %	Mn %
3.35	–	–	2.20	0.50

P %	S %	Alloys %	C Equivalent[2] %
0.20	0.10	–	4.05

[1]Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2]CE = % Total C + 0.3 (% Si + % P)

Characteristics: This class together with Class 35 (35 M psi min.) represents a great number of gray iron castings. Class 30 and 35 irons are readily castable in thin sections, possess the high machinability characteristic of gray iron, and are close grained enough to be sound in relatively heavy sections.

Uses: Typical uses include light brake drums, clutch plates, crankcases, cylinder blocks, liners, sleeves, filter grids, impellers, compressor frames, pipe and fittings, rams, grate bars and numerous automotive, electrical and machine components.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Hard BHN	Mod of Elast E M psi	Trans Resil in. lb
Cast 1.2 in. diam	1.01-2.00	2.0	30 min.	–	–	–	–	–	–
Typical	–	–	26.5[1]	7.3[2]	0.31	56	180	13,500[3]	1,500
Typical Range	–	–	24-30[1]	–	–	–	160-200	–	–

[1]1.25 in. diam machined from test bar (2)
[2]2.0 in diam X 24 in between supports
[3]At ¼ transverse load

IRON GRAY, CAST

Class 35
MEDIUM SECTIONS

Chemical Composition[1]

	Total C %	Graphitic C %	Combined C %	Si %	Mn %
Typical	3.25	2.55	0.70	2.00	0.70
Typical Range	3.10-3.40	2.35-2.70	0.60-0.80	1.50-2.50	0.55-0.75

	P %	S %	Alloys %	C Equivalent[2] %
Typical	0.20	0.10	Small amounts of	3.90
Typical Range	0.10-0.25	0.07-0.14	alloys may be used	–

[1]Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2]CE = % Total C + 0 3 (% Si + % P)

Characteristics: This class together with Class 35 (35 M psi min.) represents a great number of gray iron castings. Class 30 and 35 irons are readily castable in thin sections, possess the high machinability characteristic of gray iron, and are close grained enough to be sound in relatively heavy sections.

Uses: Typical uses include light brake drums, clutch plates, crankcases, cylinder blocks, liners, sleeves, filter grids, impellers, compressor frames, pipe and fittings, rams, grate bars and numerous automotive, electrical and machine components.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Imp S ft lb	Hard BHN	Shear S M psi	End Lt M psi
Cast 1.2 in. diam	0.51-1.00	1.2	35 min.	–	–	–	–	–	–	–
Typical	–	–	37.5[1]	2.6[2]	0.28	69	60[4]	210	43[3]	17.5
Typical Range	–	–	35-40[1]	2.3-2.9[2]	0.25-0.32	60-75	–	200-230	–	–

Form or Condition	Comp S M psi	Mod of Elast E M psi	Trans Resil in. lb
Typical	125	16,000[5]	450
Typical Range	–	–	–

[1]0.750 in. diam machined from test bar (2)
[2]1.2 in. X 18 in. between supports
[3]0.505 in. diam
[4]1.20 in. diam X 18 in. supports
[5]At ¼ transverse load

IRON GRAY, CAST

Class 35
LIGHT SECTIONS

Chemical Composition[1]

	Total C %	Graphitic C %	Combined C %	Si %	Mn %
Typical	3.25	2.55	0.70	2.00	0.70
Typical Range	3.20-3.40	–	–	–	–

	P %	S %	Alloys %	C Equivalent[2] %
Typical	0.20	0.10	Small alloy additions may be used	3.90
Typical Range	–	–		–

[1]Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2]CE = % Total C +0.3 (% Si +% P)

Characteristics: This class together with Class 35 (35 M psi min.) represents a great number of gray iron castings. Class 30 and 35 irons are readily castable in thin sections, possess the high machinability characteristic of gray iron, and are close grained enough to be sound in relatively heavy sections.

Uses: Typical uses include light brake drums, clutch plates, crankcases, cylinder blocks, liners, sleeves, filter grids, impellers, compressor frames, pipe and fittings, rams, grate bars and numerous automotive, electrical and machine components.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Hard BHN	Comp S M psi	Mod of Elast E M psi	Trans Resil in. lb
Cast 1.2 in. diam	0.50	0.875	35 min.	–	–	–	–	–	–	–
Typical	–	–	40[1]	1.5[2]	0.17	70	220	150	17,000[3]	200
Typical Range	–	–	38-42[1]	1-1.6[2]	0.15-0.20	65-73	200-240	–	–	–

[1]0.505 in. diam machined from test bar (2)
[2]0.875 in. diam X 12 in. between supports
[3]At ¼ transverse load

IRON GRAY, CAST

Class 35
HEAVY SECTIONS

Chemical Composition[1]

	Total C %	Graphitic C %	Combined C %	Si %	Mn %
Typical	3.25	–	–	2.00	0.70
Typical Range	3.15-3.35	–	–	1.50-2.20	0.50-0.75

	P %	S %	Alloys %	C Equivalent[2] %
Typical	0.20	0.10	Small amount of alloy may be used	3.90
Typical Range	0.15-0.25	0.07-0.14		–

[1]Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2]CE = % Total C +0.3 (% Si +% P)

Characteristics: This class together with Class 35 (35 M psi min.) represents a great number of gray iron castings. Class 30 and 35 irons are readily castable in thin sections, possess the high machinability characteristic of gray iron, and are close grained enough to be sound in relatively heavy sections.

Uses: Typical uses include light brake drums, clutch plates, crankcases, cylinder blocks, liners, sleeves, filter grids, impellers, compressor frames, pipe and fittings, rams, grate bars and numerous automotive, electrical and machine components.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Mod of Rupt M psi	Hard BHN	Mod of Elast E M psi	Trans Resil in. lb
Cast 1.2 in. diam	1.01-2.00	2.0	35 min.	–	–	–	–	–
Typical	–	–	31[1]	8[2]	63	190	14,500[3]	1,600
Typical Range	–	–	25-33[1]	7.5-9.0[2]	60-70	180-210	–	–

[1]1.25 in. diam machined from test bar (2)
[2]2.0 in. diam X 24 in. between supports
[3]At ¼ transverse load

IRON GRAY, CAST

Class 40
MEDIUM SECTIONS

Chemical Composition[1]

	Total C %	Graphitic C %	Combined C %	Si %	Mn %
Typical	3.10	2.25	.85	1.80	0.70
Typical Range	2.75-3.30	2.00-2.50	0.65-0.90	1.00-2.10	—

	P %	S %	Alloys %	C Equivalent[2] %
Typical	0.20	0.10	Moderate alloy additions may be used	3.70
Typical Range	—	—		—

[1]Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2]CE = % Total C + 0.3 (% Si + % P)

Characteristics: Class 40 and Class 50 irons are specified if strength and/or specific characteristics such as maintaining hardness above a certain level, resistance to growth at high temperatures, improved strength and soundness in heavy sections, etc. are of paramount importance. Although the superior castability of gray iron is maintained to a considerable degree, some sacrifice in this property is usually accepted to obtain other desirable physical characteristics. Strengths up to 50 M psi min can be obtained simply by lowering carbon equivalent and treating the irons with ladle inoculants, although actual alloying agents such as nickel, chromium, molybdenum, etc., are frequently employed.

Uses: Typical uses include diesel and other gears, camshafts, light crankshafts, large cylinder blocks, heads, liners, sleeves, steam pressure castings, pumps, compressors, valves, impellers, heavy beds, face plates, columns, gudgeons, tube supports, dies, bushings, locomotive bull rings and cylinders, anvils, rams, wheels, etc.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Imp S ft lb	Hard BHN	Shear S M psi	End Lt M psi
Cast 1.2 in. diam	0.50-1.00	1.2	40 min.	—	—	—	—	—	—	—
Typical	—	—	45[1]	2.9[2]	0.28	78	70[4]	220	57[3]	21
Typical Range	—	—	40-48[1]	2.5-3.4[2]	0.24-0.40	68-90	—	210-260	—	—

	Comp S M psi	Mod of Elast E M psi	Trans Resil in. lb
Typical	143	17,000[5]	600
Typical Range	—	—	—

[1]0.750 in. diam machined from test bar (2)
[2]1.2 in. diam X 18 in. between supports
[3]0.505 in.
[4]1.20 in. diam X 18 in. supports
[5]At ¼ transverse load

IRON GRAY, CAST

Class 40
LIGHT SECTIONS

Chemical Composition[1]

	Total C %	Graphitic C %	Combined C %	Si %	Mn %
Typical	3.10	—	—	1.80	0.70
Typical Range	2.80-3.30	—	—	1.00-1.90	—

	P %	S %	Alloys %	C Equivalent[2] %
Typical	0.20	0.10	Medium alloy additions may be used	3.70
Typical Range	—	—		—

[1]Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2]CE= % Total C + 0.3 (% Si + % P)

Characteristics: Class 40 and Class 50 irons are specified if strength and/or specific characteristics such as maintaining hardness above a certain level, resistance to growth at high temperatures, improved strength and soundness in heavy sections, etc. are of paramount importance. Although the superior castability of gray iron is maintained to a considerable degree, some sacrifice in this property is usually accepted to obtain other desirable physical characteristics. Strengths up to 50 M psi min can be obtained simply by lowering carbon equivalent and treating the irons with ladle inoculants, although actual alloying agents such as nickel, chromium, molybdenum, etc., are frequently employed.

Uses: Typical uses include diesel and other gears, camshafts, light crankshafts, large cylinder blocks, heads, liners, sleeves, steam pressure castings, pumps, compressors, valves, impellers, heavy beds, face plates, columns, gudgeons, tube supports, dies, bushings, locomotive bull rings and cylinders, anvils, rams, wheels, etc.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Hard BHN	Mod of Elast E M psi	Trans Resil in. lb
Cast 1.2 in. diam	0.50	0.875	40 min.	—	—	—	—	—	—
Typical	—	—	50[1]	1.75[2]	0.16	80	230	18,000[3]	220

[1]0.505 in. diam machined from test bar (2)
[2]0.875 in. diam X 12 in. between supports
[3]At ¼ transverse load

IRON GRAY, CAST

Class 40
HEAVY SECTIONS

Characteristics: Class 40 and Class 50 irons are specified if strength and/or specific characteristics such as maintaining hardness above a certain level, resistance to growth at high temperatures, improved strength and soundness in heavy sections, etc. are of paramount importance. Although the superior castability of gray iron is maintained to a considerable degree, some sacrifice in this property is usually accepted to obtain other desirable physical characteristics. Strengths up to 50 M psi min can be obtained simply by lowering carbon equivalent and treating the irons with ladle inoculants, although actual alloying agents such as nickel, chromium, molybdenum, etc., are frequently employed.

Chemical Composition[1]

	Total C %	Graphitic C %	Combined C %	Si %	Mn %
Typical	3.10	–	–	1.80	0.70
Typical Range	3.00-3.50	–	–	1.00-2.20	–

	P %	S %	Alloys %	C Equivalent[2] %
Typical	0.20	0.10	Moderate alloy ad-	3.70
Typical Range	–	–	ditions may be made	–

[1]Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2]CE = % Total C + 0.3 (% Si + % P)

Uses: Typical uses include diesel and other gears, camshafts, light crankshafts, large cylinder blocks, heads, liners, sleeves, steam pressure castings, pumps, compressors, valves, impellers, heavy beds, face plates, columns, gudgeons, tube supports, dies, bushings, locomotive bull rings and cylinders, anvils, rams, wheels, etc

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in	Mod of Rupt M psi	Hard BHN	Mod of Elast E M psi	Trans Resil in. lb
Cast 1.2 in. diam	1.01-2.00	2.0	40 min.	–	–	–	–	–	–
Typical	–	–	37[1]	10[2]	0.30	76.5	210	15,500[3]	1900
Typical Range	–	–	33-45[1]	8.5-13.5[2]	0.20-0.40	64-80	200-230	–	–

[1]1.25 in. diam machined from test bar (2)
[2]2.0 in. diam X 24 in. between supports
[3]At ¼ transverse load

IRON GRAY, CAST

Class 50
MEDIUM SECTIONS

Characteristics: Class 40 and Class 50 irons are specified if strength and/or specific characteristics such as maintaining hardness above a certain level, resistance to growth at high temperatures, improved strength and soundness in heavy sections, etc. are of paramount importance. Although the superior castability of gray iron is maintained to a considerable degree, some sacrifice in this property is usually accepted to obtain other desirable physical characteristics. Strengths up to 50 M psi min can be obtained simply by lowering carbon equivalent and treating the irons with ladle inoculants, although actual alloying agents such as nickel, chromium, molybdenum, etc., are frequently employed.

Chemical Composition[1]

	Total C %	Graphitic C %	Combined C %	Si %	Mn %
Typical	2.90	2.00	0.90	2.00	0.70
Typical Range	2.70-3.05	1.75-2.10	0.75-1.00	1.50-2.40	–

	P %	S %	Alloys %	C Equivalent[2] %
Typical	0.10	0.10	Moderate amounts of	3.55
Typical Range	–	–	alloys are generally used	–

[1]Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2]CE = % Total C + 0.3 (% Si + % P)

Uses: Typical uses include diesel and other gears, camshafts, light crankshafts, large cylinder blocks, heads, liners, sleeves, steam pressure castings, pumps, compressors, valves, impellers, heavy beds, face plates, columns, gudgeons, tube supports, dies, bushings, locomotive bull rings and cylinders, anvils, rams, wheels, etc.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Imp S ft lb	Hard BHN	Shear S M psi	End Lt M psi
Cast 1.2 in. diam	0.51-1.00	1.2	50 min.	–	–	–	–	–	–	–
Typical	–	–	55[1]	3.3[2]	0.28	87.5	80[4]	240	59[3]	25
Typical Range	–	–	50-57[1]	3.1-3.5[2]	0.25-0.4	82-95	–	235-265	–	–

	Comp S M psi	Mod of Elast E M psi	Trans Resil in. lb
Typical	150	19,000[5]	–
Typical Range			

[1]0.750 in. diam machined from test bar (2)
[2]1.2 in. diam X 18 in. between supports
[3]0.505 in.
[4]1.20 in. diam X 18 in. supports
[5]At ¼ transverse load

IRON GRAY, CAST

Class 50

LIGHT SECTIONS

Chemical Composition[1]

Total C %	Graphitic C %	Combined C %	Si %	Mn %
2.90	—	—	2.00	0.70

P %	S %	Alloys %	C Equivalent[2] %
0.10	0.10	Moderate amounts of alloys are used	3.65

[1]Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2]CE = % Total C + 0.3 (% Si + % P)

Uses: Typical uses include diesel and other gears, camshafts, light crankshafts, large cylinder blocks, heads, liners, sleeves, steam pressure castings, pumps, compressors, valves, impellers, heavy beds, face plates, columns, gudgeons, tube supports, dies, bushings, locomotive bull rings and cylinders, anvils, rams, wheels, etc.

Characteristics: Class 40 and Class 50 irons are specified if strength and/or specific characteristics such as maintaining hardness above a certain level, resistance to growth at high temperatures, improved strength and soundess in heavy sections, etc. are of paramount importance. Although the superior castability of gray iron is maintained to a considerable degree, some sacrifice in this property is usually accepted to obtain desirable physical characteristics. Strengths up to 50 M psi min can be obtained simply by lowering carbon equivalent and treating the irons with ladle inoculants, although actual alloying agents such as nickel, chromium, molybdenum, etc., are frequently employed.

Mechanical Properties

Form or Condition	Casting Sect Lt in	Test Bar Diam in	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Hard BHN	Mod of Elast E M psi	Trans Resil in lb
Cast 1.2 in. diam	≤0.50	0.875	50 min.	—	—	—	—	—	—
Typical	—	—	60[1]	2[2]	0 18	91	260	19,000[3]	260

[1]0.505 in. diam machined from test bar (2)
[2]0 875 in. diam × 12 in between supports
[3]At ¼ transverse load

IRON GRAY, CAST

Class 50

HEAVY SECTIONS

Chemical Composition[1]

Total C %	Graphitic C %	Combined C %	Si %	Mn %
2.90	—	—	2.00	0.70

P %	S %	Alloys %	C Equivalent[2] %
0.10	0.10	The use of alloys is essential	2.55

[1]Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2]CE = % Total C + 0.3 (% Si + % P)

Uses. Typical uses include diesel and other gears, camshafts, light crankshafts, large cylinder blocks, heads, liners, sleeves, steam pressure castings, pumps, compressors, valves, impellers, heavy beds, face plates, columns, gudgeons, tube supports, dies, bushings, locomotive bull rings and cylinders, anvils, rams, wheels, etc.

Characteristics. Class 40 and Class 50 irons are specified if strength and/or specific characteristics such as maintaining hardness above a certain level, resistance to growth at high temperatures, improved strength and soundness in heavy sections, etc. are of paramount importance. Although the superior castability of gray iron is maintained to a considerable degree, some sacrifice in this property is usually accepted to obtain other desirable physical characteristics. Strengths up to 50 M psi can be obtained simply by lowering carbon equivalent and treating the irons with ladle inoculants, although actual alloying agents such as nickel, chromium, molybdenum, etc., are frequently employed.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Hard BHN	Mod of Elast E M psi	Trans Resil in. lb
Cast 1.2 in. diam	1.01-2.00	2.00	50 min.	—	—	—	—	—	—
Typical	—	—	52[1]	10.7[2]	0.30	82	230	18,000[3]	2500

[1]1.25 in. diam machined from test bar (2)
[2]2.0 in. diam x 24 in. between supports
[3]At ¼ transverse load

IRON GRAY, CAST

Class 60
MEDIUM SECTIONS

Characteristics: Class 60 irons are the highest strength grade normally melted in the cupola. They usually require substantial additions of alloys such as combinations of nickel, molybdenum and chromium to maintain this high level of strength in medium and heavy sections. A tendency to chill limits their use (as well as Class 50 irons) in thin sections. Special founding practice and the necessity of alloys definitely increase the cost of Class 60 irons.

Chemical Composition[1]

	Total C %	Graphitic C %	Combined C %	Si %	Mn %
Typical	2.85	2.00	0.85	2.20	0.70
Typical Range	2.55-2.95	–	–	1.70-2.50	–

	P %	S %	Alloys %	C Equivalent[2] %
Typical	0.10	0.10	Alloys are	2.55
Typical Range	–	--	essential	–

[1]Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2]CE = % Total C + 0.3 (% Si + % P)

Uses: Typical uses include special brake drums, camshafts, connecting rods, truck cylinder blocks, heads, diesel liners, idler gears, diesel engine housings, truck end plates and transmission, pressure castings in chemical industry, high pressure well pumps, crusher frames, hot-forming dies, heavy duty bevel and cut gears, hydraulic cylinders, water work sluice gate valves. Classes 40, 50 or 60 are specified for pressure-containing parts for temperatures above 450°F

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Imp S ft lb	Hard BHN	Comp S M psi	Mod of Elast E M psi	Trans Resil in lb
Cast 1.2 in. diam	0.51-1.00	1.2	60 min.	–	–	–	–	–	–	–	–
Typical	–	–	65[1]	3.7[2]	0.34	98	115[3]	290	170	19,500[4]	800
Typical Range	–	–	60-66[1]	3-4[2]	0.23-0 40	85-105	–	250-300	–	–	–

[1]0.750 in. diam machined from test bar (2)
[2]1.2 in. diam X 18 in. between supports
[3]1.125 in. diam X 6 in. supports
[4]At ¼ transverse load

IRON GRAY, CAST

Class 60
LIGHT SECTIONS

Characteristics: Class 60 irons are the highest strength grade normally melted in the cupola. They usually require substantial additions of alloys such as combinations of nickel, molybdenum and chromium to maintain this high level of strength in medium and heavy sections. A tendency to chill limits their use (as well as Class 50 irons) in thin sections. Special founding practice and the necessity of alloys definitely increase the cost of Class 60 irons.

Chemical Composition[1]

Total C %	Graphitic C %	Combined C %	Si %	Mn %
2.85	–	–	2.20	0.70

P %	S %	Alloys %	C Equivalent[2] %
0.10	0.10	Alloys are essential	2.25

[1]Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2]CE = % Total C + 0.3 (% Si + % P)

Uses: Typical uses include special brake drums, camshafts, crankshafts, connecting rods, truck cylinder blocks, heads, diesel liners, idler gears, diesel engine housings, truck end plates and transmission, pressure castings in chemical industry, high pressure well pumps, crusher frames, hot-forming dies, heavy duty bevel and cut gears, hydraulic cylinders, water work sluice gate valves. Classes 40, 50 or 60 are specified for pressure-containing parts for temperatures above 450°F.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Hard BHN	Mod of Elast E M psi	Trans Resil in. lb
Cast 1.2 in. diam	0.50	0.875	60 min.	–	–	–	–	–	–
Typical	–	–	70[1]	2.5[2]	0.23	114	300	20,000[3]	350

[1]0.505 in. diam machined from test bar (2)
[2]0.875 in. diam X 12 in. between supports
[3]At ¼ transverse load

Class 60
HEAVY SECTIONS

Chemical Composition[1]

	Total C %	Graphitic C %	Combined C %	Si %	Mn %
Typical	2.85	–	–	2.20	0.70
Typical Range	2.50-3.00	–	–	–	–

	P –	S %	Alloys %	C Equivalent[2] %
Typical	0.10	0.10	Alloys are	3.50
Typical Range	–	–	essential	–

[1]Irons of this class are commonly supplied with different analyses, depending on the application. Compositions are not usually specified.
[2]CE = % Total C + 0.3 (% Si + % P)

Characteristics: Class 60 irons are the highest strength grade normally melted in the cupola. They usually require substantial additions of alloys such as combinations of nickel, molybdenum and chromium to maintain this high level of strength in medium and heavy sections. A tendency to chill limits their use (as well as Class 50 irons) in thin sections. Special founding practice and the necessity of alloys definitely increase the cost of Class 60 irons.

Uses: Typical uses include special brake drums, camshafts, crankshafts, connecting rods, truck cylinder blocks, heads, diesel liners, idler gears, diesel engine housings, truck end plates and transmission, pressure castings in chemical industry, high pressure well pumps, crusher frames, hot-forming dies, heavy duty bevel and cut gears, hydraulic cylinders, water work sluice gate valves. Classes 40, 50 or 60 are specified for pressure-containing parts for temperatures above 450°F.

Mechanical Properties

Form or Condition	Casting Sect Lt in.	Test Bar Diam in.	Tensile Strength M psi	Trans S M lb	Defl in.	Mod of Rupt M psi	Imp S ft lb	Hard BHN	Mod of Elast E M psi	Trans Resil in. lb
Cast 1.2 in. diam	1.01-2.00	2.00	60 min.	–	–	–	–	–	–	–
Typical	–	–	60[1]	15[2]	0.40	115	100[3]	275	19,000[4]	3000
Typical Range	–	–	50-75[1]	12-17[2]	0.30-0.45	–	–	270-285	–	–

[1]1.25 in. diam machined from test bar (2)
[2]2.0 in. X 24 in. between supports
[3]1.125 in. diam X 6 in. supports
[4]At ¼ transverse load

Low Cr

Specific Applications of Alloy Cast Irons

Chemical Range, Per Cent: Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements	Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse: Load Lb	Transverse: Defl. In.	Tensile Strength psi	Remarks
2.10 to 2.50	2.90 to 3.40		0.50 to 0.90	0.10 max	0.20 max	0.50 to 0.90			0.30 to 0.70		3/8 to 1-1/4	15 to 150	200 to 248	3500 to 4500	0.11 to 0.17	35,000 to 45,000	Used for wear resistance and resistance to temperatures up to 1100°F. ***Brake drums, automobile.***
2.20 to 2.60	2.90 to 3.40		0.50 to 0.90	0.10 max	0.20 max	0.50 to 0.90			0.30 to 0.60		1/2 to 1-1/4		190 to 240	3500 to 4500	0.11 to 0.17	35,000 to 45,000	Used for wear resistance. ***Clutch plates, automobile.***
2.10 to 2.50	3.00 to 3.40		0.50 to 0.90	0.10 max	0.20 max	0.50 to 0.90			0.20 to 0.40		1/4 to 2	75 to 280	187 to 240	3500 to 4500	0.11 to 0.17	35,000 to 45,000	Used for wear resistance, and wear at elevated temperatures. ***Cylinder blocks, automotive.***
2.15 to 2.40	3.10 to 3.40		0.50 to 0.90	0.10 max	0.20 max	0.50 to 0.90			0.30 to 0.90		1/4 to 2	125 to 470	200 to 250	3500 to 4500	0.11 to 0.17	35,000 to 45,000	Used for wear resistance, and wear at elevated temperature. ***Cylinder blocks, bus and truck.***
2.00 to 2.50	3.00 to 3.30		0.50 to 0.90	0.10 max	0.20 max	0.50 to 0.90			0.20 to 0.65		3/8 to 1		180 to 250	3500 to 4500	0.11 to 0.17	35,000 to 45,000	Used for wear resistance, and wear at elevated temperatures. ***Cylinder heads.***
1.90 to 2.40	3.00 to 3.30		0.50 to 0.90	0.10 max	0.20 max	0.50 to 0.90			0.30 to 0.80		3/8 to 1-1/4	14 to 150	220 to 280	3500 to 4500	0.11 to 0.17	35,000 to 45,000	Used for wear resistance, and wear at elevated temperatures. ***Cylinder liners.***
2.00 to 2.50	3.00 to 3.50		0.50 to 0.90	0.10 max	0.30 max	0.50 to 0.90			0.30 to 0.80		3/8 to 3		180 to 250	3200 to 4500	0.11 to 0.17	32,000 to 45,000	Used for wear resistance. ***Bed compressor frames.***
1.80 to 1.90	3.00 to 3.20	2.10 to 2.30	0.90	0.10 max	0.15 max	0.80 to 0.90			0.20 to 0.30		5/8 to 4	5000 to 70,000	180 to 200	2500[2]	0.25	40,000 to 50,000	Used for wear resistance and close, uniform grain structure. ***Beds, planers and boring mills.***
1.25 to 1.75	3.10 to 3.30			0.120 max	0.50 to 0.75	0.50 to 0.75			0.50 to 0.75		1/2 to 2	20 to 100					Used for heat resistance. ***Grate bars.***
2.60 to 2.66	3.00 to 3.11			0.085	0.50	0.70 to 1.00			1.00		1/4 to 2-1/2	2 to 40	240	2490[2]	0.187	37,900	Machinable and heat resistant. ***Valves, tube plants.***
1.75 to 2.25	3.00 to 3.50			0.14 max	0.40 max	0.50 to 0.80			0.85 to 1.25		1/4 to 1	1 to 100	200 to 300	3000 to 4000	0.10 to 0.17	30,000 to 45,000	Used in general service up to 1400°F. especially when temperatures tend to be high. When very light sections are made under 1/4 inch, silicon is raised to 2.50 per cent. ***Grate bars, fire pots, stoves and furnace liners.***

Footnotes at end of section, p. 38.

IRON GRAY, CAST

Low Mo

Specific Applications of Alloy Cast Irons

Chemical Range, Per Cent											Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse		Tensile Strength psi	Remarks
Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements				Load Lb	Defl. In.		
1.90 to 2.90	2.80 to 3.00	2.00 to 2.40	0.60 to 0.80	0.05 max	0.10 max	0.60 to 0.80		0.50 to 0.55			3/16 to 1-3/4	22 to 167	[3]	5700 to 6300[4]	0.13 to 0.16	54,000 to 61,000	Impact – "Swing Hammer" on 1.20 in. diam. bar on 6-in. centers – 60 to 90 ft. lb. Used for uniformity of structure, high strength, impact resistance, wear resistance, and thermal stability. NOTE – Low silicon range used for heavy sectioned drums and high silicon range used for thin sectioned drums. ***Brake drums, trucks and busses.***
1.90 to 2.10	3.20 to 3.30			0.11 max	0.20 max	0.50 to 0.70		0.25			5/8 to 1	4 to 5	207 to 241	3400 to 3800[2]	0.40 to 0.45	47,000 to 51,000	Used because of inherent damping characteristics. No service failures. ***Crankshafts, one and two-cylinder gasoline engines.***
1.30 to 1.50	2.20 to 2.55	1.50 to 1.70	0.50 to 0.75	0.08 max	0.15 max	0.35 to 0.50		0.30 to 0.50			1/4 to 3/4	To 40	160 to 235[5]	4200 to 4500[2]	0.55 to 0.95	60,000 to 85,000[6]	Used for high strength and shock resistance. Heat treatment – see footnote [7]. ***Connecting rods, gasoline and diesel engines.***
2.00 to 2.20	3.20 to 3.40			0.12 max	0.20 max	0.75 to 0.95		0.20 to 0.30			3/16 to 2	200 to 300	196			38,000	Somewhat better strength with good machinability compared to base iron. ***Cylinder blocks, truck and stationary engines.***
1.40 to 1.80	3.30 to 3.60			0.10 max	0.17 to 0.22	1.00 to 1.25		0.50 to 0.75			1/2 to 1-1/2	25 to 60	187 to 228	3400 to 3800[6]	0.100 to 0.120		***Flywheel, automobile and tractor.***
1.20 to 1.50	2.95 to 3.15	2.30 to 2.40	0.60 to 0.70	0.09 to 0.12	0.10 to 0.20	0.70 to 1.00		0.20 to 0.30			3/4 to 1-1/2	2000 to 7000	190 to 210	5000 to 5800[10]	0.17 to 0.20	40,000 to 45,000	Used for strength, wear and abrasion resistance. ***Steam pressure castings, chemical machinery.***
1.00 to 1.50	2.80 to 3.20	2.20 to 2.40	0.60 to 0.80	0.10 to 0.12	0.10 to 0.15	0.70 to 0.90		0.70 to 0.90			4 to 12	50 to 500	241 to 277[9]	5000 to 5400[10]	0.15 to 0.165	46,000 to 50,000	Used for response to heat-treatment, wear and shock resistance. ***Forging dies, drop hammer forgings.***
2.40 to 2.50	3.00 to 3.20			0.05 to 0.10	0.15 to 0.25	0.65 to 0.85		0.70 to 0.80			3/4	3 to 25	240 max	2700 to 2800[2]	0.25 to 0.35	37,000 to 42,000	Used to withstand high steam temperatures. In use for 18 months and apparently as good as special malleable castings formerly used. ***Control valves, very light valves for steam turbines-superheated steam.***
1.90 to 2.10	2.90 to 3.10			0.10 max	0.18 max	0.60 to 0.80		0.65 to 0.75		Va 0.12 to 0.16	3/8 to 2	12 to 14	229 to 255	3800 to 4000[2]	0.28 to 0.34	50,000 to 60,000	Used for wear and heat check resistance. ***Gear, brake and power transmission.***

Footnotes at end of section, p. 38.

Specific Applications of Alloy Cast Irons

Chemical Range, Per Cent: Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements	Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse: Load Lb	Transverse: Defl. In.	Tensile Strength psi	Remarks
1.60 to 1.80	2.90 to 3.10	2.25 to 2.40	0.70 to 0.85	0.08 to 0.09	0.25 to 0.30	0.45 to 0.55	0.75 to 1.00				1/2 to 1	40 to 150	215 to 225	4000 to 4500[10]	0.12 to 0.14	40,000 to 45,000	Used for resistance to wear. *Brake drums, bus and truck.*
1.90 to 2.10	3.20 to 3.40	2.70 to 2.80	0.50 to 0.60	0.09 to 0.12	0.14 to 0.18	0.70 to 0.85	1.00 to 1.10				7/32 to 9/16	240 to 270	207 to 212	3800 to 4000[4]	0.12 to 0.15		Used for strength, toughness and machinability. *Crankcases, heavy duty truck engines.*
1.60 to 1.80	2.90 to 3.10	2.25 to 2.40	0.70 to 0.85	0.08 to 0.09	0.25 to 0.30	0.45 to 0.55	0.75 to 1.00				3/8 to 1/2	20 to 40	215 to 225[9]	4000 to 4500[10]	0.12 to 0.14	40,000 to 45,000	Used for resistance to wear. *Cylinder sleeves, replacement sleeves for bus and truck engines.*
1.75	2.75			0.12	0.20	0.80	2.00				1/2 to 1-1/4	200 to 2000	240			62,800	Used for high strength and resistance to moderately elevated temperatures. *Housing, diesel engine.*
1.20 to 1.50	2.95 to 3.10	2.30 to 2.40	0.55 to 0.65	0.90 to 0.12	0.10 to 0.20	0.70 to 1.00	0.40 to 0.60				3/4 to 1-1/2	2500 to 7000	180 to 200	4700 to 5200[10]	0.15 to 0.18	40,000 to 45,000	Used for strength, wear and abrasion resistance. *Steam pressure castings, chemical equipment.*
1.40 to 1.60	3.10 to 3.40			0.05 to 0.10	0.10 to 0.25	0.60 to 0.90	1.00 to 1.50				1/2 to 1-1/2	100 to 150	190 to 210	3500 to 4000[4]	0.10 to 0.15	35,000 to 40,000	Used for pressure tightness, wear resistance and machinability. *Bodies, used in pumps and valves.*
1.60 to 1.80	3.10 to 3.30	2.35 to 2.55	0.70 to 0.80	0.12 max	0.20 max	0.55 to 0.70	1.00 to 1.25				3/8 to 1.5	200 to 300	210 to 230	4500[4] to 5500	0.17 to 0.20		Used for uniform hardness and density. *Cylinders, compressors and pumps.*
1.50 to 2.00	2.70 to 3.00			0.10 max	0.20 max	0.60 to 0.80	1.00 to 2.00				1 to 3	6000 to 40,000	220 to 260	6000 to 6500[4]	0.17 to 0.20	50,000 to 60,000	Used for strength, rigidity, and machinability. Used to replace steel castings. *Crusher frames, gyratory and jaw type crushers.*
0.90 to 1.10	2.90 to 3.10	2.15 to 2.35	0.65 to 0.85	0.12 max	0.20 max	0.60 to 0.80	1.00 to 1.25				0.75 to 1.5	75 to 150	220 to 240	4500[4] to 5500	0.15 to 0.20	40,000 to 45,000	Used for uniform structure, wear resistance and machinability. *Air pump bushings, locomotive air compressors.*
0.90 to 1.10	2.90 to 3.10	2.15 to 2.35	0.65 to 0.85	0.12 max	0.20 max	0.60 to 0.80	1.00 to 1.25				2 to 3	100 to 300	220 to 240	4500[4] to 5500	0.15 to 0.20	40,000 to 45,000	Used for uniform structure, machinability for wear resistance. *Bull rings for locomotives.*
0.90 to 1.10	2.90 to 3.10	2.15 to 2.35	0.65 to 0.85	0.12 max	0.20 max	0.60 to 0.80	1.00 to 1.25				0.75 to 1.5	500 to 1000	220 to 240	4500[4] to 5500	0.15 to 0.20	40,000 to 45,000	Used for wear resistance, machinability and uniform structure. *Cylinder bushings, locomotive cylinders and valves.*
0.90 to 1.10	2.90 to 3.10	2.15 to 2.35	0.65 to 0.85	0.12 max	0.20 max	0.60 to 0.80	1.00 to 1.25				0.75 to 2.5	6000 to 10,000	220 to 240	4500[4] to 5500	0.15 to 0.20	40,000 to 45,000	Used for wear resistance and density in heavy sections with machinability. *Cylinders, locomotive steam cylinders.*

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Specific Applications of Alloy Cast Irons

IRON GRAY, CAST

Low Ni

Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements	Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse Load Lb	Transverse Defl. In.	Tensile Strength psi	Remarks
0.90 to 1.10	2.90 to 3.10	2.15 to 2.35	0.65 to 0.85	0.12 max	0.20 max	0.60 to 0.80	1.00 to 1.25				0.75 to 1.15	75 to 150	220 to 240	4500[4] to 5500	0.15 to 0.20	40,000 to 45,000	Used for wear resistance, uniform structure and machinability. *Pistons, locomotive.*
0.90 to 1.10	2.90 to 3.10	2.15 to 2.35	0.65 to 0.85	0.12 max	0.20 max	0.60 to 0.80	1.00 to 1.25				0.75 to 1.50	75 to 150	220 to 240	4500[4] to 5500	0.15 to 0.20	40,000 to 45,000	Used for machinability, uniform structure and wear resistance. *Pedestals, locomotive and freight cars.*
0.90 to 1.10	2.90 to 3.10	2.15 to 2.35	0.65 to 0.85	0.12 max	0.20 max	0.60 to 0.80	1.00 to 1.25				0.75 to 1.5	200 to 500	220 to 240	4500[4] to 5500	0.15 to 0.20	40,000 to 45,000	Used for wear resistance, uniform structure and machinability. *Valve bushings, locomotive valves.*
0.80 to 1.00	2.90 to 3.10			0.10 to 0.12	0.20 to 0.25	0.60 to 0.80	0.75 to 1.00				1-3/4 to 6	6000 to 8000	220 to 230	3200 to 3400[2]	0.24 to 0.26	60,000 to 50,000	Used for density and pressure tightness. *Hydraulic cylinder, extruding press.*

IRON GRAY, CAST

Low Ni-Cr

Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements	Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse Load Lb	Transverse Defl. In.	Tensile Strength psi	Remarks
2.15 to 2.25	3.10 to 3.40	2.75 to 2.95	0.30 to 0.50	0.10 to 0.14	0.12 to 0.18	0.50 to 0.70	0.20 to 0.40		0.20 to 0.40		3/8 to 7/8	15 to 40	187 to 228	2300 to 2500[2]	0.20 to 0.28	32,000 to 37,000	Service life of 50,000 miles under ordinary usage. *Brake drums, automobile.*
1.90 to 2.10	3.20 to 3.40	2.60 to 2.70	0.60 to 0.70	0.10 max	0.20 max	0.50 to 0.70	1.15 to 1.55		0.55 to 0.75		1/2 to 1-1/4	35 to 150	207 to 241	2500 to 2900[2]	0.24 to 0.32	38,000 to 42,000	Selected as giving best service life after testing a variety of irons. Structure pearlitic with scattered cementite grains. Performance considered excellent. *Brake drums, truck and bus.*
2.15 to 2.25	3.10 to 3.40	2.75 to 2.95	0.30 to 0.40	0.10 to 0.14	0.12 to 0.18	0.50 to 0.70	0.20 to 0.40		0.20 to 0.40		1/2 to 1-1/4	10 to 40	187 to 228	2300 to 2500[2]	0.20 to 0.28	32,000 to 37,000	Service life of 100,000 miles ordinarily. *Clutch plates, automobile engines.*
1.90 to 2.10	3.20 to 3.40	2.60 to 2.70	0.60 to 0.70	0.10 max	0.20 max	0.50 to 0.70	1.15 to 1.55		0.55 to 0.75		1/2 to 5/8	8 to 15	207 to 241	2500 to 2900[2]	0.24 to 0.32	38,000 to 42,000	Selected as giving best service after testing various types of irons. Performance considered excellent. Structure pearlite with scattered cementite grains. *Clutch plates, truck and bus.*
2.35 to 2.50	3.30 to 3.40	2.70 to 2.90	0.50 to 0.70	0.12 max	0.15 to 0.22	0.50 to 0.70	0.15 to 0.25		0.09 to 0.20		3/16 to 3/4	110	190 to 220	3000 to 3600[4]	0.15 to 0.20	30,000 to 36,000[5]	Used for strength, rigidity and good machinability. Cylinder sleeves used in this crankcase. *Crankcases, small tractor motors.*
2.00 to 2.20	3.25 to 3.40	2.60 to 2.75	0.55 to 0.65	0.09 to 0.12	0.14 to 0.18	0.70 to 0.85	0.75 to 0.85		0.25 to 0.35				*(12)	3600 to 3900[4]	0.12 to 0.14	33,000 to 36,000	Used for improved hardness and wear resistance. *Cylinder blocks, automobile engines.*

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IRON GRAY, CAST

Low Ni-Cr

Specific Applications of Alloy Cast Irons

Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements	Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse Load Lb	Transverse Defl. In.	Tensile Strength psi	Remarks
2.15 to 2.25	3.10 to 3.40	2.75 to 2.95	0.30 to 0.50	0.10 to 0.14	0.12 to 0.18	0.50 to 0.70	0.20 to 0.40		0.20 to 0.40		3/16 to 1	75 to 200	187 to 228	2300 to 2500[2]	0.20 to 0.28	32,000 to 37,000	Fairly good wear resistance with satisfactory machinability at low cost. Life average 50,000 miles under ordinary conditions down to 20,000 miles under dusty conditions. *Cylinder blocks, automobile engines.*
2.20 to 2.40	3.20 to 3.40			0.11 max	0.17 to 0.22	0.55 to 0.70	0.55 to 0.65		0.20 to 0.25		3/8 to 1	200 to 275	179 to 228[12]	2400 to 2900[2]	0.24 to 0.34	38,000 to 43,000	Alloyed iron used to maintain hardness with good machinability. Service performance better than base unalloyed iron. *Cylinder blocks, farm tractor motors.*
2.25 to 2.40	3.25 to 3.40		0.50 to 0.65	0.15 max	0.18 max	0.55 to 0.75	0.0 to 0.25		0.30 to 0.40			200 to 300	*(13)	4500[4]	0.18	38,000 to 40,000	Used for wear resistance and machining. *Cylinder blocks, automobile.*
2.00 to 2.20	3.20 to 3.40			0.12 max	0.20 max	0.75 to 0.95	0.25 to 0.50		0.40 to 0.70		3/16 to 2	75 to 400	200 to 228			38,000	Cylinder blocks and heads, *heavy duty trucks.*
1.80 to 2.00	3.20 to 3.40	2.55 to 2.65	0.65 to 0.75	0.09 to 0.12	0.14 to 0.18	0.75 to 0.85	1.25 to 1.35		0.55 to 0.60		3/16 to 3/4	225 to 300	217 to 228	4000 to 4200[4]	0.12 to 0.14	38,000 to 40,000	Used for improved structure, wear resistance, strength, and hardness. *Cylinder blocks, heavy duty truck engines.*
1.80 to 2.00	3.10 to 3.45	2.80 to 3.00	0.30 to 0.45	0.12 max	0.15 to 0.25	0.45 to 0.60	0.25 to 0.50		0.40 to 0.70		1/8 to 1-1/4	276 to 701	*(11)				Experience has shown good service results. *Cylinder blocks, truck engines.*
2.15 to 2.35	3.10 to 3.40	2.50 to 2.70	0.60 to 0.70	0.10 max	0.20 max	0.50 to 0.70	1.10 to 1.45		0.45 to 0.65		3/16 to 3/4	95 to 110	207 to 241	2400 to 2600[2]	0.25 to 0.28	35,000 to 40,000	Has good wear resistance, castability, and fair machinability. Performance considered good. *Cylinder heads, small truck engines.*
1.75 to 2.25	2.80 to 3.30	2.25 to 2.50	0.55 to 0.80	0.10 max	0.30 max	0.50 to 0.90	1.50 to 1.75		0.50 to 0.75		3/16 to 1-1/2	80 to 700	217 to 241	3400 to 3600[2]	0.250 to 0.260	39,000 to 45,000	Used for tightness and strength. *Cylinder blocks, and heads, trucks.*
0.90 to 1.10	3.00 to 3.20	2.30 to 2.50	0.70 to 0.90	0.07 to 0.09	0.10 to 0.20	0.60 to 0.80	1.00 to 1.25		0.10 to 0.20		5/8 to 2-1/2	3000 to 4000	220 to 230[9]	4500 to 5000[10]	0.110 to 0.125	42,000 to 45,000	Used for resistance to heat. *Cylinder heads, large marine diesel engines.*
1.25 to 1.50	3.00 to 3.20	2.30 to 2.50	0.70 to 0.90	0.07 to 0.09	0.10 to 0.20	0.60 to 0.80	1.25 to 1.50		0.30 to 0.50		1-1/4 to 4	3000 to 6000	220 to 240[9]	4500 to 5000[10]	0.110 to 0.125	45,000 to 50,000	Used for resistance to heat. *Cylinder head, large diesel engine.*
1.90 to 2.10	3.20 to 3.40	2.40 to 2.60	0.75 to 0.90	0.10 max	0.20 max	0.55 max 0.75	1.80 to 2.20		0.55 to 0.75		3/8 to 7/16	14 to 18	*(14)	2400 to 2800[2]	0.20 to 0.30	37,000 to 42,000	Used for good hardening characteristics. Average life of cylinder bores between regrindings increased average of 2-1/2 times as compared to one piece cylinder blocks of Brinell hardness 229 to 241. *Cylinder liner, large truck and bus engines.*
1.40 to 1.60	2.90 to 3.10	2.25 to 2.35	0.75 to 0.85	0.08 to 0.09	0.25 to 0.35	0.45 to 0.55	1.25 to 1.35		0.20 to 0.30		3/4 to 1	75 to 125	220 to 235[9]	4500 to 5000[10]	0.11 to 0.125	43,000 to 48,000	Used for resistance to wear. *Cylinder liners, small diesel engines*

Footnotes at end of section, p. 38.

IRON GRAY, CAST

Low Ni-Cr

Specific Applications of Alloy Cast Irons

Chemical Range, Per Cent: Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements	Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse: Load Lb	Transverse: Defl. In.	Tensile Strength psi	Remarks
2.05 to 2.35	3.20 to 3.30		0.60 to 0.75	0.10 max	0.20 max	0.55 to 0.70	1.95 to 2.25		0.55 to 0.70		3/8	12 to 15	*(15)	2400 to 2800[2]	0.20 to 0.30	42,000 to 48,000	Used for wear and corrosion resistance 125,000 to 200,000 miles between regrindings. *Cylinder liners, large trucks and coach gasoline engines.*
1.40 to 1.50	3.40 to 3.60	2.65 to 2.75	0.75 to 0.85	0.05 to 0.11	0.15 to 0.25	0.80 to 1.00	0.00 to 0.20		0.50 to 0.60	Ti 0.07 to 0.08	Ti 0 07 3	2450	*(16)	2500 to 2700[2]	0.18 to 0.22	35,000 to 37,000	Used for thermal stability, and wear resistance. Metal has pearlite matrix. Machinability and wear resistance are satisfactory. *Cylinder liners, diesel and gas engines.*
2.15 to 2.30	3.30 to 3.40	2.70 to 2.90	0.50 to 0.65	0.12 max	0.22 max	0.50 to 0.70	0.50 to 0.65		0.09 to 0.20		3/8 to 5/8	7	190 to 220	3200 to 3800[4]	0.15 to 0.20	32,000 to 38,000	Used for wear resistance. Metal has good density and is readily machinable. *Cylinder sleeves, small tractor motors.*
2.15 to 2.30	3.30 to 3.40	2.70 to 2.90	0.50 to 0.65	0.12 max	0.15 to 0.22	0.50 to 0.70	0.15 to 0.25		0.09 to 0.20		3/8 to 7/8	10 to 18	190 to 220	3200 to 3800[4]	0.15 to 0.20	32,000 to 38,000	Used for wear resistance. *Cylinder sleeves, truck and tractor motors.*
2.00 to 2.15	3.30 to 3.40	2.70 to 2.90	0.50 to 0.70	0.10 max	0.20 max	0.50 to 0.70	1.65 to 1.85		0.50 to 0.70		3/16 to 3/4	15 to 50	215 to 250	2600 to 3000[2]	0.28 to 0.32	38,000 to 43,000	Used for resistance to growth and oxidation. *Exhaust manifold, truck and bus engines.*
1.80 to 2.00	3.20 to 3.40	2.60 to 2.70	0.60 to 0.70	0.09 to 0.12	0.14 to 0.18	0.70 to 0.85	1.25 to 1.35		0.35 to 0.45		3/16 to 3/4	46	212 to 228	4000 to 4200[4]	0.12 to 0.14	37,000 to 40,000	Used for improved thermal stability, growth resistance and strength. *Exhaust manifold, heavy duty truck engines.*
1.90 to 2.10	3.10 to 3.40			0.10 max	0.20 max	0.50 to 0.70	1.15 to 1.55		0.55 to 0.75		3/16 to 2.156		207 to 241	2500[2]	0.24 min	38,000 min	Used for wear resistance and strength. *Flywheel, light two cycle diesel engine.*
0.90 to 1.10	2.80 to 3.10	2.10 to 2.20	0.80 to 1.00	0.06 to 0.08	0.15 to 0.20	0.60 to 0.80	1.00 to 1.50		0.25 to 0.50		2-1/2 to 4	6000	190 to 220[17]	4900 to 4500[10]	0.08 to 0.10[18]	40,000 to 45,000[19]	Used for maximum resistance to wear and heat. Gives excellent service performance that is far superior to original installation. *Main liner, opposed piston type marine diesel engine.*
0.90 to 1.40	3.20 to 3.40					0.55 to 0.80	1.50 to 2.00		0.60 to 1.00		1-1/2 to 3	2000 to 10,000	200 to 240	3500 to 4000[9]	0.10 to 0.15	35,000 to 40,000	Used for growth resistance and resistance to cracking. *Metal melting pots, used for lead refining.*
0.90 to 1.10	2.85					0.80	0.80		0.15		18" Diam by 7 ft long	6000 to 6500	210			32,700 (20)	Has satisfactory density, wear resistance and machinability. Gland packings last twice as long as with a good grade of unalloyed "semi-steel." *Rams, used in 750 ton hydraulic press.*
0.73 to 0.98	2.73 to 2.78			0.06 max	0.181 max	0.37 to 0.45	4.45 to 4.50		1.48 to 1.57		5/8 to 2-1/2		555 *(21)	2212	0.156		Note:—Stress relieved load 3064 lb. and 0.173 in. deflection. Note:—When heated to 400 to 600°F. for one hour pef in. of thickness, plus 3 hours soaking time, and cooled at a rate of not more than 25° per hour to about 100°F. the strength of this iron is increased from 40 to 50 per cent over the as cast. *Valves.*

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IRON GRAY, CAST

Low Ni-Cr

Specific Applications of Alloy Cast Irons

Chemical Range, Per Cent											Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse		Tensile Strength psi	Remarks
Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements				Load Lb	Defl. In.		
1.20	3.30			0.10		0.60	2.00		1.00		1/2 to 1-1/2	100 to 300	260 to 300				Used for resistance to abrasion and toughness. Has three times the resistance to abrasion of plain cast iron. *Ore chutes, mining industry.*
0.80 to 1.00	3.20 to 3.40			0.08 to 0.12	0.15 to 0.20	0.50 to 0.70	4.40 to 4.60		1.40 to 1.60		1/4 to 1-1/2	10 to 40	*(23)				Used for abrasion resistance. Has 3 to 8 times the resistance to abrasion of plain white iron. *Pug mill knives, clay mixing.*
0.50 to 0.70	3.20 to 3.40					0.40 to 0.50	4.25 to 4.75		1.40 to 1.60		8	900	*(22)				Used for abrasion resistance. Has 10 times the resistance to abrasion of unalloyed chilled iron. *Roll beads, pulverizing cement, clinkers.*
1.30 to 1.70	2.80 to 3.10	0.00	2.80 to 3.10	0.08 to 0.12	0.10 to 0.20	0.50 to 0.80	4.00 to 4.50		1.30 to 1.60		1/4 to 1/2	1 to 5	525 to 550				Used for resistance to abrasion of sand. Has about 3 times the life of unalloyed white iron nozzles. *Sand blast nozzles.*
1.30 to 1.70	2.90 to 3.10	0.00	2.90 to 3.10	0.08 to 0.12	0.10 to 0.20	0.50 to 0.80	4.25 to 4.75		1.30 to 1.70		2 to 3	10 to 20	500 to 550				Used for resistance to wear and abrasion. *Wearing blocks.*
2.55	2.85			0.10	0.10	0.85	1.60		0.40		3/4 to 3	2000 to 16,000	240 min	5180[4]		54,900	Used for rigidity, high strength and wear resistance. *Beds, heavy duty machine tools.*
1.70 to 1.90	3.00 to 3.40	2.40 to 2.60	0.60 to 0.80	0.05 to 0.12	0.15 to 0.30	0.55 to 0.90	0.75 to 1.25		0.00 to 0.35		5/8 to 1-1/2	500 to 1000	190 to 210	3000 to 3800[4]	0.11 to 0.15	32,000 to 34,000	Used for density and wear resistance on ways. *Beds, light machine tools.*
1.30	3.20					0.80	1.50		0.60		3/4 to 2	400 to 600	200			40,000	Used for wear resistance, pressure tightness and good machinability. Tested at 15,000 psi. *Hydraulic cylinders, cylinder grinding machine.*
1.25 to 1.50	2.80 to 3.10			0.08 to 0.11	0.15 to 0.20	0.60 to 0.80	1.50 to 2.00		0.50 to 0.60		2 to 5	4000 to 30,000	200 to 240			40,000 to 50,000	Used for resistance to wear, freedom from frequent redressing and non-scratching of the steel sheets. Redressing of dies reduced from 4 to 6 times as compared to unalloyed iron dies and wear resistance increased proportionately. *Dies automobile body and fender forming.*
1.60 to 1.80	3.20 to 3.50			0.10 max.	0.18 max	0.60 to 0.80	1.75 to 2.00		0.00 to 0.30		2 to 24	100 to 24,000	180 to 241				*Dies, Body.*
1.35	2.90			0.09	0.07	0.80	1.75		0.35		2 to 5	4000 to 10,000	400 to 450			88,240	Heat treatment, see Footnote 24. Used for wear resistance, strength and toughness. *Dies, heavy duty sheet metal drawing.*

Footnotes at end of section, p. 38.

IRON GRAY, CAST

Low Ni-Cr

Specific Applications of Alloy Cast Irons

Chemical Range, Per Cent: Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements	Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse: Load Lb	Transverse: Defl. In.	Tensile Strength psi	Remarks
1.00 to 1.25	3.00 to 3.20	2.20 to 2.35	0.75 to 0.90	0.10 to 0.12	0.15 to 0.25	0.60 to 0.70	1.40 to 1.60		0.60 to 0.80		0.75 to 1.5	200 to 400	230 to 250	5500[4] to 6000	0.15 to 0.17	40,000 to 45,000	Used for resistance to heat, warpage and scaling. In excellent condition after continuous service for four (4) years. *Tube supports or tube sheets in low temperature range of cracking stills—1200°F. Max.*
1.40 to 1.50	3.40 to 3.50			0.06 to 0.08	0.60 to 0.70	0.50 to 0.60	0.16 to 0.20		0.28 to 0.35		1/4 to 1.0		200 to 250	2600[2] to 3000	0.28 to 0.32	30,000 to 40,000	Used for corrosion resistance. *Pipe and fittings, oil refinery piping.*
1.40 to 1.60	3.00 to 3.20	2.20 to 2.40	0.75 to 0.85	0.10 max	0.20 max	0.60 to 0.80	1.40 to 1.60		0.40 to 0.60		0.75 to 2.0	150 to 300	230 to 240	4500[4] to 5000	0.15 to 0.17	37,000 to 40,000	Used for resistance to scaling growth and thermal shock. *Grate bars, locomotive.*
1.20 to 1.60	3.00 to 3.30	2.20 to 2.40	0.70 to 0.90	0.12 max	0.20 max	0.60 to 0.80	2.50 to 2.70		0.80 to 1.00		0.75 to 1.5	400 to 800	300 to 350	4800[4] to 5500	0.10 to 0.14	40,000 to 45,000	Used for resistance to abrasive action of cinders and soot. *Smoke stacks, locomotive.*
1.40 to 1.60	3.10 to 3.30	2.40 to 2.75	0.55 to 0.70	0.05 to 0.10	0.10 to 0.40	0.55 to 0.75	1.00 to 1.50		0.00 to 0.45		3/4 to 2	25 to 200	200 to 220	3500 to 4000[4]	0.10 to 0.15	35,000 to 40,000	Used for wear resistance, strength, and toughness with good machinability. *Bushings, general use.*
2.00 to 2.30	3.40 to 3.60			0.12 max	0.25 max	0.50 to 0.70	0.75 to 1.50		0.20 to 0.40		3/4 to 2	10 to 50	180 to 200	2400 to 2600[2]	0.24 to 0.28	24,000 to 30,000	Used for resistance to heat checking, growth, scaling and wear. *Glass molds, glass manufacture (Chill Cast).*
1.40 to 1.60	3.20 to 3.60	2.50 to 2.70	0.60 to 0.90	0.04 to 0.10	0.15 to 0.40	0.60 to 0.80	1.25 to 1.75		0.50 to 0.75		3/4 to 1-1/2	50 to 150	200 to 240	3000 to 4000[4]	0.10 to 0.15	32,000 to 35,000	Used for resistance to growth and warping at moderately elevated temperatures. Has from 3 to 6 times the service life of regular gray iron. *Grate bars, stoker service.*
1.30 to 1.40	3.10 to 3.30			0.05 to 0.10	0.10 to 0.20	0.65 to 0.80	2.25 to 2.75		0.40 to 0.60		1/4 to 3/4	5 to 25					Eliminates copper "build-up" on the guides. Plain iron required cleaning 4 to 5 times daily. Alloy iron guides cleaned only every 4 days. *Guides, copper wire drawing.*
1.30 to 1.40	3.30 to 3.40		0.50 to 0.60	0.10	0.12 to 0.15	0.70 to 0.80	0.50 to 0.70		0.40 to 0.60		3	6500	190 to 210	2600 to 2800[2]	0.30	35,000 to 37,000	Used to withstand heat expansion and contraction. *Lead pot, melting lead.*
2.35 to 2.50	3.30 to 3.40	2.75 to 2.95	0.45 to 0.60	0.12 max	0.22 max	0.50 to 0.70	0.15 to 0.25		0.09 to 0.20		3/16 to 1/2	3.2 to 10.2	*(25)	3000 to 3600[4]	0.15 to 0.20	30,000 to 36,000	Used for wear resistance and strength. *Pistons, truck and tractor motors.*
1.50 to 1.60	2.90 to 3.10	2.25 to 2.35	0.75 to 0.85	0.08 to 0.09	0.25 to 0.30	0.45 to 0.55	1.00 to 1.50		0.30 to 0.50		5/8 to 2	250 to 400	225 to 240[9]	4500 to 5000[10]	0.11 to 0.125	43,000 to 48,000	Used for resistance to wear and heat. *Pistons, large diesel engines.*
1.90 to 2.25	3.40 to 3.60	2.70 to 3.10	0.45 to 0.75	0.10 max	0.35 to 0.70	0.50 to 0.70	0.90 to 1.10		0.20 to 0.30		0.250 to 0.375		297 to 311[26]				Gives better performance at elevated temperatures. *Piston rings, automobile, aircraft and diesel engines.*

Footnotes at end of section, p. 38.

Specific Applications of Alloy Cast Irons

Chemical Range, Per Cent											Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse		Tensile Strength psi	Remarks
Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements				Load Lb	Defl. In.		
2.15 to 2.30	3.30 to 3.40	2.70 to 2.90	0.50 to 0.70	0.12 max	0.15 to 0.22	0.50 to 0.70	0.15 to 0.25		0.09 to 0.20		9/16 to 3/4	0.26 to 0.70	200 to 230	3200 to 3800[4]	0.15 to 0.20	32,000 to 38,000	Used for wear resistance. *Valve stem guides, gasoline and diesel engines.*
0.60 to 0.80	3.40 to 3.60	2.75 to 2.95	0.60 to 0.70	0.10 to 0.12	0.15 to 0.20	0.40 to 0.60	2.00 to 3.00		0.30 to 0.50		2.0 to 3.5	10,000 to 16,000	240 to 270	4000[4] to 4500	0.15 to 0.18		Used for resistance to caustic corrosion and to cracking. *Kettles and pots—evaporation of caustic soda.*
1.60 to 1.80	2.80 to 3.10	2.00 to 2.20	0.80 to 0.90	0.08 max	0.15 max	0.70 to 0.80	1.80 to 2.00		0.70 to 0.80		0.75 to 2.0	40 to 100	250-270 as cast[27]			50,000 to 55,000	Used for uniform hardness and wear resistance. *Slush pump liners, for oil well drilling.*
0.60 to 0.80	3.10 to 3.30			0.10 to 0.12		0.60 to 0.70	4.50 to 5.00		1.40 to 1.60		1.0 to 2.5	500 to 3000	600 to 650	4500[4] to 6000	0.06 to 0.08	35,000 to 50,000 [28]	Used for abrasion resistance; Service life of above type of Ni-Hard liners reported 6 to 8 times that of unalloyed white iron liners. *Pump casings and impellers, handling liquids containing coal, sand and other abrasives.*
1.00 to 1.20	3.30 to 3.40					0.50 to 0.60	4.50		1.50		1/2 to 3/4	300 to 600	613				Metal is sand cast "Ni-Hard." Used to resist severe abrasion. The smooth surface facilities the flow of coke. Tests on 1/2 in. plates showed following results: Gray Iron No. 1—11,000 tons coke; Gray Iron No. 2—18,000 tons coke. Special Steel—33,500 tons coke; Ni-Hard—250,000 tons coke and still in use. *Chute plates, used in coke plants.*
0.60 to 0.80	3.40 to 3.60			0.08 to 0.12	0.15 to 0.20	0.40 to 0.60	4.40 to 4.60		1.40 to 1.60		2 to 4	1500 to 4000	*(22)				Used for abrasion resistance. Has 3 to 10 times the resistance to abrasion of plain chilled iron. *Muller tires, ceramic grinding.*
0.30 to 0.40	3.60 to 3.90			0.09 to 0.12	0.15 to 0.25	0.80 to 0.95	4.25 to 4.75		1.40 to 1.60		2 to 4	2500 to 9000	*(30)				Used for wear and abrasion resistance. *Pump impeller, sand and copper mill tailings.*
0.40 to 0.50	3.20 to 3.40	0.00	3.20 to 3.40	0.08 to 0.10	0.15 to 0.18	0.50 to 0.60	4.40 to 4.60		1.40 to 1.60		2 to 4	200 to 1500	*(29)	4500 to 6000[4]	0.06 to 0.08	35,000 to 50,000[28]	Used for resistance to wear, abrasion, and for toughness. In lead and zinc ore above type of "Ni-Hard" plates have given service of 450,000 tons as compared to 225,000 tons for manganese steel in same service. *Jaw crusher plates, crushing ore, gravel, stone.*

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Specific Applications of Alloy Cast Irons

IRON GRAY, CAST

Low Ni-Cr

Chemical Range, Per Cent											Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse		Tensile Strength psi	Remarks
Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements				Load Lb	Defl. In.		
0.40 to 0.50	3.20 to 3.40	0.00	3.20 to 3.40	0.08 to 0.10	0.15 to 0.18	0.50 to 0.60	4.40 to 4.60		1.40 to 1.60		4 to 6	6000 to 8000	*(29)	4500 to 6000[4]	0.06 to 0.08	35,000 to 50,000[28]	Used for resistance to wear, abrasion, and for toughness. In crushing lead and zinc ore "Ni-Hard" roll shells of above composition have given records of 18 weeks continuous service as compared to 12 weeks for manganese steel and 7 weeks for unalloyed chilled iron. *Roll crusher shells, crushing ore, gravel stone.*
0.50 to 1.00	3.10 to 3.60			0.120 max	0.10 to 0.20	0.40 to 0.60	4.50 to 5.00		1.50 to 2.00		1/2 to 2-1/2	100 to 500					Used for abrasion resistance. *Pump impeller, dredge or sludge pumps.*
0.50 to 1.00	3.15 to 3.45		3.10 to 3.40	0.120 max	0.10 to 0.20	0.40 to 0.60	4.50 to 5.50		1.50 to 2.00		3/4 to 2	100 to 3000	500 min	2500 to 3000[2]		30,000 min	Used for abrasion resistance. *Pump liners, dredge pumps.*
0.40 to 0.75	3.00 to 3.50			0.120 max	0.10 to 0.20	0.40 to 0.60	4.50 to 6.00		1.50 to 2.50		3 to 10	500 to 5000	*(31)				Used for abrasion resistance. *Crusher rolls crushing coal, phosphate, rock, etc.*
1.00 to 1.50	3.25 to 3.60			0.120 max	0.10 to 0.20	0.40 to 0.60	4.50 to 5.00		1.50 to 2.00		1 to 3	50 to 300	*(31)				Used for abrasion resistance. *Mill liners.*
0.60 to 1.10	3.20 to 3.60			0.08 to 0.12	0.20 max	0.35 to 0.50	4.50		1.50		1 to 2	300 to 400	*(32)				"Ni-Hard" Metal: Resists abrasion. With plain chilled iron 60,000 tons of coke is good service. With Ni-Hard over 200,000 tons have been crushed and 400,000 tons of coke is predicted ultimate life. *Roll segments, used in coke crushers.*
0.40 to 0.60	3.50 to 3.70			0.10 to 0.13	0.20 to 0.25	0.40 to 0.60	4.25 to 4.75		1.40 to 1.60		3 to 5	200 to 400	*(33)				Used for abrasion resistance. Has 4 to 5 the resistance to abrasion of unalloyed chilled iron. *Ball mill liner, ore grinding.*

SPECIAL CASTINGS

Low Ni-Cr
TYPE 1 AND TYPE 2

Chemical Range, Per Cent											Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse		Tensile Strength M psi	Remarks	
Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements				Load Lb	Defl. In.			
0.40[57] to 0.70	3.00 to 3.60	0.10 max		0.15 max	0.40 max	0.40 to 0.70	4.00 to 4.75		1.40 to 3 50		1/4 to 4	1 to 2000	550 to 650	4000 to 5000[4]	.080 to .110[4]	40 to 50[51]	Sand Cast	Type 1[58] Regular
											1 to 36	10 to 30,000	600 to 725	4500 to 6800[4]	.080 to .120[4]	50 to 60[51]	Chill Cast	
0.40[57] to 0.70	2.90 to max*	0.10 max		0.15 max	0.40 max	0.40 to 0.70	4.00 to 4.75		1.40 to 3.50		1/4 to 4	1 to 5000	525 to 625	4500 to 5500[4]	.100[4] to .120	45 to 55[51]	Sand Cast	Type 2[58] Hi-Strength
											1 to 36	10 to 30,000	575 to 675	5500 to 7000[4]		60 to 75[51]	Chill Cast	

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Low Ni-Mo

Specific Applications of Alloy Cast Irons

Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements	Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse Load Lb	Transverse Defl. In.	Tensile Strength psi	Remarks
2.00 to 2.30	3.00 to 3.15	2.10 to 2.35	0.80 to 0.90	0.100 to 0.120	0.100 to 0.150	0.85 to 0.95	1.50 to 1.75	0.80 to 0.90			1 to 2	80	241 to 285			55,000 to 70,000	Used because of high impact value. ***Crankshafts, gasoline starting motor for diesel engine.***
1.55 to 1.70	3.15 to 3.30			0.06 to 0.10	0.10 to 0.15	0.75 to 0.90	0.00 to 0.10	0.40 to 0.45		Ti 0.05 to 0.08	1/2 to 2-1/2	500 to 5000	223 to 229	2900 to 3300[2]	0.28 to 0.35	45,000 to 51,000	Used for strength, close grain, resilience, and wear resistance. Service performance satisfactory. ***Cylinder heads, diesel and gas engines used on air, natural gas and ammonia compressors.***
1.55 to 1.70	3.15 to 3.30			0.06 to 0.10	0.10 to 0.15	0.75 to 0.90	0.00 to 0.10	0.40 to 0.45		Ti 0.05 to 0.08	1/2 to 2-1/2	500 to 5000	223 to 229	2900 to 3300[2]	0.28 to 0.35	45,000 to 51,000	Used for density, strength, resilience and wear resistance. Service performance satisfactory. ***Cylinder liners, diesel and gas engines used on air, natural gas and ammonia compressors.***
2.10 to 2.30	3.10 to 3.30	2.40 to 2.80	0.50 to 0.70	0.10 to 0.13	0.15 to 0.20	0.70 to 0.90	0.60 to 0.80	0.60 to 0.80			1/2 to 3/4	13 to 17	241 to 262	5000 to 5600[4]		46,000 to 54,000	Used for wear resistance and strength at high temperature. ***Cylinder liners, diesel and truck engines.***
1.55 to 1.70	3.15 to 3.30			0.06 to 0.10	0.10 to 0.15	0.75 to 0.90	0.00 to 0.10	0.40 to 0.45		Ti 0.05 to 0.08	1/2 to 2-1/2	500	223 to 229	2900 to 3300[2]	0.28 to 0.35	45,000 to 51,000	Used for strength, close grain, resilience and wear resistance. Service performance satisfactory. ***Pistons, diesel and gas engines used on air, natural gas and ammonia compressors.***
1.65 to 1.80	2.50 to 2.70	1.80 to 2.15	0.55 to 0.70	0.07 max	0.15 max	0.50 to 0.70	1.25 to 1.75	0.55 to 0.65		Va 0.12	1 to 1.25	60 to 90	229 to 241			63,000 to 68,500	Used for wear resistance and machinability with fine lammelar pearlitic structure. ***Pistons, diesel engine.***
1.40 to 1.80	3.15 to 3.40			0.10 to 0.12	0.18 to 0.25	0.70 to 0.90	1.90 to 2.20	0.40 to 0.60			1-1/2 to 3	300 to 600	249 to 285	3000 to 3200[2]	0.26 to 0.30	40,000 to 50,000	Used for wear resistance and freedom from scratches in finished balls. ***Lapping plates, ball bearing lapping.***
2.00 to 2.10	3.10 to 3.30	2.50 to 2.65	0.60 to 0.65	0.05 to 0.10	0.20 to 0.23	0.75 to 0.85	0.50	0.50			3/4	8	234 to 245	3000[2]	0.32	48,000 to 50,000	Used for wear resistance. In service 2 years and apparently stand up as well as tool steel cams. ***Control cams, steam turbine governing mechanism.***
2.00 to 2.15	3.15 to 3.30	2.50 to 2.60	0.65 to 0.75	0.08 to 0.10	0.20 to 0.23	0.70 to 0.80	0.50	0.50			3/8 to 3/4	5 to 10	220 to 245	3000 to 3200[2]	0.35 to 0.38	48,000 to 52,000	Used to resist wear against high strength hard chains. Has appreciable shock resistance. ***Lift wheels, small wheels, for chain hoists.***

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Specific Applications of Alloy Cast Irons

IRON GRAY, CAST

Low Cr-Mo

Chemical Range, Per Cent											Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse		Tensile Strength psi	Remarks
Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements				Load Lb	Defl. In.		
1.80 to 2.20	2.90 to 3.10	2.30 to 2.50	0.60 to 0.80	0.06 to 0.80	0.06 to 0.10	0.60 to 0.80		0.30 to 0.40	0.35 to 0.45		3/8 to 1	70	228 to 248	4600 to 5000[10]	0.150 to 0.165	46,000 to 50,000	Used for high strength, wear resistance and machinability. ***Brake drums, truck and automobile, hub and drum integral.***
2.20 to 2.50	3.25 to 3.55			0.10 max	0.20 max	0.50 to 0.70		0.45 to 0.65	0.45 to 0.65		1/2 to 1-1/4	35 to 150	207 to 241	2500 to 2900[2]	0.24 to 0.34	38,000 to 44,000	Used for good resistance to wear and heat cracking. ***Brake drums and flywheels, trucks and coaches.***
1.50 to 1.70	3.00 to 3.10		0.70 to 0.80	0.10 to 0.12	0.20 to 0.25	0.70 to 0.80		0.50 to 0.60	0.50 to 0.60		1-1/2	150 to 200	230 to 250	2800 to 3000[2]	0.20 to 0.25	45,000 to 50,000	Used for strength and wear resistance. ***Com. gear diesel engine.***
1.80 to 2.00	3.20 to 3.40	2.60 to 2.80	0.60 to 0.80	0.12 to 0.15	0.16 to 0.20	0.70 to 0.90		0.15 to 0.20	0.15 to 0.20		3/16 to 2	278	212 to 231	4600 to 5000[10]	0.14 to 0.16	38,000 to 41,000	Used for high hardness in bores, freedom from cracks and good machinability at rather high strength. ***Cylinder blocks, automobile engines.***
2.15 to 2.35	3.10 to 3.35	2.50 to 2.70	0.60 to 0.70	0.08 max	0.16 max	0.60 to 0.80		0.35 to 0.55	0.30 to 0.50		3/16 to 5/8	125 to 165	207 to 241	2700 to 3200[2]	0.25 to 0.32	39,000 to 45,000	Has good wear resistance, good castability and fair machinability. Performance considered excellent. ***Cylinder blocks, small and medium sized truck engines.***
2.00 to 2.20	3.30 to 3.40		0.60 to 0.70	0.10 to 0.12	0.15 to 0.20	0.70 to 0.80		0.50 to 0.60	0.35 to 0.50		5/8 to 1-1/2	450 to 500	210 to 230	2500 to 2700[2]	0.25 to 0.30	35,000 to 37,000	Used for shock and heat resistance qualities. Very satisfactory in use for 3 years. ***Cylinder heads, diesel engines.***
1.65 to 1.75	3.20 to 3.30		0.80 to 0.85	0.10 max	0.15 to 0.20	0.70 to 0.80		0.60 to 0.70	0.40 to 0.50		1-3/4	800	220 to 240	2600 to 2800[2]	0.25	35,000 to 37,000	Used for wear resisting properties. Many installations have had no failures. ***Cylinder liners, diesel engines.***
2.20 to 2.40	3.00 to 3.20	2.20 to 2.50	0.60 to 0.80	0.10 to 0.12	0.16 to 0.20	0.70 to 0.90		0.90 to 1.10	0.20 to 0.30		1/2 to 7/8	17 to 24	269 to 286	6000 to 6500[4]		55,000 to 65,000	Used for excellent wear resisting properties. Liners are heat-treated. ***Cylinder liners, diesel engines.***
2.00 to 2.25	2.75 to 3.20			0.12 max	0.20 max	0.65 to 0.90		0.50 max	0.25 max		3/16 to 1/2	50	255 max	4200 to 4600[34]		47,500 to 52,300	Used to obtain increased strength as compared to non-alloyed metal. Apparently reduced breakage. ***Exhaust manifold, automobile engines.***
1.80 to 2.20	3.30 to 3.50	2.70 to 2.90	0.50 to 0.70	0.10 to 0.15	0.18 to 0.23	0.50 to 0.70		0.35 to 1.00	0.35 to 0.40		3/16 to 1/2	25 to 88	200 to 248	3600 to 4600[13]	0.12 to 0.15	38,000 to 50,000	Used to resist growth and oxidation and for strength at high temperatures. ***Exhaust manifold, automobile and truck engines.***
2.00 to 2.20	3.40 to 3.60			0.12 max	0.20 max	0.60 to 0.70		0.40 to 0.60	0.15 to 0.25		1/4 to 1	3 to 15	*(35)				Can be quenched and drawn to required hardness. ***Gear, cam, truck engine.***
2.40	3.35	2.75	0.60	0.07	0.19	0.60		0.50	0.12		0.035 to 0.160	1-5/8	217 to 241			39,000 to 47,000	***Pistons, automobile.***
2.60 to 2.80	3.60 to 3.75	3.05 to 3.30	0.45 to 0.55	0.06 to 0.09	0.30 to 0.40	0.60 to 0.80		0.15 to 0.25	0.15 to 0.25		1/8 to 3/16	0.1 to 0.25	*(36)	Not used	Not used	22,000 to 26,000	Used for improved wear resistance as compared to base iron unalloyed. Metal is machinable and has a pearlitic-sorbitic structure. ***Piston rings, diesel and gasoline engines.***

Footnotes at end of section, p. 38.

Specific Applications of Alloy Cast Irons

IRON GRAY, CAST

Low Cr-Mo

Chemical Range, Per Cent											Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse		Tensile Strength psi	Remarks
Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements				Load Lb	Defl. In.		
1.60 to 1.70	3.40 to 3.50			0.10 max	0.15 to 0.20	0.60 to 0.70		0.35 to 0.45	0.30 to 0.40		1/2 to 1	25	220 to 240	2900 to 3000[34]	0.2	40,000 to 45,000	*Valve gauge, diesel engine.*
1.40 to 1.60	3.40 to 3.60			0.05 to 0.07	0.60 to 0.65	0.50 to 0.60		0.40 to 0.70	0.80 to 1.10		1.0 to 1.5	1000 to 5000	243 to 301	3000[2] to 4000	0.20 to 0.30	30,000 to 50,000	Used for wear resistance. *Rollers for rolling mills.*

IRON GRAY, CAST

Low Ni-Cr-Mo

Chemical Range, Per Cent											Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse		Tensile Strength psi	Remarks
Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements				Load Lb	Defl. In.		
1.10 to 1.30	3.70 to 3.90			0.10 max	0.20 max	0.60 to 0.80	1.75 to 2.25	0.35 to 0.50	0.35 max		1/2 to 3/4	25 to 75	210 to 230	2000 to 2300[2]	0.30 to 0.38	28,000 to 34,000	Used in applications requiring resistance to heat checking and wear. *Performance excellent. Brake drums, aircraft.*
2.00 to 2.20	3.00 to 3.20	2.40 to 2.60	0.60 to 0.90	0.08 to 0.10	0.08 to 0.10	0.70 to 0.90	0.40 to 0.60	0.40 to 0.60	0.80 to 1.00		1 to 2	19 to 35	286 to 311[37]	5600 to 5900[4]		50,000 to 60,000	Used for hardness, strength and toughness. Material superior to carburized 1020 steel in fatigue tests. Wear resistance very good. The cams are heat treated to above the critical for a depth of 1/8 in. and air cooled. *Camshafts, automobile engine.*
2.10 to 2.40	3.10 to 3.40			0.10 max	0.25 max	0.50 to 0.80	0.25 to 0.40	0.40 to 0.60	0.60 to 1.00		1 to 1-3/4	1 to 10	200 to 225	4000[4]		40,000 min	Note: Brinell hardness on body, also bearings, gear blank, 269-302. Chill cam and eccentric 65 min. scleroscope. (camshaft). Brinell hardness given is on camshaft gear. *Camshafts, automotive, also diesel camshaft gear.*
2.20 to 2.50	2.60 to 2.80		0.60 to 0.75	0.08 max	0.08 max	0.90 to 1.00	0.75 to 1.00	0.70 to 1.25	0.10 to 0.20		1-1/4 to 3	200 to 1000	220 to 240	6000 to 7000[4]	0.18 to 0.22	60,000 to 80,000	Used for wear resistance, strength, cost and convenience. *Crankshafts, trucks, submarines, etc.*
2.40 to 2.80	2.40 to 2.90	1.80 to 2.10	0.60 to 0.90	0.04 to 0.07	0.05 to 0.08	0.08 to 1.00	1.00 to 1.25	1.00 to 1.25	0.10 to 0.20		3/4 to 4	80 to 2250	290 to 320	7000 to 7700[4]		60,000 to 75,000[38]	Used for wear and impact resistance and high strength. Performance equal to or superior to steel. In fatigue tests metal lasted 81 hours as against 16 hours for steel. *Crankshafts, automobile and diesel engines.*
1.90 to 2.30	2.75 to 3.00	1.90 to 2.10	0.75 to 0.90	0.10 max	0.20 max	0.55 to 0.75	0.75 to 1.00	0.40 to 0.60	0.20 max		1-1/2 to 3	15 to 40	220 to 260	3200 to 3500[2]	0.27 to 0.30	55,000 to 65,000	Used for wear resistance, strength, and impact resistance. *Crankshafts, small engines and compressors.*
2.20 to 2.40	3.05 to 3.30		0.60 to 0.75	0.085 max	0.19 max	0.65 to 0.90	0.15 to 0.30	0.30 to 0.55	0.30 to 0.55		1/4 to 3/4	160 to 310	207 to 241	2500 to 3100[2]		43,000 to 44,000	Used for good wear and corrosion resistance. *Cylinder blocks, truck and coach gasoline engine (small and medium).*

Footnotes at end of section, p. 38.

Specific Applications of Alloy Cast Irons

Chemical Range, Per Cent											Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse		Tensile Strength psi	Remarks
Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements				Load Lb	Defl. In.		
2.35	3.35	2.70	0.60	0.14	0.16	0.65	1.25	1.25	0.25		5/32 to 1	250 to 400	* (39)	6000[4]	0.21	60,000	Used for wear resistance, hardness and strength. *Cylinder blocks, trucks.*
2.25 to 2.45	3.10 to 3.40	2.60 to 2.80	0.50 to 0.70	0.08 max	0.16 max	0.60 to 0.80	0.10 to 0.30	0.20 to 0.40	0.20 to 0.40		3/16 to 3/4	200 to 220	163 to 207	2800 to 3200[2]	0.29 to 0.34	40,000 to 45,000	Used for high strength, good castability and excellent machinability. Service performance excellent. Cylinder liners are used in these blocks. *Cylinder blocks, large truck and bus valve-in-head engines*
2.20 to 2.40	3.00 to 3.10		0.70 to 0.80	0.07 max	0.15 max	0.70 to 0.90	0.20 to 0.30	0.60 to 0.80	0.20 to 0.35		1/4 to 1/2	100 to 110	223 to 248	2850 to 3550[2]		50,000 to 58,000	Used for high strength. *Cylinder heads, medium and large truck and coach gasoline engines.*
2.00 to 2.20	3.00 to 3.40			0.12 max	0.20 max	0.75 to 0.95	0.40 min	0.75 min	0.40 min		3/16 to 1-1/2	50 to 100	240 to 260			50,000	Metal shows good strength and resistance to cracking or dimensional change under conditions of heat and pressure. *Cylinder heads, truck diesel engines.*
2.20 to 2.40	3.00 to 3.20	2.30 to 2.60	0.50 to 0.70	0.08 to 0.12	0.12 to 0.17	0.70 to 0.90	0.30 to 0.50	0.30 to 0.50	0.30 to 0.50		1/2 to 7/8	19 to 24	248 to 277	4600 to 5300[4]		46,000 to 54,000	Used for wear resistance and machinability Liners are heat-treated. *Cylinder liners, automobile and truck engines.*
2.00 to 2.20	3.00 to 3.20	2.10 to 2.40	0.60 to 0.90	0.08 to 0.10	0.08 to 0.10	0.70 to 0.90	0.40 to 0.60	0.40 to 0.60	0.80 to 1.00		1/2 to 1-1/4	80 to 150	286 to 311	5000 to 5900[4]		50,000 to 60,000	Used for wear resistance and strength. Service performance considered excellent. *Cylinder liners, diesel engines.*
2.00 to 2.20	3.00 to 3.20	2.20 to 2.35	0.75 to 0.90	0.10 max	0.20 max	0.50 to 0.70	0.20 to 0.40	0.40 to 0.60	0.20 to 0.40		3/8 to 7/8	22	* (40)	4200 to 5000[4]	0.15 to 0.20	42,000 to 50,000	Used for wear resistance and strength. Heat Treatment[41]. *Cylinder sleeves, diesel engines.*
2.10 to 2.40	3.10 to 3.40			0.10 max	0.25 max	0.50 to 0.80	0.25 to 0.40	0.40 to 0.60	0.60 to 1.00		1/2 to 1-3/4	4	200 to 225	4000[4]		40,000 min	*Fuel injection pump drive gear, diesel.*
1.90 to 2.40	3.00 to 3.40		0.50 to 0.90	0.14 max	0.14 max	0.70 to 1.00	1.00 to 1.50	0.35 to 0.75	0.20 to 0.50		5/16 to 2	100 to 300	241 to 286	3500 to 3900[2]	0.260 to 0.280	50,000 to 60,000	Used for strength and stiffness. *End plates, and transmission, trucks.*
2.20 to 2.40	3.10 to 3.35		0.40 to 0.50	0.10 max	0.15 max	0.60 to 0.80	1.00 to 1.40	0.35 to 0.45	0.20 to 0.40		7/16 to 1-1/2		197 to 235	2700[2]	0.24 min	40,000 min	Has good wear resistance and high strength properties. *Gear, idler, camshaft and crankshaft, light two-cycle diesel engines.*
2.10 to 2.40	3.0 to 3.40			0.10 max	0.25 max	0.50 to 0.80	0.25 to 0.40	0.40 to 0.60	0.60 to 1.00		7/32 to 5/8	0.82 to 0.85	269 to 302	4000 min[4]		40,000 min	Ignition, distributors, drive shaft gear. *Truck—oil pump and distributor drive gear.*
1.25 to 1.40	2.80 to 3.10	2.10 to 2.30	0.80 to 1.00	0.06 to 0.08	0.10 to 0.20	0.60 to 0.80	1.00 to 1.25	0.25 to 0.35	0.20 to 0.30		2-1/2 to 4	4000	190 to 220[17]	5000 to 5500[17]	0.11 to 0.13	45,000 to 50,000[17]	Used for resistance to wear and heat. Service performance considered excellent. *Main liner, marine diesel engine.*
2.35	3.35	2.85	0.50	0.14	0.16	0.65	0.75	0.40	0.25		5/32 to 1		200	5600[4]	0.17	48,000	Good strength and wear resistance qualities. *Pistons, truck.*

Footnotes at end of section, p. 38.

Specific Applications of Alloy Cast Irons

IRON GRAY, CAST

Low Ni-Cr-Mo

Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements	Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse Load Lb	Transverse Defl. In.	Tensile Strength psi	Remarks
1.50 to 1.90	3.50 to 3.75	2.80 to 3.10	0.50 to 0.80	0.06 to 0.10	0.30 to 0.50	0.50 to 0.80	0.50 to 1.50	0.25 to 0.60	0.25 to 0.60		0.375 to 1.0; 5.0 to 30.0 diam	0.25 to 0.30	*[42]	1300 to 1600[34]	0.14 to 0.16	30,000 to 45,000[43]	Alloyed irons used for improved heat and wear resistance and higher strength as compared to unalloyed irons. ***Pistons rings, diesel and gasoline engines, compressors, etc.***
1.80 to 2.10	2.80 to 2.90	2.15 to 2.25	0.60 to 0.70	0.04 to 0.08	0.10 to 0.20	0.60 to 0.80	0.15 to 0.25	0.40 to 0.60	0.15 to 0.25		3/4 to 1-1/4	5 to 25	220 to 240	3300 to 3600[2]		50,000 to 53,000	Used for strength and pressure resistance. ***Steam pressure castings, chemical machinery.***
1.20 to 1.40	2.90 to 3.10	2.10 to 2.20	0.70 to 1.00	0.09 to 0.12	0.04 to 0.06	0.80 to 1.00	0.90 to 1.10	0.60 to 0.80	0.40 to 0.60		2 to 6	4000 to 16,000	269 to 293[38]			58,000 to 60,700	Used for high strength and density at machinable hardness. ***Pumps, well drilling, high pressure (5000 psi).***
1.40 to 1.50	3.20 to 3.30			0.11 max	0.20 max	0.60 to 0.70	0.90 to 1.00	0.80 to 0.90	0.60 to 0.70		6 to 10	400 to 3600	200 to 220				Used for strength in heavy sections. ***Dies, forming.***
2.00 to 2.40	2.60 to 2.90	1.90 to 2.10	0.65 to 0.80	0.10 max	0.20 max	0.55 to 0.70	1.40 to 1.70	0.40 to 0.60	0.35 to 0.50		2 to 15	To 5000	*[44]	3200 to 3600[2]	0.22 to 0.29	55,000 to 65,000	Heat treatment, see Footnote 45. Used for wear resistance, high strength and shock resistance. ***Dies, forming and hot bending.***
1.40 to 1.60	2.90 to 3.10					0.80 to 1.00	1.25 to 1.50	0.40	0.50		2 to 4	2500 to 3000	240 min			50,000 min[46]	Has high strength and wear resistance. Thermal stability up to 800°F. ***Cylinders, cylinder heads, uniflow steam engines.***
2.40 to 2.70	2.70 to 2.95	1.95 to 2.15	0.75 to 0.90	0.10 max	0.25 max	0.55 to 0.70	1.40 to 1.60	0.40 to 0.60	0.35 to 0.50		1/2 to 3	10 to 50	*[44]	3100 to 3400[2]	0.25 to 0.30	50,000 to 60,000	Heat treatment· See footnote 47. Used for wear resistance, strength and shock resistance. ***Gears, cut gears—general machinery.***
2.20 to 2.50	2.85 to 3.10	2.15 to 2.25	0.70 to 0.85	0.10 max	0.20 max	0.50 to 0.70	1.85 to 2.05	0.80 to 1.00	0.15 to 0.25		1/2 to 1-1/2	Up to 150	*[48]	3400 to 3700[2]	0.35 to 0.40	60,000 to 70,000	Used for wear resistance, high strength and impact resistance. Heat Treatment, see Footnote 49. ***Gears, heavy duty bevel gears.***
1.80 to 2.00	3.00 to 3.10	2.10 to 2.20	0.90	0.10 max	0.15 max	0.80 to 0.90	0.10	0.15	0.25		1 to 2-1/2	200 to 6000	180 to 210	2600[2]	0.25	40,000 to 50,000	Used for shock and wear resistance. ***Cylinder liner forging hammer cylinders.***
2.30 to 2.50	2.70 to 3.00			0.12 max	0.20 max	0.70 to 0.90	1.25 to 1.50	0.30 to 0.50[50]	0.35 max[50]		1 to 4	1500 to 8000	260 to 290	3300 to 4000[2]	0.30 to 0.40	55,000 to 70,000	Used for strength, density, erosion resistance and pressure tightness. ***Valves, water works sluice gates.***
1.90 to 2.10	2.85 to 2.95			0.120 max	0.10 to 0.20	0.80 to 1.00	1.50 to 1.75	0.20 to 0.40	0.30 to 0.40		1-1/2 to 2-1/2	1500 to 3500	262 to 275	3000[2] min		50,000	Used for high strength. ***Valve plungers, large values.***

Footnotes at end of section, p. 38.

IRON GRAY, CAST

Low Alloy

Specific Applications of Alloy Cast Irons

Chemical Range, Per Cent											Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse		Tensile Strength psi	Remarks
Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements				Load Lb	Defl. In.		
1.90 to 2.10	3.20 to 3.30			0.11 max	0.20 max	0.50 to 0.70		1.00		Cu 0.50	7/16 to 1/2	24	228 to 241	3600 to 3900[2]	0.32 to 0.36	51,000 to 55,000	Used for resistance to wear and heat. *Brake drums, aircraft.*
1.70 to 2.40	3.20 to 3.30		0.60 to 0.75	0.05 max	0.20 max	0.60 to 0.80		0.50		Cu 0.75	3/16 to 2-1/4	22 to 270	200 to 235			52,000 to 55,000[51]	Excellent wear and thermal stability. *Brake drums, trucks, busses, trolley coaches, trailers.*
1.90 to 2.10	3.30 to 3.50		0.60 to 0.70	0.10 max	0.20 max	0.50 to 0.70	0.20 to 0.50		0.55 to 0.75	Cu 1.00 to 1.50	1/2 to 1-1/4	35 to 150	207 to 241	2500 to 2900[2]	0.24 to 0.32	37,000 to 41,000	Used for good wear and heat crack resistance. *Brake drums and clutch plates, trucks, and coaches.*
1.80 to 2.10	3.15 to 3.40		0.55 to 0.65	0.10 max	0.20 max	0.60 to 0.80				Cu 0.75	3/8 to 3/4	50 to 80	207 to 217[9]	3800 to 4000[4]	0.12 to 0.14	35,000 to 38,000	*Brake drums, light trucks.*
0.55 to 0.70	3.30 to 3.65			0.10 max	0.10 max	0.15 to 0.35			0.25 max	Cu 2.50 to 3.00	1/16 to 1-1/4	6 to 12	200 to 500[52]	3500 to 3800[6]	0.10 to 0.12		*Camshafts, automobile.*
2.00 to 2.30	2.90 to 3.20	2.40 to 2.60	0.60 to 0.80	0.08 to 0.10	0.15 to 0.20	0.60 to 0.70		0.35 to 0.45	0.15 to 0.25	Ti 0.05 to 0.10	1/2 to 3/4	12	223 to 248	2800 to 3000[2]	0.33 to 0.38	40,000 to 48,000	Used for strength, wear resistance, and machinability. *Clutch plates, automobile.*
1.80 to 2.10	3.15 to 3.40			0.10 max	0.10 to 0.20	0.60 to 0.80				Cu 0.50 to 0.75	1/4 to 1	105 to 217	180 to 228	3300 to 3800[6]	0.11 to 0.13		*Cylinder blocks, automobile engines.*
2.25 to 2.40	3.25 to 3.40		0.50 to 0.65	0.15 max	0.18 max	0.55 to 0.75	0.25 to 0.30		0.20 to 0.30	Cu 0.75 to 1.00		200 to 300	190 to 220	4000 to 4500[4]	0.17 to 0.20	38,000 to 42,000	Used for wear resistance and machining. *Cylinder blocks, automobiles.*
2.00 to 2.20	3.20 to 3.40			0.12 max	0.20 max	0.75 to 0.95			0.15 to 0.25	Cu 0.40 to 0.60	3/16 to 3	100 to 900	196 to 220			36,000	Used for maintaining pearlitic structure in cylinder bore sections. *Cylinder blocks, light truck and tractor, Navy motor boats.*
2.00 to 2.25	3.15 to 3.35	2.50 to 2.70	0.65 to 0.85	0.08 to 0.13	0.15 to 0.21	0.60 to 0.80	0.10 to 0.20	1.00 to 1.10	0.70 to 0.90	Cu 1.00 to 1.20	3/16 to 2-1/2	220 to 470	248 to 269[9]	3100 to 3300[2]	0.330 to 0.444	50,000 to 53,000	Used for high strength, hardness, toughness, graphite distribution, and structure. *Cylinder blocks, truck diesel engines.*
1.55 to 1.70	3.15 to 3.30			0.06 to 0.10	0.10 to 0.15	0.75 to 0.90	0.00 to 0.10	0.40 to 0.45		Ti 0.05 to 0.08	1/2 to 2-1/2	500 to 5000	223 to 229	2900 to 3300[2]	0.28 to 0.35	45,000 to 51,000	Used for strength, close grain, resilience, and wear resistance. Service performance satisfactory. *Cylinder Heads, diesel and gas engines used on air, natural gas and ammonia compressors.*
2.40 to 2.70	3.20 to 3.50		0.50 to 0.60	0.10 max	0.18 max	0.60 to 0.80				Cu 0.50 min	1/4 to 1/2	25 to 50	196 to 212[9]	3700 to 3900[4]	0.12 to 0.14	32,000 to 35,000	*Cylinder heads, eight cylinder automobile engine.*
1.60 to 2.25	2.80 to 3.30	2.25 to 2.50	0.55 to 0.80	0.10 max	0.30 max	0.50 to 0.90	0.20 to 0.40		0.20 to 0.40	Cu 1.00 to 1.25	3/16 to 1-1/2	80 to 700	217 to 241	3400 to 3600[2]	0.250 to 0.270	39,000 to 45,000	Used for tightness and strength. *Cylinder blocks, and heads, trucks.*
2.05 to 2.25	3.25 to 3.50			0.12 max	0.25 max	0.55 to 0.60	0.10 to 0.25		0.55 to 0.80	Cu 1.00 to 1.50	0.288 to 0.490		*(56)	2400[2] min	0.20 min	37,000	Used for wear and hardenability properties. *Cylinder liners, light, two-cycle diesel engines.*

Footnotes at end of section, p. 38.

IRON GRAY, CAST

Low Alloy

Specific Applications of Alloy Cast Irons

Chemical Range, Per Cent											Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse		Tensile Strength psi	Remarks
Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements				Load Lb	Defl. In.		
1.40 to 1.50	3.40 to 3.60	2.65 to 2.75	0.75 to 0.85	0.05 to 0.11	0.15 to 0.25	0.80 to 1.00	0.00 to 0.20		0.50 to 0.60	Ti 0.07 to 0.08		2450	*[14]	2500 to 2700[2]	0.18 to 0.22	35,000 to 37,000	Used for thermal stability, and wear resistance. Metal has pearlitic matrix. Machinability and wear resistance are satisfactory. ***Cylinder liners, diesel and gas engines.***
1.75 to 2.25	2.75 to 3.45	1.75 to 2.50	0.50 to 1.10	0.14 max	0.20 max	0.75 to 1.20		0.35 to 0.70	0.50 to 1.00	Cu 1.00 to 1.50	3/8 to 5/8	20 to 60	*[54]	2500 to 3000[55]	0.24 to 0.30[55]	40,000 to 55,000	Used for wear resistance, hardenability and good machinability. ***Cylinder sleeves, diesel motors.***
1.80 to 2.10	3.20 to 3.40		0.55 to 0.60	0.12 max	0.20 max	0.60 to 0.80			0.15 to 0.25	Cu 0.40 to 0.60	3/8 to 3/4	50 to 150	207 to 217[4]	3500 to 3800[4]	0.12 to 0.14	35,000 to 38,000	***Flywheel housing side rails, steering gradient, farm tractor.***
1.40 to 1.60	3.05 to 3.25			0.12 max	0.20 max	0.75 to 0.90				Cu 1.50	1/4 to 5/8	97	240 min	3000 to 3300[2]	0.23 to 0.33	50,000 to 55,000	Used because of excellent wear properties. ***Gear, Idler.***
1.90 to 2.10	2.90 to 3.10			0.10 max	0.18 max			0.60 to 0.80		Va 0.12 to 0.16	3/8 to 1-1/2	8 to 20	217 to 241	3600 to 3900[2]	0.30 to 0.36	50,000 to 55,000	Used for wear resistance and impact properties. ***Gear, truck.***
1.55 to 1.70	3.15 to 3.30			0.06 to 0.10	0.10 to 0.15	0.75 to 0.90	0.00 to 0.10	0.40 to 0.45		Ti 0.05 to 0.08	1/2 to 2-1/2	500	223 to 229	2900 to 3300[2]	0.28 to 0.35	45,000 to 51,000	Used for strength, close grain, resilience and wear, resistance. Service performance satisfactory. ***Pistons, diesel and gas engines used on air, natural gas and ammonia compressors.***
1.65 to 1.80	2.50 to 2.70	1.80 to 2.15	0.55 to 0.70	0.07 max	0.15 max	0.50 to 0.70	1.25 to 1.75	0.55 to 0.65		Va 0.12	1 to 1.25	60 to 90	229 to 241			63,000 to 68,500	Used for wear resistance and machinability with fine lammelar pearlitic structure. ***Pistons, diesel engine.***
2.70 to 2.90	3.70 to 3.80	3.00 to 3.10	0.65 to 0.75	0.10 max	0.40 to 0.50	0.60 to 0.70	0.45 to 0.55	0.45 to 0.55	0.07 to 0.12	Cu 0.70 to 0.80 Va 0.05 to 0.10	1/8 to 5/16	2 to 4 oz	*[53]			45,000 to 52,000[54]	Used for holding tension in piston rings under severe heat conditions and for wear resistance. ***Piston rings, aircraft tank and diesel motors.***
2.60 to 2.80	3.60 to 3.75	3.05 to 3.30	0.45 to 0.55	0.06 to 0.09	0.30 to 0.40	0.60 to 0.80				Ti 0.10 to 0.20 Va 0.10 to 0.15	1/8 to 3/16	0.1 to 0.25	*[36]	Not Used	Not Used	22,000 to 26,000	Used for improved wear resistance as compared to that of the base iron. Alloy used produces a dense pearlite that is sorbitic in character. ***Piston rings, diesel and gasoline engines.***
0.30 to 0.65	3.60 to 3.90			0.10 max	0.10 max	0.15 to 0.50				Cu 0.75 to 1.00	1/16 to 1/8		*[55]				***Valve Tappets, automobile and tractor.***
1.60 to 1.80	2.60 to 2.80	1.80 to 2.00	0.80 to 0.90	0.04 to 0.08	0.10 to 0.20	0.40 to 0.60	0.40 to 0.50	0.80 to 1.00	0.50 to 0.60	Ti 0.10 to 0.20	3/4 to 1-1/2	5 to 25	250 to 270	4400 to 4600[2]		64,000 to 66,000	Used for high strength and resistance to pressure. ***Pressure castings—high strength castings for chemical machinery.***

Footnotes at end of section, p. 38.

Low Alloy

Specific Applications of Alloy Cast Irons

Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements	Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse Load Lb	Transverse Defl. In.	Tensile Strength psi	Remarks
2.20 to 2.50	3.10 to 3.50	2.60 to 2.90	0.40 to 0.60	0.07 to 0.10	0.20 max	0.60 to 0.80			0.25 to 0.50	Cu 0.80 to 1.10	3/8 to 1-1/4	9	200 to 255			35,000 to 40,000	Used for density, resistance to high pressure and corrosion resistance. Structure pearlitic. Service performance reported excellent. *Compressor frame, domestic refrigerators.*
1.40 to 1.50	3.20 to 3.30			0.11 max	0.20 max	1.40 to 1.60		0.50 to 0.60		Cu 0.40 to 0.60	6	1200 to 1300	187 to 210				Used for wear and fatigue resistance. *Compressor crankshafts, refrigerators.*
1.85 to 2.10	2.90 to 3.10			0.07 max	0.20 max	0.50 to 0.75				Ti 0.08 to 0.12 Va 0.09 to 0.11	3/8 to 1.5	1 to 200	207	2650[2] to 2750	0.23 to 0.26	40,000 to 46,000	Used for uniform hardness over wide section range. *Compressors and pumps, refrigeration and air.*
2.00 to 2.25	3.00 to 3.20			0.08 to 0.11	0.09 to 0.11	0.65 to 0.90	3.00 to 3.50		0.25 to 0.35	Ti 0.22 to 0.24	3/8 to 1	20 to 40	241 to 255	4800 to 5200[10]	0.12 to 0.13	45,000 to 50,000	Valve seats give good service. Two years in operation. *Feather valve seats, ammonia and carbon dioxide compressors.*
1.40 to 1.60	3.10 to 3.30			0.12 max	0.20 max	0.70 to 0.85				Cu 1.00	1/2 to 2-1/2	300 to 600	207 to 235	2600 to 2900[2]	0.23 to 0.33	43,000 to 47,000	Structural refinement reflected in increased hardness, better wear properties and improved finish. *Main columns, stationary drill presses.*
1.25 to 1.50	3.30 to 3.45			0.11 max	0.20 max	0.60 to 0.80			0.30 to 0.40	Va 0.15	1-1/4 to 4	2000 to 40,000	197 to 235	2700 to 2900[2]	0.28 to 0.32	35,000 to 40,000	Used for high density. *Dies, body.*
0.90 to 1.20	3.70 to 3.90			0.11 max	0.20 max	0.70 to 1.00		0.90 to 1.10	0.40 to 0.50	Va 0.18 to 0.24	2-1/2 to 3-1/2	1800 to 2600	207 to 255	2800[2]	0.21	35,000 to 38,000	Used for resistance to galling. *Dies, hot draw deep drawn tube.*
0.90 to 1.20	3.80 to 4.00			0.11 max	0.20 max	0.60 to 1.00		0.90 to 1.10	0.30 to 0.40	Va 0.18 to 0.24	1-1/2 to 4-1/2	2000 to 6000	229 to 263	2600[2]	0.19	30,000 min	Used for resistance to wear and heat checks. *Dies, swage, reducing diameter of steel tubing.*
1.40 to 2.00	3.40 to 3.50			0.06 to 0.08	0.30 to 0.60	0.50 to 0.60				Cu 0.75 to 1.00	0.37 to 0.75		200 to 225	2400[2] to 2800	0.25 to 0.30	30,000 to 35,000	Used for corrosion resistance. *Pipe and fittings, oil refinery, condenser coils.*
1.90 to 2.10	2.90 to 3.10			0.10 max	0.18 max	0.60 to 0.80		0.65 to 0.75		Va 0.12 to 0.16	3/8 to 2	12 to 14	229 to 255	3800 to 4000[2]	0.28 to 0.34	50,000 to 60,000	Used for wear and heat check resistance. *Gears, brakes and power transmission.*
1.00 to 1.20	3.50 to 3.70			0.10 max	0.16 max	0.50 to 0.80		0.30 to 0.40	0.20 to 0.30	Va 0.12 to 0.15	1-1/2 to 2-1/4	12 to 30	229 to 255	2800 to 3000[2]	0.28 to 0.32	35,000 to 40,000	Used for wear and heat checking. *Glass house plunger, glass manufacturing.*
2.00 to 2.40	3.20 to 3.50			0.11 max	0.20 max	0.60 to 0.80		0.35 to 0.45		Va 0.12 to 0.15	3/8 to 7/8	9 to 16	197 to 229	2800[2]	0.24	38,000 to 44,000	Used for impact and wear resistance. *Outboard bearing, starting motor.*
1.25 to 1.45	3.40 to 3.60			0.07 to 0.11	0.15 to 0.25	0.70 to 0.90				Ti 0.12 to 0.15	1-1/4 to 2-1/2	9000		2300 to 2500[2]	0.24 to 0.28	34,000 to 36,000	Used for density in heavy sections and elimination of chills. Service performance entirely satisfactory. *Power cylinders, for 1250 horse power natural gas units.*
1.40 to 1.60	3.40 to 3.55			0.08 to 0.11	0.15 to 0.25	0.75 to 0.90	0.00 to 0.10		0.25 to 0.35	Ti 0.06 to 0.08	12	1000 to 3000	• [illegible]			38,000 to 41,000	Has close grain in 12-in. diameter section. Service performance satisfactory. *Stock cylinder, heavy 12 in. diameter stock to make liners, pistons and sleeves.*

Footnotes at end of section, p. 38.

Specific Applications of Alloy Cast Irons

Chemical Range, Per Cent											Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse		Tensile Strength psi	Remarks
Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements				Load Lb	Defl. In.		
1.25 to 2.00	2.60 to 3.00			0.04 to 0.12	0.04 to 0.30	0.80 to 1.30	14.00 to 16.00		2.00 to 3.50	Cu 5.00 to 7.00			150 to 200			25,000 to 30,000	"Ni-Resist" metal. Used because coefficient of expansion is about the same as the aluminum alloy crankcases in which the liners are shrunk. *Cylinder liners, used in aircraft engines with aluminum alloy crankcases.*
1.70 to 2.10	2.80 to 3.10	2.00 to 2.50	0.60 to 0.80	0.10 max	0.20 max	0.80 to 1.25	14.00 to 16.00		1.50 to 2.50	Cu 5.00 to 7.00	3/16 to 3/4	15 to 50	140 to 170	2200 to 2600[4]	0.40 to 0.60	25,000 to 30,000	"Ni-Resist," austenitic iron. Used for resistance to oxidation and growth at elevated temperatures. Service performance considerably better than that of pearlitic irons. *Exhaust manifold medium and large sized truck and bus engines.*
1.25 to 2.00	2.60 to 3.00			0.04 to 0.12	0.04 to 0.30	0.80 to 1.30	14.00 to 16.00		2.00 to 3.50	Cu 5.00 to 7.00			150 to 200			25,000 to 30,000	"Ni-Resist" metal. Used because coefficient of expansion is about the same as that of the aluminum alloy with which it is used and for heat and growth resistance. *Exhaust port flanges, used on aircraft engines with aluminum alloy crankcases and cylinder heads.*
2.00 to 2.20	2.80 to 3.00			0.10 max	0.20 max	1.00 to 1.10	14.00 to 16.00		2.00	Cu 5.50 to 6.50	5/8 to 1-1/2	25 to 200	108 to 160			25,000 to 30,000	Used for resistance to brine corrosion and erosion. Weight loss in mgms. per sq. in. after 2000 hours service: "Ni-Resist" (above composition)—23.0; Unalloyed cast iron—225.0. *Pump casings—handling concentrated brine solutions.*
1.50 to 1.80	2.70 to 3.00	2.15 to 2.35	0.50 to 0.70	0.10 max	0.20 max	1.00 to 1.10	20.0 to 22.0		2.00 to 2.50		0.5 to 2.0	25 to 200	150 to 170	2500[4] to 4000	0.25 to 0.35	25,000 to 35,000	Used for resistance to corrosion. *Valve bodies and fittings, handling caustic soda.*
2.00 to 2.20	2.80 to 3.00			0.10 max	0.20 max	1.00 to 1.10	14.00 to 16.00		2.00	Cu 5.50 to 6.50	5/8 to 1-1/2	25 to 200	160 to 180			25,000 to 30,000	Used for resistance to brine corrosion and erosion. Weight loss in mgms. per sq. in. after 2000 hours service: "Ni-Resist" (Above composition)—23.0; unalloyed cast iron—225.0. *Filter Grids, pump impellers, pump shaft sleeve, handling concentrated brine solutions.*
1.50 to 1.80	2.70 to 2.90	2.00 to 2.20	0.60 to 0.80	0.10 max	0.20 max	1.00 to 1.20	14.00 to 16.00		2.50 to 3.00	Cu 5.50 to 6.50	0.75 to 1.5	200 to 500	180 to 200	2500[4] to 4000	0.25 to 0.35		Used for corrosion resistance[56]. *Compressor liners, gas compressors handling refinery gas containing hydrogen sulphide.*

Footnotes at end of section, p. 38.

IRON GRAY, CAST

No. 9

Specific Applications of Alloy Cast Irons

Chemical Range, Per Cent											Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse		Tensile Strength psi	Remarks
Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements				Load Lb	Defl. In.		
1.40 to 1.60	2.60 to 2.80			0.03 to 0.05	0.09 to 0.13	0.80 to 0.90	20.00	0.50	5.00	Cu 6.00 Ti 0.25	3/8 to 1	20 to 40	197 to 207	2700 to 2900[2]	0.55 to 0.65	35,000 to 37,000	Used for corrosion resistance. Good service results. When chromium was raised to 5.00, titanium was added for structural advantages and to promote machinability. *Feather valve seats, ammonia and carbon dioxide.*
1.50 to 1.80	2.70 to 2.90	2.00 to 2.20	0.60 to 0.80	0.10 max	0.20 max	1.00 to 1.20	14.00 to 16.00		2.00 to 2.50	Cu 5.50 to 6.50	0.5 to 1.5	200 to 600	180 to 200	2500[4] to 4000	0.25 to 0.35	25,000 to 35,000	Used for corrosion resistance. *Low pressure oil refinery service.*
1.50 to 1.80	2.70 to 2.90		0.60 to 0.80	0.10 max	0.20 to 0.60	1.00 to 1.20	14.00 to 16.00		2.00 to 2.50	Cu 5.50 to 6.50	1/4 to 1/2		180 to 200	2500[4] to 4000	0.25 to 0.35	25,000 to 30,000	Used for corrosion resistance. *Pipe and fittings, oil refinery service on crude and acid treated oil and caustic soda.*
1.80 to 2.20	2.80 to 3.10			0.10 max	0.20 max	1.00 to 1.20	14.00 to 16.00		1.50 to 2.50	Cu 5.75 to 6.25	1/4 to 1-1/2	6 to 15	150 to 180	2200 to 2600	0.40 to 0.60	22,000 to 30,000	"Ni-Resist" metal. Used for resistence to corrosion of acid, caustic and salt solutions. *Bubble caps, oil refinery handling sour, crude or acid treated oils.*
1.80 to 2.20	2.80 to 3.10			0.10 max	0.20 max	1.00 to 1.20	14.00 to 16.00		1.50 to 2.50	Cu 5.75 to 6.25	1/4 to 1-1/2	20 to 500	150 to 180	2200 to 2600[2]	0.40 to 0.60	22,000 to 30,000	"Ni-Resist" metal. Used for resistance to corrosion of acid, caustic and salt solutions. *Condenser headers, pump casings, pump impellers, pump sleeves, valve bodies, oil refinery, handling sour, crude or acid treated oils.*
2.00 to 2.50	2.60 to 2.75			0.120 max	0.10 to 0.25	1.00 to 1.25	14.00 to 16.00		1.50 to 2.50	Cu 4.50 to 6.50	1/4 to 2	5 to 8000	190 to 220			30,000 min	Good corrosion resistance and tensile strength. *Pipes and tubes, refinery equipment.*
1.50 to 2.00	2.75 to 3.00			0.120 max	0.10 to 0.30	1.00 to 1.50	14.00 to 16.00		1.50 to 2.50	Cu 4.50 to 6.50							Used for corrosion resistance. *Deaerator pans, pretreatment of boiler water.*
1.40 to 1.60	2.90 to 3.00			0.10 max	0.20 max		14.00 to 16.00		2.00 to 2.50	Cu 5.50 to 6.50	3/4 to 1-1/2	1000 to 2000	120 to 170	2500 to 4000[4]	0.20 to 0.40	25,000 to 30,000	Used for resistance to growth and distortion. Reduction of eddy currents. "Ni-Resist" metal. *Hoppers, electric furnace, used in phosphate smelting.*
1.50 to 2.00	2.60 to 2.80			0.12 max	0.25 max	1.00 to 1.25	14.00 to 16.00		2.00 to 3.00	Cu 6.00 to 7.00	1/4 to 1-1/2	5 to 150	160 to 180	2000 to 2500[2]	0.35 to 0.50	20,000 to 30,000	Used for resistance to growth and warpage at high temperatures. Has 5 times the resistance to growth and warpage of unalloyed cast iron. *Stove tops, heavy duty ranges.*
1.00 to 2.00	1.75 to 2.00			0.10 max	0.10 max	0.30 to 0.75			22.00 to 25.00		1/4 to 5/8	1	320 to 350	4000 to 4500[4]	0.18 to 0.22	80,000 to 90,000	Used for growth and oxidation resistance up to 1800°F. *Chain links, conveyor links used in heat treat furnace.*

Footnotes at end of section, p. 38.

Specific Applications of Alloy Cast Irons

Chemical Range, Per Cent											Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse		Tensile Strength psi	Remarks
Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements				Load Lb	Defl. In.		
1.50 to 2.00	1.50 to 2.00			0.10 max	0.12 max	0.30 to 0.65			22.00 to 26.00		1/2 to 1	300 to 800	320 to 370	3800 to 4700[2]	0.17 to 0.24	65,000 to 86,000	Used for resistance to oxidation, growth and warping at temperatures up to about 1900°F. *Liner plates, used to receive hot clinker in cement plant.*
1.50 to 2.00	2.85 to 3.75			0.08 to 0.12	0.35 max	0.50 to 0.80			12.00 to 17.00		1/2 to 1-1/2	8 to 15	400 to 650				Adequately resists growth and oxidation up to 1600°F. Suitable for medium to heavy sections not subjected to shock. Practically unmachinable. *Stoker links, boiler service.*
1.50 to 1.80	2.70 to 3.00	2.15 to 2.35	0.50 to 0.70	0.10 max	0.20 max	1.00 to 1.10	20.0 to 22.0		2.00 to 2.50		0.5 to 2.0	25 to 200	150 to 170	2500[4] to 4000	0.25 to 0.35	25,000 to 35,000	Copper free "Ni-Resist ". Used for resistance to corrosion. Chemical Equipment.—*Valve bodies and fittings, handling caustic soda.*
1.20 to 1.40	2.80 to 2.90						20.00 to 22.00		1.50 to 2.50		1 to 2	1000 to 4000	130 to 150			24,000 to 26,000	Copper free "Ni-Resist". Used for corrosion resistance and elimination of iron contamination. Weight loss after 119 days: Cast Iron 11.03 per cent, Ni-Resist—0.00 per cent. Chemical equipment, *Mixing kettle, Chemical—Handling boiling sulphur chloride.*

Footnotes at end of section, p. 38.

Nodular Iron

Chemical Range, Per Cent											Metal Section Range In.	Weight Range Lb	Hardness Brinell	Transverse		Tensile Strength psi	Remarks
Si	TC	GC	CC	S	P	Mn	Ni	Mo	Cr	Other Elements				Load Lb	Defl. In.		
1.00 to 2.50	3.00 max					0.80 to 1.50	18.00 to 22.00		3.00 to 6.00	(Cu) 0.50 max	1/4* to 4 High Cr	1 to 2000	170 to 250	2400 to 2800	.2 to .4	25,000 to 45,000	Type 26 Heat Resistant. Used for heat applications up to 1500F. *Firebox castings, dampers*
1.00 to 2.00	2.75 max					0.40 to 0.80	28.00 to 32.00		2.50 to 3.50	0.50 max	1/4 to 4	1 to 2000	120 to 150	2000 to 2400	.5 to 1.0	25,000 to 35,000	Type 3 30% nickel. Used for severe thermal shock service under repeated heating and cooling (r.t.-450F)
5.00 to 6.00	2.60 max					0.40 to 0.80	29.00 to 32.00		4.5 to 5.5	0.50 max	1/4 to 4	1 to 2000	150 to 180	1800	.3 to .6	25,000 to 35,000	Type 4 Heat and Stain Resistant 30-5-5. Recommended for food handling.
1.00 to 2.00	2.40 max					0.40 to 0.80	34.00 to 36.00		0.10 max	0.50 max	1/4 to 4	1 to 2000	125 to 140 100 to 125 Low Cr	1800 to 2000	.5 to 1.0	20,000 to 25,000	Type 5 "Minovar" (34-36Ni). Used when minimum thermal expansion is desired. *Provides dimensional stability for accurate machine tool parts, scientific instruments, expansion joints.*
1.0 to 4.0		3.2 to 4.2			0.10	0.1 to 0.8	0 to 3.5			0.05 to 0.10	1/8 to 4	1 to 20,000				60	Broad-range, *Automotive, agricultural implements railroad and allied industries*
1.25 to 2.0		3.6 to 4.2			0.08	0.35	0 to 1.0			0.05 to 0.08	1/8 to 4	1 to 20,000				60	Ferritic high-ductility. *Machinery, machine tools, crankshafts, pumps, compressors, valves and heavy industrial equipment.*
2.25 to 3.25		3.4 to 3.8			0.10	0.35	0 to 1.0			0.05 to 0.08	1/8 to 4	1 to 20,000				60	Ferritic high-strength. Used for engine, furnace and other parts at elevated temperatures.
2.25 to 2.75		3.2 to 3.8			0.10	0.6 to 0.8	1.5 to 3.5			0.05 to 0.08	1/8 to 4	1 to 20,000				60	Pearlitic, high-strength. *Paper, textile and electrical machinery, marine equipment and pipe.*

Footnotes at end of section, p. 38.

FOOTNOTES TO SPECIFIC APPLICATIONS OF ALLOY CAST IRONS

1 Source, by permission: Alloy Cast Irons Handbook, Second Edition, American Foundrymen's Association

2 1.20 in. diam, 18.0 in. supports

3 Light thin drums subject to low brake pressure, Brinell 180 to 207. Heavy thick drums subject to high brake pressure, Brinell 223 to 225

4 1.20 in diam, 12 0 in. supports

5 Heat treated

6 1.00 in sq, 12.0 in. centers

7 Heat treatment: Heat to 1850°F hold 6 hr. Cool at 60°F per hr for low hardness Cool at 100°F per hr for high hardness.

8 Elongation 2% to 6% in 2 in.

9 Test bar

10 1 25 in diam, 12.0 in. supports

11 Brinell 201 to 229 (Bore). Brinell 223 to 248 (Flange)

12 Brinell 202 to 212 (Test Bar); Brinell 187 to 196 (Cylinder Bore)

13 Brinell 185 to 200 (Bore). Pan rail 200 to 217

14 As cast Brinell 212 to 241. Hardened Rockwell "C" 48 to 52. Brinell 480 to 520. Heat treatment normalized 1050-1100°F, oil quenched from 1550°F, drawn 2 hrs at 350°F

15 Brinell 212 to 241 as cast. Rockwell "C" 48 to 52 after heat treating

16 Brinell 217 to 235 (Test bar) Brinell 180 to 200 (Castings)

17 Casting

18 Bars tend to be mottled

19 Specimen from extension of bore

20 Bar from casting

21 Chill cast 600 Brinell, 450-500 Brinell after quenching from 1550°F and drawing at 400°F

22 Brinell Chill Cast 650 to 700

23 Brinell Chill Cast 600 to 650

24 Heat treatment Oil quenched from 1550°F, drawn 600 to 800°F

25 Hardness after normalizing at 1200°F, Brinell 185 to 210

26 Rockwell "C" 28 to 32

27 450-500 Brinell after quenching from 1550°F and drawing at 400°F

28 On gray core – tensile strength on chilled section 60 to 80 M psi

29 Hardness. sand cast, Brinell 600 to 650, chill cast, Brinell 700 to 750

30 Brinell chill cast 680 to 720

31 Brinell 450 interior, 600 chilled surface

32 Hardness: sand cast, Brinell 550 to 625, chill cast, Brinell 700 to 725

33 Brinell chill cast 700 to 750

34 0.875 in. diam, 12 in. supports

35 Rockwell "B" 97 to 104

36 Rockwell "D" 40 to 45

37 Cams Scleroscope 70 (hardened)

38 2 in. sections

39 Annealed at 1400°F, hardness 200

40 Brinell as cast 241 to 280, Brinell hardened 450 to 550, Rockwell "C" hardened 45 to 55

41 Heat treatment, normalized 1 hr at 1550°F, oil quenched from 1575°F, drawn at 450°F

42 Brinell 190 to 220, Rockwell "B" 92 0 to 99.0

43 In rings

44 Hardness as cast, Brinell 240 to 270, (hardened) Brinell 450 to 550

45 Heat treatment (small dies) oil quenched 1550°F, drawn 350 to 400°F

46 In 2 to 4 in. sections

47 Heat treatment for hardening, oil quench 1550°F, drawn 350 to 400°F

48 Hardness as cast, Brinell 280 to 300, annealed, Brinell 265 to 285

49 Heat treatment heat to 1050°F, hold 1 hr, cool n furnace

50 Mo and Cr 0.75 max

51 1 20 in. diam bars

52 Rockwell 6 to 50

53 Brinell 217 to 235 (Test Bar)

54 Brinell, as cast, 248

55 As cast 1.2 in. diam, 18.0 in. supports

56 Above type of Ni-Resist liner after three years' service in still gases containing high hydrogen sulphide content, showed 0.015 in. wear on 17.5 in. – diam liner versus 0.075 in. wear for plain cast iron after one year's service

57 Silicon content may exceed 0.70% in light sectioned or gray-backed castings.

58 Stress relieved 4 hrs at 400F.

59 Hardness Test Bar – Brinell 207 to 217, Casting 12 in. diam – 160 to 175.

60 Grade 80-60-03 80 M psi, Grade 60-45-10 60 M psi

SPECIAL CASTINGS

Corrosion Resistant

CA

Chemical Composition[1]

	C % max	Mn % max	P % max	S % max
CA-15, CA-15M, CA-40	0.15[4]	1.00	0.04[3]	0.04[3]
Type C6[2]	0.15	0.75	–	–

	Ni % max	Si % max	Cr %	Mo % max
CA-15, CA-15M, CA-40	1	1.50	11.5-14	0.5[5]
Type C6[2]	–	–	11.5-13.5	0.5[5]

[1]Alloy Casting Institute
[2]ASTM Special Technical Bulletin No. 52A
[3]ASTM allows 0 05%
[4]CA-40, 0.20-0.40%
[5]Not intentionally added

Physical Properties

Specific resistivity, microhm/cm³ at 70F	CA 15 78
	CA 40 76
Specific heat, Btu/lb/°F at 70F	0.11
Density, at 70F	0.275 lb/cu in. (7.61 S.G.)
Magnetism	Ferromagnetic

Characteristics Popular corrosion - resistant casting alloy, and can be heat treated to improve the hardness and mechanical properties. Drawing at 900F lowers the notch toughness. Is resistant to oxidation, corrosion, and erosion

Uses: Valve trim.

Thermal Conductivity

Btu/hr/ft²/ft/F	r.t.-212F	14.5
	-1000F	16.7
Cal/cm²/cm/sec/C	r.t.-100C	.060
	-538	.069

Technological Properties

Machinability, relative to annealed 18Cr-8Ni	CA 15 good CA 40 equivalent
Weldability, relative to annealed 18Cr-8Ni	CA 15 equivalent (preheat 400-600F recommended before welding castings previously drawn at 1100) CA 40 fair (preheat 500-750F recommended before welding)
Hardening temp	1800F, AQ or OQ
Tempering temp	600-1400F
Melting point, solidus	CA-15 2700-2790F CA-40 2700-2750F

Coef. of Thermal Expansion

Temp Range Deg C	Temp Range Deg F	Coefficient × 10⁻⁶ per Deg C	Coefficient × 10⁻⁶ per Deg F
r.t. – 100	r.t. – 212	9.9	5.5
– 538	– 1000	11.5	6.4
0 – 704	32 – 1300	12.1	6.7

Stress Rupture Strength (M psi)

Temp	Stress to rupture in 100 hr	Stress to rupture in 1000 hr
950	47	42
1050	29	23
1100	22	17

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hr
1050F	11.0
1100	8.9

Mechanical Properties[1]

Form or Condition		Draw Temp	Tensile Strength M psi	Yield Strength 0 02% offset M psi	Elong 2 in. %	Hard BHN	Impact Resistance[4] Ft lb Room Temp
CA 15	AC from 1850F	1400-1500	100	75	30	185	35
	AC from 1800F	1100	135	115	17	260	10
	OQ from 1800F	1200	95	75	–	–	–
	AC from 1800-1850F[2]	1300-1350	95	78	22	185	38
	OQ from 1850F[2]	1125	120	110	18	241	18
CA 15M	AC from 1850F[2]	1450	95	70	25	196	–
		1125	130	115	16	273	–
CA 40	AC from 1850	1400	110	67	18	212	–
		1125	135	120	12	269	–
	Annealed (nominal)[3]	–	95	65	25	170	–

Effect of heat treatment. See Fig 7 p551 Metals Handbook.
Modulus of elasticity, E in M psi 29 × 10³

[1]Alloy Casting Institute
[2]ASTM Special Technical Bulletin No 52A
[3]ASM Metals Handbook
[4]Charpy, vee-notch

SPECIAL CASTINGS	
Corrosion	Heat Resistant
CB	**HB**

Chemical Composition

	C % max	Mn % max	P % max	S % max	Ni % max	Si % max	Cr %
CB-30[1]	0.30	1.00	0.04[2]	0.04	2	1.00[4]	18-22[3]

[1] Alloy Casting Institute
[2] ASTM allows 0.05%
[3] ASTM allows 18.0-21.0
[4] HB, 2.0% max (ASM Metals Handbook)

Technological Properties

Machinability, relative to annealed 18Cr-8Ni	equivalent
Weldability, relative to annealed 18Cr-8Ni	poor (preheat 600-800 recommended before welding. After welding, reheat, treat immediately. Fabrication welding not recommended.)
Magnetic permeability	magnetic
Annealing temp	1400-1500F, AC
Scaling temp oxidizing	1500F. In comparison to alloys with higher Cr and to alloys with at least 15% Cr with Ni, HB has relatively low resistance to scaling.
Melting point, solidus	CB 2700-2750

Characteristics: CB has greater corrosion resistance than CA but is not hardenable by quenching.

Uses: Valve bodies and trim. For nitric acid the carbon is held below 0.20%. This grade is being replaced by CF(19.9).

Physical Properties

Specific resistivity microhm/cm^2 at 70F 76
Specific heat, Btu/lb/°F at 70F 0.11
Density, at 70F 0.272 lb/cu in. (7.53 S.G.)

Thermal Conductivity

Btu/hr/ft^2/ft/F	r.t.–212F	12.8
	–1000F	14.5
Cal/cm^2/cm/sec/C	r.t.–100C	.053
	–538	.060

Coef. of Thermal Expansion

Temp Range Deg C	Temp Range Deg F	Coefficient × 10^{-6} per Deg C	Coefficient × 10^{-6} per Deg F
r.t. – 100	r.t. – 212	10.3	5.7
– 538	– 1000	11.7	6.5
– 704	– 1300	12.1	6.7

Mechanical Properties[2]

Form or Condition	Draw Temp	Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in %	Hard BHN	Impact Resist Ft lb Room Temp
CB-30 AC 1450-1500, FC 1100[4]	1400F	75	50	10[3]	170	2[1]

Modulus of elasticity, E in M psi 29 × 10^3

[1] Charpy Keyhole
[2] Alloy Casting Institute
[3] CB 15%, HB 25% (ASM Metals Handbook)
[4] ASTM shows same values for CB-30, OQ from 1850F

STEELS, ASTM	
Corrosion	Heat Resistant
CC	**HC**

Chemical Composition

	C % max	Mn % max	P % max	S % max
CC-50[1]	0.50	1.00	0.04[3]	0.04[3]
HC [2]	0.50	1.00	0.04	0.04

	Ni % max	Si % max	Cr %	Mo % max
CC-50[1]	4	1.00	26-30	–
HC [2]	4	2.0	26-30	0.50

[1]Alloy Casting Institute
[2]ASTM Special Technical Bulletin No. 52A
[3]ASTM allows 0.05%

Characteristics: CC is highly resistant to oxidizing corrodants, and acid pride waters. May be used "as cast".

Uses: HC is used in sulphur-bearing atmospheres at high temperatures where strength is not important. A grade with 3.0% is supplied for wear at high temperatures. N is added up to over .15%, with Ni over 2% to improve the mechanical properties. HC is embrittled by heating to 750-1025 F.

Technological Properties

Machinability, relative to annealed 18Cr-8Ni	CC	Fair (Ni content < 1%) Equivalent (Ni content > 2% with 0.15%N)
	HC	Fair
Weldability, relative to annealed 18Cr-8Ni	CC	Poor (Preheat 400-800 recommended before welding. After welding heat to 1100-1400F, then air cool)
	HC	Poor (Preheat 600-1000F AC from 1550 after welding)
Magnetic permeability	CC	Magnetic
	HC	14.7 (48 hrs at 1600F) 9.9 (2100-2 hrs WQ)
Melting point, solidus	CC	2700-2750F
	HC	2650-2750F
Scaling temp oxidizing	HC	2000 F. highly resistant to oxidizing or reducing atmospheres, and in the presence of sulphur.

Physical Properties

Density, at 70F	CC 0.272 lb/cu in. (7.53 S.G.)
	HC 0.274 lb/cu in. (7.56 S.G.)
Specific restivity, microhm/cm³ at 70F	77.0
Specific heat, Btu/lb/°F at 70F	0.12

Coef. of Thermal Expansion (HC)

Temp Range Deg C	Deg F	Coefficient × 10^{-6} per Deg C	per Deg F
r.t. – 100	r.t. – 212	10.6[1]	5.9[1]
– 538	–1000	11.5[1], 11.3	6.4[1], 6.3
– 649	–1200	11.3	6.3
– 760	–1400	11.9	6.6
– 871	–1600	12.6	7.0
– 982	–1800	13.3	7.4
–1010	–1850	13.7	7.6
–1093	–2000	13.9	7.7

[1]CC

Thermal Conductivity

Btu/hr/ft²/ft/°F	r.t.-212F	12.6
	-1000F	17.9
	-1500	20.3
	-1200	24.2
Cal/cm²/cm/sec/°C	r.t.-100C	.052
	-538	.074
	-816	.084
	-1093	.100

Stress Rupture Strength (M psi) HC

Temp	Stress to rupture in 10 hr	100 hr	1000 hr
1400F	5.1	3.3	2.3
1600	1.1	1.7	1.3
1800	–	1.0	.62

Creep Strength (M psi) HC

Temp	Stress for 1% creep in 10,000 hr
1400F	1.3
1600	.75
1800	.36

Mechanical Properties[8]

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi 0 2% offset	Elong 2 in %	Hard BHN	Impact Resist Ft lb Room Temp
CC-50[1] As cast	–	70[5]	65	2	212	2[3]
CC-50[2] As cast	–	95	60	19, 15[9]	193	2[3]
AC from 1900F Heat Treated	–	97	65	38, 18[9]	187, 210[9]	45[3]
HC[1] As cast	–	70	65	2	212[6]	–
HC (high N)[7]	–	110	75	19	223	–
HC (2.8% Ni) Effect of temp	1400F	10.5[4], 11[7]	8.7[4]	65[4], 65[7]	–	–
	1600	5.1[4], 3[7]	3.84[4]	94[4], 95[7]	–	–
	1800	2.45[4], 2[7]	2.1[4]	110[4], 110[7]	–	–

Modulus of elasticity, E in M psi 29 × 10^3

[1]Nickel content < 1%
[2]Nickel content > 2% with 0.15%N
[3]Izod, vee-notch
[4]From single source
[5]Metals Handbook shows 65
[6]Metals Handbook shows 179
[7]ASM Metals Handbook
[8]Source ASTM
[9]Alloy Casting Institute

SPECIAL CASTINGS	
Corrosion	Heat Resistant
CE	**HE**

Chemical Composition

	C % max	Mn % max	P % max	S % max
CE-30[1]	0.30	1.50	0.04[2]	0.04[2]
HE[1]	0.20-0.50	2.00	0.04	0.04

	Ni % max	Si % max	Cr %	Mo %
CE-30[1]	8-11	2.00	26-30	–
HE[1]	8-11	2.00	26-30	0.5[3]

[1] Alloy Casting Institute
[2] ASTM allows 0 05%
[3] Not intentionally added

Technological Properties

Annealing temp	2000F, AC, OQ	
Machinability, relative to annealed 18Cr-8Ni	CE-30	Good
	HE	Equivalent
Weldability, relative to annealed 18Cr-8Ni	CE	Equivalent } No preheat or after heat is required
	HE	Fair
Magnetic Permeability	CE-30	Over 1.5
	HE	1.3-1.8
Scaling temp oxidizing	2000F. HE is highly resistant to scaling in oxidizing or reducing atmospheres and in the presence of sulphur.	
Melting point, solidus	2600-2700F	

Characteristics: A ductile corrosion resistant alloy which can be used "as cast," though preferably "quench annealed." Is less susceptible to intergranular attack than CF and is better for use as cast or as welded.

Uses: Valves, pumps, and fittings for sulphite liquor in the paper industry.

Physical Properties

Density at 70F	CE-30	0.277 lb/cu in. (7.67 S.G.)
	HE	0 276 lb/cu in. (7.65 S.G.)
Specific resistivity, Microhm/cm^3 at 70F		85 0
Specific heat, Btu/lb/°F at 70F		0 14

Coef. of Thermal Expansion

Temp Range Deg C	Deg F	Coefficient × 10^{-6} per Deg C	per Deg F
r.t.-537	r.t.-1000	17.3[2] 17.1[1]	9.6[2] 9.5[1]
-649	-1200	17.8	9 9
-760	-1400	18.4	10.2
-870	-1600	18.9	10.5
-982	-1800	19.4	10.8

[1] HE
[2] CE

Thermal Conductivity HE

Btu/hr/ft^2/ft/°F	r.t. – 1500	10.0
Cal/cm^2/cm/sec/°C	r.t. – 816	.041

Creep Strength (M psi) HE

Temp	Stress for 1% creep in 10,000 hr
1400F	3.5
1600	2.0
1800	1.0

Stress Rupture Strength (M psi) HE

Temp	Stress to rupture in 100 hr
1400F	11.0
1600	5.3
1800	2.5

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength 0 2% offset M psi	Elong 2 In %	Hard BHN	Impact Resist Ft Lb Room Temp
CE-30	As cast	95[1] 90[2]	60[1] 50[2] 65[3]	15	170[1] 197[2]	–
	WQ from 1950-2050F	97	63[1] 67[3]	18	170	–
HE –	As cast	87[1] 85[2] 80[3]	45	10	200[1] 201[2]	10[4]
	24 hrs at 1400F, FC	85	65	3	270	–

Modulus of elasticity, E in M psi 22×10^3

[1] Alloy Casting Institute
[2] ASM Metals Handbook
[3] ASTM Special Technical Publication No 52A
[4] Charpy, Vee-notch

Chemical Composition[1]

	C	Mn max	P max	S max	Ni
CF-8, CF-8M, CF-8C	0.08 max	1.50	0.04[5]	0.04[5]	9-12[2]
CF-20	0.20 max	1.50	0.04[5]	0.04[5]	8-11
CF-12M	0.12 max	1.50	0.04	0.04	9-12
CF-16F	0.16 max	1.50	0.17	0.04[5]	9-12
HF	0.20-0.40	2.00	0.04	0.04	8-12
	Si max	**Cr**	**Mo**	**Cb**	**Se**
CF-8, CF-8M, CF-8C[1]	2.00[6]	18-21	–[7]	–[3]	–
CF-20[1]	2.00	18-21	–	–	–
CF-12M[1]	1.50	18-21	2.0-3.0	–	–
CF-16F[1]	2.00	18-21	1.5 max	–	0.20-0.30
HF[1]	2.00	18-23	0.5 max[4]	–	–

[1] Alloy Casting Institute
[2] CF-8 8-11%
[3] CF-8C 8×C min, 1.0% max or Cb-Ta 10×C min, 1.35% max
[4] Not intentionally added
[5] ASTM allows 0.05%
[6] CF-8M 1.50%
[7] CF-8M 2.0-3.0%

Characteristics: Most widely used corrosion-resistant casting alloy, produced with several different carbon contents. It is quench-annealed for corrosive service, with the low carbon CF-8 the best. For Sulfuric acid, 2.3% Mo is added and Cb for welding, and Se for machining. It is not hardened by heat treatment. HF is similar to CF with higher C for use at moderately high temperatures. CG is related type with higher carbon content.

Technological Properties

Annealing temp	1900-2100F, OQ or WQ[1]
Scaling temp oxidizing	1600F. Is inferior to HF, especially to sulphur.
Machinability, relative to annealed 18Cr-8Ni	CF-8 Machinable (by cutting tools at about 40-45% rate of Bessemer Screw Stock). CF-8M, CF-12M, CF-20, HF[2] Equivalent. CF-8C Good. CF-16F Improved
Weldability, relative to annealed 18Cr-8Ni	CF-8 By gas, electric-arc without pre-heat.[3] CF-12M, CF-20, CF-8M Equivalent, no pre-heat required.[3] CF-8C Good, HF Equivalent, no pre-heat or after-heat treatment required. CF-16F Repair welded satisfactorily. Fabrication welding may require special techniques. No preheat required.[3]
Melting point, solidus, approx	CF-8, CF-8C, HF 2600F CF-8M, CF-12M, CF-16F 2550F
Magnetic permeability, heat-treated	CF-8 1.0-1.30, CF-8M 1.5-2.5, CF-8C 1.2-1.8, CF-16F 1.0-2.0, CF-20 1.01, HF non-magnetic.

[1] With Mo the quenching temperature should be on the high side
[2] Tapping operations difficult.
[3] After welding, WQ from 1950-2050F

Creep Strength (M psi)

Temp	CF-8	CF-8M	CF-8C	CF-20	HF
	Stress for 1% creep in 10,000 hr				
1000F	20.5	26	–	–	–
1200	8.7	10	14[1]	7	13
1300	–	–	–	4.8	–
1350	–	–	8.7	–	–
1400	5.2	3.7	–	–	6
1600	2.4	–	–	–	3.2

[1] 1900F 2 hr, AC, 1600F 4 hr, AC

Stress Rupture Strength (M psi)

Stress to rupture in		Temp, deg F 1000	1100	1200	1300	1350	1400	1600
10 hr	CF-8C	–	–	30	–	–	–	–
	HF	–	–	37	–	–	20	10
100 hr	CF-8	33	–	14.5	–	–	9.6	2.9
	CF-8M	–	–	25	–	–	–	–
	CF-8C	–	35[1]	25.5[1]	–	12.5	–	–
	HF	–	–	30	–	–	14	6
1000 hr	CF-8	24	–	10.5	–	–	6.8	2.0
	CF-8M	–	–	15.5	13.0	–	–	–
	CF-8C	–	30[1]	20[1]	–	9.4	–	–
	CF-20	12	–	–	9.8	–	–	–
	HF	–	–	17	–	–	8	3.8
10,000 hr	CF-8	17.5	–	7.6	–	–	4.9	1.4
	CF-8M	–	–	9.8	8.0	–	–	–
	CF-8C	–	–	17.0	–	7.0	–	–
	CF-20	–	–	7.8	6.2	–	–	–

[1] 1900F 2 hr, AC 1600F 4 hr, AC.

(Continued on page 44)

SPECIAL CASTINGS

Corrosion	Heat Resistant
CF	**HF**

(Continued from page 43)

Thermal Conductivity

	CF-8	CF-16F CF-8M CF-12M	CF-8C	HF
		Btu/hr/ft²/ft/°F		
r.t.-212F	9.2	9.4	9.3	9.0
-1000F	12.1	12.3	12.8	13.4
-1500F	–	–	–	15.0
-2000F	–	–	–	16.9
		Cal/cm²/cm/sec/°C		
-100C	16.6	16.9	16.7	16.2
-538C	21.8	22.1	23.0	24.1
-816C	–	–	–	27.0
-1093C	–	–	–	30.4

Physical Properties

Density at 70F	0.280 lb/cu in (7.75 S.G.)
Specific resistivity, microhm/cm³ at 70F	CF-8: 76.2, CF-8M, CF-12M 82.0, CF-8C: 71.0, CF-16F: 72.0, CF-20 77.9, HF 80.0
Specific heat, Btu/lb/°F at 70F	0.12

Coef. of Thermal Expansion

Temp Range Deg C	Deg F	CF-8 per°C	CF-8 per°F	CF-8M, CF-12M per°C	CF-8M, CF-12M per°F	CF-8C per°C	CF-8C per°F	CF-16F per°C	CF-16F per°F	CF-20 per°C	CF-20 per°F	HF per°C	HF per°F
		Coefficient × 10^{-6}											
r.t.-100	r.t.-212	16.2	9.0	15.8	8.9	16.7	9.3	16.2	9.0	17.3	9.6	–	–
-538	-1000	18.0	10.0	17.5	9.7	18.5	10.3	17.8	9.9	18.7	10.4	17.8	9.9
-649	-1200	18.4	10.2	–	–	–	–	–	–	–	–	18.2	10.1
-704	-1300	18.5	10.3	–	–	–	–	–	–	–	–	–	–
-760	-1400	–	–	–	–	–	–	–	–	–	–	18.5	10.3
-816	-1500	–	–	–	–	–	–	–	–	–	–	18.5	10.3
-870	-1600	–	–	–	–	–	–	–	–	–	–	18.7	10.4
-982	-1800	–	–	–	–	–	–	–	–	–	–	18.9	10.5
-1093	-2000	–	–	–	–	–	–	–	–	–	–	19.6	10.9

Mechanical Properties[1]

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength 0 2% offset M psi	Elong 2 in %	Hard BHN	Impact Strength Charpy Keynote Ft Lb r.t	0	100	200	300	423
CF-8 As cast	–	78	43	45	150	75[4]	–	–	–	–	–
WQ from 1950-2050F	–	75[1],78[2],80[3]	35[1],38[2],40[3]	55	140	75[4]	71	66	62	58	52
Effect of Temp	1000F	52	14.5	39	–	–	–	–	–	–	–
	1200	41	14	29	–	–	–	–	–	–	–
	1400	25	–	13	–	–	–	–	–	–	–
	1600	16	11	16	–	–	–	–	–	–	–
CF-12M[5], CF-8M WQ from 1950-2050F	–	88	45	50	156[1],156-170[3]	70[4]	66	60	51	45	–
CF-8M Effect of Temp	1000	45	20	38	–	–	–	–	–	–	–
	1200	35	18	33	–	–	–	–	–	–	–
	1400	19	–	–	–	–	–	–	–	–	–
CF-8C WQ from 1950-2050F	–	85	44	45	149	30	–	–	–	–	–
Effect of Temp	1000	52.5	–	32	–	–	–	–	–	–	–
	1200	44.5	–	30	–	–	–	–	–	–	–
	1400	31.5	–	50	–	–	–	–	–	–	–
CF-16F WQ from 1950-2050	–	80	42	45	150	150	–	–	–	–	–
CF-20 Heated > 2000F WQ	–	83	42	55	163	60[1],75[2]	–	–	–	–	–
Effect of Temp	1000	53.5	24.5	10	–	–	–	–	–	–	–
	1200	36	22.7	4.5	–	–	–	–	–	–	–
	1400	29	22	2	–	–	–	–	–	–	–
	1600	20	–	2.5	–	–	–	–	–	–	–
HF As cast	–	85[1],80[2,3]	45	35	170	–	–	–	–	–	–
24 hrs at 1400F, FC	–	100	50	25	190[1],192[3]	–	–	–	–	–	–
Effect of Temp	1200	57	–	16	–	–	–	–	–	–	–
	1400	35	–	20	–	–	–	–	–	–	–
	1600	22	–	22	–	–	–	–	–	–	–

Cold Bend, 180 degrees

Modulus of Elasticity, E in M psi[2] 28×10^3

[1] Alloy Casting Institute
[2] ASTM Special Technical Publication No. 52-A
[3] ASM Metals Handbook, WQ from 2000F
[4] See Fig 27, p 70, ASTM Publ. No 52-A
[5] Heated > 2000F, WQ

SPECIAL CASTINGS	
Corrosion	Heat Resistant
CH	HH

Chemical Composition[1]

	C %	Mn % max	P % max	S % max	Ni %
CH-10[2]	0.10 max	1.5	0.05	0.05	12-15
CH-20	0.20 max	1.5	0.04[3]	0.04[3]	12-15
HH	0.20-0.50	2.0	0.04	0.04	11-14

	Si % max	Cr %	Mo %	N %
CH-10[2]	2.00	22-26	2.0-3.0%[5]	–
CH-20	2.00	22-26	–	–
HH	2.00	24-28	0.5 max[4]	0.2 max

[1] Alloy Casting Institute
[2] ASTM Special Technical Publication No. 52-A
[3] ASTM allows 0 05%
[4] Not intentionally added
[5] ASM Metals Handbook

Characteristics: This is similar to Ce[1]. HH is resistant to sulphur-bearing atmospheres, both oxidizing and reducing.

Uses: Used in the paper and chemical industries. Mo is added to CH-10 for sulphite liquor etc. HH is very widely used for high temperatures.

[1] A ductile corrosion resistant casting alloy which can be used "as cast," though preferably "quench annealed." Is less susceptible to intergranular attack than CF and is better for use as cast or as welded.

Physical Properties

Density, at 70F 0.279 lb/cu in.	(7.72 S.G.)
Specific resistivity, Microhm/cm^3 at 70F	CH-20 84; HH 75-85
Specific heat, Btu/lb/°F at 70F	0.12

Thermal Conductivity

BTU/hr/ft^2/ft/°F	r.t.-212	8.2
	-1000	10.9
	-1500	14.3 (HH)
	-2000	16.4 (HH)
Cal/cm^2/cm/sec/°C	r.t.-100	.034
	-537	.045
	-816	.059
	-1093	.068

Technological Properties

Annealing temp	1900-2100 F, OQ or WQ
Scaling temp oxidizing	2000 F
Machinability, relative to annealed 18Cr-8Ni	Fair
Weldability, relative to annealed 18Cr-8Ni	Equivalent (No preheat required. After welding WQ 1950-2050F for CF-20. No heat treatment after welding required for HH)
Magnetic Permeability	HH Type 1 1.1 to 1.9; 2 1.0 to 1.5; CC-20 1.71 (heat treated)
Melting Point, Approx	2600 CH-20; 2500 HH

Coef. of Thermal Expansion

	Temp Range Deg C	Deg F	Coefficient × 10^{-6} per Deg C	per Deg F
CH-20	r.t.-100	r.t.-212	14.9	8.3[3]
	-537	-1000	17.3	9.6[3]
HH	-704	-1300	17.8	9.9
	-897	-1650	18.2	10.1
	-1010	-1850	19.4, 20.4[1], 19.8[2]	10.8, 11.5[1], 11.0[2]
	648-870	1200-1600	19.8	11.0
	27-648	80-1200	2.0%[4,2]	1.09%[4,2]
	-760	-1400	2.3%[4,2]	1.30%[4,2]
	-871	-1600	2.7%[4,2]	1.53%[4,2]
	-982	-1800	3.2%[4,2]	1.78%[4,2]
	-1093	-2000	3.7%[4,2]	2.03%[4,2]

[1] CH-20
[2] Amer. Brake Shoe Co. for wholly austenitic alloy
[3] ASM Metals Handbook shows same value for range 32-212F.
[4] Total expansion

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength 0 2% offset M psi	Elong 2 in %	Hard BHN	Cold Bend Deg	Impact Strength[6] Room Temp Ft Lb
CH-10 Annealed[3]	–	82	44	38	187[2] 170[3]	180	–
As cast[2]	–	82	40	–	–	180	–
CH-10M[4] WQ from 2000F[3]	–	90	66	15	180	–	–
CH-20 WQ from 2000F[3]	–	88	50	38	184[2] 180[3]	–	30[1]
As cast[2]	–	84	48	24	196	–	–
HH As cast Type 1[1]	–	80	50	25	185	–	–
Type 2[1]	–	85	45	15	180	–	15
As cast[3]	–	70-95	35-50	15-30	150-210	–	8[2]
24 hrs at 1400F FC[3]	–	80-100	40-55	4-20	180-250	–	8[2]
Type 1[1]	–	86	55	11	200	–	–
FC Type 2[1]	–	92	40	8	200	–	4[5]
Effect of Temp[1] Type 1	70F	85[7]	–	–	–	–	–
	1400	33[1] 35[7]	17	18	–	–	–
	1600	18.5[1] 20[7]	13.5	30	–	–	–
	1800	9[1] 16[7]	6.3	45	–	–	–
Type 2	1400	35	18	12	–	–	–
	1600	22	14	16	–	–	–
	1800	11	7	30	–	–	–

Modulus of elasticity, E in M psi CH 28 × 10^3
HH 23.5 × 10^3 (American Brake Shoe Co.)

[1] Alloy Casting Institute
[2] ASTM Special Technical Publication No. 52-A
[3] ASM Metals Handbook
[4] Containing Mo
[5] 48 hrs at 1600F AC
[6] Charpy Keyhole
[7] ASM Metals Handbook – no information as to type.

(Continued on page 46)

SPECIAL CASTINGS	
Corrosion	Heat Resistant
CH	**HH**

(Continued from page 45)

Creep Strength (M psi)

	Stress for 1% creep in			
	1000 hr	10,000 hr		
			HH Type 1[2]	HH Type 2[2]
1400F	8[1], 8.4[3]	6[1], 5.9[3]	3.0	7.0
1600	4.5[1], 4.6[3]	3.5[1], 3.2[3]	1.7	4.0
1800	2.5[1]	1.7[1]	1.1	2.1
2000	1.2[1]	0.8[1]	0.3	0.8

[1] Amer. Brake Shoe Co (Avery) for a fully austenitic alloy HH alloys whose compositions give a partially ferritic structure (u > 1.0) are weaker.
[2] Alloy Casting Institute.
[3] ASM Metals Handbook.

Stress Rupture Strength (M psi)

Temp	Stress for rupture in 100 hr		
		HH Type 1[2]	HH Type 2[2]
1200F	–	–	35.0
1400	12[1], 13[3]	14.0	14.0
1600	7[1], 6.8[3]	6.4	7.5
1800	4[1]	3.1	4.0
2000	1.6[1]	1.5	1.8
	1000 hr		
1200F	–	–	22.0
1400	8[1]	6.5	10.0
1600	4.5[1]	3.8	4.7
1800	2.5[1]	2.1	2.5
2000	2.2[1]	–	1.2

[1] Amer. Brake Shoe Co (Avery) for a fully austenitic alloy. HH alloys whose compositions give a partially ferritic structure (u > 1 0) are weaker.
[2] Alloy Casting Institute.
[3] ASM Metals Handbook

SPECIAL CASTINGS
Corrosion Resistant
CM-25

Chemical Composition

C %	Mn %	Si %	Cr %
.25 max	1.50 max	2.00 max	8.0/11.0
Ni %	**Mo %**	**Cb %**	**Se %**
19.0/22.0	–	–	–

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Hard BHN
CM 25	71	34	38	128

Characteristics: Specially resistant to sulphuric acid.

Uses: In oil refineries, etc.

SPECIAL CASTINGS
Corrosion Resistant
CN-7MCu

Chemical Composition[1]

	C %	Mn %	P %	S %
CN-7MCu	0.07 max	1.50 max	0.04 max	0.04 max
	Ni %	**Si %**	**Cr %**	**Mo %**
CN-7MCu	21-31[2]	–[3]	18-22	–[3]

[1] Alloy Casting Institute
[2] ASM Metals Handbook shows 20-30% for CN-7
[3] ASM Metals Handbook show 2 00% max Si and optional for Mo for CN-7. Alloy Casting Institute indicates that there are several proprietary alloy compositions falling within the stated Cr and Ni ranges, and containing varying amounts of Si, Mo and Cu. Such alloys are available from licensed producers only

SPECIAL CASTINGS

Corrosion	Heat Resistant
CK	**HK**

Chemical Composition

	C %	Mn % max	P % max	S % max	Ni %
CK-20[1]	0.20 max[3]	1.50	0.04	0.04	19-22
CK-20[2]	0.20 max	2.0[4]	0.05	0.05	19-22
HK[1]	0.20-0.60	2.00	0.04	0.04	18-22

	Si % max	Cr %	Mo %	Cb %
CK-20[1]	2.00	23-27	–	–
CK-20[2]	2.0	23-27	–	8 × C[4]
HK[1]	3.00[6]	24-28	0.5 max[5]	–

[1] Alloy Casting Institute
[2] ASTM Special Technical Bulletin No. 52A
[3] ASM Metals Handbook allows .25% max C for CK
[4] ASTM shows 1 50% Mn and 8 × C% Cb for CK-20C.
[5] Not intentionally added.
[6] ASTM shows 2.00% max.

Characteristics: CK has very good corrosion resistance. HK has very good resistance to scaling even in sulphur-containing atmospheres both oxidizing and reducing. HK is similar to an austenitic HH alloy, but is less sensitive to variations in composition.

Uses: Used in the paper and pulp industry. Cb may be added to lessen the effect of carbide precipitation, and Se to improve the machinability.

Technological Properties

Machinability, relative to annealed 18Cr-8Ni	Equivalent	
Weldability, relative to annealed 18Cr-8Ni	CK-20	Equivalent (No preheat required. After welding WQ from 2100F)
	HK	Fair (No preheat or heat treatment after welding required)
Magnetic Permeability	1.02	
Melting Point, Approx	CK-20	2600
	HK	2550
Annealing temp	2000F, OQ or WQ	
Scaling temp oxidizing	2100F	

Physical Properties

Specific resistivity, Microhm/cm[3] at 70F	90
Specific heat, Btu/lb/°F at 70F	0.12
Density, at 70F 0.280 lb/cu in.	(7.75 S.G.)

Thermal Conductivity HK

Btu/hr/ft^2/ft/°F	r.t.-212	8.2
	-1000	12.9
	-1500	11.9
Cal/cm^2/cm/sec/°C	-100	.034
	-537	.053
	-816	.049

Creep Strength (M psi) HK

Temp	Stress for 1% creep in 1000 hr	10,000 hr
1400F	8.5[2]	6.8[1], 5.8[2]
1600	5.1[2]	4.2[1], 3.8[2]
1800	–	2.7[1]
2000	–	1.0[1]
2150	–	.2[1]

[1] Alloy Casting Institute
[2] ASM Metals Handbook

Coef. of Thermal Expansion[1]

Temp Range Deg C	Deg F	Coefficient × 10^{-6} per Deg C	per Deg F
r.t.-100	r.t.-212	14.4	8.0
-537	-1000	16.6	9.2
-648	-1200	16.9, 1.89%[2]	9.4, 1.05%[2]
-760	-1400	17.3, 2.27%[2]	9.6, 1.26%[2]
-816	-1500	17.5	9.7
-870	-1600	17.5, 2.66%[2]	9.7, 1.48%[2]
-981	-1800	18.0, 3.10%[2]	10.0, 1.72%[2]
-1082	-2000	18.2, 3.50%[2]	10.1, 1.94%[2]
648-981	1200-1800	19.2	10.7

[1] Alloy Casting Institute
[2] American Brake Shoe Co for wholly austenitic alloy. Total expansion.

Stress Rupture Strength (M psi) HK

Temp	Stress to rupture in 10 hr	100 hr	1000 hr
1400F	23.0	14.5	9.0
1600	11.0	7.8	5.0
1800	6.5	4.5	3.0
2000	–	2.5	–

Mechanical Properties[1]

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength 0.2% offset M psi	Elong 2 in. %	Red Area %	Hard BHN	Impact Strength[5] Ft Lb r.t.	0	100	200	300
CK-10[7] 2100F, WQ[2]	–	73	33	48	–	–	–	–	–	–	–
CK-20 As Cast	–	65	35	22	–	196	–	–	–	–	–
CK-20 2100F, WQ	–	76	38	21	–	180[1], 184[2]	50[4]	46	37	25	18
CK-20C As Cast[2]	–	84	32	41	–	–	–	–	–	–	–
CK-20C 2100F, WQ[2]	–	72	34	38	–	–	–	–	–	–	–
HK As Cast	–	75[1], 71.75[3]	50[1], 47[2], 42.5[3]	17[1], 16[3]	30.5	170[1], 187[2]	27[6]	–	–	–	–
HK 24 hrs at 1400F, AC	–	85[1], 78[2]	50[1], 51.25[2]	10[1], 7.5[3]	10.4	190[1], 205[2]	–	–	–	–	–
Effect of Temp CK-20	1600	16.4	11.9	11.0	–	–	–	–	–	–	–
Effect of Temp CK-20	1800	10.6	6.2	24.0	–	–	–	–	–	–	–
Effect of Temp HK	1600	23.0	–	21	–	–	–	–	–	–	–
Modulus of Elasticity[3] CK	29×10^3										
Modulus of Elasticity[3] HK	23×10^3										

[1] Alloy Casting Institute
[2] ASTM Special Technical Bulletin No. 52A
[3] ASM Metals Handbook
[4] See Fig 27 p 70 ASTM Bulletin 52A
[5] Charpy, vee-notch
[6] Izod, vee-notch
[7] Content, 0.10% max

SPECIAL CASTINGS

Corrosion Resistant

HD

Chemical Composition[1]			
C %	Mn %	P %	S %
0.50 max	1.50 max	.04 max	.04 max
Ni %	Si %	Cr %	Mo %
4-7	2.0 max	26-30	0.50

[1]Alloy Casting Institute

Physical Properties

Specific resistivity, Microhm/cm³ at 70F 81
Specific heat, Btu/lb/°F at 70F 0.12
Density, at 70F .274 lb/cu in. (7.584 S.G.)

Thermal Conductivity		
Btu/hr/ft²/ft/°F	r.t.-212	12.6
	-1000	17.9
	-1500	20.3
	-2000	24.2
Cal/cm²/cm/sec/°C	r.t.-100	.05
	-537	.07
	-815	.08
	-1092	.10

Technological Properties

Machinability, relative to annealed 18Cr-8Ni — Equivalent
Weldability, relative to annealed 18Cr-8Ni — Similar to HE[1] Fair (No preheat or heat treatment after welding required)
Magnetic Permeability — Magnetic
Melting Point, Approx — 2700

Coef. of Thermal Expansion

Temp Range Deg C	Deg F	Coefficient × 10^{-6} per Deg C	per Deg F
20-537	r.t.-1000	13.9	7.7
-815	-1500	15.3	8.5
-1092	-2000	16.6	9.2

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hr
1400F	3.5
1600	1.9
1800	0.9

Stress Rupture Strength (M psi)

Temp	Stress to rupture in 100 hr
1400F	10.0
1600	5.0
1800	2.5

Mechanical Properties[1]

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength 0.2% offset M psi	Elong 2 in. %	Hard BHN
As cast	–	85	48	16	190
Effect of Temp	1400	36	–	14	–
	1600	23	–	18	–
	1800	15	–	40	–

[1]Alloy Casting Institute

SPECIAL CASTINGS

Corrosion Resistant

HI

Chemical Composition[1]			
C %	Mn %	P %	S %
0.20-0.50	2.0 max	.04 max	.04 max
Ni %	Si %	Cr %	Mo %
14-18	2.0 max	26-30	0.50 max

[1]Alloy Casting Institute

Technological Properties

Machinability, relative to annealed 18Cr-8Ni Equivalent

Stress Rupture Strength (M psi)

Temp	Stress to rupture in 100 hr	1000 hr
1400F	13.0	8.5
1600	7.5	4.8
1800	4.1	2.6
2000	1.9	1.25

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hr
1400F	6.6
1600	3.6
1800	1.9
2000	0.8
2150	0.15

Coef. of Thermal Expansion

Temp Range Deg C	Deg F	Coefficient × 10^{-6} per Deg C	per Deg F
20-648	r.t.-1200	18.0	10.0
-754	-1400	18.2	10.1
-870	-1600	18.5	10.3
-981	-1800	18.9	10.5
-1092	-2000	19.4	10.8
648-870	1200-1600	19.8	11.0

Mechanical Properties[1]

Form or Condition	Tensile Strength M psi	Yield Strength 0.2% offset M psi	Elong 2 in. %	Hard BHN
As cast	80	55	8	180
24 hrs at 1400F, FC	90	70	6	200

[1]Alloy Casting Institute

SPECIAL CASTINGS

Corrosion Resistant

HL

Chemical Composition[1]

C %	Mn %	P %	S %
0.20-0.60	2.0 max	.04 max	.04 max
Ni %	**Si %**	**Cr %**	**Mo %**
18-22	3.0 max	28-32	0.50 max

[1]Alloy Casting Institute

Technological Properties

Machinability, relative to annealed 18Cr-8Ni	Equivalent
Weldability, relative to annealed 18Cr-8Ni	Fair (No preheat or heat treatment after welding required)
Melting Point, Approx	2600

Physical Properties

Specific resistivity, Microhm/cm³ at 70F	94
Specific heat, Btu/lb/°F at 70F	0.12
Density, at 70F .279 lb/cu in.	(7.723 S.G.)

Stress Rupture Strength (M psi)

Temp	Stress to rupture in 100 hr
1400F	15.0
1600	9.2
1800	5.2

Thermal Conductivity

Btu/hr/ft²/ft/°F	r.t.-212	8.2
	-1000	10.9
	-1500	11.9
Cal/cm²/cm/sec/°C	r.t.-100	.03
	-537	.045
	-815	.05

Coef. of Thermal Expansion

Temp Range Deg C	Temp Range Deg F	Coefficient × 10^{-6} per Deg C	Coefficient × 10^{-6} per Deg F
20-537	r.t.-1000	16.6	9.2
-815	-1500	17.5	9.7
-1092	-2000	18.2	10.1
648-981	1200-1800	19.3	10.7

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hr
1400F	7.0
1600	4.3

Mechanical Properties[1]

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength 0.2% offset M psi	Elong 2 in. %	Hard BHN
As cast	–	86	53	19	192
Effect of Temp	1400	50	–	–	–
	1600	30.4	–	–	–
	1800	18.7	–	–	–

[1]Alloy Casting Institute

SPECIAL CASTINGS

Corrosion	Heat Resistant
CN-7	**HN**

Chemical Composition

	C %	Mn %	Si %	Cr %
CN-7	.07 max	1.50 max	2.00 max	18.0/22.0
	Ni %	**Mo %**	**Cb %**	**Se %**
CN-7	20/30	–[1]	–	–

[1]Optional

Characteristics. HN (20:25) has good resistance to scaling at high temperatures, even in the presence of sulphur.

Uses. Hot sulphuric acids and for certain severe corrosive conditions. Mo is usually added.

Technological Properties

Machinability	Poor
Weldability	Good
Scaling temp oxidizing	2000 F

SPECIAL CASTINGS	
Corrosion	Heat Resistant
CT-7	**HT**

Characteristics: CT is similar to CN[1]
HT has good resistance to scaling under oxidizing conditions but is sensitive to sulphur in reducing atmospheres.

Uses: Castings which are subject to rapid heating and cooling, and for parts in carburizing furnaces.

[1]HN (20:25) has good resistance to scaling at high temperatures, even in the presence of sulphur.

Chemical Composition[1]

	C %	Mn %	P %	S %
HT	0.35-0.75	2.0 max	0.04 max	0.04 max
CT[4]	.07 max	1.50 max	–	–

	Ni %	Si %	Cr %	Mo %
HT	33.0-37.0	2.5 max	13.0-17.0	0.50 max[3]
CT[4]	34-37	2.0 max	13-17	–[2]

[1]Alloy Casting Institute
[2]Optional
[3]Not intentionally added
[4]ASM Metals Handbook

Technological Properties HT

Machinability, relative to annealed 18Cr-8Ni	Good: as cast
Weldability, relative to annealed 18Cr-8Ni	Equivalent: heat treated Fair (No preheat or heat treatment after welding required)
Magnetic Permeability	Partially magnetic
Melting Point, Approx	2400-2450
Scaling temp, oxidizing	2100F (2000F, reducing)

Physical Properties HT

Specific resistivity, Microhm/cm^3 at 70F	100.0
Specific heat, Btu/lb/°F at 70F	0.11
Density, lb/cu in. at 70F	.286 lb/cu in. (7.816 S.G.)

Thermal Conductivity HT

BTU/hr/ft^2/ft/°F	r.t.-212	7.7
	-1000	11.4
Cal/cm^2/cm/sec/°C	r.t.-100	.03
	-537	.05

Coef. of Thermal Expansion HT

Temp Range Deg C	Deg F	Coefficient × 10^{-6} per Deg C	per Deg F
20-537	r.t.-1000	15.3	8.5
-648	-1200	16.0	8.9
-759	-1400	16.6	9.2
-870	-1600	16.7	9.3
-981	-1800	17.6	9.8
-1092	-2000	17.6	9.8

Creep Strength (M psi) HT

Temp	Stress for 1% creep in 100 hr	1000 hr	10,000 hr
1400F	–	–	8.0[1]
1600	8.2[2]	6.8[2]	4.5[1], 5[2]
1800	–	–	2.0[1]
1900	–	–	1.2[1]
2000	–	–	0.5[1]
2100	–	–	0.25[1]
2150	–	–	0.15[1]

[1]Alloy Casting Institute
[2]American Brake Shoe Co (Avery). These values are not sensitive to Cr and Ni, but are lowered by Si above 1.5% and are raised by lower Si, especially at high loads.

Stress Rupture Strength (M psi) HT

Temp	Stress to rupture in 10 hr	100 hr	1000 hr	10,000 hr
1400F	–	18.0[1]	12.5[1]	–
1600	11.0[1]	8.5[1], 8.2[2]	7.0[1], 6.8[2]	5[2]
1800	5.8[1]	4.5[1]	3.7[1]	–
2000	–	2.5[1]	1.8[1]	–

[1]Alloy Casting Institute
[2]American Brake Shoe Co (Avery). These values are not sensitive to Cr and Ni, but are lowered by Si above 1.5% and are raised by lower Si, especially at high loads.

Mechanical Properties[1]

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength 0.2% offset M psi	Elong 2 in %	Hard BHN	Impact Strength[3] Room Temp Ft Lb
HT As Cast	–	70[1], 69[4]	40[1], 37.5[4]	10	180[1], 192[4], 168[2]	4
HT 48 hr at 1800F, AC	–	75	45	5	200[1], 197[4], 187[2]	5
Effect of Temp	70F	70[4]	–	–	–	–
	1000	53.5	33	6	–	–
	1200	42.4	28	5	–	–
	1400	35.0	26	10	–	–
	1600	18.8[1], 19[4]	15	14	–	–
	1800	11.0[1], 10[4]	8	26	–	–
	2000	6.0	–	28	–	–

[1]Alloy Casting Institute
[2]ASTM Technical Bulletin No. 52A
[3]Charpy Keyhole
[4]ASM Metals Handbook

SPECIAL CASTINGS

Heat Resistant

HU

Chemical Composition[1]

	C %	Mn %	P %	S %
HU	0.35-0.75	2.0 max	0.04 max	0.04 max
	Ni %	Si %	Cr %	Mo %
HU	37.0-41.0	2.5 max	17.0-21.0	0.50 max[2]

[1]Alloy Casting Institute
[2]Not intentionally added

Characteristics. HU is a little better than HT and resists scaling a little better, especially that due to S in reducing atmospheres.

Uses. HU is used for parts which are subjected to rapid heating and cooling and for parts in carburizing furnaces.

Technological Properties

Machinability, relative to annealed 18Cr-8Ni	Good, as cast
Weldability, relative to annealed 18Cr-8Ni	Equivalent, heat treated Fair (No preheat or heat treatment after welding required)
Magnetic Permeability	Partially magnetic
Melting Point, Approx	2400-2450

Physical Properties

Specific resistivity, Microhm/cm[3] at 70F 105.0
Specific heat, Btu/lb/°F at 70F 0.11
Density, lb/cu in. at 70F .290 lb/cu in. (8.03 S.G.)

Coef. of Thermal Expansion[1]

Temp Range Deg C	Temp Range Deg F	Coefficient × 10^{-6} per Deg C	Coefficient × 10^{-6} per Deg F
20-537	r.t.-1000	16.0	8.9
-815	-1500	16.4	9.1
-1092	-2000	17.5	9.7
0-1000[2]	32-1850[2]	17.1[2]	9.5[2]

[1]Alloy Casting Institute
[2]ASM Metals Handbook

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hr
1400F	8.5
1600	5.0
1800	2.2
2000	0.6

Stress Rupture Strength (M psi)

Temp	Stress to rupture in 100 hr	Stress to rupture in 1000 hr
1400F	15.0	–
1600	8.0	6.0
1800	4.5	2.9

Mechanical Properties[1]

Form or Condition		Test Temp	Tensile Strength M psi	Yield Strength 0.2% offset M psi	Elong 2 in %	Hard BHN	Impact Strength[2] Room Temp Ft Lb
HU	As cast	–	70	40	9	170	4
	48 hr at 1800F, AC	–	73	43	5	190	5
	Effect of Temp	1400	40	–	–	–	–
		1600	19.6	–	20	–	–
		1800	10	6.2	28	–	–

[1]Alloy Casting Institute
[2]Charpy Keyhole

SPECIAL CASTINGS

Heat Resistant

HW

Characteristics: HW has good resistance to thermal shock and high electrical resistivity. It is not satisfactorily resistant to sulphur, and HH or HL is usually substituted.

Uses: Parts which are subjected to rapid heating and cooling or are used in carburizing furnaces, also cast resistors.

Chemical Composition

	C %	Mn %	P %	S %
HW	0.35-0.75	2.00 max	0.04 max	0.04 max
	Ni %	**Si %**	**Cr %**	**Mo %**
HW	58-62	2.50 max	10-14	0.5 max[2]

[1] Alloy Casting Institute
[2] Not intentionally added

Technological Properties[2]

Machinability, relative to annealed 18Cr-8Ni	Good
Weldability, relative to annealed 18Cr-8Ni	Equivalent (No preheat or heat treatment after welding required)
Resistance to Scaling[1]	2050F, oxidizing, 1900F, reducing
Magnetic Permeability	
Melting Point, Approx	2350F

[1] ASM Metals Handbook
[2] Alloy Casting Institute

Physical Properties

Density, lb/cu in. at 70F .30 lb/cu in. (8.30 S.G.)

Coef. of Thermal Expansion

Temp Range Deg C	Deg F	Coefficient × 10^{-6} per Deg C	per Deg F
20-648	r.t.-1200	14.6	8.1
-759	-1400	15.1	8.4
-870	-1600	15.5	8.6
-981	-1800	14.9	8.3
-1000	-1850	16.2	9.0
-1092	-2000	16.6	9.2

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hr
1400F	6.0
1600	3.0
1800	1.4
2000	0.5[1]

[1] Extrapolated

Stress Rupture Strength (M psi)

Temp	Stress to rupture in 10 hr	100 hr	1000 hr
1400F	16.0	10.0	7.8
1600	8.2	6.0	4.5
1800	4.3	3.6	2.6

Mechanical Properties[1]

	Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength 0.2% offset M psi	Elong[3] 2 in %	Hard BHN
HW	As cast	–	68	36[1], 50[2]	8[1], 4[2]	185[1], 179[3]
	48 hr at 1800F, AC[3]	–	75	38	4	205
	24 hr at 1400F, FC	–	84[1], 75[2]	52[1], 38[2]	6[1], 4[2]	205
	Effect of Temp	70F[3]	65	–	–	–
		1400	32[4]	23[4]	–	–
		1600	19[1], 20[3]	15	–	–
		1800	10	8	40	–

[1] Alloy Casting Institute
[2] ASTM Special Technical Bulletin No 52A
[3] ASM Handbook
[4] Extrapolated

SPECIAL CASTINGS

Heat Resistant

HX

Chemical Composition[1]				
	C %	Mn %	P %	S %
HX	0.35-0.75	2.00 max	0.04 max	0.04 max
	Ni %	Si %	Cr %	Mo %
HX	64-68	2.50 max	15-19	0.5 max[2]

[1] Alloy Casting Institute
[2] Not intentionally added

Characteristics: HX is resistant to thermal shock, and though comparable to HW is more resistant to corrosion and is considerably more resistant to high S in reducing atmospheres.

Uses: Parts which are subjected to rapid heating and cooling, and also for parts for carburizing furnaces.

Technological Properties

Machinability, relative to annealed 18Cr-8Ni	Good
Weldability, relative to annealed 18Cr-8Ni	Equivalent (No preheat or heat treatment after welding required)
Melting Point, Approx	2350F

Coef. of Thermal Expansion

Temp Range Deg C	Temp Range Deg F	Coefficient × 10^{-6} per Deg C	Coefficient × 10^{-6} per Deg F
20-1017	r.t.-1850	15.3	8.5

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hr
1400F	6.4
1600	3.2
1800	1.6
2000	0.6

Stress Rupture Strength (M psi)

Temp	Stress to rupture in 10 hr	100 hr	1000 hr
1400F	18.0	13.0	–
1600	10.0	6.7	4.0
1800	5.4	3.5	2.2
2000	2.5	1.7	0.9

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength 0.2% offset M psi	Elong 2 in. %	Hard BHN
HX As cast	–	55.6[1], 75[2]	25[1], 45[2], 40[3]	9	170[1], 172[2]
48 hr at 1800F, AC	–	82	50[1], 42[2]	9	185[1], 183[2]
Effect of Temp[4]	1000	48	21	9	–
	1200	45	20	8	–
	1350	42	19.5	11	–
	1500	29	13.8	31	–
	1600	–	17.5	–	–
	1800	10.7	6.9	48	–
	2000	–	–	40	–

[1] Alloy Casting Institute
[2] ASTM Special Technical Bulletin No. 52A
[3] ASM Metals Handbook

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
.08/.20	2.00 max	1.00 max	.040 max	.030 max

Cr %	Ni %	Mo %	Se %	Zr %
16.0/18.0	6.00/8.00	–	–	–

Ti %	Cb %	Al %
–	–	–

Characteristics. A general purpose steel. A good cold-drawing grade, work hardens rapidly.

Uses. Hardware, household utensils, trim, and structural purposes.

Technological Properties

Forging temp	2300-1700F
Annealing temp	1850-2050F, Cool Rapidly
Hardening temp	Hardens only by cold working
Freezing point	2550-2590F 1400-1420C
Machinability	Poor
Weldability	Good
Scaling temp, oxidizing	1550F continuous 1400F intermittent
Drawability	Very good
Stress relieving	400-750F

Physical Properties

Density, at 70F	0.286 lb/cu in. (7.93 S.G.)
Specific heat, cal/gm at 212F	0.118
Specific resistivity, microhm/cm^3	72 or 28.3/in.^{3}
Magnetism, annealed	Nonmagnetic

Thermal Conductivity

Btu/ft^2/hr/ft/$^{\circ}$F at	212F	9.4
	932F	12.4

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per Deg F	Coefficient × 10^{-6} per Deg C
32-212F	0-100C	9.4	16.9
-600F	-316C	9.5	17.1
-1000F	-538C	10.1	18.2
-1200F	-649C	10.4	18.7

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi 0.2% Offset	Elong 2 in. %	Red Area %	Hard BHN	Rock Hard	Impact Resist. Ft Lb Charpy	Impact Resist. Ft Lb Izod
Sheet, Strip, Plate, Bars — Annealed	–	105-110	40	55-60	70	–	B85	110	165
Sheet, Strip, Plate, Bars — Cold Rolled	–	125-185	75-140	8-25	–	–	C25-C-41	–	–
Annealed	–	80-90	35-45	60-55	65-55	135-185	75-90	–	110-70
Cold Rolled	–	100-180	50-150	50-10	–	190-330	92-109	–	–
Effect of Temp	70F	87	–	–	–	–	–	–	–
	200	78.5	–	–	–	–	–	–	–
	300	75.5	–	–	–	–	–	–	–
	400	74	–	–	–	–	–	–	–
	500	73.5	–	–	–	–	–	–	–
	600	73	–	–	–	–	–	–	–
	700	71.5	–	–	–	–	–	–	–
	800	69	–	–	–	–	–	–	–
	900	65	–	–	–	–	–	–	–
	1000	58	–	–	–	–	–	–	–
	1100	51.5	–	–	–	–	–	–	–
	1200	44.5	–	–	–	–	–	–	–
	1300	37.5	–	–	–	–	–	–	–
	1400	39.5	–	–	–	–	–	–	–
	1500	22	–	–	–	–	–	–	–
	1600	16	–	–	–	–	–	–	–
	1700	12	–	–	–	–	–	–	–
	1800	8.5	–	–	–	–	–	–	–
	1900	6.5	–	–	–	–	–	–	–
	2000	5.5	–	–	–	–	–	–	–

Modulus of Elasticity, E in psi 28.0×10^{-6} in tension (lowered by cold work)
12.5×10^{-6} in torsion (lowered by cold work)

36840.

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STEEL STAINLESS, WROUGHT

302

Technological Properties

Forging temp	2300-1700F
Annealing temp	1850-2050 (Cool Rapidly)
Hardening temp	Hardens only by cold work
Melting range	2550-2590F 1400-1420C
Machinability	Poor
Weldability	Good
Scaling temp, oxidizing	1600 continuous 1450 intermittent
Drawability	Very good
Stress relieving	400-750F

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
.08/.20	2.00 max	1.00 max	.040 max	.030 max
Cr %	**Ni %**	**Mo %**	**Se %**	**Zr %**
17.0/19.0	8.00/10.00	–	–	–
Ti %	**Cb %**	**Al %**		
–	–	–		

Characteristics. One of the most widely used stainless steels. It is easy to fabricate for decorative and corrosion applications. It is workable hot and cold and is strong at elevated temperatures. Silicon is increased in 302B for resistance to scaling.

Physical Properties

Density, at 70F	0.286 lb/cu in. (7.93 S.G.)
Specific heat, cal/gm at 212F	0.118
Specific resistivity, microhm/cm³	72 or 28.3/in.³
Magnetism, annealed	Nonmagnetic

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	per deg C
32-212F	0-100C	9.6	17.3
-600F	-316C	9.9	17.8
-1000F	-538C	10.2	18.4
-1200F	-649C	10.4	18.7
-1800F	-982C	11.2	20.2

Thermal Conductivity

Btu/ft²/hr/ft/ °F at	212F	9.4
	932F	12.4

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in. %	Red Area %	Hard BHN	Rock Hard	Impact Resist Ft Lb Charpy	Izod
Sheet, Strip, Plate, Bars Annealed	–	85-90	35-40	50-60	70	150	B-80	80	110
Sheet, Strip, Plate, Bars Cold Rolled	–	100-125	75-95	12-35	55-60	240-277	–	–	90
Annealed	–	80-90	35-45	60-55	65-55	135-185	75-90	–	110-70
Cold Rolled	–	100-180	50-150	50-10	–	190-330	92-109	–	–
Effect of Temp	70F	87	–	–	–	–	–	–	–
	200	78.5	–	–	–	–	–	–	–
	300	75.5	–	–	–	–	–	–	–
	400	74	–	–	–	–	–	–	–
	500	73.5	–	–	–	–	–	–	–
	600	73	–	–	–	–	–	–	–
	700	71.5	–	–	–	–	–	–	–
	800	69	–	–	–	–	–	–	–
	900	65	–	–	–	–	–	–	–
	1000	58	–	–	–	–	–	–	–
	1100	51.5	–	–	–	–	–	–	–
	1200	44.5	–	–	–	–	–	–	–
	1300	37.5	–	–	–	–	–	–	–
	1400	29.5	–	–	–	–	–	–	–
	1500	22	–	–	–	–	–	–	–
	1600	16	–	–	–	–	–	–	–
	1700	12	–	–	–	–	–	–	–
	1800	8.5	–	–	–	–	–	–	–
	1900	6.5	–	–	–	–	–	–	–
	2000	5.5	–	–	–	–	–	–	–

Modulus of elasticity, E in psi 28.0 × 10^{-6} in tension; 12.5 × 10^{-6} in torsion; lowered by cold work

Fatigue Strength

Condition	Temp	10^7 cycles M psi
Quench-Annealed	70F	42
	800[1]	37
	1000[1]	38
	1200[1]	32

[1]There seems to be no real endurance limit at elevated temperatures but rather the S-N curve slopes downward at all reversals investigated. (Metals Handbook)

Creep Strength (M psi)[1]

Temp	Stress for 1% creep in 10,000 hr	100,000 hr
1000F	17.5, 17[2]	11.3
1100	12	7.5
1200	7	4.1
1300	4	2.2
1350	–	–
1400	2.5	1.2
1500	1, 1.2[2]	.7
1600	–	–

[1]Metals Handbook
[2]AISI Steel Products Manual

Stress-Rupture Strength (M psi)

Temp	1,000 hr	100,000 hr
1000F	–	–
1100	28	–
1200	15	8.5
1300	9	4
1350	–	–
1400	6	3
1500	3.7	1.5
1600	–	–
1700	–	–
1800	–	–

SPECIAL CASTINGS

302B

Chemical Composition (AISI)

C %	Mn %	P %	S %
.08/.20	2.00 max	.040 max	.030 max
Ni %	**Si %**	**Cr %**	
8.00/10.00	2.00/3.00	17.0/19.0	

Characteristics. One of the most widely used stainless steels. It is easy to fabricate for decorative and corrosion applications. It is workable hot and cold and is strong at elevated temperatures.

Physical Properties

Density, at 70F	0.29 lb/cu in. (7.93 S.G.)
Specific heat, cal/gm at 212F	0.12
Specific resistivity, microhm/cm³	72 or 28.3/in.³

Thermal Conductivity

Btu/ft²/hr/ft/°F at	212F	9.2
	932F	12.5

Technological Properties

Forging temp	2250-1700F (Cool rapidly)
Annealing temp	1850-2050F
Hardening temp	Hardens only by cold work
Melting range	2500-2550F 1370-1400C
Machinability	Poor
Weldability	Fair
Scaling temp, oxidizing	1800 continuous 1450 intermittent
Drawability	Good
Stress relieving	400-750F

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	per deg C
32-212F	0-100C	9.0	16.2
-600F	-316C	10.0	18.0
-1000F	-538C	10.8	19.4
-1200F	-649C	11.2	20.2

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in. %	Red Area %	Hard BHN	Rock Hard	Impact Resist. Ft Lb Charpy	Izod
Sheet, strip, plate, bars	Annealed	90-95	40	50-55	65	160	B85	90	90

Modulus of elasticity, E in psi 28 × 10^{-6} in tension
in torsion

STEEL STAINLESS, WROUGHT

303

Composition (AISI)

C %	Mn %	Si %	P %	S %
.15 max	2.00 max	1.00 max	.07 min¹	.07 min¹
Cr %	**Ni %**	**Mo %**	**Se %**	**Zr %**
17.0/19.0	8.00/10.00	.60 max²	.07 min¹	.60 max²
Ti %	**Cb %**	**Al %**		
—	—	—		

¹P,S, or SE 07% min ²Mo or Zr 60% max

Characteristics. This is free machining 18:8. It is highly resistant to corrosion though inferior to 301 or 304.

Physical Properties

Density, at 70F	0.286 lb/cu in. (7.93 S.G.)
Specific heat, cal/gm at 212F	0.118
Specific resistivity, microhm/cm³	72 or 28.3/in.³
Magnetism, annealed	Nonmagnetic

Thermal Conductivity

Btu/ft²/hr/ft/°F at	212F	9.4
	932F	12.4

Technological Properties

Forging temp	2350-1700F
Annealing temp	1850-2050F, Cool rapidly
Freezing point	2550-2590F 1400-1420C
Machinability	Good
Weldability	Poor, except with low-hydrogen electrodes
Scaling temp, oxidizing	1600F continuous 1450F intermittent
Drawability	Good
Stress relieving	400-750F

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	per deg C
32-212F	0-100C	9.6	17.3
-600F	-316C	9.9	17.9
-1000F	-538C	10.2	18.4
-1200F	-649C	10.4	18.7

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in. %	Red Area %	Hard BHN	Impact Resist. Ft Lb Izod
Bar: Annealed	90	35	50	55	160	80
Cold drawn, high tensile	110-125	75-95	20-30	50	240-277	35

Modulus of elasticity, E in psi 28 × 10^{-6} in tension

STEEL STAINLESS, WROUGHT
304

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
.08 max[1]	2.00 max	1.00 max	.040 max	.030 max
Cr %	**Ni %**	**Mo %**	**Se %**	**Zr %**
18.0/20.0	8.00/11.00	–	–	–
Ti %	**Cb %**	**Al %**		
–	–	–		

[1] 304L, .03% max.

Technological Properties

Forging temp	2300-1700F
Annealing temp	1850-2050F, Cool rapidly
Hardening temp	Hardens by cold work only
Melting range	Solidus 2600F or 1425C Liquidus 2750F or 1508C
Machinability	Poor
Weldability	Good
Scaling temp, oxidizing	1600F continuous 1450F intermittent
Drawability	Very good
Stress relieving	400-750F

Characteristics. This is the popular low carbon grade of 18:8 for welding. It can be worked hot and cold.

Physical Properties

Density, at 70F	0.29 lb/cu in. (7.9 S.G.)
Specific heat cal/gm at 212F	0.12
Specific resistivity, microhm/cm³	72 or 28.3/in.³
Magnetism, annealed	Nonmagnetic

Thermal Conductivity

Btu/ft²/hr/ft/°F at	
212F	9.4
392F	10.3
572F	11.0
752F	11.8
932F	12.5

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	per deg C
32-212F	0-100C	9.6	17.3
-600F	-316C	9.9	17.8
-1000F	-538C	10.2	18.4
-1200F	-649C	10.4	18.7
-1800F	-982C	11.2	20.2

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in %	Red Area %	Hard BHN	Rock Hard	Impact Resist. Ft Lbs Izod
Sheet, strip, plate, bars } annealed	–	85	30-35	50-60	70	150	B-80	110
Bars, cold drawn, high tensile	–	110-125	75-95	25-60	–	240-277	–	90
Effect of Temp	70F	87	–	–	–	–	–	–
	200	78.5	–	–	–	–	–	–
	300	75.5	–	–	–	–	–	–
	400	74	–	–	–	–	–	–
	500	73.5	–	–	–	–	–	–
	600	73	–	–	–	–	–	–
	700	71.5	–	–	–	–	–	–
	800	69	–	–	–	–	–	–
	900	65	–	–	–	–	–	–
	1000	58	–	–	–	–	–	–
	1100	51.5	–	–	–	–	–	–
	1200	44.5	–	–	–	–	–	–
	1300	37.5	–	–	–	–	–	–
	1400	29.5	–	–	–	–	–	–
	1500	22	–	–	–	–	–	–
	1600	16	–	–	–	–	–	–
	1700	12	–	–	–	–	–	–
	1800	8.5	–	–	–	–	–	–
	1900	6.5	–	–	–	–	–	–
	2000	5.5	–	–	–	–	–	–

Modulus of elasticity, E in psi 28.0 × 10^{-6} in tension
12.5 in torsion

Fatigue Strength

Condition	Temp	M psi
Quench annealed	70F	40
	800	32
	1000	32
	1200	30

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hr	100,000 hr
1000F	17.5, 17[1]	11.3
1100	12	7.5
1200	7	4.1
1300	4	2.2
1350	–	–
1400	2.5	1.2
1500	1, 1.2[1]	.7
1600	–	–

[1] ASM Metals Handbook

Stress-Rupture Strength (M psi)

Temp	1,000 hr	100,000 hr
1000F	–	–
1100	38	–
1200	15	8.5
1300	9	4
1350	–	–
1400	6	3
1500	3.7	1.5
1600	–	–
1700	–	–
1800	–	–

STEEL STAINLESS, WROUGHT

309 309S

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
–[1]	2.00 max	1.00 max	.040 max	.030 max

Cr %	Ni %	Mo %	Se %	Zr %
22.0/24.0	12.00/15.00	–	–	–

Ti %	Cb %	Al %
–	–	–

[1] 309 = .20 max, 309 S = .08 max

Characteristics. Has good strength and resistance to scaling at elevated temperatures. The low carbon grade is better for welding characteristics.

Technological Properties

Forging temp	2300 to 1800F
Annealing temp	1900 to 2050F, Cool rapidly
Melting range	Solidus 2550F or 1397C Liquidus 2650F or 1453C
Machinability	Poor
Weldability	Good
Scaling temp, oxidizing	2000 F continuous, 1800 F intermittent
Drawability	Good
Stress relieving	400-750F

Physical Properties

Density, at 70F	0.288 lb/cu in. (7.98 S.G.)
Specific heat, cal/gm at 212F	0.118
Specific resistivity, microhm/cm^3 at 70F	78 or 30.7/in.^{3}
Magnetism, annealed	Nonmagnetic

Thermal Conductivity

Btu/ft^2/hr/ft/°F at	212F	8.0
	392F	
	572F	
	752F	
	932F	10.8
Cal/cm^2/sec/cm/°C at	100C	
	200C	
	300C	
	400C	
	500C	

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	per deg C
32-212F	0-100C	8.3	14.9
-600F	-316C	9.3	16.7
-1000F	-538C	9 6	17.3
-1200F	-649C	10.0	18.0
-1800F	-982C	11.5	20.7

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in %	Red. Area %	Hard BHN	Rock Hard	Impact Resist. Ft Lbs Izod
Sheet, strip, plate, bars } annealed	–	90-95	40-45	45-65	–	160-170	B-83, B-85	110
Effect of Temp	70F	91	–	–	–	–	–	–
	200	84.5	–	–	–	–	–	–
	300	81	–	–	–	–	–	–
	400	79	–	–	–	–	–	–
	500	77	–	–	–	–	–	–
	600	75	–	–	–	–	–	–
	700	74	–	–	–	–	–	–
	800	72	–	–	–	–	–	–
	900	69	–	–	–	–	–	–
	1000	65.5	–	–	–	–	–	–
	1100	61	–	–	–	–	–	–
	1200	55	–	–	–	–	–	–
	1300	45	–	–	–	–	–	–
	1400	34	–	–	–	–	–	–
	1500	25.5	–	–	–	–	–	–
	1600	19.5	–	–	–	–	–	–
	1700	15	–	–	–	–	–	–
	1800	11.5	–	–	–	–	–	–
	1900	8.5	–	–	–	–	–	–
	2000	6.5	–	–	–	–	–	–
	2100	4.5	–	–	–	–	–	–
	2200	3.5	–	–	–	–	–	–
	2300	2.5	–	–	–	–	–	–
	2400	2	–	–	–	–	–	–

Modulus of elasticity, E in psi 29.0 × 10^{-6} in tension

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hr	100,000 hr
1000F	17 , 15.9[1]	–
1100	13 , 11.6[1]	–
1200	8 5, 8.0[1]	–
1300	4.5	–
1350	–	–
1400	2	–
1500	1	–
1600	–	–

[1] ASM Metals Handbook

Stress-Rupture Strength (M psi)

Temp	1,000 hr	100,000 hr
1000F	–	–
1100	–	–
1200	20.5	11.25
1300	11.7	3.725
1350	–	–
1400	–	–
1500	4.8	–
1600	2.75	–
1700	–	–
1800	1.025	–

STEEL STAINLESS, WROUGHT

308

Technological Properties

Forging temp	2300-1700
Annealing temp	1850-2050 Cool Rapidly
Hardening temp	Hardens by cold work only
Freezing point	2550-2590F
	1400-1420C
Stress relieving	400-750F

Physical Properties

Density, at 70F	0.29 lb/cu in. (7.9 S.G.)	
Specific heat, cal/gm at 212F	0.12	
Specific resistivity, microhm/cm³	72	or 28.3/in.³
Magnetism, annealed		

Thermal Conductivity

Btu/ft²/hr/ft/°F at	212F	8.8
	932F	12.5

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
.08 max	2.00 max	1.00 max	0.040 max	0.030 max
Cr %	**Ni %**	**Mo %**	**Se %**	**Zr %**
19.0/21.0	10.00/12.00	—	—	—
Ti %	**Cb %**	**Al %**		
—	—	—		

Characteristics. Similar to 304 but is used where greater corrosion resistance is desired. It is weldable and can be worked hot and cold.

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	Coefficient × 10^{-6} per deg C
32-212F	0-100C	9.6	17.3
-600F	-316C	9.9	17.8
-1000F	-538C	10.2	18.4
-1200F	-649C	10.4	18.7

Mechanical Properties

		Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in %	Red Area %	Hard BHN	Rock Hard	Impact Resist Ft Lb Izod
Sheet, strip plate, bars	Annealed	85	30-35	50-55	60-65	150	B-80	110

Modulus of elasticity, E in psi 28.0 × 10^{-6} in tension.

STEEL STAINLESS, WROUGHT

317

Technological Properties

Forging temp	2100-2550F
Annealing temp	1850-2050F, Cool rapidly
Hardening temp	Hardens by cold work only
Freezing point	2500-2550F
	1370-1400C
Stress relieving	400-750F

Physical Properties

Density, at 70F	0.29 lb/cu in. (7.9 S.G.)
Specific heat, cal/gm at 212F	0.12
Specific resistivity, microhm/cm³	74 or 29 1/in.³

Thermal Conductivity

Btu/ft²/hr/ft/°F at	212F	9.4
	932F	12.4

Chemical Composition

C %	Mn %	Si %	P %	S %
.10 max	2 00 max	1 00 max	0 04 max	0 03 max
Cr %	**Ni %**	**Mo %**	**Se %**	**Zr %**
18.0/20.0	11.00/14.00	3.00/4.00	—	—
Ti %	**Cb %**	**Al %**		
—	—	—		

Characteristics. Superior to Type 316 for certain applications but is also more difficult to produce.

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	Coefficient × 10^{-6} per deg C
32-212F	0-100C	8.9	16.0
-600F	-316C	9.0	16.2
-1000F	-538C	9.7	17.5
-1200F	-649C	10.3	18.6
-1500F	- C	11.1	20.0

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi 0 2% offset	Elong 2 in. %	Hard BHN	Rock Hard	Impact Resist Ft Lb Izod
Sheet, strip, plate, bars	annealed	85-90	40	45-50	160	B-85	110

Modulus of elasticity, E in psi 28.0 × 10^{-6} in tension

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
.25 max[3]	2.00 max	–[1]	.040 max	.030 max

Cr %	Ni %	Mo %	Se %	Zr %
24.0/26.0[2]	19.0/22.0	–	–	–

Ti %	Cb %	Al %
–	–	–

[1] 310 = 1.50 max, 314 = 1.50/3.00
[2] 314 = 23.0/26.0
[3] 310S = .08 max

Technological Properties

Forging temp	2300-1800F
Annealing temp	1900 to 2050F, Cool rapidly
Melting range[1]	Solidus 2550F or 1397C Liquidus 2650F or 1453C
Machinability	Poor
Weldability[3]	Good
Scaling temp, oxidizing[2]	2000F continuous, 1900F intermittent
Drawability	Good
Stress relieving	400-750F

[1] 310B melts at a little lower temperature than 310
[2] Values are for 310, 310B is more resistant
[3] 314 Fair

Characteristics. 310 has higher Ni than the 25:12 which gives it greater stability, and is preferred to 18:8 as an electrode for welding ferritic steels.

Uses. 310B is used as carburizing boxes and as furnace hardware.

Physical Properties

Density, at 70F	0.288 lb/cu in. (7.98 S.G.)
Specific heat, cal/gm at 212F	0.118
Specific resistivity, microhm/cm[3]	78 or 30.7/in.[3]
Magnetism, annealed	Nonmagnetic

Coef. of Thermal Expansion

Temp Range		Coefficient × 10⁻⁶ per deg F	per deg C
32-212F	0-100C	8 0	14.4
-600F	-316C	9 0	16.2
-1000F	-538C	9.4	16.9
-1200F	-649C	9 7	17 5
-1800F	-982C	10.6	19.1

Thermal Conductivity

Btu/ft²/hr/ft/°F at		
212F	8.0[1],	7.5[2]
392F		8.2[2]
572F		8.8[2]
752F		9.5[2]
932F	10.8[1],	10.0[2]

[1] AISI Steel Products Manual
[2] ASTM Technical Publication No. 52A

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi 0 2% offset	Elong 2 in. %	Red Area %	Hard BHN	Rock Hard	Impact Resist. Izod Ft Lb
Sheet, strip, plate, bars } annealed	–	95-100	45	45-50	65	170-185	B-85 to B-89	90
Effect of Temp	70F	96	–	–	–	–	–	–
	200	93	–	–	–	–	–	–
	300	90.5	–	–	–	–	–	–
	400	88	–	–	–	–	–	–
	500	86	–	–	–	–	–	–
	600	85	–	–	–	–	–	–
	700	85	–	–	–	–	–	–
	800	84.5	–	–	–	–	–	–
	900	83.5	–	–	–	–	–	–
	1000	80	–	–	–	–	–	–
	1100	72	–	–	–	–	–	–
	1200	61.5	–	–	–	–	–	–
	1300	50.5	–	–	–	–	–	–
	1400	41	–	–	–	–	–	–
	1500	32.5	–	–	–	–	–	–
	1600	25	–	–	–	–	–	–
	1700	18.5	–	–	–	–	–	–
	1800	13.5	–	–	–	–	–	–
	1900	10	–	–	–	–	–	–
	2000	8	–	–	–	–	–	–
	2100	6.5	–	–	–	–	–	–
	2200	5	–	–	–	–	–	–
	2300	4	–	–	–	–	–	–
	2400	3.5	–	–	–	–	–	–

Modulus of elasticity, E in psi 29.0 × 10⁻⁶ in tension

Creep Strength (M psi) 310

Temp	Stress for 1% creep in 10,000 hr	100,000 hr
1000F	20, 17[1]	13
1100	15. 13[1]	8.7
1200	9	5.8
1300	5	3.6
1350	–	–
1400	2.3	2.2
1500	1	0.8
1600	–	–

[1] ASM Metals Handbook

Stress-Rupture Strength (M psi)

Temp	1,000 hr	100,000 hr
1000F	32	16
1100	24	13
1200	17	8
1300	11	4.6
1350	–	–
1400	7	2.6
1500	4.5	1.2
1600	3	–
1700	–	–
1800	1.95	–

STEEL STAINLESS, WROUGHT

321

Chemical Composition (AISI)

C	Mn	Si	P	S
%	%	%	%	%
.08 max	2.00 max	1.00 max	.040 max	.030 max
Cr	Ni	Mo	Se	Zr
%	%	%	%	%
17.0/19.0	8.00/11.00	–	–	–
Ti	Cb	Al		
%	%	%		
5 x C min	–	–		

Technological Properties

Forging temp	2300 to 1700F
Annealing temp	1950 to 2050F, Cool rapidly
Freezing point	2550 to 2590F or 1400 to 1420C
Machinability	Poor
Weldability	Good
Scaling temp, oxidizing	1650 F
Drawability	Good
Hardening	By cold work only
Stabilizing	1550 to 1650F
Stress relieving	400 to 750F

Characteristics. This is 18:8 with the carbon stabilized by Ti for welding and elevated temperature service. This type is useful when the weldment is not annealed after welding.

Physical Properties

Density, at 70F	0.290 lb/cu in. (8.02 S.G.)
Specific heat, cal/gm at 212F	0.118
Specific resistivity, microhm/cm^2 at 70F	72 or 28.3/in.^{2}
Magnetism, annealed	Nonmagnetic

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	per deg C
32-212F	0-100C	9.3	16.7
-600F	-316C	9.5	17.1
-1000F	-538C	10.3	18.6
-1200F	-649C	10.6	19.1
-1500F	-815C	11.1	20.0

Thermal Conductivity

Btu/ft^2/hr/ft/°F at	212F	9.3
	932F	12.8

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in. %	Red Area %	Hard BHN	Rock Hard	End Lt M psi Fatigue	Impact Resist. Izod Ft Lbs
Sheet, Strip, and Bars } annealed	–	90-95	35-40	45-50	65	160	B-85	39	110
Sheet, Strip, and Bars } annealed and cold drawn	–	100	65	40	60	212	–	–	–
Effect of Temp	70F	83.5	–	–	–	–	–	–	–
	200	73.5	–	–	–	–	–	–	–
	300	68	–	–	–	–	–	–	–
	400	64	–	–	–	–	–	–	–
	500	62	–	–	–	–	–	–	–
	600	61	–	–	–	–	–	–	–
	700	60	–	–	–	–	–	–	–
	800	59	–	–	–	–	–	–	–
	900	58	–	–	–	–	–	–	–
	1000	54	–	–	–	–	–	–	–
	1100	50	–	–	–	–	–	–	–
	1200	44.5	–	–	–	–	–	–	–
	1300	36.5	–	–	–	–	–	–	–
	1400	28.5	–	–	–	–	–	–	–
	1500	22	–	–	–	–	–	–	–
	1600	17.5	–	–	–	–	–	–	–
	1700	15	–	–	–	–	–	–	–

Modulus of elasticity, E in psi 28.0 × 10^{-6} in tension

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hr	100,000 hr
1000F	18	–
1100	13	–
1200	8	–
1300	4.5	–
1350	–	–
1400	2.0	–
1500	0.85	–
1600	–	–

Stress-Rupture Strength (M psi)

Temp	1,000 hr	100,000 hr
1000F	–	–
1100	27	–
1200	17.5	–
1300	10	–
1350	–	–
1400	5.5	–
1500	3.7	–
1600	2.75	–
1700	–	–
1800	–	–

STEEL STAINLESS, WROUGHT
316

Chemical Composition (AISI)

C[1] %	Mn %	Si %	P %	S %
.10 max	2.00 max	1.00 max	.040 max	.030 max
Cr %	**Ni %**	**Mo[2] %**	**Se %**	**Zr %**
16.0/18.0	10.00/14.00	2.00/3.00	–	–
Ti %	**Cb %**	**Al %**		
–	–	–		

[1] 316L = .03% max
[2] 316L, TS316, 1.75/2.50%. Estab per Nat'l Prod Auth Order M52

Characteristics. Type 316 with Mo, is more resistant to some media, such as sulphite liquor, etc., and is preferred to 18:8.

Technological Properties

Forging temp	2100 to 2300F
Annealing temp	1850 to 2050F (Cool rapidly)
Hardening temp	Hardens by cold work only
Freezing point	2500 to 2550F or 1370 to 1400C
Machinability	Poor – Tough
Weldability	Good
Scaling temp, oxidizing	1650F
Drawability	Good
Stress relieving	400 to 750F

Physical Properties

Density, at 70F	0.288 lb/cu in. (7.98 S.G.)
Specific heat, cal/gm at 212F	0.118
Specific resistivity, microhm/cm[3] at 70F	74 or 29.2/in.[3]
Magnetism, annealed	Nonmagnetic

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	per deg C
32-212F	0-100C	8.9	16.0
-600F	-316C	9.0	16.2
-1000F	-538C	9.7	17.5
-1200F	-649C	10.3	18.5
-1500F	-816C	11.1	19.98

Thermal Conductivity

Btu/ft²/hr/ft/°F at	212F	9.4
	932F	12.4

Mechanical Properties

	Test Temp	Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in. %	Red Area %	Hard BHN	Rock Hard	End Lt M psi Fatigue	Impact Resist. Izod Ft Lbs
Sheet, Strip, Plate & Bars — annealed	–	80-90	30-40	50-60	70	150	B-78 to B85	38-39	110
Sheet, Strip, Plate & Bars — annealed and cold drawn	–	90	60	45	65	190	–	40	–
Effect of Temp	70F	82.5	–	–	–	–	–	–	–
	200	77	–	–	–	–	–	–	–
	300	75	–	–	–	–	–	–	–
	400	74	–	–	–	–	–	–	–
	500	73.5	–	–	–	–	–	–	–
	600	73	–	–	–	–	–	–	–
	700	72.5	–	–	–	–	–	–	–
	800	71.5	–	–	–	–	–	–	–
	900	70	–	–	–	–	–	–	–
	1000	67.5	–	–	–	–	–	–	–
	1100	63	–	–	–	–	–	–	–
	1200	56.5	–	–	–	–	–	–	–
	1300	46.5	–	–	–	–	–	–	–
	1400	35	–	–	–	–	–	–	–
	1500	27	–	–	–	–	–	–	–
	1600	22	–	–	–	–	–	–	–
	1700	18.5	–	–	–	–	–	–	–

Modulus of Elasticity, E in psi 28.0 × 10^{-6} in tension

Creep Strength (M psi)[1]

Temp.	Stress for 1% creep in 10,000 hrs
1000F	25.0, 24[2]
1100	18.2
1200	12.7
1300	7.9
1500	2.8

[1] AISI Steel Products Manual
[2] ASM Metals Handbook

Stress-Rupture Strength (M psi)

Temp	1,000 hr	100,000 hr
1000F	–	–
1100	33	–
1200	25	12.5
1300	17	9
1350	–	–
1400	11	4.2
1500	7	1.5
1600	4	–
1700	–	–
1800	1.3	–

STEEL STAINLESS, WROUGHT

330

Chemical Composition

C %	Mn %	Si %	P %	S %
.25 max	2.00 max	1.00 max	.040 max	.030 max
Cr %	**Ni %**	**Mo %**	**Se %**	**Zr %**
14.0/16.0	33.0/36.0	—	—	—
Ti %	**Cb %**	**Al %**		
—	—	—		

Characteristics. Not a standard AISI Type but is used in the wrought form.

STEEL STAINLESS, WROUGHT

403

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
.15 max	1.00 max	.50 max	.040 max	.030 max
Cr %	**Ni %**	**Mo %**	**Se %**	**Zr %**
11.50/13.00	—	—	—	—
Ti %	**Cb %**	**Al %**		
—	—	—		

Characteristics. This is a hardenable stainless steel, useful where strength but not great hardness is needed.

Uses. Forged turbine blades.

Technological Properties

Forging temp	2100 to 1650F
Annealing temp	1200 to 1250F, AC
Hardening temp	1700 to 1850F, Cool rapidly
Melting point	2700 to 2750F or 1480 to 1510C
Machinability	Fair
Weldability	Fair — needs precautions
Scaling temp, oxidizing	1300F
Drawability	Fair
Tempering temp	400 to 1400F

Physical Properties

Density, at 70F	0.279 lb/cu in. (7.75 S.G.)
Specific heat, cal/gm, 212F	0.154
Btu/lb/°F, 32-212	0.11
Magnetism, annealed	Ferromagnetic
Specific resistivity, microhm/cm³	57 or 22.4/in.³

Thermal Conductivity

Btu/ft²/hr/ft/°F at	
212F	14.4
932F	16.6

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	per deg C
32-212F	0-100C	5.5	9.9
-600F	-316C	5.6	10.1
-1000F	-538C	6.4	11.5
-1200F	-649C	6.5	11.7

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hr
1000	9.2
1100	4.2
1200	2.0
1300	1.0

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in. %	Red Area %	Hard BHN	Rock Hard	End Lt M psi Fatigue	Impact Resist. Izod Ft Lbs
Sheet, Strip & Bars	annealed	65-75	35-40	25-35	70	155	B-80 to B-82	40	90
Bars —	heat treated	110	85	23	67	225	B-97	55	75

Modulus of elasticity, E in psi 29.0 × 10^{-6} in tension

STEEL STAINLESS, WROUGHT

347

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
.08 max	2.00 max	1.00 max	.040 max	.030 max
Cr %	**Ni %**	**Mo %**	**Se %**	**Zr %**
17.0/19.0	9.00/12.00	–	–	–
Ti %	**Cb[1] %**	**Al %**		
–	10 x C min	–		

[a] TS 347A, Cb + Ta 8 × C min Estab per Nat'l Prod Auth Order M-3.

Characteristics. This is 18 8 with the carbon stabilized by Cb for welding and elevated temperature service. This type is useful when the weldment is not annealed after welding.

Technological Properties

Forging temp	2300 to 1800F
Annealing temp	1950 to 2050F (Cool rapidly)
Freezing point	2550 to 2590F or 1400 to 1420C
Machinability	Poor
Weldability	Good
Scaling temp, oxidizing	1650 F
Drawability	Very good

Physical Properties

Density, at 70F	0.288 lb/cu in. (7.98 S.G.)
Specific heat, cal/gm at 212F	0.118
Specific resistivity, microhm/cm³ at 70F	73 or 28.7/in.³
Magnetism, annealed	Nonmagnetic

Coef. of Thermal Expansion

Temp Range		coefficient X 10^{-6} per deg F	per deg C
32-212F	0-100C	9 3	16 7
-600F	-316C	9 5	17 1
-1000F	-538C	10 3	18 5
-1200F	-649C	10 6	19 1
-1500F	-816C	11 1	20 0

Thermal Conductivity

Btu/ft²/hr/ft/ °F at	212F	9.3
	932F	12.8

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in. %	Red Area %	Hard BHN	Rock Hard	End Lt M psi Fatigue	Impact Resist Izod Ft Lbs
Sheet, Strip, Plates & Bars, annealed	–	90-95	35-40	45-50	60-65	160	B-85	39	110
Bars, annealed & cold drawn	–	100	65	40	60	212	–	–	–
Effect of Temp	70F	90	–	–	–	–	–	–	–
	200	79	–	–	–	–	–	–	–
	300	75	–	–	–	–	–	–	–
	400	71.5	–	–	–	–	–	–	–
	500	69.5	–	–	–	–	–	–	–
	600	68	–	–	–	–	–	–	–
	700	67	–	–	–	–	–	–	–
	800	66	–	–	–	–	–	–	–
	900	64.5	–	–	–	–	–	–	–
	1000	61.5	–	–	–	–	–	–	–
	1100	57	–	–	–	–	–	–	–
	1200	50	–	–	–	–	–	–	–
	1300	40.5	–	–	–	–	–	–	–
	1400	31.5	–	–	–	–	–	–	–
	1500	24	–	–	–	–	–	–	–
	1600	18.5	–	–	–	–	–	–	–
	1700	14.5	–	–	–	–	–	–	–
	1800	12	–	–	–	–	–	–	–
	1900	10	–	–	–	–	–	–	–
	2000	8.5	–	–	–	–	–	–	–
	2100	7	–	–	–	–	–	–	–
	2200	5.5	–	–	–	–	–	–	–
	2300	4	–	–	–	–	–	–	–

Modulus of elasticity, E in psi 28.0 × 10^{-6} in tension

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hrs
1000F	19
1100	15, 14[1]
1200	9.5, 8.2[1]
1300	5, 4.6[1]
1400	2.5
1500	1.1, 1.5[1]

[1] ASM Metals Handbook

Stress-Rupture Strength (M psi)

Temp	1,000 hr	100,000 hr
1000F	–	–
1100	30	16.5
1200	17	11
1300	11.2	4.5
1350	–	–
1400	7.5	–
1500	4.4	–
1600	–	–
1700	–	–
1800	–	–

STEEL STAINLESS, WROUGHT

405

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
.08 max	1.00 max	1.00 max	0.040 max	0.030 max
Cr %	**Ni %**	**Mo %**	**Se %**	**Zr %**
11.5/13.5	–	–	–	–
Ti %	**Cb %**	**Al %**		
–	–	.10/.30		

Technological Properties

Forging temp	1950 to 2050F
Annealing temp	1350 to 1500F
Hardening temp	Not appreciably hardenable
Melting point	2700 to 2790F or 1480 to 1530C

Characteristics. This is a non-airhardening ferritic steel, good for hot and cold working. It has lower strength at elevated temperatures than similar steels with Mo, but has good resistance to scaling and corrosion. Welds have excessive grain coarsening, unless high in N. Machinability is improved by S or Se.

Uses. It is used extensively to line oil stills.

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	Coefficient × 10^{-6} per deg C
32-212F	0-100C	6.0	10.8
-600F	-316C	6.4	11.5
-1000F	-538C	6.7	12.1
-1500F	-815C	7.5	13.5

Physical Properties

Density, at 70F	0.28 lb/cu in. (7.7 S.G.)
Specific heat, Btu/lb/°F 32-212F	0.11
Specific resistivity, microhm/cm^3	60 or 23.6/$in.^3$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in %	Red Area %	Hard BHN	Rock Hard
Sheet, Plate and Bars – annealed	65-70	40	25-30	60	150	B-75
Bars – annealed and cold drawn	85	70	20	60	185	–

Modulus of elasticity, E in psi 29.0 × 10^{-6} in tension

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
.15 max	1.00 max	1.00 max	.040 max	.030 max

Cr %	Ni %	Mo %	Se %	Zr %
11.5/13.5	–	–	–	–

Ti %	Cb %	Al %
–	–	–

Characteristics. Low-priced, general purpose, heat-treatable stainless steel. It can be cold worked and otherwise fabricated fairly well. Its resistance to atmospheric corrosion, water and sonic chemicals is good and is improved by heat treatment.

Physical Properties

Density, at 70F Btu/lb/°l , 32-212	0.279 lb/cu in. (7 75 S.G.)
Specific heat, Btu/lb/°F (32-212)	0.11
Specific resistivity, microhm/cm³	57 or 22 7/in.³
Magnetism, annealed	Ferromagnetic

Thermal Conductivity

Btu/ft²/hr/ft/ °F at	212F	14.4
	392F	15.0
	572F	15.5
	752F	16.1
	932F	16.6

Technological Properties

Forging temp	2100 to 1650F
Annealing temp	1200 to 1250 F, AC
Hardening temp	1750 to 1825 F, OQ
Tempering temp	400 to 1200 F
Melting point	2700 to 2750 F or 1480 to 1510C
Machinability	Fair
Weldability	Fair—needs precautions
Scaling temp, oxidizing	1300 F
Drawability	Fair

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	per deg C
32-212F	0-100C	5.5, 6.1[1]	9.9, 10.9[1]
-600F	-316C	5.6	10.1
-1000F	-538C	6.4, 7.2[1]	11.5, 13.0[1]
-1200F	-649C	6.5	11.7
-1800F	-982C	7.6[1]	13.7[1]

[1] ASTM Technical Publication No. 52A

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi 0 2% offset	Elong 2 in. %	Red Area %	Hard BHN	Rock Hard	Impact Resist. Izod Ft Lb
Sheet, strip, plate, bars — annealed	–	65-75	35-40	25-35	70	150-155	B-80 to B-82	90
heat treated	–	110 min	85	23	65	225	B-97	75
tempered & cold drawn	–	100 min	85	17	60	205	B-94	70-90
Effect of Temp	70F	89	–	–	–	–	–	–
	200	83	–	–	–	–	–	–
	300	79	–	–	–	–	–	–
	400	76	–	–	–	–	–	–
	500	74.5	–	–	–	–	–	–
	600	73	–	–	–	–	–	–
	700	71	–	–	–	–	–	–
	800	66	–	–	–	–	–	–
	900	55.5	–	–	–	–	–	–
	1000	44.5	–	–	–	–	–	–
	1100	33	–	–	–	–	–	–
	1200	22	–	–	–	–	–	–
	1300	13.5	–	–	–	–	–	–
	1400	9	–	–	–	–	–	–
	1500	9	–	–	–	–	–	–
	1600	9.5[1]	–	–	–	–	–	–
	1700	9	–	–	–	–	–	–
	1800	7	–	–	–	–	–	–
	1900	5.5	–	–	–	–	–	–
	2000	4.5	–	–	–	–	–	–
	2100	3	–	–	–	–	–	–
	2200	2.5	–	–	–	–	–	–
	2300	1.5	–	–	–	–	–	–
	2400	0.5	–	–	–	–	–	–

[1] Ferrite ↔ austenite transformation

Modulus of elasticity, E in psi 29.0 × 10^{-6} in tension

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hr	100,000 hr
1000F	11 , 9.2[1]	10
1100	4.5, 4.2[1]	3.7
1200	2	1.3
1300	1.3, 1.0[1]	0.8
1350	–	–
1400	–	–
1500	–	–
1600	–	–

[1] ASM Metals Handbook

Fatigue Strength[1]

Temp	E.L. 10^7 cycles M psi
70F	58
700	49
850	43.5
1000	27.2

[1] Comp 12.3 Cr, 0.38 Ni, .10C, .29 Mn Ann.5 hr 1175, FC, 570 F, AC TS 111,700 psi

STEEL STAINLESS, WROUGHT

416

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
.15 max	1.25 max	1.00 max	.07 min[1]	.07 min[1]
Cr %	**Ni %**	**Mo %**	**Se %**	**Zr %**
12.0/14.0	–	.60 max[2]	.07 min[1]	.60 max[2]

[1] P,S or Se 0.07% min
[2] Zr or Mo 0.60% max

Technological Properties

Forging temp	2150-1700F
Annealing temp	1200-1400F
Hardening temp	1700-1850F, Cool rapidly
Melting point	2700-2790F 1480-1530C
Machinability	Good
Weldability	Poor, unless welded with low-hydrogen electrodes
Scaling temp, oxidizing	1250F continuous 1400F intermittent
Drawability	Poor

Characteristics. A free machining stainless steel similar to 410.

Physical Properties

Density, at 70F	0.278 lb/cu in. (7.73 S.G.)
Specific heat, Btu/lb/°F, 32-212F	0.11
Specific resistivity, microhm/cm³	57 or 22.7/in.³
Magnetism, annealed	ferromagnetic

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	per deg C
32-212F	0-100C	5.5	9.9
-600F	-316C	5.6	10.1
-1000F	-538C	6.4	11.5
-1200F	-649C	6.5	11.7

Thermal Conductivity

Btu/ft²/hr/ft/°F at	212F	14.4
	932F	16.6

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in %	Red Area %	Hard BHN	Rock Hard	Fatigue End Lt M psi	Impact Resist. Izod Ft Lb
Bars	annealed	75	40	30	60	155	B-82	40	70
	heat treated	110	85	18	55	230	B-97	55	25
	tempered & cold drawn	100	85	13	50	205	B-94	53	20

Modulus of elasticity, E in psi 29.0 × 10^{-6} in tension

STEEL STAINLESS, WROUGHT

414

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
.15 max	1.00 max	1.00 max	0.040 max	0.030 max
Cr %	**Ni %**	**Mo %**	**Se %**	**Zr %**
11.5/13.5	1.25/2.50	–	–	–
Ti %	**Cb %**	**Al %**		
–	–	–		

Characteristics. Stainless steel of intermediate hardness.
Uses. Springs, knife blades, tempered rules, etc.

Technological Properties

Forging temp	2100 to 2200F
Annealing temp	1200 to 1300F
Hardening temp	1800 to 1900F, cool rapidly
Tempering temp	400 to 1300F

Physical Properties

Density, at 70F	0.28 lb/cu in. (7.7 S.G.)
Specific heat, Btu/lb/°F, 32-212F	0.11
Specific resistivity, microhm/cm³	70 or 27.6/in.³
Magnetism, annealed	ferromagnetic

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	per deg C
32-212F	0-100C	5.8	10.4
-600F	-316C	6.1	10.98
-1000F	-538C	6.7	12.1

Thermal Conductivity

Btu/ft²/hr/ft/°F at	212F	14.4
	932F	16.6

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in %	Red Area %	Hard BHN	Rock Hard	Impact Resist. Izod Ft Lbs
Sheet, strip, plate & bars	annealed	115-120	90-105	15-20	60[1]	235	B-98	50
	annealed & cold drawn	130	115	15	58	270	–	–

Modulus of elasticity, E in psi 29.0 × 10^{-6} in tension
in torsion

SPECIAL CASTINGS

420

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
.15 min	1.00 max	1.00 max	0.04 max	0.03 max
Cr %	**Ni %**	**Mo %**	**Se %**	**Zr %**
12.0/14.0	–	–	–	–
Ti %	**Cb %**	**Al %**		
–	–	–		

Characteristics. A higher carbon, heat-treatable stainless steel. A free machining grade is also supplied, formerly listed as 420F.

Uses. Cutlery, surgical instruments, valves, ball bearings, magnets.

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	per deg C
32-212F	0-100C	5.7	10.5
-600F	-316C	6.0	11.0
-1000F	-538C	6.5	11.7
-1200F	-649C	6.8	12.2

Technological Properties

Forging temp	2100-1650F
Annealing temp	1350-1450F
Hardening temp	1800-1900, Cool rapidly
Melting point	2650-2750F 1450-1510C
Machinability	Fair
Weldability	Fair
Drawability	Poor

Physical Properties

Density, at 70F	0 277 lb/cu in. (7.70 S.G.)
Specific heat, Btu/lb/°F, 32-212F	0 11
Specific resistivity, microhm/cm³	55 or 21 6/in.³
Magnetism, annealed	ferromagnetic

Thermal Conductivity

Btu/ft²/hr/ft/°F at 212F 14.4

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi 0 2% offset	Elong 2 in %	Red Area %	Hard BHN	Rock Hard
Bars: annealed	95	50	25	55	195	B-92
Bars: annealed and cold drawn 1 in.	105	85	17	50	215	B-95

Modulus of elasticity, E in psi 29.0 × 10^{-6} in tension; 11.7 in torsion

STEEL STAINLESS, WROUGHT

440A 440B 440C

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
(1)	1.00 max	1.00 max	0.04 max	0.03 max
Cr %	**Ni %**	**Mo %**	**Se %**	**Zr %**
16.0/18.0	–	.75 max	–	–
Ti %	**Cb %**	**Al %**		
–	–	–		

[1] 440A = 60/.75, 440B = .75/ 95, 440C = .95/1.20

Characteristics. This is a stainless type which gives high hardness.

Uses. Instruments, cutlery, valves, etc.

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	per deg C
32-212F	0-100C	5.6	10.1
-600F	-316C	5.9	10.6

Technological Properties

Forging temp	1900 to 2100F[1], 2150F[2], 2200F[3]
Annealing temp	1350 to 1450F
Hardening temp	1850 to 1950F cool rapidly
Melting point	2500-2700F[3], 2750F[1,2]
Tempering	300 to 800F

[1] 440A [2] 440B [3] 440C

Physical Properties

Density, at 70F	0.277 lb/cu in. (7 68 S.G.)
Specific heat, Btu/lb/°F, 32-212F	0.11
Specific resistivity, microhm/cm³	60 or 24.0/in.³
Magnetism, annealed	ferromagnetic

Thermal Conductivity

Btu/ft²/hr/ft/°F at 212F 14.0

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi 0 2% offset	Elong 2 in %	Red Area %	Hard BHN	Rock Hard	Impact Resist. Izod Ft Lbs
Bars: annealed	105-110	60-65	14-20	25-45	215-230	B-95 to B-97	2
Bars: annealed and cold drawn, 1 in.	115-125	90-100	7-12	20	240-260	B-99, C-23-C-24	2

Modulus of elasticity, E in psi 29.0 × 10^{-6} in tension; in torsion

STEEL STAINLESS, WROUGHT

430 430F

Chemical Composition (AISI)

C	Mn	Si	P	S
%	%	%	%	%
.12 max	1.00 max[2]	1.00 max	–[1]	–[1]
Cr	**Ni**	**Mo**	**Se**	**Zr**
%	%	%[1]	%[1]	%
14.00/18.00	–	–	–	–

[1] 430 = .040 max P, .030 max S.
430F = P or S or Se .07 min, Mo or Zr .60 max
[2] 430F = 1.25

Characteristics. This is easily formed and is used for auto trim. It is more resistant than 405 and is used for chemical equipment. 430F is free machining.

Technological Properties

Forging temp	1950 to 2100[1]
Annealing temp	1400 to 1500F and 1250 to 1400F[1]
Melting range	Solidus to > 2400F or > 1435C; Liquidus to > 2750F or > 1508C
Machinability	430 Fair, 430F Good
Weldability	Fair, welds are brittle
Scaling temp, oxidizing	1500F continuous, 1600F intermittent
Drawability	Good

Physical Properties

Density, at 70F	0.277 lb/cu in. (7.70 S.G.)
Specific heat, cal/gm, 212F	.152
Btu/lb/°F, 32-212	.11
Specific resistivity, microhm/cm³ at 70F	60
Magnetism	Ferromagnetic

Coef. of Thermal Expansion

Temp Range Deg C	Temp Range Deg F	per Deg C $\times 10^{-6}$	per Deg F $\times 10^{-6}$
-18-93	0-200	9.7	5.4
-18-316	0-600	10.1	5.6
-18-538	0-1000	11.0	6.1
-18-816	0-1500	11.3	6.3
0-100	32-212	10.4	5.8
0-315	32-600	10.98	6.1
0-537	32-1000	11.3	6.3
0-648	32-1200	11.8	6.6
0-815	32-1500	12.2	6.9

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hr	Stress for 1% creep in 100,000 hr
1000F	8.5	7
1100	4.3	4.5
1200	1.6	1.6
1300	1.3	.9
1350	–	–
1400	0.8	–
1500	–	–
1600	–	–

Thermal Conductivity

Btu/ft²/hr/ft/°F at	212F	15.1
	932°	15.2

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in %	Red Area %	Hard BHN	Rock Hard	End Lt M psi
Sheet, strip, Plate and Bars – annealed	–	75-85	40-70	25-30	60-65	155-170	B-80	40-45
Sheet, strip, Plate and Bars – annealed and cold drawn	–	75-90	45-80	15-25	55-65	185-190	B-80	46-48
Effect of Temp	70F	74.5	–	–	–	–	–	–
	200	69	–	–	–	–	–	–
	300	66	–	–	–	–	–	–
	400	64	–	–	–	–	–	–
	500	62.5	–	–	–	–	–	–
	600	60.5	–	–	–	–	–	–
	700	57.5	–	–	–	–	–	–
	800	54	–	–	–	–	–	–
	900	48	–	–	–	–	–	–
	1000	39	–	–	–	–	–	–
	1100	29	–	–	–	–	–	–
	1200	20.5	–	–	–	–	–	–
	1300	14	–	–	–	–	–	–
	1400	9.5	–	–	–	–	–	–
	1500	6.5	–	–	–	–	–	–
	1600	4.5	–	–	–	–	–	–
	1700	3.5	–	–	–	–	–	–

Modulus of elasticity, E in psi 29×10^{-6}

STEEL STAINLESS, WROUGHT

443

Chemical Composition (AISI)

C	Mn	Si	P	S
%	%	%	%	%
.20 max	1.00 max	1.00 max	0.040 max	0.030 max
Cr	**Ni**	**Mo**	**Se**	**Zr**
%	%	%	%	%
18.0/23.0	–		–	–
Ti	**Cb**	**Al**	**Cu**	
%	%	%	%	
–	–	–	.90/1.25	

Characteristics. Compared with 430 and 442, this is a more easily worked steel for corrosive and elevated temperature service. (No longer listed by AISI as a standard type.)

STEEL STAINLESS, WROUGHT

431

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
.20 max	1.00 max	1.00 max	0.04 max	0.03 max
Cr %	**Ni %**	**Mo %**	**Se %**	**Zr %**
15.0/17.0	1.25/2.50	–	–	–
Ti %	**Cb %**	**Al %**		
–	–	–		

Characteristics. This is a stainless steel which gives high mechanical properties.

Technological Properties

Forging temp (Initial) retarded cool	2100 to 2250F
Annealing temp (Low)	1150 to 1225F
Hardening temp cool rapidly from	1800 to 1950F
Tempering	400 to 1200F

Physical Properties

Density, at 70F	0.28
Specific heat, BTU/lb/°F	0.11
Specific resistivity, microhm/cm³	72

Thermal Conductivity

Btu/ft²/hr/ft/°F at 212F 11.7

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	per deg C
32-212F	0-100C	6.5	11.7
-600F	-316C	6.7	12.1

Mechanical Properties

	Form or Condition	Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in %	Red Area %	Hard BHN	Rock Hard	Impact Resist. Ft Lbs Izod
Bars	Annealed	125	95	20	55	260	C-24	50
	Annealed and cold drawn 1 in.	130	110	15	35	270	C-26	

Modulus of elasticity, E in psi 29.0 × 10^{-6} in tension
in torsion

STEEL STAINLESS, WROUGHT

442

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
.25 max	1.00 max	1.00 max	.040 max	.030 max
Cr %	**Ni %**	**Mo %**	**Se %**	**Zr %**
18.0/23.0	–	–	–	–
Ti %	**Cb %**	**Al %**		
–	–	–		

Characteristics. This is more resistant to corrosion than the lower Cr types. It is used for high temperature service but is not easily fabricated. (No longer listed by AISI as standard type.)

Technological Properties

Melting range	Solidus	2600F or 1425C
	Liquidus	2750F or 1508C
Scaling temp, oxidizing	1750F	

Physical Properties

Density, at 70F	.28 lb/cu in. (7.7 S.G.)
Specific heat, Btu/lb/°F, 32-212	.11
Specific resistivity, microhm/cm at 70F	64 or 25.2/in.³
Magnetism	Ferromagnetic

Mechanical Properties

Modulus of elasticity, E in psi 29 x 10^6

Thermal Conductivity

Cal/cm²/cm/sec/°C at	18C	–
	100	–
	500	–
Btu/ft²/hr/in/°F	200F	150
	1000	170

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hr	100,000 hr
1000F	8.5	–
1100	5	–
1200	1.6	–
1300	1	–
1350	–	–
1400	–	–
1500	.6	–
1600	–	–

Coef. of Thermal Expansion

Temp Range Deg C	Deg F	per Deg C x 10^{-6}	per Deg F x 10^{-6}
0-100	32-212	8.8	4.9
0-315	32-600	10.3	5.7
0-537	32-1000	11.5	6.4
0-815	32-1200	12.1	6.7

STEEL STAINLESS, WROUGHT

446

Technological Properties

Forging temp	1950 to 1450F
Annealing temp	1450 to 1600F (Cool rapidly)
Hardening temp	Not hardenable by thermal treatment
Melting range	Solidus 2550F or 1370C
	Liquidus 2750F or 1510C
Machinability	Fair
Weldability	Fair (High N)
Scaling temp, oxidizing	1900F continuous
	2000F intermittent
Drawability	Poor

Physical Properties

Density, at 70F	0.273 lb/cu in. (7.60 S.G.)
Specific heat, cal/gm, 100C	.144
Btu/lb/°F, 32-212	.12
Specific resistivity, microhm/cm[3] at 70F	67 or 26.5/in.[3]
Magnetism	Ferromagnetic

Thermal Conductivity

Btu/ft²/hr/ft/°F at	212F	12.1
	932F	14.1

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
.35 max	1.00 max	1.00 max	.040 max	.030 max

Cr %	Ni %	Mo %	Se %	Zr %
23.0/27.0	–	–	–	–

Ti %	Cb %	Al %	N %
–	–	–	.25 max

Characteristics. This has high resistance to corrosion and scaling and, with high N, is relatively fine grained and ductile.

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	per deg C
32-212F	0-100C	5.8	10.4
-600F	-316C	6.0	10.8
-1000F	-538C	6.2	11.2
-1200F	-649C	6.4	11.5
-1800F	-982C	6.7	12.1

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in %	Red Area %	Hard BHN	Rock Hard	End Lt M psi	Impact Resist Izod Ft Lb
Sheet, Strip, Plate & Bars 1 in. annealed	–	80-85	50-55	20-25	45	170	B-83 to B-86	47	2
Sheet, Strip, Plate & Bars 1 in. annealed and cold drawn[2]	–	85	70	20	45	185	B-90	–	–
Annealed	–	75-95	45-60	30-20	50-40	140-185	78-90b	–	–
Effect of Temp	70F	83	–	–	–	–	–	–	–
	200	78	–	–	–	–	–	–	–
	300	75	–	–	–	–	–	–	–
	400	73.5	–	–	–	–	–	–	–
	500	72.5	–	–	–	–	–	–	–
	600	71.5	–	–	–	–	–	–	–
	700	70.5	–	–	–	–	–	–	–
	800	68.5	–	–	–	–	–	–	–
	900	66	–	–	–	–	–	–	–
	1000	61	–	–	–	–	–	–	–
	1100	43.5	–	–	–	–	–	–	–
	1200	24	–	–	–	–	–	–	–
	1300	17	–	–	–	–	–	–	–
	1400	12	–	–	–	–	–	–	–
	1500	8	–	–	–	–	–	–	–
	1600	5.5	–	–	–	–	–	–	–
	1700	4	–	–	–	–	–	–	–
	1800	3	–	–	–	–	–	–	–
	1900	2.5	–	–	–	–	–	–	–
	2000	2	–	–	–	–	–	–	–
	2100	1.5	–	–	–	–	–	–	–
	2200	1.25	–	–	–	–	–	–	–
	2300	1.0	–	–	–	–	–	–	–

Modulus of elasticity, E in psi 29.0 × 10^{-6} in tension

Creep Strength[1] (M psi)

Temp	Stress for 1% creep in 10,000 hr	100,000 hr
1000F	6.0	4.2
1100	3.0	2.3
1200	1.5	1
1300	0.6, 0.7[2]	0.25
1400	–	0.1
1500	0.3	–

[1] ASM Metals Handbook
[2] AISI

Stress-Rupture Strength (M psi)

Temp	1,000 hr	100,000 hr
1000F	–	–
1100	6	–
1200	4	2
1300	2.8	1.5
1350	–	–
1400	1.7	0.9
1500	1.1	0.5
1600	–	–
1700	–	–
1800	–	–

STEEL STAINLESS, WROUGHT

501

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
.10 min	1.00 max	1.00 max	.040 max	.030 max
Cr %	**Ni %**	**Mo %**	**Se %**	**Zr %**
4.00/6.00	–	–[1]	–	–
Ti %	**Cb %**	**Al %**		
–	–	–		

[1] Commonly produced with about 0.5% Mo

Technological Properties

Forging temp	2100 to 2200F
Annealing temp	1325 to 1375F
Hardening temp	1600 to 1700F
Melting range	2700 to 2800F or 1480 to 1535C
Scaling temp, oxidizing	1150F
Tempering	400 to 1400F

Characteristics. Relatively corrosion resistant, compared to plain carbon and low alloy steels, with good properties at moderately high temperatures. Mo may be added for strength and Al and Si for resistance to scaling.

Physical Properties

Density, at 70F	0.28 lb/cu in. (7.75 S. G.)
Specific heat, Btu/lb/°F, 32-212	0.11
Specific resistivity, microhm/cm^3	40 or 15.8/in.^{3}
Magnetism	Ferromagnetic

Thermal Conductivity

Btu/ft²/hr/ft/°F at	212F	21.2
	932F	19.5

Coef. of Thermal Expansion

Temp Range Deg C	Deg F	per Deg C x 10^{-6}	per Deg F x 10^{-6}
0-100	32-212	11.2	6.2
0-315	32-600	12.2	6.8
0-537	32-1000	13.0	7.2
0-815	32-1200	13.1	7.3

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in %	Red Area %	Hard BHN
Plate Annealed – Heat treated	–	70	30	28	65	160
Bars Annealed – Cold drawn	–	70	30	28	65	160
Oil Quenched from 1650F & tempered as shown	1000F	175	135	15	50	370
	1100F	140	110	18	55	290
	1200F	115	90	20	60	240
Effect of Temp[1]	70F	76.5	–	–	–	–
	200	63	–	–	–	–
	300	62	–	–	–	–
	400	60	–	–	–	–
	500	58.5	–	–	–	–
	600	58	–	–	–	–
	700	57	–	–	–	–
	800	56	–	–	–	–
	900	52.5	–	–	–	–
	1000	44	–	–	–	–
	1100	32.5	–	–	–	–
	1200	24	–	–	–	–
	1300	17.5	–	–	–	–
	1400	12	–	–	–	–
	1500	9.5	–	–	–	–

Modulus of elasticity, E in psi 29 x 10^6

[1] 501 + 0.5% Mo

Creep Strength[1] (M psi)

Temp	Stress for 1% creep in 10,000 hr	100,000 hr
1000F	9	7.2
1100	5	2.5
1200	2	0.9
1300	1.5	–
1350	–	–
1400	–	–
1500	–	–
1600	–	–

[1] 501 +0.5% Mo

Stress-Rupture Strength[1] (M psi)

Temp	1,000 hr	100,000 hr
1000F	19	14.5
1100	11	7
1200	6	2.5
1300	3.3	1.2
1350	–	–
1400	2	–
1500	1.5	–
1600	–	–
1700	–	–
1800	–	–

[1] 501+0.5% Mo

STEEL STAINLESS, WROUGHT

502

Chemical Composition (AISI)

C %	Mn %	Si %	P %	S %
.10 max	1.00 max	—	0.04 max	0.03 max

Cr %	Ni %	Mo[1] %	Se %	Zr %
4.00/6.00	—	—	—	—

Ti %	Cb %	Al %
—	—	—

[1]Commonly produced with about 0.5%

Technological Properties

Forging temp	2100 to 2200F
Annealing temp	1325 to 1375F
Hardening temp	Generally used in the annealed condition only
Melting point	2700 to 2800F or 1480 to 1535C

Characteristics. Similar to 501 but with lower carbon.

Physical Properties

Density, at 70F	0.28 lb/cu in. (7 7 S.G.)
Specific heat, BTU/lb/°F 32-212F	0.11
Specific resistivity, microhm/cm³	40 or 15.8/in.³

Thermal Conductivity

Btu/ft²/hr/ft/°F at	212F	21.2
	932F	19.5

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hrs
900	16.0
1000	9.0
1100	5.0
1200	2.0
1300	1.5

Coef. of Thermal Expansion

Temp Range		Coefficient × 10^{-6} per deg F	per deg C
32-212F	0-100C	6 2	11.2
-600F	-316C	6.8	12.2
-1000F	-538C	7.2	12.96
-1200F	-649C	7.3	13.2

Mechanical Properties

Form or Condition[1]	Tensile Strength M psi	Yield Strength M psi 0.2% offset	Elong 2 in. %	Red Area %	Hard BHN	Rock Hard	Impact Resist. Ft Lbs Charpy	Izod
Sheet, Strip, Plate and Bars	65-70	25	30	75	150	B-75	45	85

[1]Properties based on steel with about 0.5% Mo

Modulus of elasticity, E in psi 29.0 × 10^{-6} in tension

STEEL STAINLESS, WROUGHT

7 Cr-Mo

Chemical Composition

C %	Mn %	Si %	P %	S %
.15 max	.60 max	.50/1.00	.030 max	.030 max
Cr %	**Ni %**	**Mo %**	**Se %**	**Zr %**
6.00/8.00	–	.45/.65	–	–
Ti %	**Cb %**	**Al %**		
–	–	–		

Technological Properties
Scaling temp, oxidizing 1200 F

Characteristics. An intermediate grade capable of operating at higher temperatures than 501.

Physical Properties

Density, at 70F	0.28 lb/cu in. (7.75 S.G.)
Specific heat, Btu/lb/°F, 32-212	0.11
Specific resistivity, microhm/cm³ at 70F	45 or 17.7/in.³
Magnetism	Ferromagnetic

Coef. of Thermal Expansion

Temp Range Deg C	Deg F	per Deg C x 10^{-6}	per Deg F x 10^{-6}
0-100	32-212	11.2	6.2
0-315	32-600	11.7	6.5
0-537	32-1000	12.6	7.0
0-815	32-1200	13.0	7.2

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi	2" Elong %	Red. Area %	Hard BHN	Rock Hard	Izod Ft Lb
Effect of Temp	70F	72.5	–	–	–	–	–	–
	200	70	–	–	–	–	–	–
	400	67	–	–	–	–	–	–
	600	65.5	–	–	–	–	–	–
	800	54	–	–	–	–	–	–
	900	45	–	–	–	–	–	–
	1000	43	–	–	–	–	–	–
	1100	34	–	–	–	–	–	–
	1200	23.5	–	–	–	–	–	–
	1300	17	–	–	–	–	–	–
	1400	11	–	–	–	–	–	–
	1500	8	–	–	–	–	–	–
	1600	9[1]	–	–	–	–	–	–

[1]This reversal is due to austenite formation

Modulus of elasticity, E in psi 29×10^6

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hr	100,000 hr
1000F	8	5
1100	4.2	2.5
1200	2.3	1.3
1300	1.4	–
1350	–	–
1400	–	–
1500	–	–
1600	–	–

Stress-Rupture Strength (M psi)

Temp	1,000 hr	100,000 hr
1000F	–	–
1100	14	8.4
1200	6.5	3.2
1300	3.4	1.3
1350	–	–
1400	–	–
1500	1.0	–
1600	–	–
1700	–	–
1800	–	–

9 Cr-Mo

Chemical Composition

C %	Mn %	Si %	P %	S %
.15 max	.60 max	1.00 max	.030 max	.030 max

Cr %	Ni %	Mo %	Se %	Zr %
8.00/10.00	–	.90/1.10	–	–

Ti %	Cb %	Al %
–	–	–

Characteristics. An intermediate grade capable of operating at higher temperatures than 7 Cr-Mo because it is more resistant to scaling.

Physical Properties

Density, at 70F	0.28 lb/cu in. (7.75 S.G.)
Specific heat, Btu/lb/°F, 32-212	.11
Specific resistivity, microhm/cm³ at 70F	53 or 20.9/in.³
Magnetism	Ferromagnetic

Coef. of Thermal Expansion

Temp Range Deg C	Temp Range Deg F	per Deg C x 10⁻⁶	per Deg F x 10⁻⁶
0-100	32-212	11.2	6.2
0-315	32-600	12.1	6.7
0-537	32-1000	12.8	7.1
0-815	32-1200	13.1	7.3

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi	2" Elong %	Red. Area %	Hard BHN	Rock Hard	Izod Ft Lb
Effect of Temp	70F	75.5	–	–	–	–	–	–
	900	61	–	–	–	–	–	–
	1000	53.5	–	–	–	–	–	–
	1100	41.5	–	–	–	–	–	–
	1200	30	–	–	–	–	–	–
	1300	19	–	–	–	–	–	–
	1400	13	–	–	–	–	–	–
	1500	10[1]	–	–	–	–	–	–
	1600	14[1]	–	–	–	–	–	–

[1] Reversal is due to austenite formation

Modulus of elasticity, E in psi 29×10^6

Creep Strength (M psi)

Temp	Stress for 1% creep in 10,000 hr	Stress for 1% creep in 100,000 hr
1000F	12	8.5
1100	6.7	3
1200	2.6	1.6
1300	1.5	–
1350	–	–
1400	–	–
1500	–	–
1600	–	–

Stress-Rupture Strength (M psi)

Temp	1,000 hr	100,000 hr
1000F	–	–
1100	18	11.8
1200	8.3	3.5
1300	3.8	1.6
1350	–	–
1400	–	–
1500	1.25	–
1600	–	–
1700	–	–
1800	–	–

STEELS, ASTM

A 7-50T

Chemical Composition

C[1] %	Mn[2] %	P[3] %		
.20-.33 approx	.35-.50 approx	.06[4]	.04[5]	.11[6]

S %	Cu %
.05 max	.20 min when specified

[1]Carbon is not specified but is controlled by the strength and ductility requirements of the section thickness.
[2]Manganese is not specified but is adjusted with the carbon content to meet the mechanical requirements.
[3]Maximum allowable phosphorus (heat analysis).
[4]Acid open hearth or electric furnace.
[5]Basic open hearth or electric furnace.
[6]Acid Bessemer

Characteristics. This is an open-hearth or electric-furnace carbon steel. If intended for plates, shapes or bars <7/16 in. for use in those parts of structures not subject to dynamic loads, the steel may be made by acid-bessemer process unless otherwise specified.

Uses. Structural steel for bridges and ships. Used as shapes, plates and bars for bridges, buildings, ships and general structural purposes.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong Min % 8"	Elong Min % 2"	Ratio[3]
	60-72[1]	.5TS[2]	1,500M+TS or 21-25	22	–
Bend Test, 180 deg ≤ ¾ in	–	–	–	–	½
> ¾-1 in. incl.	–	–	–	–	1
> 1-1½ in. incl.	–	–	–	–	1½
> 1½-2 in. incl.	–	–	–	–	2½
> 2 in.	–	–	–	–	3

[1]In longitudinal tests. May be increased by 3 M psi for material > 1½ in. thick.
[2]But not under 33 M psi.
[3]Bend diam/specimen thickness
NOTE – See specification for details and modifications

STEELS, ASTM

A 8-51T

Chemical Composition

	C %	Mn %	P %
Ladle[1]	0.43 max	0.80 max	0.04 max
	S %	**Ni %**	**Cu %**
	0.05 max	3.00-4.00	0.20 min[2]

[1]For check analysis, see ASTM Spec.
[2]When copper steel is specified.

Characteristics: This is an open-hearth or electric-furnace high-strength structural nickel steel.

Uses: Shapes, plates and bars up to and including 1¼ in. in thickness intended primarily for special use in main stress-carrying structural members.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 8" %	Red Area %	Ratio[3]
	90-115	55 min	14 min[1]	30 min[2]	–
Bend Test: 180 deg					
≤ ¾ in.	–	–	–	–	1½
> ¾ in. to 1¼ in. incl.	–	–	–	–	2

[1]Deduct 2.00% from specified min. for each 1/32 in. decrease in thickness below 5/16 in.
[2]Deduct 0 50% from specified min., for each 1/16 in. increase above ¾ in.
[3]Bend Diam/Specimen thickness.
Note See specification for details and modifications.

STEELS, ASTM

A 21-47T

Characteristics. This is an open-hearth or electric-furnace steel for tapered axles up to and including 6½ in. nom. diam at center. Axles > 6½ in. nom. diam shall be normalized (in accordance Grade D, A236).

Chemical Composition

C %	Mn %	P %	S %
0.40-0.55	0.60-0.90	0.045 max	0.05 max

Mechanical Properties

Axles Drop Test Requirements Class	Form or Condition Size of Journal in	Diam at Center Nominal In.	Length In.	Height Drop In.	Number of Blouse	Max Permanent Set In.	Weight, max lb. Smooth[1] Forged	Weight, max lb. Rough Turned All Over
A	3¾ by 7	4¼ 4⅜ 4½	83¼	18 19 20	5	8¾ 8⅜ 8	435	425
B	4¼ by 8	4¾ 4⅞ 5	84¼	22½ 23½ 25	5	7½ 7¼ 7	530	520
C	5 by 9	5⅜ 5½ 5⅝	86½	29 30 31½	5	6¼ 6 5¾	705	695
D	5½ by 10	5⅞ 6 6⅛	88½	34½ 36 37½	5	5½ 5¼ 5	835	825
E	6 by 11	6 7/16 6 9/16 6 11/16	90¾	41½ 43 44½	5	4¾ 4½ 4¼	1015	1005

[1]With Rough Turned Journals and Wheel Seats
Note See specification for details and modifications

STEELS, ASTM

A 27-46T

Characteristics. This is an open-hearth, electric-furnace, converter or crucible mild- to medium-strength carbon-steel in eight grades (see specification for details).

Uses. Castings for general applications

Chemical Composition[2]

Grades	C[1] %	Mn[1] %	P %	S %	Si %
N-1	0.25 max	0.75 max	0.05 max	0.06 max	0.60 max
N-2	0.35 max	0.60 max	0.05 max	0.06 max	0.60 max
N-3	–	1.00 max	0.05 max	0.06 max	–
U 60-30	0.25 max	0.75 max	0.05 max	0.06 max	0.60 max
60-30	0.30 max	0.60 max	0.05 max	0.06 max	0.60 max
65-30	–	–	0.05 max	0.06 max	–
65-35	0.30 max	0.70 max	0.05 max	0.06 max	0.60 max
70-36	0.35 max	0.70 max	0.05 max	0.06 max	0.60 max

[1]For each red. of 0.01% C < max specified an increase of 0.04% Mn > max specified will be permitted up to a max of 1.00%.
[2]For check analysis, see ASTM Spec.

Mechanical Properties

Form or Condition	Tensile Strength M psi min	Yield Point M psi min	Elong 2 in. % min	Red. Area % min
Grades U-60-30	60	30	22	30
60-30	60	30	24	35
65-30	65	30	20	30
65-35	65	35[1]	24	35
70-36	70	36	22	30

[1]When agreed upon by manufacturer and purchaser, and when full annealing is required by purchaser, YP value shall be 33.
Note See specification for details and modifications.

A 30-50T

Chemical Composition

	C[1] %	C[2] %	Mn[1] %	Mn[2] %
Flange	–[6]	–[6]	.30-.80	.30-.80
Firebox	.25 max	.30 max	.30-.80	.30-.80

	P[3] %	P[4] %	S %	Cu[5] %
Flange	.05 max	.04	.05 max	–
Firebox	.04 max	.035	.04 max	.25 max

[1]For plates ¾ in. and under
[2]For plates over ¾ in.
[3]For Acid Steel
[4]For Basic Steel
[5]Incidental
[6]Not specified but normally less than 0.35%

Characteristics. This is an open hearth or electric-furnace steel which is suitable for boilers and fireboxes of steam locomotives. Only plates 2 in. and under in thickness are made to this specification.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point Min M psi	Elong 8 in. min %	Elong 2 in. min %	Ratio[1]
Flange	55-65	.5TS	1,500M+TS	1,750M+TS	–
Firebox Grade A	55-65	.5TS	1,550M+TS	1,750M+TS	–
Firebox Grade B	48-58	.5TS	1,550M+TS	1,750M+TS	–
Bend Test[2]					
Plate thickness ≤ 1 in.	–	–		–	1
> 1 in.	–	–		–	2

NOTE—See the specification for details and deviations
[1] Mandrel diam to plate thickness
[2]Through 180 deg

A 31-51T

Chemical Composition

	C %	Mn %	P %	S %
Grade A Ladle[1]	–	0.30-0.60	0.040 max	0.050 max
Grade B Ladle[1]	0.28 max	0.30-0.80	0.040 max	0.050 max

[1]For check analysis, see ASTM Specs.

Characteristics. This is an open-hearth or electric-furnace rivet steel covering two grades.

Uses. Boilers and other pressure vessels.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 8 in. min %	Ratio[4]
Grade A	45-55	0.5 T.S. min	1,500M+TS[2] min	–
Grade B	58-68	0.5 T.S. min[1]	1,500M+TS[3] min	–
Bend Test·				
Grade A, 180 deg	–	–	–	flat on itself
Grade B, 180 deg, ≤ ¾ in. diam	–	–	–	½
> ¾ in. diam	–	–	–	1

[1]but not less than 32
[2]but need not exceed 30
[3]but not less than 23
[4]pin/specimen diam
Note: See specification for detail and modification

STEELS, ASTM

A 41-36

Characteristics. This specification covers refined iron bars made from new wrought iron or a mixture of new wrought iron[1] and iron scrap[1] and shall be free from any admixture of steel.

[1]For definition, see ASTM Spec.

Chemical Composition
Mn %
0.15 max

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 8 in. % min	Ratio[2]
	48 [1]min.	25 min	22[2]	–
20% of the test specimen may show the following:				
Round Bars.				
Tested as rolled $\geq 1/2$ in	–	–	20	–
$< 1/2$ in	–	–	16	–
Reduced by machining	–	–	18	–
Flat Bars:				
Tested as rolled $\geq 3/8$ in	–	–	18	–
$< 3/8$ in	–	–	16	–
reduced by machining	–	–	16	–
Bend Tests:				
Hot Bend Test - If heated between 1700 + 1800F (925-980C)				flat on itself
Round bars: ≤ 2 sq. in. thru 180 deg; Rd. bars and all flat bars ≥ 2 sq. in. thru 180 deg	–	–	–	1
Nick Bend Test - When nicked 25% around rd. bars, along one side flat bars to depth $> 8 < 16$ % diam or thickness specimen and broken, shall not show more than 10% of the fractured surface to be crystalline.				
Cold Bend Test - Bars ≤ 4 sq in. through 180 deg	–	–	–	2

[1]For material >4 sq. in. (cross-sectional area) a reduction of 500 psi will be permitted for each additional 2 sq. in. and proportionate reduction for fractional parts thereof, to a minimum of 45.
[2]Bend diam/specimen diam
Note See specification for details and modifications.

STEELS, ASTM

A 42-47

Characteristics. This specification covers standard and special forming wrought iron plates, rolled from blooms, piles, or slabs made from all pig-puddled or processed wrought iron[1] and shall be free from any admixture of iron scrap[1] or steel.

Uses. Plates for general fabrication purposes, including bending and flanging, in thicknesses $\geq 5/16$ in.

[1]For definition, see ASTM Spec.

Chemical Composition
Mn %
0.06 max

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 8 in %	Ratio[5]
Standard plate-longitudinal test specimens	48 min[1]	27 min[2]	14 min[3]	–
Special forming plate	51-1.5 transverse ductility[4]	27 min	16 - transverse ductility[4]	–
Bend Test: Cold-Bend Test – Thru 90 deg	–	–	–	Around pin

[1]For material > ¼ in. in thickness, a decrease of Mpsi will be permitted for each additional ⅛ in in thickness and a proportionate amount of reduction for fractional parts thereof, provided that the tensile strength shall not be less than 39 M psi.
[2]For material $\geq$ ¼ in. in thickness the minimum yield point shall be $\geq$ ½ TS.
[3]For material < 7/16 in. in thickness, a deduction of 1% for each decrease of 1/16 in. in thickness below 7/16 in. shall be made, providing the elongation $\geq$ 8%.
[4]Expressed as percentage elongation in 8 in.

[5]$\text{Diam} = \dfrac{40 \times \text{thickness of plate}}{\text{Specified long. elong. in 8 in \%}}$

Note: See specification for details and modifications.

STEELS, ASTM

A 44-41

Characteristics. This is a cast-iron, pit-cast pipe cast vertically with dry sand molds and cores, ends to be specified at time of purchase. Pipe shall be smooth, free from scales, lumps, blisters, sand holes and other defects. No plugging, filling, burning-in, or welding allowed except as permitted by purchaser. See specification for details on breaking strength.

Uses. Pipe for water or other liquids.

Chemical Composition

P %	S %
0.90 max	0.10 max

All pipes shall be of cast iron of such good quality, and of such character and so adapted in chemical composition, that iron shall be strong, tough, resilient, of even grain and soft enough for satisfactory drilling and cutting. The metal shall be melted in a cupola or other suitable furnace.

STEELS, ASTM

A 47-48T

Characteristics. This is an air-furnace, open-hearth, electric-furnace or multiplex process malleable iron.

Uses. Castings for railroad, marine, motor vehicle, agricultural implement, and general machinery purposes.

Mechanical Properties

	Tensile Strength M psi	Yield Point M psi	Elong 2 in. %
Grades 32510	50 min	32.5 min	10 min
35018	53 min	35 min	18 min

Note See specifications for details and modifications

STEELS, ASTM

A 48-48

Characteristics. This specification covers general gray iron castings not covered by other ASTM specifications and apply where strength is a consideration.

Chemical Composition

It is the intent of this specification to subordinate chemical composition to physical properties. The quantities of any chemical element may be specified by purchaser.

Mechanical Properties

Form or Condition	Tensile Strength M psi
Class no. 20	20 min
25	25 min
30	30 min
35	35 min
40	40 min
50	50 min
60	60 min

Note See specification for details and modifications.

STEELS, ASTM

A 53-51T

Characteristics. This is a black, hot-dipped-galvanized[1] welded and seamless steel pipe of nominal wall. Grade B bessemer pipe shall be killed steel made by deoxidized acid bessemer process[1]. Electric-resistance-welded pipe 1/8 to 1/4 in. in diam shall be made from open-hearth steel. Furnace-welded pipe shall be of soft weldable steel; if $\leq$ 4 in. nominal diam, it may be butt-welded unless otherwise specified but if $>$ 4 in. nominal diam, it shall be lap-welded.

[1]See specification for details.

Uses. Coiling, bending, flanging and other special purposes. Suitable for welding but Grade A should be specified when seamless or electric-resistance-welded pipe is intended for close coiling, cold bending or forge welding. Butt-welded pipe is not intended for flanging. Order should state purpose for which pipe is intended.

Chemical Composition

			C %	P %
Ladle[1]	Seamless	OH	–	0.040
		Bessemer	–	0.10
	Furnace welded	OH	–	0.07
		Bessemer	–	0.12
	Electric-resistance-welded,	OH	0.10[2]	0.040

[1]For check analysis, See ASTM Spec.
[2]Applies only to sizes 1/8 to 1/4 in. diam.

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Point M psi	Elong 8 in. %	Elong 2 in. %	Ratio[3]
Furnace-Welded	Acid-Bessemer	50 min	30 min	18[1]	–	–
	OH or electric-furnace	45 min	25 min	20[1]	30[2]	–
Seamless or Electric-Resistance-Welded	Grade A	48 min	30 min	–	–	–
	Grade B	60 min	35 min	–	–	–
Basic min elong for walls $\geq$ 5/16 in, longitudinal strip tests, and all small sizes tested in full section	Grade A	–	–	–	35	–
	Grade B	–	–	–	30	–
Standard rd. 2 in. gage length test specimen	Grade A	–	–	–	28	–
	Grade B	–	–	–	22	–
For long. strip tests, deduct for each 1/32 in. below 5/16 in. from basic min	Grade A	–	–	–	1.75	–
	Grade B	–	–	–	1.50	–
Bend Test: Thru 90 deg	$\leq$ 2 in. nom. diam	–	–	–	–	12
Thru 180 deg		–	–	–	–	8

[1]Gage length 6 in. for pipe 3/4 and 1/2 in., 4 in. for 3/8 and 1/4 in. and 2 in. for 1/8 in. pipe.
[2]Standard rd. 2 in. gage length test specimen.
[3]Mandrel/nom. diam pipe.
Note See specification for details and modifications.

STEELS, ASTM

A 59-49

Characteristics. This is an open-hearth or electric-furnace hot-rolled Si–Mn bar steel.

Uses. Springs. (Widths over 6 in. are classified as plates and will be furnished only by mutual agreement between manufacturer and purchaser.)

Chemical Composition[1]

C %	Mn %	P %	S %	Si %	Cr %
0.55-0.65	0.70-1.00	0.040 max	0.040 max	1.80-2.20	–[2]

[1]For check variation, see ASTM Spec
[2]A Cr content of 0.10 to 0.25% or 0.25 to 0 40 shall be furnished when specified.

A 56-39

Characteristics. This is iron and steel chain in two classes: crane chain shall be lap fire-welded from all pig-puddled or processed wrought iron[1] free from iron scrap[1] or steel, proof coil (unless otherwise specified) shall be made by fire-welding or electric-welding from open-hearth steel.

Uses. Crane chain slings, cranes, steam shovels, and marine uses.
Proof coil railroad cars, construction and forestry work.

[1]See ASTM Spec. for definition

Chemical Composition

	Mn %	P %	S %
Wrought Iron Crane Chains	0.06 max.	–	–
Steel Proof Coil	–	0.05 max	0.05 max

Mechanical Properties

Nominal Size of Chain Bar, in	Proof Test Load M lb Crane	Proof Test Load M lb Proof	Elong[1] %	Break Test Load M lb Crane	Break Test Load M lb Proof	Safe Working Load M lb Crane	Safe Working Load M lb Proof
	–	–	≥15	–	–	–	–
1/4	1.345	1.7	–	3.535	3.4	1.060	.85
5/16	2.1	2.65	–	5.52	5.3	1.655	1.325
3/8	3.02	3.85	–	7.95	7.7	2.385	1.925
7/16	4.115	5.25	–	10.83	10.5	3.25	2.625
1/2	5.375	6.85	–	14.145	13.7	4.24	3.425
9/16	6.8	8.65	–	17.895	17.3	5.37	4.325
5/8	8.395	10.7	–	22.095	21.4	6.63	5.35
3/4	12.08	15.35	–	31.8	30.7	9.54	7.675
7/8	16.43	20.9	–	43.245	41.8	12.96	10.45
1	21.49	27.35	–	56.55	54.7	16.95	13.675
1 1/8	25.38	–	–	66.8	–	20.04	–
1 1/4	31.35	–	–	82.5	–	24.75	–
1 3/8	37.92	–	–	99.8	–	29.91	–
1 1/2	45.1	–	–	118.7	–	35.6	–
1 5/8	53	–	–	139.5	–	41.8	–
1 3/4	61.4	–	–	161.6	–	48.45	–
1 7/8	70.5	–	–	185.5	–	55.3	–
2	80.2	–	–	211.1	–	63.3	–

[1]Gage length, 12–18 in. to nearest link
Note See specification for details and modifications.

A 60-49

Chemical Composition[1]

C %	Mn %	P %	S %	Si %	Cr %	V %
0.48-0.53	0.70-0.90	0.040 max	0.040 max	0.20-0.35	0.80-1.10	0.15 max

[1]For check variation, see ASTM Spec

Characteristics. This is an open-hearth or electric-furnace hot-rolled Cr–V bar[1] steel used in the manufacture of springs.

[1]Widths > 6 in. are classified as plates, and will be furnished only by mutual agreement between manufacturer and purchaser.

STEELS, ASTM

A 68-49

Characteristics. This is an open-hearth or electric-furnace hot-rolled carbon bar[1] steel with silicon requirements.

Uses. Railway and general purpose springs.

[1]Widths > 6 in. are classified as plates and will be furnished only by mutual agreement between manufacturer and purchaser

Chemical Composition[1]

C %	Mn %	P %	S %	Si %
0.90-1.05	0.30-0.50	0.040 max	0.050 max	0.15-0.30

[1]For check variations, see ASTM Spec

STEELS, ASTM

A 72-45

Chemical Composition

Mn %
0.05 max

Characteristics. This is a welded wrought-iron pipe, black and galvanized, "standard weight", "extra strong" and "double extra strong". The pipe shall be made from all pig-puddled or processed wrought iron[1] and shall be free from iron scrap[1] or steel. All pipe ≤ 2 in. nom. diam may be butt-welded, all pipe > 2 in. nom. diam shall be lap-welded.

Uses. Coiling, bending, flanging and other special purposes. Butt-welded pipe is not intended for flanging and is not recommended for close bending or coiling in sizes ≥ 1¼ in.

[1]For definition, see ASTM Spec.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 8 in min % Full Sect	Elong 8 in min % Strip	Ratio[1]
	40 min	24 min	12	9	–
Bend Tests [2]					
Pipe ≤ 2 in. diam, thru 90 deg	–	–	–	–	15

[1]Mandrel diam/specimen diam
[2]Pipe > 1¼ in. nom size need not be subjected to bend test

Note See specification for details and modifications.

STEELS, ASTM

A 83-46

Characteristics. This is an open-hearth or electric-furnace lap-welded and seamless steel, and lap-welded iron. The material for wrought-iron tubes shall be made by the knobbled hammered charcoal-iron process.

Uses. Boiler tubes and boiler flues, including safe ends, arch and stay tubes, and seamless superheater and small boiler tubes.

Chemical Composition

Types		C %	Mn %	P %	S %	Cu %	Mo %
Low Carbon Steel	A	0.08-0.18	0.30-0.60	0.04 max	0.045 max	–[1]	–
Open Hearth Iron	B	0.03 max	0.03 max	0.02 max	0.045 max	–	–
Open Hearth Iron Alt.	B	0.05 max	0.35 max	0.02 max	0.045 max	0.40 min	0.05-0.15

[1]When type A tubes are specified with carbon content, the range shall be 0.20 - 0.35 %.

STEELS, ASTM

A 84-39

Chemical Composition

Mn %
0.06 max

Characteristics. This is a wrought iron for solid staybolts,[1] round bars only. The bars shall be rolled from a slab pile or box pile made from all pig-puddled, knobbled charcoal, or processed wrought iron.[2] The original muck bars shall be piled, rolled, repiled, and rerolled. The component parts of the slab pile[2] or box pile[2] shall be free from any admixture of iron scrap or steel.

[1]Other grades of bar iron formerly covered in this specification will be found in ASTM A189.
[2]For definitions, see ASTM Spec

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point min M psi	Elong 2 in. min %	Red Area min %	Ratio
	47-52[1]	0.60TS	30[2]	48[3]	–
Bend Test:					
Cold-Bend Test – thru 180 deg	–	–	–	–	Flat on itself

[1]For material > 1¼ sq. in. in cross-sectional area, a decrease of 250 psi from the minimum TS for each additional 1 sq. in. to minimum 46 M psi.
[2]Minimum elongation for material 11/16 to 7/8 in incl diam is 28%
Minimum elongation for material ≤ 5/8 in. diam is 25%.
[3]For material > 1¼ sq. in in cross-sectional area, a decrease of 3% from that amount indicated above for each additional 1 sq in to minimum 40%.

Note See specifications for details and modifications.

STEELS, ASTM

A 86-39

Chemical Composition

Mn %
0.06 max

Characteristics. This is a wrought iron for hollow-rolled staybolts, round bars only, rolled from a slab pile[1] or box pile[1] made from all pig-puddled, knobbled charcoal or processed wrought iron.[1] The original muck bars shall be piled, rolled, repiled, and rerolled. The component parts of the slab pile or box pile shall be free from any admixture of iron scrap or steel.

[1]For definition, see specification.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point min M psi	Elong 8 in. min %	Elong 4 in. min %	Red Area min %	Ratio
	47-52	0.60TS	28	35	48	–
Bend Test						
Cold-Bend Test – thru 180 deg	–	–	–	–	–	Flat on itself

Nick-Bend Tests (When nicked 25% around, with tool having 60-deg cutting edge, to depth > 8 < 16% specimen diam) When broken slowly, shall show clean fibers, free from crystallization.

Note See specification for details and modifications.

STEELS, ASTM

A 94-49T

Chemical Composition

	C %	P % Acid	P % Base	S %	Cu %	Si %
Ladle[2]	0.40 max	0.06 max	0.04 max	0.05 max	0.20 min[1]	0.20 min

[1] When specified.
[2] For check analysis, see ASTM Spec

Characteristics. This is an open-hearth or electric-furnace special high-strength structural steel. In the conditioning of surface imperfections no welding shall be employed.

Uses. Shapes, plates and bars intended primarily for use in main stress-carrying structural members.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point min M psi	Elong 2 in. min %	Elong 8 in. min %	Red Area min %	Ratio[2]
	80-95	45	1600M + TS	1500M + TS	30[1]	–
For material > 3/4 in. deduct from 8 in. min. for every increase of 1/16 in. above 3/4 in. to a minimum of 14%	–	–	–	0.25	–	–
For material < 5/16 in. deduct from 8 in. min. for every 1/32 in. below 5/16 in.	–	–	–	2.00	–	–
Bend Test						
Cold Bend thru 180 deg ≤ 3/4 in.	–	–	–	–	–	1
Cold Bend thru 180 deg > 3/4 in. to 1 in. incl.	–	–	–	–	–	1½
Cold Bend thru 180 deg > 1 in. to 1¼ in. incl.	–	–	–	–	–	2
Cold Bend thru 180 deg > 1¼ in.	–	–	–	–	–	2½

[1] For material > 3/4 in. a deduction of 0.50% for each increase of 1/16 in. of the specified thickness or diam > 3/4 in. to a minimum of 24% shall be made
[2] Bend diam/specimen thickness

Note See specification for details and modifications

STEELS, ASTM

A 95-44

Chemical Composition

C %	Mn %	P %	S %	Si %
0.15-0.45	0.50 min	0.05 max	0.06 max	0.20 min

Mechanical Properties

Tensile Strength M psi	Yield Point M psi	Elong 2 in. %	Red Area %
70 min	36 min	22 min	30 min

Bend Tests shall be required only when specified in order. When a bend test is specified, specimen shall stand being bent cold through an angle of 90 deg around a pin 1 in. diam without cracking. Bend test specimens shall be machined to 1 by 1/2 in. in section with the corners rounded to a radius not over 1/16 in.

Note See specification for details and modifications.

Characteristics. This is an open-hearth, electric-furnace carbon steel. See specification for details of heat treatment.

Uses. Castings for valves, flanges, fittings or other pressure-containing parts for high-temperature service.[1]

[1] See specification for explanatory note.

A 106-51T

Chemical Composition

Grades		C %	Mn %	P %	S %	Si %
Ladle[1]	A	0.23 max	0.30-0.90	0.040 max	0.050 max	0.12 min
	B	0.27 max	0.35-1.00	0.040 max	0.050 max	0.12 min

[1]See specification for check analysis

Characteristics. This is an open-hearth or electric-furnace seamless C-steel pipe of nominal wall, suitable for bending, flanging and similar forming operations. Supplementary requirements are provided for pipe intended for use in central stations having steam service pressures of 400 psi and over.

Uses. Pipe for high-temperature service.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elongation 2 in, Longitudinal, % min, Grade A	Elongation 2 in, Longitudinal, % min, Grade B	Elongation 2 in, Transverse, % min, Grade A	Elongation 2 in, Transverse, % min, Grade B	Ratio[1]
Grade A	48 min	30 min	–	–	–	–	–
Grade B	60 min	35 min	–	–	–	–	–
Basic minimum for walls ≥ 5/16 in. thick, strip tests, and all small sizes tested in full section	–	–	35	30	25	16.5	–
Standard rd. 2 in. gage length test specimen	–	–	28	22	20	12	–
For strip tests, deduct from basic min for each 1/32 in. decrease in wall thickness below 5/16 in.	–	–	1.75	1.50	1.25	1.00	–
Bend Test, Thru 90 deg	–	–	–	–	–	–	12
Bend Test, Thru 180 deg, close coiling Grade A	–	–	–	–	–	–	8

[1]Mandrel diam/nom diam specimen.
Note See specification for details and modifications

A 107-49T

Chemical Composition[3]

Grades[1]	C %	Mn %	P %	S %	Si %
1000 series Open-Hearth	0.08-1.03	0.25-1.00	0.040	0.050	–[2]
1100 series OH, free cutting	0.13-0.55	0.60-1.65	0.045	0.08-0.13	–
B1010 Bessemer	0.13 max	0.30-0.60	0.07-0.12	0.060 max	–
B1111, B1112, B1113 Bessemer, free cutting	0.13 max	0.60-1.00	0.07-0.12	0.08-0.33	–

[1]These grades cover AISI designations "C" and "B". See specification for details.
[2]Si content may not be specified on bars of open-hearth grades ordered as merchant quality See specification for details.
[3]For check variations, see ASTM Spec

Characteristics. This is an open-hearth or acid-bessemer hot-rolled carbon bar steel in two fundamental qualities. Purchaser shall specify quality by grade designation or chemical composition. Sections include rounds, squares, and hexagons of all sizes, flats < 6 in. width; bars < 3 in. maximum sectional dimension.

Uses. Merchant quality is generally used for structural purposes and similar miscellaneous bar applications. Special quality is used for applications involving forging, heat treating, cold drawing, turning, or similar uses.

STEELS, ASTM

A 108-49T

Chemical Composition[3]

Grades[1]	C %	Mn %	P %	S %	Si %
1000 Series Open-Hearth	0.08-1.03	0.25-1.00	0.040 max	0.050 max	–[2]
1100 Series OH, free cutting	0.13-0.55	0.60-1.65	0.045 max	0.08-0.33	–
B1010 Bessemer	0.13 max	0.30-0.60	0.07-0.12	0.060 max	–
B1111, B1112, B1113 Bessemer, free cutting	0.13 max	0.60-1.00	0.07-0.12	0.08-0.33	–

[1]These grades cover AISI steels "C" and "B" designations See specification for details.
[2]Si ranges may be specified for open-hearth grades See specification for details.
[3]For check variation, see ASTM spec.

Characteristics. This is an open-hearth, electric, or acid-bessemer cold-finished carbon steel of various grades, qualities and cross-sections rounds $\leq 7\frac{3}{4}$ in. diam, squares ≤ 4 in. between // surfaces, hexagons $\leq 3\frac{1}{8}$ in. between // surfaces, flats $\leq \frac{1}{8}$ in. thick and < 12 in. wide. Purchaser shall specify grade designation or chemical composition.[1]

Uses. Bars for heat treatment and for machining into components, or shafting, in constructional applications, or for other similar purposes. The free-cutting grades are for use on high-speed cutting machines, generally automatic.

[1]See specification for supplementary requirements

STEELS, ASTM

A 109-49T

Chemical Composition

Tempers	C %	Mn %	P %	S %	Cu %
#1 and 2	0.25 max	0.60 max	0.04 max	0.05 max	0.20 min[1]
#3, 4 and 5	0.15 max	0.60 max	0.04 max	0.05 max	0.20 min[1]

[1]When specified.

Characteristics. This is an open-hearth or electric-furnace cold-rolled carbon steel made in strip for general use in five tempers.

Mechanical Properties

Form or Condition	Temper	Ladle Carbon Content max %	Rock B Hard Thickness	Rock B Hard Min	Rock B Hard Max	Tensile[1] Strength M psi	Elong[1] 2 in. %
Cold-rolled strip							
Hard Temper	Hard #1	0.25	$\geq$ 0.070 in.	84	–	90 ± 10	3 ± 2
			< 0.070 in.	90	–		
Soft Tempers	½ Hard #2	0.25	–	70	85	65 ± 10	10 ± 6
	¼ Hard #3	0.15	–	60	75	55 ± 10	20 ± 7
	Skin rolled #4	0.15	–	–	65	48 ± 6	32 ± 8
	Dead soft #5	0.15	–	–	55	44 ± 6	39 ± 6

– Bend Required –

Bend Test Requirements	
Hard #1	Not required to make bends in either direction.
½ Hard #2	Bend 90 deg across the direction of rolling around a thickness = that of the specimen.
¼ Hard #3	Bend 180 deg across the direction of rolling and 90 deg in the direction of rolling around the thickness = that of the specimen.
Skin rolled #4	Flat upon itself.
Dead soft #5	Flat upon itself.

[1]Values are given only for information and are not intended as criteria for acceptance or rejection. See specification for remarks and explanatory notes.
Note See specification for details and modifications

STEELS, ASTM
A 113-50T

Chemical Composition

C[1] %	Mn[2] %	P %	S %	Cu %
—	—	.06 max[3] .04 max[4]	.06 max[5]	.20 min[6]

[1]Carbon is not specified but is used to secure the specified properties.
[2]Manganese is not specified but is used to secure the specified properties.
[3]Acid Steel
[4]Basic Steel
[5]The S of the locomotive grade is .05 max.
[6]When specified.

Characteristics. This is an open hearth steel of low to medium as-rolled strength. With limits on P and S it is purchased on the basis of tension and bend tests. There are three grades under this specification whose properties are given below. This includes a cold forming grade.

Uses. It is supplied as shapes, plates, and bars for general locomotive and car construction but not as boiler and firebox plate.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 8'' min[2] %	Elong 2'' min %	Ratio[1] Grade A	Ratio[1] Grade B
Grade A	60-72	33	21	22	—	—
Grade B	50-62	27	24	26	—	—
Grade C	48-58	26	26	—	—	—
Bend Tests						Flat on
Thickness $\leq$ 3/4 in	—	—	—	—	1/2	itself
> 3/4-1 in. incl.	—	—	—	—	1	1/2
> 1-1 1/2 in. incl.	—	—	—	—	1 1/2	1
> 1 1/2-2 in. incl.	—	—	—	—	2 1/2	2
> 2 in.	—	—	—	—	3	2 1/2

NOTE See specification for details and modifications

[1]Mandrel Diam to Plate thickness
[2]For material > 3/4 in. deduct 0.25% for each increase of 1/32 in. to a minimum of 18%. For material < 5/16 in. deduct 2.00% for every decrease of 1/32 in.

STEELS, ASTM
A 125-50T

Chemical Composition

Material shall be a matter of agreement between manufacturer and purchaser. If carbon-steel bars are used, springs shall conform to ASTM Specification A68-49, if silicon-manganese or chromium-vanadium steel is specified, bars shall conform respectively to ASTM Specifications A59-49 and A60-49.

Characteristics. This is a heat-treated, C or alloy, helical compression, hot-coiled spring steel made of round bars $\geq$1/2 in. diam.

Uses. Springs, suitable for use on railway equipment.

Mechanical Properties

Hardness: Maximum hardness shall not exceed 461 BHN. Purchaser may not specify a total range spread of less than 50 Brinell numbers.

Note: See specification for details of test procedures

STEELS, ASTM

A 126-42

Chemical Composition	
P %	S %
0.75 max	0.12 max

Characteristics. This is a gray iron in three classes: A, regular gray iron; B, higher-strength gray iron including the so-called semi-steels used in valves and fittings, C, high-test cast iron whether regular or alloy composition.

Uses. Castings such as valve bodies, fittings, flanges, including parts to be assembled into valves, manufactured in advance and supplied for sale from stock by the manufacturer, jobber, or other dealer.

Mechanical Properties

Form or Condition	Tensile Strength M psi
Class A (regular gray iron)	21 min
B (higher strength gray iron)	31 min
C (high-test cast iron)	41 min

Note See specification for details and modifications. tions.

STEELS, ASTM

A 128-42

Characteristics. This is an austenitic Mn steel (often known as Hadfield's Mn steel) made by open-hearth, electric-furnace, convertible or crucible process.

Chemical Composition			
C %	Mn %	P %	S %
1.00-1.40	10.0 min	0.10 max	0.05 max

Mechanical Properties

Bend Tests: When specified – the specimens shall stand being bent cold through 150 deg without breaking around a pin 1 in. in diam.

Note See specification for details and modifications.

STEELS, ASTM

A 129-50T

Chemical Composition

Grades	Total Metalloids[1] %	P %	S %	Cu %	Mo %
Ladle[2] A	0.10 max	0.015 max	0.04 max	–	–
Ladle[2] B	0.25 max	0.015 max	0.04 max	0.40 min	0.05 min
Ladle[2] C	0.25 max	0.015 max	0.04 max	0.20 min	–

[1] C, Mn, P, S, Si
[2] For check analysis, see ASTM Spec.

Characteristics. This is an open-hearth iron plate of 2 in. max thickness. Material is furnished in three grades.

Mechanical Properties

Form or Condition	Tensile Strength min M psi	Yield Point min M psi	Elong 2 in min %	Elong 8 in. min %	Ratio
Grades A	40	22	23	20	–
B	44	27	28	25	–
C	42	23	25	22	–
For material $> \frac{3}{4}$ in., deduct for each $\frac{1}{32}$ in. above $\frac{3}{4}$ in. from above min	–	–	–	0.125	–
For material $< \frac{5}{16}$ in., deduct for each $\frac{1}{32}$ in. below $\frac{5}{16}$ in., from above min	–	–	–	1.25	–
Bend Test: Shall stand being bent cold through 180 deg without cracking on outside					
For material $\leq$ 1 in.	–	–	–	–	Flat on itself
For material > 1 in.	–	–	–	–	To i. d. equal to thickness

Note See specification for details and modifications

STEELS, ASTM

A 131-50T

Chemical Composition

	C %	Mn %	P %	S %	Si %
Ladle[1] Grade A	–	–	0.04 max	0.05 max	–
Ladle[1] Grade B For plates $> \frac{1}{2} \geq 1$ in.	0.23 max	0.60-0.90	0.04 max	0.05 max	–
Ladle[1] Grade C[2] For plates > 1 in.	0.25 max	0.60-0.90	0.04 max	0.05 max	0.15-0.30

[1] For check analysis, see ASTM Spec.
[2] Plate steel shall be made with fine grain practice

Characteristics. This is an open-hearth or electric-furnace structural steel.

Uses. Plates, bars and rivets intended primarily for use in ship construction.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2 in. min %	Elong 8 in. min %	Ratio[2] Structural Steel	Ratio[2] Rivet Steel[3]
Structural Steel	58-71[1]	32	22	21	–	–
Rivet Steel and steel for cold bending	55-65	30	–	23	–	–
For material $> \frac{3}{4}$ in., deduct for each $\frac{1}{32}$ in. above $\frac{3}{4}$ in. from above min (but to a minimum of 18%)	–	–	–	0.25	–	–
For material $< \frac{5}{16}$ in., deduct for each $\frac{1}{32}$ in. above $\frac{5}{16}$ in. from above min	–	–	–	2.00	–	–
Bend Test Thru 180 deg $\leq \frac{3}{4}$ in.	–	–	–	–	1	Flat on itself
Bend Test Thru 180 deg $> \frac{3}{4}$ to $1\frac{1}{4}$ in. incl.	–	–	–	–	2	1
Bend Test Thru 180 deg $> 1\frac{1}{4}$ in.	–	–	–	–	3	2

[1] Shapes less than 1 sq. in. in cross section and bars other than flats, less than ½ in in thickness or diam need not be subjected to tension tests
[2] Bend diam specimen thickness.
[3] And steel for cold flanging
Note See specification for details and modifications

STEELS, ASTM

A 134-51T

Characteristics. This is an electric-fusion (arc)-welded straight seam or spiral seam steel plate piping ≥ 16 in diam with wall thickness ≤ ¼ in. See specification for details of manufacture and material quality.

Uses. Intended for conveying liquid gas or vapor. Suitability of pipe for various purposes is somewhat dependent on its dimensions, properties, and conditions of service.

Tensile Properties of Production Welds:
Reduced-section tensile test specimens taken perpendicularly across the weld with the weld reinforcement removed shall show a TS not less than 95% of min. specified TS of the plate.

STEELS, ASTM

A 135-51T

Characteristics. This is an open-hearth or electric-furnace steel pipe 30 in. and under in diam with nominal walls. It is electric-resistance-welded and comes in two grades but only Grade A is adapted for flanging and bending.

Uses. Conveying liquid, gas, or vapor. Purchase order should state purpose for which pipe is intended, as suitability varies with dimensions, properties and conditions of service.

Chemical Composition

	P %	S %
Ladle	0.040 max	0.050 max
Check	0.050 max	0.060 max

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Point M psi	Elong 2 in. %
Grade A		48 min	30 min	–
Grade B		60 min	35 min	–
Basic min. elong for walls ≥ 5/16 in., longitudinal strip tests, and all small sizes tested in full section	Grade A	–	–	35 min
	Grade B	–	–	30 min
For longitudinal strip tests deduct for each 1/32 in. below 5/16 from basic min.	Grade A	–	–	1.75
	Grade B	–	–	1.50

Note See specifications for details and modifications

STEELS, ASTM

A 139-51T

Chemical Composition

		C %	Mn %	P %	S %
Ladle[1]	Grade A	–	0.30-1.00	0.040 max	0.050
	Grade B	0.30	0.30-1.00	0.040 max	0.050

[1]For check analysis, see ASTM spec.

Characteristics. This is an open-hearth or electric-fumace steel pipe ≤ 4 in. in diam with nominal wall thicknesses up to 5/8 in. inclusive. It is electric-fusion (arc)-welded straight or spiral-seam and comes in two pipe mill grades.

Uses. Conveying liquid, gas or vapor. Suitability varies with dimensions, properties or conditions of service. For high temp service, see ASTM Spec A-155.

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Point M psi	Elong 2 in %	Elong 8 in %
Grade A		48 min	30 min	–	–
Grade B		60 min	35 min	–	–
Basic min elong for walls ≥ 6/16 in., longitudinal strip tests	Grade A			35 min	1,500M[1] TS
	Grade B			30 min	1,500M[1] TS
For long. strip tests, deduct for each 1/32 in. below 5/16 in. from basic min.	Grade A			1.75	–
	Grade B			1.50	–

[1]For wall thicknesses ≥ 1/2 in. but need not exceed 30 per cent
NOTE See specification for details and modifications.

STEELS, ASTM

A 147-49T

Characteristics. This is a heat-treated carbon steel or alloy steel for springs. The bands shall be of wrought-iron or grade 1008 or 1010 open-hearth steel bars and shall be welded by lap-weld or electric process. Subject to agreement between manufacturer and purchaser, bands may be made of steel castings.

Uses. Hot formed leaf springs for railway use. May also be used for miscellaneous springs of flat material.

Mechanical Properties

Hardness Maximum Brinell Hardness shall not exceed 444. When hardness limits are specified by purchaser, total range shall be not less than 50 Brinell numbers.

Note See specification for details and modifications

STEELS, ASTM

A 148-46T

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Point M psi	Elong 2 in % min	Red Area % min
Grades	80-40	80 min	40 min	18	30
	80-50	80 min	50 min	22	35
	90-60	90 min	60 min	20	40
	105-85	105 min	85 min	17	35
	120-100	120 min	100 min	14	30
	150-125	150 min	125 min	9	22
	175-145	175 min	145 min	6	12

Note See specification for details and modifications

Chemical Composition[1]

Grades	P %	S %
80-40	0.05 max	0.06 max
80-50	0.05 max	0.06 max
90-60	0.05 max	0.06 max
105-85	0.05 max	0.06 max
120-100	0.05 max	0.06 max
150-125	0.05 max	0.06 max
175-145	0.05 max	0.06 max

[1]C, Mn, S, and alloying elements shall be selected by manufacturer to obtain the mechanical properties specified.

Characteristics. This is a carbon or alloy steel for castings made by open-hearth, electric-furnace, converter or crucible process in seven grades for use for structural purposes. (See specification for details of heat treatment.)

STEELS, ASTM

A 155-51T

Chemical Composition

	Grade	C %	Mn %	P %	S %	Si %
Ladle[1]	A	0.12 max[2] 0.14 max[3]	0.30-0.60	0.040 max	0.050 max	0.12 min
	B	0.16 max[2] 0.20 max[3]	0.30-0.60	0.040 max	0.050 max	0.12 min
	C	0.21 max[2] 0.26 max[3]	0.30-0.60	0.040 max	0.050 max	0.12 min

[1]For check analysis, see ASTM Spec
[2]For plates ≤ ¾ in in thickness.
[3]For plates > ¾ in in thickness

Characteristics: This is an open-hearth or electric-furnace killed steel pipe, electric-fusion-welded, 18 in and over o.d. Pipe is suitable for bending, flanging, corrugating and similar forming operations.

Uses: High temperature and high-pressure service[1].

[1]See specification for explanatory note on working stresses. Supplementary requirements are also provided for pipe intended for service at 400 psi.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 8" % M psi	Ratio[4]
Grade A	45 min	0.5TS[1] min	$\frac{1500^3}{TS}$ min	–
Grade B	50 min	0.5TS[2] min	$\frac{1500^3}{TS}$ min	–
Grade C	55 min	0.5TS	$\frac{1500^3}{TS}$ min	–
Bend Test: 180 deg				
≤ 1 in.	–	–	–	1
> 1 in.	–	–	–	2

[1]but not less than 24
[2]but not less than 27
[3]Deduct from the specified min. 0.125% for each increase of 1/32 in above ¼ in, to a minimum of 20 per cent.
[4]Pin diam/specimen thickness

A 157-50T

Chemical Composition

Grade		C %	Mn %	P %	S %	Ni %
Ferritic Austenitic Steels	C 6	0.15 max	0.75 max	0.05 max	0.05 max	0.80 max
	C 9[1]	0.15 max	1.00 max	0.05 max	0.05 max	8.00 min
	C10	0.35 max	1.50 max	0.05 max	0.05 max	19.00-22.0
For free-machining or better non-seizing or non-galling		–	–	0.17 max[2]	0.20-0.40[2]	–

Grade		Si %	Cr %	Mo %	Se %
Ferritic Austenitic Steels	C 6	1.00 max	11.5-13.5	0.50 max	–
	C 9[1]	2.00 max	18.0 min	As agreed upon	–
	C10	2.00 max	8.0-10.0	–	–
For free-machining or better non-seizing or non-galling		–	–	0.40-0.80[2]	0.20-0.35[2]

[1]For more severe general corrosive conditions, when specified, carbon content shall not exceed 0.07% Addition of such elements as Mo, W, Ti, Cb and V for stabilization shall be a matter of agreement between manufacturer and purchaser

[2]Suitable combinations of Se and P, or Mo and S

Characteristics. This is an electric-furnace alloy-steel in several grades.[1]

Uses. Castings for valves, flanges, fittings or other pressure containing parts for high-temperature service.

[1]See Spec for details of gradings, heat treatment and high temp service

Mechanical Properties

Form or Condition		Tensile Strength min M psi	Yield Point min M psi	Elong 2 in min %	Red Area min %
Grades	C 6	85	55	20	40
	C 9	70	30	35	40
	C10	65	30	30	35
Bend Test (Only when specified in order)		Thru 90 deg around 1 in. diam pin. Grade C 9, thru 120 deg.			

Note See specification for details and modifications

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Chemical Composition[5]

Identification Symbol	Grade	C %	Mn %	P %	S %	Ni %
Ferritic						
P3a	Cr-Mo	0.14 max	0.33-0.57	–	0.025 max	0.45-0.75
P3b	Cr-Mo	0.14 max	0.33-0.57	–	0.025 max	0.45 max
P5a	4-6% Cr	0.15 max	0.30-0.60	0.030 max	0.030 max	-
P5b	4-6% Cr-Si-Mo	0.15 max	0.30-0.60	0.030 max	0.030 max	–
P5c	4-6% Cr-Mo[2]	0.12 max	0.30-0.60	0.030 max	0.030 max	–
P11	Cr-Si-Mo	0.14 max	0.33-0.57	0.025 max	0.025 max	1.05-1.45
P15	Si-Mo	0.14 max	0.33-0.57	0.025 max	0.025 max	–
P16	7% Cr	0.15 max	0.30-0.60	0.030 max	0.030 max	–
P17	9% Cr	0.15 max	0.30-0.60	0.030 max	0.030 max	–
Austenitic						
P8a	18Cr-8Ni	0.08 max	2.00 max	0.030 max	0.030 max	8.00-11.00
P8b[1]	18Cr-10Ni[3]	0.08 max	2.00 max	0.030 max	0.030 max	9.00-13.00
P8d[1]	18Cr-10Ni[4]	0.08 max	2.00 max	0.030 max	0.030 max	9.00-13.00

Identification Symbol	Grade	Cr %	Mo %	Ti %	Cb %	Si %
Ferritic						
P3a	Cr-Mo	1.50-2.00	0.63-0.78	–	–	0.025
P3b	Cr-Mo	1.75-2.25	0.48-0.63	–	–	0.025
P5a	4-6% Cr	4.00-6.00	0.45-0.65	–	–	0.50 max
P5b	4-6% Cr-Si-Mo	4.00-6.00	0.45-0.65	–	–	1.00-2.00
P5c	4-6% Cr-Mo[2]	4.00-6.00	0.45-0.65	$\geq 4C < 0.70$	8-10C	0.50 max
P11	Cr-Si-Mo	0.48-0.63	–	–	–	0.55-0.95
P15	Si-Mo	0.48-0.63	–	–	–	1.20-1.60
P16	7% Cr	6.00-8.00	0.45-0.65	–	–	0.50-1.00
P17	9% Cr	8.00-10.00	0.90-1.10	–	–	0.50-1.00
Austenitic						
P8a	18Cr-8Ni	18.00-20.00	–	–	–	0.75 max
P8b[1]	18Cr-10Ni[3]	17.00-20.00	–	$\geq 5C < 0.60$	–	0.75 max
P8d[1]	18Cr-10Ni[4]	17.00-20.00	–	–	$\geq 10C < 1.0$	0.75 max

[1]P8b and P8d were formerly one grade, P8b, which could be stabilized with either Ti or Cb
[2]Stabilized with Ti or Cb
[3]Stabilized with Ti.
[4]Stabilized with Cb
[5]For check analysis, see ASTM Spec.

Characteristics. This is an open-hearth or electric-furnace alloy-steel pipe of nominal wall thickness. It is seamless and made in twelve grades unless otherwise specified. Pipe $\geq$2 in. nominal diam shall be furnished hot-finished, pipe < 2 in. nominal diam may be hot-finished or cold-drawn, unless otherwise specified. See specification for details of heat treatment, supplementary requirements for pipe intended for superior service, and other specific requirements.

Uses. For high temperature service.

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Point M psi	Elong 2 in. % long.	Elong 2 in. % transv.	Ratio[1]
Ferritic Steel		60 min	30 min	–	–	–
Austenitic steel		75 min	30 min	–	–	–
Basic minimum for walls $\geq$ 5/16-in., strip tests, and all small sizes tested in full section	ferritic	–	–	30	20	–
	austenitic	–	–	50	40	–
Standard 2-in. gage length test specimen	ferritic	–	–	22	14	–
	austenitic	–	–	35	25	–
For strip tests deduct for each 1/32 in. below 5/16 in. from basic min	ferritic	–	–	1.50	1.00	–
	austenitic	–	–	2.50	2.00	–
Bend Test $\leq$ 2 in. nom diam	Thru 90 deg	–	–	–	–	12
	Thru 180 deg	–	–	–	–	8

[1]Mandrel diam/nom diam specimen
Note See specification for details and modifications.

A 159-49T

Chemical Composition

Alloy	C %	Mn %	P %	S %	Si %
113	3.40 min.	0.60-0.90	0.20 max.	0.14 max.	1.10-1.70
114	3.40 min.[1]	0.60-0.90	0.20 max.	0.14 max.	1.10-1.70
110[2]	3.40-3.70	0.50-0.80	0.25 max.	0.12 max.	2.30-2.80
111[2]	3.25-3.50	0.60-0.90	0.20 max.	0.12 max.	2.00-2.30
120[2]	3.20-3.40	0.60-0.90	0.15 max.	0.12 max.	1.90-2.20
121[2]	3.10-3.30	0.60-0.90	0.12 max.	0.12 max.	1.80-2.10
122[2]	3.00-3.20	0.70-1.00	0.10 max.	0.10 max.	1.80-2.10

[1] Mandatory
[2] This data is for information only—from appendix-and does not constitute a part of the specification.

Characteristics. This is a gray iron used for castings for automotive and allied industries.

Uses. 110· Miscellaneous soft iron castings in which strength is not primary, either as cast or annealed.

111· Small cylinder blocks, cylinder heads, air-cooled cylinders, pistons, clutch plates, oil pump bodies, transmission cases, gear boxes, clutch housings, lightweight brake drums, etc.

113· Brake drums and clutch plates for moderate service requirements where high-C iron is desired and heat checking is a problem.

114· Heavy duty drums and clutch plates where both heat checking and strength are definite requirements.

120· Automobile cylinder blocks, cylinder heads, fly wheels, truck brake drums, cylinder sleeves, cylinder liners, pistons, etc.

121 Truck and tractor cylinder blocks and heads, heavy flywheels, tractor transmission cases, differential carrier castings, heavy gear boxes.

122 Diesel engine castings, liners, cylinders, piston and heavy parts in general.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Transverse Strength M lb	Deflection in.	Hardness BHN
Castings for Brakedrums and Clutchplates·				
Alloy No. 113 } Test bar 1.2 in. diam	30 min	2.2 min	0.20 min	179-229
114 } broken on 18 in.	40 min	2.6 min	0.27 min	207-269
} supports	—	—	—	—
All other Castings.				
Alloy No. 110 } Test bar	20 min	1.8 min	0.15 min	187 max
111 } 1.2 in. diam	30 min	2.2 min	0.20 min	170-223
120 } broken on	35 min	2.4 min	0.24 min	187-241
121 } 18 in.	40 min	2.6 min	0.27 min	202-255
122 } supports	45 min	2.8 min	0.30 min	217-269

Note See specification for details and modifications.

STEELS, ASTM

A 161-51T

Chemical Composition

	C %	Mn %	P %	S %	Si %	Mo %
Low C, Ladle[1]	0.12-0.18	0.33-0.77	0.040 max	0.050 max	0.23 max	–
C-Mo, Ladle[1]	0.11-0.19	0.33-0.77	0.040 max	0.040 max	0.15-0.45	0.48-0.63

[1] For check analysis, see ASTM Specs

Characteristics. This is an open-hearth or electric-furnace killed low C or C-Mo steel tubing 2 in. and over in outside diameter and thicker than No. 5 B.w.g. in minimum wall. Tubing shall be seamless and hot-rolled or cold-drawn as specified. Order should specify outside diam and min wall thickness, inside diam shall not be specified.

Uses. In carrying oil at elevated temperatures and pressures in various types of oil stills, in which the tubes may be subjected to a furnace temperature higher than that of the contained fluid.

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Point M psi	Elong 2 in %	Hardness, BHN Hot Rolled	Hardness, BHN Cold Drawn
Low Carbon Steel tubes		47 min	26 min	–	137	125
Carbon Molybdenum Steel tubes		55 min	30 min	–	150	137
Basic minimum, $\geq 5/16$ in. wall thickness	Low C	–	–	35 min	–	–
	C-Mo	–	–	30 min	–	–
Standard rd tension test specimen, 2 in. gage length	Low C	–	–	28 min	–	–
	C-Mo	–	–	22 min	–	–
For longitudinal strip tests, deduct from basic min for every 1/32 in. below 5/16 in.	Low C	–	–	1.75	–	–
	C-Mo	–	–	1.50	–	–

Note See specification for details and modifications

STEELS, ASTM

A 176-49

Chemical Composition

Grades		C %	Mn %	P %	S %	Ni %	Si %	Cr %
1	403	0.15 max	1.00 max	0.040 max	0.040 max	0.60 max	1.00 max	11.50-13.00
2	410	0.15 max	1.00 max	0.040 max	0.040 max	0.60 max	1.00 max	11.50-13.50
4	430	0.12 max	1.00 max	0.040 max	0.040 max	0.60 max	1.00 max	14.00-18.00
5	442	0.35 max	1.00 max	0.040 max	0.040 max	0.60 max	1.00 max	18.00-23.00
6	446	0.35 max	1.00 max	0.040 max	0.040 max	0.60 max	1.00 max	23.00-27.00

Characteristics. This is an electric-arc or electric-induction soft corrosion-resisting Cr steel. It is furnished in plate, sheet and strip in various finishes.

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi	Elong 2 in. % min	Rockwell-Hardness Max	Hardness BHN Max	Cold Bend[2] degree
Grades	1	70 min	35 min	25[1]	B88	202	180
	2	70 min	35 min	25[1]	B88	202	180
	4	70 min	35 min	22[1]	B88	202	180
	5	75 min	40 min	20	B95	202	180
	6	75 min	40 min	20	B95	217	135

[1] Material $\leq$ 0 050 in. (U.S. gage No. 18 and under) minimum of 20 0%.
[2] Specimens shall stand being bent cold through the angles stated above without cracking on the outside of the bent portion
Material $> 3/8$ in. shall be bent around a pin the diam of which is 2 × the thickness of the specimen.
Material $\leq 3/8$ in. shall be bent around a pin the diam of which = the thickness of the specimen.
Note See specification for details and modifications

STEELS, ASTM
A 177-44

Chemical Composition

C %	Mn %	P %	S %	Ni %	Si %	Cr %
0.12 max[1]	1.50 max	0.035 max	0.035 max	7.0 min	1.00 max	17.00 min

[1] For material ¾ or full-hard temper, 15% max C is allowed.

Characteristics. This is an electric-arc or electric-induction high-strength corrosion-resisting Cr–Ni steel. It is furnished in sheet or strip in four tempers.

Mechanical Properties

Temper	Tensile Strength M psi	Yield[1] Strength M psi	Elongation 2 in % Min ≤0.015 in.	Elongation 2 in % Min 0.016-0.030 in	Elongation 2 in % Min >0.030 in	Bend Test Requirements[3] ≤0.030 in Angle Deg	≤0.030 in N[2]	0.031–0.050 in Angle Deg	0.031–0.050 in N[2]	≥0.051 in Angle Deg	≥0.051 in N[2]
¼ hard	125 min	75 min	25.0	25.0	25.0	180	1	180	1	90	2
½ hard	150 min	110 min	9.0	10.0	10.0	180	2	180	4	90	2
¾ hard	175 min	135 min	3.0	5.0	7.0	180	4	90	2½	–	–
Full hard	185 min	140 min	3.0	4.0	5.0	180	6	90	3½	–	–

[1] 0.2% permanent offset
[2] Radius of bend = N × thickness of specimen.
[3] One specimen shall be bent in the longitudinal and one in the transverse direction. Specimens shall be bent cold through angles as indicated above without fracture

Note See specification for details and modifications

STEELS, ASTM
A 178-51T

Chemical Composition

Type	C %	Mn %	P %	S %
A Low C, Ladle[1]	0.08-0.15	0.30-0.60	0.040 max	0.050 max
B Open hearth	0.03 max	0.03 max	0.020 max	0.045 max
C Medium C, Ladle[1]	0.31 max	0.26 max	0.040 max	0.050 max

[1] For check analysis, see ASTM Spec

Characteristics. This is an open-hearth iron or electric-furnace steel tubing made by electric-resistance welding and normalized above upper critical temperature.

Uses: Boiler tubes, boiler flues, superheater flues and safe ends. Type C tubes are not suitable for safe-ending by forge welding.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2" %
Type C tubes	60	37 min	30[1]

[1] For longitudinal strip tests, deduct 1.50% from basic minimum for every 1/32 in. decrease in wall thickness below 5/16 in.
Note See specification for details and modifications.

STEELS, ASTM

A 179-51T

Chemical Composition

	C %	Mn %	P %	S %
Ladle[1]	0.08-0.16	0.30-0.60	0.040 max	0.050 max

[1]For check analysis, see ASTM Spec.

Characteristics: This is an open-hearth or electric-furnace, seamless, cold-drawn, low-carbon steel tubing made in sizes 1/2 in. to but excluding 2 in. o.d. Tubes shall be annealed to insure ductility. Tubes over 0.065 in. in wall thickness shall have a Rockwell hardness number not to exceed B72.

Uses:[1] Tubular heat exchangers, condensers, and similar heat transfer apparatus.

[1]When intended for corrosion, resistance at elevated temperatures, special requirements as to chemical composition and hardness shall be a matter of agreement between manufacturer and purchaser.

STEELS, ASTM

A 189-42

Characteristics. This is a refined wrought iron in two grades. A, double refined, round, hexagonal and rectangular bars, and B, single refined, round, hexagonal and rectangular bars. The bars shall be made from all pig-puddled or processed wrought iron[1] and shall be free from any admixture of iron scrap[1] or steel.

[1]See specification for definition.

Chemical Composition

Mn %
0.06 max

Mechanical Properties

Form or Condition	Tensile[3] Strength M psi	Yield Point M psi	Elong 8 in min	Red Area % min	Ratio[4]
Round, square and hexagonal bars					
Grade A Double Refined					
$< 1\frac{5}{8}$ in.	48-54	0.60TS	28[2]	45	–
$\geq 1\frac{5}{8}$ in. – $2\frac{1}{2}$ in.	47-54	0.55TS	25	40	–
$\geq 2\frac{1}{2}$ in. (also flat bars)	46-54[1]	0.50TS	22	35	–
Grade B Single Refined					
$< 1\frac{5}{8}$ in.	48 min	0.60TS	25[2]	40	–
$\geq 1\frac{5}{8}$ in. – $2\frac{1}{2}$ in.	47 min	0.55TS	22	35	–
$\geq 2\frac{1}{2}$ in. (also flat bars)	46 min[1]	0.50TS	20	30	–
Bend Tests, thru 180 deg					
Cold bend	–	–	–	–	1
Hot bend heated 1700-1800F or 925-980C	–	–	–	–	Flat on itself

[1]When cross sectional area exceeds 12 sq. in., allowable min. TS shall be 45 M psi
[2]Bars from 1/2 in. – 7/8 in. diam will be accepted if elongation in 8 in. $>$ 25% for Grade A or 22% for Grade B.
Bars $\leq$ 7/16 in. diam will be accepted if the elongation in 8 in. $>$ 22% for both grades.
[3]Allowable to deduct 1 M psi for specimens reduced by machining.
[4]Pin diam/specimen diam
Note See specification for details and specifications.

STEELS, ASTM

A 192-51T

Chemical Composition	C %	Mn %	P %	S %	Si %
Ladle[1]	0.08-0.16	0.30-0.60	0.040 max	0.050 max	0.23 max

[1]For check analysis, see ASTM Specs.

Characteristics. This is an open-hearth or electric-furnace seamless steel tubing ½ in. and larger o.d. Tubes less than 2 in. o.d. shall have wall thicknesses of not less than 8% o.d. but in no case less than 0.085 in. Tubes greater than 2 in. o.d. shall have wall thicknesses of not less than 0.200 in. Cold-drawn tubes shall be annealed "dead soft" after final cold-drawn pass. Hot-finished tubes need not be annealed unless specified by purchaser.

Uses. Boiler and superheater tubes.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Hard[1] BHN	Rock[2] Hard
Hot finished tubes } Annealed	–	–	–	137	B77
	–	–	–	125	B72
Cold drawn tubes } Annealed	–	–	–	125	B72
Assumptions for design purposes	47 min	26 min	35 min	–	–

[1]0.200 in. and over in wall thickness
[2]<0.200 in wall thickness
Note See current specification for details and modifications

STEELS, ASTM

A 195-50T

Chemical Composition	C %	Mn %	P % Acid	P % Basic	S %	Cu[1] %	Si %
Ladle[2]	0.30 max	1.65 max	0.06 max	0.04 max	0.05 max	0.20 min	0.25 max

[1]When specified
[2]For check analysis, see ASTM Specs.

Characteristics. This is an open-hearth or electric-furnace rivet steel. In cold-heading process, bars shall first be annealed by heating to 1450F (788C) and cooling slowly in furnace or in still air. No annealing need be used in hot heading process.

Uses. With proper riveting technique, suitable for use with structural silicon steel.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 8 in. Min %
Rivet steel	68-82	38 min	20

Note See specification for details and modifications.

STEELS, ASTM

A 194-51T

Chemical Composition[1]

Symbol	Grade	C %	Mn %	P %	S %	Ni %	Si %
–	0	0.25 max	–	0.10 max	0.23 max	–	–
–	1	0.15 min	–	0.05 max	0.05 max	–	–
–	2 and 2H	0.40 min	–	0.05 max	0.05 max	–	–
–	3[2]	0.35 max	–	0.05 max	0.05 max	–	0.50 max
–	4	0.40 to 0.50	0.50 to 0.95	0.04 max	0.05 max	–	0.15 min
8	TP304	0.08 max	2.00 max	0.04 max	0.03 max	8.00 to 11.00	1.00 max
8c	TP347	0.08 max	2.00 max	0.04 max	0.03 max	9.00 to 12.00	1.00 max
8t	TP321	0.08 max	2.00 max	0.04 max	0.03 max	8.00 to 11.00	1.00 max
8f	TP303	0.15 max	2.00 max	0.14[4]	0.50[4,5]	8.00 to 10.00	1.00 max

Symbol	Grade	Cr %	Zr %	Mo %	W %	Ti %	Cb %	Se %
	0							
	1	–	–	–	–	–	–	–
	2,2H	–	–	–	–	–	–	–
	3[2]	4.0 to 6.0	–	0.40 to 0.60[3]	0.75 to 1.25[3]	–	–	–
	4	–	–	0.20 min	–	–	–	–
8	TP304	18.00 to 20.00	–	–	–	–	–	–
8c	TP347	17.00 to 19.00	–	–	–	–	10 times C min	–
8t	TP321	17.00 to 19.00	–	–	–	5 times C min	–	–
8f	TP303	17.00 to 19.00	[6]	[6]	–	–	–	0.50[4,5]

[1]For check analysis, see ASTM Spec
[2]Other types of alloy steel, with appropriate heat treatments, approved by purchaser, may be submitted under these specs
[3]Either molybdenum or tungsten may be used, if desired
[4]Phosphorus content shall be 0 040 max when sulfur is added, and 0 140 max when selenium is added.
[5]When specified, either element may be used.
[6]Molybdenum, plus Zirconium, shall not exceed 0.60%

Hardness:

Class	Sample nut as finished BHN	Rock C	Rock B	Sample nut after treatment[1] BHN	Rock B
0	120 min	–	–	–	–
1	120 min	–	70 min	120 min	70 min
2	160 min	–	84 min	160 min	84 min
2H	248-352	24-37	–	180 min	89 min
3	248-352	24-37	–	200 min	94 min
4	248-352	24-37	–	200 min	94 min
8,8c,8t,8f	149 min	–	81 min	–	–

[1]Heat 24hr to 850F (455C) for grade 1, 1000F (540C) for grades 2 and 2H, 1100F (590C) for grades 3 and 4, and then cooled slowly.

Uses. Grade 0 for least exacting service.
Grades 3,4,8, 8c,8t,8f for most severe conditions of service.
Grades 1,2,2H for service between two extremes above.

Characteristics. This is an open-hearth, electric furnace or acid-bessemer steel covering ten grades of nuts for bolts used in high-pressure or high-temp service, or both. Grade O shall be made by hot-forged or cold process[1], or machined from bar stock. Grades 1 and 2 shall be made by hot-forged or cold process, or machined from hot-forged or hot-rolled bars. Grades 2H, 3 and 4 shall be made by hot-forged or cold process, or machined from hot-forged, hot-rolled or cold-drawn bars and heat treated to meet required physical properties. Unless otherwise specified, these grades of nuts shall be reheated above critical range of the steel and quenched in suitable medium at temp not less than 850F for 2H and 3, and not less than 1100 for 4. Grades 8, 8c and 8f shall be made by hot-forged or cold punching process, or machined from forged or rolled bars and annealed by quenching in water from min temp of 2000F. When increased mechanical properties are desirable, nuts may be machined from cold-drawn bars without annealing.

[1]All nuts, excepting grades 0,8,8c,8t and 8f, made by cold process shall be heated in process of manufacturing to a temp of at least 1000F (538C). Nuts made by hot process or from hot-forged or hot-rolled bars need not be stress-relieved.

STEELS, ASTM

A 210-51T

Chemical Composition

	C %	Mn %	P %	S %	Si %
Ladle[1]	0.32 max	0.77 max	0.040 max	0.050 max	0.12 min

[1]For check analysis, see ASTM Specs

Characteristics. This is an open-hearth or electric-furnace killed steel tubing. Tubes shall be seamless and hot-finished or cold-drawn, as specified. Hot-finished tubes shall be annealed by heating to at least 1300F (690C). Cold-drawn tubes shall be annealed after the final cold-draw pass.

Uses. Boiler tubes and flues, including safe ends,[1] arch and stay tubes, and superheater tubes.

[1]This type is not suitable for safe-ending by forge welding

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2 in %	Hard[1] BHN	Rock[2] Hard
	60 min	37 min	25 min	143 max	B79 max
For longitudinal strip tests, deduct for every $\frac{1}{32}$ in. below $\frac{5}{16}$ in. from basic min.	–	–	1.25	–	–

[1]For tubes $\geq$ 0 200 in
[2]For tubes 0 065 < 0.200 in. For tubes < 0 065 in., no hardness test shall be required
Note See specification for details and modifications.

Chemical Composition[7]

Identification Symbol	Grade	C %	Mn %	P %	S %	Ni %	Si %
Ferritic							
BA	–	–	–	0.04 max	0.04 max	–	–
BB	–	–	–	0.04 max	0.04 max	–	–
BC	–	–	–	0.04 max	0.04 max	–	–
B5	5% Cr (TP501)	0.10-0.30	0.30-0.60	0.04 max	0.03 max	–	0.30-0.60
B6	12% Cr (TP416)	0.15 max	1.25 max	0.14 max[2,3]	0.50 max[2,3,4]	–	0.30-0.60
B7	Cr-Mo (4140-4142-4145)	0.38-0.48[5]	0.75-1.00	0.04 max	0.04 max	–	0.20-0.35
B7a	Cr-High Mo	0.38-0.46	0.70-1.00	0.04 max	0.04 max	–	0.20-0.35
B14	Cr-Mo-V	0.41-0.49	0.45-0.70	0.04 max	0.04 max	–	0.20-0.35
B16	Cr-Mo-V	0.35-0.45	0.40-0.70	0.04 max	0.04 max	–	0.20-0.35
Austenitic							
B8	Unstabilized 18Cr-8Ni (TP304)	0.08 max	2.00 max	0.04 max	0.03 max	8.00-11.00	1.00 max
B8c	Stabilized 18Cr-8Ni (TP347)	0.08 max	2.00 max	0.04 max	0.03 max	9.00-12.00	1.00 max
B8t	Stabilized 18Cr-8Ni (TP321)	0.08 max	2.00 max	0.04 max	0.03 max	8.00-11.00	1.00 max
B8F[1]	Free machining 18Cr-8Ni (TP303)	0.15 max	2.00 max	0.14 max[2,3]	0.50 max[2,3,4]	8.00-10.00	1.00 max

Identification Symbol	Grade	Cr %	V %	Mo %	Zr %	Ti %	Cb %	Se %
Ferritic								
BA	–	–	–	–	–	–	–	–
BB	–	–	–	–	–	–	–	–
BC	–	–	–	–	–	–	–	–
B5	5% Cr (TP501)	4.00-6.00	–	0.45-0.65	–	–	–	–
B6	12% Cr (TP416)	12.00-14.00	–	[6]	–	–	–	0.50 max[3,4]
B7	Cr-Mo (4140-4142-4145)	0.80-1.10	–	0.15-0.25	–	–	–	–
B7a	Cr-High Mo	0.80-1.15	–	0.50-0.70	–	–	–	–
B14	Cr-Mo-V	0.80-1.15	0.20-0.30	0.30-0.40	–	–	–	–
B16	Cr-Mo-V	0.80-1.15	0.25-0.35	0.45-0.65	–	–	–	–
Austenitic								
B8	Unstabilized 18Cr-8Ni (TP304)	18.00-20.00	–	–	–	–	–	–
B8c	Stabilized 18Cr-8Ni (TP347)	17.00-19.00	–	–	–	–	10C min	–
B8t	Stabilized 18Cr-8Ni (TP321)	17.00-19.00	–	–	–	5C min	–	–
B8F[1]	Free machining 18Cr-8Ni (TP303)	17.00-19.00	–	[6]	[6]	–	–	0.50[3,4]

[1]Not recommended for temperatures over 800F.
[2]If S is added for machinability, P shall not exceed 0 04%.
[3]P and/or S and/or Se shall total not less than 0.07%.
[4]Either element may be specified.
[5]For bar sizes over 3½ to 4 in. incl., the C content may be 0.50% max.
[6]Mo plus Zr shall not exceed 0.60%.
[7]For check analysis, see ASTM Spec.

Characteristics: This is an open-hearth, electric furnace or crucible alloy-steel bolting material including rolled, forged or cold-drawn bars, and bolts, screws, studs, and stud bolts. See specification for details of heat treatment and other design factors.

Uses: Pressure vessels, valves, flanges and fittings for high-temperature service.

(continued on page 104)

(continued from page 103)

Mechanical Properties

Grade	Form or Condition Diam, in.	Draw Temp min	Tensile Strength M psi min	Yield Point M psi min	Elong 2 in. % min	Red Area % min	Hard BHN
Ferritic Steels: BA	≤ 2½	1200F	95	70	20	50	–
	> 2½-4 incl.		90	65	20	50	–
BB	≤ 2½	1100	105	80	20	50	–
	> 2½-4 incl.		100	75	20	50	–
BC	≤ 2½	1000	125	105	16	50	–
	> 2½-4 incl.		115	95	16	45	–
B5 4-6% Cr	≤ 2½	1000	120	95	15	45	–
		1100	110	90	16	50	–
		1200	100	85	17	55	–
	> 2½-4 incl.	1000	105	85	15	45	–
		1100	100	80	16	50	–
		1200	95	75	17	55	–
B6 13% Cr	≤ 2½	1000	150	125	13	45	–
		1100	120	100	15	50	–
		1200	105	85	17	55	–
	> 2½-4 incl.	1000	140	120	13	45	–
		1100	115	95	15	50	–
		1200	100	80	17	55	–
B7 Cr-Mo	≤ 2½	1000	135	115	15	50	–
		1100	125	105	16	50	–
		1200	105	90	17	55	–
	> 2½-4 incl.	1000	125	105	15	50	–
		1100	115	95	16	50	–
		1200	105	85	17	50	–
	> 4-7 incl.	1000	110	85	16	45	–
		1100	100	75	18	50	–
		1200	90	65	20	50	–
B7a Cr-High Mo	≤ 2½	1000	140	120	15	45	–
		1100	135	115	15	50	–
		1200	125	105	16	50	–
	> 2½-4 incl.	1000	130	110	15	45	–
		1100	125	105	15	50	–
		1200	115	95	16	55	–
B14 Cr-Mo-V (Special normalizing treatment required)	≤ 2½	1000	145	120	14	45	–
		1100	135	115	15	45	–
		1200	125	105	16	50	–
	> 2½-4 incl.	1000	–	–	–	–	–
		1100	–	–	–	–	–
		1200	–	–	–	–	–
B16 Cr-Mo-V	≤ 2½	1200	125	105	18	50	–
	> 2½-4 incl.		110	95	17	45	–
	> 4-7 incl.		100	85	16	45	–
Austenitic Steels: B8, B8c, B8t and B8F 18 Cr-8Ni Regular and Free machining	all diam — Carbide solution treated	–	75	30	35	50	–
	≤ ¾ — Cold drawn to surface	–	125	100	12	35	320 max
	> ¾-1 incl.	–	115	80	15	35	320 max
	> 1-1¼ incl.	–	105	65	20	35	320 max
	> 1¼-1½ incl.	–	100	50	28	45	320 max

Note: Charpy impact properties may be specified as agreed upon by manufacturer and purchaser
See specification for details and modifications

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Mechanical Properties Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2" %	Rock Hard
	60 min	25 min	30 min[1]	
Tubes > 0.065 in. Grades 1-6,8	–	–	–	B85
Grades 7,9	–	–	–	B89

[1]For longitudinal strip tests deduct 1.50% from specified min for every $\frac{1}{32}$ in. decrease in wall thickness below $\frac{5}{16}$ in.
NOTE See specification for details and modifications.

Characteristics: This is an electric-furnace chromium-molybdenum and chromium-molybdenum-silicon seamless cold-drawn intermediate alloy steel tubing in sizes ½ in. to but excluding 2 in. o.d. Purchaser shall not specify inside diameter.

Uses. Heat exchangers, condenser tubes and similar heat-transfer apparatus.

Chemical Composition[1]

Grades	C %	Mn %	P[2] %	S %	Si %	Cr %	Mo %
Ladle: 1	0.14 max	0.33-0.57	0.025 max	0.025 max	0.55-0.95	1.05-1.45	0.48-0.63
2	0.14 max	0.33-0.57	0.025 max	0.025 max	0.55-0.95	2.25-2.75	0.48-0.63
3	0.14 max	0.33-0.57	0.025 max	0.025 max	0.45-0.75	1.50-2.00	0.63-0.78
4	0.14 max	0.33-0.57	0.025 max	0.025 max	0.45 max	1.75-2.25	0.48-0.63
5	0.14 max	0.33-0.57	0.025 max	0.025 max	0.45 max	2.75-3.25	0.83-1.03
6	0.14 max	0.33-0.57	0.025 max	0.025 max	0.45 max	2.00-2.50	0.90-1.10
7	0.15 max	0.30-0.60	0.03 max	0.03 max	0.50-1.00	6.00-8.00	0.45-0.65
8	0.15 max	0.30-0.60	0.03 max	0.03 max	0.50 max	4.00-6.00	0.45-0.65
9	0.15 max	0.30-0.60	0.03 max	0.03 max	0.50-1.00	8.00-10.00	0.90-1.10

[1]For check analysis, see ASTM Specs.
[2]Emergency alternate provisions allow max 0.045%P.

A 202-50T

Chemical Composition

	C %	Mn %	P %	S %	Si %	Cr %
Grade A	0.17 max	1.05-1.40	0.035 max	0.04 max	0.60-0.90	0.30-0.60
B	0.25 max	1.05-1.40	0.035 max	0.04 max	0.60-0.90	0.30-0.60

Characteristics. This is an open-hearth or electric-furnace Cr-Mn-Si alloy steel plate of firebox quality in two high tensile strength ranges up to 2 in. incl. in thickness. Grade A is a ductile material of maximum workability, suitable for rivets[1]. Grade B is a high tensile material with sufficient ductility to be workable without heating.

Uses. Boilers and other pressure vessels.

[1]When so used, the bars shall be subject to ASTM A31, except chemical and mechanical properties

Mechanical Properties

Form or Condition	Tensile Strength M psi[1]	Yield Point M psi	Elongation 2 in. min %	Elongation 8 in. min %	Ratio[2] Grade A	Ratio[2] Grade B
Grades A	75-90	0.60TS	1750M ÷ TS	1600M ÷ TS	–	–
B	85-100	0.55TS	1750M ÷ TS	1600M ÷ TS	–	–
For plates > ¾ in., deduct from 8 in. min. for each $\frac{1}{32}$ in. above ¾ in.	–	–	–	0.125[3]	–	–
Bend Test Thru 180 deg ≤ 1 in.	–	–	–	–	2	2½
> 1 to 1½ in. incl.	–	–	–	–	2½	3
> 1½ to 2 in. incl.	–	–	–	–	3	3½

[1]TS need only be determined on specimen taken from top of firebox plates. Shall not exceed 92M psi for Grade A, 102M psi for Grade B
[2]Bend diam/specimen thickness
[3]Minimum 19% for Grade A, 16% for Grade B. For further details see Spec.
Note See specification for details and modifications

STEELS, ASTM

A 200-50T

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Hard BHN
	60 min	25 min	–	163[1]
Basic minimum ≥ 5/16 in. wall thickness, longitudinal strip tests, and for all small sizes tested in full section	–	–	30 min	–
Standard rd. 2 in. gage length	–	–	22 min	–
For longitudinal strip tests, deduct for every 1/32 in. below 5/16 in. from basic min.	–	–	1.50	–

[1] For grades 1-6 incl. and grade 8. Grades 7 and 9 shall have max BHN of 179.
Note See specification for details and modifications.

Characteristics. This is an electric-furnace, seamless, Cr-Mo and Cr-Mo-Si intermediate alloy-steel tubing 2 in. and over in outside diam and thicker than No. 5 B.w.g. in minimum wall. Tubes shall be hot-rolled or cold-drawn and heat-treated as specified. Order shall specify grade desired, outside diam and minimum wall thickness, inside diam shall not be specified.

Uses. In carrying oil at elevated temperatures and pressures in various types of oil stills, in which the tubes may be subjected to a furnace temp higher than that of the contained fluid.

Chemical Composition[1]

Grades		C %	Mn %	P[2] %	S %	Si %	Cr %	Mo %
Ladle	1	0.14 max	0.33-0.57	0.025 max	0.025 max	0.55-0.95	1.05-1.45	0.48-0.63
	2	0.14 max	0.33-0.57	0.025 max	0.025 max	0.55-0.95	2.25-2.75	0.48-0.63
	3	0.14 max	0.33-0.57	0.025 max	0.025 max	0.45-0.75	1.50-2.00	0.63-0.78
	4	0.14 max	0.33-0.57	0.025 max	0.025 max	0.45 max	1.75-2.25	0.48-0.63
	5	0.14 max	0.33-0.57	0.025 max	0.025 max	0.45 max	2.75-3.25	0.83-1.03
	6	0.14 max	0.33-0.57	0.025 max	0.025 max	0.45 max	2.00-2.50	0.90-1.10
	7	0.15 max	0.30-0.60	0.03 max	0.03 max	0.50-1.00	6.00-8.00	0.45-0.65
	8	0.15 max	0.30-0.60	0.03 max	0.03 max	0.50 max	4.00-6.00	0.45-0.65
	9	0.15 max	0.30-0.60	0.03 max	0.03 max	0.50-1.00	8.00-10.00	0.90-1.10

[1] For check analysis, see ASTM Specs.
[2] Emergency alternate provisions allow max 0.045% P

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Chemical Composition

Grade		C %	Mn %	P %	S %	Si %	Mo %
Ladle[1]	T1	0.11-0.19	0.33-0.77	0.040 max	0.040 max	0.15-0.45	0.48-0.63
	T1a	0.16-0.24	0.33-0.77	0.040 max	0.040 max	0.15-0.45	0.48-0.63
	T1b	0.13 max	0.33-0.77	0.040 max	0.040 max	0.15-0.45	0.48-0.63

[1] For check analysis, see ASTM specs.

Characteristics. This is an open-hearth or electric-furnace, killed, C-Mo alloy-steel tubing of three grades. Tubes shall be seamless and hot finished or cold drawn, as specified. Hot-finished tubes shall be annealed or normalized and drawn. Cold-drawn tubes shall be annealed after the final cold-drawn pass. Order should specify grade desired.

Uses. Boiler and super-heater tubes.

Mechanical Composition

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2 in. %	Hard[1] BHN	Rock[2] Hard
Grades T1	55 min	30 min	30 min	137 max	B77 max
T1a	60 min	32 min	30 min	143 max	B79 max
T1b	53 min	28 min	30 min	137 max	B77 max
For longitudinal strip tests, deduct for every 1/32 in. below 5/16 in. from basic min., all three grades	–	–	1.50	–	–

[1] For tubes ≥ 0.200 in.
[2] For tubes 0.065 < 0.200 in. Tubes < 0.065 in. shall not require hardness test.
Note. See specification for details and modifications.

A 201-50T

Chemical Composition

	C % max	Mn % max	P % max	S % max	Si %
Grade A	.20[1] .24[2] .27[3] .31[4] .35[5]	.80	.04[7] .035[8]	.05[7] .04[8]	.15-.30
Grade B	.24[1] .27[2] .30[3] .35[4] —[6]	.80	.04[7] .035[8]	.05[7] .04[8]	.15-.30

[1] ≤ 1 in.
[2] > 1-2 in incl.
[3] > 2-4 in. incl
[4] > 4-8 in incl
[5] > 8-12 in incl
[6] Grade B is not supplied over 8 in
[7] Flange
[8] Firebox

Characteristics. This is an open-hearth or electric furnace carbon-silicon plate steel of intermediate strength and intended for fusion-welded boilers and other pressure vessels. It is supplied in two grades in both flange and firebox qualities. Plates over 2 in in thickness are to be heat treated for grain refinement. This means normalizing since liquid quenching is not permitted under this specification. The carbon content is permitted to run high enough in the heavier plates to require special precautions in welding to avoid base metal cracking.

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Point Min psi	Elong 8" min %	Elong 2" min %	Ratio[3]
Grade A		55-65	.5TS	1500 M + TS[1]; 1550 M + TS[2]	1750 M + TS[2]	—
Grade B		60-72	.5TS	1500 M + TS[1]; 1550 M + TS[2]	1750 M + TS[2]	—
Bend Test[4]						
Thickness ≤ 1 in.	Grade A	—	—	—	—	½
	Grade B	—	—	—	—	1
> 1-1½ in. incl.,	Grade A	—	—	—	—	1
	Grade B	—	—	—	—	1½
> 1½-3 in. incl.,	Grade A	—	—	—	—	1½
	Grade B	—	—	—	—	2
> 3-4 in. incl.,	Grade A	—	—	—	—	2
	Grade B	—	—	—	—	2½
> 4-6 in. incl.,	Grade A	—	—	—	—	2½
	Grade B	—	—	—	—	3
> 6-9 in. incl.,	Grade A	—	—	—	—	3
	Grade B	—	—	—	—	3½
> 9-12 in. incl.,	Grade A	—	—	—	—	3½
	Grade B	—	—	—	—	—

[1] Flange
[2] Firebox
[3] Bend diameter to specimen thickness
[4] 180 deg cold bend
NOTE: See specification for details and deviations.

A 203-50T

Characteristics. This is an open-hearth or electric-furnace nickel steel plate in three tensile strength ranges, intended particularly for fusion welding. Maximum thickness of flange quality shall be 2 in., of Grades A and B, firebox quality, 6 in., of Grades C, D and F, firebox quality, 4 in. Welding technique is of fundamental importance. See Spec. for details of heat treatment.

Uses. Locomotive boiler shells, boilers for stationary service and other pressure vessels.

Chemical Composition

Grade	C max % ≤ 2 in.	C max % > 2-4 in. incl.	C max % > 4-6 in. incl.	Mn max % ≤ 2 in.	Mn max % > 2-4 in. incl.	Mn max % > 4-6 in. incl.	P % Flange	P % Firebox
A	0.17	0.20	0.23	0.80	0.90	0.90	0.04	0.035
B	0.20	0.23	0.25	0.80	0.90	0.90	0.04	0.035
C	0.25	0.27	–	0.80	0.90	–	0.04	0.035
D	0.17	0.20	–	0.80	0.90	–	0.04	0.035
F	0.20	0.23	–	0.80	0.90	–	0.04	0.035

Grade	S % Flange	S % Firebox	Ni %	Si %
A	0.05	0.04	2.00-2.75	0.15-0.30
B	0.05	0.04	2.00-2.75	0.15-0.30
C	0.05	0.04	2.00-2.75	0.15-0.30
D	0.05	0.04	3.25-3.75	0.15-0.30
F	0.05	0.04	3.25-3.75	0.15-0.30

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elongation 2 in. Min %	Elongation 8 in. Min % Flange	Elongation 8 in Min % Firebox	Ratio ≤ 1 in	Ratio > 1-2 in incl.	Ratio > 2-4 in incl	Ratio > 4-6 in incl.
Grades A and D	65-77[4]	0.55TS	1750M + TS[1]	1600M + TS	1650M + TS	–	–	–	–
B and E	70-85[5]	0.55TS	1750M + TS[2]	1600M + TS	1650M + TS	–	–	–	–
C	75-87[6]	0.55TS	1750M + TS[3]	1600M + TS	1650M + TS	–	–	–	–
For plates over ¾ in. deduct from 8 in. min, for each 1/32 in. above ¾ in.	–	–	0.125[7]	–	–	–	–	–	–
For plates > 2 in. deduct from 2 in. min, for each ½ in. above 2 in.	–	–	0.5	–	–	–	–	–	–
Bend Test: Ratio of bend diam/specimen thickness — Grades A	–	–	–	–	–	1	1½	1½	2
B	–	–	–	–	–	1½	2	2	2½
C	–	–	–	–	–	2	2½	3	–
D	–	–	–	–	–	1	1½	1½	–
E	–	–	–	–	–	1½	2	2	–

[1] but no less than 37
[2] but no less than 40
[3] but no less than 43
[4] maximum 80
[5] maximum 88
[6] maximum 90
[7] Grades A, B, D, E minimum 19%. Grade C, minimum 18%. See specification for further details.
Note See specification for details and modifications.

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Chemical Composition

Grade	C % ≥ 1 in.	C % > 1 to 2 in. incl.	C % > 2 to 4 in. incl.	C % > 4 to 6 in. incl.	Mn %	Mo %
A, B up to 6 in. incl. — A	0.18 max	0.21 max	0.23 max	0.25 max	0.90 max	0.40-0.60
A, B up to 6 in. incl. — B	0.20 max	0.23 max	0.25 max	0.27 max	0.90 max	0.40-0.60
C up to 4 in. incl.	0.23 max	0.26 max	0.28 max	–	0.90 max	0.40-0.60

Grade	P % Flange	P % Firebox	S % Flange	S % Firebox	Si %
A, B up to 6 in. incl. — A	0.04 max	0.035 max	0.05 max	0.04 max	0.15-0.30
A, B up to 6 in. incl. — B	0.04 max	0.035 max	0.05 max	0.04 max	0.15-0.30
C up to 4 in. incl.	0.04 max	0.035 max	0.05 max	0.04 max	0.15-0.30

Characteristics. This is an open-hearth or electric-furnace molybdenum-steel plate, in three high tensile strength ranges intended particularly for fusion welding. Maximum thickness of flange quality plates under this specification shall be 2 in., of grades A and B firebox quality, 6 in.; of Grade C firebox quality, 4 in. Welding technique is of fundamental importance. See ASTM Spec. for details of heat treatment.

Uses. Locomotive boiler shells, boilers for stationary service and other pressure vessels.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elongation 2 in. Min[8] %	Elongation 8 in. Min[9] % Flange[7]	Elongation 8 in. Min[9] % Firebox[7]	Ratio[10] Grade A	Ratio[10] Grade B	Ratio[10] Grade C
Grades A	65-77[4]	0.55TS	1750M + TS[1]	1600M + TS	1650M + TS	–	–	–
B	70-85[5]	0.55TS	1750M + TS[2]	1600M + TS	1650M + TS	–	–	–
C	75-90[6]	0.55TS	1750M + TS[3]	1600M + TS	1650M + TS	–	–	–
Bend Test thru 180 deg ≤ 1 in.	–	–	–	–	–	1	1½	2
> 1 to 2 in. incl.	–	–	–	–	–	1½	2	2½
> 2 to 4 in. incl.	–	–	–	–	–	1½	2	3
> 4 to 6 in. incl.	–	–	–	–	–	2	2½	–

[1]but no less than 37 M psi
[2]but no less than 40 M psi
[3]but no less than 43 M psi
[4]maximum 80 M psi
[5]maximum 88 M psi
[6]maximum 93 M psi
[7]For plates > ¾ in., deduct 0.125% for each increase of 1/32 in. of the specified thickness above ¾ in. to a minimum of 19% for A & B and 18% for Grade C. See Spec for further details.
[8]For plates > 2½ in., deduct 0.5% for each ½ in. above 2½ in.
[9]For material ≤ ¾ in., elongation shall be measured on a gage length 24 times the thickness of specimen and shall conform to 8 in. gage length minimums.
[10]Bend diam/specimen thickness
Note See specification for details and modifications.

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Chemical Composition

	C % max	Mn % max	P % max	S % max	Si %
Grade A	.28[3]	.90	.04[1]	.05[1]	.15-.30
	.31[4]	–	.035[2]	.04[2]	–
	.33[5]	–	–	–	–
Grade B	.31[3]	.90	.04[1]	.05[1]	.15-.30
	.33[4]	–	.035[2]	.04[2]	–
	.35[5]	–	–	–	–

[1]Flange
[2]Firebox
[3]≤ 1 in.
[4] > 1-2 in. incl
[5] > 2-6 in. incl.

Characteristics. These are two high-strength, open-hearth or electric-furnace carbon-silicon plate steels. They are supplied in flange quality up to 2 in. in thickness and in firebox quality up to 6 in. in thickness. Plates > 2 in. thick shall be heat treated for grain refinement.

Uses. Locomotive boiler shells, boilers for stationary service, and other pressure vessels. They are suitable for fusion welding but the carbon is so high that precautions need to be taken to avoid base plate cracking.

Mechanical Properties

Form or Condition	Grade	Tensile Strength M psi	Yield Point Min psi	Elong 8" min %	Elong 2" min %	Ratio[3]
Grade A		65-77	.5TS	1550 M + TS[1] 1600 M + TS[2]	1750 M + TS	–
Grade B		70-85	.5TS	1550 M + TS[1] 1600 M + TS[2]	1750 M + TS	–
Bend Test[4] Thickness ≤ 1 in.	A	–	–	–	–	1½
	B	–	–	–	–	2
> 1-1½ in., incl.	A	–	–	–	–	2
	B	–	–	–	–	2
> 1½-3 in., incl.	A	–	–	–	–	2
	B	–	–	–	–	2½
> 3-4½ in., incl.	A	–	–	–	–	2½
	B	–	–	–	–	3
> 4½-6 in., incl.	A	–	–	–	–	3
	B	–	–	–	–	3½

[1]Flange
[2]Firebox
[3]Bend Diam/Specimen Thickness
[4]180 deg cold bend
NOTE: See specification for details and deviations.

SPECIAL CASTINGS

A 206-51T

Chemical Composition

Symbol	Grade	C %	Mn %	P %	S %	Si %	Mo %
P1[2]	C-Mo Ladle[1]	0.11-0.19	0.33-0.77	0.040 max	0.040 max	0.15-0.45	0.48-0.63

[1]For check analysis, see ASTM Specs.
[2]The similiar alloy in the corresponding specifications for alloy-steel forgings and castings for high-temperature service bears the numbers F1 and C1, respectively

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2 in. % Long.	Elong 2 in. % Trans.	Ratio[1]
	55 min	30 min	–	–	–
Basic minimum, ≥ 5/16 in. wall thickness, strip tests, and for all small sizes tested in full section	–	–	30 min	20 min	–
Standard rd. test specimen, 2 in. gage length	–	–	22 min	14 min	–
For strip tests, deduct for every 1/32 in. below 5/16 in. from basic min.	–	–	1.50	1.00	–
Bend Test ≤2 in nom diam: Thru 90 deg	–	–	–	–	12
Bend Test ≤2 in nom diam: Thru 180 deg for close coiling	–	–	–	–	8

[1]Mandrel diam/nom. diam specimen
Note See specification for details and modifications

Characteristics. This is an open-hearth or electric-furnace seamless C-Mo alloy-steel pipe of nominal wall. See specification for supplementary requirements for superior service and for heat treatment and finishing. Order shall specify maximum temp at which pipe will be operating.

Uses. High-temperature service. Suitable for bending, flanging (vanstoning) and similar forming operations, and for fusion welding.

SPECIAL CASTINGS

A 220-50T

Characteristics. This is a pearlitic mealleable iron made by air-furnace, open hearth, electric-furnace or any of the multiplex processes.

Uses. Castings for railroad, motor vehicle, marine, agricultural implement and general machinery purposes, both for general use and for localized hardening purposes.

Mechanical Properties

Form or Condition	Tensile[1] Strength Min M psi	Yield[1] Point Min M psi	Elong 2 in Min %	Hard BHN Typical
Grade 43010	60	43	10	163-207
48005	70	48	5	179-228
53004	80	53	4	197-241
60003	80	60	3	197-241
70002	90	70	2	241-285

[1]Higher tensile and yield strengths may be obtained by use of conventional quench-and-temper treatment
Note See specification for details and modifications

SPECIAL CASTINGS

A 225-50T

Characteristics. This is an open-hearth or electric-furnace Mn-V steel plate in two high tensile strength ranges, intended particularly for fusion welding. Maximum thickness of flange quality shall be 2 in., of grades A and B firebox quality, 4 in. Welding technique is of fundamental importance. See specification for details of heat treatment.

Uses. Locomotive boiler shells, boilers for stationary service and other pressure vessels.

Chemical Composition

Grade	C %	Mn %	P % Flange	P % Firebox	S % Flange	S % Firebox	Si %	V %
A	0.18 max	1.45 max	0.04 max	0.035 max	0.05 max	0.04 max	0.15-0.30	0.08-0.14
B	0.20 max	1.45 max	0.04 max	0.035 max	0.05 max	0.04 max	0.15-0.30	0.08-0.14

Mechanical Properties

Form or Condition	Tensile Strength[3] M psi	Yield Point min M psi	Elongation 2 in. min %	Elongation 8 in min % Flange	Elongation 8 in. min % Firebox	Ratio[4] Grade A	Ratio[4] Grade B
Grades A	70-85	0.55TS[1]	1750M + TS	1600M + TS	1650M + TS	–	–
B	75-90	0.55TS[2]	1750M + TS	1600M + TS	1650M + TS	–	–
For plates > 3/4 in. deduct from 8 in. min for each 1/32 in. above 3/4 in.[5]	–	–	–	0.125	–	–	–
For plates > 2 1/2 in. deduct from 2 in. min for each 1/2 in. above 2 1/2 in.	–	–	0.5	–	–	–	–
Bend Test thru 180 deg ≤ 1 in.	–	–	–	–	–	1 1/2	2
Bend Test thru 180 deg > 1 to 2 in. incl.	–	–	–	–	–	2	2 1/2
Bend Test thru 180 deg > 2 to 4 in. incl.	–	–	–	–	–	2	3

[1]But not less than 40 M psi
[2]But not less than 43 M psi
[3]TS need only be determined on specimen taken from top of firebox plates, maximum 88 M psi for grade A, 93 M psi for grade B.
[4]Bend diam/specimen thickness.
[5]Minimum 19% for grade A, 18% for grade B. See spec for further details
Note. See specification for details and modifications

SPECIAL CASTINGS

A 213-51T

Chemical Composition[1]

Identification Symbol	Grade	C %	Mn %	P[2] %	S %	Ni %
Ferritic						
T3	Cr-Mo	0.14 max	0.33-0.57	0.025 max	0.025 max	–
T5	Cr-Mo	0.15 max	0.30-0.60	0.03 max	0.03 max	–
T7	7% Cr	0.15 max	0.30-0.60	0.03 max	0.03 max	–
T9	9% Cr	0.15 max	0.30-0.60	0.03 max	0.03 max	–
T11	Cr-Si-Mo	0.14 max	0.33-0.57	0.025 max	0.025 max	–
T12	Cr-Mo	0.14 max	0.33-0.58	0.040 max	0.040 max	–
T13	Cr-Si-Mo	0.15 max	0.30-0.60	0.03 max	0.03 max	–
T14	Cr-Mo	0.14 max	0.33-0.57	0.025 max	0.025 max	–
T16	Cr-Mo-Ti	0.12 max	0.30-0.60	0.03 max	0.03 max	–
T17	Cr-V	0.16-0.24	0.33-0.58	0.040 max	0.040 max	–
T21	Cr-Mo	0.14 max	0.33-0.57	0.025 max	0.025 max	–
T22	Cr-Mo	0.14 max	0.33-0.57	0.025 max	0.025 max	–
Austenitic						
TP304	Cr-Ni	0.08 max	2.00 max	0.03 max	0.03 max	8.00-11.00
TP310	Cr-Ni	0.15 max	2.00 max	0.03 max	0.03 max	19.00-22.00
TP321	Cr-Ni-Ti	0.08 max	2.00 max	0.03 max	0.03 max	9.00-13.00
TP347	Cr-Ni-Cb	0.08 max	2.00 max	0.03 max	0.03 max	9.00-13.00
TP316	Cr-Ni-Mo	0.08 max	2.00 max	0.03 max	0.03 max	11.00-14.00

Identification Symbol	Grade	Cr %	Mo %	Si %	Other[3]
Ferretic					
T3	Cr-Mo	1.50-2.00	0.63-0.78	0.45-0.75	
T5	Cr-Mo	4.00-6.00	0.45-0.65	0.50 max	–
T7	7% Cr	6.00-8.00	0.45-0.65	0.50-1.00	–
T9	9% Cr	8.00-10.00	0.90-1.10	0.50-1.00	–
T11	Cr-Si-Mo	1.05-1.45	0.48.0.63	0.55-0.95	–
T12	Cr-Mo	0.85-1.20	0.48-0.63	0.28 max	–
T13	Cr-Si-Mo	4.00-6.00	0.45-0.65	1.00-2.00	–
T14	Cr-Mo	1.75-2.25	0.48-0.63	0.45 max	–
T16	Cr-Mo-Ti	4.00-6.00	0.45-0.65	0.50 max	–
T17	Cr-V	0.85-1.20	–	0.17-0.33	$\geq$ 5C < 0.60 (Ti)
T21	Cr-Mo	2.75-3.25	0.83-1.03	0.45 max	0.17 min (V)
T22	Cr-Mo	2.00-2.50	0.90-1.10	0.45 max	–
Austenitic					–
TP304	Cr-Ni	18.00-20.00	–	0.75 max	–
TP310	Cr-Ni	24.00-26.00	–	0.75 max	–
TP321	Cr-Ni-Ti	17.00-20.00	–	0.75 max	$\geq$ 5C < 0.60 (Ti)
TP347	Cr-Ni-Cb	17.00-20.00	–	0.75 max	$\geq$ 10C < 1.00 (Cb)
TP316	Cr-Ni-Mo	16.00-18.00	2.00-3.00	0.75 max	–

[1]For check analysis, see ASTM Spec
[2]Emergency alternate provisions allow a maximum phosphorus content on check analysis to read 0.045%
[3]Ti, V and Cb as shown

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Point M psi	Elong 2 in. %	Hard[2] BHN	Rock[3] Hard
Ferritic steel		60 min	25 min	30 min	163 max[1]	B85 max[1]
Austenitic steel		75 min	30 min	35 min	190 max	B90 max
For longitudinal strip tests, deduct for each 1/32 in. below 5/16 in. from basic min	ferritic	–	–	1.50	–	–
	austenitic			1.75		

[1]Except grades T7 and T9 shall not exceed 179 BHN (Rock B89)
[2]For tubes $\geq$ 0.200 in
[3]For tubes 0.065 < 0.200 in. Tube < 0.065 in. shall not require hardness tests.
Note See specification for details and modifications.

Characteristics: This is an electric-furnace steel tubing made by seamless process and either hot-finished or cold-drawn as specified.

Uses. Seamless ferritic and austenitic steel boiler and superheater tubes, and austenitic steel heat exchanger tubes.

SPECIAL CASTINGS

A 214-51T

Chemical Composition

	C %	Mn %	P %	S %
Ladle[1]	0.15 max	0.30-0.60	0.040 max	0.050 max

[1]For check analysis, see ASTM Specs

Hardness Test

Tubes < 0.065 in. in wall thickness shall not require hardness test.
Tubes $\geq$ 0.065 in. shall not exceed Rock B72.

Characteristics.[1] This is an open-hearth or electric-furnace steel tubing made by electric-resistance welding. Tubes shall be normalized at a temperature above the upper critical temperature. Order shall specify outside diam and minimum wall thickness, inside diam shall not be specified.

Uses. Heat exchangers, condensers, and similar heat transfer tubing in sizes up to but not including 2 in. o. d.

[1]These specifications are applicable to types of "low-alloy" steels intended to produce greater strength at elevated temperatures, but not intended specifically for corrosion resistance at elevated temperatures. See specification for details on special requirements.

STEELS, ASTM

A 216-47T

Characteristics. This is an open-hearth or electric-furnace C steel in two grades. Selection will depend upon design and service conditions, mechanical properties, and the high-temperature characteristics.[1]

Uses. Castings for valves, flanges, fittings or other pressure-containing parts for high-temperature service and of quality suitable for assembly with other castings or wrought-steel parts by fusion welding. (See also ASTM A217).

[1]See specification for details on welding characteristics and heat treatments.

Chemical Composition

Grades	C %	Mn %	P %	S %	Ni[1] %
WCA	0.25 max[2]	0.70 max[2]	0.05 max	0.06 max	0.50 max
WCB	0.35 max[2]	0.70 max[2]	0.05 max	0.06 max	0.50 max

Grades	Cu[1] %	Si %	Cr[1] %	Mo plus W[1] %
WCA	0.50 max	0.60 max	0.25 max	0.25 max
WCB	0.50 max	0.60 max	0.25 max	0.25 max

[1]Unspecified alloying elements should be so restricted to an overall total of 1.0% max

[2]For each reduction of 0.01% below specified max C content, an increase of 0.04% Mn above specified max will be permitted up to a max 1.10%

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2 in. %	Red Area %	Pin Diam
Grades WCA	60 min	30 min	24 min	35 min	–
WCB	70 min	36 min	22 min	35 min	–
Bend Test[1]					
Cold Bend, thru 90 deg	–	–	–	–	1 in.

[1]When specified.

Note See specification for details and modifications

STEELS, ASTM

A 217-49T

Characteristics. This is an open-hearth or electric-furnace alloy steel in seven grades. Selection will depend on design and service conditions, mechanical properties and the high-temperature and corrosion-resistant characteristics. See specification for details.

Uses. Castings for valves, flanges, fittings and other pressure containing parts[1] intended primarily for high-temperature and corrosive services[2].

[1]See also ASTM A95 and A216 for C steel castings

[2]See specification for details on welding techniques.

Chemical Composition

Grade	Ident. Symbol	C %	Mn %	P %	S %	Ni %
C-Mo	WC1	0.25 max	0.50-0.80	0.05 max	0.06 max	0.50 max[1]
Ni-Cr-Mo	WC4	0.20 max	0.50-0.80	0.05 max	0.06 max	0.70-1.10
Ni-Cr-Mo	WC5	0.20 max	0.40-0.70	0.05 max	0.06 max	0.60-1.00
Cr-Mo	WC6	0.20 max	0.50-0.80	0.05 max	0.06 max	0.50 max[1]
Cr-Mo	WC9	0.18 max	0.40-0.70	0.05 max	0.06 max	0.50 max[1]
Cr-Mo	C5	0.20 max	0.40-0.70	0.05 max	0.06 max	0.50 max[1]
Cr-Mo	C12	0.20 max	0.35-0.65	0.05 max	0.06 max	0.50 max[1]

Grade	Ident. Symbol	Si %	Cr %	Mo %	W %
C-Mo	WC1	0.60 max	0.35 max[1]	0.45-0.65	0.10 max[1]
Ni-Cr-Mo	WC4	0.60 max	0.50-0.80	0.45-0.65	0.10 max[1]
Ni-Cr-Mo	WC5	0.60 max	0.50-0.90	0.90-1.20	0.10 max[1]
Cr-Mo	WC6	0.60 max	1.00-1.50	0.45-0.65	0.10 max[1]
Cr-Mo	WC9	0.60 max	2.00-2.75	0.90-1.20	0.10 max[1]
Cr-Mo	C5	0.75 max	4.00-6.50	0.45-0.65	0.10 max[1]
Cr-Mo	C12	1.00 max	8.00-10.00	0.90-1.20	0.10 max[1]

[1]Restrictions on unspecified alloying elements, to overall total 1.00% max (except total for grades WC4 and WC5 shall be 0.60% max)

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[2] Point M psi	Elong 2 in. %	Red Area %	Pin Diam
Grades WC1	65 min	35 min	24 min	35 min	–
WC4, WC5, WC6, WC9	70 min	40 min	20 min	35 min	–
C5, C12	90 min	60 min	18 min	35 min	–
Bend Test[1]					
Cold Bend, thru 90 deg	–	–	–	–	1 in.

[1]When specified.

[2]Where definite Yield Point is not exhibited, shall use 0.2% permanent offset.

Note: See specification for details and modifications.

STEELS, ASTM

A 226-51T

Characteristics. This is an open-hearth or electric-furnace killed steel. Tubes shall be manufactured by electric-resistance welding and shall be normalized at a temperature above upper critical temperature. Tubes < 2 in. o.d. shall have wall thicknesses not less 8% o.d. and in no case less than 0.085 in. Tubes ≥ 2 in. o.d. shall have wall thicknesses not less than 0.200 in.

Uses. Boiler tubes and superheater tubes with o.d. ≥ ½ in.

Chemical Composition

C %	Mn %	P %	S %	Si %
0 08-0 15	0 30-0 60	0 040 max	0 050 max	0 22 max

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2" %	Hard BHN	Rock Hard
Assumptions for design	47 min	26 min	35 min	125 max[1]	B72 max[2]

[1]Tubes ≥ 0.200 in. diam wall thickness
[2]Tubes < 0 200 in diam wall thickness

NOTE See specification for details and modifications

STEELS, ASTM

A 227-47

Chemical Composition

C[1] %	Mn[2] %	P %	S %	Si %
0.45-0 75	0 60-1.20	0.045 max	0.050 max	0.10-0.30

[1]Carbon in any one lot shall not vary more than 0 20%.
[2]Manganese in any one lot shall not vary more than 0.30%.

Characteristics. This is an open-hearth round steel wire known as hard-drawn spring wire, uniform in quality, intended especially for the manufacture of springs. The wire shall be cold-drawn to desired mechanical properties.

Mechanical Properties

Form or Condition	Tensile Strength M psi Min	Tensile Strength M psi Max
Diameter, in.[1]		
0.028-0.041	271-255	311-293
0.047-0.072	248-232	286-266
0.080-0.120	227-210	261-241
0.135-0.177	206-195	237-225
0.192-0.250	192-182	221-210
0.312-0.437	174-165	200-190
0.500-0.625	156-147	180-170

[1]For intermediary sizes, see specification.
Note See specification for details and modifications.

STEELS, ASTM

A 228-51T

Chemical Composition

C %	Mn %	P %	S %	Si %
0.70-1.00	0.20-0.60	0.03 max	0.03 max	0.12-0.30

Characteristics. This is an open-hearth or electric-furnace, high quality round steel wire, uniform in strength and hardness. The wire shall be cold-drawn to produce the desired mechanical properties.

Uses. Music spring wire.

Mechanical Properties

Form or Condition	Tensile Strength M psi min	max
0.004 in. diam.	439	485
0.010 in. diam.	387	428
0.015 in. diam.	365	404
0.026 in. diam.	337	373
0.036 in. diam.	321	355
0.051 in. diam.	303	335
0.072 in. diam.	287	317
0.100 in. diam.	271	300
0.121 in. diam.	263	290
0.140 in. diam.	256	283

Note For intermediate values see ASTM Spec. Also see specification for details and modifications.

STEELS, ASTM

A 229-41

Chemical Composition

		C %	Mn %	P %	S %	Si %
Grade A	≥ 7/32 in.	0.55-0.75	0.80-1.20	0.045 max	0.050 max	0.10-0.30
B	< 7/32 in.	0.55-0.75	0.60-0.90	0.045 max	0.050 max	0.10-0.30

Characteristics. This is an open-hearth round steel wire known as oil-tempered spring wire, uniform in quality, intended especially for the manufacture of springs. The wire shall be hardened and tempered to produce the desired mechanical properties.

Mechanical Properties

Diameter, In [1]	Tensile Strength M psi Min	Max
0.032-0.093	275-225	310-260
0.105-0.192	220-190	255-220
0.207-0.250	185-180	215-210
0.312-0.375	178-175	208-205
0.437	170	200
0.500	165	195

[1] A single lot shall not vary more than 30 M psi in sizes 0 120 in and finer, and not more than 25 M psi for sizes courser than 0 120 in.

For intermediary sizes, see specification

Note See specification for details and modifications

STEELS, ASTM

A 230-47

Chemical Composition

C %	Mn %	P %	S %	Si %
0.60-0.70	0.50-0.80	0.03 max	0.03 max	0.12-0.30

Characteristics. This is an open-hearth or electric-furnace highest quality round C steel valve spring wire, uniform in quality and temper. The wire shall be hardened and tempered to desired mechanical properties. Wire may also be purchased in untempered condition, in which case the mechanical properties specified shall not apply.

Uses. Intended especially for the manufacture of valve springs and other springs requiring high-fatigue properties.

Mechanical Properties

Diameter, In	Tensile Strength M psi Min	Max	Red Area % Min
0.093-0.128	210	230	45
0.129-0.162	205	225	45
0.163-0.192	200	220	45
0.193-0.250	195	215	45

Note See specification for details and modifications.

STEELS, ASTM

A 231-41

Chemical Composition

C %	Mn %	P %	S %	Si %	Cr %	V %
0.45-0.55	0.60-0.90	0.040 max	0.050 max	0.15-0.30	0.80-1.10	0.15 min (0.18 desired)

Characteristics. This is an open-hearth round untempered steel wire known as Cr–V spring wire, uniform in quality. The wire shall be in the annealed or cold-drawn condition as specified by purchaser.

Uses. Intended for the manufacture of springs, especially when used at moderately elevated temperatures.

STEELS, ASTM

A 232-47

Chemical Composition

C %	Mn %	P %	S %	Si %	Cr %	V %
0.45-0.55	0.60-0.90	0.030 max	0.030 max	0.12-0.30	0.80-1.10	0.15-0.25

Characteristics. This is an open-hearth or electric-furnace highest quality Cr-V steel valve spring wire. Wire shall be either annealed, cold-drawn or oil-tempered as specified by purchaser.

Uses. Intended for the manufacture of valve springs and other springs requiring high-fatigue properties, especially when used at moderately elevated temperatures.

Mechanical Properties

Diameter, In		Tensile[1] Strength M psi Min	Tensile[1] Strength M psi Max	Red[2] Area Min %
≤0.032-0.062	Oil Tempered[3]	295-265	315-285	45
0.080-0.162	Oil Tempered[3]	255-225	275-245	45-40
0.192-0.437	Oil Tempered[3]	220-195	240-215	40

[1] Values for intermediate sizes may be interpolated.
[2] For sizes ≤0.156 in diam, 45%
For sizes >0 156 in. diam, 40%
[3] When annealed and cold drawn, the wire shall have been given sufficient final cold working to meet purchaser's coiling requirements, and respond properly to heat treatment In special cases, the hardness, if desired, shall be stated in purchase order.

Note. See specification for details and modifications.

STEELS, ASTM

A 234-51T

Chemical Composition

	Grade[1]	Pipe		Permissible Raw Materials Plate		Forgings	
Carbon	WPA	A106-51T	Grade A	A285-50T	Grades B,C	A105-46	Grade I
	WPB	A106-51T	Grade B	A212-50T	Grade A	A105-46	Grade II
C-Mo	WP1	A206-51T	Grade P1	A204-50T	Grade B	A182-49T	Grade F1
1¼Cr-Mo	WP11	A158-51T	Grade P11	[3]		[3]	
2¼Cr-Mo	WP22	[2]		[2]		A182-49T	Grade F22
5Cr-Mo	WP5a	A158-51T	Grade P5a	[4]		A182-49T	Grade F5

[1]When fittings are of welded construction, symbols shall be supplemented by letter "W."
[2]No ASTM specification has yet been written for pipe or plate of this chemical composition. However fittings may be made from pipe or plate which conform in their mechanical and chemical properties to forging specification shown for this grade.
[3]No ASTM specification has yet been written for plate or forgings of this chemical composition. However fittings may be made from plate or forgings which conform in their mechanical and chemical properties to pipe specification shown for this grade.
[4]No ASTM specification has yet been written for plate of this chemical composition. However fittings may be made from plate which conform in their mechanical and chemical properties to pipe or forging specification shown for this grade.

Characteristics. This is an open-hearth or electric furnace wrought carbon steel and ferritic alloy. When fittings are to be used for service at temperatures over 750F, and when specified in the order, the steel shall be silicon-killed.

Uses. Steel welding fittings for pressure piping.

Forms. Blooms, billets, slabs and of forging quality bars, plates or seamless tubes.

Heat Treatment:	Forming Temp	Treatment
Hot-finished Carbon-Steel Fittings	>1150F<1650F >1650F	None if cooled in still air. Normalized.
Cold-finished Carbon-Steel Fittings.	<1150F	Stress relieved reheat 1100-1200F 1 hr/in., cooled in furnace or air.
Alloy-Steel Fittings	As prescribed in specifications listed in Chemical Composition above.	
Cr-Mo Steel Fittings	Unless otherwise specified, Full annealed or normalized and tempered[1]	
Fusion-Welded Fittings		In accordance ASA No. B31.1-1951

[1]See specification for details and modifications. Tension tests are not required.

STEELS, ASTM

A 246-48T

Chemical Composition

	C[1] %	P %	S %	Cu[2] %
Open-Hearth	0.25 max	0.06 max	0.05 max	0.20 min
Acid-Bessemer	0.10 max	0.11 max	0.06 max	0.20 min

[1]As C increases above 0.15% spot welding becomes increasingly difficult.
[2]When specified.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2 in %	Bend Test at room temp
Grades	min	min	min	–
Commercial	subject to bend test only			flat on itself
A	45	25	25	flat on itself
B	50	30	23	180 deg[2]
C	52	33	18[1]	180 deg[3]

[1]Variable percentage decreasing 1% for each even Mfgrs' Standard gage number below No. 18 gage (Example 17% for 20 gage).
[2]Around one thickness of material.
[3]Around 1½ x thickness of material.
Note. See specification for details and modifications.

Characteristics. This is an open-hearth or acid bessemer flat rolled C sheet steel. It may be spot welded in the "hot rolled" condition but for best results the oxide or scale should be removed before welding.

Uses. Intended for structural purposes where mechanical test values are required.

A 235-49T

Chemical Composition

	Mn %	P %	S %
Ladle[1]	0.90 max	0.050 max	0.050 max

[1]For check variations, see ASTM Spec

Characteristics. This is an open-hearth or electric-furnace C steel for various classes of untreated and heat-treated forgings.[1] Purchaser shall specify class desired, choice depending on design and stress or service. See specification for details of heat treatment.

Uses. Forgings for general industrial use.

[1]When semi-finished steel is desired to process these forgings, ASTM A273 is recommended.

Mechanical Properties

Form or Condition	Class	Solid Diam or Thickness	Tensile Strength M psi	Yield Point M psi	Elong 2 in. %	Red Area %
Untreated	A	≤ 20 in.	47-60	—	—	—
Annealed, Normalized or Normalized and Tempered	C	≤ 12 in.	60 min	30 min	25 min	38 min
		> 12 in.	60 min	30 min	24 min	36 min
	C 1	≤ 12 in.	66 min	33 min	23 min	36 min
		> 12-20 in. incl.	66 min	33 min	22 min	34 min
	E	≤ 8 in.	75 min	37.5 min	24 min	40 min
		> 8-12 in. incl.	75 min	37.5 min	22 min	35 min
		> 12-20 in. incl.	75 min	37.5 min	20 min	32 min
		> 20 in.	75 min	37.5 min	19 min	30 min
Normalized and Tempered	F	≤ 8 in.	80 min	40 min	22 min	35 min
		> 8-12 in. incl.	80 min	40 min	21 min	33 min
		> 12-20 in. incl.	80 min	40 min	20 min	31 min
Double Normalized & Tempered	F1	≤ 8 in.	85 min	44 min	25 min	40 min
		> 8-12 in. incl.	83 min	43 min	23 min	37 min
		> 12-20 in. incl.	83 min	43 min	22 min	35 min
Quenched & Tempered or Normalized, Quenched & Tempered	G[1]	≤ 4 in.	90 min	55 min	20 min	39 min
		> 4-7 in. incl.	85 min	50 min	20 min	39 min
		> 7-10 in. incl.	85 min	50 min	19 min	37 min
			82.5 min	48 min	19 min	36 min

[1]Bored wall thickness for class G is as follows

≤ 2 in   > 3½–5 in incl
> 2–3½ in incl.   > 5–10 in. incl

Note See specification for details and modifications.

A 252-46

Characteristics. This is an open-hearth, electric-furnace, or acid-bessemer steel for nominal wall furnace- or electric-welded and seamless black pipe piles of cylindrical shape. The specifications are not intended to apply to pipe for general structural purposes.

Uses. Piles in which the steel cylinder acts as a permanent load-carrying member, or alternatively acts as a shell to form cast-in-place concrete piles.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elongation 2 in. %	Elongation 8 in. %
Grades 1	50 min	30 min	30 min[1]	18 min
2	60 min	35 min	25 min[1]	14 min
3	75 min	45 min	20 min[1]	—

[1]For walls ≥ 5/16 in. thick, basic minimum
[2]For walls < 5/16 in. a deduction of 1.50 for grade 1, 1.25 for grade 2, and 1.0 for grade 3 shall be made, for each 1/32 in. decrease in wall thickness, from the basic minimum elongations in 2 in

Note: See specification for details and modifications.

STEELS, ASTM
A 236-49T

Chemical Composition[2] Classes		C %	Mn %	P %	S %	Si %
Ladle[1]	A	0.15 max	0.30-0.60	0.045 max	0.050 max	–
	B	0.15-0.25	0.30-0.60	0.045 max	0.050 max	–
	C, D, E & F	0.40-0.55	0.60-0.90	0.045 max	0.050 max	0.15 min
	G & H	–	0.60-0.90	0.045 max	0.050 max	0.15 min

[1]For check variations, see ASTM Spec.
[2]Purchaser may specify that residual alloy elements not intentionally added, shall not exceed 0.25%Ni, 0.15%Cr, and 0.06%Mo

Characteristics. This is an open-hearth or electric-furnace C steel for various classes of untreated and heat treated forgings.

Uses. Locomotive and car construction.
Classes A and B[1], soft steel forgings for miscellaneous uses.
Classes C, D, E, F and G[1], for driving axles, engine truck axles, trailing truck axles, tender truck axles, car axles, main and side rods, straps, crank-pins, piston rods etc.
Class H, for locomotive and tender axles, piston rods, and similar locomotive and car forgings.

[1]See specification for heat treatments and supplementary requirements.

Mechanical Properties

Form or Condition		Solid Diam or Thickness		Bored Wall Thickness		Tensile Strength M psi	Yield Point M psi	Elong 2 in % min	Red Area % min
Annealed	C		<8 in	–		75 min	37.5 min	20	33
Normalized, or		> 8 in < 14 in	–	–		75 min	37.5 min	19	31
Normalized and	D	–	<8 in	–		80 min	40 min	22	35
Tempered		> 8 in < 14 in	–	–		80 min	40 min	21	33
Normalized	E	–	<8 in	–		85 min	44 min	25	40
and Tempered		> 8 in < 14 in	–	–		83 min	43 min	23	37
Double Normalized		–	<8 in		<4 in	88 min	50 min	25	40
and Tempered	F	> 8 in < 12 in	–	>4 in	<6 in	86 min	48 min	24	38
		>12 in < 14 in	–	–		84 min	46 min	23	36
Quenched		–	<4 in		<2 in	90 min	55 min	20	39
and	G	> 4 in < 7 in	–	>2 in	<3½ in	85 min	50 min	20	39
Tempered		> 7 in < 10 in	–	>3½ in	<5 in	85 min	50 min	19	37
		–	–	>5 in	<8 in	82.5 min	48 min	19	36
Normalized,		–	<7 in	–		115 min	75 min	16	35
Quenched and	H	> 7 in < 10 in	–		<4 in	105 min	65 min	18	35
Tempered		–	–	>4 in	<8 in	100 min	60 min	18	35

Note See specification for details and modification

STEELS, ASTM
A 261-47

Chemical Composition

	C %	Mn %	P %	S %	Si %
Ladle[1]	0.55 max	1.00 max	0.04 max	0.05 max	0.15 min

[1]For check analysis, see ASTM Spec.

Characteristics. This is an open-hearth or electric-furnace heat-treated C-steel bolting material[1] ≤ 2 in. diam.

Uses. Pressure vessels, valves, flanges, and fittings.

[1]Includes bars, headed bolts, screws, studs and stud bolts.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2 in. %	Red Area %	Hard BHN[1]
Grade BO	100 min	75 min	16 min	45min	200-260

[1]When used.

Note: See specification for details and modifications.

A 237-49T

Chemical Composition

	P %	S %
Ladle[1]	0.050 max	0.050 max

[1] See specification for check variations.

Characteristics. This is an open-hearth or electric-furnace heat-treated alloy steel in various classes. See specification for heat treatments.

Uses. Forgings for general industrial use.

Mechanical Properties

Form or Condition	Class	Diam or Thickness	Bored Wall Thickness	Tensile Strength M psi	Yield Point M psi	Elong 2 in % min	Red Area % min
Annealed, Normalized or Normalized and Tempered	A	< 12 in	–	80 min	50 min	24	40
		> 12 in < 20 in	–	80 min	50 min	22	38
Normalized and Tempered	B	< 7 in	< 4 in	80 min	55 min	26	52
		> 7 in < 20 in	> 4 in < 7½ in	80 min	55 min	24	50
	C	< 7 in	< 4 in	90 min	60 min	22	44
		> 7 in < 20 in	> 4 in < 7½ in	90 min	58 min	21	42
Normalized Quenched and Tempered	D	< 7 in	< 3½ in	95 min	70 min	20	50
		> 7 in < 10 in	> 3½ in < 5 in	90 min	65 min	20	50
	E	< 7 in	< 3½ in	105 min	80 min	20	50
		> 7 in < 10 in	> 3½ in < 5 in	100 min	75 min	19	50
		> 10 in < 20 in	> 5 in < 8 in	95 min	70 min	19	50
	F	< 4 in	< 2 in	125 min	105 min	16	50
		> 4 in < 7 in	> 2 in < 3½ in	115 min	95 min	16	45
		> 7 in < 10 in	> 3½ in < 5 in	110 min	85 min	16	45
	G	< 4 in	< 2 in	145 min	120 min	15	45
		> 4 in < 7 in	> 2 in < 3½ in	140 min	115 min	14	40
		> 7 in < 10 in	> 3½ in < 5 in	135 min	110 min	13	40
	H	< 4 in	< 2 in	170 min	140 min	13	40
		> 4 in < 7 in	> 2 in < 3½ in	165 min	135 min	12	35
		> 7 in < 10 in	> 3½ in < 5 in	160 min	130 min	11	35

Note See specification for details and modifications

A 242-50T

Chemical Composition[2]

	C %	Mn %	S %
Ladle[1]	0.20 max	1.25 max	0.05 max

[1] See ASTM Spec. for check analysis.
[2] Manufacturer shall use such alloying elements combined with C, Mn and S within limits above specified as will give mechanical properties described below and such that the atmospheric corrosion resistance of this steel will be materially increased.

Characteristics. This is an open-hearth or electric-furnace low-alloy structural steel for welded or riveted construction, 3/16 to 2 in. thick.

Uses. Primarily for use as stress-carrying material of structural members where saving in weight and atmospheric corrosion resistance are important.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2 in. %	Elong 8 in. %	Ratio[1]
3/16 to 3/4 in. incl.	70 min	50 min	–	18 min	–
> 3/4 to 1½ in. incl.	66 min	45 min	–	19 min	–
> 1½ to 2 in. incl.	63 min	40 min	22 min	20 min	–
For material > 3/4 in. deduct from 8 in. min for each 1/32 in. above 3/4 in. to min 18%	–	–	–	0.125	–
For material < 5/16 in. deduct from 8 in. min for each 1/32 in. below 5/16 in.	–	–	–	2.00	–
Bend Test: thru 180 deg — 3/16 to 3/4 in. incl.	–	–	–	–	1
Bend Test: thru 180 deg — > 3/4 to 1 in. incl.	–	–	–	–	1½
Bend Test: thru 180 deg — > 1 to 1½ in. incl.	–	–	–	–	2
Bend Test: thru 180 deg — > 1½ to 2 in. incl.	–	–	–	–	2½

[1] Bend diam/specimen thickness.
Note: See specification for details and modifications.

A 238-49T

Characteristics. This is an open-hearth or electric-furnace heat-treated alloy steel in various classes. See specification for heat treatments.

Uses. Forgings for use in locomotive and car construction· for ·shafts, driving axles, engine truck axles, trailing truck axles, crankpins, main and side rods, piston rods, valve stems, rod straps, eccentric cranks, etc.

Chemical Composition

	P[2] %	S[2] %
Ladle[1]	0.045 max	0.050 max

[1]For check variations, see ASTM Spec.
[2]Limits for other elements shall be agreed upon by manufacturer and purchaser. Purchaser may specify that residual alloy elements, not intentionally added, shall not exceed 0.35% Cu, 0.25 % Ni, 0.20 % Cr, and 0.06% Mo.

Mechanical Properties

Form or Condition		Diam or Thickness of Forgings	Bored Wall Thickness	Tensile Strength M psi	Yield Point M psi	Elong 2 in % min	Red Area % min
Normalized	A	< 8 in	≤ 4 in	80 min	55 min	28	60
		> 8 in < 20 in	> 4 in – 8 in incl	80 min	55 min	28	55
		< 5 in	≤ 2½ incl	90 min	60 min	24	48
and	B	> 5 in < 9 in	> 2½ in – 4½ in incl	90 min	60 min	22	44
		> 9 in < 13 in	> 4½ in – 6½ in incl	90 min	58 min	21	42
Tempered		> 13 in < 20 in	> 6½ in – 8 in incl	88 min	56 min	20	40
		< 5 in	≤ 2½ in	95 min	72 min	23	55
	C	> 5 in < 9 in	> 2½ in – 4½ in incl	95 min	70 min	22	53
		> 9 in < 13 in	> 4½ in – 6½ in incl	93 min	67 min	22	50
		> 13 in < 20 in	> 6½ in – 8 in incl	91 min	65 min	21	48
		< 7 in	≤ 3½ in incl	95 min	70 min	23	54
Normalized,	D	> 7 in < 10 in	> 3½ in – 5 in incl	90 min	65 min	20	50
		–	> 5 in – 8 in incl	85 min	60 min	20	50
Quenched,		< 7 in	≤ 3½ in incl	105 min	80 min	20	50
and	F	> 7 in < 10 in	> 3½ in – 5 in incl	100 min	75 min	19	50
		–	> 5 in – 8 in incl	95 min	70 min	19	50
Tempered		< 4 in	≤ 2 in	125 min	105 min	16	50
	F	> 4 in < 7 in	> 2 in – 3½ in incl	115 min	95 min	16	45
		> 7 in < 10 in	> 3½ in – 5 in incl	110 min	85 min	16	45

Note See specification for details and modifications.

Chemical Composition

Type No.	Grade	C[1] %	Mn %	P %	S %	Si %	Ni %
410 modified	A	0.12 max	0.60 max	0.030 max	0.030 max	0.75	0.60 max
	B	0.12 max	1.00 max	0.030 max	0.030 max	0.75	0.60 max
347 modified	C	0.08 max	2.50 max	0.035 max	0.030 max	0.85	9.50 min
430 modified	D	0.12 max	1.00 max	0.030 max	0.030 max	0.75	0.60 max
316 modified	M	0.08 max	2.50 max	0.035 max	0.030 max	0.85	10.00 min
405 modified	O	0.08 max	1.00 max	0.040 max	0.040 max	1.00	0.60 max
304 modified	S	0.08 max	2.50 max	0.035 max	0.030 max	0.85	8.00 min
321 modified	T	0.08 max	2.50 max	0.035 max	0.030 max	0.85	9.00 min

Type No.	Grade	Cr %	Al %	Mo %	Ti %	Cb %
410 modified	A	12.00-14.00	–	–	–	–
	B	14.00-16.00	–	–	–	–
347 modified	C	17.00 min	–	–	–	> 10XC content[2] 1.00
430 modified	D	16.00-18.00	–	–	–	–
316 modified	M	17.00 min	–	2.0 min	–	–
405 modified	O	11.50-13.50	0.10-0.30	–	–	–
304 modified	S	18.00 min	–	–	–	–
321 modified	T	17.00 min	–	–	> 5XC content < 0.60	–

[1] C analysis shall be reported to nearest one hundredth of one per cent.
[2] Emergency provisions allow stabilizing addition to consist of columbium plus tantalum. Ratio and quantity depends on end use and shall be agreed upon by manufacturer and purchaser.

Characteristics. This is an electric-arc or electric-induction soft corrosion-resisting Cr and Cr-Ni steel in plate, sheet and strip[1].

Uses. For fusion-welded unfired pressure vessels.

[1] See specification for definitions and heat treatment.

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi	Elong 2 in %	Rockwell - B Hardness	Hardness BHN	Cold[1] Bend Degree
Grade *	Type No.	min	min	min	max	max	
A	410	65	30	22.0[2]	88	202	180
B	–	70	35	22.0	88	202	180
C	347	75	30	30.0	88	202	180
D	430 modified	70	35	22.0	88	202	180
M	316	75	30	30.0	95	217	180
O	405	60	25	25.0	88	202	180
S	304	75	30	30.0	88	202	180
T	321	75	30	30.0	98	202	180

[1] Material $\leq \frac{3}{8}$ in. shall be bent around a pin = to diam of material.
Material $> \frac{3}{8}$ in. shall be bent around a pin = to 2X diam of specimen.
[2] Material < 0.050 in (U.S. gage No. 18 and under) min. Elongation of 20.0%.
Note See Specification for details and modifications.

STEELS, ASTM

A 245-48T

Characteristics. This is an open-hearth or acid-bessemer flat hot-rolled C sheet steel. It may be spot welded in the "hot-rolled" condition but for best results the oxide or scale should be removed before welding.

Uses. Intended for structural purposes where mechanical test values are required.

Chemical Composition

	C %	P %	S %	Cu[2] %
Open-hearth	0.25 max[1]	0.04 max	0.05 max	0.20 min
Acid-Bessemer	0.10 max	0.11 max	0.06 max	0.20 min

[1] As C increases above 0.15% spot welding becomes increasingly difficult.
[2] When specified.

Mechanical Properties

Form or Condition Grades	thickness	Tensile Strength M psi min	Yield Point M psi min	Elong 2 in % min	Elong 8 in % min	Bend Test at room temp
Commercial		Subject to Bend Test only				flat on itself
A	0.2299-0.1450 in incl	48	25	27.0	20.0	flat on itself
	0.1449-0.0890 in incl	48	25	24.5	18.0	flat on itself
	0.0889-0.0610 in incl	48	25	23.0	–	flat on itself
	0.0609-0.0449 in incl	48	25	21.0	–	flat on itself
B	0.2299-0.1450 in incl	52	30	25.0	18.5	180 deg[1]
	0.1449-0.0890 in incl	52	30	23.0	17.0	180 deg[1]
	0.0889-0.0610 in incl	52	30	21.5	–	180 deg[1]
	0.0609-0.0449 in incl	52	30	20.0	–	180 deg[1]
C	0.2299-0.1450 in incl	55	33	23.5	17.5	180 deg[2]
	0.1449-0.0890 in incl	55	33	21.5	15.5	180 deg[2]
	0.0889-0.0610 in incl	55	33	20.0	–	180 deg[2]
	0.0609-0.0449 in incl	55	33	18.5	–	180 deg[2]

[1] Around one thickness of the material.
[2] Around 1½ thickness of the material.
Note See specification for details and modifications.

STEELS, ASTM

A 249-51T

Characteristics. This is an electric-furnace welded austenitic steel. Tubes shall be made from strip steel by welding and heat treated as specified.

Uses. Alloy steel boiler, superheater, heat exchanger and condenser tubes.

Chemical Composition

Grade –	TP	C %	Mn %	P[1] %	S %	Ni %
Cr-Ni	304	0.08 max	2.00 max	0.030 max	0.030 max	8.0-11.0
Cr-Ni	310	0.15 max	2.00 max	0.030 max	0.030 max	19.0-22.0
Cr-Ni-Mo	316	0.08 max	2.00 max	0.030 max	0.030 max	11.0-14.0
Cr-Ni-Mo	317	0.08 max	2.00 max	0.030 max	0.030 max	11.0-14.0
Cr-Ni-Ti	321	0.08 max	2.00 max	0.030 max	0.030 max	9.0-13.0
Cr-Ni-Cb	347	0.08 max	2.00 max	0.030 max	0.030 max	9.0-13.0

Grade –	TP	Si %	Cr %	Mo %	Ti %	Cb %
Cr-Ni	304	0.75 max	18.0-20.0	–	–	–
Cr-Ni	310	0.75 max	24.0-26.0	–	–	–
Cr-Ni-Mo	316	0.75 max	16.0-18.0	2.00-3.00	–	–
Cr-Ni-Mo	317	0.75 max	18.0-20.0	3.00-4.00	–	–
Cr-Ni-Ti	321	0.75 max	17.0-20.0	–	5C min-0.60 max	–
Cr-Ni-Cb	347	0.75 max	17.0-20.0	–	–	10C min-1.00 max

[1] Emergency alternate provisions allow 0.045% P max for check analysis for all grades.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2" %	Hard BHN	Rock Hard
	75 min	30 min	35 min	190 max[1]	B90 max[2]
For longitudinal strip tests deduct for each 1/32 in. decrease in wall thickness below 5/16 in. from basic minimum the following percentage	–	–	1.75	–	–

[1] Tubes $\geq$ 0.200 in. wall thickness
[2] Tubes 0.065 in. to but not including 0.200 in. wall thickness
NOTE: See specification for details and modifications

STEELS, ASTM

A 250-51T

Chemical Composition

		C %	Mn %	P %	S %
T1	Ladle[1]	0.11-0.19	0.33-0.77	0.040 max	0.040 max
T1a	Ladle[1]	0.16-0.24	0.33-0.77	0.040 max	0.040 max
T1b	Ladle[1]	0.13 max	0.33-0.77	0.040 max	0.040 max

		Si %	Mo %
T1	Ladle[1]	0.15-0.45	0.48-0.63
T1a	Ladle[1]	0.15-0.45	0.48-0.63
T1b	Ladle[1]	0.15-0.45	0.48-0.63

[1]For check analysis, see ASTM Specs.

Characteristics. This is an open-hearth or electric-furnace killed steel with three grades. Tubes shall be made from strip by electric-resistance welding and shall be normalized above critical temperature.

Uses. Carbon-molybdenum alloy-steel boiler and superheater tubes.

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Point M psi	Elong 2" %	Hard[1] BHN	Rock Hard[2]
Grade	T1	55 min	30 min	30 min	137 max	B77 max
	T1a	60 min	32 min	30 min	143 max	B79 max
	T1b	53 min	28 min	30 min	137 max	B77 max

[1]Tubes $\geq$ 0.200 in wall thickness [2]Tubes < 0.200 in. wall thickness
NOTE· See specification for details and modifications.

STEELS, ASTM

A 253-51T

Chemical Composition

	C %	Mn %	P %
Open-hearth, Type A[1]	0.05 max	0.35 max	0.02 max
Alloyed, Open-hearth, Type B[2]	0.05 max	–	0.015 max

	S %	Cu %	Mo %
Open-hearth, Type A[1]	0.045 max	–	–
Alloyed, Open-hearth, Type B[2]	0.040 max	0.40 min	0.05 min

[1]An alternate open hearth Type A Iron may contain 0.20% Cu, min.
[2]Total C, Mn, P, S, and Si 0.25% max. A variation in combined percentages will be permitted but shall not exceed 0.31%.

Characteristics. This is an open-hearth, black and galvanized, iron pipe. It may be seamless, furnace butt-welded or electric-resistance welded and is of nominal wall thickness.

Uses. For coiling, bending, flanging and other special purposes; pipe 2 in. and under may be used for close coiling. Furnace butt-welded pipe is not intended for flanging.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2" %	Ratio[2]
Type A and Alternate Type A	40 min	25 min	–	–
Type B	46 min	30 min	–	–
Standard round[1]	–	–	28	–
For walls 5/16 in. and over in thickness, longitudinal strip tests; all small sizes tested in full section (basic minimum)[1]	–	–	35	–
For longitudinal strip test deduct for each 1/32-in decrease in wall thickness below 5/16 in from basic minimum the following percentage[1]	–	–	1.75	–
Bend Test: pipe $\leq$ 2 in				
90 deg around mandrel	–	–	–	12
180 deg for close coiling	–	–	–	8

[1]For all types
[2]Mandrel diam/nom.diam pipe
NOTE See specification for details and modifications.

STEELS, ASTM

A 254-51T

Characteristics. This is an open-hearth or electric furnace copper brazed steel tubing 3/16 in. and over o.d. There are two general classes: I double wall 360 deg and II single wall.

Uses. For general engineering uses, particularly in automobile, refrigerator and stove industries, for fuel lines, brake lines, oil lines, heating and cooling units, etc.

Chemical Composition

	C %	Mn %	P %	S %
Ladle[1]	0.07-0.12	0.30-0.60	0.040 max	0.050 max

[1] For check analysis, see ASTM Specs.

Mechanical Properties

Form or Condition	Tensile[1] Strength M psi	Yield Point M psi	Elong 2" %	Hard, Rock[2] BHN
	42 min	28 min	29 min	55 max

[1] See ASTM. E8
[2] See ASTM· E18

STEELS, ASTM

A 264-44T

Characteristics. This is an open-hearth or electric-furnace C or low-alloy steel base in plate, sheet and strip[1] to which is integrally and continuously bonded on one or both sides a layer of corrosion-resisting Cr—Ni steel. This material is single or double-clad. See specification for physical properties.

[1] See specification for definition.

Chemical Composition

	Grades		C %	Mn %	P %	S %	Ni %
Alloy Cladding Metal[1]	301	1	0.08-0.20	2.00 max	0.035 max	0.030 max	6.00-8.00
	302	2	0.08-0.20	2.00 max	0.035 max	0.030 max	8.00-10.00
	304 modified	3	0.08 max[2]	2.50 max	0.035 max	0.030 max	8.00 min
	308	4	0.08 max	2.00 max	0.035 max	0.030 max	10.00-12.00
	321 modified	5	0.08 max[2]	2.50 max	0.035 max	0.030 max	9.00 min
	347 modified	6	0.08 max[2]	2.50 max	0.035 max	0.030 max	9.50 min
	309	8	0.20 max	2.00 max	0.035 max	0.030 max	12.00-15.00
	310	10	0.25 max	2.00 max	0.035 max	0.030 max	19.00-22.00
	316 modified	11	0.08 max[2]	2.50 max	0.035 max	0.030 max	10.00 min

	Grades		Si %	Cr %	Mo %	Ti %	Cb %
Alloy Cladding Metal[1]	301	1	1.00 max	16.00-18.00	–	–	–
	302	2	1.00 max	17.00-19.00	–	–	–
	304 modified	3	0.85 max	18.00 min	–	–	–
	308	4	1.00 max	19.00-21.00	–	–	–
	321 modified	5	0.85 max	17.00 min	–	> 5 × C content < 0.60%	–
	347 modified	6	0.85 max	17.00 min	–	–	> 10 × C content < 1.00%
	309	8	3.50 max	22.00-24.00	–	–	–
	310	10	2.00 max	24.00-26.00	–	–	–
	316 modified	11	0.85 max	17.00 min	2.00 min	–	–

[1] Base metal shall conform to ASTM specifications for flange quality or better.
[2] C analysis shall be reported to nearest hundredth of one per cent.

STEELS, ASTM

A 265-43T

Chemical Composition

		C %	Mn %	S %	Ni %	Cu %
Cladding Metal[1]	Nickel	0.20 max	0.35 max	0.02 max	99.00 min	0.25 max
	Ni-Cu-Alloy	0.30 max	2.00 max	0.02 max	63.00-70.00	remainder
	Ni-Cr-Fe Alloy	0.15 max	1.00 max	0.02 max	75.00 min	0.50 max

		Si %	Cr %	Fe %	Al %
Cladding Metal[1]	Nickel	0.50 max	–	0.50 max	–
	Ni-Cu-Alloy	0.50 max	–	2.50 max	0.50 max
	Ni-Cr-Fe Alloy	0.50 max	12.00-15.00	9.00 max	–

[1] Base metal shall conform to ASTM Specifications of flange quality or better.

Characteristics. This is an open-hearth or electric-furnace C or low-alloy plate steel base to which is integrally and continuously bonded on one or both sides a layer of Ni or Ni-base alloy. It is single or double-clad and plate is ≥ 3/16 in. thick. See specification for physical properties

STEELS, ASTM

A 266-51T

Chemical Composition[3]

	C %	Mn %	P[1] %	P[2] %
Class I and II	0.35	0.40-0.90	0.050 max	0.040 max
Class III	0.50	0.50-0.90	0.050 max	0.040 max

	S %	Si %
Class I and II	0.040 max	0.15-0.35
Class III	0.040 max	0.35 max

[1]Acid steel
[2]Base steel
[3]For check analysis, See ASTM Spec.

Characteristics.[1] This is an open-hearth or electric furnace carbon steel for drum forgings made in three classes of tensile strength.

[1]When semi-finished steel is desired to process these forgings, A273-49 is recommended.

Uses. Hollow drums and headers for use in boilers and other pressure vessels and also for forgings for heads, covers, plugs and other component parts. Class I and II[1] are suitable for fusion welding. Class III is not to be used when it will in any way be subjected to fusion welding.

[1]The term class is used to distinguish between materials of different tensile strengths.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2 in.[1] %	Elong 2 in.[2] %	Red Area %[1]	Red Area %[2]	Ratio[3]
Class I	60 min	30 min	26 min	23 min	42 min	38 min	–
II	70 min	35 min	25 min	20 min	38 min	33 min	–
III	75 min	37.5 min	24 min	19 min	38 min	30 min	–
Bend Test: 180 deg							
Class I	–	–	–	–	–	–	1
II	–	–	–	–	–	–	1¼
III	–	–	–	–	–	–	1½

[1]Longitudinal
[2]Transverse
[3]Inside diam, in.
NOTE: See specification for details and modifications.

STEELS, ASTM

A 268-47

Characteristics. This is an electric-furnace stainless steel tubing in six grades. These are commonly known as "straight-chromium" types and are characterized by being ferromagnetic. The high-Cr, ferritic alloys are sensitive to notch-brittleness on slow cooling to ordinary temperatures. Purchaser shall specify o.d. and average wall thickness. Inside diam shall not be specified.

Uses. Tubing for general corrosion-resisting and high-temperature service.

Chemical Composition

	C %	Mn %	P[1] %	S %	Ni %	Cu %
TP 405	0.08 max	1.00 max	0.030 max	0.030 max	0.50 max	–
410	0.15 max	1.00 max	0.030 max	0.030 max	0.50 max	–
430	0.12 max	1.00 max	0.030 max	0.030 max	0.50 max	–
443	0.20 max	1.00 max	0.030 max	0.030 max	0.50 max	0.90-1.25
446	0.20 max	1.50 max	0.030 max	0.030 max	0.50 max	–
329	0.20 max	1.00 max	0.030 max	0.030 max	2.50-5.00	–

	Si %	Cr %	Mo %	Al %	N %
TP 405	0.75 max	11.5-13.5	–	0.10-0.30	–
410	0.75 max	11.5-13.5	–	–	–
430	0.75 max	14.0-18.0	–	–	–
443	0.75 max	18.0-23.0	–	–	–
446	0.75 max	23.0-30.0	–	–	0.10-0.25
329	0.75 max	23.0-28.0	1.0-2.0	–	–

[1]Emergency alternate provisions allow 0.040% max.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[4] Point M psi	Elong[1] 2 in %	Rock B[6] Hard	Hard[5] BHN
TP 405	60 min	30 min	20 min	95 max	207 max
410[3]	60 min	30 min	20 min	95 max	207 max
430	60 min	35 min	20 min	90 max	190 max
443	70 min	40 min	20 min	95 max	207 max
446	70 min	40 min	18 min	95 max	207 max
329[3]	75 min	45 min	10 min[2]	100 max	241 max

[1]For longitudinal strip tests a deduction of 1% from basic minimum elongation for each $\frac{1}{32}$ in. decrease in wall thickness below $\frac{5}{16}$ in shall be permitted

[2]Minimum elongation in no case shall be $<$5%.

[3]Amenable to hardening by heat treatment.

[4]When definite yield point is not exhibited, 0.2% permanent offset method shall be used.

[5]For tubes $\geq$ 0.200 in.

[6]For tubes $<$ 0.200 in. to 0.065 in incl. Hardness tests shall not be required on tubes $<$ 0.065 in.

Note See specification for details and modifications

STEELS, ASTM

A 269-47

Chemical Composition

Grade	Ident. Symbol	C %	Mn %	P[1] %	S %	Ni %
Cr-Ni	TP 304	0.08 max	2.00 max	0.030 max	0.030 max	8.0-11.0
Cr-Ni-Ti	TP 321	0.08 max	2.00 max	0.030 max	0.030 max	9.0-13.0
Cr-Ni-Cb	TP 347	0.08 max	2.00 max	0.030 max	0.030 max	9.0-13.0
Cr-Ni-Mo	TP 316	0.08 max	2.00 max	0.030 max	0.030 max	11.0-14.0
Cr-Ni-Mo	TP 317	0.08 max	2.00 max	0.030 max	0.030 max	11.0-14.0

Grade	Ident. Symbol	Si %	Cr %	Mo %	Ti %	Cb %
Cr-Ni	TP 304	0.75 max	18.0-20.0	–	–	–
Cr-Ni-Ti	TP 321	0.75 max	17.0-20.0	–	$> 5 \times$ C content; $<$ 0.60%	–
Cr-Ni-Cb	TP 347	0.75 max	17.0-20.0	–	–	$> 10 \times$ C content; $<$ 1.00%
Cr-Ni-Mo	TP 316	0.75 max	16.0-18.0	2.0-3.0	–	–
Cr-Ni-Mo	TP 317	0.75 max	18.0-20.0	3.0-4.0	–	–

[1]Emergency alternate provisions allow 0.040% max.

Mechanical Properties

Hardness Test:
Tubes shall have a Brinell hardness number not to exceed 200 or a Rockwell hardness number not to exceed B90. Brinell hardness test shall be used on tubes $\geq$ 0.200 in. Rockwell hardness test shall be used for tubes $<$ 0.200 to and including 0.065 in. Hardness tests shall not be required on tubes $<$ 0.065 in.

Note See specification for details and modifications.

Characteristics. This is an electric-furnace stainless steel tubing in five grades. Purchaser shall specify grade, o.d. and average wall thickness. Inside diam shall not be specified. See specification for details of heat treatment.

Uses. For corrosion-resisting and high-temperature service.

STEELS, ASTM

A 270-50T

Chemical Composition

Grade	Ident. Symbol	C %	Mn %	P[1] %	S %
Cr-Ni	304	0.08 max	2.00 max	0.030 max	0.030 max

Grade	Ident. Symbol	Ni %	Si %	Cr %
Cr-Ni	304	8.0-11.0	0.75 max	18.0-20.0

[1]Emergency alternate provisions allow 0.040% max

Characteristics. This is an electric-furnace seamless and welded austenitic stainless steel sanitary tubing in sizes up to and including 4 in. o.d. These tubes are furnished with special surface finishes, order, therefore, should specify finish, o.d. and average wall thickness. The inside diam shall not be specified.

Uses. Dairy and food industry.

STEELS, ASTM

A 271-47

Chemical Composition

	C %	Mn %	P[1] %	S %	Ni %
TP 304	0.08 max	2.00 max	0.030 max	0.030 max	8.0-11.0
TP 321	0.08 max	2.00 max	0.030 max	0.030 max	9.0-13.0
TP 347	0.08 max	2.00 max	0.030 max	0.030 max	9.0-13.0

	Si %	Cr %	Ti %	Cb %
TP 304	0.75 max	18.0-20.0	–	–
TP 321	0.75 max	17.0-20.0	{> 5 × C content {< 0.60%	–
TP 347	0.75 max	17.0-20.0	–	{> 10 × C content[2] {< 1.0%

[1]Emergency alternate provisions allow 0.040% max.
[2]Emergency alternate provisions allow that stabilizing addition to consist of columbium plus tantalum.

Mechanical Properties

Tensile Strength M psi	Yield[2] Point M psi	Elong[1] 2 in. %	Hard BHN
75 min	30 min	35 min	200 max

[1]For longitudinal strip tests a deduction of 1.75% from basic minimum elongation for each 1/32 in. decrease in wall thickness below 5/16 in. in wall thickness shall be used.
[2]When definite Yield Point is not exhibited, the yield strength corresponding to a limited permanent offset of 0.2% shall be reported.

Note See specification for details and modifications.

Characteristics. This is an electric-furnace seamless austenitic Cr–Ni steel still tubing in three grades from 2–7½ in. o.d. and > 0.220 in. min. wall thickness. Purchaser shall specify grade, o.d. and minimum wall thickness, inside diam shall not be specified.

Uses. For carrying fluids at elevated temperatures and pressures in various types of heaters in which the tubes may be subjected to a furnace temperature higher than that of the contained fluid.

A 276-49T

Chemical Composition

Type No.	C %	Mn %	P %	S %	Ni %	Si %
302	>0.08-0.20	2.00 max	0.040 max	0.030 max	8.00-10.00	1.00 max
303	0.15 max	2.00 max	–	–	8.00-10.00	1.00 max
304	0.08 max	2.00 max	0.040 max	0.030 max	8.00-11.00	1.00 max
316	0.10 max	2.00 max	0.040 max	0.030 max	10.00-14.00	1.00 max
321	0.08 max	2.00 max	0.040 max	0.030 max	8.00-11.00	1.00 max
347	0.08 max	2.00 max	0.040 max	0.030 max	9.00-12.00	1.00 max
410	0.15 max	1.00 max	0.040 max	0.030 max	–	1.00 max
416	0.15 max	1.25 max	–	–	–	1.00 max
420	>0.15 max	1.00 max	0.040 max	0.030 max	–	1.00 max
430	0.12 max	1.00 max	0.040 max	0.030 max	–	1.00 max
440	0.60-0.75 Grade 1 0.75-0.95 Grade 2 0.95-1.20 Grade 3	1.00 max	0.040 max	0.030 max	–	1.00 max

Type No.	Cr %	Other Elements
302	17.00-19.00	–
303	17.00-19.00	P, S, Se min 0.07%, Zr, Mo, max 0.60%
304	18.00-20.00	–
316	16.00-18.00	Mo, 2.00 - 3.00%
321	17.00-19.00	Ti, 5 x C content, min
347	17.00-19.00	Cb, 10 x C content, min[2]
410	11.50-13.50	–
416	12.00-14.00	P, S, Se min 0.07%, Zr, Mo, max 0.60%
420	12.00-14.00	–
430	14.00-18.00[1]	–
440	16.00-18.00	Mo 0.75% max

[1] Unless otherwise specified, TP 430 will be furnished with 16.00-18.00% Cr.
[2] Emergency alternate provisions allow that the stabilizing addition consist of columbium plus tantalum. Ratio and max. shall be according to end use.

Characteristics. This is a hot-rolled and cold-finished corrosion-resisting bar steel furnished in rounds, squares and shapes, ground and ground-and-polished rounds.

Mechanical Properties

Type	Form or Condition	Diam or Thickness in	Tensile Strength M psi min	Yield Strength 0.2% offset	Elong % 4X diam min	Red Area % min	Rockwell Hardness Case min	Hardness BHN max
302, 303, 304, 316, 321, 347	Annealed	All sizes	75	30	35	50	–	–
410, 416, 430	Annealed	All sizes	70	40	22	50	–	202
420	Annealed	All sizes	–	–	–	–	C45[1]	220[1]
440	Annealed	All sizes	–	–	–	–	C50[1]	260[1]
302	Cold Finished	≤ 3/4 in	125	100	12	35	–	–
303	Cold Finished	> 3/4 in-1 in incl	115	80	15	35	–	–
304	Cold Finished	> 1 in-1 1/4 in incl	105	65	20	35	–	–
316	Cold Finished	> 1 1/4 in-1 1/2 in incl	100	50	28	45	–	–
321	Cold Finished	> 1 1/2 in-3 in incl	95	45	28	45	–	–
347	Cold Finished	> 3 in	80	35	28	45	–	–
410, 416	Heat-Treated	All sizes	120	90	13	45	–	302
410, 416, 430	Cold-finished	All sizes	70	40	16	45	–	–

[1] Types 420 & 440 shall be used only in the fully heated condition, in which case they shall have above Rock C hardness.
Note See specification for details and modifications.

A 277-44T

Characteristics. This is a malleable iron. See specification for details and modifications.

Uses. Iron flanges, pipe fittings, and valve parts, including parts to be assembled, manufactured in advance and supplied from stock.

A 278-51T

Chemical Composition[2]

Class	C[1] %	P %	S %
40	3.8	0.25 max	0.12 max
50	3.8	0.25 max	0.12 max
60	3.8	0.25 max	0.12 max

[1] Maximum carbon content equivalent calculated as Total carbon & 0.3 (Silicon & Phosphorus)

[2] It is the intent of these specifications to subordinate chemical composition to mechanical properties

Mechanical Properties

Form or Condition	Tensile Strength M psi
Class No. 20	20
Class No. 25	25
Class No. 30	30
Class No. 35	35
Class No. 40	40
Class No. 50	50
Class No. 60	60

Characteristics. This is a gray-iron for castings suitable for pressure-containing parts for use at temperatures up to 650F. Castings intended for use above 450F shall be stress relief annealed, only classes 40, 50 and 60 shall be used at that temperature. Alloys may be used to facilitate the development of mechanical properties, or stabilize the structure at elevated temperatures.

A 280-51T

Chemical Composition

	C %	Mn %	P %	S %
Ladle[2]	0.11-0.19	0.33-0.58	0.040 max	0.040 max
	Si %	**Cr %**	**Mo %**	
Ladle[2]	0.12-0.28	0.53-0.78	0.48-0.63	

[2] For check analysis, see ASTM Specs.

Mechanical Properties

Form or Condition	Tensile[2] Strength M psi	Yield Point M psi	Elong 2" %	
Standard round	55 min	30 min	22 min[1]	14 min[2]
Walls, 5/16 in. and over in thickness, strip tests, all small sizes tested in full Section (basic minimum)	55 min	30 min	30[1]	20[1]
For strip tests deduct for each 1/32-in. decrease in wall thickness below 5/16 in. from the basic minimum, the following percentage	–	–	1.50[1]	1.00[2]

NOTE See specification for details and deviations.
[1] Longitudinal
[2] Transverse
[3] ASTM E8

Characteristics. This is an open-hearth or electric-furnace, seamless, alloy-steel pipe intended for service at high temperatures and suitable for bending, flanging and similar forming operations, and for fusion welding. This chromium-molybdenum alloy is a course-grained steel having a carburized austenitic grain size of 1 to 5 as determined[1] by carburizing at 1700F for 8 hr.

[1] ASTM. E 19.

A 283-50T

Characteristics. This is an open hearth or electric-furnace steel which is supplied in four grades of low to intermediate strength for structural plates 2 in. and under in thickness.

Chemical Composition

C[1] %	Mn[2] %	P[3] %	S %	Cu %
.10 to over .30	.30-.50	.06[4]	.05 max	.20 min[6]
–	–	.04[5]	–	–

[1]Not specified but is adjusted to give the required properties.
[2]Same as C.
[3]The maximum allowable phosphorus (heat analysis).
[4]Acid open hearth or electric furnace.
[5]Basic open hearth or electric furnace
[6]When specified.

Mechanical Properties

Form or Condition	Grade	Tensile Strength Min M psi	Yield Point Min psi	Elong[7] 8" min %	Elong 2" min %	Ratio[6]
Grade A		45-55	.5TS[1]	27	30	–
B		50-60	.5TS[2]	25	27	–
C		55-65	.5TS[3]	23	24	–
D		60-72[8]	.5TS[4]	21	22	–
Bend Test[5]-thru 180 deg. Thickness ≤ ¾ in.	A	–	–	–	–	flat on itself
	B	–	–	–	–	"
	C	–	–	–	–	"
	D	–	–	–	–	½
> ¾-1 in. incl.	A	–	–	–	–	flat on itself
	B	–	–	–	–	"
	C	–	–	–	–	½
	D	–	–	–	–	1
> 1-1½ in. incl.	A	–	–	–	–	½
	B	–	–	–	–	¾
	C	–	–	–	–	1
	D	–	–	–	–	1½
> 1½-2 in. incl.	A	–	–	–	–	1
	B	–	–	–	–	1½
	C	–	–	–	–	2
	D	–	–	–	–	2½

[1]But not less than 24M
[2]But not less than 27M
[3]But not less than 30M
[4]But not less than 33M
[5]Requirements for cold bending.
[6]Mandrel Diam to Plate Thickness.
NOTE See specification for details and modifications.

[7]For material > ¾ in deduct 0 25% for every increase of 1/32 in above ¾ in. to minimum of 20% for grade A, 19% for grade B, 18% for grades C and D. For material < 5/16 in. deduct 2 00% for every 1/32 in. below 5/16 in.
[8]May be increased by 3 M psi for material > 1½ in. thick.

A 284-51T

Chemical Composition

	C max% $\leq$1 in.	C max% >1-2 in. incl	C max% >2-4 in. incl	C max% >4-8 in. incl	C max% >8-12 in. incl
Grades A	0.20	0.22	0.25	0.29	0.32
B	0.22	0.25	0.28	0.32	0.35
C	0.25	0.28	0.32	0.36	0.38
D	0.29	0.32	0.35	0.38	–

	Mn % max	P % max	S % max	Si % max
Grades A[1]	0.90	0.04	0.05	0.10-0.30
B	0.90	0.04	0.05	0.15-0.30
C	0.90	0.04	0.05	0.15-0.30
D	0.90	0.04	0.05	0.15-0.30

[1]See Spec. for check analysis

Characteristics. This is an open-hearth or Electric-furnace C-Si plate steel made in four grades. Maximum thickness for grades A, B and C is 12 in., and for grade D, 8 in. Welding technique is of fundamental importance.

Plates over 4 in. thick are given a grain refining heat treatment (normalizing) to improve their uniformity and characteristics.

Uses. Machine parts and general construction (other than pressure vessels by gas cutting, welding, etc.

Mechanical Properties

	Tensile Strength M psi	Yield Point M psi	Elong 8 in.[1] %	Elong 2 in.[2] %
Grade A	50 min	25 min	25 min	27 min
B	55 min	27.5 min	23 min	24 min
C	60 min	30 min	21 min	22 min
D	60 min	33 min	21 min	22 min

Bend Test thru 180 deg — Ratio Inside Diameter / Thickness of Specimen

	Grade A	B	C	D
$\leq$¾ in.	flat on itself	flat on itself	½	½
>¾ - 1 in. incl	flat on itself	½	1	1
> 1 - 1½ in. incl	½	1	1½	1½
> 1½ - 2 in. incl	1	1½	2	2½
> 2 - 3 in. incl	1½	2	2½	3
> 3 - 4 in. incl	2	2½	3	3½
> 4 in.	2½	3	3⅛	4

[1]For material < 5/16 in. deduct 2.00% for each decrease of 1/32 in. below 5/16 in.
For material > 3/4 in. - 2½ in. incl. deduct 0.125% for each increase of 1/32 in. above ¾ in. to a minimum of 22% for Grade A, 20% for Grade B and 18% for Grades C and D.
[2]For Grade A material >2½ in., deduct 0.5% for each increase of ½ in. above 2½ in. to a minimum of 26%.

A 287-46T

Chemical Composition

	C %	Mn %	P %	S %	Si %
Ladle[1]	0.38 max	0.70-1.00	0.04 max	0.05 max	0.15-0.30

[1]For check variations, see ASTM Spec.

Characteristics. This is an open-hearth or electric-furnace normalized and tempered rolled C-steel. See specification for details of heat treatment.

Uses. Locomotive frames.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2 in. %	Red Area %
	70 min	35 min	25.0 min	45.0 min

Bend Test:
Thru 180 deg inside diam of bend = thickness of specimen.

Note See specification for details and modifications.

A 285-50T

Chemical Composition[5]

	C % max	Mn % max	P % max	S % max	Cu %
Flange					
Grade A	–	.80	.06[3]	.05	0 20-0.35
	–	–	.04[4]	–	–
Grade B	–	.80	.06[3]	.05	0.20-0.35
	–	–	.04[4]	–	–
Grade C	–	.80	.06[3]	.05	0.20-0 35
	–	–	.04[4]	–	–
Firebox					
Grade A	.15[1]	.80	.04[3]	.04	0.20-0.35
	.17[2]	–	.035[4]	–	–
Grade B	.20[1]	.80	.04[3]	.04	0 20-0.35
	.22[2]	–	.035[4]	–	–
Grade C	.25[1]	.80	.04[3]	.04	0 20-0.35
	.30[2]	–	.035[4]	–	–

[1] ≤ ¾ in
[2] > ¾-2 in.
[3] Acid steel
[4] Basic steel

[5] Required mechanical properties and current mill practice result in 0 35 max %. However, such determination is made only when specified.

Characteristics. This is an open hearth or electric furnace plate steel of low to intermediate tensile strength of flange and firebox qualities for stationary boilers and pressure vessels, in thicknesses up to 2 in.

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Point Min M psi	Elong[5] 8" min %	Elong 2" min %	Ratio[4]
Flange						
Grade A		45-55	.5TS[1]	1500 M + TS	1750 + TS	–
B		50-60	.5TS[2]	1500 M + TS	1750 + TS	–
C		55-65	.5TS[3]	1500 M + TS	1750 + TS	–
Firebox						
Grade A		45-55	.5TS[1]	1550 M + TS	1750 + TS	–
B		50-60	.5TS[2]	1550 M + TS	1750 + TS	–
C		55-65	.5TS[3]	1550 M + TS	1750 + TS	–
Bend Test - thru 180 deg						
Thickness ≤ 1 in.	Sheared, gas cut	–	–	–	–	1
	Univer. mill	–	–	–	–	1½
> 1-1½ in. incl.	Sheared, gas cut	–	–	–	–	1½
	Univer. mill	–	–	–	–	2½
> 1½-2 in. incl.	Sheared, gas cut	–	–	–	–	2
	Univer. mill	–	–	–	–	3

[1] But not under 24M
[2] But not under 27M
[3] But not under 30M
[4] Mandrel Diam to Plate Thickness
NOTE: See specification for details and deviations.

[5] For material >¾-2 in. incl., deduct 0 125% for every 1/32 in increase above ¾ in to 22% min for flange, 23% min for firebox, grades A and B., 21% min for flange, 22% min for firebox, grade C

A 288-50T

Characteristics. This is an open-hearth or electric-furnace annealed or normalized, quenched and tempered carbon and alloy forging steel. Purchaser shall specify grade of steel desired.[1] See specification for details of machining and heat treatment.

Uses. Magnetic retaining rings for turbine generators.

[1]When semi-finished steel is desired to process these forgings, A273 and A274 are recommended.

Chemical Composition

	P %	S %
Ladle[1]	0.050 max	0.050 max

[1]For check analysis, see ASTM Spec.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi 0.02% offset	Elong 2 in. %	Red. Area %
Class 1	70 min	45 min	18 min	40 min
2	90 min	65 min	20 min	50 min
3	110 min	80 min	18 min	45 min
4	120 min	95 min	16 min	40 min
5	130 min	110 min	16 min	40 min
6	140 min	125 min	14 min	35 min
7	150 min	135 min	13 min	35 min

Note See specification for details and modifications.

A 289-49T

Chemical Composition

Class		C %	Mn %	P %	S %	Ni %
Ladle[1]	A	0.25-0.40	10.50-12.50	0.050 max	0.050 max	7.00- 8.50
	B	0.50-0.75	5.00-10.00	0.050 max	0.060 max	6.00-10.00

Class		Si %	Cr %	V %	Mo %	W %
Ladle[1]	A	0.50 max	–	–	–	–
	B	0.70 max	3.50-6.00	0.20 max	0.60 max	0.60 max

[1]For check variations, see ASTM Spec.

Characteristics. This is an electric-furnace alloy forging steel. See specification for supplementary requirements. Purchaser shall specify class of steel desired.

Uses. Coil retaining rings for turbine generators. The finished rings shall be non-magnetic as determined by zero deflection of a compass needle as the compass is moved directly adjacent to and in and about the finished rings.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi 0.02% offset	Elong 2 in. %	Red Area %
Class A	90 min	65 min	20 min	35 min
B	120 min	95 min	15 min	20 min

Note. See specifications for details and modifications.

STEELS, ASTM

A 290-49T

Chemical Composition

Class		C %	Mn %	P %	S %	Si %
Ladle[1]	A	0.25-0.35	0.55-0.90	0.050 max	0.050 max	0.15 min
	B	0.30-0.40	0.55-0.90	0.050 max	0.050 max	0.15 min
	C	0.40-0.60	0.55-0.90	0.050 max	0.050 max	0.15 min

[1]For check variations, see ASTM Spec.

Mechanical Properties

Form or Condition	Hardness BHN
Forgings:	
Average	163-197
Maximum & Minimum Range	159-207
Permissible Range	< 30 numbers

Note: See specification for details and modifications.

Characteristics. This is an open-hearth or electric-furnace normalized and tempered, and quenched and tempered C forging steel, in three grades. When semi-finished steel is desired to process these forgings, ASTM A273 is recommended. See specification for heat treatment and welding procedures.

Uses. Rings for main reduction gears, also ring forgings for auxiliary drives.

STEELS, ASTM

A 291-49T

Chemical Composition

Class		C %	Mn %	P %	S %	Si %
Ladle[1]	1	0.40 min	0.55 min	0.050 max	0.050 max	0.15 min
	2	–	–	0.050 max	0.050 max	–

[1]For check variations, see ASTM Spec.

Characteristics. This is an open-hearth or electric-furnace normalized and tempered C or alloy forging steel. See specification for supplementary requirements and heat treatment.

Uses. Pinions for main reduction gears, also forgings for auxiliary drives.

Mechanical Properties

Class	Size, Solid Diam or Thickness	Tensile Strength M psi	Yield[1] Point M psi	Elong 2 in % Long	Elong 2 in % Trans	Red Area Long %	Red Area Trans %	Hardness BHN
1	< 7 in	85 min	50 min	20 min	–	39 min	–	170-223
1	> 7 in - 10 in incl	85 min	50 min	19 min	16 min	37 min	30 min	170-223
1	> 10 in	80 min	40 min	19 min	16 min	31 min	28 min	159-212
2	< 10 in	95 min	70 min	20 min	–	45 min	–	201-241
2	> 10 in - 20 in incl	95 min	70 min	20 min	18 min	45 min	30 min	201-241
2	> 20 in	95 min	70 min	18 min	16 min	35 min	28 min	201-241

[1]When definite yield point is not exhibited, 0.2% permanent offset method is used.
Note: See specification for details and modifications.

A 292-50T

Chemical Composition[2]

P[1] %	S[1] %
0.050 max	0.050 max

[1]Limits for other elements shall be agreed upon by manufacturer and purchaser.
[2]For check variations, see ASTM spec.

Characteristics. This is an open-hearth or electric-furnace heat treated carbon and alloy forging steel. Purchaser shall specify the class of steel desired.[1] When semi-finished steel is desired to process these forgings, it is recommended that A273 or A274 specifications be used.

Uses. Turbine generator rotors and shafts.

[1]See specification for supplementary requirements and details of heat treatment.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength 0.02% offset M psi	Elong 2 in.[1] %	Elong 2 in.[2] %	Red. Area %[1]	Red. Area %[2]
Class 1	60 min	25 min	25 min	18[3] min	45 min	30[3] min
2	75 min	35 min	22 min	18[3] min	40 min	30[3] min
3	80 min	45 min	20 min	16[3] min	35 min	28[3] min
4	85 min	55 min	20 min	15 min	35 min	27 min
5	90 min	65 min	18 min	14 min	35 min	26 min
6	95 min	75 min	17 min	13 min	32 min	25 min
7	105 min	85 min	16 min	12 min	30 min	23 min

[1]Longitudinal prolongation
[2]Radial body.
[3]When agreed upon by manufacturer and purchaser, these requirements may be reduced to 12% for elongation, and 22% for reduction of area for forgings under 30 in in body diam.
Note See specification for details and modifications

A 293-50T

Chemical Composition

	Class	C %	Mn %	P %	S %
Ladle[1]	1	0.50 max	1.00 max	0.050 max	0.050 max
	2-6	–	–	0.050 max	0.050 max

Class	Si %	V %	Mo %
1	0.15 min	See Suppl. Req. S4	See Suppl. Req. S5
2-6	–		

[1]For check analysis, see ASTM Spec

Characteristics. This is an open-hearth or electric-furnace heat-treated carbon and alloy forging steel. Purchaser shall specify grade of steel desired.[1] See specification for details of supplementary requirements and heat treatment.

Uses. Turbine rotors and shafts.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength 0.02% offset M psi	Elong. 2 in. min% Longitudinal Prolongation	Elong. Radial Body	Elong. Tangential Body >radius[1]	Elong. Tangential Body ≤radius[1]	Red Area min% Longitudinal Prolongation	Red Area Radial Body	Red Area Tangential Body >radius[1]	Red Area Tangential Body ≤radius[1]
Class 1	75 min	40 min[1]	22	18	20	18	40	30	35	30
2	75 min	40 min	22	18	20	18	40	30	35	30
3	85 min	55 min	22	18	20	18	40	30	35	30
4	90 min	65 min	21	18	18	16	45	35	35	30
5	100 min	70 min	20	18	18	16	40	35	35	30
6	105 min	80 min	20	16	18	16	40	30	35	30

[1]At ends of body
Note: See specification for details and modifications

STEELS, ASTM

A 294-50T

Characteristics. This is an open-hearth or electric-furnace treated carbon and alloy forging steel.[1] When semi-finished steel is desired to process these forgings, it is recommended that A273 and A274 specifications be used. Purchaser shall specify class of steel desired.

Uses. Turbine bucket wheels.

[1]See specification for supplementary requirements (addition of V and Mo) and details of heat treatment

Chemical Composition[2]

Classes	C %	Mn %	P %	S %	Si %
A1 & A2	0.50 max	1.00 max	0.050 max	0.050 max	0.15 min
B1 & B4	–	–	0.050 max[1]	0.050 max[1]	–

[1]The limits for elements may be agreed upon by manufacturer and purchaser.
[2]For check variation, see ASTM Spec.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength 0.02% offset M psi	Elong 2 in %	Red. Area %	Hard[1] BHN
Classes A1	70 min	40 min	20 min	50 min	131-183
A2	80 min	50 min	18 min	45 min	149-201
B1	100 min	70 min	20 min	50 min	192-241
B2	110 min	85 min	19 min	48 min	207-255
B3	120 min	105 min	18 min	45 min	229-277
B4	150 min	125 min	15 min	40 min	293-341

[1]Group tested
Note See specification for details and modifications.

STEELS, ASTM

A 295-46T

Chemical Composition

Type	C %	Mn %	P %	S %	Ni[1] %
A 52100	0.95-1.10	0.25-0.45	0.025 max	0.025 max	0.35 max
B 51100	0.95-1.10	0.25-0.45	0.025 max	0.025 max	0.35 max
C 50100	0.95-1.10	0.25-0.45	0.025 max	0.025 max	0.35 max

Type	Cu[1] %	Si %	Cr %	Mo[1] %
A 52100	0.25 max	0.20-0.35	1.30-1.60	0.08 max
B 51100	0.25 max	0.20-0.35	0.90-1.15	0.08 max
C 50100	0.25 max	0.20-0.35	0.40-0.60	0.08 max

[1]Ni, Cu, and Mo are incidental alloying elements to be reported if required.

Characteristics. This is an electric-furnace high C-Cr steel in three types.

Uses. Billets for rolling or forgings, tube rounds, bars, rods, wire and tubes to be used in the manufacture of ball and roller bearings.

Mechanical Properties

Form or Condition	Rockwell Hardness	Hardness BHN
Annealed bars or tubes[2]		
Hot rolled finish	–	207 max
Cold drawn finish[1]	–	250 max
Finished ball wire	B92 max	–

[1]Cold-swaged material is not included.
[2]Small sizes where Rockwell B scale hardness readings are impractical shall show a max TS of 110 M psi.
Note See specification for details and modifications.

STEELS, ASTM

A 299-50T

Chemical Composition

C % max	Mn %	P % max	S % max	Si %
.28[1]	.90-1.40	.040[3]	.05[3]	.15-.30
.31[2]	–	.035[4]	.04[4]	–

[1]Plates ≤ 1 in.
[2]Plates > 1-2 in incl
[3]Flange grade
[4]Firebox grade

Characteristics. This is a high strength, low manganese, open-hearth or electric furnace steel for boilers and pressure vessels manufactured by fusion welding. Plates up to 2 in. in thickness are produced to this specification and they may be normalized and/or stress relieved. Definite Si and Mn contents are specified to limit C to lowest practical amount consistent with specified tensile strength and thickness of material. The relatively high C and Mn should be taken into account when welding and precautions taken to avoid cracking.

Mechanical Properties[1]

Form or Condition	Tensile Strength M psi	Yield Point Min M psi	Elong[6] 8" min %	Elong 2" min %	Ratio[4]
Plates ≤ 1 in.	75-90	42	1550 M + TS[2]	1750 M + TS	–
	–	–	1600 M + TS[3]	–	–
Plates > 1-2 in.	75-90	40	1550 M + TS[2]	1750 M + TS	–
	–	–	1600 M + TS[3]	–	–
Bend Test[5]					
Thickness ≤ 1 in.	–	–	–	–	3
> 1-1½ in. incl.	–	–	–	–	3
> 1½-2 in. incl.	–	–	–	–	4

[1]Normalized and/or stress relieved.
[2]Flange
[3]Firebox
[4]Bend Diam to Plate Thickness
[5]Samples must bend 180 deg without cracking
NOTE See specification for details and deviations

[6]For material > ¾ in. deduct 0.125% for every ⅟₃₂ in. increase above ¾ in. to 15% minimum for flange steel and 16% minimum for firebox.

STEELS, ASTM

A 300-50T

Characteristics. This is a steel plate made to fine grain melting practice. Plates shall be furnished in heat-treated (normalized) condition unless otherwise specified.

Uses. Welded pressure vessels that operate at subzero temp.

Mechanical Properties

Form or Condition		Norm Temp deg F	Min Service Temp deg F	Min Impact Value: Specimen Size mm	Aver 3 Spec ft lb	One Spec ft lb
Steel Plate:						
Class	ASTM Spec & Grade					
1	A201, A212	1575-1650	-50	–	–	–
2	A203 Firebox } Grades A and B	1475-1550	-75	–	–	–
3	A203 Firebox } Grade D	1475-1550	-150	–	–	–
Plate, as rolled: Charpy impact requirements for subsize specimen. Shall be not less than 15 ft lb when tested at min temp listed above for respective classes		–	–	10 by 7.5	12.5	8.5
		–	–	10 by 5	10.0	7.0

Note See specification for details and modifications, particularly regarding test specimens

STEELS, ASTM

A 301-51T

Characteristics. This is an open-hearth or electric-furnace chromium-molybdenum steel[1] made in two compositions, Grades A and B. Grade A is a coarse-grained steel having a carburized austenite grain size of 1 to 5[2] determined by carburizing at 1700F for 8 hr. Welding technique is of fundamental importance.

[1]Conforming with ASTM. A 20. [2]ASTM: E19

Uses. Plates for use in boilers and other pressure vessels for service at high temperatures.

Chemical Composition

	C %	Mn %	P[1] %	P[2] %	S[1] %
Grade A	0.21 max	0.80 max	0.040 max	0.035	0.050
Grade B	0.21 "	0.65 "	0.040 "	0.035	0.050

	S[2] %	Si %	Cr %	Mo %
Grade A	0.040	0.15-0.30	0.50-0.75	0.45-0.65
Grade B	0.040	0.15-0.30	0.80-1.15	0.45-0.65

[1]Flange
[2]Firebox

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong[5] 8 in.[3] %	Elong[5] 8 in.[4] %	Elong[5] 2 in. %	Ratio[6]
Grade A	65-82	.55TS min[1]	1600M÷TS	1650M÷TS	1750M÷TS	–
B	60-77	.55TS min[2]	1600M÷TS	1650M÷TS	1750M÷TS	–
Bend Test: 180 deg						
≤ 1 in.	–	–	–	–	–	1½
>1 ≤ 4 in.	–	–	–	–	–	2
>4 ≤ 6 in.	–	–	–	–	–	2½

[1]but not less than 40 M psi
[2]but not less than 35 M psi
[3]Flange
[4]Firebox
[5]Plates > ¾ in., deduct from 8 in. table 0.125% for each 1/32 in. thickness above ¾ in. to minimum of 18%. Plates ¼ to ¾ in. percentage elongation may fall 3% below table provided elongation in 2 in. across break is not less than 30%. Plates > 2½ in., deduct from 2 in. table 0.5% for each ½ in. above 2½ in.
[6]Bend diam/Specimen thickness
NOTE. See specification for details and modifications

STEELS, ASTM

A 302-50T

Characteristics. This is an open-hearth or electric-furnace Mn-Mo steel plate in two high tensile strength ranges. Maximum thickness shall be 2 in. for flange quality, 4 in. for firebox. Welding technique is of fundamental importance. See specification for details of heat treatment.

Uses. Boilers and other pressure vessels.

Chemical Composition

Grades	C % ≤ 1 in.	C % > 1-2 in. incl.	C % > 2-4 in. incl.	Mn %	P % Flange	P % Firebox
A	0.20 max	0.23 max	0.25 max	0.90-1.30	0.040 max	0.035 max
B	0.20 max	0.23 max	0.25 max	1.10-1.50	0.040 max	0.035 max

Grades	S % Flange	S % Firebox	Si %	Mo %
A	0.050 max	0.040 max	0.15-0.30	0.40-0.60
B	0.050 max	0.040 max	0.15-0.30	0.40-0.60

Mechanical Properties

Form or Condition	Tensile Strength[1] M psi	Yield Point M psi	Elongation 2 in. min %	Elongation 8 in. min % Flange	Elongation 8 in. min % Firebox	Ratio[2] Grade A	Ratio[2] Grade B
Grades A	75-95	45 min	1750M + TS	1600M + TS	1650M + TS	–	–
B	80-100	50 min	1750M + TS	1600M + TS	1650M + TS	–	–
For plates > ¾ in. deduct from 8 in. min for each 1/32 in. above ¾ in. to minimum of 16% for grade A, 15% for grade B. See spec for further details.	–	–	–	0.125	–	–	–
For plates > 2½ in. deduct from 2 in. min for each ½ in. above 2½ in.	–	–	–	0.5	–	–	–
Bend Test: thru 180 deg ≤ 1 in.	–	–	–	–	–	2	2½
> 1 to 2 in. incl.	–	–	–	–	–	2½	3
> 2 to 4 in. incl.	–	–	–	–	–	3	3½

[1]TS need only be determined on specimen from top of firebox plates. It shall not exceed 98 M psi for grade A, 103 M psi for grade B.
[2]Bend diam/specimen thickness.
Note: See specification for details and modifications.

A 303-48T

Chemical Composition

		C %	P %	S %	Cu[1] %
Ladle[3]	Open-Hearth	0.25 max[2]	0.04 max	0.05 max	0.20 min
	Acid-Bessemer	0.10 max	0.11 max	0.06 max	0.20 min

[1]When specified
[2]As C increases above 0.15% spot welding becomes increasingly difficult.
[3]For check variations, see ASTM Spec.

Characteristics. This is an open-hearth or acid-bessemer hot-rolled C steel. Flat hot-rolled C-steel may be spot welded in the "hot-rolled" condition, but for best results the oxide or scale should be removed before welding.

Uses. Strip intended for structural purposes where mechanical test valves are required.

Mechanical Properties

Grades	Thickness	Tensile Strength M psi	Yield Point M psi	Elong 2 in % min	Elong 8 in % min	Bend Test at room temp
Commercial			Subject to Bend Test only			flat on itself
A	0.2299-0.1450 in. incl	48 min	25 min	27.0	20.0	flat on itself
	0.1499-0.0890 in. incl			24.5	18.0	
	0.0889-0.0610 in. incl			23.0	–	
	0.0609-0.0410 in. incl			21.0	–	
	0.0409-0.0255 in. incl			19.0	–	
B	0.2299-0.1450 in. incl	52 min	30 min	25.0	18.5	thru 180 deg around 1 thickness of material
	0.1499-0.0890 in. incl			23.0	17.0	
	0.0889-0.0610 in. incl			21.5	–	
	0.0609-0.0410 in. incl			20.0	–	
	0.0409-0.0255 in. incl			18.0	–	
C	0.2299-0.1450 in. incl	55 min	33 min	23.5	17.5	thru 180 deg around 1½ thickness of material
	0.1499-0.0890 in. incl			21.5	15.5	
	0.0889-0.0610 in. incl			20.0	–	
	0.0609-0.0410 in. incl			18.5	–	
	0.0409-0.0255 in. incl			17.0	–	

Note See specification for details and modifications

STEELS, ASTM

A 313-47T

Chemical Composition

C %	Mn %	P %	S %	Ni %	Si %	Cr %
0.15 max	2.00 max	0.04 max	0.03 max	8.00-9.50	1.00 max	18.00-20.00

Characteristics. This is an electric-furnace round spring steel wire with a nominal composition of 18%Cr, 8%Ni, uniform in quality. The wire has approximately the same corrosion resistance as annealed 18%Cr, 8%Ni alloy steel. It shall be cold drawn to the desired physical properties.

Uses. Intended especially for the manufacture of springs. Springs made from this wire will operate at temperatures up to 350 F without noticeable loss in physical properties, and even at temperatures as high as 600 F, the percentage loss in physical properties is small enough to make their use feasible for many applications such as thermostat, stove, and hot oil valve springs.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Tensile Strength M psi
Diameter In.[1]	min	max
≤0.009 – 0.014	325-312	355-342
0.015 – 0.022	310-296	340-326
0.024 – 0.036	292-273	322-303
0.041 – 0.080	269-245	299-275
0.092 – 0.177	240-195	270-225
0.207 – 0.375	185-140	215-170

[1]See specification for intermediary sizes
Note: See specification for details and modifications

A 306-50T

Chemical Composition[1]

	P %	S %	Cu %
Open-hearth & electric-furnace	0.040 max	0.050 max	0.20 min
Bessemer	0.11 max	0.060 max	when specified

[1]When tension tests are waived, chemistry consistent with mech properties must be applied
For check analysis, see ASTM Spec.

Shapes

Bar sections are all cross-sections generally considered as hot-rolled bars, including rolled shapes of bar sizes as follows:

Rounds	¼ – 8¼ in. incl. (diam)
Squares	¼ – 5½ in. incl. (between // surfaces)
Round-Cornered Squares	⅜ – 8 in. incl. (between // surfaces)
Hexagons	¼ – 4 1/16 in. incl. (between // surfaces)
Flats	13/64 (0.2031) in. and over in thickness not over 6 in. in width
Shapes and Special Sections	Angles, channels, tees and zees, when greatest cross-sectional dimension is under 3 in.
	Ovals, half ovals and half rounds
	Special Sections

Characteristics. This is an open-hearth or electric-furnace hot-rolled, carbon steel. For grades 55, 60, 65 and 70, Bessemer steel may be supplied subject to agreement between manufacturer and purchaser.

Uses. Bars of special quality subject to mechanical property requirements and intended for general constructional applications.

Mechanical Properties

Form or Condition	Tensile Strength[1] M psi	Yield Point min M psi	Elong 2 in min %	Elong 8 in min %	Ratio[2] Bend Diam Specimen Thickness ≤ ¾ in	> ¾ to 1 in incl	> 1 to 1½ in incl	> 1½ to 2 in incl	> 2 to 3 in incl.	> 3 to 5 in incl	> 5 in
Grade 45	45-55	22.5	33	27	flat	flat	½	1	1	2	3
50	50-60	25	30	25	flat	½	1	1½	2½	3	3½
55	55-65	27.5	26	23	½	1	1½	2	2½	3	3½
60	60-72	30	22	21	½	1	1½	2½	3	3½	4
65	65-77	32.5	20	17	1	1½	2	3	3½	4	5
70	70-85	35	18	14	1½	2	2½	3	3½	4	5
75	75-90	37.5	16	13	2	2½	3	3½	4	4½	6
80	80 min	40	14	12	2	2½	3	3½	4	4½	6
For material > ¾ in. deduct from 8 in. min for each 1/32 in. above ¾ in.	—	—	—	0.25	-	—	—	—	—	—	—
For material < 5/16 in. deduct from 8 in. min for each 1/32 in. below 5/16 in.	—	—	—	2.00	—	—	—	—	—	—	—
For material > 2 in. deduct from 2 in. min for each 1 in. above 2 in.	—	—	1.00	—	—	—	—	—	—	—	—

[1]Shapes < 1 in.² in cross-section and bars (other than flats) < ½ in need not be subjected to TS tests.
[2]Bend Tests, thru 180 deg.

Note. See specification for details and modifications

A 307-50T

Chemical Composition[1]

	P %	S %
Bolts	0.06 max	0.15 max
Nuts	0.13 max	0.23 max

[1] Resulfurized material is not subject to rejection based on check analysis for sulfur. Bolts and nuts are customarily furnished from stock, in which case individual heats of steel cannot be identified.

Characteristics. This is an open-hearth or electric-fumace steel covering two classes of machine bolts and nuts and tap bolts. Steel for the manufacture of nuts shall also be made by acid-bessemer process. If no grade is specified, A will be furnished.

Uses. Grade A for general applications.
Grade B for flanged joints in piping systems where one or both flanges are cast iron.

Mechanical Properties

Form or Condition	Bolt Size in	Threads Per in.	Stress Area, Sq. in.[1]	Breaking Load of Bolts: Grades A and B min[2] M lb	Breaking Load of Bolts: Grade B max[3] M lb	Stripping Load of Nuts min[4] lb	Rock B Hard min	Rock B Hard max	Hardness BHN min	Hardness BHN max
Grade A	—	—	—	—	—	—	66	—	104	—
B	—	—	—	—	—	—	66	92	104	183
	1/4	20	0.0317	1.7	2.9	2.9	—	—	—	—
	5/16	18	0.0522	2.8	4.7	4.7	—	—	—	—
	3/8	16	0.0773	4.2	6.9	6.9	—	—	—	—
	7/16	14	0.1060	5.6	9.5	9.5	—	—	—	—
	1/2	13	0.1416	7.7	12.7	12.7	—	—	—	—
	9/16	12	0.1816	10.0	16.3	16.3	—	—	—	—
	5/8	11	0.2256	12.4	20.3	20.3	—	—	—	—
	3/4	10	0.3340	18.3	30.1	30.1	—	—	—	—
	7/8	9	0.4612	25.3	41.5	41.5	—	—	—	—
	1	8	0.6051	33.2	54.5	54.5	—	—	—	—
	1 1/8	7	0.7627	41.9	68.6	68.6	—	—	—	—
	1 1/4	7	0.9684	53.2	87.2	87.2	—	—	—	—
	1 3/8	6	1.1538	62.3	104.0	104.0	—	—	—	—
	1 1/2	6	1.4041	77.2	126.5	126.5	—	—	—	—
	1 3/4	5	1.8983	104.4	171.0	171.0	—	—	—	—
	2	4 1/2	2.4971	137.3	224.5	224.5	—	—	—	—
	2 1/4	4 1/2	3.2464	178.5	292.0	292.0	—	—	—	—
	2 1/2	4	3.9976	218.8	360.0	360.0	—	—	—	—
	2 3/4	4	4.9326	271.2	443.0	443.0	—	—	—	—
	3	4	5.9659	328.1	537.0	460.0	—	—	—	—
	3 1/4	4	7.0992	390.4	639.0	470.0	—	—	—	—
	3 1/2	4	8.3268	457.9	749.0	560.0	—	—	—	—
	3 3/4	4	9.6546	530.9	869.0	650.0	—	—	—	—
	4	4	11.0805	609.4	997.5	750.5	—	—	—	—

[1] Area at mean of mean root and pitch diam of class 3 external thread
[2] Based on 55 M psi min TS.
[3] Based on 90 M psi max TS. No max specified for Grade A.
[4] Based on TS in threaded mandrel of 90 M psi min for < 3 in. and somewhat lower for larger sizes. No max specified for Grade A.

Note: See specification for details and modifications.

STEELS, ASTM

A 311-49T

Chemical Composition

		C %	Mn %	P %	S %
Ladle[1]	1137	0.32-0.39	1.35-1.65	0.040 max	0.08-0.13
	1141	0.37-0.45	1.35-1.65	0.040 max	0.08-0.13
	1144	0.40-0.48	1.35-1.65	0.040 max	0.24-0.33
	1151	0.48-0.55	0.70-1.00	0.040 max	0.08-0.13

[1] For check variations, see ASTM Spec.

Characteristics. This is an open-hearth stress-relieved-annealed, cold-drawn, open-hearth, free-cutting C bar steel in four grades. It is furnished in rounds, squares, and hexagons < 2½ in. in diam or with a distance between // surfaces and flats < 2 in. in thickness or < 6 in. in width and < 6 sq. in. in cross sectional area.

Uses. Suitable for applications where high strength, good machinability, and decreased distortion are important.

Mechanical Properties

Grade[1]	Diam Thickness or Distance between Parallel Faces	Tensile Strength M psi	Yield Point M psi	Elong 2 in. % min	Red Area % min
1137	≤ 9/16 in.	100 min	80 min	15	40
	> 9/16 in - 1¼ in. incl	95 min	75 min	15	40
	> 1¼ in - 2½ in. incl	90 min	70 min	14	40
1141	≤ 9/16 in.	105 min	85 min	12	40
	> 9/16 in - 1¼ in. incl	100 min	80 min	12	40
	> 1¼ in - 2½ in. incl	95 min	75 min	12	40
1144	≤ 9/16 in.	105 min	85 min	12	35
	> 9/16 in - 1¼ in. incl	100 min	80 min	12	35
	> 1¼ in - 2½ in. incl	95 min	75 min	12	35
1151	≤ 9/16 in.	105 min	85 min	10	35
	> 9/16 in - 1¼ in. incl	100 min	80 min	10	35
	> 1¼ in - 2½ in. incl	95 min	75 min	10	35

[1] Rectangular material is limited to 6 sq in in cross sectional area.
Note See specification for details and modifications.

STEELS, ASTM

A 315-51T

Chemical Composition

	C %	Mn %	P %	S %	Si %	Cr %	Mo %
Ladle[1]	0.14 max	0.33-0.58	0.040 max	0.040 max	0.28 max	0.85-1.20	0.48-0.63

[1] For check analysis, see ASTM Specs.

Characteristics. This is an open-hearth or electric-furnace seamless Cr-Mo alloy-steel piping of nominal wall. Unless otherwise specified, pipe ≥ 2 in. shall be hot-finished and pipe < 2 in. may be hot-finished or cold-drawn. The steel shall be made by coarse grain melting practice. For details of processing, heat treatment and supplementary requirements, see specification.

Uses. High-temperature service. Suitable for bending, flanging (vanstoning) and similar forming operations, and for fusion welding.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2 in. Long.	Elong 2 in. Transv.	Ratio[1]
	60 min	25 min	–	–	–
Basic minimum ≥ 5/16 in. wall thickness, strip tests, and for all small sizes tested in full section	–	–	30 min	20 min	–
Standard round test specimen, 2 in. gage length	–	–	22 min	14 min	–
For strip tests, deduct for every 1/32 in. below 5/16 from basic min	–	–	1.50	1.00	–
Bend Test ≤ 2 in. nom. diam: Thru 90 deg	–	–	–	–	12
Bend Test ≤ 2 in. nom. diam: Thru 180 deg, for close coiling	–	–	–	–	8

[1] Mandrel diam/nom diam specimen.
Note: See specification for details and modifications.

A 312-51T

Chemical Composition

Grade	Ident	C %	Mn %	P[1] %	S %	Ni %
Cr-Ni	TP 304	0.08 max	2.00 max	0.030 max	0.030 max	8.0-11.0
Cr-Ni	TP 309	0.15 max	2.00 max	0.030 max	0.030 max	12.0-15.0
Cr-Ni	TP 310	0.15 max	2.00 max	0.030 max	0.030 max	19.0-22.0
Cr-Ni-Ti	TP 321	0.08 max	2.00 max	0.030 max	0.030 max	9.0-13.0
Cr-Ni-Cb	TP 347	0.08 max	2.00 max	0.030 max	0.030 max	9.0-13.0
Cr-Ni-Mo	TP 316	0.08 max	2.00 max	0.030 max	0.030 max	11.0-14.0
Cr-Ni-Mo	TP 317	0.08 max	2.00 max	0.030 max	0.030 max	11.0-14.0

Grade	Ident	Si %	Cr %	Mo %	Ti %	Cb %
Cr-Ni	TP 304	0.75 max	18.0-20.0	–	–	–
Cr-Ni	TP 309	0.75 max	22.0-24.0	–	–	–
Cr-Ni	TP 310	0.75 max	24.0-26.0	–	–	–
Cr-Ni-Ti	TP 321	0.75 max	17.0-20.0	–	5C-0.60	–
Cr-Ni-Cb	TP 347	0.75 max	17.0-20.0	–	–	10C-1.00[2]
Cr-Ni-Mo	TP 316	0.75 max	16.0-18.0	2.0-3.0	–	–
Cr-Ni-Mo	TP 317	0.75 max	18.0-20.0	3.0-4.0	–	–

[1] Emergency alternate provisions allow 0.040%
[2] Emergency alternate provisions allow columbium plus tantalum.

Characteristics. This is an electric furnace austenitic steel pipe, seamless or welded, made in seven grades and intended for high temperature and general corrosive service.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2 in.[1] %	Elong 2 in.[2] %	Ratio[3]
	75 min	30 min	–	–	–
Basic minimum, 5/16 in. and over in thickness, strip tests and for all small sizes tested in full section	–	–	35 min	25 min	–
Standard 2 in. rd. gage test specimen	–	–	28 min	20 min	–
For strip tests, deduct for each 1/32 in. decrease below 5/16 in. from basic minimum	–	–	1.75	1.25	–
Bend Test:					
$\leq$ 2 in. nom diam, 90 deg	–	–	–	–	12
For close coiling, 180 deg	–	–	–	–	8

[1] Longitudinal
[2] Transverse
[3] Mandrel/nom diam specimen
NOTE: See specification for details and modifications

STEELS, ASTM

A 320-51T

Characteristics. This is an open-hearth or electric-furnace alloy steel for low-temperature service. Seven grades are covered in rolled, forged, cold-drawn bars and bolts, screws, studs & stud bolts including both ferritic and austenitic steels.

Uses. Bolting materials for pressure vessels, valves, flanges, fittings.

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Point M psi[1]	Elong 2 in. %	Red Area %
L7 and L9	≤ 2½ in. diam	125 min	105 min	16 min	50 min
	> 2½ to 4 incl.	105 min	80 min	20 min	50 min
L 10	≤ 4 in. diam	70 min	40 min	25 min	40 min
L8, L8c, L8t and L8F					
annealed,	all diam	75 min	30 min	35 min	50 min
cold drawn	≤ ¾ in. diam	125 min	100 min	12 min	35 min
	> ¾ to 1 incl	115 min	80 min	15 min	35 min
	> 1 to 1¼ incl	105 min	65 min	20 min	35 min
	> 1¼ to 1½ min	100 min	50 min	28 min	45 min

[1]0.2%

Note: See specification for details and modifications.

Chemical Composition

	Symbol	Grade	C %	Mn %	P %	S %
Ferritic Steels Range[1]	L7	Cr-Mo, TP 4140, 4142, 4145	0.38-0.48[2]	0.75-1.00	0.040 max	0.040 max
	L9	Ni TP 2340	0.38-0.43	0.70-0.90	0.040 max	0.040 max
	L 10	Ni TP 2317	0.15-0.20	0.40-0.60	0.040 max	0.040 max
Austenitic Steels Range[1]	L8	Unstabilized 18, Cr 8, Ni TP 304	0.08 max	2.00 max	0.04 max	0.03 max
	L8c	Stabilized 18 Cr 8, Ni TP 347	0.08 max	2.00 max	0.04 max	0.03 max
	L8t	Stabilized 18 Cr 8, Ni TP 321	0.08 max	2 00 max	0.04 max	0.03 max
	L8F	Free Machining 18, Cr 8, Ni TP 303	0.15 max	2.00 max	0.14[3]	0.50[3,4]

	Symbol	Grade	Ni %	Si %	Cr %	Mo %
Ferritic Steels Range[1]	L7	Cr-Mo, TP 4140, 4142, 4145	–	0.20-0.35	0.80-1.10	0.15-0.25
	L9	Ni TP 2340	3.25-3.75	0.20-0.35	–	–
	L 10	Ni TP 2317	3.25-3 75	0.20-0 35	–	–
Austenitic Steels Range[1]	L8	Unstabilized 18, Cr 8, Ni TP 304	8.00-11.00	1.00 max	18.00-20.00	–
	L8c	Stabilized 18 Cr 8, Ni TP 347	9.00-12.00	1.00 max	17.00-19.00	–
	L8t	Stabilized 18 Cr 8, Ni TP 321	8.00-11.00	1.00 max	17.00-19.00	–
	L8F	Free Machining 18, Cr 8, Ni TP 303	8.00-10.00	1 00 max	17.00-19.00	[5]

	Symbol	Grade	Ti %	Cb %	Se %
Ferritic Steels Range[1]	L7	Cr-Mo, TP 4140, 4142, 4145	–	–	–
	L9	Ni TP 2340	–	–	–
	L 10	Ni TP 2317	–	–	–
Austenitic Steels Range[1]	L8	Unstabilized 18, Cr 8, Ni TP 304	–	–	–
	L8c	Stabilized 18 Cr 8, Ni TP 347	–	10 C min	–
	L8t	Stabilized 18 Cr 8, Ni TP 321	5 C min	–	–
	L8F	Free Machining 18, Cr 8, Ni TP 303	–	–	0.50[3,4]

[1]For check variation see ASTM Spec.
[2]For bar sizes over 3½ to 4 in., inclusive, the carbon content may be 0.50%, max.
[3]P content shall be 0.040% max when sulfur is added and 0.140% max when Se added.
[4]Either element may be specified.
[5]Mo, plus zirconium, shall not exceed 0.60%.

1006 1008

Chemical Composition

	C %	Mn %	P %	S %
C1006	.08 max	.25-.40	.040 max	.050 max
C1008	.10 max	.25-.50	.040 max	.050 max

Characteristics. This is usually produced as rimmed steel with a good surface finish but is also made as a fully killed, "fine grained" steel to eliminate or minimize the strain-aging behavior of the rimmed quality. It is a very soft, mild steel of low strength and high ductility and is easy to forge or to form and shape cold. It is easy to weld or braze and hence is suitable where ease of fabrication is desired and strength is not important. It is hardened or strengthened by cold working and can be restored to its initial soft condition by annealing. It is not heat-treatable in the usual sense (by quenching and tempering) but it can be surface-hardened by case hardening or cyaniding.

Typical Uses. For structures and assemblies where strength is not needed or is only a minor requirement but where the maximum ease of forming and joining is important. For the more severe drawing operations, such as certain automobile body parts, the killed type must be applied to avoid too great losses in fabrication.

Common Forms. Hot rolled bars, strip, sheet, plate; cold drawn bars, cold rolled bars; wire; cold headed parts; auto body stock cold finished and annealed; pipe and tubing; tin plate, galvanized sheets.

Aging of Mild Steel and Non-Aging Steel. Ordinary mild steel of the open-hearth, rimmed type ages at room temperature. For a full description of this, see ASM Metals Handbook, pp. 000-000 and Figs 6, 7, 8 and 9, p 441.

Physical Properties[1]

Density at room temp 0.284 lb/cu in. (7.871 S.G.)

[1] ASM Metals Handbook

Electrical Resistivity[1]

Temp Range Deg C	Deg F	Microhm-cm .06 C	.08 C
20	68	13.0	14.2
100	212	17.8	19.0
200	392	25.2	26.3
400	752	44.8	45.8
600	1112	72.5	73.4
700	1292	89.8	90.5
800	1472	107.3	108.1
900	1652	112.4	113.0
1000	1832	116.0	116.5
1100	2012	118.9	119.3
1200	2192	121.6	122.0
1300	2372	124.1	124.4

[1] Data from Ntl. Phys. Lab. Materials .06C, .38Mn, .01Si

Thermal Conductivity[1]

Temp Range Deg C	Deg F	$Cal/cm^2/cm/$ $°C/sec$	$Btu/sec/ft^2/$ $°F/in.$
0	32	.142	.114
100	212	.138	.111
200	392	.127	.102
300	572	.118	.095
400	752	.109	.088
500	932	.098	.079
600	1112	.088	.071
700	1292	.079	.064
800	1472	.068	.055
1000	1832	.066	.053
1200	2192	.071	.057

[1] Materials .08C, .31Mn, .07Ni, .045Cr, .02Mo. Data from NH. Phys. Lab.

Mean Apparent Specific Heat

Material .08C, .31Mn, .07Ni, .045Cr, .02Mo, Tr Cu

Temp Range Deg C	Deg F	cal/gm/°C	Temp Range Deg C	Deg F	cal/gm/°C
50-100	122-212	.115	450-500	842-932	.158
150-200	302-392	.125	550-600	1022-1112	.177
200-250	392-482	.130	650-700	1202-1292	.205
250-300	482-572	.133	700-750	1292-1382	.272
300-350	572-662	.136	750-800	1382-1472	.229
350-400	662-752	.142	850-900	1562-1652	.195

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2 in %	Red Area %	Hard Rb	Hard BHN	Yield Point M psi	Olsen Cup In.
Rimmed Steel[1]								
.035 in. sheets, Hand mill	65	50	10	–	70	–	–	.200
.035 in. sheets, Hand mill annealed	38	22	30	–	40	–	–	.390
.035 in. sheets, Hand mill normalized	45	28	35	–	48	–	–	.400
.035 in. sheets, Cold rolled	85	85	2	–	90	–	–	.100
.035 in. sheets, Cold rolled annealed	44	28	40	–	45	–	–	.410
.048 in. sheets, Hot strip	60	40	30	–	65	–	–	.380
.048 in. sheets, Hot strip annealed	52	33	35	–	55	–	–	.400
.048 in. sheets, Hot strip normalized	48	30	40	–	50	–	–	.420
.048 in. sheets, Hot strip normalized and annealed	43	25	45	–	45	–	–	.420
Grade C 1008[2]								
Hot rolled or annealed bars ¾-1¼" diam tested full size	42 Min	21 Min	–	–	–	–	–	–
Cold rolled bar ¼-3" diam	50-65	40-55	20-30	50-60	–	95-121	–	–
C 1008[5] Normal Processing, to 9/16 in.	54-71	42-59[6]	25-35	58-68	–	109-140	–	–
C 1008[5] Normal Processing, >9/16–1 1/2 incl.	53-70	41-58[6]	25-35	55-68	–	109-140	–	–
C 1008[5] Normal Processing, >1 1/2–3 1/2 in. incl.	52-67	39-55	25-35	50-65	–	105-137	–	–
Aver. prop. 1 in. rd. bars, Cold drawn 1/16 in. draft, cold drawn	60	–	28	64	–	124	48	–
Aver. prop. 1 in. rd. bars, Cold drawn 1/16 in. draft, annealed and cold drawn	58	–	30	66	–	121	45	–
Steel B 1006[4]								
1 in. sections[3] Hot rolled	60	–	30	–	–	–	40	–
1 in. sections[3] Cold drawn	73	63	18	–	–	–	–	–
Steel C 1008								
1 in. sections[3] Hot rolled	52	–	38	–	–	–	33.5	–
1 in. sections[3] Cold drawn	68	58	24	–	–	–	–	–

[1] Typical industry values for .05-.10%C (ASM Metals Handbook)
[2] ASTM data — apply to A-108
[3] Average expected values (Source—Jones and Laughlin Steel Corp.)
[4] This is a Bessemer steel and, at the same carbon level, is stronger and less ductile than an open-hearth steel.
[5] Bliss & Laughlin
[6] At .5% extension under load

(Continued on page 146)

SPECIAL CASTINGS

1006 1008

(Continued from page 145)

Treatment Temperatures (Collected)

Rolling	2200-2350F
Normalizing	1650-1750
Quenching	1650-1700
Annealing	1000-1350[1]
Annealing	950-1200[2]

[1]After cold work
[2]For stress relief

Coef. of Thermal Expansion (Linear)
Material .08C, .31Mn, annealed

Temp Range Deg C	Temp Range Deg F	Coefficient α $\times 10^{-6}/^{\circ}C$	Coefficient α $\times 10^{-6}/^{\circ}F$
0-100	32-212	12.2	6.77
0-200	32-392	13.0	7.20
0-300	32-572	13.5	7.50
0-400	32-752	13.9	7.72
0-500	32-932	14.3	7.94
0-600	32-1112	14.7	8.17
0-700	32-1292	15.0	8.33

Technical Properties
Machinability (On basis of B1112 = 100). Both C1006 and C1008 cold drawn to 126-163 BHN, about 50-55%.
Critical Points [1] (C1008) Ac_1 1350F Ar_3 1570F
Ac_3 1605 Ar_1 1255
[1]Bliss & Laughlin

Critical Points[1] (C1008)
Ac_1 1350F Ar_3 1570F
Ac_3 1605 Ar_1 1255
[1]Bliss & Laughlin

STEELS, AISI

1010 1012 1013

Treatment Temperatures

Annealing	1000-1350F
Normalizing	1650-1750
Quenching	1650-1700
Carburizing	1650-1700[1]

[1]Dr 250-325

Chemical Composition

	C %	Mn %	P %	S %
C1010	.08-.13	.30-.60	.040 max	.050 max
C1012	.10-.15	.30-.60	.040 max	.050 max
C1013	.11-.16	.50-.80	.040 max	.050 max

Critical Points[1] (C1010)
Ac_1 1350F Ar_3 1570F
Ac_3 1605 Ar_1 1255
[1]Bliss & Laughlin

Notched Bar Tests[1]

Steel 1010[2]

Temp	Charpy test, key hole notch, Bessemer	Charpy test, key hole notch, Open Hearth	Ft Lbs Izett
148F	37	36	–
68	26	32	47
32	4	26	–
0	3	3	42
-40	–	–	35
-80	–	–	5

[1]Low temp (Source—S. Epstein, Tran. ASTM, 1932, II, 293)
[2]TS of Bessemer steel 55 M psi
TS of Open Hearth steel 48 M psi

Characteristics. These steels are a little stronger than C1008 and a little less ductile and formable. They are less expensive and can be used when the requirements for drawing and forming are less exacting. Their higher strength may be advantageous for surface-hardened parts.

Typical Uses. Hot rolled bars, strip, sheet, plate; cold drawn bars; cold rolled bars; wire; cold headed parts; auto body stock cold finished and annealed; pipe and tubing; tin plate; galvanized sheets.

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red. Area %	Hard BHN	Shear Stress Elastic M psi	Shear Stress Max M psi	Degs of Twist Elastic	Degs of Twist Max
C1010											
Hot rolled, turned } 1 in. rds., aver.[7]	–	44.8	–	40.1	31.4	67.1	107	19.6	56	3.0	2220
Cold drawn } 1 in. rds., aver.[7]	–	60	–	20.6	54.2	62.7	129	29.4	58	3.4	2110
Hot rolled or ann.[1] 3/4-1 1/4 in. bars[2]	–	45 min	–	–	22.5 min	–	–	–	–	–	–
Cold rolled[1] 1/4-3 in. bars	–	55/70	–	18/28	45/60	45/60	111/143	–	–	–	–
Cold drawn[3] 5/8-2 in. diam	–	67	55	25	–	57	137	–	–	–	–
Normal processing[9] } to 9/16 in.	–	57-77	42-62[8]	24-34	–	53-65	114-156	–	–	–	–
Normal processing[9] } > 9/16-1 1/2 in. incl.	–	55-75	43-60[8]	23-33	–	53-65	112-149	–	–	–	–
Normal processing[9] } > 1 1/2-3 1/2 in. incl.	–	53-70	40-60[8]	23-33	–	50-65	107-146	–	–	–	–
Aver. prop. 1 in. rd. bars; cold drawn	–	65	–	27	50	60	134	–	–	–	–
Cold drawn 1/16 in. draft[9] annealed } cold drawn	–	64	–	28	48	65	131	–	–	–	–
B1010[5]											
Hot rolled } 1 in. bars or sect., aver.[4]	–	64	–	28	42	–	–	–	–	–	–
Cold drawn } 1 in. bars or sect., aver.[4]	–	78	68	16	–	–	–	–	–	–	–
C1012											
Hot rolled } 1 in. bars or sect., aver.[4]	–	55	–	35	36	–	–	–	–	–	–
Cold drawn } 1 in. bars or sect., aver.[4]	–	70	60	22	–	–	–	–	–	–	–
C1013											
As rolled, Effect of Temp[6]	70F	66.3	–	29.7	54.7	71.8	–	–	–	–	–
	-85	80.7	–	33.6	67.7	70.3	–	–	–	–	–
	-292	121.3	–	26.5	–	55	–	–	–	–	–

[1]ASTM Bull. 194, for A108.
[2]Tested full size.
[3]ASM Metals Handbook, industry values.
[4]Jones and Laughlin Steel Corp.
[5]This is a Bessemer steel and, at the same carbon level, is stronger and less ductile than an open-hearth steel.
[6]Colbeck McGillivray
[7]LaSalle Steel Co.
[8]At .5% extension under load.
[9]Bliss & Laughlin.

1015

Chemical Composition

C	Mn	P	S
%	%	%	%
.13-.18	.30-.60	.040 max	.050 max

Technological Properties
Machinability[1] (On basis of B1112 = 100)
Cold drawn to 131-170 BHN = 50%
Industry value = 60%[2]
[1]ASM Metals Handbook
[2]Ryerson

Critical Points

Case Ac_1[1]	1355F	Ac_3[2]	1560F
Core Ac_3[1]	1585	Ar_3[2]	1510
Ac_1[2]	1390	Ar_1[2]	1390

[1]International Nickel Co.
[2]Bethlehem Steel Co.

Characteristics. A popular carburizing grade and can be strengthened by cold working or surface hardened by carburizing or cyaniding. In the hot rolled or annealed condition it is relatively soft and has good weldability and formability for fabrication. It can be readily brazed for joining parts. It is less expensive than the softer and more ductile grades.

Typical Uses. It is normally used in the as-rolled condition as bars, shapes, sheets, etc. where ease of forming and joining are important and the more expensive grades are not needed, and where stiffness rather than strength is important.

Common Commercial Forms. Hot rolled bars, billets, slabs, plate, sheet, strip, shapes, wire, cold rolled bars, cold drawn bars.

Treatment Temperatures

Annealing	1600-1650F
Normalizing	1650-1700
Quenching	1650-1700
Carburizing	1650-1700
Carburizing, high quench	–
Carburizing, low quench	1400-1450
Process anneal	1000-1350

As Quenched Hardness
(Treatment 1675F for 8 hrs, furnace cool, reheat to 1425F, quench in water.)

	Center	Hardness Half Radius	Surface
½ in. diam	22 Rc	23 Rc	36.5 Rc
1 in. diam	90 Rb	91 Rb	99 Rb
2 in. diam	82 Rb	84 Rb	98 Rb
4 in. diam	78 Rb	80 Rb	97 Rb

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in %	Yield Point M psi	Red Area %	Hard BHN	Shear Stress Elastic M psi	Shear Stress Max M psi	Degs of Twist Elastic	Degs of Twist Max	NBT[6] Ft Lb
Hot rolled, turned } 1 in. rds, aver.[14]	–	47.2	–	39.7	32.2	66.5	113	19.84	60	3.0	2175	–
Cold drawn } 1 in. rds, aver.[14]	–	67	–	19.0	59.4	61.3	140	31.3	61.2	3.6	2070	–
Hot rolled or ann.[1] ¾-1¼ in. diam rd bars[2]	–	50 min	–	–	25 min	–	–	–	–	–	–	–
Cold rolled[1] ¼-3 in. diam bars	–	60/75	–	15/25	50/65	45/55	121/156	–	–	–	–	–
Hot rolled[3] } Approx aver.[4]	–	50/70	25/45	30/40	–	50/65	110/140	–	–	–	–	–
Cold drawn } Approx aver.[4]	–	70/85	60/70	15/25	–	45/55	149/170	–	–	–	–	–
As rolled[5]	–	61	–	39	45.5	61	126	–	–	–	–	81.5
Normal processing[15] } to 9/16 in.	–	64-84	52-72[16]	19-29	–	50-63	126-166	–	–	–	–	–
Normal processing[15] } > 9/16-1½ in. incl.	–	62-82	50-70[16]	18-28	–	50-63	121-163	–	–	–	–	–
Normal processing[15] } > 1½-3½ in. incl.	–	55-75	42-62[16]	18-25	–	40-55	123-156	–	–	–	–	–
Turned & polished[15], 2½-4 in. rd.	–	50-65	25-35	30-40	–	50-65	105-134	–	–	–	–	–
Aver. prop. 1 in. bars, cold drawn 1/16 in. draft[15] } cold drawn	–	72	–	28	48	64	146	–	–	–	–	–
Aver. prop. 1 in. bars, cold drawn 1/16 in. draft[15] } annealed &cold drawn	–	70	–	25	55	60	143	–	–	–	–	–
Normalized, 1700F, air cool[5]	–	60	–	38	48	61	121	–	–	–	–	82
Annealed, 1600F, furnace cool[5]	–	56	–	40	37.5	66	116	–	–	–	–	84
Core properties,[7] tested 0.505 in. rd[8]	–	77.5	–	32	51	71	174	–	–	–	–	82.5
Effect of Mass[9]												
As rolled { 1 in. diam, ctr.	–	62.5	–	35.5	40.5	66.4	126	–	–	–	–	87.3
As rolled { 2 in. diam, ½ r.	–	61.75	–	35.5	44	66.4	121	–	–	–	–	88.3
As rolled { 4 in. diam, ½ r.	–	59	–	35.5	34.5	64.7	116	–	–	–	–	79.5
Core properties, 1 in. diam, ctr[10]	–	73.25	–	32.0	45.5	71.2	149	–	–	–	–	91.5
Annealed, 1 in. diam, ctr[11]	–	61.25	–	37.0	51.25	69.7	111	–	–	–	–	83.3
Normalized, 1700F cool in air { ½ in. diam, ctr[12]	–	63.25	–	38.6	48	71.0	126	–	–	–	–	84.8
Normalized, 1700F cool in air { 1 in. diam, ctr	–	61.5	–	37.0	47	69.6	121	–	–	–	–	85.2
Normalized, 1700F cool in air { 2 in. diam, ½ r.	–	60	–	37.5	44.5	69.2	116	–	–	–	–	86.3
Normalized, 1700F cool in air { 4 in. diam, ½ r.	–	59.25	–	36.5	41.8	67.8	116	–	–	–	–	83.3
Mock carburized, 1675F for 8 hr, furnace cool, reheat to 1425F, quench in water, draw at 350F } ½ in. diam, ctr[12]	–	106.25	–	15.0	60	32.9	217	–	–	–	–	50
Mock carburized … } 1 in. diam, ctr	–	75.5	–	30.0	44	69.0	156	–	–	–	–	85
Mock carburized … } 2 in. diam, ½ r.	–	70.75	–	32.0	41.375	70.4	131	–	–	–	–	94
Mock carburized … } 4 in. diam, ½ r.	–	67.25	–	30.5	39	69.5	121	–	–	–	–	96
Effect of Temp:[13]												
Annealed at 1475F Composition .14C	70F	45.7	–	27.5	42.7	77.5	–	–	–	–	–	–
	-296	137	–	7.5	–	–	–	–	–	–	–	–
	-423	155	–	0.3	155	2.5	–	–	–	–	–	–

[1]ASTM, Spec. A108
[2]Tested full size.
[3]Turned and polished.
[4]Union Drawn Steel Co.
[5]Bethlehem Steel Co. – average values.
[6]Izod test, Vee notch
[7]Case depth 0.045 in; Hardness 66 Rc
[8]Carburized 8 hr at 1675F, pot cooled, reheated to 1425F and quenched in water, tempered at 350F. Size treated, 1 in. rd. Bethlehem Steel Co.
[9]Bethlehem Steel Co. Single heat results. Chemical composition. Ladle .16C, .52Mn, .015P, .038S and .18Si. Check .15C, .53Mn, .018P, .031S, and .17Si. Grain size. 100% 6-8 by McQuaid-Ehn Test. Size tested: 0.505 in. diam tension test bars and 0.450 in. diam. Izod test bars. Aver. values.
[10]Carburized 8 hr at 1675F, furnace cooled, reheated to 1425F, quenched in water, drawn at 350F. Case depth 0.048 in. Case hardness: 62 Rc.
[11]1600F, furnace cool at 30°F/hr to 1340F, cool in air.
[12]Size tested, 0.357 in. diam
[13]R. A. Hadfield, Jour. Iron and Steel Inst., 1905, I, 147.
[14]LaSalle Steel Co.
[15]Bliss & Laughlin.
[16]At .5% extension under load.

(Continued on page 148)

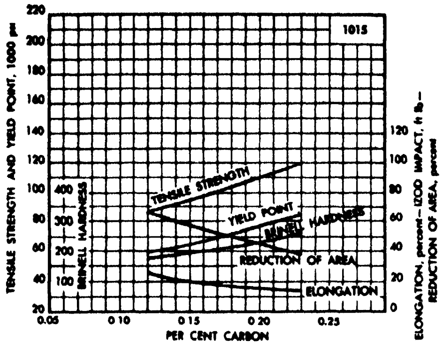
STEELS, AISI

1015

(Continued from page 147)

Source – International Nickel Co. Properties: Case hardened. Representative core properties of 1 in. bars, pseudo-carburized at 1650-1700F, direct quenched from the box into water and tempered at 300F. The values are representative of medium to fine grained steels as determined by the McQuaid-Ehn test. This chart covers the range from .12 to .23%C as found in the steels 1012, 1015, 1017, 1020 and 1023.

Direct Quench from the Box into Water



STEELS, AISI

1016 1018
1017 1019

Chemical Composition[1]

	C %	Mn %	P %	S %
C1016	.13-.18	.60-.90	.040 max	.050 max
C1017	.15-.20	.30-.60	.040 max	.050 max
C1018	.15-.20	.60-.90	.040 max	.050 max
C1019	.15-.20	.70-1.00	.040 max	.050 max

[1]AISI

Characteristics. Generally similar to C1015 except for a little greater strength from the higher C and Mn.

Typical Uses. It is normally used in the as-rolled condition as bars, shapes, sheets, etc. where ease of forming and joining are important and the more expensive grades are not needed, and where stiffness rather than strength is important.

Common Commercial Forms. Hot rolled bars, billets, slabs, plate, sheet, strip, shapes, wire, cold rolled bars, cold drawn bars.

Technological Properties Machinability[1]
(On basis of B1112 = 100)

C1016	78%
C1017	61
C1018	62-73
C1019	73
C1016	78 (ASM value for cold drawn to 137-174 BHN[2])

[1]ASM and industry values
[2]Metals Handbook

Treatment Temperatures For C1018[1]

Forging	2050-2350F
Normalizing	1650-1750
Annealing	1575-1650
Quenching	1600-1650

[1]Ryerson

Critical Points[1] **(Approx)**

	(1016)	(1019)
Ac_1	1350	1350
Ac_3	1560	1545
Ar_3	1520	1505
Ar_1	1260	1255

[1]Bliss & Laughlin

(Continued on page 149)

(Continued from page 148)

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red. Area %	Hard BHN	Izod Ft Lbs	Hard Rock C case	Degs of Twist Elastic	Degs of Twist Max	NBT Ft Lb[5]
C1016												
Hot rolled or ann.[1] ¾-1¼ in. diam	–	56 min	–	–	28 min	–	–	–	–	–	–	–
Cold drawn[1] ¼-3 in. diam	–	65-80	–	15-25	55-70	45-55	131-167	–	–	–	–	–
Hot rolled[2] turned and polished	–	60-80	30-50	30-40	–	50-65	137-170	–	–	–	–	–
Cold drawn[2]	–	75-90	65-75	15-25	–	50-65	170-187	--	–	–	–	–
Normal processing[9} to 9/16 in.	–	69-87	57-77[10]	16-26	–	53-65	137-174	–	–	–	–	–
Normal processing[9] > 9/16 - 1½ in. incl.	–	67-87	55-75[10]	15-25	–	53-65	134-174	–	–	–	–	–
Normal processing[9] > 1½ - 3½ in. incl.	–	58-80	43-63[10]	12-22	–	35-55	128-163	–	–	–	–	–
Turned and polished[9], 2½ - 4 in. rd.	–	53-67	–	30-40	26-36	50-65	112-137	–	–	–	–	–
Aver. prop.[9] 1 in. bars cold drawn 1/16 in. draft, cold drawn	–	77	–	20	65	60	159	–	–	–	–	–
Aver. prop.[9] 1 in. bars cold drawn 1/16 in. draft, annealed cold drawn	–	72	–	22	60	62	146	–	–	–	–	–
C1017												
Hot rolled[3] } 1 in. bars or sect, aver.	–	58	–	34	37.5	–	–	–	–	–	–	–
Cold drawn[3] } 1 in. bars or sect, aver.	–	72	62	20	–	–	–	–	–	–	–	–
C1018[4]												
Hot rolled, Not treated, Before Carburizing	–	69	–	30	47	58	143	54	–	–	–	–
Cold drawn, Not treated, Before Carburizing	–	78	–	23	53	54	165	52	–	–	–	–
Hot rolled, Normalized, Before Carburizing	–	68	–	30	45	59	143	56	–	–	–	–
Hot rolled, Annealed, Before Carburizing	–	63	–	32	42	60	135	58	–	–	–	–
Cold drawn[7] ⅝ - ⅞ in. incl.	–	70	60	18	–	40	143	–	–	–	–	–
Cold drawn[7] > ⅞ - 1¼ in. incl.	–	65	55	16	–	40	131	–	–	–	–	–
Cold drawn[7] > 1¼ - 2 in. incl.	–	60	50	15	–	35	121	–	–	–	–	–
Cold drawn[7] > 2 - 3 in. incl.	–	55	45	15	–	35	111	–	–	–	–	–
After carburizing 8 hrs at 1700 F, cooling in carburizing box and heat treating as shown: 1 in. rd, water-quenched 1625 F and tempered	No T	109	–	7	85	23	225	45	63	–	–	–
	300 F	108	–	9	84	27	225	56	62	–	–	–
	400	106	–	11	82	30	220	48	60	–	–	–
	500	102	–	14	79	36	217	50	58	–	–	–
	600	97	–	18	75	43	207	53	56	–	–	–
1 in. rd, double quenched oil – 1625F, water 1450F, and tempered	No T	98	–	19	70	50	201	53	62	–	–	–
	300	97	–	20	68	50	196	54	61	–	–	–
	400	96	–	21	66	51	196	57	60	–	–	–
	500	94	–	22	63	52	190	61	58	–	–	–
	600	91	–	24	59	54	182	66	56	–	–	–
1 in. rd, oil-quenched 1625F and tempered	No T	85	–	22	60	52	160	63	60	–	–	–
	300	85	–	22	60	52	160	64	59	–	–	–
	400	84	–	23	60	53	159	66	57	–	–	–
	500	83	–	24	60	54	158	70	55	–	–	–
	600	82	–	26	59	55	155	73	53	–	–	–
C1019								Shear Stress Elastic M psi	Shear Stress Max M psi			End Lt M psi
Hot rolled[3] } 1 in. bars or sect, aver.[8]	–	60	–	33	39	–	–			–	–	
Cold drawn[3] } 1 in. bars or sect, aver.[8]	–	74	64	18	–	–	–			–	–	
Hot rolled, turned } 1 in. rds, aver.	–	64.8	–	38.5	43	66	121	23.8	67.9	3.4	2129	–
Cold drawn } 1 in. rds, aver.	–	80.75	–	17.2	72.6	60.7	156	35.2	68.8	5.2	1927	–
Cold drawn[1] ¼-3 in. diam	–	68-83	–	15-25	58-78	40-55	149-183	–	–	–	–	–
Longitudinal, typ. or represent. for commercially rolled products[6]	–	64	36.3	43.5	–	66.5	–	–	–	–	–	88
Transverse, typ. or represent. for commercially rolled products[6]	–	61.8	32.7	36	–	53.7	–	–	–	–	–	35
Cold drawn or drawn - ground and polished[9] to 9/16 in. rd.	–	76-96	64-84[10]	16-26	–	50-63	153-197	–	–	–	–	36
Cold drawn or drawn - ground and polished[9] > 9/16 - 1½ in. rd.	–	74-94	62-82[10]	15-25	–	50-63	146-187	–	–	–	–	35
Cold drawn or drawn - ground and polished[9] > 1½ - 3½ in. rd.	–	65-85	50-70[10]	12-22	–	35-55	131-174	–	–	–	–	30.5
Turned and polished or turned, ground and polished[9] 1⅝ - 4 in. rd.	–	60-75	–	30-40	28-40	50-65	121-153	–	–	–	–	28
Aver. prop.[9] 1 in. rd. bars cold drawn 1/16 in. draft, cold drawn	–	84	–	20	72	58	170	–	–	–	–	–
Aver. prop.[9] 1 in. rd. bars cold drawn 1/16 in. draft, annealed cold drawn	–	77	–	21	65	60	156	–	–	–	–	–

[1]ASTM, Bull. tested as full sized bars.
[2]Union Drawn Steel Co., approx values.
[3]Jones and Laughlin Steel Corp.
[4]Ryerson, aver values.
[5]Charpy Vee notch
[6]ASM, Metals Handbook. Data from Battelle Memorial Institute.
[7]AISI Steel Products Manual, Section 9.
[8]LaSalle Steel Co.
[9]Bliss & Laughlin.
[10]At .5% extension under load.

NOTE: Recommended treatment for case hardening—carburize and quench from 1600F in water or brine for maximum core strength, or from 1425F in water for maximum case hardness and freedom from distortion.

STEELS, AISI

1020

Treatment Temperatures

Annealing	1600-1650 F
Normalizing	1650-1750
Quenching	1600-1675
Carburizing	1650-1700
Process anneal	1000-1350

Critical Points[1]

Ac_1	1350 F	Ar_3	1470 F
Ac_3	1540	Ar_1	1340

[1]Data from Bethlehem Steel Co.

Technological Properties
Machinability (On basis of B1112 = 100) Cold drawn to 137-174 BHN = 65%. (ASM Metals Handbook) Union Drawn Steel gives 72%.

Chemical Composition

C	Mn	P	S
%	%	%	%
.18-.23	.30-.60	.040 max	.050 max

Characteristics. Similar to C1015 though it is somewhat stronger and less easily formed cold. In the case-hardened condition it has higher core strength than C1015. As with similar steels, soft spots in the case can be guarded against by specifying that the steel be "normal" in the McQuaid-Ehn Test; the type which gives an "abnormal" structure will have soft, unhardened areas. Another aid is the use of a NaOH or NaCl solution for quenching, while the steel C1022 may be used to take advantage of its higher Mn content.

Typical Uses. Internal combustion engine parts in the case-hardened condition where core strength is not critical, spline shafts of larger cross section which are not highly stressed, lightly stressed gears with hard wearing surfaces, case-hardened pins. Also used for chains, see below.

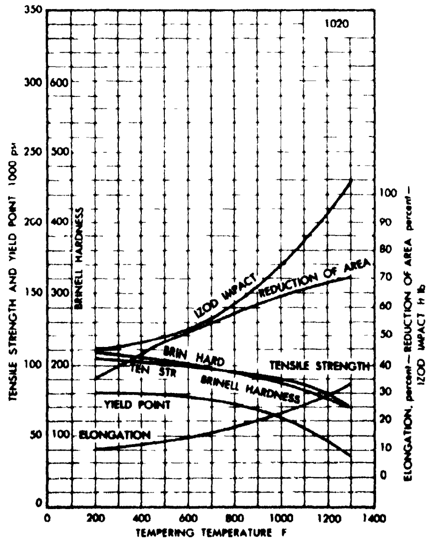
Common Commercial Forms. Hot rolled bars, billets, slabs, plate, sheet, strip, wire, cold rolled bars, cold drawn bars, shapes.

As Quenched Hardness
(Treatment 1675F for 8 hrs, and furnace cooled; 1425F quenched in water.)

Diam	Center	Hardness Half Radius	Surface
½ in.	28 Rc	30 Rc	40.5 Rc
1 in.	93 Rb	96 Rb	29.5 Rc
2 in.	83 Rb	85 Rb	95 Rb
4 in.	77 Rb	78 Rb	94 Rb

Source – International Nickel Co. Treatment: Water quenched from 1575-1625F and drawn. Size treated 1 in. diam or thickness. Size tested. Not stated but probably 0.505 in. diam. The values are representative of this steel.

Quenched and Drawn Parts



Heat Treated Chains: Source – ASM Metals Handbook. The chain of approximately C1020 analysis is heat treated to about the following properties 55 Mpsi YS, 85 Mpsi TS; 28% Elong. in 2 in.; 45% RA. It then resists work hardening and low temperature embrittlement and should not require annealing.

(Continued on page 151)

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red. Area %	Hard BHN	Shear Stress Elastic M psi	Shear Stress Max M psi	Degs of Twist Elastic	Degs of Twist Max	NBT Ft Lb[4]
Hot rolled, turned, 1 in. rds, aver.[13]	–	50.46	–	39.1	36.65	66.1	117	19.95	62.46	3.1	2109	–
Cold drawn, 1 in. rds, aver.[13]	–	70.05	–	17.2	68.75	59.4	148	33.6	62.7	4.1	1901	–
Hot rolled or ann., rds.	–	56 min	28 min	–	–	–	–	–	–	–	–	–
Cold drawn, range, rds.[1]	–	68-83	55-70	15-25	–	40-50	149-183	–	–	–	–	–
Cold drawn, aver, 3/8 - 2 in. rds.[2]	–	75.0	63.7	20	–	52	156	–	–	–	–	–
Rolled; Size treated, 1 in. diam; size tested, 0.505 in. diam[3]	–	65	–	36	43	59	143	–	–	–	–	64
Normalized; Size treated, 1 in. diam; size tested, 0.505 in. diam[3]	1700F	64	–	37	39	60	137	–	–	–	–	72
Annealed; Size treated, 1 in. diam; size tested, 0.505 in. diam[3]	1600	60	–	38	36.5	60	126	–	–	–	–	80
Normal Processing[14], to 9/16 in.	–	70-90	58-78[15]	16-26	–	48-61	137-183	–	–	–	–	–
Normal Processing[14], > 9/16 - 1½ in. incl.	–	68-88	56-76[15]	15-25	–	48-61	134-179	–	–	–	–	–
Normal Processing[14], > 1½ - 3½ in. incl.	–	61-82	45-65[15]	12-22	–	35-55	128-166	–	–	–	–	–
Turned and polished[14], 2½ - 4 in. rd.	–	55-70	–	30-40	25-38	50-65	114-143	–	–	–	–	–
Aver. prop.[14] 1 in. rd. bars cold drawn 1/16 in. draft, cold drawn	–	78	–	20	68	55	159	–	–	–	–	–
Aver. prop.[14] 1 in. rd. bars cold drawn 1/16 in. draft, annealed cold drawn	–	73	–	22	61	58	149	–	–	–	–	–
Core, fine grained, 1 in. rds.[5] aver.	–	96	–	19	60	41	192	–	–	–	–	48
Fine grain, size 8[6], Box quench[7]	–	102	–	–	–	54.4	–	–	–	–	–	42
Coarse grain, size 2-3[6], Box quench[7]	–	109	–	–	–	39.5	–	–	–	–	–	16
Fine grain, size 8[6], Single quench[7]	–	83	–	–	–	62.2	–	–	–	–	–	58
Coarse grain, size 2-3[6], Single quench[7]	–	92	–	–	–	45.8	–	–	–	–	–	13
Fine grain, size 8[6], Double quench[7]	–	82	–	–	–	69.2	–	–	–	–	–	99
Coarse grain, size 2-3[6], Double quench[7]	–	86	–	–	–	59.2	–	–	–	–	–	52
Effect of Mass												
Single heat, mean comp, tension test bars 0.505 in. diam, notched test bars 0.450 in. rd. Aver.[8]: As rolled, 1 in., ctr.	–	68.5	–	32.0	55.75	66.5	137	–	–	–	–	84
As rolled, 2 in. ½ r.	–	62	–	34.5	37.5	63.5	126	–	–	–	–	60
As rolled, 4 in. ½ r.	–	60.25	–	34.3	32.75	62.3	121	–	–	–	–	66
Annealed[9] 1 in. ctr.	–	57.25	–	36.5	52.75	66	111	–	–	–	–	80
Normalized at 1700F, ½ in. ctr.[10]	–	64.5	–	39.3	50.25	69.1	131	–	–	–	–	91
Normalized at 1700F, 1 in. ctr.	–	64	–	35.8	50.25	67.9	131	–	–	–	–	87
Normalized at 1700F, 2 in. ½ r.	–	63.5	–	35.5	46.5	65.5	126	–	–	–	–	83
Normalized at 1700F, 4 in. ½ r.	–	60	–	36.0	40.75	66.6	121	–	–	–	–	84
Core Prop: 1 in. diam[11]	–	74.25	–	31.3	48.25	70.9	156	–	–	–	–	94
Mock carburized, 1675F for 8 hr, furnace cooled 1425F and quenched in water Dr at 350F, ½ in. ctr.[10]	–	129	–	11.4	72	29.4	255	–	–	–	–	40
Mock carburized, 1 in. ctr.	–	89	–	23.0	54	64.2	179	–	–	–	–	80
Mock carburized, 2 in. ½ r.	–	75.5	–	31.3	43.75	67.9	156	–	–	–	–	98
Mock carburized, 4 in. ½ r.	–	71.25	–	33.0	43.25	67.6	143	–	–	–	–	97
Effect of temp[12]	70	62.6	–	35.5	39.8	53	–	–	–	–	–	–
	-114	69	–	35.5	47.8	56.8	–	–	–	–	–	–

[1] ASTM Bulletin, October, 1947.
[2] ASM Metals Handbook.
[3] Bethlehem Steel Co. Commercial rds, Aver. prop.
[4] Izod test with Vee notch.
[5] Size tested = 0.505 in. rd. Case Depth = 0.050 in. Hardness = 66 Rc. Treatment—Cool in the box, reheat to 1400-1450F and quench in oil, Dr at 350-425F, after carburizing 8 hr at 1675F. Bethlehem Steel Co.
[6] McQuaid-Ehn test.
[7] International Nickel Co. with data from H.W. McQuaid and O.W. McMullan.
[8] Bethlehem Steel Co. Ladle analysis: .19C, .48Mn, .014P, .030S, .18Si. Check analysis .18C, .48Mn, .012P, .022S, .18Si. McQuaid-Ehn grain size = 100% 6-8.
[9] Annealed at 1600F, cooled at 30°F/hr to 1290F, air cooled.
[10] Tensile test bar size 0.357 in. diam.
[11] Treatment—carburized 8 hr at 1675F, furnace cooled, reheat to 1425F and quenched in water, Dr at 350F. The case depth was 0.046 in. and the case hardness, 62 Rc.
[12] J. W. Sands, Indus. Heating, June 1937. Comp. C1020 with 0.21%C.
[13] LaSalle Steel Co.
[14] Bliss & Laughlin.
[15] At .5% elongation under load.

NOTES:
Case-Hardened Parts' Treatments. Carburize at 1650-1700F.
1) Quench from the box in oil, Dr at 350-425F.
2) Cool in the box, reheat to 1400-1450F and quench in oil, Dr at 350-425F.
3) Cool in the box, reheat to 1550F and quench in oil, reheat to 1400-1450F and quench in oil, Dr at 350-425F.

Treatment and Test Bars: Unnotched Charpy bars, carburized 4 hr at 1650F to a depth of 0.030 in., reheated to 1425F and quenched in water, and Dr at 300F. The test bars were broken as usual, but not notched.

Test Temp	210F	70F	20F	-15F	-70F
Ft Lbs	45	8	5	4	3

R. Sergeson, Trans. ASST, 1932, Vol. 19, p. 368.

SPECIAL CASTINGS

1022

Chemical Composition	C %	Mn %	P %	S %
C1022	.18-.23	.70-1.00	.040 max	.050 max

Technological Properties
Machinability: Drawn to 159-192 BHN = 78%
(On basis of B1112 = 100)

Characteristics. C1022 is similar to C1020. Its higher Mn makes it surer in heat treatment and better adapted to use in larger sections than 1020.

Physical Properties[1,2]
Density 0.2839 lb/cu in. (7.859 S. G.)
[1]Steel. .23C, .63Mn, .11Si, annealed
[2]ASM Metals Handbook

Critical Points[1]

Ac_1	1360F	Ar_3	1440F
Ac_3	1530	Ar_1	1300

[1]Bethlehem Steel Co.

Treatment Temperatures

Annealing	1600-1650F
Normalizing	1650-1750
Quenching	–
Carburizing	1650-1700

Coef. of Thermal Expansion[1,2]

Temp Range Deg C	Temp Range Deg F	Coefficient α $\times 10^{-6}/^{\circ}C$	Coefficient α $\times 10^{-6}/^{\circ}F$
0-100	32-212	12.2	6.8
0-200	32-392	12.7	7.0
0-300	32-572	13.1	7.3
0-400	32-752	13.5	7.4
0-500	32-932	13.9	7.7
0-600	32-1112	14.4	8.0
0-700	32-1292	14.9	8.3

[1]Steel: .23C, .63Mn, .11Si, annealed
[2]ASM Metals Handbook

As Quenched Hardness
(Treatment: 1675F for 8 hrs, and furnace cooled, reheated to 1425F quenched in water.)

Diam	Center	Hardness Half Radius	Surface
½ in.	27 Rc	29 Rc	45 Rc
1 in.	92 Rb	95 Rb	41 Rc
2 in.	84 Rb	88 Rb	38 Rc
4 in.	81 Rb	84 Rb	34 Rc

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red. Area %	Hard BHN	Shear Stress Elastic M psi	Shear Stress Max M psi	Degs of Twist Elastic	Degs of Twist Max	NBT, Ft Lb[3]
Hot rolled, turned, 1 in. rds, aver.[10]	64.8	–	38.5	43	66	121	23.8	67.9	3.4	2129	–
Cold drawn, 1 in. rds, aver.[10]	80.75	–	17.2	72.6	60.7	156	35.2	68.8	5.2	1927	–
As rolled or ann.[1] ¾-1¼ in. diam	63 min	–	–	31.5 min	–	–	–	–	–	–	–
Cold drawn[1] 3 in. diam	70-90	–	15-25	60-80	40-50	163-197	–	–	–	–	–
As rolled[2]	73	–	35	52	67	149	–	–	–	–	60
Normalized[2]	70	–	36	49	68	137	–	–	–	–	70
Annealed[2]	67	–	36	46	69	131	–	–	–	–	73
Normal Processing[11] to 9/16 in.	78-98	66-86[12]	16-26	–	50-63	156-197	–	–	–	–	–
Normal Processing[11] > 9/16 - 1½ in. incl.	76-96	64-84[12]	15-25	–	50-63	153-192	–	–	–	–	–
Normal Processing[11] > 1½ - 3½ in. incl.	68-88	53-73[12]	12-22	–	30-50	137-179	–	–	–	–	–
Turned and polished[11], 2½ - 4 in. rd.	63-75	–	30-40	30-43	45-60	126-156	–	–	–	–	–
Aver. prop.[11] 1 in. rd. bars cold drawn 1/16 in. draft: cold drawn	86	–	20	76	58	174	–	–	–	–	–
Aver. prop.[11] 1 in. rd. bars cold drawn 1/16 in. draft: annealed, cold drawn	80	–	21	70	60	163	–	–	–	–	–
Case hardened—core[2,4]	97	–	26	61	47	207	–	–	–	–	36
Effect of Mass											
Single heat, aver. Tension test bars 0.505 in. diam, Izod test bars 0.450 in. diam[3]: As rolled 1 in., ctr.	70.25	–	33.0	52.25	65.2	137	–	–	–	–	82
As rolled 2 in., ½ r.	70.75	–	33.0	44.25	64.4	137	–	–	–	–	87
As rolled 4 in., ½ r.	65.25	–	33.5	39.25	62.7	131	–	–	–	–	80
Annealed[6] 1 in., ctr.	65.25	–	35.0	51.5	63.6	137	–	–	–	–	89
Normalized 1700F air cooled ½ in., ctr.[7]	70.5	–	35.7	50	68.3	143	–	–	–	–	88
Normalized 1700F air cooled 1 in., ctr.	70	–	34.0	49.5	67.5	143	–	–	–	–	86
Normalized 1700F air cooled 2 in., ½ r.	68.75	–	34.0	45.25	66.6	137	–	–	–	–	90
Normalized 1700F air cooled 4 in., ½ r.	67.25	–	33.8	45	63.9	131	–	–	–	–	85
Core[8] 1 in., ctr.	81	–	26.3	45.375	65.9	163	–	–	–	–	85
Mock carburized prop[9] ½ in., ctr.[7]	117.5	–	11.1	63.25	27.0	248	–	–	–	–	13
Mock carburized prop[9] 1 in., ctr.	87	–	25.5	55	57.3	179	–	–	–	–	70
Mock carburized prop[9] 2 in., ½ r.	82	–	30.0	50.25	69.6	163	–	–	–	–	105
Mock carburized prop[9] 4 in., ½ r.	74	–	32.5	40.25	71.6	149	–	–	–	–	98

[1]ASTM Bulletin.
[2]Bethlehem Steel Co. for fine grained steel
[3]Izod test with Vee notch.
[4]Carburized 8 hr at 1675F, pot cooled, reheated to 1425F, water quenched, Dr at 350F. Case depth = .056 in. Case hardness = 66Rc.
[5]Bethlehem Steel Co. Chemical comp—Ladle. .20C, .83Mn, .015P, .031S, .19Si. Check: .22C, .82Mn, .016P, .023S, .20Si. McQuaid-Ehn Grain Size = 100% 6-8.
[6]1600F, furnace cooled at 30°F/hr to 1250F and air cooled.
[7]Tensile test bar was 0.357 in. diam.
[8]Carburized 8 hr at 1675F, cooled in furnace, reheated to 1425F, quenched in water, drawn at 350F. Case hardness = 62Rc. Case depth = 0.046 in.
[9]Heated 8 hr at 1675F, furnace cooled, reheated to 1425F, quenched in water, drawn at 350F.
[10]LaSalle Steel Co.
[11]Bliss & Laughlin.
[12]At .5% extension under load.

Chemical Composition

	C %	Mn %	P %	S %
C1023	.20-.25	.30-.60	.040 max	.050 max
C1025	.22-.28	.30-.60	.040 max	.050 max

Critical Points (Approx) (1025)

Ac_1	1355F	Ar_3	1440F
Ac_3	1530	Ar_1	1285

Technological Properties
Machinability - 64% (On basis of B1112 - 100)

Electrical Resistivity[1]

Temp Range Deg C	Deg F	Micro-cm	Temp Range Deg C	Deg F	Micro-cm
20	68	16.9	800	1472	109.4
100	212	21.9	900	1652	113.6
200	392	29.2	1000	1832	116.7
400	752	48.7	1100	2012	119.4
600	1112	75.8	1200	2192	121.9
700	1292	92.5	1300	2372	123.9

[1]Ntl Phys Lab. Jour. Iron and Steel Inst , 1946, II. Steel .23C, 635Mn, 07Ni, .13Cu, Tr Cr

Physical Properties[1]

[1]Ntl Phys. Lab. Jour. Iron and Steel Inst., 1946, II. Steel: .23C, 635Mn, 07Ni, .13Cu, Tr. Cr.

Thermal Conductivity[1]

Temp Range Deg C	Deg F	Cal/cm²/cm/°C/sec	Btu/sec/ft²/°F/in.
0	32	.124	[illegible]
100	212	.122	.098
200	392	.117	.094
300	572	.110	.089
400	752	.102	.082
500	932	.094	.076
600	1112	.085	.068
700	1292	.076	.061
800	1472	.062	.050
1000	1832	.065	.052
1200	2192	.071	.057

[1]Ntl. Phys. Lab. Jour. Iron and Steel Inst., 1946, II Steel .23C, .635Mn, .07Ni, .13Cu, Tr. Cr.

Mean Apparent Specific Heat[1]

Temp Range Deg C	Deg F	Cal/gm/°C	Temp Range Deg C	Deg F	Cal/gm/°C
50-100	122-212	.116	450-500	842-932	.158
150-200	302-392	.124	550-600	1022-1112	.179
200-250	392-482	.127	650-700	1202-1292	.202
250-300	482-572	.133	700-750	1292-1382	.342
300-350	572-662	.137	750-800	1382-1472	.227
350-400	662-752	.143			

[1]Ntl. Phys. Lab. Jour. Iron and Steel Inst., 1946, II. Steel .23C, .635Mn, .07Ni, .13Cu, Tr Cr

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red. Area %	Hard BHN	Shear Stress Elastic M psi	Shear Stress Max M psi	Degs of Twist Elastic	Degs of Twist Max
C1023											
Hot rolled[1] } 1 in. sect. aver.	–	64	–	31	42	–	–	–	–	–	–
Cold drawn } 1 in. sect. aver.	–	78	68	17	–	–	–	–	–	–	–
C1025											
Hot rolled, turned } 1 in. rds, aver.[4]	–	61	–	35.0	38.3	64.8	131	27.2	65.2	3.6	2011
Cold drawn } 1 in. rds, aver.[4]	–	80.2	–	17.2	74.2	59.2	161	33.6	68.3	4.6	1605
As rolled or ann.[2] ¾-1¼ in. diam.	–	60 min	–	–	30 min	–	–	–	–	–	–
As drawn[2]	–	70-90	–	15-25	60-80	35-45	163-197	–	–	–	–
As drawn[3] ⅝-2 in. diam, aver.	–	80	68	18.5	–	50	163	–	–	–	–
Hot rolled, Cold drawn[4] to 9/16 in.	–	82-102	70-90	15-25	–	45-58	163-207	–	–	–	–
Hot rolled, Cold drawn[4] > 9/16 - 1½ in. incl.	–	80-100	65-85	14-24	–	45-58	156-187	–	–	–	–
Hot rolled, Cold drawn[4] > 1½ - 3½ in. incl.	–	72-92	60-80	12-22	–	30-50	137-187	–	–	–	–
Hot rolled, turned and polished[4] } 2¼ - 4 in.	–	65-80	40-50	25-35	–	45-65	131-163	–	–	–	–
Quenched and tempered[6] heat treated in 1 in. diam sect. Tensile specimen 0.505 in. diam cut at bar center. Water quenched	400 F	103	–	12	82	45	212	–	–	–	–
	600	101	–	14	78	52	207	–	–	–	–
	800	96	–	18	72	57	192	–	–	–	–
	1000	92	–	22	65	62	187	–	–	–	–
	1200	86	–	26	54	65	174	–	–	–	–
Aver. prop.[6] 1 in. rd. bars cold drawn 1/16 in. draft } cold drawn	–	87	72	19	–	50	174	–	–	–	–
Aver. prop.[6] 1 in. rd. bars cold drawn 1/16 in. draft } annealed cold drawn	–	81	68	21	–	55	163	–	–	–	–

[1]Jones and Laughlin Steel Corp.
[2]ASTM
[3]ASM Metals Handbook
[4]LaSalle Steel Co.
[5]AISI.
[6]Bliss & Laughlin.

STEELS, AISI

1029 1030

Critical Points[1]

Ac_1	1350F	Ar_3	1395F
Ac_3	1485	Ar_1	1250

[1]Bethlehem Steel Co.

Chemical Composition

	C %	Mn %	P %	S %
C1029	.25-.31	.60-.90	.040 max	.050 max
C1030	.28-.34	.60-.90	.040 max	.050 max

Characteristics. C1029 and C1030 are water-hardening steels, suitable for small parts of moderate strength.

Uses. For cold headed parts, after normalizing, annealing or (more frequently) spheroidizing annealing to improve workability, and then quenched and drawn for final properties. Used for machinery parts and can be machined after heat treatment to a hardness of less than 320 BHN, for moderate duty. For gears and sprockets of moderate strength and can be surface-hardened in a cyanide or activated bath.

Technological Properties
Relative machinability (On basis of B1112 = 100)
Cold drawn to 170-212 BHN = 65%, according to ASM Metals Handbook. A lower "industry" value of 57% has been given.

As Quenched Hardness

	Center	Hardness Half Radius	Surface
½ in. diam	23 Rc	50 Rc	50 Rc
1 in. diam	21 Rc	23 Rc	46 Rc
2 in. diam	90 Rb	93 Rb	30 Rc
4 in. diam	85 Rb	88 Rb	97 Rb

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in %	Yield Point M psi	Red Area %	Hard BHN	Shear Stress Elastic M psi	Shear Stress Max M psi	Degs of Twist Elastic	Degs of Twist Max	NBT Ft Lb[2]
As rolled (1 in. diam, aver. tested 0.505 in. diam[2])	–	80	51	32	–	55	179	–	–	–	–	55
Annealed, 1550F (1 in. diam, aver. tested 0.505 in. diam[2])	–	77	50	32	–	58	163	–	–	–	–	62
Normalized, 1700F (1 in. diam, aver. tested 0.505 in. diam[2])	–	78	53	30	–	53	167	–	–	–	–	60
Rolled or annealed[3] Bars	–	68 min	–	–	34 min	–	–	–	–	–	–	–
Cold drawn[3] Bars	–	75-95	–	13-22	65-85	35-45	179-207	–	–	–	–	–
Cold drawn, ⅝-2 in.[4] Bars	–	87	–	17.5	73.9	48	179	–	–	–	–	–
C1029												
Hot rolled (1 in. sect., aver.[5])	–	71	–	29	46	–	–	–	–	–	–	–
Cold drawn (1 in. sect., aver.[5])	–	85	75	16	–	–	–	–	–	–	–	–
C1030												
Hot rolled, turned (1 in. rds, aver.[9])	–	72	–	31.0	44.1	63	140	29.4	71.2	4.0	1907	–
Cold drawn (1 in. rds, aver.[9])	–	83.5	–	16.0	76	57	177	35.1	71.7	5.2	1520	–
Hot rolled, Cold drawn[10] to 9/16 in.	–	88-108	76-96	12-22	–	45-58	179-223	–	–	–	–	–
Hot rolled, Cold drawn[10] > 9/16 - 1½ in. incl.	–	83-103	68-88	12-22	–	40-53	163-217	–	–	–	–	–
Hot rolled, Cold drawn[10] > 1½ - 3½ in. incl.	–	76-96	63-83	12-22	–	30-50	149-197	–	–	–	–	–
Hot Rolled, Turned & Polished, 2¼ - 4 in.	–	70-85	42-52	22-32	–	40-60	143-174	–	–	–	–	–
Water quenched and tempered heat treated in 1 in. diam. section; tensile specimen .505 in. diam. cut at bar ctr.[10]	400F	123	–	17	93	46	495[11]	–	–	–	–	–
	600	116	–	19.	90	52	401[11]	–	–	–	–	–
	800	107	–	23	84	60	302[11]	–	–	–	–	–
	1000	97	–	28	75	66	255[11]	–	–	–	–	–
	1200	87	–	32	64	70	201[11]	–	–	–	–	–
Aver. prop.[10] 1 in. rd. bars cold drawn 1/16 in. draft — cold drawn	–	90	76	18	–	48	183	–	–	–	–	–
Aver. prop.[10] 1 in. rd. bars cold drawn 1/16 in. draft — annealed cold drawn	–	85	70	20	–	54	174	–	–	–	–	–
Effect of Mass[6] (Tensile test, 0.505 in. diam; Izod, 0.450 in. diam. Aver.)												
Annealed[7] 1 in. ctr.	–	67.25	–	31.2	49.5	57.9	126	–	–	–	–	51
Normalized 1700F, A.C. ½ in.[8] ctr.	–	77.5	–	32.1	50	61.1	156	–	–	–	–	70
Normalized 1700F, A.C. 1 in. ctr.	–	75.5	–	32.0	51	60.8	149	–	–	–	–	69
Normalized 1700F, A.C. 2 in. ½ r.	–	74	–	29.5	49.5	58.9	137	–	–	–	–	63
Normalized 1700F, A.C. 4 in., ½ r.	–	72.5	–	29.7	47.25	56.2	137	–	–	–	–	61
Quenched and Tempered 1700F, A.C. 1600F, W.Q.												
Tempered 1000F ½ in.[8] ctr.	–	91.5	–	28.2	75	58.0	187	–	–	–	–	88
Tempered 1000F 1 in., ctr.	–	88	–	28.0	68.5	68.6	179	–	–	–	–	92
Tempered 1000F 2 in., ½ r.	–	86.5	–	28.2	63.75	65.9	170	–	–	–	–	93
Tempered 1000F 4 in., ½ r.	–	80.75	–	32	54.75	68.2	163	–	–	–	–	95
Tempered 1100F ½ in.[8] ctr.	–	88.5	–	28.9	64	69.7	179	–	–	–	–	94
Tempered 1100F 1 in., ctr.	–	85.25	–	29.0	67.75	70.8	170	–	–	–	–	99
Tempered 1100F 2 in., ½ r.	–	83.75	–	29.0	57.75	69.1	167	–	–	–	–	101
Tempered 1100F 4 in., ½ r.	–	80.3	–	32.0	54.5	68.5	163	–	–	–	–	96
Tempered 1200F ½ in.[8] ctr.	–	85.5	–	30.0	62	70.5	174	–	–	–	–	99
Tempered 1200F 1 in., ctr.	–	84.5	–	28.5	61.5	71.4	170	–	–	–	–	103
Tempered 1200F 2 in., ½ r.	–	80	–	30.2	56.75	70.9	156	–	–	–	–	105
Tempered 1200F 4 in., ½ r.	–	74.5	–	34.2	49.5	71.0	149	–	–	–	–	101

[1]Bethlehem Steel Co.
[2]Izod test with Vee notch.
[3]ASTM Bulletin 1947, Comm.
[4]ASM Metals Handbook.
[5]Jones and Laughlin Steel Corp.
[6]Bethlehem Steel Co., single heat values. Analysis—Ladle: .32C, .68Mn, .011P, .033S, .15Si. Check: .31C, .65Mn, .023P, .026S, .14Si. McQuaid-Ehn Grain Size = 100% 5-7.
[7]1550F, furnace cooled at 20F/hr to 1200F, A.C.
[8]The tensile test bar was 0.357 in. diam.
[9]LaSalle Steel Co.
[10]Bliss & Laughlin.
[11]Hardness determined at surface of quenched 1 in. rd.

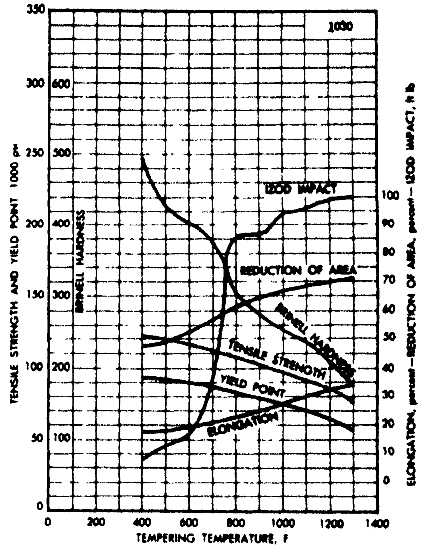
(Continued on page 155)

(Continued from page 154)

STEELS, AISI

1029 1030

Quenched and Tempered



Treatment: Normalized ⟶ at 1700F, water quenched from 1600F, and drawn.

STEELS, AISI

1034 1035

Treatment Temperatures

Forging	2000-2250F
Normalizing	1600-1700
Annealing	1475-1550
Quenching	1525-1575
Quenching, W[1]	1525
Quenching, Oil[1]	1575

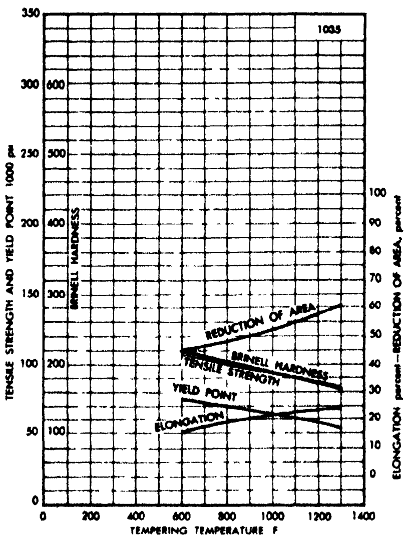
[1]Union Drawn Steel Co Quench in oil for thin or intricate sections.

Critical Points[1]

Ac_1	1345F	Ar_3	1455F
Ac_3	1475	Ar_1	1275

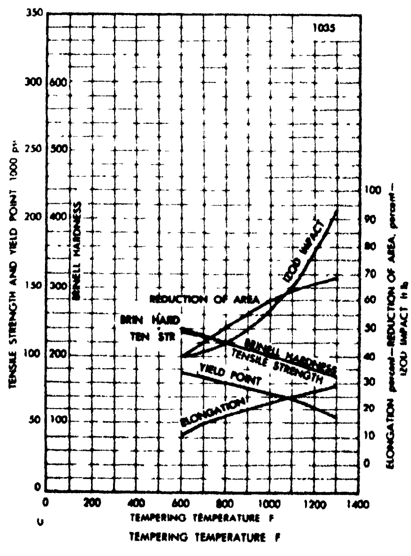
[1]Ryerson

Oil Quenched and Tempered



Source—International Nickel Co. Treatment. Quenched as 1 in. sections from 1525-1575F.

Water Quenched and Tempered



(Continued on page 156)

1034 1035

(Continued from page 155)

Technological Properties
Machinability — C1035
(On basis of B1112 = 100)
Cold drawn to 174-217BHN = 65%[1]
Hot rolled = 70%
Cold drawn = 70%
[1]ASM Metals Handbook

Chemical Composition

	C %	Mn %	P %	S %
C1034	.32-.38	.50-.80	.040 max	.050 max
C1035	.32-.38	.60-.90	.040 max	.050 max

Characteristics. Similar to C1030 but has a little greater hardenability and higher strength. Like C1030 it has moderate strength and hardness in the as-rolled or as-forged condition and can be strengthened by cold drawing. The presence of residual alloys may raise the hardenability and cause cracking in water quenching. These medium carbon steels are satisfactory for forging and brazing and fair for welding.

Uses. Typical applications are shafts, bolts, medium strength parts. It may be water quenched, or quenched in brine or caustic and used as gears or sprockets of moderate strength.

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red. Area %	Hard BHN	Shear Stress Elastic M psi	Shear Stress Max M psi	Degs of Twist Elastic	Degs of Twist Max	NBT Ft Lb[6]
C1035 Bars												
Hot rolled, turned } 1 in. rds, aver.[8]	–	79.1	–	30.0	48.5	60.0	150	34.2	76	4.4	1805	–
Cold drawn } 1 in. rds, aver.[8]	–	90.5	–	15.3	83.0	53.5	181	36.4	77.2	5.7	1445	–
Hot rolled or ann, ¾-1¼ in.[1] bars	–	73 min	–	–	36.5 min	–	–	–	–	–	–	–
Cold drawn[1]	–	80-100	–	12-20	70-90	35-45	179-217	–	–	–	–	–
Cold drawn, ⅝ - 2 in. diam[2]	–	92	–	17	78.2	45	187	–	–	–	–	–
Hot rolled } 1 in. sect, aver[3]	–	82	–	26	52	–	–	–	–	–	–	–
Cold drawn } 1 in. sect, aver[3]	–	93	83	14	–	–	–	–	–	–	–	–
Hot rolled, turned and polished } Approx[4]	–	70-90	30-50	20-30	–	35-50	143-182	–	–	–	–	–
Cold drawn } Approx[4]	–	90-110	75-90	10-20	–	40-55	170-202	–	–	–	–	–
Hot rolled } Aver[5]	–	85	–	30	54	53	183	–	–	–	–	–
Hot rolled, normalized } Aver[5]	–	86	–	31	56	59	176	–	–	–	–	–
Hot rolled, annealed } Aver[5]	–	81	–	31	52	59	163	–	–	–	–	–
Cold drawn	–	92	–	25	59	50	201	–	–	–	–	–
Cold drawn[9] ⅝ - ⅞ in. incl.	–	85	75	13	–	35	170	–	–	–	–	–
> ⅞ - 1¼ in. incl.	–	80	70	12	–	35	163	–	–	–	–	–
> 1¼ - 2 in. incl.	–	75	65	12	–	35	149	–	–	–	–	–
> 2 - 3 in. incl.	–	70	60	10	–	30	143	–	–	–	–	–
Quenched in water, 1525 to 1575F, tempered at 800F[10]	–	110	–	17.5	81	51 0	220	–	–	–	–	–
Hot rolled, cold drawn[10] to 9/16 in.	–	93-113	78-98	12-22	–	40-53	192-228	–	–	–	–	–
> 9/16 - 1½ in. incl.	–	86-106	71-91	12-22	–	40-53	170-217	–	–	–	–	–
> 1½ - 3½ in. incl.	–	80-100	67-87	11-21	–	30-50	163-212	–	–	–	–	–
Hot rolled, turned & polished[10], 2¼ - 4 in.	–	75-90	45-55	20-30	–	40-60	156-187	–	–	–	–	–
Water quenched and tempered heat treated in 1 in. diam. section, tensile specimen 0.505 in. diam. cut at bar ctr[10]	400 F	126	–	17	95	46	495[11]	–	–	–	–	–
	500	122	–	18	92	52	415[11]	–	–	–	–	–
	800	115	–	22	,88	58	321[11]	–	–	–	–	–
	1000	102	–	26	80	63	262[11]	–	–	–	–	–
	1200	92	–	30	69	69	207[11]					
Aver. prop.[10] 1 in. rd. bars } cold drawn	–	95	78	17	–	47	193	–	–	–	–	–
cold drawn 1/16 in. draft. } annealed cold drawn	–	90	76	19	–	53	181	–	–	–	–	–
Quenched and Tempered Aver.[5] — Water quenched at 1525F and tempered as shown, 1 in. rd.	No T	151	–	9	125	34	341	–	–	–	–	14
	400 F	146	–	10	122	39	331	–	–	–	–	14
	500	135	–	12	113	43	311	–	–	–	–	15
	600	127	–	15	102	47	293	–	–	–	–	17
	700	118	–	18	95	50	269	–	–	–	–	20
	800	113	–	21	86	54	255	–	–	–	–	29
	900	108	–	22	82	58	241	–	–	–	–	38
	1000	103	–	24	78	62	229	–	–	–	–	45
	1100	97	–	26	72	64	219	–	–	–	–	50
	1200	91	–	28	67	66	207	–	–	–	–	53
Oil quenched at 1550F and tempered as shown, 1 in. rd.	No T	115	–	10	85	40	262	–	–	–	–	16
	400	112	–	12	79	42	255	–	–	–	–	18
	500	109	–	13	77	43	248	–	–	–	–	22
	600	107	–	15	75	45	241	–	–	–	–	25
	700	104	–	17	72	47	223	–	–	–	–	29
	800	101	–	19	69	48	217	–	–	–	–	35
	900	98	–	20	67	51	212	–	–	–	–	42
	1000	94	–	22	64	53	207	–	–	–	–	48
	1100	90	–	23	61	55	197	–	–	–	–	51
	1200	87	–	24	57	58	187	–	–	–	–	54
Effect of Temp Normalized[7]	Test Temp											
	25	85	–	29	50	52	–	–	–	–	–	–
	-25	95	–	29	60	48	–	–	–	–	–	–
	-60	102	–	30	76	48	–	–	–	–	–	–
	-190	144	–	5	143	5	–	–	–	–	–	–

[1]ASTM, Bulletin 1947, Rep. of Comm.
[2]ASM, Metals Handbook.
[3]Jones and Laughlin Steel Corp.
[4]Union Drawn Steel Co.
[5]Ryerson
[6]Izod test
[7]A. B. Kinzel, W. Crafts and J. J. Egan, Trans. AIME, 1937, Vol. 125, p. 560.
[8]La Salle Steel Co.
[9]AISI Steel Products Manual, Section 9.
[10]Bliss & Laughlin, Inc., Sect. III Suplement Manual, Cold Finished Bar Steels.
[11]Hardness determined at surface of quenched 1 in. rd.

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red. Area %	Hard BHN	Shear Stress Elastic M psi	Shear Stress Max M psi	Degs of Twist Elastic	Degs of Twist Max	NBT Ft Lb	Yield Strength M psi	End Lt M psi
Hot rolled, turned, 1 in. rds, aver.	–	83.58	28.9	53.2	57.6	163	32.2	83.1	4.7	1761	–	–	–
Cold drawn, 1 in. rds, aver.	–	99.75	15.1	92	54.6	192	36	85.6	5.4	1504	–	–	–
Hot rolled, annealed[1]	–	77 min	–	38.5 min	–	–	–	–	–	–	–	–	–
Cold drawn[1]	–	85-105	12-20	75-95	35-45	187-223	–	–	–	–	–	–	–
Cold drawn[2] ⅝ - 2 in.	–	97	16	82.4	40	197	–	–	–	–	–	–	–
Cold drawn[9] ⅝ - ⅞ in. incl.	–	90	12	–	35	179	–	–	–	–	–	80	–
> ⅞ - 1¼ in. incl.	–	85	12	–	35	170	–	–	–	–	–	75	–
> 1¼ - 2 in. incl.	–	80	10	–	30	163	–	–	–	–	–	70	–
> 2 - 3 in. incl.	–	75	10	–	30	149	–	–	–	–	–	65	–
As rolled cold drawn or drawn, ground and polished[10] to 9/16 in. incl.	–	98-118	12-22	–	35-48	212-248	–	–	–	–	–	80-100	47
> 9/16 - 1½ in. incl.	–	90-110	12-22	–	35-48	187-229	–	–	–	–	–	78-98	43
> 1½ - 3½ in. incl.	–	86-106	10-20	–	28-48	187-229	–	–	–	–	–	70-90	41
As rolled turned and polished or turned ground and polished[10] 2½ - 4 in. incl.	–	80-100	16-26	–	30-50	156-212	–	–	–	–	–	45-65	38
Aver. prop.[10], quenched and tempered, heat treated in 1 in. diam. sect, tensile specimen 0.505 in. diam. cut at bar ctr.; water quenched	400F	130	17	97	46	514[11]	–	–	–	–	–	–	–
	600	128	18	95	52	444[11]	–	–	–	–	–	–	–
	800	123	21	92	56	352[11]	–	–	–	–	–	–	–
	1000	107	24	86	61	269[11]	–	–	–	–	–	–	–
	1200	96	28	73	68	207[11]	–	–	–	–	–	–	–
oil quenched	400	113	19	86	47	262[11]	–	–	–	–	–	–	–
	600	112	20	85	53	255[11]	–	–	–	–	–	–	–
	800	109	21	80	54	241[11]	–	–	–	–	–	–	–
	1000	105	25	72	57	212[11]	–	–	–	–	–	–	–
	1200	93	28	63	65	192[11]	–	–	–	–	–	–	–
Aver. prop.[10] 1 in. rd. bars cold drawn 1/16 in.	Test Temp												
cold drawn		102	16	–	42	207	–	–	–	–	–	85	–
annealed, cold drawn	–	93	18		50	18[illegible]	–	–	–	–	–	80	–
Effect of Temp[3] Annealed	70F	79.4	30.8	45.8	49	–	–	–	–	–	–	–	–
	-300	139.4	7.3	114.1	7.1	–	–	–	–	–	–	–	–
Heat treated	70	104.4	25	76.9	61.3	–	–	–	–	–	–	–	–
	-300	160.4	9.8	150.2	9.4	–	–	–	–	–	–	–	–
Water quenched and drawn to 230 BHN at 0.420 in. sq. and tested as Charpy bars with keyhole notch[4]	70	–	–	–	–	–	–	–	–	–	45	–	–
	0	–	–	–	–	–	–	–	–	–	42	–	–
	-50	–	–	–	–	–	–	–	–	–	30	–	–
	-75	–	–	–	–	–	–	–	–	–	15	–	–
	-100	–	–	–	–	–	–	–	–	–	10	–	–
	-150	–	–	–	–	–	–	–	–	–	6	–	–
Effect of Mass — Tensile test, 0.505 in. diam; Izod test, 0.450 in. diam. Aver.[5]													
Annealed[6] 1 in. ctr.	–	75.25	30.2	51.25	57.2	149	–	–	–	–	33	–	–
Normalized 1650F air-cooled ½ in.[7] ctr.	–	88.25	30.0	58.5	56.5	183	–	–	–	–	52	–	–
1 in. ctr.	–	85.5	28.0	54.25	54.9	170	–	–	–	–	48	–	–
2 in. ½ r.	–	84.25	28.0	53	53.3	167	–	–	–	–	51	–	–
4 in. ½ r.	–	83.5	27.0	49.25	51.8	167	–	–	–	–	39	–	–
1650F air-cooled, 1575F, oil tower quenched tempered as shown 1000F ½ in.[7] ctr.	–	104.75	27.0	72.5	62.0	217	–	–	–	–	66	–	–
1 in. ctr.	–	96.25	26.5	68	61.1	197	–	–	–	–	68	–	–
2 in. ½ r.	–	92.25	27.0	59.75	59.7	187	–	–	–	–	75	–	–
4 in. ½ r.	–	90	27.0	57.5	60.3	179	–	–	–	–	61	–	–
1100F ½ in.[7] ctr.	–	100.5	27.0	69.5	65.2	207	–	–	–	–	76	–	–
1 in. ctr.	–	91.5	28.2	64.25	63.5	187	–	–	–	–	81	–	–
2 in. ½ r.	–	86.75	28.0	56.875	62.5	174	–	–	–	–	91	–	–
4 in. ½ r.	–	82.75	30.0	52.25	61.6	170	–	–	–	–	81	–	–
1200F ½ in.[7] ctr.	–	95	28.9	66.625	65.4	197	–	–	–	–	86	–	–
1 in. ctr.	–	85.25	30.0	60.25	67.4	170	–	–	–	–	88	–	–
2 in. ½ r.	–	82.5	31.0	54.5	66.4	167	–	–	–	–	94	–	–
4 in. ½ r.	–	78.75	31.2	50	64.5	156	–	–	–	–	85	–	–
1650F air-cooled, 1550F W.Q. tempered as shown 1000F ½ in.[7] ctr.	–	109	23.8	81.5	61.5	223	–	–	–	–	75	–	–
1 in. ctr.	–	107.75	23.2	78.5	62.6	217	–	–	–	–	72	–	–
2 in. ½ r.	–	101.75	24.7	69.5	63.6	207	–	–	–	–	85	–	–
4 in. ½ r.	–	99	24.7	63.825	60.2	201	–	–	–	–	62	–	–
1100F ½ in.[7] ctr.	–	101.25	26.4	71	65.2	212	–	–	–	–	79	–	–
1 in. ctr.	–	100	26	69.5	65.0	207	–	–	–	–	75	–	–
2 in. ½ r.	–	95	29	68	69.2	197	–	–	–	–	100	–	–
4 in. ½ r.	–	94.25	27	59.125	63.4	192	–	–	–	–	73	–	–
1200F ½ in.[7] ctr.	–	96	27.7	69	66.6	201	–	–	–	–	91	–	–
1 in. ctr.	–	93.5	27	68	67.9	197	–	–	–	–	83	–	–
2 in. ½ r.	–	89	28.7	59.875	69	183	–	–	–	–	107	–	–
4 in. ½ r.	–	85	30.2	54.75	67.2	170	–	–	–	–	93	–	–

[1] ASTM, Bulletin.
[2] ASM, Metals Handbook.
[3] J. Strauss, Trans. ASST, 1929, Vol. 16, p. 191.
[4] H. W. Gillett and F. T. McGuire.
[5] Bethlehem Steel Co., single heat. Composition – Ladle: .33C, .71Mn, .019P, .044S, .16Si. Check: .39C, .71Mn, .019P, .036S, .15Si. McQuaid-Ehn grain size = 100% 5-7.
[6] 1450F, furnace cooled at 20°F per hr to 1200F, air cooled
[7] Tensile test bar was 0.357 in. diam.
[8] LaSalle Steel Co.
[9] AISI Steel Products Manual.
[10] Bliss & Laughlin.
[11] Hardness determined at surface of quenched 1 in. rd.

(Continued on page 158)

STEELS, AISI

1040

(Continued from page 157)

Chemical Composition

C %	Mn %	P %	S %
.37-.44	.60-.90	.040 max	.050 max

Technological Properties

Machinability (On basis of B1112 = 100)

Mill annealed to 179-229 BHN = 60%[1]
Hot rolled at 201 BHN = 63%[2]
Cold drawn at 207 BHN = 65%[2], 64%[3]

[1] ASM Metals Handbook
[2] Ryerson
[3] AISI Steel Products Manual

Characteristics. Very similar to C1035 though with a little higher strength and hardness.

Typical Uses. Some examples of applications of C1040 are given in the table.

Part	Hard BHN	Part	Hard BHN
Crankshafts	228-286	Couplings	207-321
Connecting rods	187-241	Thrust washers	341-514
Wheel flanges	302-444	Wheel lugs	364-477
Steering arms	207-269	Gears, sprockets	250±

Coef. of Thermal Expansion[1]
Material Tested—.42C, .68Mn, .23Si, annealed

Temp Range Deg C	Deg F	Coefficient α $\times 10^{-6}/^{\circ}C$	$\times 10^{-6}/^{\circ}F$
25-100	77-212	9.4	5.2
25-200	77-392	10.9	6.0
25-300	77-572	12.1	6.7
25-400	77-752	13.0	7.2
25-500	77-932	13.7	7.6
25-600	77-1112	14.3	7.9
25-700	77-1292	14.7	8.2

[1] ASM, Metals Handbook; data from the Nat'l. Phys. Lab., Jour. Iron and Steel Inst., 1946, No. II.

Thermal Conductivity[1]
Material Tested—.415C, .643Mn, .063Ni, .12Cu, Tr Cr

Temp Range Deg C	Deg F	$Cal/cm^2/cm/{}^{\circ}C/sec$	$BTU/sec/ft^2/{}^{\circ}F/in.$
0	32	.124	.100
100	212	.121	.098
200	392	.115	.093
300	572	.109	.088
400	752	.100	.081
500	932	.091	.073
600	1112	.081	.065
700	1292	.072	.058
800	1472	.059	.048
1000	1832	.064	.052
1200	2192	.071	.057

[1] ASM, Metals Handbook, data from the Nat'l. Phys. Lab., Jour. Iron and Steel Inst., 1946, No. II.

Critical Points

Ac_1	1340F[1]	1340F[2]
Ac_3	1445	1455
Ar_3	1350	—
Ar_1	1250	1255

[1] Average values of Bethlehem Steel Co.
[2] Approximate values of Republic Steel Corp.

Treatment Temperatures

Forging—start	2350-2100F
Forging—finish	1850-1600
Normalizing	1625-1675
Annealing	1450-1500
Quenching	1525-1575

Electrical Resistivity
Material Tested—.415C, .643Mn, .063Ni, .12Cu, Tr Cr

Temp Range Deg C	Deg F	Micro-cm	Temp Range Deg C	Deg F	Micro-cm
20	68	17.1	800	1472	111.1
100	212	22.1	900	1652	114.9
200	392	29.6	1000	1832	117.9
400	752	49.3	1100	2012	120.7
600	1112	76.6	1200	2192	123.0
700	1292	93.2			

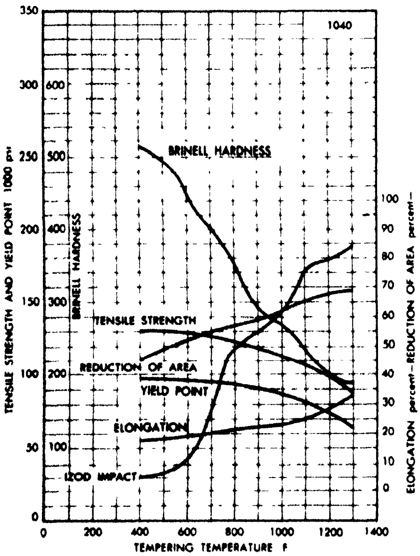
[1] ASM, Metals Handbook, data from the Nat'l. Phys Lab, Jour. Iron and Steel Inst., 1946, No. II.

Mean Apparent Specific Heat[1,2]
Material Tested—.415C, .643Mn, .063Ni, .12Cu, Tr Cr

Temp Range Deg C	Deg F	$Cal/gm/{}^{\circ}C$	Temp Range Deg C	Deg F	$Cal/gm/{}^{\circ}C$
50-100	122-212	.116	450-500	842-932	.155
150-200	302-392	.123	550-600	1022-1112	.169
200-250	392-482	.126	650-700	1202-1292	.184
250-300	482-572	.131	700-750	1292-1382	.378
300-350	572-662	.136	750-800	1382-1472	.149
350-400	662-752	.140	850-900	1562-1652	.131

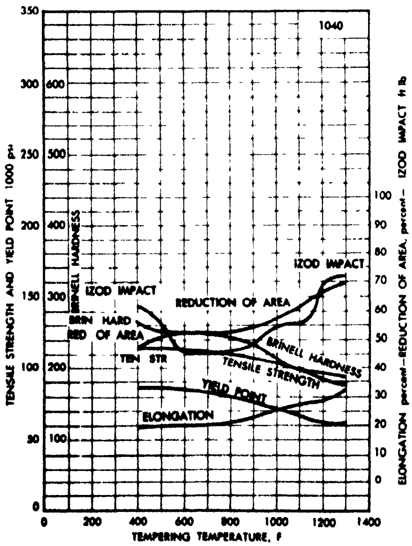
[1] ASM, Metals Handbook, data from the Nat'l Phys Lab., Jour. Iron and Steel Inst., 1946, No. II.
[2] Heating rate—3 Deg C per min.

Water Quenched and Tempered



Source — Bethlehem Steel Corp., aver. values. Size treated: 1 in. rd. Size tested: 0.505 in. rd. Treatment: Fine grained steel, normalized, water quenched and oil quenched and tempered, as indicated.

Oil Quenched and Tempered



(Continued on page 159)

STEELS, AISI
1040

(Continued from page 158)

As Quenched Rockwell Hardness

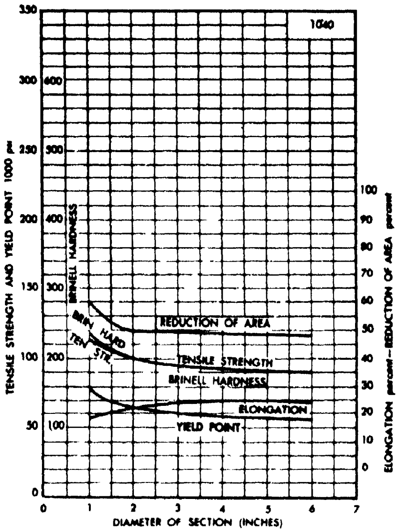
Treatment – 1650F, air cooled, 1575F, oil tower quenched

Diam	Center	Hardness Half Radius	Surface
½ in.	21Rc	22Rc	28Rc
1 in.	18Rc	21Rc	23Rc
2 in.	91Rb	92Rb	93Rb
4 in.	89Rb	91Rb	91Rb

Treatment – 1650F, air cooled, 1550F, water quenched

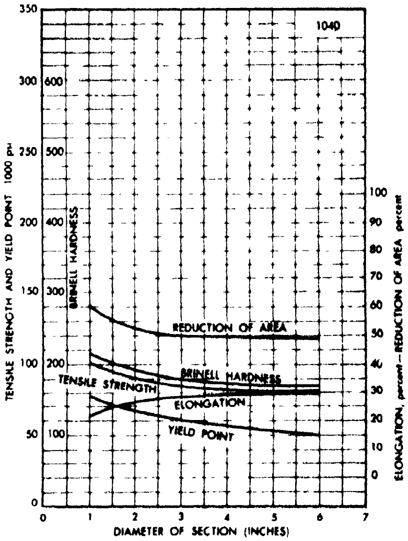
Diam	Center	Hardness Half Radius	Surface
½ in.	53Rc	53Rc	54Rc
1 in.	18Rc	22Rc	50Rc
2 in.	95Rb	97Rb	50Rc
4 in.	95Rb	96Rb	98Rb

Tempered at 1000F



Source – Republic Steel Corp. Treatment: Water quenched, tempered at 1000F and 1200F. Test samples: Above 1½ in. diam. the test bars were taken from mid-radius. The test bars were 0.505 in. diam.

Tempered at 1200F



STEELS, AISI
1055

Chemical Composition

C %	Mn %	P %	S %
.50-.60	.60-.90	.040 max	.050 max

Treatment Temperatures

Forging	—
Annealing	1500-1575F
Normalizing	1550-1650
Quenching	1450-1550

Characteristics. This steel gives high surface hardness, when heat treated, combined with relatively good toughness. It has good forging characteristics. It is shallow hardening and its useful section size is limited.

Uses. Battering tools, ground working tools, wear resistant parts, springs, shafts, collars, heavy machinery parts, wrenches, hammers, pliers, screw drivers, axes, hatchets, knife blades, parts of agricultural implements to get strength at low cost such as control rods, shafts, and parts used for turning earth. Parts requiring high hardness are water quenched and parts requiring strength are oil quenched.

1060

Chemical Composition			
C %	Mn %	P %	S %
.55-.65	.60-.90	.040 max	.050 max

Characteristics and Uses. Very similar to C1055.

Coef. of Thermal Expansion[1]

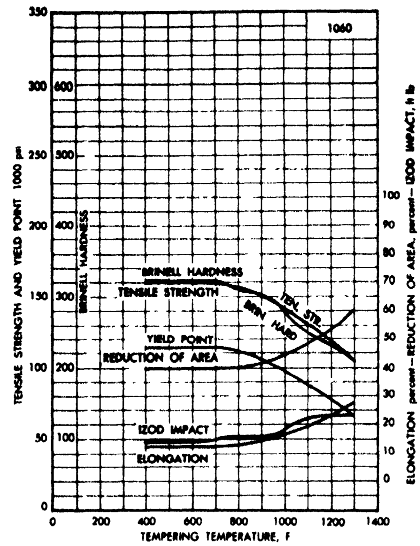
Material .59C, .92Mn, .25Si, annealed

Temp Range Deg C	Temp Range Deg F	Coefficient $\times 10^{-6}/^{\circ}C$	Coefficient $\times 10^{-6}/^{\circ}F$
25-100	77-212	11.1	6.2
25-200	77-392	11.9	6.6
25-300	77-572	12.9	7.2
25-400	77-752	13.5	7.5
25-500	77-932	14.1	7.8
25-600	77-1112	14.6	8.1
25-700	77-1292	14.9	8.3

[1]ASM, Metals Handbook

Quenched and Tempered

Source—Bethlehem Steel Co.→ Aver values. Treatment and samples: Heat treated as 1 in. bars and tested as 0.505 in. rds.



As Quenched Rockwell Hardness

Treatment—1650F, air cooled, 1550F, oil tower quenched

Diam	Center	Hardness Half Radius	Surface
½ in.	35Rc	37Rc	59Rc
1 in.	30Rc	32Rc	34Rc
2 in.	25Rc	27½Rc	30½Rc
4 in.	24Rc	26Rc	29Rc

Critical Points

Ac_1	1355F[1]	Ar_3	1300F
Ac_3	1400	Ar_1	1250

[1]Bethlehem Steel Co.

Treatment Temperatures

Forging	–
Annealing	1450-1550F
Normalizing	1550-1650
Quenching	1450-1550

Mechanical Properties

Form or Condition			Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red. Area %	Hard BHN	Izod NBT Ft Lb
Bars									
Hot rolled[1]			–	102 min	–	56 min	–	–	–
Hot rolled[2] 1 in. sect.			–	112	11	70	–	–	–
Oil Quenched and Tempered, heat treated in 1 in. diam, tensile specimen 0.505 in. diam. cut at bar ctr.[6]			600F	160	12	113	40	321	–
			800	156	14	111	42	311	–
			1000	140	17	97	45	277	–
			1200	115	23	77	54	229	–
Effect of Mass[3]									
Annealed[4] 1 in. ctr.			–	90.75	22.5	40	38.2	179	8
Normalized 1650F, air cooled		½ in.[5] ctr.	–	113	20.3	62	40.6	229	12
		1 in. ctr.	–	112.5	18	61	37.2	229	10
		2 in. ½r.	–	110	17.7	57.5	34	223	10
		4 in. ½r.	–	108.25	18	51.25	31.3	223	8
1650F, air cooled, 1550F, oil tower quenched, tempered as shown	900F	½ in.[5] ctr.		149	15	98.25	46	302	12
		1 in. ctr.		145.5	16.2	93	44	293	15
		2 in. ½r.		142.75	16.5	89.5	46.2	285	13
		4 in. ½r.		134.75	18.2	75.25	44.8	269	11
	1000F	½ in.[5] ctr.		139.5	19.6	92	52.1	277	13
		1 in. ctr.		136.5	17.7	85.75	48	269	15
		2 in. ½r.		133	18.5	79.25	50.3	262	15
		4 in. ½r.		124.5	20	66.25	48	248	12
	1100F	½ in.[5] ctr.		131.5	20.7	82.5	53.5	262	16
		1 in. ctr.		127.75	20	79	51.7	255	16
		2 in. ½r.		125.25	20.2	76.5	53.3	248	16
		4 in. ½r.		118.75	21.5	62	49.4	241	12

[1]ASTM Bulletin
[2]Jones and Laughlin Steel Corp.
[3]Bethlehem Steel Co. Single heat. Composition—Ladle: .60C, .68Mn, .014P, .050S, .20Si. Check: .60C, .66Mn, .016P, .046S, .17Si. McQuaid-Ehn grain size = 90% 5-7 and 10% 1-3. The tensile test bars were 0.505 in. diam. unless otherwise noted and the Izod bars were 0.450 in. diam. All values are the average of two tests.
[4]1450F, furnace cooled at 20F/hr to 1200F, air cooled.
[5]Tensile test bar was 0.357 in. diam.
[6]Bliss & Laughlin

1045

Chemical Composition

C %	Mn %	P %	S %
.43-.50	.60-.90	.040 max	.050 max

Technological Properties
Machinability (On basis of B1112 = 100)
Mill annealed to 179-229 BHN =60%[1], 72%[3]
As rolled = 56%[2]
Cold drawn = 60%[2], 57%[3]

[1] ASM metals Handbook.
[2] Ryerson.
[3] AISI.

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red. Area %	Hard BHN	Shear Stress Elastic M psi	Shear Stress Max M psi	Degs of Twist Elastic	Degs of Twist Max
Hot rolled, turned } 1 in. rds, aver.[7]	–	87	–	27.1	54.1	56.5	187	35.6	85.9	4.9	1740
Cold drawn } 1 in. rds, aver.[7]	–	102.5	–	14.8	93.45	52.5	202	36.8	86.4	5.6	1485
Bars											
Hot rolled[1]	–	98	–	24	59	45	212	–	–	–	–
Hot rolled, norm.[1]	–	99	–	25	61	49	207	–	–	–	–
Hot rolled, annealed[1]	–	90	–	27	55	54	174	–	–	–	–
Cold drawn[1]	–	103	–	14	90	40	217	–	–	–	–
Cold drawn, single heat 9/16 in. diam[2]	–	98.6	–	17.5	80.4	–	–	–	–	–	–
Cold drawn, aver, 5/8 - 2 in. diam[3]	–	102	–	15	86.7	35	207	–	–	–	–
Hot rolled, annealed[4]	–	84 min	–	–	42 min	–	–	–	–	–	–
Cold drawn[4]	–	90-115	–	10-18	80-100	30-45	187-241	–	–	–	–
Hot rolled } aver., 1 in. sect.[5]	–	100	–	17	63	–	–	–	–	–	–
Cold drawn } aver., 1 in. sect.[5]	–	109	99	10	–	–	–	–	–	–	–
Hot rolled, turned and polished[6]	–	80-100	–	20-30	35-55	30-45	156-202	–	–	–	–
Cold drawn[6]	–	85-115	–	10-15	80-110	30-45	183-228	–	–	–	–
Cold drawn[8] 5/8 - 7/8 in. incl.	–	95	85	12	–	35	187	–	–	–	–
> 7/8 - 1 1/4 in. incl.	–	90	80	11	–	30	179	–	–	–	–
> 1 1/4 - 2 in. incl.	–	85	75	10	–	30	170	–	–	–	–
> 2 - 3 in. incl.	–	80	70	10	–	30	163	–	–	–	–
Hot rolled, cold drawn[9] } to 9/16 in.	–	98-118	83-103	10-20	–	33-53	202-241	–	–	–	–
> 9/16 - 1 1/2 in. incl.	–	95-115	80-100	10-20	–	30-50	192-235	–	–	–	–
> 1 1/2 - 3 1/2 in. incl.	–	87-107	73-93	9-18	–	25-45	183-223	–	–	–	–
Hot rolled, turned & polished[9], 2 1/4 - 4 in.	–	82-97	50-65	18-28	–	35-55	179-201	–	–	–	–
Aver. prop.[9] Water quenched, drawn as shown: 1/2 in. rd.	800F	160	–	13	130	43	331	–	–	–	–
1 in. rd.	800F	137	–	15	101	45	280	–	–	–	–
2 in. rd.	800F	115	–	15	80	45	228	–	–	–	–
4 in. rd.	800F	104	–	16	75	46	200	–	–	–	–
6 in. rd.	800F	104	–	16	75	46	200	–	–	–	–
1/2 in. rd.	1000	130	–	16	110	56	260	–	–	–	–
1 in. rd.	1000	119	–	21	91	54	240	–	–	–	–
2 in. rd.	1000	110	–	23	70	50	205	–	–	–	–
4 in. rd.	1000	94	–	25	59	49	180	–	–	–	–
6 in. rd.	1000	92	–	25	56	49	180	–	–	–	–
1/2 in. rd.	1200	110	–	23	84	61	220	–	–	–	–
1 in. rd.	1200	105	–	25	75	61	210	–	–	–	–
2 in. rd.	1200	98	–	26	64	58	190	–	–	–	–
4 in. rd.	1200	93	–	28	55	55	186	–	–	–	–
6 in. rd.	1200	92	–	28	54	52	186	–	–	–	–
Quenched and Tempered } Bars 9/16 in. diam. } Single heat[2] water quenched drawn as shown	800	182.4	162.2	12	–	–	–	–	–	–	–
	1000	134.15	119.25	17.5	–	–	–	–	–	–	–
	1100	120.57	105.340	19	–	–	–	–	–	–	–
Water quenched at 1500F and tempered as shown, 1 in. rds, aver.[1]	No T	174	–	5	138	27	385	–	–	–	–
	400	165	–	9	128	33	363	–	–	–	–
	500	162	–	11	125	35	352	–	–	–	–
	600	156	–	13	119	39	341	–	–	–	–
	700	150	–	15	114	43	331	–	–	–	–
	800	141	–	16	108	47	311	–	–	–	–
	900	132	–	18	102	50	293	–	–	–	–
	1000	120	–	20	93	52	277	–	–	–	–
	1100	112	–	22	85	55	255	–	–	–	–
	1200	105	–	24	77	57	241	–	–	–	–
Oil quenched at 1525F and tempered as shown, 1 in. rds, aver.[1]	No T	160	–	10	105	35	352	–	–	–	–
	400	152	–	13	100	38	331	–	–	–	–
	500	149	–	14	98	40	331	–	–	–	–
	600	145	–	15	95	41	321	–	–	–	–
	700	138	–	16	94	44	311	–	–	–	–
	800	128	–	17	91	48	293	–	–	–	–
	900	120	–	19	87	52	269	–	–	–	–
	1000	112	–	21	81	54	248	–	–	–	–
	1100	105	–	23	75	58	229	–	–	–	–
	1200	100	–	25	69	60	217	–	–	–	–

[1] Ryerson
[2] Jones and Laughlin Steel Corp. The composition was .44C, .67Mn, .009P.
[3] ASM, Metals Handbook.
[4] ASTM, Bulletin No.---, 1947.
[5] Jones and Laughlin Steel Corp.
[6] Union Drawn Steel.
[7] LaSalle Steel Co.
[8] AISI Steel Products Manual
[9] Bliss & Laughlin

(Continued on page 162)

STEELS, AISI
1045

(Continued from page 161)

Critical Points[1]

Ac_1	1340F	Ar_3	1405F
Ac_3	1450	Ar_1	1275

[1]Ryerson

Treatment Temperatures

Forging	2000-2300F
Annealing	1450-1525
Normalizing	1575-1675
Quenching	1475-1550

As Quenched Brinell Hardness[1]

Treatment – Water quenched at 1500F

	Diam	Center	Hardness Half Radius	Surface
Temper 800F	½ in.	321	321	321
	1 in.	311	321	321
	2 in.	269	285	311
	3 in.	262	269	302
Temper 1000F	½ in.	285	285	285
	1 in.	269	277	277
	2 in.	241	248	269
	3 in.	235	235	262
Temper 1200F	½ in.	255	255	255
	1 in.	241	248	248
	2 in.	212	217	235
	3 in.	207	207	229

Treatment – Oil quenched at 1525F

	Diam	Center	Hardness Half Radius	Surface
Temper 800F	½ in.	302	302	302
	1 in.	293	293	293
	2 in.	241	255	285
	3 in.	235	241	269
Temper 1000F	½ in.	262	262	262
	1 in.	255	255	255
	2 in.	217	223	255
	3 in.	217	217	241
Temper 1200F	½ in.	223	223	223
	1 in.	217	217	217
	2 in.	187	197	212
	3 in.	187	187	207

[1]Ryerson

Characteristics. Steel 1045 is typical for flame hardening and can produce a surface hardness of 500 BHN to a depth of 0.10 in. This applies particularly to shafts and gears. In general it is medium strong in the as-rolled or as-forged condition, and can be heat-treated by a liquid quench (water or oil) or by flame or induction hardening. It forges satisfactorily and is fair in brazing. It is used for parts requiring medium strength, and for parts with a wearing surface.

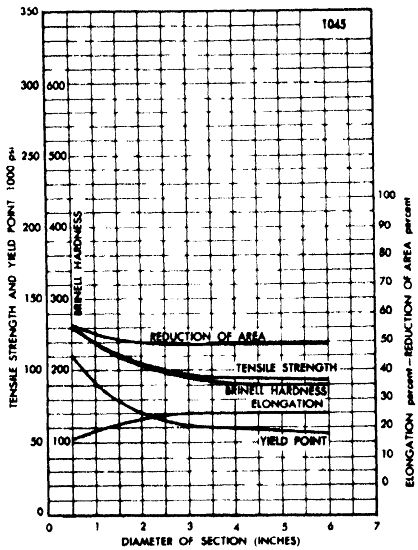
Uses. Typical uses of heat treated 1045 are listed below –

Part	BHN	Part	BHN
Crankshafts	228-286	Couplings	207-321
Connecting rods	187-241	Thrust washers	341-514
Shafts	228-402	Wheel lugs	364-477
Spline shafts	Steel 1045 is used for splined shafts but is not usually so reliable as the alloy steels in response to heat treatment.		

Common Commercial Forms. Billets and forging stock, forgings, hot rolled, annealed, cold rolled, cold drawn rod and strip.

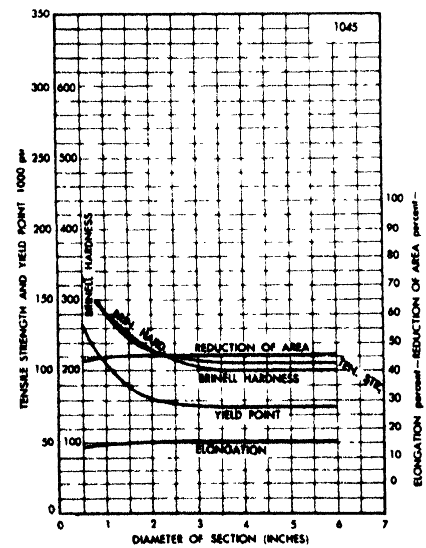
Physical Properties
Density .435C, .69Mn, .20Si, annealed = 0.2834 lb/cu in. (7.844 S.G.)

Water Quenched, Tempered at 1000F

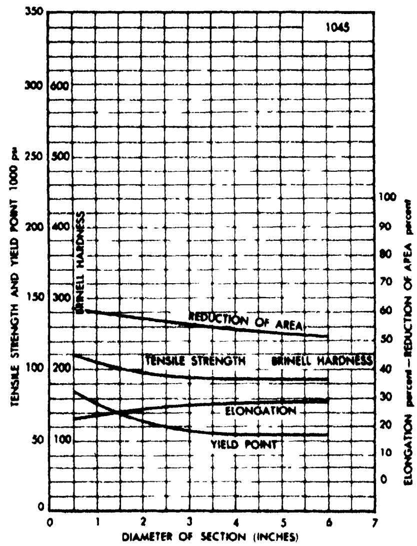


Source International Nickel Co. Sections from ½ to 2 in. inclusive were quenched from 1475-1525F, over 2 in. to 4 in. inclusive, from 1500-1550F, and over 4 in. from 1525-1575F. In sizes over 1 in. the test bars were taken from the mid-section position.

Water Quenched, Tempered at 800F



Water Quenched, Tempered at 1200F

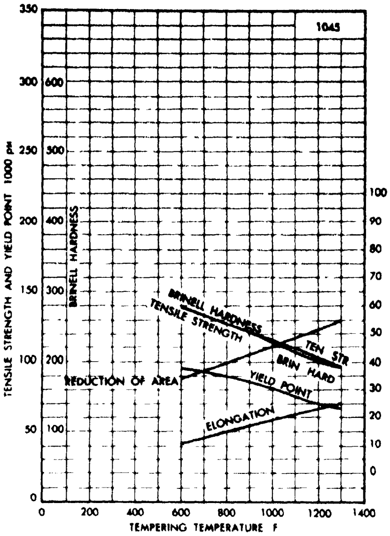


(Continued on page 163)

(Continued from page 162)

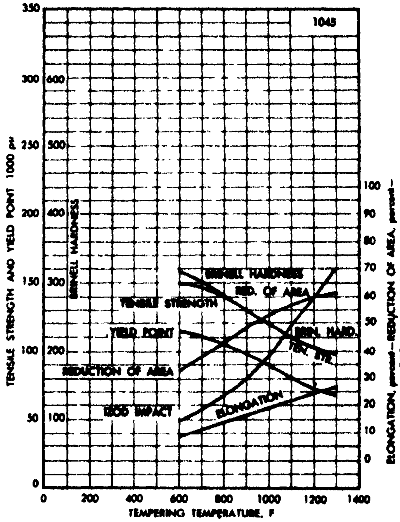
1045

Oil Quenched and Tempered



Source—International Nickel Co. Material: 1 in. rds, quenched from 1475-1525F. Aver. properties.

Water Quenched and Tempered



1080

Chemical Composition

C %	Mn %	P %	S %
.75-.88	.60-.90	.040 max	.050 max

Characteristics and Uses. Similar to C1055.

Mean Apparent Specific Heat[1,2]
Material tested—.80C, .32Mn, .13Ni, .11Cr, .01Mo, .07Cu

Temp Range Deg C	Deg F	Cal/gm/°C	Temp Range Deg C	Deg F	Cal/gm/°C
50-100	122-212	.117	450-500	842-932	.160
150-200	302-392	.127	550-600	932-1112	.170
200-250	392-482	.131	650-700	1202-1292	.184
250-300	482-572	.135	700-750	1292-1382	.497
300-350	572-662	.140	750-800	1382-1472	.147
350-400	662-752	.145			

[1]ASM, Metals Handbook, Data from Nat'l. Phys. Lab., Jour. Iron and Steel Inst. 1946, No. II.
[2]Heated at 3 Deg C per min.

Electrical Resistivity[1]
Material tested—.80C, .32Mn, .13Ni, .11Cr, .01Mo, .07Cu

Temp Range Deg C	Deg F	Micro-cm	Temp Range Deg C	Deg F	Micro-cm
20	68	18.0	800	1472	112.9
100	212	23.2	900	1652	116.4
200	392	30.8	1000	1832	119.1
400	752	50.5	1100	2012	121.4
600	1112	77.2	1200	2192	123.1
700	1292	93.5	1300	2372	124.6

[1]ASM, Metals Handbook. Data from Nat'l. Phys. Lab., Jour. Iron and Steel Inst. 1946, No. II.

Coefficient of Thermal Expansion[1]
Material tested—.75C, .69Mn, .21Si

Temp Range Deg C	Deg F	Coefficient $\times 10^{-6}$/°C	$\times 10^{-6}$/°F
0-100	32-212	11.5	6.4
0-200	32-392	12.3	6.8
0-300	32-572	13.0	7.2
0-400	32-752	13.8	7.6
0-500	32-932	14.1	7.8
0-600	32-1112	14.6	8.1
0-700	32-1292	14.9	8.3

[1]ASM, Metals Handbook. Data from Nat'l. Phys. Lab., Jour. Iron and Steel Inst. 1946, No. II.

Thermal Conductivity[1]
Material tested—.80C, .32Mn, .13Ni, .11Cr, .01Mo, .07Cu

Temp Range Deg C	Deg F	Cal/cm²/cm/°C/sec	BTU/sec/ft²/°F/in.
0	32	.119	.096
100	212	.115	.093
200	392	.108	.087
300	572	.099	.080
400	752	.091	.073
500	932	.084	.068
600	1112	.078	.063
700	1292	.072	.058
800	1472	.058	.047
1000	1832	.064	.052
1200	2192	.072	.058

[1]ASM, Metals Handbook. Data from Nat'l. Phys. Lab., Jour. Iron and Steel Inst. 1946, No. II.

(Continued on page 164)

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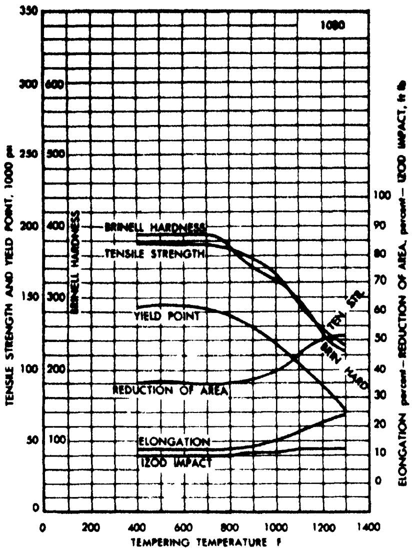
(Continued from page 163)

Source–Bethlehem Steel Co. ⟶
Aver properties of fine grained steel. Test samples and treatment: Treated as 1 in. rds. as indicated and tested as 0.505 in. rds.

Quenched and Tempered



Treatment Temperatures

Forging	–
Annealing	1250-1450F
Normalizing	1575-1650
Quenching	1475-1525

Critical Points

Ac_1	1350F[1]	Ar_3	1280F
Ac_3	1370	Ar_1	1250

[1] Bethlehem Steel Co.

As Quenched Rockwell Hardness
Treatment – 1650F, air cooled, 1500F, oil tower quenched

Diam	Center	Hardness Half Radius	Surface
½ in.	40Rc	43Rc	60Rc
1 in.	39Rc	42Rc	45Rc
2 in.	37Rc	40Rc	43Rc
4 in.	32Rc	37Rc	39Rc

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Izod NBT Ft Lb
Bars							
Hot rolled[1]	–	118 min	–	65 min	–	–	–
Hot rolled[2] 1 in. sect. aver.	–	122	8	76	–	–	–
Effect of Mass[3]							
Annealed[4] 1 in. diam. ctr.	–	89.25	24.7	54.5	45	174	5
Oil quenched and Tempered[6] Heat treated in 1 in. diam. Tensile specimen 0.505 in. diam. cut at bar ctr.	600F	188	12	143	35	388[7]	–
	800	186	13	138	36	375[7]	–
	1000	165	15	118	40	321[7]	–
	1200	129	21	87	50	255[7]	–
Normalized 1650F, air cooled — ½ in.[5] ctr.	–	150.5	12.4	80.5	27.7	293	7
1 in. ctr.	–	146.5	11	76	20.6	293	5
2 in. ½ r.	–	141	10.7	70	17	285	5
4 in. ½ r.	–	134.75	10.7	64.5	15.5	269	5
1650F, air cooled, 1500F, oil tower quenched, tempered as shown — 900F — ½ in.[5] ctr.		184	12.1	125.5	34.4	363	7
900F — 1 in. ctr.		181.5	13	112.5	35.8	352	8
900F — 2 in. ½ r.		180	12.7	110	37.3	352	7
900F — 4 in. ½ r.		171.25	11.7	104	28.7	341	6
1000F — ½ in.[5] ctr.		169	15	121.5	38.6	341	8
1000F — 1 in. ctr.		166	15	103.5	37.6	331	8
1000F — 2 in. ½ r.		163.5	15.2	102.625	38	321	7
1000F — 4 in. ½ r.		157	11.5	89.75	24.4	311	6
1100F — ½ in.[5] ctr.		152	17	107	43.6	302	8
1100F — 1 in. ctr.		150	16.5	97	40.3	302	9
1100F — 2 in. ½ r.		140.25	17.7	87.5	42.2	277	7
1100F — 4 in. ½ r.		134.5	15.7	75	33.1	269	6

[1] ASTM, Bulletin
[2] Jones and Laughlin Steel Corp.
[3] Bethlehem Steel Co. Single heat. Composition – Ladle. .84C, .77Mn, .020P, .035S, .18Si. Check. .85C, .76Mn, .012P, .027S, .13Si. McQuaid-Ehn grain size = 80% 5-7; 20% 1-4. The tensile test bars were 0.505 in. diam. unless otherwise noted, and the Izod bars were 0.450 in. diam. All results are the average of two tests.
[4] 1450F, furnace cooled at 20F/hr to 1200F, air cooled.
[5] Tensile test bar was 0.357 in. diam.
[6] Bliss & Laughlin
[7] Hardness determined on tensile test specimens

Chemical Composition

C %	Mn %	P %	S %
.48-.55	.60-.90	.040 max	.050 max

Technological Properties
Machinability (On basis of B1112 = 100)
Mill annealed to 179-229 BHN = 50%[1], 70%[2]
Cold drawn 54%

[1] ASM Metals Handbook
[2] AISI

Characteristics. Very similar to C1045.

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red. Area %	Hard BHN	Izod NBT Ft Lb	Yield Strength M psi
Bars								
As rolled, annealed[1]	–	93 min	–	51.5 min	–	–	–	–
Cold drawn[1]	–	90-115	10-20	80-100	30-45	201-235	–	–
Hot rolled, 1 in. sect, aver.[2]	–	105	15	67	–	–	–	–
Cold drawn, 1 in. sect, aver.[2]	–	114	9	104	–	–	–	–
Hot rolled, turned and polished, Approx[3]	–	90-110	15-25	45-65	20-35	179-223	–	–
Cold drawn, Approx[3]	–	100-120	10-15	85-100	30-45	202-235	–	–
Cold drawn[7] 5/8 - 7/8 in. incl.	–	100	11	–	35	197	–	90
> 7/8 - 1 1/4 in. incl.	–	95	11	–	30	187	–	85
> 1 1/4 - 2 in. incl.	–	90	10	–	30	179	–	80
> 2 - 3 in. incl.	–	85	10	–	30	170	–	75
Hot rolled, cold drawn[8] to 9/16 in.	–	102-123	10-20	–	33-53	207-255	–	87-108
> 9/16 - 1 1/2 in. incl.	–	100-120	10-20	–	30-50	202-241	–	85-105
> 1 1/2 - 3 1/2 in. incl.	–	90-110	9-18	–	25-45	192-235	–	75-95
Hot rolled, turned and polished[8], 2 1/4 - 4 in.	–	85-100	18-28	–	35-55	174-207	–	50-65
Aver. prop.[8] 1 in. rd. bars cold drawn 1/16 in. draft, cold drawn	–	113	12	–	35	229	–	95
Aver. prop.[8] 1 in. rd. bars cold drawn 1/16 in. draft, annealed cold drawn	–	100	16	–	44	202	–	86
Quenched and tempered[8] Heat treated in 1 in. diam. sect. Tensile specimen 0.505 in. diam. cut at bar ctr. — Water quenched	400F	163	8	–	26	514	–	117
	600	157	12	–	36	444	–	116
	800	145	18	–	48	375	–	110
	1000	125	23	–	58	293	–	96
	1200	105	29	–	65	235	–	78
Oil quenched	400	–	–	–	–	–	–	–
	600	142	13	–	46	321	–	104
	800	137	20	–	50	277	–	95
	1000	127	23	–	53	262	–	84
	1200	107	28	–	60	223	–	68
Effect of Mass[4]								
Annealed[5] 1 in. diam, ctr.	–	92.25	23.7	43	39.9	187	12	–
Normalized, 1650F, air-cooled — 1/2 in. ctr[6]	–	111.5	21.5	62.5	45.1	223	18	–
1 in. ctr.	–	108.5	20	62	39.4	217	20	–
2 in. 1/2 r.	–	106.25	20	58.325	38.8	212	17	–
4 in. 1/2 r.	–	100	21.7	56	41.6	201	20	–
Oil Quenched: 1650F, air cooled, 1550F, oil tower cooled, tempered as shown — 1000F, 1/2 in. ctr[6]		132.5	20.7	87.5	52.9	262	22	–
1000F, 1 in. ctr		123.5	20.2	76	53.3	248	22	–
1000F, 2 in. 1/2 r.		122.5	19.7	74.875	51.4	248	20	–
1000F, 4 in. 1/2 r.		121	19.7	69	48	241	22	–
1100F, 1/2 in. ctr[6]		122	22.8	81	58.1	248	22	–
1100F, 1 in. ctr		114	23.5	70.5	57.6	223	23	–
1100F, 2 in. 1/2 r.		112	23	68	55.6	223	20	–
1100F, 4 in. 1/2 r.		101	25.2	58.75	54.5	207	22	–
1200F, 1/2 in. ctr[6]		112.5	24.6	74	61.8	229	32	–
1200F, 1 in. ctr		106	24.7	64.25	60.5	217	22	–
1200F, 2 in. 1/2 r.		105	25	64	59.1	217	20	–
1200F, 4 in. 1/2 r.		96.75	25.5	55.75	56.6	197	28	–
Water Quenched: 1650F, air cooled, tempered as shown — 1000F, 1/2 in. ctr[6]		134	20	99	54.4	269	42	–
1000F, 1 in. ctr		131.25	20	92.25	55.2	262	21	–
1000F, 2 in. 1/2 r.		129.5	20.7	84.125	56.6	255	24	–
1000F, 4 in. 1/2 r.		122.75	21.5	78.25	55.3	248	15	–
1100F, 1/2 in. ctr[6]		119	21.7	88	59.9	241	51	–
1100F, 1 in. ctr		118	22.5	80	59.9	241	24	–
1100F, 2 in. 1/2 r.		117.25	23	78.75	61	235	24	–
1100F, 4 in. 1/2 r.		112.25	23.7	68.25	55.5	229	16	–
1200F, 1/2 in. ctr[6]		110	24.8	86	60.6	229	66	–
1200F, 1 in. ctr		109	23.7	76.5	61.2	229	24	–
1200F, 2 in. 1/2 r.		107.75	24.7	68.5	61	223	25	-
1200F, 4 in. 1/2 r.		104.5	25.2	65.25	60.8	217	17	-

[1] ASTM Bulletin 1947.
[2] Jones and Laughlin Steel Corp.
[3] Union Drawn Steel.
[4] Bethlehem Steel Co., single heat. Composition—Ladle: .54C, .72Mn, .017P, .037S, .21Si. Check: .54C, .69Mn, .012P, .030S, .19Si. McQuaid-Ehn Grain Size = 100% 5-7.

The tensile test bars were 0.505 in. diam, unless otherwise noted, and the Izod bars were 0.450 in. diam. Values are averages of two tests.
[5] 1450F, furnace cooled at 20F/min to 1200F, air cooled.
[6] Tensile test bar was 0.357 in. diam.
[7] AISI Steel Products Manual.
[8] Bliss & Laughlin.

(Continued on page 166)

STEELS, AISI

1050

(Continued from page 165)

As Quenched Rockwell Hardness

Treatment – 1650F, air cooled 1550F, oil tower cooled

Diam	Hardness Center	Hardness Half Radius	Hardness Surface
½ in.	34Rc	37Rc	57Rc
1 in.	26Rc	30Rc	33Rc
2 in.	21Rc	25Rc	27Rc
4 in.	91Rb	95Rb	98Rb

Treatment – 1650F, air cooled, 1525F, water quenched

Diam	Hardness Center	Hardness Half Radius	Hardness Surface
½ in.	57Rc	59Rc	64Rc
1 in.	33Rc	35Rc	60Rc
2 in.	26Rc	32Rc	50Rc
4 in.	20Rc	27Rc	33Rc

Critical Points[1]

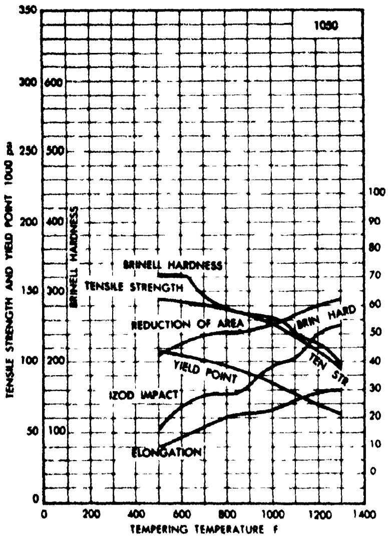
Ac_1	1340F	Ar_3	1320F
Ac_3	1420	Ar_1	1250

[1]Aver. values by Bethlehem Steel Co.

Treatment Temperatures

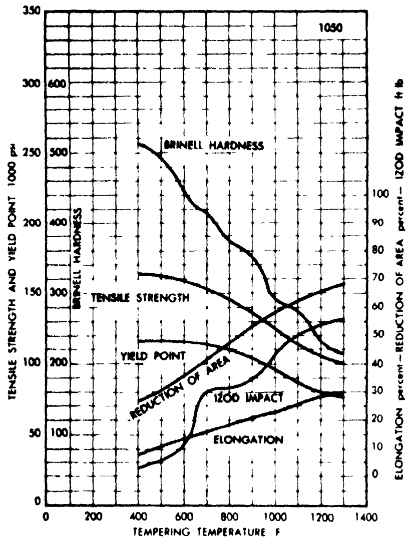
Normalizing	1600-1650F
Annealing	–
Quenching	1500-1575

Oil Quenched and Tempered



Source – Bethlehem Steel Co. Aver values; fine grained. Test samples: Treated at 1 in. rd. Tested at 0.505 in. rd.

Water Quenched and Tempered



STEELS, AISI

1070

Chemical Composition

C %	Mn %	P %	S %
.65-.75	.60-.90	.040 max	.050 max

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Yield Point M psi	Elong 2 in. %	Red Area %	Hard BHN
Bars						
Hot rolled[1]	–	100 min	60.5 min	–	–	–
Hot rolled[2] aver.	–	117	73	9	–	–
Oil quenched and tempered[3]	600F	174	128	12	37	352
Heat treated in 1 in. diam.	800	162	118	14	39	341
Tensile specimen 0.505 in.	1000	152	110	16	43	302
diam. cut at bar ctr.	1200	122	82	22	52	241

[1]ASTM Bulletin
[2]Jones and Laughlin Steel Corp.
[3]Bliss & Laughlin

Characteristics and Uses. Similar to C1055.

Technological Properties
Machinability (On basis of B1112 = 100)
Mill annealed to 183-241BHN = 45%[1]
[1]ASM, Metals Handbook

Chemical Composition

C %	Mn %	P %	S %
.90-1.03	.30-.50	.040 max	.050 max

Characteristics. Produces maximum surface hardness and high strength with some sacrifice of toughness.

Uses. Edge tools, grass and grain cutting tools, springs, wear-resistant parts. Widely used for hot coiled springs.

Treatment Temperatures

Forging	–
Annealing	1250-1400F
Normalizing	1575-1650
Quenching	1450-1500

Critical Points

Ac_1	1350F[1]	Ar_3	1320F
Ac_3	1365	Ar_1	1265

[1]Bethlehem Steel Co.

Coefficient of Thermal Expansion[1]
Material tested – 1.1C, .3Mn, .2Si

Temp Range Deg C	Temp Range Deg F	Annealed $\times10^{-6}/°C$	Annealed $\times10^{-6}/°F$	Hardened $\times10^{-6}/°C$	Hardened $\times10^{-6}/°F$
-94.8-0	-138-32	9.7	5.4	10.8	6.0
20-100	68-212	11.4	6.3	13.4	7.4

[1]ASM, Metals Handbook

As Quenched Rockwell Hardness

Treatment – 1650F, air cooled, 1475F, oil tower quenched

Diam	Hardness Center	Hardness Half Radius	Hardness Surface
½ in.	41Rc	44Rc	60Rc
1 in.	40Rc	42Rc	46Rc
2 in.	37Rc	40Rc	43Rc
4 in.	30Rc	37Rc	40Rc

Treatment – 1650F, air cooled, 1450F, water quenched

Diam	Hardness Center	Hardness Half Radius	Hardness Surface
½ in.	48Rc	55Rc	65Rc
1 in.	44Rc	46Rc	64Rc
2 in.	40Rc	43Rc	63Rc
4 in.	30Rc	38Rc	63Rc

Mechanical Properties

Form or Condition			Tensile Strength M psi	Elong 2 in %	Yield Point M psi	Red. Area %	Hard BHN	Izod NBT Ft Lb
Bars								
Hot rolled[1]			130 min	–	71.5 min	–	–	–
Cold drawn[1]			90-115	10-20	80-100	30-40	201-235	–
Hot rolled[2] 1 in. sect, aver.			140	5	81	–	–	–
Effect of Mass[3]								
Annealed[4] 1 in. diam, ctr.			95.25	13	38.25	20.6	192	2
Normalized 1650F, air cooled		½ in.[5] ctr.	151	12.4	80.5	27.7	302	5
		1 in. ctr.	147	9.5	72.5	13.6	293	4
		2 in. ½ r.	132.5	9.2	58	13.4	269	3
		4 in. ½ r.	128.25	10	57.25	13.9	255	3
1650F, air cooled, 1475F, oil tower quenched, tempered as shown	900F	½ in.[5] ctr.	184	12.8	116	35.5	363	5
		1 in. ctr.	175.75	10	102.25	23.4	352	6
		2 in. ½ r.	167.75	12	98.25	29.8	331	4
		4 in. ½ r.	165	12.2	93	17.3	331	4
	1000F	½ in.[5] ctr.	165.5	15.7	101.5	40	331	6
		1 in. ctr.	159.75	13.2	95.25	32.4	321	6
		2 in. ½ r.	151	13.7	92.5	31.4	311	4
		4 in. ½ r.	148	11.7	80	22.1	302	5
	1100F	½ in.[5] ctr.	147	17.4	87	42.8	293	6
		1 in. ctr.	142	17.3	79	38.8	277	6
		2 in. ½ r.	134.5	18.7	77.25	43.4	269	5
		4 in. ½ r.	131.25	17.2	65.75	34.4	262	5
1650F, air cooled, 1450F, water quenched, tempered as shown	900F	½ in.[5] ctr.	191.5	12.3	135.5	31.7	375	5
		1 in. ctr.	182	13	121	37.3	363	5
		2 in. ½ r.	179.5	12.7	113	33.8	352	4
		4 in. ½ r.	167.25	12.5	94.5	31.4	331	3
	1000F	½ in.[5] ctr.	172	14.4	111	44.1	321	6
		1 in. ctr.	165	16	102.5	41.5	311	5
		2 in. ½ r.	154.75	15.7	98.5	39.1	302	5
		4 in. ½ r.	150	15.7	79.5	35.3	285	4
	1100F	½ in.[5] ctr.	144	17.2	99	44.9	293	5
		1 in. ctr.	143	16.7	96.5	43.8	293	6
		2 in. ½ r.	140	17.5	90	43.7	285	5
		4 in. ½ r.	131.25	18.7	78	41.1	262	5
		Draw Temp						
Quenched and Tempered[6] Heat treated in 1 in. diam. Tensile specimen 0.505 in. diam. cut at bar ctr.	Oil quenched	600F	184	10	118	30	375[7]	–
		800	176	11	112	32	363[7]	–
		1000	160	14	98	38	321[7]	–
		1200	130	21	80	47	269[7]	–
	Water quenched	600	213	11	150	33	534[7]	–
		800	200	13	138	36	388[7]	–
		1000	165	15	110	40	293[7]	–
		1200	121	84	20	47	235[7]	–

[1]ASTM Bulletin
[2]Jones and Laughlin Steel Corp.
[3]Bethlehem Steel Co. Single heat. Composition – Ladle 1.02C, .39Mn, .016P, .039S, .21Si. Check .96C, 40Mn .012P, .029S, .20Si. McQuaid-Ehn grain size = 50% 5-7 and 50% 1-4. The tensile test bars were 0.505 in. diam, unless otherwise noted and the Izod bars were 0.450 in. diam. All values are the average of the two tests.
[4]1450F, furnace cooled at 20F/hr to 1215F, air cooled.
[5]Tensile test bar was 0.357 in. diam.
[6]Bliss & Laughlin
[7]Hardness determined on tensile test specimens

(Continued on page 168)

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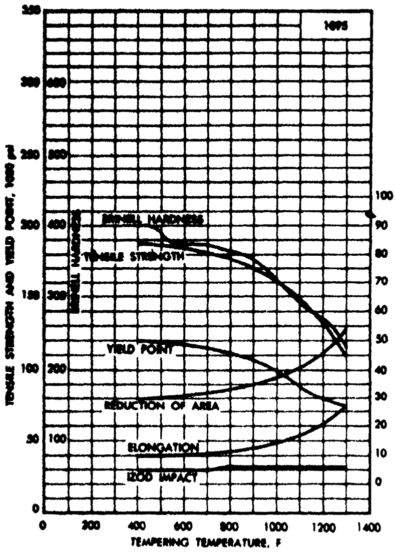
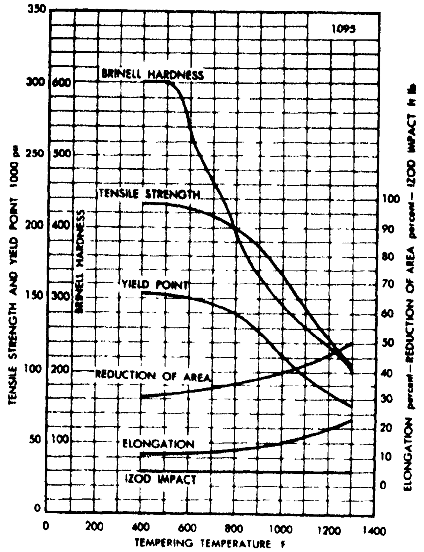
Oil Quenched and Tempered



Source — Bethlehem Steel Co. Aver values for fine grained steel. Test samples and treatment: Treated as 1 in. rds. Tested as 0.505 in. rds. after heat treatments indicated.

Water Quenched and Tempered



B1111

Chemical Composition (AISI)

C %	Mn %	P %	S %
.13 max	.60-.90	.07-.12	.08-.15

Characteristics. Its special virtues are ease of machining and good surface finish. It has good brazing characteristics but is hard to weld except with the low hydrogen electrode E 6015 (AWS). It is only fair in case hardening and for high surface hardness a similar open-hearth grade should be substituted. Only mild cold forming can be performed and it is not suited to cold heading.

Uses. This and similar grades are widely applied for parts made on screw machines which can sacrifice ductility and toughness for machinability. It is used for bolts, nuts, studs, and screws, not for vital parts or parts subjected to severe stresses and shocks.

Forms. A Bessemer steel grade available in a wide variety of sizes and shapes, such as rounds, squares, hexagons and flats.

Technological Properties

Machinability Index (On basis of B1112 = 100)	Cold drawn to 179-229 BHN = 94%

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN
Bars: Hot rolled[1]	60 min	–	–	30 min	–	–
As drawn[1]	75/100	–	10/20	70/95	35/50	179/229
Hot rolled } 1 in. sect, aver[2]	68	–	26	45	–	–
Cold drawn } 1 in. sect, aver[2]	82	72	15	–	–	–

[1] ASTM, Bulletin
[2] Jones and Laughlin Steel Corp.

B1113

Chemical Composition (AISI)

C %	Mn %	P %	S %
.13 max	.70-1.00	.07-.12	.24-.33

Characteristics and Uses. Same as B1111 and B1112[1] except that B1113 has still better machinability.

[1] Characteristics. Its special virtues are ease of machining and good surface finish. It has good brazing characteristics but is hard to weld except with the low hydrogen electrode E 6015 (AWS). It is only fair in case hardening and for high surface hardness a similar open hearth grade should be substituted. Only mild cold forming can be performed and it is not suited to cold heading

Uses. This and similar grades are widely applied for parts made on screw machines which can sacrifice ductility and toughness for machinability. It is used for bolts, nuts, studs, and screws, not for vital parts or parts subjected to severe stresses and shocks.

Forms. A Bessemer steel grade available in a wide variety of sizes and shapes, such as rounds, squares, hexagons and flats.

Technological Properties

Machinability Index (On basis of B1112 = 100)	Cold drawn to 179-229 BHN = 136%

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Shear Stress Elastic M psi	Shear Stress Max M psi	Degs of Twist Elastic	Degs of Twist Max
Bars: Hot rolled, turned } Aver 1 in. rds[4]	63	–	26.5	41	55.7	150	21.7	59.3	3.1	1019
Cold drawn } Aver 1 in. rds[4]	80	–	14.8	73	48.7	190	34	68.5	3.9	840
Hot rolled[1] 3/4-1 1/4 in. diam	60 min	–	–	30 min	–	–	–	–	–	–
As drawn[1] 1/4-3 in.	75/100	–	10/20	70/95	35/50	–	–	–	–	–
Hot rolled[2] } turned & polished approx	60/80	–	30/40	35/55	45/60	125/150	–	–	–	–
Cold drawn[2] } turned & polished approx	80/95	–	10/20	70/80	40/50	170/202	–	–	–	–
Hot rolled[3] } Aver	68	–	26	45	–	–	–	–	–	–
Cold drawn[3] } Aver	82	72	15	72	–	–	–	–	–	–

[1] ASTM, Bulletin. Tested full size.
[2] Union Drawn Steel.
[3] Jones and Laughlin Steel Corp.
[4] La Salle Steel Co.

STEELS, AISI

B1112

Chemical Composition (AISI)

C %	Mn %	P %	S %
.13 max	.70-.90	.07-.12	.16-.23

Technological Properties

Machinability B1112 is used as the standard for rating other steels for machinability. The ASM Metals Handbook rates steels to the nearest even 5% of B1112 as cold drawn or cold rolled to 179-229 BHN when machined with suitable cutting fluid at 180 fpm under normal cutting conditions with high speed steel tools. Ryerson gives a 100% rating to cold drawn B1112 with properties as shown below.[1] Union Drawn Steel bases its ratings on the use of high speed tools (type not stated) and on 8 hr tool life. With a feed of 0.0025 in. and a depth of cut of 0.500 in., the surface speed for B1112 is 165 fpm. The feed is based on the use of multiple-spindle-type machines using both rough and finish-forming tools. Machinability rating is 100%.

[1]See Mechanical Prop, cold drawn values from ASM Metals Handbook.

Characteristics and Uses. Same as B1111[1] except that B1112 has better machinability. Can be surface hardened by heating in cyanide at 1500 - 1650F, followed by single or double quench and draw.

[1] Characteristics Its special virtues are ease of machining and good surface finish It has good brazing characteristics but is hard to weld except with the low hydrogen electrode E 6015 (AWS). It is only fair in case hardening and for high surface hardness a similar open hearth grade should be substituted Only mild cold forming can be performed and it is not suited to cold heading.

Uses This and similar grades are widely applied for parts made on screw machines which can sacrifice ductility and toughness for machinability It is used for bolts, nuts, studs, and screws, not for vital parts or parts subjected to severe stresses and shocks.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Shear Stress Elastic M psi	Shear Stress Max M psi	Degs of Twist Elastic	Degs of Twist Max
Bars: Hot rolled turned } Aver 1 in. rds.[8]	65	–	27.1	41.1	57.1	142	23	66 2	3.4	1220
Bars: Cold drawn } Aver 1 in. rds.[8]	83	–	15.1	76	50.2	190	34.7	71.2	4.2	970
Bars: Hot rolled[1]	60 min	–	–	30 min	–	–	–	–	–	–
Bars: As drawn[1]	75/100	–	10/20	70/95	35/50	179/229	–	–	–	–
Bars: Cold drawn[2] 5/8-2 in., aver	87	–	17	74	45	183	–	–	–	–
Bars: Hot rolled } 1 in. sect, aver[3]	68	–	26	45	–	–	–	–	–	–
Bars: Cold drawn } 1 in. sect, aver[3]	82	72	15	–	–	–	–	–	–	–
Bars: Hot rolled, } turned & polished approx[4]	60/80	–	30/40	35/55	45/60	126/150	–	–	–	–
Bars: Cold drawn } turned & polished approx[4]	80/100	–	10/20	70/80	40/50	170/202	–	–	–	–
Transverse vs Longitudinal Prop[5]									NBT[7] Ft Lbs	
Longitudinal	66.9	39.9	37.5[6]	–	60.5	–	–	–	18	–
Transverse	62.5	35.9	22.6[6]	–	24.5	–	–	–	9	–

[1] ASTM, Bulletin.
[2] ASM, Metals Handbook.
[3] Jones and Laughlin Steel Corp.
[4] Union Drawn Steel
[5] ASM, Metals Handbook. Data from Battelle Memorial Institute.
[6] ¾ in.
[7] Charpy Vee notch.
[8] La Salle Steel Co.

STEELS, AISI

C1113

Chemical Composition (AISI)

C %	Mn %	P %	S %
.10-.16	1.00-1.30	.040 max	.24-.33

Technological Properties

Machinability Index (On basis of B1112 = 100)	Cold drawn bars = 100% (Source - Union Drawn Steel)

Characteristics and Uses. This is a free machining, open-hearth steel. It is a little softer and more ductile than the high sulphur Bessemer steel B1113.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi
Bars Hot rolled } Aver[1]	59	–	35	38
Bars Cold drawn } Aver[1]	74	65	18	–

[1] Jones and Laughlin Steel Corp.

STEELS, AISI

C1211

Chemical Composition[1] (AISI)			
C %	Mn %	P %	S %
0.13 max	0.60/0.90	0.07/0.12	0.08-0.05

[1]July 1952.

STEELS, AISI

C1212

Chemical Composition[1] (AISI)			
C %	Mn %	P %	S %
0.13 max	0.70-1.00	0 07-0.12	0.16-0.23

[1]July 1952.

STEELS, AISI

C1213

Chemical Composition[1] (AISI)			
C %	Mn %	P %	S %
0.13 max	0.70-1.00	0.07-0.12	0.24-0.33

[1]July 1952.

STEELS, AISI

C1115

Chemical Composition (AISI)			
C %	Mn %	P %	S %
.13-.18	.60-.90	.040 max	.08-.13

Characteristics. Free machining open-hearth steel, less ductile and formable than C1015 but freer machining. It has better mechanical properties than Bessemer steel but is not as machinable. It is satisfactory for small amounts of cold forming, and can be used for more important parts than Bessemer steel. It is satisfactory for forging and b: ing but is only fair for case hardening.

Uses. For bar and forging applications where free machining is desirabl.. A typical use is piston pins.

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Shear Stress Elastic M psi	Shear Stress Max M psi	Degs of Twist Elastic	Degs of Twist Max
Bars	Hot rolled, turned } Aver 1 in. rds.[4]	64.2	–	29.2	42.1	60.5	131	23.2	66.4	3	1510
	Cold drawn } Aver 1 in. rds.[4]	78.6	–	16	72.5	53.5	160	35.1	67.3	4.4	1210
	Hot rolled[1]	57 min	–	–	28.5 min	–	–	–	–	–	–
	As drawn[1]	65/80	–	15/25	55/70	40/50	137/170	–	–	–	–
	As drawn[2]	70/80	–	15/25	60/70	45/55	140/170	–	–	–	–
	Hot rolled } Approx[3]	50/70	–	25/35	25/45	45/55	110/140	–	–	–	–
	Cold drawn } Approx[3]	70/80	–	15/25	60/70	45/55	140/170	–	–	–	–

[1]ASTM, Bulletin.
[2]ASM, Metals Handbook
[3]Union Drawn Steel.
[4]La Salle Steel Co.

STEELS, AISI

C1116

Chemical Composition (AISI)			
C %	Mn %	P %	S %
.14-.20	1.10-1.40	.040 max	.16-.23

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi
Bars:	Hot rolled	64	–	33	41
	Cold drawn	77	67	17	–

C1117

Chemical Composition (AISI)

C %	Mn %	P %	S %
.14-.20	1.00-1.30	.040 max	.08-.13

Technological Properties

Machinability Rating (On basis of B1112 = 100)

Cold drawn to 143-179 BHN = 85% (Source-ASM, Metals Handbook)

Hot rolled at 137 BHN = 85%
Cold drawn at 170 BHN = 91%
(Source - Ryerson.)

Characteristics. Same as C1115[1] but with good case hardening characteristics. Is more ductile than the lower mangasese grades and will stand somewhat severe cold deformations.

Uses. Is used where good machinability and case hardening are required. Can be satisfactorily hardened superficially in activated baths and subsequently heat treated. Typical uses are distributor cams, cam shafts, universal joints.

[1] Characteristics Free machining open-hearth steel, less ductile and formable than C1015 but freer machining. It has better mechanical properties than Bessemer steel but is not as machinable. It is satisfactory for small amounts of cold forming, and can be used for more important parts than Bessemer steel It is satisfactory for forging and brazing but is only fair for case hardening.

As Quenched Rockwell Hardness

Treatment – 1700F for 8 hr., furnace cooled, reheated to 1450F, water quenched, no temper.

Diam.	Center	Midway	Surface
½ in.	29½ Rc	34½ Rc	42 Rb
1 in.	93 Rb	96 Rb	37 Rb
2 in.	86 Rb	90 Rb	33 Rb
4 in.	81 Rb	83 Rb	32 Rb

Critical Points[1]

Ac_1	1345	Ar_3	1450
Ac_3	1540	Ar_1	1340

[1]Bethlehem Steel Co

Treatment Temperatures[1]

Annealing	1575-1625F
Normalizing	1650-1700
Carburizing	1650-1700
Quenching	1450-1650

[1]Industry values

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Shear Stress Elastic M psi	Shear Stress Max M psi	Degs of Twist Elastic	Degs of Twist Max
Hot rolled turned, Aver 1 in rds[10]	–	64.79	–	37.5	44	66	132	24.5	67.69	3.4	1664
Cold drawn, Aver 1 in rds[10]	–	79.5	–	16.9	75	60.3	156	36.5	68.4	5.4	1432
Bars: Hot rolled[2]	–	62 min	–	–	31 min	–	–	–	–	–	–
Cold drawn[2]	–	70/85	60/75	15/25	–	40/50	149/183	–	–	NBT Ft Lbs[1]	–
Cold drawn[3] typ, 5/8-2 in.	–	80	68	19	–	51	163	–	–	–	–
Hot rolled[4]	–	73	–	33	47	63	149	–	–	47	–
Cold drawn[4]	–	80	60	20	–	47	160	–	–	45	–
Hot rolled[5]	–	70.6	–	33	44.3	63	134	–	–	73	–
Normalized 1700F[4]	–	72	–	33	50	67	146	–	–	47	–
Normalized 1650F[5]	–	70	–	33	41.6	63	137	–	–	66	–
Annealed 1600F[4]	–	68	–	44	44	66	139	–	–	48	–
Annealed 1575F[5]	–	66	–	32	41.3	58	121	–	–	65	–
Case Hardened Properties[4]								Case Hard RC			
Carburized 8 hr. at 1700F cooled in box Drawn as shown; 1 in. rd, water quenched 1600F - 1650F and tempered	–	140	–	6	104	27	300	64	–	38	–
	300F	139	–	8	102	30	293	62	–	40	–
	400	137	–	10	100	31	285	61	–	42	–
	500	136	–	12	99	32	277	59	–	43	–
	600	131	–	15	97	36	269	57	–	44	–
1 in. rd. double quenched oil, 1600F water, 1450F and tempered	–	110	–	22	82	54	223	62	–	46	–
	300	102	–	23	74	57	212	60	–	49	–
	400	101	–	24	72	59	207	58	–	51	–
	500	101	–	25	71	62	201	57	–	53	–
	600	97	–	26	69	63	195	55	–	55	–
Core properties[6] Aver	–	96.5	–	23	59.3	52.7	192	65	–	33	–
Effect of Mass[7]											
As rolled 1 in. ctr.	–	69.75	–	33.5	49.5	61.1	149	–	–	60	–
As rolled 2 in. ½r.	–	65.5	–	33.5	39	65.6	137	–	–	78	–
As rolled 4 in. ½r.	–	65.25	–	33.5	37.25	63.8	131	–	–	80	–
Annealed[8] 1 in. diam. ctr.	–	62.25	–	32.8	40.5	58	121	–	–	69	–
Normalized 1650F air cooled ½ in.[9] ctr.	–	69.75	–	34.3	45	61	143	–	–	76	–
Normalized 1650F air cooled 1 in. ctr.	–	67.75	–	33.5	44	63.8	137	–	–	63	–
Normalized 1650F air cooled 2 in. ½r.	–	67	–	33.5	41.5	64.7	137	–	–	83	–
Normalized 1650F air cooled 4 in. ½r.	–	63.75	–	34.3	35	64.7	126	–	–	85	–
Mock Carburized Properties											
1700F, 8 hr furnace cooled reheated to 1450F water quenched drawn at 350F air cooled; ½ in.[9] ctr.	–	124.75	–	9.7	66.5	18.4	235	–	–	13	–
1 in. ctr.	–	89.5	–	22.3	50.5	48.8	183	–	–	37	–
2 in. ½r.	–	78	–	26.3	47.75	65.7	156	–	–	62	–
4 in. ½r.	–	77	–	27.3	45	62.6	156	–	–	86	–

[1] Izod test.
[2] ASTM, Bulletin
[3] ASM, Metals Handbook.
[4] Ryerson. Aver.
[5] Bethlehem Steel Co. Average values for coarse grained.
[6] Bethlehem Steel Co. for coarse grained steel. Carburized as 1 in rds 8 hr at 1700 F, pot cooled, reheat to 1450 F, water quenched, drawn at 350F. Case 0.045 in. deep.
[7] Source Bethlehem Steel Co. Single heat results. Composition Ladle 19%C, 1.12% Mn, 018% P, 099% S, 09% Si; Check 19% C, 1 10% Mn, 015% P, 084% S, 11% Si. McQuaid-Ehn grain Size = 100% 2-4 Test specimens. Tensile bars 0.505 in. diam, Izod 0.450 in. diam. Values are average of two tests.
[8] 1575 F, furnace cooled at 30 F/hr to 1290 F, air cooled.
[9] The tensile text bar was 0 357 in diam.
[10] La Salle Steel Co.

C1118

Chemical Composition (AISI)			
C %	Mn %	P %	S %
.14-.20	1.30-1.60	.040 max	.08-.13

Critical Points[1]

Ac_1	1330F	Ar_3	1385F
Ac_3	1515	Ar_1	1175

[1] Bethlehem Steel Co.

Characteristics. Same as C1115[1] except that its case hardening characteristics are good.

Uses. It is used about the same as C1117[2] except its greater hardenability makes C1118 better for solid parts or for heavier walls. For more drastic quenching or for lighter sections, the C1117 is preferred. In cold forming, C1118 is about the same as the straight carbon grade.

[1] Characteristics. Free machining open-hearth steel, less ductile and formable than C1015 but freer machining. It has better mechanical properties than Bessemer steel but is not as machinable. It is satisfactory for small amounts of cold forming, and can be used for more important parts than Bessemer steel. It is satisfactory for forging and brazing but is only fair for case hardening.

Uses. Is used where good machinability and case hardening are required. Can be satisfactorily hardened superficially in activated baths and subsequently heat treated. Typical uses are distributor cams, cam shafts, universal joints.

Technological Properties

Machinability Index (On basis of B1112 = 100) — Cold drawn to 143-179 BHN = 80% C1119 is given as 91%

As Quenched Rockwell Hardness

Treatment — 1700F, furnace cooled, reheated to 1450F, water quenched, not drawn.

Diam	Center	Midway	Surface
½ in.	33 Rc	36 Rc	43 Rc
1 in.	96½ Rb	99 Rb	36 Rc
2 in.	87 Rb	91 Rb	34 Rc
4 in.	82 Rb	84 Rb	32 Rc

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Shear Stress Elastic M psi	Shear Stress Max M psi	Degs of Twist Elastic	Degs of Twist Max
Hot rolled, turned, Aver 1 in. rds[12]	–	67.5	–	33	45.1	61	132	25.1	69.9	3.6	1595
Cold drawn, Aver 1 in. rds[12]	–	82.5	–	15.5	78.9	56.5	171	37.4	71.4	5.6	1376
Bars: Hot rolled[1]	–	64 min	–	–	32 min	–	–	–	–	–	–
Cold drawn[1]	–	75/90	–	15.25	65/80	40/50	149/183	–	–	–	–
Cold drawn[2] Aver, 5/8-2 in. diam	–	82.5	–	18.5	70.1	50	167	–	–	–	–
Hot rolled, Aver[3]	–	55/75	–	25/35	30/50	45/55	115/140	–	–	–	–
Cold drawn, Aver[3]	–	75/85	–	15/25	60/75	45/55	143/170	–	–	–	–
Hot rolled, Aver[4] 1 in. sect.	–	70	–	30	46	–	–	–	–	–	–
Cold drawn, Aver[4] 1 in. sect.	–	82	72	16	–	–	–	–	–	–	–
Cold drawn[5] ½ in. diam[4]	–	85.9	70.55	20	–	–	–	–	–	–	–
Strain drawn, cold drawn and tempered, drawn as shown ½ in. diam[4] [5]	600F	89.47	75.15	21.5	–	–	–	–	–	–	–
	800	88.7	74.64	24	–	–	–	–	–	–	–
	1000	84.62	70.55	26.5	–	–	–	–	–	–	–
Annealed	1200	72.86	54.2	31	–	–	–	–	–	–	–
Water quenched, drawn as shown[4] [5]	600	180.7	160.16	12.5	–	–	–	–	–	NBT	–
	800	148.86	137.05	15.5	–	–	–	–	–	Ft Lbs	–
	1000	113.7	104.73	20	–	–	–	–	–	–	–
	1100	104.2	93.43	24	–	–	–	–	–	–	–
1 in. Bars: Hot rolled, aver, coarse-grained[6]	–	75.6	–	32	45.9	70	149	–	–	80	–
Norm, 1700F, aver, coarse-grained[6]	–	75.8	–	32	44.8	69	143	–	–	79	–
Ann, 1450F, aver, coarse-grained[6]	–	70.7	–	33	41.9	67	126	–	–	76	–
Effect of Mass[7]											
As rolled, 1 in. ctr.	–	70.5	–	32.3	51.5	63	143	–	–	76	–
As rolled, 2 in. ½r.	–	69.25	–	35	43.375	68.2	137	–	–	81	–
As rolled, 4 in. ½r.	–	66.25	–	34.8	41.5	67.1	131	–	–	84	–
Annealed[8] 1 in. ctr.	–	65.25	–	34.5	41.25	66.8	131	–	–	79	–
Normalized 1700F air cooled, ½ in.[9] ctr.	–	72.75	–	33.3	47.8	62.8	156	–	–	67	–
Normalized 1700F air cooled, 1 in. ctr.	–	69.25	–	33.5	46.25	65.9	143	–	–	76	–
Normalized 1700F air cooled, 2 in. ½r.	–	68.5	–	33	43.25	67.7	137	–	–	84	–
Normalized 1700F air cooled, 4 in. ½r.	–	66.25	–	34	37.75	67.4	131	–	–	83	–
Mock Carburized, Quenched and Tempered											
1700F for 8 hr furnace cooled, reheated to 1460F, water quenched, drawn at 350F, ½ in.[9] ctr.	–	144.5	–	13.2	90	30.8	285	–	–	15	–
1 in. ctr.	–	102.5	–	19	59.25	48.9	207	–	–	34	–
2 in. ½r.	–	82.25	–	27.3	47.875	65.5	167	–	–	37	–
4 in. ½r.	–	74.75	–	31	42.75	67.4	149	–	–	60	–
Core Properties[10] (Case 0.065 in. deep 61Rc)	–	113	–	17	76.5	45	229	–	–	16[11]	–

[1] ASTM, Bulletin.
[2] ASM, Metals Handbook.
[3] Union Drawn Steel.
[4] Jones and Laughlin Steel Co.
[5] Single heat results. The composition was .18 C, 1.37 Mn, .017 P. The bars were ½ in. diam.
[6] Source—Bethlehem Steel Co. Treated at 1 in. diam., tested at 0.505 in. diam.
[7] Bethlehem Steel Co. Single heat results. Chemical Composition, Ladle: .18 C, 1.36 Mn, .017 P, .08 S, Check: .20 C, 1.34 Mn, .017 P, .08 S, .09 Si; McQuaid-Ehn grain size = 90% 3-5; 10% 2, Test samples - The tensile test bars were 0.505 in. diam., and the Izod bars were 0.450 in diam. Results are the average of two tests.
[8] Treatments - 1450F, furnace cooled at 30 deg F per hr to 1125F, air cooled.
[9] Tensile test bar was 0.357 in. diam.
[10] Bethlehem Steel Co. Average values. Coarse grained steel at 1 in. diam carburized 8 hr at 1700F, pot cooled, reheated to 1450F, water quenched, tempered at 350F.
[11] Izod test.
[12] La Salle Steel Co.

STEELS, AISI

C1120

Chemical Composition (AISI)

C %	Mn %	P %	S %
.18-.23	.70-1.00	.040 max	.08-.13

Technological Properties

Machinability Rating (On basis of B1112 = 100): Cold drawn to 143-179 = 81% (Source - ASM, Metals Handbook)

Characteristics. Same as C1115[1]. This is a water hardening steel, quenching temperature = 1500- 1550 F.

[1] Characteristics Free machining open-hearth steel, less ductile and formable than C1015 but freer machining. It has better mechanical properties than Bessemer steel but is not as machinable It is satisfactory for small amounts of cold forming, and can be used for more important parts than Bessemer steel It is satisfactory for forging and brazing but is only fair for case hardening

Mechanical Properties

Form or Condition	Tensile Strength M psi	Elong 2 in %	Yield Point M psi	Red Area %	Hard BHN
Bars Hot rolled[1]	62 min	–	31 min	–	–
Cold drawn[2] Aver, 5/8-2 in. diam	78	19.5	66.3	49	159

[1] ASTM, Bulletin.
[2] ASM, Metals Handbook

STEELS, AISI

SAE 1132

Chemical Composition (AISI)

C %	Mn %	P %	S %
.27-.34	1.35-1.65	0.40	.08-.13

Technological Properties

Machinability Rating (On basis of B1112 = 100): Cold drawn to 187-229 BHN = 75% (ASM, Metals Handbook)

Uses. Used in place of C1035 and C1040 when more hardenability and higher properties are required with good machinability.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength[3] M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Shear Stress Elastic M psi	Shear Stress Max M psi	Degs of Twist Elastic	Degs of Twist Max
Hot rolled, turned, Aver 1 in. rds[1]	79.7	–	31.3	49.54	63.7	165	35.91	82.08	3.7	2208
Cold drawn, Aver 1 in. rds[1]	93.25	–	16.4	85	58.3	191	36.6	82.1	6	1507
Hot Rolled, and cold drawn ≤9/16 in.	93-113	75-95	14-24	–	38-58	187-229	–	–	–	–
Hot Rolled, and cold drawn >9/16 in.-1½ in. incl.	88-110	70-90	13-23	–	35-60	179-217	–	–	–	–
Hot Rolled, and cold drawn > 1½ in.-3½ in. incl.	80-100	65-85	13-23	–	30-55	164-202	–	–	–	–
ann.-cold drawn >9/16 in.-1½ in. incl.	84-104	68-88	15-25	–	46-62	169-212	–	–	–	–
Hot rolled, turned and polished[2] 2½ in.-4 in. incl.	72-92	45-65	22-32	–	40-60	146-179	–	–	–	–

[1] La Salle Steel Co.
[2] C 1132. Bliss & Laughlin.
[3] 0.5% extension under load.

C1137

Chemical Composition (AISI)			
C %	Mn %	P %	S %
.32-.39	1.35-1.65	.040 max	.08-.13

Characteristics. It has good heat treating and brazing characteristics and is of fair forging quality. It can be used in the cold drawn or heat-treated condition, either oil or water-quenched, though care is needed in water quenching. This steel combines heat treating and free cutting. It can be induction or flame hardened but C1141 is better.

Uses. It is used in place of C1045 and C1050 for better machining. Typical uses are for generator shafts, worm gears, wheel puller bolts where parts must resist wear and also be tough with good machinability.

Treatment Temperatures	
Annealing	1450-1500F
Normalizing	1550-1650
Quenching	1525-1600

Critical Points[1]			
Ac_1	1330F	Ar_3	1310
Ac_3	1450	Ar_1	1180

[1]Bethlehem Steel Co.

Technological Properties

Machinability Rating (On basis of B1112 = 100)	Cold drawn to 187-229 BHN = 73% (ASM, Metals Handbook)

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Shear Stress Elastic M psi	Shear Stress Max M psi	Degs of Twist Elastic	Degs of Twist Max
Hot rolled, turned, Aver 1 in. rds[9]	–	86.4	–	27.3	54.6	61	180	36.1	85.1	4.9	1850
Cold drawn, Aver 1 in. rds[9]	–	103.5	–	15.1	93	56.3	217	37.9	87.25	6.4	1620
Bars Hot rolled[1]	–	87 min	–	–	48 min	–	–	–	–	–	–
Cold drawn[1]	–	90/115	–	12/20	80/100	35/45	187/235	–	–	–	–
Cold drawn[2] 5/8-2 in. diam	–	100/120	–	10/15	85/100	30/45	187/235	–	–	–	–
range & typ values	–	105	–	16	89.2	35	217	–	–	–	–
Hot rolled, turned & polished aver[3]	–	70/90	–	20/30	45/65	35/50	152/187	–	–	–	–
Cold drawn aver[3]	–	100/120	–	10/15	85/100	30/45	187/235	–	–	–	–
Bars Hot rolled, Aver for 1 in. sect.[4]	–	98	–	17	63	–	–	–	–	–	–
Cold drawn, Aver for 1 in. sect.[4]	–	107	97	12	–	–	–	–	–	–	–
Cold drawn	–	104.1	99.1	18	–	–	–	–	–	–	–
Strain drawn, Single heat results, 13/16 in. Comp: .33C 1.49 Mn .024P[4]	600F	113.07	104.1	15.5	–	–	–	–	–	–	–
	800F	108.58	94.36	18.5	–	–	–	–	–	–	–
	1000F	102	79 7	21	–	–	–	–	–	–	–
Annealed	1200F	89.87	–	26	66.16	–	–	–	–	–	–
C1141, Low C											
Cold drawn, Single heat results Comp: .38C, 1.49 Mn, 026P[4]	–	122.3	110.27	12.5	–	–	–	–	–	–	–
Strain drawn	750F	125.3	102 26	13	–	–	–	–	–	–	–
	850F	122.05	97	14.5	–	–	–	–	–	–	–
Effect of Mass[5]										NBT Ft Lbs[7]	
Hot rolled 1 in. ctr.	–	98	–	24	65.75	61	197	–	–	–	–
2 in. 1/2r.	–	97	–	24.3	57.25	56.9	197	–	–	–	–
4 in. 1/2r.	–	94.25	–	24.5	51.5	51.3	192	–	–	–	–
Annealed[6] 1 in. ctr.	–	84.75	–	26.8	55.75	53.9	174	–	–	37	–
Normalized 1650F air cooled 1/2 in. ctr.[8]	–	98	–	25	58.5	58.5	201	–	–	70	–
1 in. ctr.	–	97	–	22.5	57.5	48.5	197	–	–	47	–
2 in. 1/2r.	–	96	–	21 8	49	51.6	197	–	–	22	–
4 in. 1/2r.	–	94	–	23.3	48	51	192	–	–	31	–
1650F air cooled, 1575F quenched in agitated oil, drawn as shown 1/2 in ctr.[8]	1000F	127.5	–	18.2	100	55.8	255	–	–	44	–
1 in. ctr.	1000F	108	–	21.3	75.75	56	223	–	–	50	–
2 in. 1/2r.	1000F	105	–	23	63	56.2	217	–	–	31	–
4 in. 1/2r.	1000F	100.5	–	22.3	58.75	55.5	201	–	–	32	–
1/2 in. ctr.[8]	1100F	112.5	–	21.8	90	61	229	–	–	58	–
1 in. ctr.	1100F	100.75	–	23.5	68.75	60.1	207	–	–	56	–
2 in. 1/2r.	1100F	98	–	23	61.5	57.8	207	–	–	40	–
4 in. 1/2r.	1100F	95.25	–	24.5	57	59.5	192	–	–	32	–
1/2 in. ctr.[8]	1200F	104	–	24.6	80.5	63.6	217	–	–	68	–
1 in. ctr.	1200F	97.75	–	23.5	68.75	60.8	201	–	–	60	–
2 in. 1/2r.	1200F	97	–	25	57.25	64.1	197	–	–	46	–
4 in. 1/2r.	1200F	94.5	–	24	56	61.1	192	–	–	41	–
1650F air cooled 1550F quenched in water, drawn as shown 1/2 in. ctr.[8]	1000F	129.5	–	17.1	112	51.3	262	–	–	41	–
1 in. ctr.	1000F	122	–	16.9	98	51.2	248	–	–	38	–
2 in. 1/2r.	1000F	110	–	20.8	71.25	56.1	229	–	–	46	–
4 in. 1/2r.	1000F	108	–	20.3	69	52.1	223	–	–	23	–
1/2 in.[8] ctr.	1100F	112.5	–	21.4	95	57.6	229	–	–	44	–
1 in. ctr.	1100F	107.75	–	21	87.75	59.2	223	–	–	50	–
2 in. 1/2r.	1100F	105.25	–	22	76	61.7	217	–	–	61	–
4 in 1/2r.	1100F	97.75	–	23.5	61.25	60.9	201	–	–	29	–
1/2 in.[8] ctr.	1200F	105	–	23.9	89	61.2	223	–	–	74	–
1 in. ctr.	1200F	102.5	–	22.3	81.75	58.8	217	–	–	60	–
2 in. 1/2r.	1200F	97.5	–	24	67	64.1	201	–	–	62	–
4 in. 1/2r.	1200F	95.5	–	24	60	63.5	197	–	–	38	–

[1] ASTM, Bulletin.
[2] ASM, Metals Handbook.
[3] Union Drawn Steel.
[4] Jones and Laughlin Steel Corp.
[5] Source—Bethlehem Steel Co. Single heat results. Chemical Composition, Ladle .37C, 1.37 Mn, .019 P, .086 S, .16 Si, Check .37 C, 1.40 Mn, .015 P, .08 S, .17 Si. McQuaid-Ehn grain size = 100 ∘ 1-4, Test Specimens - Tensile test bars were 0.505 in. diam., and the Izod bars were 0.450 in. diam. The results are the average of two tests.
[6] 1450F, furnace cool at 20 Deg F per hr to 1130F, air cool.
[7] Izod test.
[8] Tensile test bar was 0.357 in. diam.
[9] La Salle Steel Co.

(Continued on page 176)

STEELS, AISI

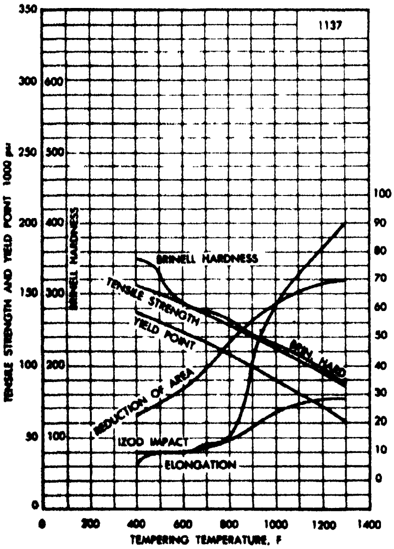
C1137

(Continued from page 175)

As Quenched Rockwell Hardness

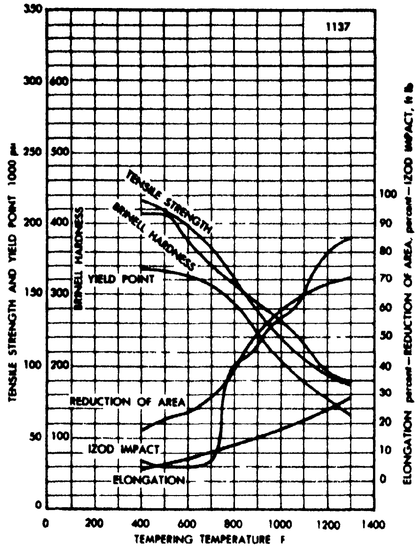
Treatment - 1650F, air cooled 1575F, quenched in agitated oil.				Treatment - 1650F, air cooled 1550F, quenched in water.			
Diam	Center	Midway	Surface	Diam	Center	Midway	Surface
½ in.	42 Rc	43 Rc	48 Rc	½ in.	50 Rc	53 Rc	57 Rc
1 in.	23 Rc	28 Rc	34 Rc	1 in.	45 Rc	50 Rc	56 Rc
2 in.	18 Rc	22 Rc	28 Rc	2 in.	24 Rc	35 Rc	52 Rc
4 in.	16 Rc	18 Rc	21 Rc	4 in.	20 Rc	23 Rc	48 Rc

Oil Quenched



Source: Bethlehem Steel Co. Treatment and samples: 1 in. diam bars were treated as shown and tested as .505 in. rds. Data are average values for coarse grained steels.

Water Quenched



STEELS, AISI

C1151

Chemical Composition (AISI)

C %	Mn %	P %	S %
.48-.55	.70-1.00	.040 max	.08-.13

Characteristics. Similar to C1141 though more responsive to heat treatment.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength[3] M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN
Bars: Hot rolled[1]	93 min	–	–	51 min	–	–
Cold drawn[1]	100/130	–	9/18	90/110	30/40	197/248
Hot rolled and cold drawn ≤ ⁹⁄₁₆ in.	103-123	85-105	10-20	–	33-53	207-248
Hot rolled and cold drawn > ⁹⁄₁₆ in. - 1½ in. incl.	98-118	80-100	10-20	–	30-50	197-235
Hot rolled and cold drawn > 1½ in. - 3½ in. incl.	88-108	73-93	8-18	–	25-45	174-217
annealed - cold drawn > ⁹⁄₁₆ in. - 1½ in. incl.	90-110	75-95	12-22	–	38-58	183-221
Hot rolled, turned and polished, 2½ in. - 4 in.	82-102	50-70	18-28	–	36-56	164-217

[1]ASTM, Bulletin
[2]Bliss & Laughlin
[3]0.5% extension under load

C1144

Chemical Composition (AISI)			
C %	Mn %	P %	S %
.40-.48	1.35-1.65	.040 max	.24-.33

Characteristics. Similar to C1141 though with higher sulphur for improved machinability.

Technological Properties

Machinability Rating (On basis of B1112 = 100) As rolled = 76% Annealed = 85%

Mechanical Properties

Form or Condition		Draw Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	NBT Ft Lbs[6]
Bars: Hot rolled	Aver for 1 in. sect[1]	–	108	–	12	68	–	–	–
Cold drawn	Aver for 1 in. sect[1]	–	115	105	10	–	–	–	–
Cold drawn	Single heat 1-1/8 in.[1]	–	129.33	119.78	13.0	–	–	–	–
Strain drawn	Single heat 1-1/8 in.[1]	560F	139.33	134.2	12.0	–	–	–	–
									End Lt M psi
Cold drawn[5]	5/8 - 7/8 in. incl.	–	110	100	10	–	30	223	–
	> 7/8 - 1¼ in. incl.	–	105	95	10	–	30	212	–
	> 1¼ - 2 in. incl.	–	100	90	10	–	25	197	–
	> 2 - 3 in. incl.	–	95	85	10	–	20	187	–
Aver Prop[5] As rolled Cold drawn or drawn, ground and polished	≤ 9/16 in. incl.	–	105-125	90-110[6]	10-20	–	30-50	212-255	50
	> 9/16 in. - 1½ in. incl.	–	100-120	85-105[6]	8-18	–	30-45	197-235	48
	> 1½ in. - 3½ in. incl.	–	95-120	80-110[6]	7-17	–	20-40	183-235	43
As rolled turned & polished, 2½ - 4 in. incl.		–	87-107	54-74[6]	16-26	–	34-54	183-231	41.5
Annealed - cold drawn	> 9/16 in. - 1½ in. incl.	–	90-110	80-100[6]	11-21	–	35-55	183-221	–
Effect of Mass[2]									
As rolled	1 in. ctr.	–	96.5	–	20.5	55.5	37.1	192	38
	2 in. ½r.	–	95.5	–	21.5	53	43.7	192	28
	4 in. ½r.	–	92.75	–	22	50.5	43.2	183	39
Annealed[3]	1 in. ctr.	–	84.75	–	24.8	50.25	41.3	167	48
Normalized 1650F air cooled	½ in.[4] ctr.	–	98	–	24.6	60.5	51	201	34
	1 in. ctr.	–	96.75	–	21	58	40.4	197	32
	2 in. ½r.	–	95.5	–	21.5	54	45	192	43
	4 in. ½r.	–	94.25	–	21.5	52.5	42.7	192	47
1650F air cooled 1550F, oil tower quenched tempered as shown	½ in.[4] ctr.	1000F	113.5	–	20.4	79	52.1	235	40
	1 in. ctr.	1000F	108.5	–	19.3	72.75	46	223	41
	2 in. ½r.	1000F	105	–	20.5	67.75	49.6	212	51
	4 in. ½r.	1000F	101.75	–	21.5	63	50	207	53
	½ in.[4] ctr	1100F	104	–	20.7	71.25	51.2	217	46
	1 in. ctr.	1100F	102.75	–	21.5	68	51.4	212	47
	2 in. ½r.	1100F	101	–	23.3	65	56.5	207	56
	4 in. ½r.	1100F	94.25	–	23.8	57.75	54.4	192	60
	½ in.[4] ctr.	1200F	97.5	–	23.2	69	55.2	201	56
	1 in. ctr.	1200F	97	–	23	68	52.4	201	57
	2 in. ½r.	1200F	94	–	24	61.5	57.7	192	62
	4 in. ½r.	1200F	89	–	25.8	54.5	57.7	183	61
1650F air cooled 1550F water quenched tempered as shown	½ in.[4] ctr.	1000F	121.5	–	15.7	100.5	50.9	255	39
	1 in. ctr.	1000F	116.5	–	18.5	82.75	44.3	235	41
	2 in. ½r.	1000F	115.75	–	19.5	80.5	51.7	229	49
	4 in. ½r.	1000F	111.5	–	19.3	70.5	48.6	223	45
	½ in.[4] ctr.	1100F	118.5	–	21.4	99.75	51	241	47
	1 in. ctr.	1100F	113.75	–	19	82.75	51.3	229	45
	2 in. ½r.	1100F	107	–	21	72.5	54.8	217	53
	4 in. ½r.	1100F	96	–	23.5	60.75	57.2	197	51
	½ in.[4] ctr.	1200F	103.5	–	21.1	89	54	217	49
	1 in. ctr.	1200F	103	–	21.8	77.5	53.8	212	47
	2 in. ½r.	1200F	100.75	–	22.5	69.25	57.5	201	54
	4 in. ½r.	1200F	95	–	23.8	61.75	56.9	197	52

[1] Jones and Laughlin Steel Corp. For additional data on lower carbon C1144, see C1141. Comp. .48C, 1.63Mn, .030P.

[2] Bethlehem Steel Co. Single heat results. Chemical Composition Ladle .46 C, 1.41 Mn, .021 P, .26 S, .09 Si. Check' .46 C, 1.37 Mn, .019 P, .24 S, .05 Si, McQuaid-Ehn grain size = 70% 1-4, 25% 5-6. Test Specimens - The tensile test bars were 0.505 in. diam Izod bars 0.450 in. The values are the average of two tests.

[3] 1450F, furnace cooled at 20 Deg F per hr to 1150 F, air cooled.

[4] Tensile test bar was 0.357 in. diam.

[5] Bliss & Laughlin.

[6] 0.5% extension under load.

(Continued on page 178)

C1144

Critical Points[1]

Ac_1	1335F	Ar_3	1285F
Ac_3	1400	Ar_1	1200

[1]Bethlehem Steel Co.

(Continued from page 177)

As Quenched Rockwell Hardness

Treatment – 1650 F, air cooled, 1550F, oil tower quenched.

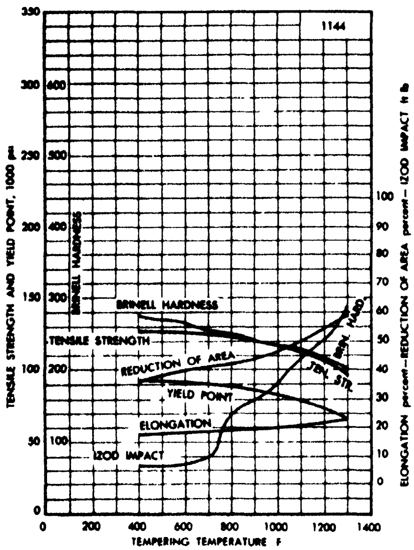
Diam	Center	Midway	Surface
½ in.	28 Rc	32 Rc	39 Rc
1 in.	24 Rc	29 Rc	36 Rc
2 in.	22 Rc	27 Rc	30 Rc
4 in.	19 Rc	21 Rc	27 Rc

As Quenched Rockwell Hardness

Treatment – 1650 F, air cooled, 1550F, water quenched.

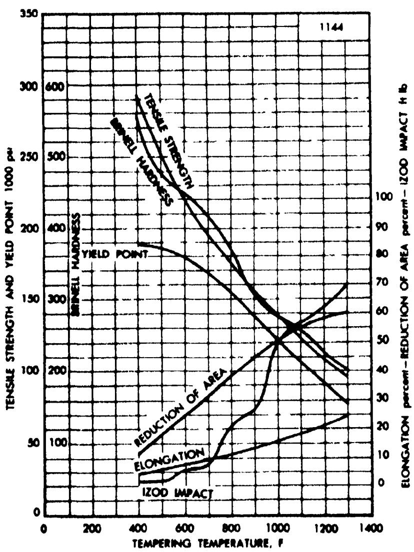
Diam	Center	Midway	Surface
½ in.	50 Rc	53 Rc	58 Rc
1 in.	29 Rc	33 Rc	57 Rc
2 in.	25 Rc	30 Rc	55 Rc
4 in.	23 Rc	25 Rc	35 Rc

Oil Quenched and Tempered



Source. Bethlehem Steel Co. Treatment and samples: 1 in. diam bars were treated as shown and tested as .505 in. rds. Data are average values for coarse grained steels.

Water Quenched and Tempered



STEELS, AISI
C1141

Chemical Composition (AISI)

C %	Mn %	P %	S %
.37-.45	1.35-1.65	.040 max	.08-.13

Treatment Temperatures[1]

Forging	1950-2200F
Normalizing	1600-1700
Annealing	1450-1500
Quenching	1500-1550

[1]Ryerson

Critical Points

Ac_1	1315F	Ar_3	1360F
Ac_3	1420	Ar_1	1220

Characteristics. This is an oil-hardening steel, with higher carbon than C1137 it is better for flame and induction hardening and responds better generally to heat treatment. It has good machinability and is used in the as- rolled, cold drawn, and heat treated conditions.

Effect of Mass[1] **Brinell Hardness**

Treatment: Oil Quenched at 1525F

	Draw Temp	½	1	2	3	4	5	6
Surface	800F	331	331	321	311	302	302	293
Midway	800F	331	331	285	277	269	255	241
Center	800F	331	311	269	262	262	248	241
Surface	1000F	285	285	285	277	269	262	255
Midway	1000F	285	285	277	255	235	229	217
Center	1000F	285	269	262	241	229	223	217
Surface	1200F	229	229	229	223	217	212	212
Midway	1200F	229	229	223	212	201	197	197
Center	1200F	229	223	217	207	201	197	197

(Diam in inches)

Technological Properties

Machinability Rating (On basis of B1112 = 100)

Cold drawn to 183-241 BHN = 70% (ASM, Metals Handbook), though the rating may be as high as 75% (Ryerson)

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Shear Stress Elastic M psi	Shear Stress Max M psi	Degs of Twist Elastic	Degs of Twist Max
Hotrolled, turned } Aver. 1 in. rds[7]	–	90	–	26.5	57.8	58.5	193	37.3	87	5.0	1830
Cold drawn } Aver. 1 in. rds[7]	–	110.3	–	14.8	99	52.7	228	38.2	91	6.5	1595
Bars: Hot rolled } Aver[1]	–	97	–	25	60	51	201	–	–	–	–
Bars: Normalized } Aver[1]	–	100	–	22	70	43	212	–	–	–	–
Bars: Annealed } Aver[1]	–	93	–	28	65	48	187	End Lt M psi	–	–	–
Bars: Cold drawn } Aver[1]	–	111	–	14	95	40	223		–	–	–
Cold drawn[8] ⅝ - ⅞ in. incl.	–	105	95	11	–	30	212	–	–	-	–
Cold drawn[8] > ⅞ - 1¼ in. incl.	–	100	90	10	–	30	197	–	–	–	–
Cold drawn[8] > 1¼ - 2 in. incl.	–	95	85	10	–	30	187	–	–	–	–
Cold drawn[8] > 2 - 3 in. incl.	–	90	80	10	–	20	179	–	–	–	–
Aver. Prop.[8] As rolled cold drawn or drawn, ground and polished } ≤ 9/16 in. incl.	–	105-125	87-107[9]	10-20	–	33-53	212-255	50	–	–	–
Aver. Prop.[8] As rolled cold drawn or drawn, ground and polished } > 9/16 in. - 1½ in. incl.	–	100-120	83-103[9]	9-19	–	30-50	202-241	48	–	–	–
Aver. Prop.[8] As rolled cold drawn or drawn, ground and polished } > 1½ in. - 3½ in. incl.	–	90-110	75-95[9]	8-18	–	20-45	179-221	43	–	–	–
As rolled turned and polished or turned, ground and polished } 2½ - 4 in. incl.	–	84-104	52-72[9]	18-28	–	36-56	170-221	40	–	–	–
annealed, cold drawn > 9/16 in. - 1½ in.	–	92-112	78-98[9]	12-22	–	38-58	187-228	–	–	–	–
Hot rolled } Aver for 1 in. sect[2]	–	105	–	13	66	–	–	–	–	–	–
cold drawn } Aver for 1 in. sect[2]	–	112	102	10	–	–	–	–	–	–	–
Cold drawn } Single heat values for 2 in. bars Analysis:.020P .42C, 1.59Mn[2]	–	118.8	111.13	6.5	–	–	–	–	–	–	–
Strain drawn represents cold drawn after drawing } Single heat values for 2 in. bars Analysis:.020P .42C, 1.59Mn[2]	550F	128.8	122.8	8	–	–	–	–	–	–	–
	750F	126.8	112.35	10.5	–	–	–	–	–	–	–
	950F	118.35	85.54	16	–	–	–	–	–	–	–
Cold drawn } Single heat 7/8 in. bars[2]	–	119.3	107.76	12	–	–	–	–	–	–	–
strain drawn } Single heat 7/8 in. bars[2]	800F	122.56	101.26	16	–	–	–	–	–	–	–
Hot rolled } .015P[2] industry values[3]	–	92 min	–	–	50.5 min	–	–	–	–	–	–
As drawn } .015P[2] industry values[3]	–	95/120	–	10/20	85/105	35/45	197/248	–	–	–	–
As drawn[4] Aver for 5/8-2 in. diam bars	–	112	–	14	95.2	30	223	–	–	–	–
Single heat values. Water quenched & drawn. Analysis .42C, 1.49Mn, .013P } 9/16 in. bars[2]	800F	184.2	167.9	12	–	–	–	–	–	–	–
	1000F	138.8	122.83	18	–	–	–	–	–	–	–
	1100F	126.56	110.34	20	–	–	–	–	–	–	–
										NBT Ft Lbs[6]	
1525F quenched in oil, drawn as shown } Aver of 1 in. bars[1]	No Temper	197	–	7	169	17	415	–	–	8	–
	400F	190	–	9	163	22	401	–	–	6	–
	500F	187	–	12	154	26	388	–	–	6	–
	600F	180	–	15	141	31	375	–	–	7	–
	700F	168	–	17	125	35	352	–	–	11	–
1525F quenched in oil, drawn as shown } Aver of 1 in. bars[1]	800F	154	–	18	110	41	331	–	–	15	–
	900F	146	–	19	105	44	321	–	–	25	–
	1000F	136	–	20	99	47	293	–	–	43	–
	1100F	128	–	21	93	50	269	–	–	49	–
	1200F	121	–	22	88	52	248	–	–	57	–

[1]Ryerson, Aver.
[2]Jones and Laughlin Steel Corp. Analysis. .45C, 1.61Mn, .015P.
[3]ASTM, Bulletin.
[4]ASM, Metals Handbook
[5]Though this steel is not usually water quenched, the following values are given to present the properties.
[6]Izod test.
[7]La Salle Steel Co.
[8]Bliss & Laughlin, Inc.
[9]0.5% extension under load.

1320

Chemical Composition[1]

C %	Mn %	P %	S %	Si %
.18-.23	1.60-1.90	.040 max	.040 max	.20-.35

[1] AISI

Critical Points

Case	Ac_1	1325F
Core	Ac_3	1500F

Characteristics. A relatively cheap, low-alloy carburizing steel with greater hardenability than the 1000 and 1100 steels of comparable carbon content, and with poorer machinability than the sulphurized 1100 steels.

Electrical Resistivity[1]

Temp Range Deg C	Deg F	Microhm-cm	Temp Range Deg C	Deg F	Microhm-cm
20	68	20.8	800	1472	110.3
100	212	25.9	900	1652	114.3
200	392	33.3	1000	1832	117.4
400	752	52.3	1100	2012	120.2
600	1112	78.6	1200	2192	122.7
700	1292	94.6	1300	2372	125.0

[1] Source — ASM, Metals Handbook. Data from Natl. Phys. Lab., Jour. Iron and Steel Inst., 1946, No. II. Steel Analysis — .23C, 1.51 Mn, .105 Cu.

Technological Properties

Machinability Rating (On basis of B1112 = 100) cold drawn to 170-229 = 50% (ASM, Metals Handbook.) An industry value of 55% is also given for the hot rolled condition.

Mean Apparent Specific Heat[1]

Temp Range Deg F	Deg C	Cal/gm/°C	Temp Range Deg F	Deg C	Cal/gm/°C
122-212	50-100	.114	842- 932	450-500	.155
302-392	150-200	.122	1022-1112	550-600	.177
392-482	200-250	.126	1202-1292	650-700	.200
482-572	250-300	.130	1292-1382	700-750	.346
572-662	300-350	.135	1382-1472	750-800	.196
662-752	350-400	.141	1562-1652	850-900	.128

[1] Source — ASM, Metals Handbook. Data from Natl. Phys. Lab., Jour. Iron and Steel Inst., 1946, No II. Steel Analysis — .23C, 1.51 Mn, .105 Cu.

Mechanical Properties

Common Case Hardening Treatments — For fine grained steel (1) Direct box quench in oil, draw (2) Cool in box, oil quench from a high temp draw.

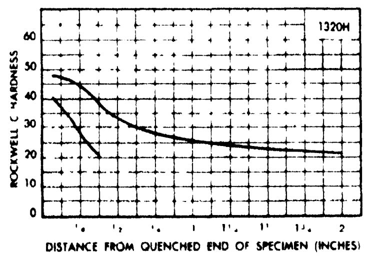
Mechanical Properties[1]

Form or Condition			Tensile Strength M psi	Yield Point M psi	Yield Strength M psi	Elong 2 in %	Red Area %	Hard[2] BHN	Impact Resist Ft. Lbs.[3]
Aver prop 1 in rd mean chemistry	Cold drawn-Normal Draft	unannealed	102	80	–	20	57	207	–
		annealed	84	72	–	24	60	179	–
	Turned and Polished	unannealed	90	67	–	23	59	187	–
		annealed	82	57	–	30	65	163	–
Core Prop pseudo carburized 1700F 8 hrs, oil quenched tempered at 300F	Direct quench	1 in. rd. ctr.	127	–	100	20.0	50.5	321	50
	Reheat 1425F		118	–	85.5	26.0	47.0	229	30
	Reheat 1475F		100	–	73.5	28.0	65.0	217	80
	Reheat 1525F		97.5	–	70.25	31.0	68.0	229	79
	Direct quench	2 in. rd. ctr.	104.7	–	71.5	27.0	63.5	255	55
	Reheat 1425F		102.5	–	63.25	29.0	55.0	207	26
	Reheat 1475F		97	–	63.5	31.5	66.3	187	80
	Reheat 1525F		98.5	–	62.75	31.5	59.8	187	80

[1] Bliss & Laughlin
[2] surface of bar
[3] Izod 0.394 in. sq. specimens

1320H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	P %	S %	Si %
.17-.24	1.50-2.00	–[1]	–[1]	.20-.35

[1] P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

"J" Distance in Inches[1]

	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	48.0	47.5	46.5	45.0	42.5	39.0	36.0	33.5	31.5	30.0	29.0	28.0	27.5	27.0	26.5	26.0	25.0	24.0	23.5	23.0	22.5	22.0	21.5	21.0
Min	40.5	37.0	33.0	28.5	24.0	20.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

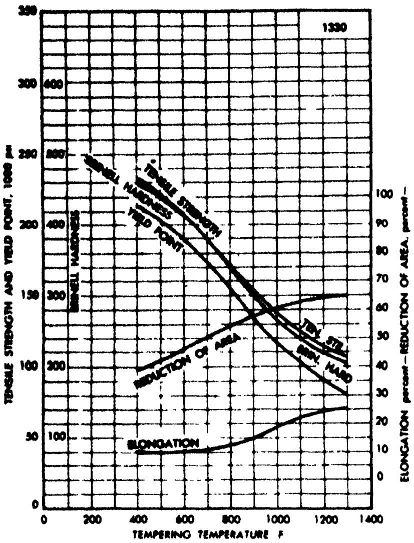
[1] Note - These values are to be used when points are selected and specified.

1330

Chemical Composition[1]				
C	Mn	P	S	Si
%	%	%	%	%
.28-.33	1.60-1.90	.040 max	.040 max	.20-.35

[1]AISI

Quenched and Tempered Properties



Source – Republic Steel Corp. Approx properties. Treatment: 1 in. rds 1600F, air cooled, 1525F, water quenched, tempered as shown. Tested as 0.505 in. rds.

Characteristics. This is a water-hardening, low-alloy steel.

Technological Properties
Machinability Rating (On basis of B1112 = 100) mill annealed to 179-235 BHN = 50% (ASM, Metals Handbook)

Critical Points[1]			
Ac_1	1320F	Ar_3	–
Ac_3	1470	Ar_1	1120

[1] Republic Steel Corp.

Treatment Temperatures[1]	
Forging	2200-2300F
Normalizing	1575-1750
Annealing	1525-1700
Quenching	1500-1550

[1] Republic Steel Corp.

Mechanical Properties

Form or Condition		Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN
Bars Annealed[1]		–	–	–	–	–	174
Bars Normalized[1]		–	–	–	–	–	241
Forged at 2350F to $1\frac{1}{16}$ in. rd. to 1550F, quenched in still water at 70-90F[4]	Average	–	142.359	18.13	131.116	59.42	–
	Most Probable[2]	–	150-154	18-18.9	135-139	59-59.9	–
	Range for 80%[3]	–	130-159	16-19.9	110-149	55-62.9	–
Aver. Physical Properties[5] 1 in. rd., Mean Chemistry	Cold drawn-Normal draft unannealed	–	113	15	93	50	235
	Cold drawn-Normal draft annealed	–	97	21	83	57	197
	Turned and Polished unannealed	–	105	21	72	57	217
	Turned and Polished annealed	–	90	27	62	62	187
Water quenched and tempered[6] from 1525F. 0.505 in. tensile specimens, 1 in. rd. ctr.		800F	162	14	137	42	331
		900	140	17	118	48	285
		1000	122	19	100	52	248
		1100	108	25	85	60	217
		1200	98	73	27	65	202

[1] Republic Steel Corp.
[2] A tabulation of the results shows the most probable values come within the ranges given, which is about as close a statement as can be made with limited data.
[3] The ranges shown include about 4 out of 5 of the individual values.
[4] Variability of 50 Heats of SAE 1330 (Source - Buick Motor Divn, GM Corp, R. B. Schenck) drawn at 900F, air cooled. Test bars 0.505 in. diam machined from center and tested in duplicate.
[5] Bliss & Laughlin.
[6] surface of bar.

Chemical Composition[1]

C %	Mn %	P %	S %	Si %
.38-.43	1.60-1.90	.040 max	.040 max	.20-.35

[1]AISI

Treatment Temperatures

Forging	2250F
Annealing	1475-1550
Normalizing	1550-1650
Quenching	1475-1550

Critical Points[1]

Ac_1	1340F	Ar_3	1195
Ac_3	1420	Ar_1	1160

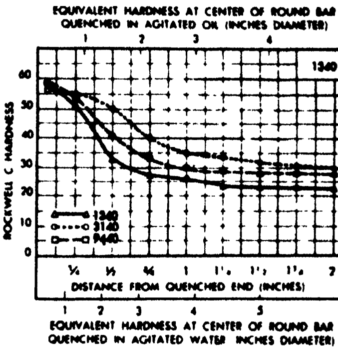
[1] Bethlehem Steel Co.

Characteristics. This is an oil-hardening steel.

Technological Properties

Machinability Rating (On basis of B1112 = 100) mill annealed to 187-241 BHN = 45% The corresponding rating of A1335 = 50%.

End-Quench Hardenability



Oil Quenched Rockwell "C" Hardness

Treatment: 1600 F - A.C. 1525 F - Oil Tower Quenched

	Center	Midway	Surface
½" diam	57	57	58
1" diam	50	56	57
2" diam	32	34	39
4" diam	26	30	32

Source – Bethlehem Steel Co. ⟶ Single heat results. Analysis: .40C, oil-hardening grades (1340) .43%C, 1.70%Mn, .23%Si, .03%Ni, .02%Cr, Tr.Mo.(3140).39%C, .76%Mn, .25%Si, 1.20%Ni, .65%Cr, .08%Mo. (9440) .39%C, 1.06%Mn, .28%Si, .39%Ni, .32%Cr, .11%Mo. Grain size, carburized at 1700F, 6-8.

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard[8] BHN	NBT[5] ft lbs
Average[1] 50 heats, R.B.	–	159.781	15.16	144.324	50.98	–	–
Average[2] Schenck, Buick Motor Divn, GM Corp.	–	266.729	10.97	238.333	37.88	–	–
Aver. Properties[7] 1 in. rd. Mean Chemistry – Cold drawn-Normal draft annealed	–	110	18	94	54	223	–
Aver. Properties[7] 1 in. rd. Mean Chemistry – Turned and Polished annealed	–	98	24	67	56	197	–
Effect of Mass:[7]							
Oil quenched at 1550F & tempered at 1000F, tensile specimens – 1 in. rd. ctr.	–	135	19	115	55	285	–
2 in. rd. mid.	–	120	23	98	60	269	–
3 in. rd. way.	–	110	22	80	60	241	–
Oil quenched at 1550F and tempered as shown, 0.505 in. tensile specimens, 1 in. rd. ctr.[7]	800F	162	12	136	40	331	–
	900	149	14	122	49	302	–
	1000	137	19	118	55	285	–
	1100	118	21	98	60	241	–
	1200	112	22	86	62	229	–
Effect of Mass[3]							
As rolled – 1 in. diam ctr.	–	135	18.7	90	51	269	20
As rolled – 2 in. diam ½r.	–	125.5	20.5	75.25	57	255	19
As rolled – 4 in. diam ½r.	–	104.5	19.7	49.5	40.7	212	7
Annealed[4] – 1 in. diam ctr.	–	102	25.5	63.25	57.3	207	52
Normalized 1600F, air cooled – ½ in. diam ctr.[6]	–	132	20	81.5	51	269	24.5
Normalized 1600F, air cooled – 1 in. diam ctr.	–	121.25	22	81	62.9	248	68.2
Normalized 1600F, air cooled – 2 in. diam ½r.	–	120	23.5	76.25	61	235	48
Normalized 1600F, air cooled – 4 in. diam ½r.	–	120	21.7	72.25	59.2	235	23
Normalized, Quenched, & Tempered 1600F, air cooled 1525F, oil tower, air cooled tempered as shown – ½ in. diam ctr.[6]		142.5	18.8	131.5	55.2	285	50
1 in. diam ctr.	1000F	137.75	19.3	121	57.5	285	56.5
2 in. diam ½r.		120.5	21.2	84.25	60.7	248	78
4 in. diam ½r.		116.5	21.7	83	57.9	241	34.2
½ in. diam ctr.[6]		127	21	118	58	255	63.7
1 in. diam ctr.	1100F	118	21.7	98.25	60.1	241	69.2
2 in. diam ½r.		108.75	24.7	82.25	64.3	217	85.2
4 in. diam ½r.		103.25	25.5	71	64.5	217	64.5
½ in. diam ctr.[6]		118.5	22.1	108.5	59.6	241	69.7
1 in. diam ctr.	1200F	112	23.2	96	62.5	229	75.5
2 in. diam ½r.		105.75	25.5	79.5	66.2	217	90.5
4 in. daim ½r.		102.25	26	72	64.9	212	86.7

[1]Samples forged at 2350F to 1-1/16 in. rd, quenched from 1600F into still oil at 100-120F, drawn at 900F, air cooled, tested as 0.505 in. diam. bars from the center, in duplicate.
[2]Samples forged at 2350F to 1-1/16 in. rd, 1600F and cooled in mica. Oversize 0.505 in. bars from the center quenched from 1550F into still oil at 100-120F, drawn at 450F.
[3]Bethlehem Steel Co. Single heat results, Analysis: Ladle C .41%, Mn 1.82%, Si .29%, Ni .10%, Cr .11%, Mo .03%; Check: C .40%, Mn 1.77%, P .027%, S .016%, Si .25%, Ni .10%, Cr .12%, Mo .01%, McQuaid-Ehn Grain Size· 100% 6-8, Test Specimens The tensile test bars were 0.505 in. diam, unless otherwise stated, and the Izod bars 0.450 in. The values are the average of two tests.
[4]1475F, F.C. 20F/hr. to 1110F, A.C.
[5]Izod average
[6]0.357 in. diam. tensile strength
[7]Bliss & Laughlin
[8]surface of bar

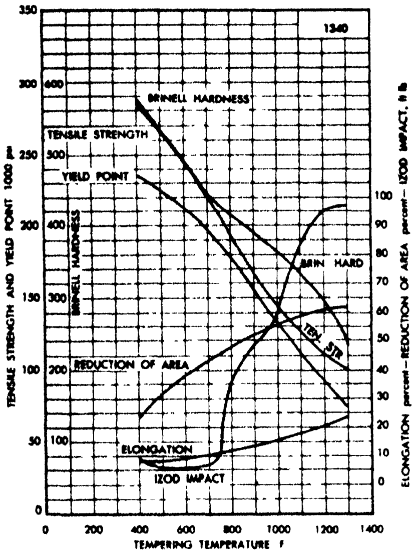
(Continued on page 184)

STEELS, AISI

1340

(Continued from page 183)

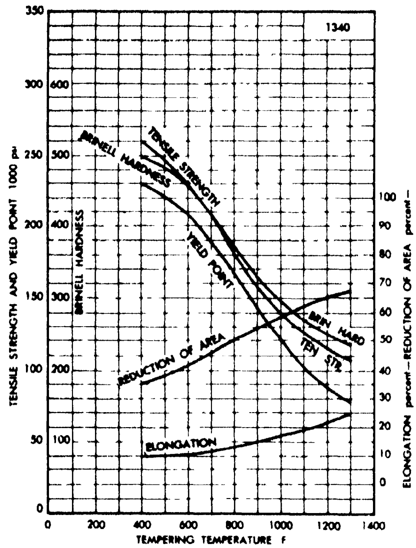
Quenched and Tempered Properties



←Source—Bethlehem Steel Co. Single heat results. Composition: .43C, 1.70Mn, .015P, .039S, .23Si, .03Ni, .02Cr, Mo nil, McQuaid-Ehn Grain Size = 6-8 Treatment: 0.565 in. rd bars normalized at 1600F, quenched in agitated oil from 1525F, drawn as shown, tested at 0.505 in. rds.

Source—Republic Steel Corp.→ Approx properties. Treatment 1 in. rds normalized at 1585F, reheated to 1550F, quenched in oil, drawn as shown for 1 hr. Tested as 0.505 in. rds.

Quenched and Tempered Properties



STEELS, AISI

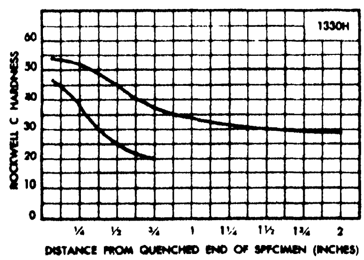
1330H

Chemical Composition

C	Mn	P	S	Si
%	%	%	%	%
.27-.34	1.50-2.00	—[1]	—[1]	.20-.35

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

End-Quench Hardenability Band



	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	54.0	53.5	53.0	52.0	50.5	49.0	47.5	45.0	43.0	40.0	38.0	37.0	36.0	35.0	34.5	34.0	33.0	32.0	31.5	31.0	30.0	30.0	29.5	29.0
Min.	46.5	44.5	42.0	38.0	33.5	29.5	27.0	25.0	23.0	21.5	21.0	20.0	—	—	—	—	—	—	—	—	—	—	—	—

[1]Note - These values are to be used when points are selected and specified.

13T45

Chemical Composition [1]

C	Mn	P	S	Si
%	%	%	%	%
.42	1.59	.027	.025	.30

[1] AISI

Critical Points
Limited tests indicated no effect on the critical points, with Ae_1 = 1300F and Ae_3 = 1425F.

Notch Toughness
In notched bar tests the boron treatment was favorable at high hardness (Dr. at 400 to 600F) but not with high drawing temperatures. This same situation held down to -70F.

Characteristics. Boron Treated A 1345[1]. The hardenability was materially improved by the boron addition, especially at higher hardness levels of 50 Rc. It was not as good as 4145 at 42 Rc.

Uses. Certain suggested uses are indicated under tests.

[1] SAE. Report, "Investigation of Boron Treated Steels," Aug. 2, 1946. Single heat results.

Grain Size. Generally fine, but varied from coarse to fine depending on the boron alloy.

Fatigue Strength
Treatment - 1650F, air cooled, 1550F, quenched in oil at 100-120F, and drawn.

Steel	Draw Temp	Plain Endur. Limit M psi	Notched r = .010 in. M psi	Endur. r = .025 in. M psi	Limit r = .060 in. M psi
Steel 1345	450F	125[1]	50	65[1]	90
	800	98	30	48	65
	950	80	28	40	53
	1100	70	25	35	45
Steel 13T45	450	120	80	80	102
	800	88	35	50	65
	950	80	30	38	53
	1100	68	30	35	45
Steel 4145	450	110[1]	60	75	100
	950	91	33	48	58
	1100	84	28	40	55
	1200	78	30	38	48

[1] Results approximate only.

Stroking Fatigue Tests

Steel	Number Tested	Aver. Number of Cycles	Relative Performance	Hard BHN
3140	–	176,000	100%	255-321[1]
13T45	4	227,350	129	255-262
8645	2	267,500	152	285-293
4140	2	145,450	83	269-285

[1] Specified hardness range for 3140.

Technological Properties
Machining Tests. Tests were conducted on 1¼ in. diam bars, cold drawn after annealing to 100% pearlite, 50% pearlite plus 50% spheroidal pearlite, and 100% spheroidal pearlite, with both light and heavy feeds. Steel 13T45 was compared with 4145 on the basis of cutting speed, as follows.

	Hard BHN	Cutting Speed for a 10 Min. Tool Life 13T45	4145
Light Feed[1]			
100% Lamellar	229-241	258-360 FPM	273 FPM
50:50	212-223	282-295	273
100% Spheroidal	201-212	435	500
Heavy Feed[2]			
100% Lamellar	229-241	131 FPM	142 FPM
50:50	212-223	173	180
100% Spheroidal	201-212	206-227	191

[1] Feed = 0.002 in., depth of cut = 0.050 in.
[2] Feed = 0.0127 in., depth of cut = 0.050 in.

Other Tests. 13T45 compared favorably with 4145 in forging, annealing, heat treatment, cold forming and machining.

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Red Area %	Hard RC
1¼ in. rds, 1650F, air cooled, machine to oversize 0.505 in. bars from the center, 1550F, oil quench, tempered as shown. The values in parentheses are for the comparison steel, 4145, tempered to same hardness level. Draw temp is given in each case. An untreated ingot, as water quenched, gave very similar prop. when drawn at 800F and above, but inferior prop. at higher hardness, especially lower ductility.	450	278.9	215.8	12	42.8	54
	(450	283.8	224	12.5	41.2	52)
	600	254.4	220.4	12.5	45.8	50
	(700	250.5	221.8	12	45.8	50)
	800	186.8	174.6	16.5	56	42
	(950	186.8	175.1	15.8	52.3	42)
	1000	142.5	130.3	20.8	56.1	31
	(1200	135.9	121.9	23.3	62	31)
	1200	110.8	94.9	27.3	63	21
	(1300	114.2	100	26.5	66	24)
13T45 is softer than 4145 in normalized & annealed cond. — Normalized at 1650F at 1¼ in. diam		111.9	66.1	25.5	65.5	19
		(156.8	105.8	14.8	35.7	32)
Annealed at 1650F		97.4	51.1	27	54.4	10
Same for 4145		(109.8	55.4	21	45.1	14)

Laboratory Tests
Part Torque rod end pin.
Test Impact test with 40 lb hammer falling 7 ft. The number of blows to produce failure through the threaded section nearest the shoulder was determined.

Steel Tested	Number of Pins	Impact Tests Aver No. Blows	RC Hardness Center	RC Hardness Surface
8640	3	11.0	36.6	37.7
9445	3	10.7	39.5	39.2
4145	2	13.5	39.0	40.0
13T45	3	10.0	40.5	41.5
13T45	8	15.1	37.1	37.2

Part Rifle components. When tried at 40/43 and 50/53 Rc hardness levels, 13T45 gave a better performance than the production steel 8745.

Part Truck steering knuckle. In limited tests 13T45 compared favorably with the production steel 3140. Some test results are given above.

STEELS, AISI

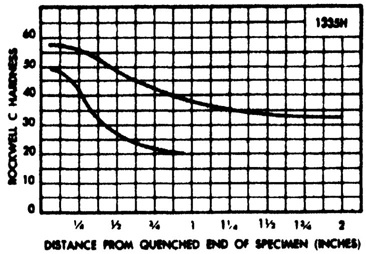
1335H

Chemical Composition

C %	Mn %	P %	S %	Si %
.32-.39	1.50-2.00	—[1]	—[1]	.20-.35

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

End-Quench Hardenability Band



"J" Distance in Inches[1]	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	57.0	57.0	56.5	56.0	55.0	53.5	51.0	49.0	47.0	45.0	43.0	42.0	40.5	39.5	39.0	38.0	36.5	35.0	34.5	34.0	33.5	33.0	32.5	32.0
Min	49.5	48.0	46.0	41.5	36.0	32.0	29.0	27.0	25.0	24.0	23.0	22.0	21.0	20.5	20.0	—	—	—	—	—	—	—	—	—

[1]Note - These values are to be used when points are selected and specified.

STEELS, AISI

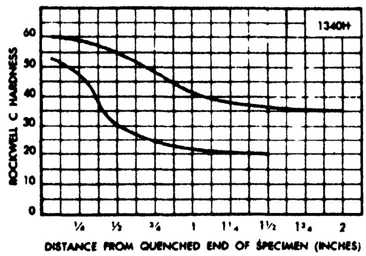
1340H

Chemical Composition

C %	Mn %	P %	S %	Si %
.37-.45	1.50-2.00	—[1]	—[1]	.20-.35

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

End-Quench Hardenability Band



"J" Distance in Inches[1]	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	60.0	60.0	59.5	59.0	58.5	57.5	56.5	55.0	53.0	51.5	49.5	48.0	46.0	44.5	43.0	41.5	39.5	38.0	37.0	36.5	36.0	36.0	35.5	35.0
Min	52.5	51.5	49.5	47.0	43.0	37.0	32.5	30.0	28.0	27.0	25.5	24.5	24.0	23.0	22.5	22.0	21.0	21.0	20.5	20.0	—	—	—	—

[1]Note - These values are to be used when points are selected and specified.

2317

Chemical Composition (AISI)					
C %	Mn %	P %	S %	Si %	Ni %
.15-.20	.40-.60	.040 max	.040 max	.20-.35	3.25-3.75

Characteristics. An alloy carburizing steel, long used for important and highly stressed case-hardened parts.

Uses. A typical use is for medium sized pins for roller chains, (A. E. Focke, Diamond Chain Co.) pins, bolts, studs, etc. in aircraft service.

Compressive Strength[1]
Compressive strength is important in resisting loads on case-hardened parts such as gears, bearings, and races.

The permissible compressive stress is 200 Mpsi for intermittently loaded gears, assuming good practice—particularly freedom from carbide network in the case, adequate carbon content of the core and section thickness.

[1]International Nickel Co.

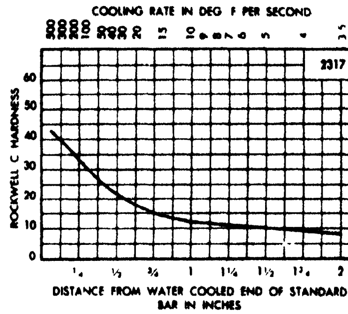
Rockwell "C" Core Hardness
Quenched in Oil at 1700 F

Size of Rd.	7/8 Radius	½ Radius	Center
1 in. rd	36	31.5	30
2 in. rd	25	18.5	16
3 in. rd	17.5	13.5	12

Technological Properties

Machinability Rating (On basis of B1112 = 100)
Cold drawn to 174-217 BHN = 55% (ASM, Metals Handbook)

End-Quench Hardenability



Source — Ryerson

Mechanical Properties

Form or Condition	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard[11] BHN	Impact Resistance Ft. Lbs.[12]	NBT[6] rt	NBT -100 F	NBT -180F	NBT -310 F
Bar Properties: hot rolled approx[1]	–	–	–	–	140-170	–	–	–	–	–
Bar Properties: cold drawn approx[1]	–	–	–	–	170-196	–	–	–	–	–
Aver. Properties[10] 1 in. rd. Mean Chemistry — Cold drawn-Normal draft, unannealed	97	21.0	84	56.0	197	–	–	–	–	–
Cold drawn-Normal draft, annealed	95	24.0	83	58.0	192	–	–	–	–	–
Turned and Polished, unannealed	82	29.0	56	60.0	163	–	–	–	–	–
Turned and Polished, annealed	77	32.0	54	63.0	153	–	–	–	–	–
Core Properties									–	
1 in. rd. pseudo-carburized at 1680F for 8 hrs.—OQ, Tempered 300F 1 hr. 0.505 in. Tensile Specimens & .394 in. sq. Izod specimens, etc. — Direct quench 1680F	158	15.0	128	45.0	327	40	–	–		–
Reheat 1375	90	32.0	57	60.0	190	75	–	–	–	–
Reheat 1425	144	17.5	115	47.8	308	38	–	–	–	–
Reheat 1475	148	18.0	117	49.8	318	37	–	–	–	–
Reheat 1525	151	18.3	117	48.0	318	36	–	–	–	–
1700F 8 hrs iron chips, box cooled, then heat treated as shown. Tempered 300F, tested 2 x .505 in. rd[4] — Direct OQ from box, 1 in. rd	145	15	115	50	302[2]	–	–	–	–	–
OQ 1425F, 1 in. rd	130	18	100	50	277[2]	–	–	–	–	–
1475F, 1 in. rd	138	18.5	109	52	285[2]	–	–	–	–	–
1525F, 1 in. rd	140	20	112	54	293[7]	–	–	–	–	–
Direct OQ from box, .515 in. rd	151	14.5	125	44	321[3]	–	–	–	–	–
OQ 1425F, .515 in. rd	132	15	103	50	277[3]	–	–	–	–	–
1475F, .515 in. rd	139	15	110	50	293[3]	–	–	–	–	–
1525F, .515 in. rd	142	16.5	115	55	302[3]	–	–	–	–	–
Core[5]: OQ from carb. temp 1700F	162	20	128	48	34[13]	–	–	–	–	–
Cooled in Box: Reheat 1475F, OQ	153	20	120	54	32[13]	–	–	–	–	–
1425F, OQ	150	18	119	45	32[13]	–	–	–	–	–
Double OQ, 1475 & 1425F	151	21	115	55	32[13]	–	–	–	–	–
Low Temp Notched Bar tests. Steel: .16C fine-grained type[7] — As rolled	–	–	–	–	180	–	43	11	4	–
Normalized	–	–	–	–	197	–	52	–	26	5
WQ-Dr at 1000F	–	–	–	–	262	–	53	–	47	17
Normalized[8]	–	–	–	–	133	–	58	–	40	3
Low Temp tests of Case-Hardened, Solid Charpy bars unnotched, broken in Charpy machine. Carburized 4 hr at 1650F to depth 0.022 in., 1400F, quenched in water, drawn 300F[9] — 210F	–	–	–	–	–	50	–	–	–	–
70	–	–	–	–	–	55	–	–	–	–
20	–	–	–	–	–	40	–	–	–	–
-15	–	–	–	–	–	33	–	–	–	–
-70	–	–	–	–	–	25	–	–	–	–

[1]Union Drawn Steel.
[2]At 3/4 radius
[3]On surface
[4]Republic Steel Corp.
[5]Ryerson. Carburize 8 hr at 1700F, quench in oil from temp indicated, drawn at 300F. Test bars were 1 in. Test Results: The effective case depth was 0.042 in. and the case hardness was 62 Rc except 63 for reheat 1425F. Core properties as shown.
[6]Charpy test with key hole notch.
[7]H.W. Gillett and McGuire.
[8]International Nickel Co. data, with key hole notch.
[9]R. Sergeson. Trans. ASST, 1932, Vol. 19, p. 368.
[10]Bliss & Laughlin
[11]Surface of bar
[12]Izod
[13]Rock C Case

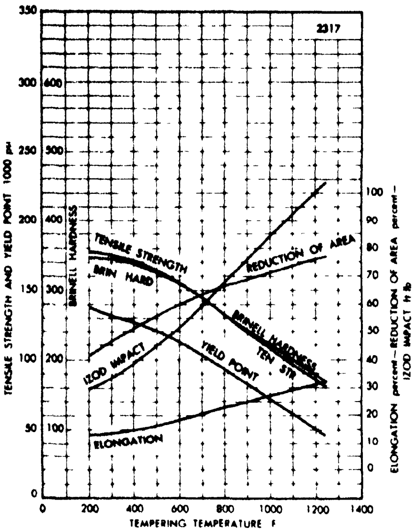
(Continued on page 188)

STEELS, AISI

2317

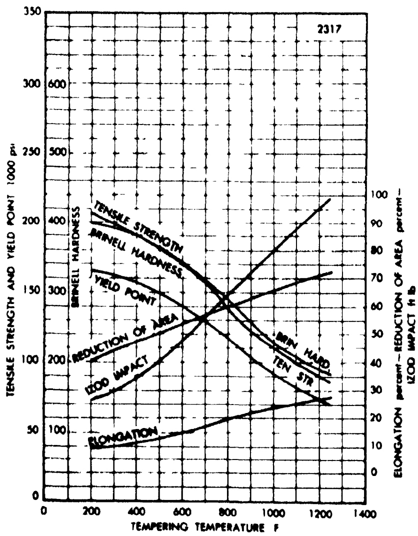
(Continued from page 187)

Oil Quenched and Tempered

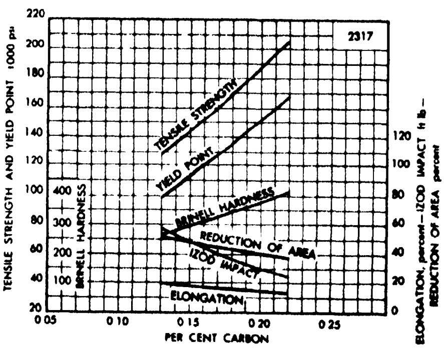


Source — International Nickel Co. Aver values. Treatment: 1 in. bars or sections quenched from 1450-1500F in either oil or water, drawn as shown.

Water Quenched and Tempered



Direct Quench



Source—International Nickel Co. Test bars and treatment: 1 in. diam. bars were pseudo-carburized at 1650-1700F, direct quenched into oil, and drawn 300F after treatment.

Core Properties

Form or Condition			Tensile Strength M psi	Yield Point M psi	Elong %	Izod Impact Ft. Lbs.	Red Area %
Box cooled, Reheated for	1425F	0.15%C	132	105	20	44	50
		0.20%C	175	140	16	26	42
hardening, OQ drawn	1475F	0.15%C	140	110	22	42	62
		0.20%C	185	145	16	24	42
300F, 1 in. diam[1]	1525F	0.15%C	142	110	22	42	52
		0.20%C	190	145	17	24	44

[1]International Nickel Co.

Treatment Temperatures

Forging	1900-2200F
Normalizing	1600-1700
Annealing	1500-1550
Quenching — core	1525
Quenching — case	1375

Critical Points

Ac_1	1300F - case	Ar_3	—
Ac_3	1425 - core	Ar_1	1110

2330

Chemical Composition[1]

C	Mn	P	S	Si	Ni
%	%	%	%	%	%
.28-.33	.60-.80	.040 max	.040 max	.20-.35	3.25-3.75

[1] AISI

Characteristics. A heat treatable steel which develops high strength and toughness in moderate sections.

Uses. Highly stressed bolts, nuts, studs, turnbuckles and the like, as heat-treated tubing with high torsional and fatigue strength for axle and propeller shaft tubes; as cold drawn for good machinability, strength and ductility.

Notched Bar Tests

	75F	0F	-40F	-100F	BHN
Normalized 1700F[1]	24	20	15	–	195
Normalized 1675[1]	49	32	17	9	195
OQ, 1450F Dr 1050F[2]	106	106	105	106	217

[1] International Nickel Co. Values are ft lb for the Charpy key hole notch. Fine grained steel.
[2] A. J. Herzig and R. M. Parke, Metals and Alloys, 1938, Vol. 9, p. 90. Values are ft lb for the Izod Vee Notch. Fine grained steel

Physical Properties
Source—ASM, Metals Handbook. Data from Natl. Phys. Lab., Jour. Iron and Steel Inst., 1946, No. II

Density* – 0.2838 lb/cu in. (7.855 S.G.)

Electrical Resistivity *

Temp Range Deg C	Deg F	Microhm-cm
20	68	27.1
100	212	32.0
200	392	39.0
400	752	56.7
600	1112	81.4
700	1292	99.2
800	1472	112.2
900	1652	114.9
1000	1832	118.0
1100	2012	120.4
1200	2192	122.8
1300	2372	124.8

Coef. of Thermal Expansion[1] *

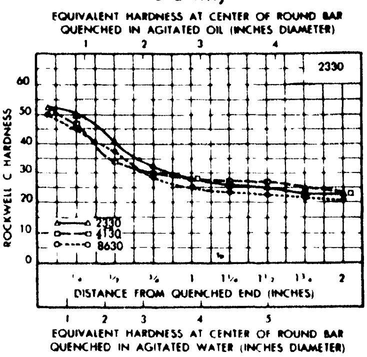
Temp Range Deg C	Deg F	Mean Coefficient $\times 10^{-6}/°C$	$\times 10^{-6}/°F$
20-100	68-212	10.9	6.05
20-200	68-392	11.2	6.2
20-300	68-572	12.1	6.7
20-400	68-752	12.9	7.2
20-500	68-932	13.4	7.4
20-600	68-1112	13.8	7.7

[1] Steel– 33C, 78Mn, 09Si, 3 59Ni, Annealed)

Mean Apparent Specific Heat *

Temp Range Deg F	Deg C	Spec. Heat	Temp Range Deg F	Deg C	Spec. Heat
112-212	50-100	.115	842-932	450-500	.158
302-392	150-200	.125	1022-1112	550-600	.179
392-482	200-250	.128	1202-1292	650-700	.391
482-572	250-300	.131	1292-1382	700-750	.228
572-662	300-350	.136	1382-1472	750-800	.144
662-752	350-400	.141	1472-1562	800-900	.153

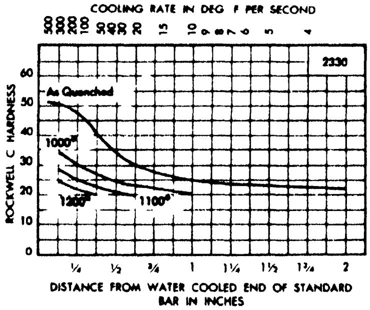
End-Quench Hardenability



Source – Bethlehem Steel Co. Single heat results. Carburized at 1700F. Composition (2330) 31C, .70Mn, 26Si, 3 46Ni, 03Cr, .05Mo. (4130) .31C, 54Mn, .27Si, 14Ni, 1.02Cr, .17Mo (8630) .30C, 80Mn, .27Si, 65Ni, .48Cr, 18Mo. Grain Size 6-8 for all three steels.

End-Quench Hardenability

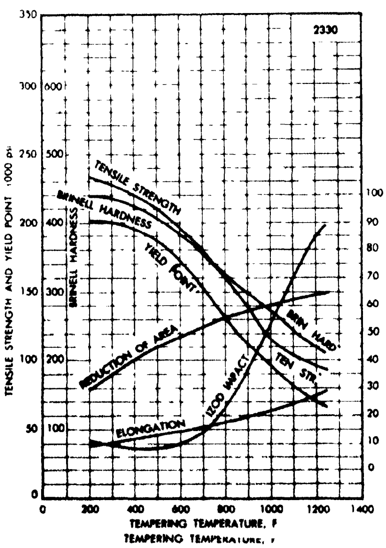
Source – Ryerson. Fine grained steel.



Thermal Conductivity *

Deg C	Deg F	Cal/cm/cm²/°C/sec	Btu/sec/ft²/°F/in.
0	32	.087	.070
100	212	.090	.073
200	392	.093	.075
300	572	.094	.076
400	752	.088	.071
500	932	.084	.068
600	1112	.078	.079
700	1292	.063	.051
800	1472	.060	.048
1000	1832	.066	.053
1200	2192	.072	.058

Oil Quenched and Tempered



(Source – International Nickel Co.) Test bars and Treatment– 1 in. diam bars, quenched from 1425-1475 F into oil or water, drawn as shown. Tested as 0.505 in. diam bars from the center. Average properties.

Treatment Temperatures

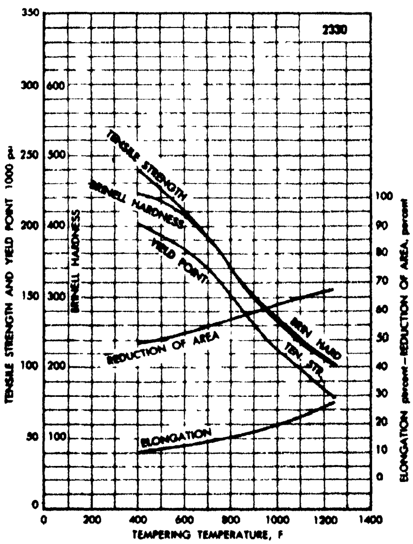
Forging	2000-2250F
Annealing	1450-1600
Normalizing	1550-1700
Quenching	1450-1500

Critical Points

Ac_1	1280 F	Ar_3	1200
Ac_3	1375	Ar_1	1025

*Steel .325C, .55 Mn, .17 Cr, .04 Mo, .09 Cu. Annealed.

Water Quenched and Tempered



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As Quenched Rockwell Hardness
(Treatment – 1600 F, air cooled, 1425 F, water quenched)

Diam	Center	Midway	Surface
½ in.	51 Rc	51 Rc	52 Rc
1 in.	48 Rc	50 Rc	52 Rc
2 in.	35 Rc	39 Rc	51 Rc
4 in.	24 Rc	25 Rc	46 Rc

Technological Properties
Machinability Rating (On basis of B1112 = 100) mill annealed to 179-229 BHN = 50% (ASM, Metals Handbook)
Industry values range from 45%, as rolled, to 70%, mill annealed.

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard[7] BHN	Izod Aver Ft lbs
Aver. Prop.[6] 1 in. rd. Mean Chemistry; Cold drawn-Normal draft, unannealed	–	108	17.0	92	50.0	217	–
Cold drawn-Normal draft, annealed	–	105	20.0	90	50.0	212	–
Turned and Polished, unannealed	–	96	25.0	66	54.0	192	–
Turned and Polished, annealed	–	89	29.0	62	58.0	177	–
Effect of Temp[6]							
0.505 in. tensile specimens cut from center of 1 in. rounds; Water quenched from about 1450F	800F	171	16.0	153	52.0	355	–
	900	150	18.0	130	56.0	308	–
	1000	133	21.0	111	59.0	271	–
	1100	119	23.0	99	62.0	242	–
	1200	107	25.0	90	64.0	220	–
Oil quenched from about 1500F	800	159	18.0	129	55.0	319	–
	900	140	19.5	110	57.5	288	–
	1000	124	21.0	94	60.5	260	–
	1100	111	22.5	81	62.5	234	–
	1200	103	24.5	72	64.5	208	–
Effect of Mass[1] As rolled; 1 in. diam ctr.	–	104.25	22.7	67	54	212	43.3
2 in. diam ½r.	–	100	23.2	63.5	54.9	197	47.5
4 in. diam ½r.	–	97.5	23	58.25	50.9	192	30.2
Annealed[2] 1 in. diam ctr.	–	86	28.3	61	58	179	67
Normalized 1600F air cooled; ½ in.[3] diam ctr.	–	104.25	25	66	54.8	212	61.3
1 in. diam ctr.	–	100	25.5	67.5	55.7	207	63
2 in. diam ½r.	–	97.75	25.8	66.25	57.7	201	71
4 in. diam ½r.	–	94.5	26.5	62.75	58.3	197	70.2
Quenched & tempered 1600F, air cooled 1425F water quenched, drawn as shown, air cooled; ½ in.[3] diam ctr.	900F	144.5	19.2	139.5	62.6	285	60.5
1 in. diam ctr.	900F	136	20	122.5	63.6	269	65.8
2 in. diam ½r.	900F	123.25	21.8	103.75	62.9	248	73.5
4 in. diam ½r.	900F	107.5	24.5	82	63.9	217	81.3
½ in.[3] diam ctr.	1000F	125.25	21.4	114	65	255	79.5
1 in. diam ctr.	1000F	122.25	21.5	116	64.8	248	87.7
2 in. diam ½r.	1000F	113.25	23.5	97.25	66.8	229	96.5
4 in. diam ½r.	1000F	105.5	25.7	84.75	65.1	207	87
½ in.[3] diam ctr.	1100F	119.75	23.5	111.5	65.6	241	82.7
1 in. diam ctr.	1100F	111.75	24.5	98	68	229	91.2
2 in. diam ½r.	1100F	103.75	25.2	81.25	70	212	102.5
4 in. diam ½r.	1100F	99.5	27	80.75	68.1	197	98
Effect of Mass[5] interpreted from End-Quench Hardenability curve. Oil quenched, 1550F, drawn as shown; 1 in. diam ctr.	1000F	130	20.6	106	56.3	262	–
2 in. diam ½r.	1000F	120	21.8	94	58.2	241	–
3 in. diam ½r.	1000F	111	22.7	85	60	223	–
4 in. diam ½r.	1000F	108	23	81	60.6	217	–
1 in. diam ctr.	1100F	119	21.9	93	58.4	238	–
2 in. diam ½r.	1100F	111	22.7	85	60	223	–
3 in. diam ½r.	1100F	108	23	81	60.6	217	–
4 in. diam ½r.	1100F	103	23.7	76	61.6	207	–
1 in. diam ctr.	1200F	111	22.7	85	60	223	–
2 in. diam ½r.	1200F	106	23.4	79	61.1	212	–
3 in. diam ½r.	1200F	103	23.7	76	61.6	207	–
4 in. diam ½r.	1200F	98	24.3	72	62.6	197	–
Bar properties[4] Hot rolled approx; 2330	–	–	–	–	–	156-202	–
2335	–	–	–	–	–	159-217	–
Cold drawn approx; 2330	–	–	–	–	–	182-212	–
2335	–	–	–	–	–	187-235	–

[1] Bethlehem Steel Co. Single heat results. Composition: Ladle: C .29%; Mn .66%; P -%; S -%; Si .31%, Ni 3.32%; Cr .10%; Mo .03%; Check: C .28%; Mn .64%; P .018%; S .017%; Si .29%; Ni 3.27%; Cr .09%, Mo .01%; McQuaid-Ehn grain size: 100% 6-8, Test Bars: The tensile test bars were 0.505 in. diam, unless otherwise stated, and the Izod bars 0.450 in. The values are the average of two tests.

[2] 1425F, furnace cooled at 20 Deg F per hr to 860F, air cooled.

[3] Tensile test bar was 0.357 in. diam

[4] Union

[5] Ryerson

[6] Bliss & Laughlin

[7] Surface of bar

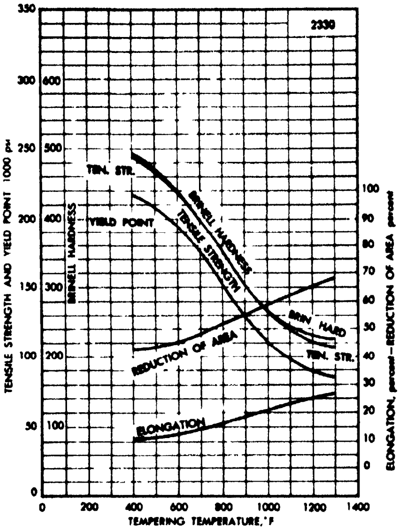
(Continued on page 191)

(Continued from page 190)

SPECIAL CASTINGS

2330

Quenched and Tempered

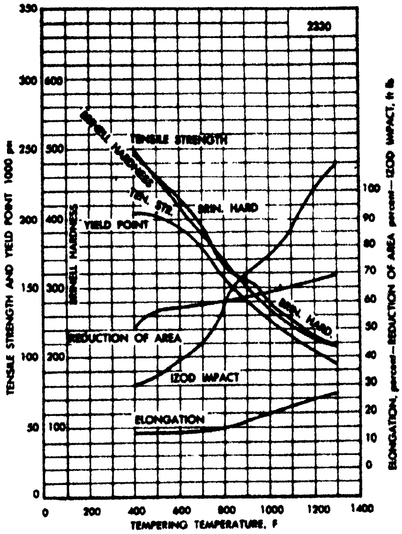


← (Source—Republic Steel Corp.) Test bars and Treatment—1 in. rounds, normalized at 1650 F, quenched from 1475 F into water, drawn for 1 hr at temperatures shown. Tested as 0.505 in. rounds.

(Source—Bethlehem Steel Co.) → Test bars and Treatment—0.530 in. diam bars, normalized at 1600 F, quenched from 1425 F into water, drawn as shown. Tested as 0.505 in. rounds. Single heat results.

Composition: .31C, .70Mn, .013P, .027S, .26Si, 3.45Ni, .03Cr, .05Mo. Grain size: 6-8.

Quenched and Tempered



STEELS, AISI

2340

Chemical Composition [1]

C %	Mn %	P %	S %	Si %	Ni %
.38-.43	.70-.90	.040 max	.040 max	.20-.35	3.25-3.75

[1] AISI

Characteristics. Similar to 2330 but of greater strength. An oil-hardening steel.

Uses. Shafting, drive shafts, connecting rods, highly stressed bolts and studs.

Notched Bar Tests [1,2]
(Fine grained steel)

Temp 75F	Treatment: OQ, 1425, Dr 500F 16 Ft Lb	OQ1425, Dr 1200F 45 Ft Lb	OQ & Dr to 255 BHN 42 Ft Lb
0	–	–	40
-50	–	–	38
-80	11	37	–
-100	–	–	36
-180	8	27	–
-200	–	–	25
-300	–	–	17
-310	6	16	–

[1] Charpy test with key hole notch. The hardness drawn at 500F was 495 BHN, and at 1200F was 235 BHN.
[2] H.W. Gillett and McGuire. Behavior of Ferritic Steels at Low Temperatures.

Treatment Temperatures

Forging	1950-2200F
Annealing [1]	1450-1600
Normalizing [2]	1600-1700
Quenching	1400-1500

[1] Hardness = 202 BHN (Republic Steel)
[2] Hardness = 269 BHN (Republic Steel)

Critical Points

Ac_1	1275F	Ar_3	1180
Ac_3	1360	Ar_1	1050

(Continued on page 192)

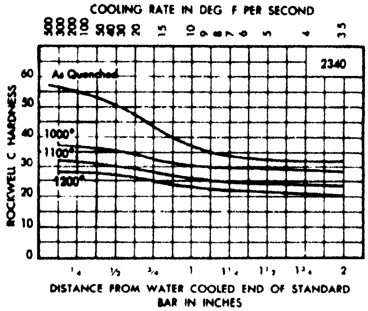
2340

(Continued from page 191)

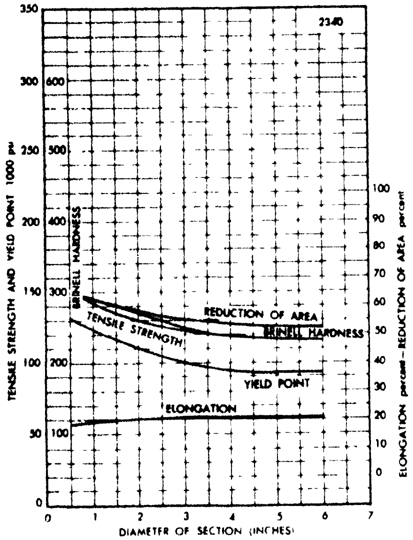
Technological Properties
Machinability Rating (On basis of B1112 = 100) mill annealed to 187-241 BHN = 45%.

End-Quench Hardenability →

Source – Ryerson.

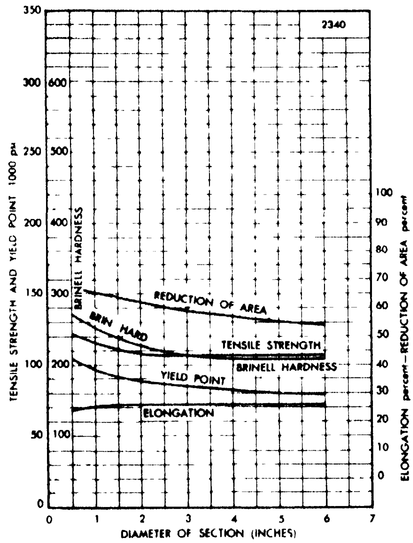


Water Quenched, Tempered at 1000F

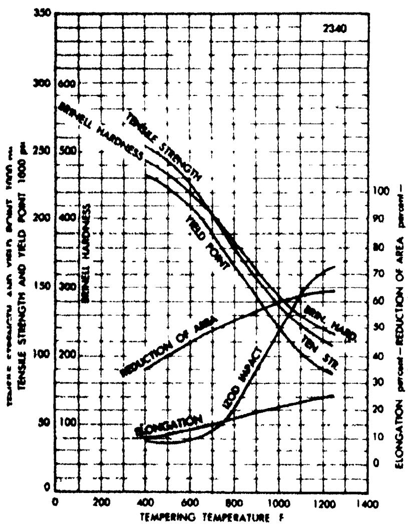


Source–International Nickel Co. Treatment. ½ to 2 in. sections inclusive quenched from 1400-1450F, over 2 to 4 in. inclusive from 1425-1475F and over 4 in. from 1450-1500F. In sizes over 1 in. the properties are those of the midway section.

Water Quenched, Tempered at 1200F



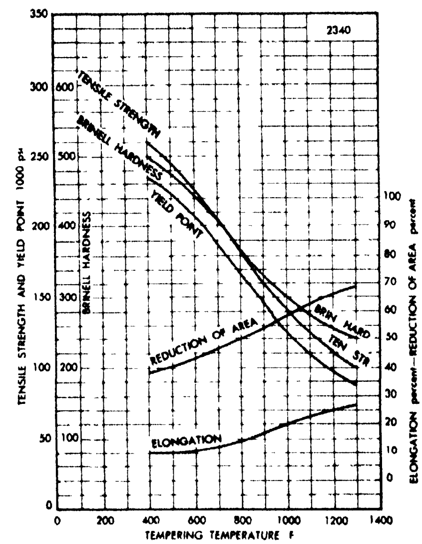
Quenched and Tempered



←Source – International Nickel Co. Treatment 1 in. diam bars quenched in oil from 1400-1450F and drawn as shown. Tensile test bars 0.505 in. diam from the center section.

Source – Republic Steel Co. → Treatment: 1 in. rds, 1600F, air cooled, 1425F, oil quenched, drawn as shown for 1 hr. Tested as 0.505 in. rds.

Quenched and Tempered



(Continued on page 193)

SPECIAL CASTINGS
2340

(Continued from page 192)

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard[4] BHN	Izod Aver Ft Lbs
Steel[1] Heat Treatment								
1040 1500F WQ	1300F	90	53	25	–	62	–	59
2340 1425F OQ	1250F	109	85	25	–	62	–	76
1040 1500F WQ	960F	125	92	18	–	51	–	36
2340 1425F OQ	1090F	125	104	23	–	60	–	59
1040 1500F WQ	600F	150	112	9	–	34	–	13
2340 1425F OQ	910F	150	137	18	–	56	–	36
Aver. Prop.[3] 1 in. rd. mean chem. annealed: Cold drawn-Normal draft	–	111	–	16.0	97	45.0	223	–
Aver. Prop.[3] 1 in. rd. mean chem. annealed: Turned & Polished	–	100	–	25.0	69	50 0	202	–
Effect of Mass[3]								
OQ from about 1450F, drawn at 1000F, 0.505 in. tensile specimens: 1 in. rd. ctr.	–	135	–	19.5	116	57.5	287	–
2 in. rd. ½r.	–	126	–	20.0	104	57.0	262	–
3 in. rd. ½r.	–	118	–	21.0	96	56.0	255	–
OQ[3] from about 1450F, 0.505 in. tensile specimens cut from center of 1 in. rds.	800F	174	–	16.5	156	51.5	356	–
	900	154	–	18.0	135	54.5	320	–
	1000	135	–	19.5	116	57.5	287	–
	1100	120	–	21.0	100	60.0	256	–
	1200	111	–	23.0	88	62.5	228	–
Effect of Mass								
Interpreted from End-Quench Hardenability curve. Quenched in oil at 1475F[2] drawn as shown. 1 in. rd, ctr.	1000F	168	–	16.1	148	48.5	341	–
	1100F	149	–	18.4	127	52.3	302	–
	1200F	131	–	20.4	107	56.0	269	–
2 in. rd, ½ r.	1000F	161	–	17.0	140	50.0	326	–
	1100F	143	–	19.0	120	53.5	288	–
	1200F	130	–	20.6	106	56.3	262	–
3 in. rd, ½ r.	1000F	145	–	18.7	123	53.0	293	–
	1100F	130	–	20.6	106	56.3	262	–
	1200F	120	–	21.8	94	58.2	241	–
4 in. rd, ½ r.	1000F	139	–	19.5	116	54.4	281	–
	1100F	124	–	21.3	99	57.5	248	–
	1200F	114	–	22.4	88	59.3	229	–

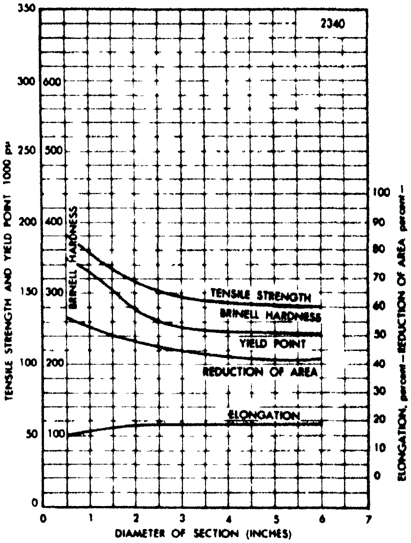
[1]Comparison of Alloy Steel with Carbon Steel in the Heat Treated Condition. International Nickel Co.

[2]Ryerson

[3]Bliss & Laughlin

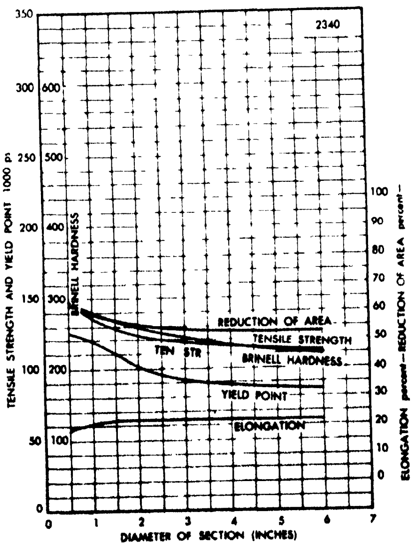
[4]surface of bar

Oil Quenched Tempered at 800F

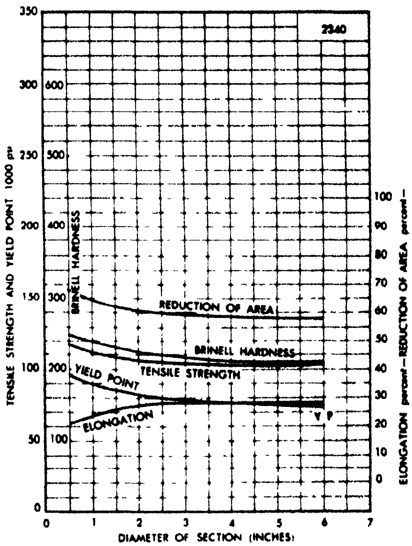


Source — International Nickel Co. Treatment: ½ to 2 in. sections inclusive quenched from 1400-1450F, over 2 to 4 in. inclusive from 1425-1475F and over 4 in. from 1450-1500F. In sizes over 1 in. the properties are those of the mid-way section.

Oil Quenched Tempered at 1000F

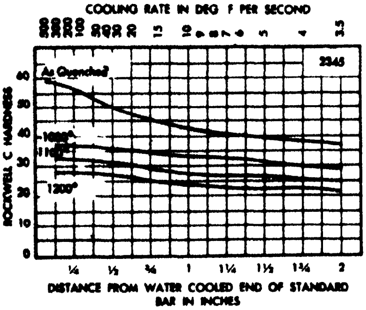


Oil Quenched Tempered at 1200F



2345 2350

End-Quench Hardenability



Source – Ryerson. Fine grained steel, 5-8.

Treatment Temperatures[1]	
Forging	1950-2150F
Annealing	1475-1525
Normalizing	1475-1675
Quenching	1425-1500

[1] Ryerson

Critical Points			
Ac_1	1280F	Ar_3	1180
Ac_3	1340	Ar_1	1070

Chemical Composition[2]

	C %	Mn %	P %	S %	Si %	Ni %
2345	.43-.48	.70-.90	.040 max	.040 max	.20-.35	3.25-3.75
2350[1]	.48-.53	.70-.90	.040 max	.040 max	.20-.35	3.25-3.75

[1] 2350 is not a standard steel
[2] AISI

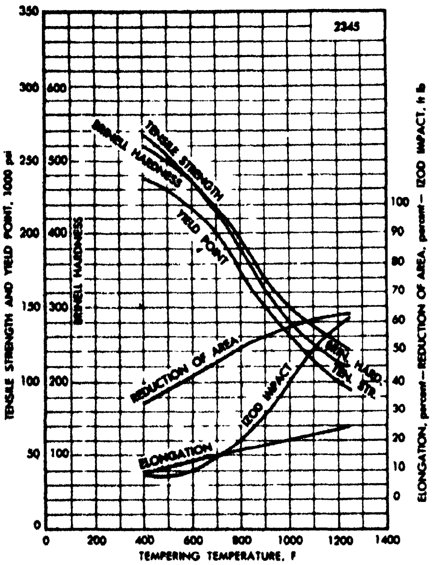
Characteristics. Very similar to A2340. The higher carbon makes possible the development of greater strength and hardness.

Mechanical Properties

Form or Condition		Draw Temp	Tensile Strength M psi	Yield Point M psi	Elong 2 in. %	Red Area %	Hard[3] BHN
Aver. Prop.[2] 1 in. rd. Mean Chemistry annealed	Cold drawn-Normal draft	–	115	102	15.0	43.0	235
	Turned & Polished	–	103	72	24.0	48.0	207
Effect of Mass[2] Oil quenched from about 1450F, tempered at 1000F. 0.505 in. tensile specimens	1 in. rd. ctr.	–	141	126	18.5	56.5	301
	2 in. rd. ½r.	–	139	120	19.0	55.5	295
	3 in. rd. ½r.	–	134	112	19.5	54.5	287
Oil quenched from about 1450F; 0.505 in. tensile specimens cut from center of 1 in. rds.[2]		800F	183	171	15.5	50.5	383
		900	160	147	17.0	53.5	339
		1000	141	126	18.5	56.5	301
		1100	126	110	20.5	59.0	269
		1200	116	97	22.5	61.5	239
Effect of Mass Interpreted from End-Quench Hardenability curve. Quenched in oil at 1475F, drawn as shown[1]	1 in. rd, ctr.	1000	174	154	15.5	47.3	352
		1100	154	132	18.0	51.4	311
		1200	138	114	19.7	54.6	277
	2 in. rd, ½ r.	1000	163	143	16.8	49.5	331
		1100	145	123	18.7	53.0	293
		1200	130	106	20.6	56.3	262
	3 in. rd, ½ r.	1000	156	135	17.4	51.0	316
		1100	138	114	19.7	54.6	277
		1200	124	99	21.3	57.5	248
	4 in. rd, ½ r.	1000	149	127	18.4	52.3	302
		1100	131	107	20.4	56.0	269
		1200	119	93	21.9	58.4	238

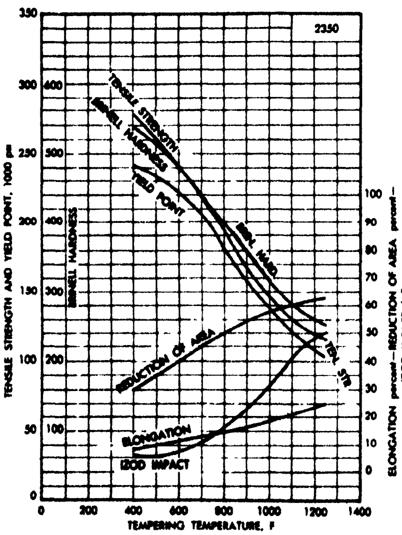
[1] Ryerson. Fine grained steel, 5-8.
[2] Bliss & Laughlin
[3] surface of bar

Oil Quenched and Tempered



Source—International Nickel Co. Aver values. Treatment: 1 in. rds quenched from 1400-1450F into oil and drawn as shown.

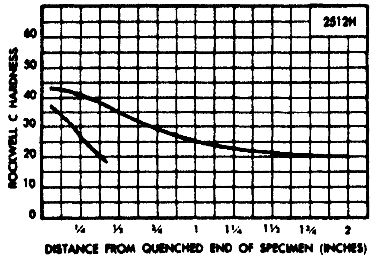
Oil Quenched and Tempered



STEELS, AISI

2512 H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %
.08-.15	.35-.65	.20-.35	4.70-5.30

[1]The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

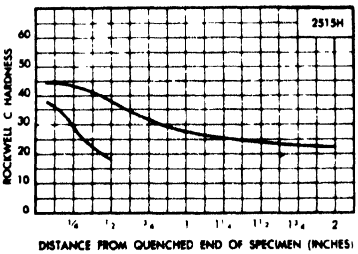
	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	43.0	43.0	42.0	41.0	40.0	38.5	36.5	35.0	33.5	32.0	30.5	29.5	28.0	27.0	26.5	25.5	24.0	23.0	22.0	21.5	21.0	20.5	20.0	20.0
Min	36.5	33.5	30.0	26.5	23.0	21.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

[1]Note - These values are to be used when points are selected and specified.

STEELS, AISI

2515 H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %
.11-.18	.35-.65	.20-.35	4.70-5.30

[1]The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	44.5	44.5	44.0	43.0	42.0	41.0	39.5	38.0	36.0	34.5	33.0	32.0	30.5	29.5	28.5	28.0	26.5	26.0	25.0	24.0	23.5	23.0	23.0	23.0
Min	37.5	36.0	33.0	29.0	26.0	23.0	21.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

[1]Note - These values are to be used when points are selected and specified

STEELS, AISI

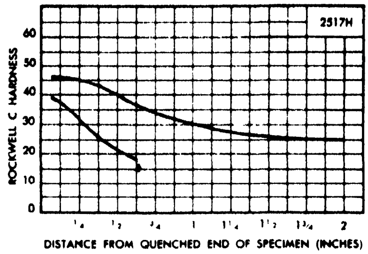
2517 H

Chemical Composition

C %	Mn %	Si %	Ni %
.14-.21	.35-.65	.20-.35	4.70-5.30

[1] The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel AISI

End-Quench Hardenability Band



	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	46.0	46.0	45.5	45.0	44.0	43.0	42.0	40.5	38.5	37.0	35.5	34.5	33.0	32.5	31.5	31.0	29.5	28.5	27.5	27.0	26.0	26.0	25.5	25.0
Min	39.0	37.5	35.0	31.0	28.0	25.5	23.5	21.5	20.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

[1] Note - These values are to be used when points are selected and specified

Chemical Composition - AISI

	C %	Mn %	P %	S %	Si %	Ni %
E2512	.09-.14	.45-.60	.025 max	.025 max	.20-.25	4.75-5.25
2515	.12-.17	.40-.60	.040	.040	.20-.35	4.75-5.25
E2517	.15-.20	.45-.60	.025	.025	.20-.35	4.75-5.25

Critical Points

Ac_1	1285F	Ar_3	—
Ac_1	1400	Ar_1	825

Treatment Temperatures[3]

Forging	2200 F max
Annealing[1]	1500
Normalizing[2]	1650-1750
Quenching	1425-1525

Notes [1]Hardness = 212 BHN
[2] " = 227 BHN
[3]Republic Steel Corp

Technological Properties

Machinability Rating (on basis of B1112 = 100)
2515, mill annealed to 170-229
BHN = 30%
Industry values for these three steels run up to 48-51%. (ASM, Metals Handbook).

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Impact Resistance Ft. Lbs.[10]	NBT ft lbs	
Aver. — As rolled-Cold drawn-Normal draft		108-117	17-19	90-98	54-58	221-235	–	–	–
Prop.[8] 1 in. — Tempered-Cold drawn-Normal draft-annealed		101-105	18-21	89-92	56-58	205-212	–	–	–
rds. Mean — As rolled, Turned and Polished		98-107	25-28	66-77	63-68	197-219	–	–	–
Chemistry — Tempered, Turned and Polished-annealed		88-93	29-30	60-63	62-64	174-183	–	–	–
Core Properties.[8]									
1 in. rd. pseudo-carburized at 1680F — Direct quench		150-190	13-16	115-155	48-57	319-400	30-47	–	–
8 hrs. OQ tempered at 300F 1 hr. — Reheat 1425F		142-181	13.5-17	107-146	47-58	303-379	34-49	–	–
0 505 in. tensile specimens 0.394 in. — Reheat 1475		143-182	13.5-18	108-148	48-59	311-381	35-50	–	–
sq. Izod specimens-ctr. — Reheat 1525		145-184	14.0-18	110-150	49-59	313-388	36-51	–	–
							Shear S M psi		
Bars[1] Cold drawn — Annealed		–	–	–	–	193-235	–	–	–
Hot rolled — Annealed		–	–	–	–	212-248	–	–	–
2515									
1 in. rd[2] Direct oil quench from box		163	16	138	51	–	341[3]	–	–
1425F oil quench		158	15.5	134	50	–	321[3]	–	–
1475F oil quench		159	16	134	52	–	331[3]	–	–
1525F oil quench		159	16	135	52	–	331[3]	–	–
515 in. rd[2] Direct oil quench from box		174	15.5	150	50	–	363[4]	–	–
1425F oil quench		166	15.5	142	50	–	341[4]	–	–
1475F oil quench		171	16	146	52	–	352[4]	–	–
1525F oil quench		172	16	148	52	–	352[4]	–	–
Tension Tests[5] Steel tested - .13C, 5.13Ni, oil quenched from 1560F, drawn at 1200F	68F	103	25	–	74	–	–	–	–
	-240	153	25	–	57	–	–	–	–
	-300	160	19	–	47	–	–	–	–
	-320	175	21	–	50	–	–	(2512)	(1020)
Test Material[6] Values in parentheses are interpolated	210F	–	–	–	–	–	–	84	45
	70	–	–	–	–	–	–	82	8
	50	–	–	–	–	–	–	(74)	(7)
	0	–	–	–	–	–	–	(62)	(5)
	-15	–	–	–	–	–	–	57	4
	-70	–	–	–	–	–	–	45	3
Notched Bar Tests **2510** Normalized to 147 BHN[7]	75F	–	–	–	–	–	–	55	–
	-80	–	–	–	–	–	–	51	–
	-180	–	–	–	–	–	–	42	–
	-310	–	–	–	–	–	–	6	–
2810 Normalized to 224 BHN[7] (for comparison)	75F	–	–	–	–	–	–	44	–
	-80	–	–	–	–	–	–	40	–
	-180	–	–	–	–	–	–	35	–
	-310	–	–	–	–	–	–	20	–

[1]Union Drawn Steel. Annealed.
[2]Treatment—Treated in two sizes 8 hr at 1700F in iron chips, direct quench from the box or cooled in the box and quenched as shown, drawn at 300F, tested as 0.505 in. rounds. Republic Steel Corp.
[3]At ¾ r.
[4]On surface.
[5]G. Gruschka, Forschungsarb.a.d. Gebiet d. Ingenieurwes, 1934, B, Vol. 364.
[6]Test Material—Unnotched Charpy bars carburized 4 hr at 1650F, water quenched from 1375F, and drawn at 300F. The case depth was 0.030 in. The bars were tested with the Charpy machine with the results as shown. A straight carbon steel is given for comparison. Source — R. Sergeson. Trans. ASST, 1932, Vol 19, p 368.
[7]International Nickel Co. Charpy test.
[8]Bliss & Laughlin
[9]surface of bar
[10]Izod

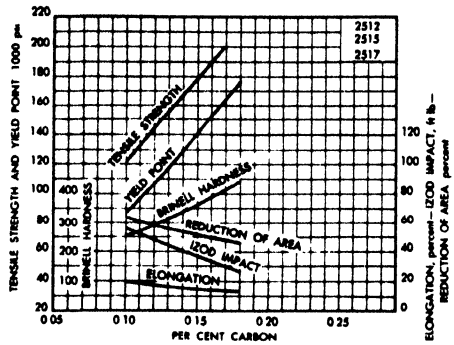
(Continued on page 198)

STEELS, AISI

2512 2515 2517

(Continued from page 197)

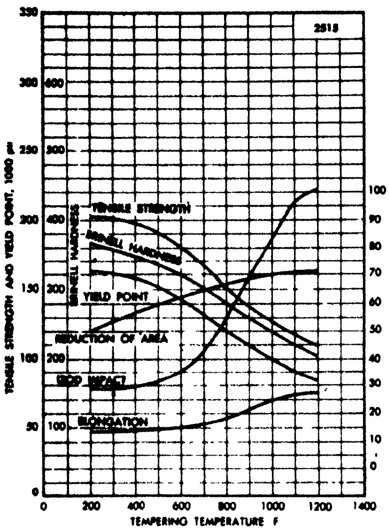
Direct Quench



Source — International Nickel Co. Treatment: 1 in. bars pseudo-carburized 8 hr at 1650-1700F, direct quenched into oil, and drawn at 300F, tested as 0.505 in. rds.

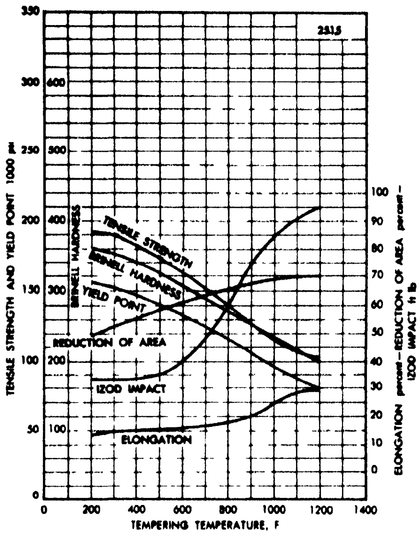
Core Properties		Draw Temp	Tensile Strength M psi	Yield Point M psi	Elong %	Red Area %	Izod Ft Lbs
Box cooled, reheated, oil quenched (0.15%C)	1425F	300F	170	140	13	50	40
	1475F		170	140	14	52	42
	1525F		170	140	15	54	44

Water Quenched and Tempered



Treatment: 1 in. bars quenched from 1425-1475 in water and from 1450-1500 in oil, drawn as shown. Source: International Nickel Co.

Oil Quenched and Tempered



3115

Chemical Composition[1]

C %	Mn %	P %	S %
.13-.18	.40-.60	.040 max	.040 max

Si %	Ni %	Cr %
.20-.35	1.10-1.40	.55-.75

[1]AISI

Treatment Temperatures[1]

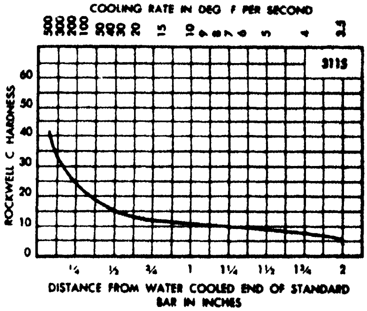
Forging	1950-2200F
Annealing	1550-1600
Normalizing	1625-1725
Quenching	1425-1525

[1]Ryerson

Critical Points

Ac_1	1355F	Ar_3	–
Ac_3	1500	Ar_1	–

End-Quench Hardenability



Technological Properties

Machinability Rating – Industry values for relative machinability, as hot rolled and cold drawn, are approximately 60% and 65% respectively.

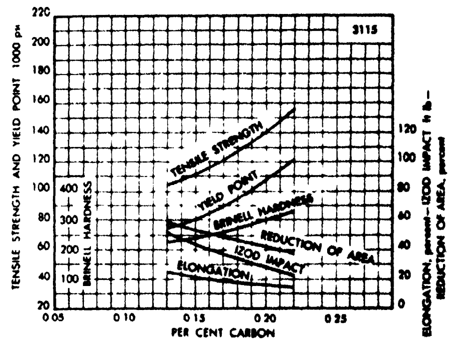
Rockwell "C" Core Hardness[1]
Treatment – Quenched in oil at 1700F

Size of Round	¾ Radius	½ Radius	Center
1 in. rd	29	23	21
2 in. rd	18.5	14	12.5
3 in. rd	13.5	11	10

[1]Ryerson

Direct Quench

Source – International Nickel Co. Test conditions. 1 in. bars were pseudo-carburized at 1650-1700F, direct quenched into oil and drawn at 300F.



Core Properties

		Draw Temp	Tensile Strength M psi	Yield Point M psi	Elong %	Red Area %	Izod Ft lbs
3115	Box cooled, 1425F	300F	125	88	18	48	24
3120			155	115	12	36	9
3115	Reheated 1475F		125	86	22	54	36
3120			155	115	16	43	20
3115	Oil quenched 1525F		125	86	22	56	43
3120			155	110	18	45	27

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard[4] BHN	Rockwell C Hardness Core	Rockwell C Hardness Case	NBT Ft Lbs
Bars									
Hot rolled[1]	–	–	–	–	–	134-170	–	–	–
Cold drawn[1]	–	–	–	–	–	179-296	–	–	–
Aver. prop.[5] 1 in. rds. Mean chemistry – Cold drawn, as rolled	–	93	21	78	61	187	–	–	–
Cold drawn, annealed	–	86	23	71	63	174	–	–	–
Turned and Polished, as rolled	–	76	31	54	68	153	–	–	–
Turned and Polished, annealed	–	70	33	50	69	143	–	–	–
Core									
1 in. rds Temp at 300F aver.[2] – Oil quench from Carb Temp 1700F	–	118	21	83	53	–	21	61	–
Cooled in box, reheat 1525F, OQ	–	122	22	85	56	–	22	61	–
Cooled in box, reheat 1425F, OQ	–	120	18	83	48	–	21	62	–
Cooled in box, 1525 & 1425F, double OQ	–	120	24	79	56	–	21	62	–
Low Temp Properties									
Transverse Tests of Case Hardened Bars. Charpy Bars, carburized 4 hr at 1650F, quenched in water from 1425F, drawn at 300F. Case depth 0.022 in. Test bars broken in unnotched condition on Charpy machine.[3]	210F	–	–	–	–	–	–	–	43(45)[4]
	70	–	–	–	–	–	–	–	26 (8)[4]
	20	–	–	–	–	–	–	–	19
	-15	–	–	–	–	–	–	–	15
	-70	–	–	–	–	–	–	–	8

[1]Union Drawn Steel. Approx values.
[2]1 in. rds carburized 8 hr at 1700F, quenched in oil as indicated. Steel grain size 5-8. The case depth was 0.055 in. Ryerson.
[3]R. Sergeson. Trans. ASST, 1932, 19, 368.
[4]Values in parentheses are for A1020 for comparison.
[5]Jlies & Laughlin
[6]surface of bar

SPECIAL CASTINGS

3145 3150

Treatment Temperatures[1]

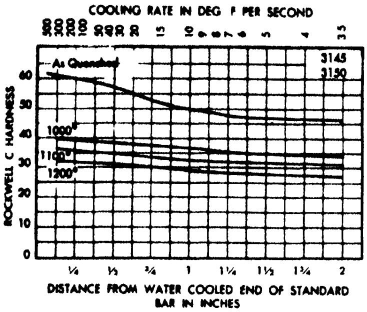
Forging	1950-2150F
Annealing	1475-1525
Normalizing	1475-1675
Quenching	1425-1500

[1]Ryerson for Steel A3150

Critical Points

Ac_1	1355F	Ar_3	1275F
Ac_3	1380	Ar_1	1215

End-Quench Hardenability



Steel A3150 of Grain Size 5-8.
(Source – Ryerson. Average values)

Chemical Composition[1]

	C %	Mn %	P %	S %
A3145	.43-.48	.70-.90	.040 max	.040 max
A3150	.48-.53	.70-.90	.040 max	.040 max

	Si %	Ni %	Cr %
A3145	.20-.35	1.10-1.40	.70-.90
A3150	.20-.35	1.10-1.40	.70-.90

[1]AISI

Characteristics and Uses. Similar to 3140 but capable of developing greater strength and hardness in the same sections.

Technological Properties

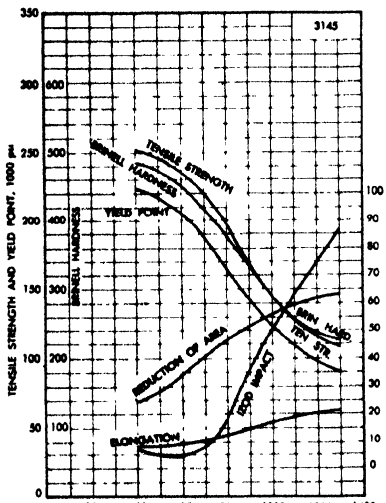
Machinability Rating (On basis of B1112 = 100) Annealed for machining = about 50% Industry values.

Mechanical Properties

Form or Condition		Draw Temp	Tensile Strength M psi	Yield Point M psi	Elong 2 in. %	Red Area %	Hard[3] BHN
Effect of Mass: Interpreted from end-quench hardenability curve. Quenched in oil at 1475F, drawn as shown. Average.[1]	1 in. rd. ctr.	1000F	186	167	14.1	45	375
		1100	163	143	16.8	49.5	331
		1200	149	127	18.4	52.3	302
	2 in. rd. ½ r.	1000	180	161	15.0	46.1	363
		1100	159	137	17.2	50.5	321
		1200	149	127	18.4	52.3	302
	3 in. rd. ½ r.	1000	174	154	15.5	47.3	352
		1100	156	135	17.4	51.0	316
		1200	141	118	19.2	54.0	285
	4 in. rd. ½ r.	1000	163	143	16.8	49.5	331
		1100	151	129	18.2	52.0	306
		1200	138	114	19.7	54.6	277
Aver. Prop.[1] 1 in. rd. Mean Chemistry	annealed cold drawn	–	111-114	94-96	14-15	44-48	221-229
	annealed Turned & polished	–	96-98	66-69	21-23	52-54	197-202
Effect of Mass:[2] OQ and tempered at 1000F 0.505 in. tensile specimens	1 in. rd. ctr.	–	149-154	128-136	17-17 5	56-57	293-321
	2 in. rd. ½r.	–	135-140	116-118	18	54	285-293
	3 in. rd. ½r.	–	125-127	105-107	19-19.5	52-53	255-285
Effect of Temp:[4] 0.505 in. tensile, cut from center of 1 in. rds. Oil quenched from about 1500F[2]		800	195-205	169-177	10-12	42.5-46 5	388-405
		900	168-191	150-164	15-16	50	388-341
		1000	149-159	128-135	15-17 3	55 7-56	302-321
		1100	130-150	117-130	18	57-58	262-302
		1200	118-129	100-110	19-21 5	59-62	238-258

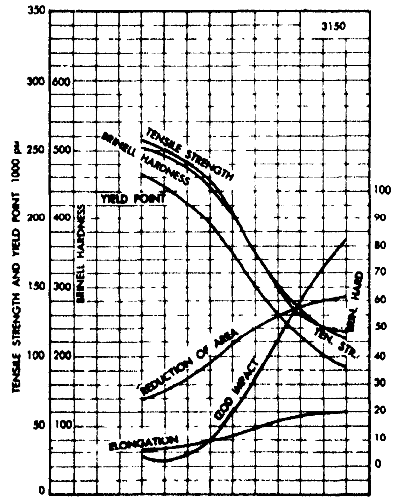
[1]Ryerson [3]surface of bar
[2]Bliss & Laughlin [4]Max. safe tempering temp is 1250F

Oil Quenched and Tempered



Test Conditions: 1 in. sections of 3145 quenched in oil from 1450-1500F and of 3150 from 1425-1475F, and drawn as shown. (Source – International Nickel Co. Aver. values)

Oil Quenched and Tempered



STEELS, AISI

3120

Chemical Composition[1]

C	Mn	P	S
%	%	%	%
.17-.22	.60-.80	.040 max	.040 max
Si	Ni	Cr	
%	%	%	
.20-.35	1.10-1.40	.55-.75	

[1] AISI

Treatment Temperatures[1]

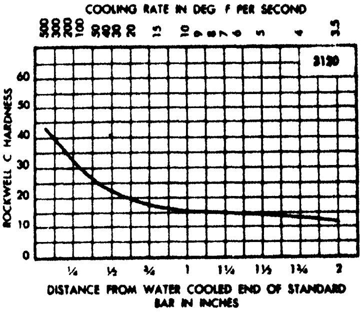
Forging	1950-2250F
Annealing	1525-1575 (170)
Normalizing	1650-1750 (207)
Quenching	–

[1] Values in parentheses are BHN of the condition.

Critical Points

Ac_1	1350F	Ar_3	–
Ac_3	1480	Ar_1	1230F

End Quench Hardenability



Source—Ryerson. Aver values. Grain size = 5-8

Technological Properties

Machinability Rating[1] (On basis of B1112 = 100) Cold drawn to 163-207 = 60%. Industry data run from 60% to 66%.

[1] ASM, Metals Handbook

Compressive Strength[1]

Permissible compressive stresses for case hardened parts, such as gears, bearings, and races, is 180,000 psi for intermittent loading. For constant loading this should be reduced 20-25%. This assumes good practice and freedom from carbide network in the case.

[1] International Nickel Co.

Rockwell "C" Core Hardness
Treatment—Quenched in oil at 1700F

Size of Round	¾ Radius	½ Radius	Center
1 in. rd	36	32.5	30
2 in. rd	26	20.5	19
3 in. rd	20	17	15

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Point M psi	Elong 2 in. %	Red Area %	Hard BHN	Rockwell C Hardness Core	Rockwell C Hardness Case	NBT Ft Lbs
Bars								
Hardness: Hot rolled	–	–	–	–	156-196	–	–	–
Hardness: Cold drawn	–	–	–	–	187-212	–	–	–
Aver Prop.[7] 1 in. rds. Mean Chemistry: Cold drawn, as rolled	96	82	19	54	197[8]	–	–	–
Cold drawn, annealed	90	76	22	58	183[8]	–	–	–
Turned and Polished, as rolled	81	55	27	62	163[8]	–	–	–
Turned and Polished, annealed	78	53	31	64	159[8]	–	–	–
Case hardened properties[2]								
Pseudo-Carburized 8 hr at 1700F, then heat treated as shown. Final draw 300F. Tested as 0.505 in. rds.[3] — Direct OQ from box, 1 in. rd.	147[3], 141[7]	121[3], 111[7]	14.5[3], 16.5[7]	51[3], 44.6[7]	301[7,8]	–	–	311[4]
1425F, OQ, 1 in. rd.	133[3], 138[7]	105[3], 103[7]	15.5[3], 14.5[7]	52[3], 42.7[7]	288[7,8]	–	–	277[4]
1475F, OQ, 1 in. rd.	134[3], 139[7]	108[3], 106[7]	16[3], 16.5[7]	54[3], 48.7[7]	290[7,8]	–	–	285[4]
1525F, OQ, 1 in. rd.	144[3], 142[7]	116[3], 109[7]	17[3], 17.2[7]	55[3], 50.0[7]	297[7,8]	–	–	302[4]
Direct OQ from box, .515 in. rd.	154	128	14	45	–	–	–	331[5]
1425F, OQ, .515 in. rd.	134	109	15	44	–	–	–	285[5]
1475F, OQ, .515 in. rd.	140	113	15.5	47	–	–	–	293[5]
1525F, OQ, .515 in. rd.	150	122	17	50	–	–	–	321[5]
Core[6]								
Oil quench from carb temp at 1700F	150	108	16	42	–	30	62	–
Cooled in box: Reheat 1525F, OQ	152	109	18	43	–	31	62	–
Cooled in box: Reheat 1425F, OQ	149	107	13	37	–	30	63	–
Cooled in box: 1525 & 1425F, double OQ	150	102	19	45	–	30	63	–

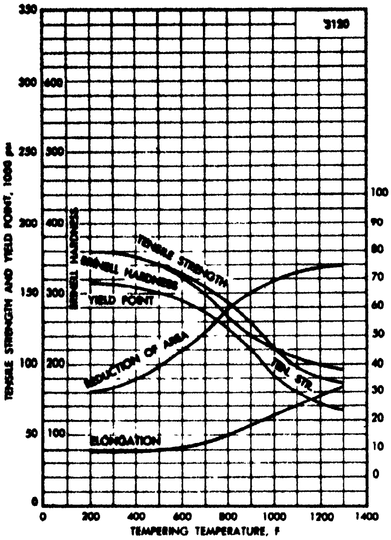
[1] Union Drawn Steel. Approx values..
[2] For data on 3120, see 3115.
[3] Republic Steel Corp.
[4] At ¼ radius
[5] On surface.
[6] Ryerson. Carburized 8 hr. at 1700F, treated as shown. 1 in. rds. tempered at 300F. Effective case depth. 0.055 in. Hardness: 62Rc.
[7] Bliss & Laughlin
[8] surface of bar

(Continued on page 202)

STEELS, AISI
3120

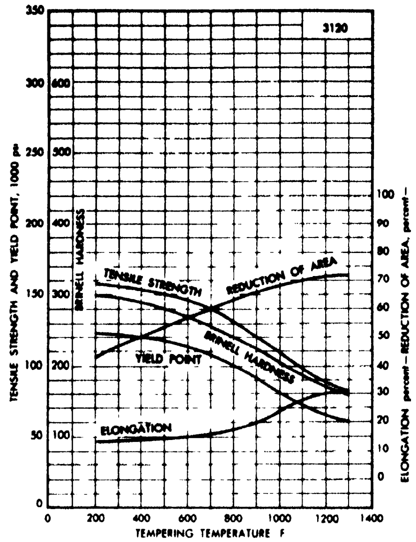
(Continued from page 201)

Water Quenched and Tempered



Test conditions: 1 in. sections quenched from 1525-1575F into oil or water, drawn as shown, and tested as 0.505 in. rds. (Source-International Nickel Co.)

Oil Quenched and Tempered



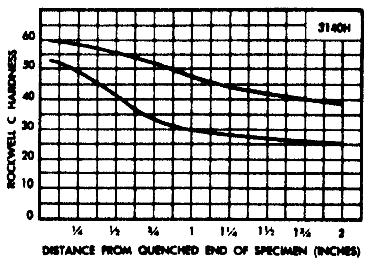
STEELS, AISI
3140H

Chemical Composition[1]

C %	Mn %	Si %	Ni %	Cr %	P %	S %
.37-.45	.60-.95	.20-.35	1.00-1.50	.50-.80	—[2]	—[2]

[1] AISI
[2] The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel.

End Quench Hardenability Band



	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	60.0	59.5	59.0	58.5	58.0	57.5	56.5	56.0	55.0	54.0	53.0	52.0	51.0	50.0	48.5	47.5	46.0	44.5	43.0	42.0	41.0	40.5	40.0	39.0
Min	52.5	51.5	50.0	49.0	47.5	45.5	43.5	41.0	38.5	36.5	34.5	33.5	32.0	31.5	30.5	30.0	29.0	28.5	28.0	27.5	27.0	26.5	26.0	25.0

[1] NOTE — These values are to be used when points are selected and specified.

SPECIAL CASTINGS

3130

Chemical Composition[1]

C %	Mn %	P %	S %
.28-.33	.60-.80	.040 max	.040 max

Si %	Ni %	Cr %
.20-.35	1.10-1.40	.55-.75

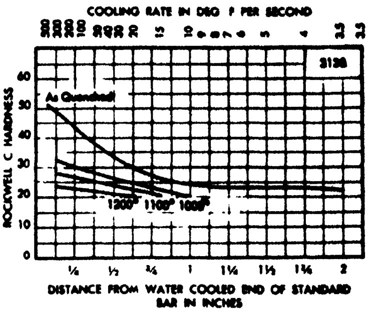
[1]AISI

Treatment Temperatures[3]

Forging	1950-2250F
Annealing	1500-1600[1]
Normalizing	1575-1675[2]
Quenching, oil	1525-1575
Quenching, water	1475-1525

[1]174 BHN
[2]241 BHN
[3]Ryerson and Republic Steel Corp.

End Quench Hardenability



Source — Ryerson. Aver values.
Grain size = 5-8.

Characteristics. A moderately deep hardening steel for liquid quenching, water quenched as simpler parts in sections up to 2 in.

Uses. Axles, drive shafts, bolts, nuts, studs, steering knuckles, steering arms, drill collars, etc. Develops high toughness at high draw temperatures.

Critical Points

Ac_1	1345F	Ar_3	1360F
Ac_3	1460	Ar_1	1220

Mechanical Properties

Form or Condition	Test Temperatures 75F	0F	-40F	-100F	Hard BHN
Bars					
Hardness } as hot rolled	—	—	—	—	154-197
Annealed } cold drawn	—	—	—	—	183-228
Normalized at 1700F[1]	88FP	46FP	30FP	11FP	192
OQ from 1500F, Drawn 1175F[1]	120+	120+	120+	170	207

[1]Low temperature Notched Bar Tests. H. W. Gillett. "Impact Resistance and Tensile Properties of Metals at Low Temperatures." Fine grained steel.

Technological Properties

Machinability Rating[1] (On basis of B1112 = 100)
Mill annealed to 179-217BHN = 55%
Industry values range from 48%, as rolled, to 64%, annealed for machining.

[1]ASM, Metals Handbook

Mechanical Properties

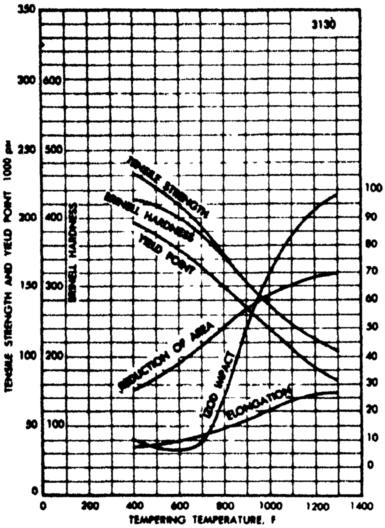
Form or Condition		Draw Temp	Tensile Strength M psi	Yield Point M psi	Elong 2 in. %	Red Area %	Hard BHN
Aver. Prop.[2] 1 in. rds. Mean Chemistry	Cold drawn as rolled	—	107	90	18	50	217[4]
	Cold drawn annealed	—	97	84	20	55	197[4]
	Turned and Polished as rolled	—	98	66	25	59	197[4]
	Turned and Polished annealed	—	86	58	29	61	174[4]
Effect of Mass[2] OQ and tempered at 1000F, 0.505 in. tensile specimens	1 in. rd., ctr.	—	125	104	20	64	269[4]
	2 in. rd. ½r.	—	117	110	21	63	241[4]
	3 in. rd. ½r.	—	114	97	22	60	231[4]
Effect of Temp[2] 0.505 in. tensile specimens cut from center of 1 in. rds.[2]	water quenched from about 1500F	800F	173	152	12	53	342[4]
		900	155	139	16	60	311[4]
		1000	133	112	19.5	60.8	264[4]
		1100	123	107	23	66	248[4]
		1200	106	85	24	67	212[4]
	oil quenched from about 1550F	800	159	135	16	55	313[4]
		900	150	119	19	62	302[4]
		1000	125	104	20	64	269[4]
		1100	117	81	23	68	235[4]
		1200	99	70	25	68	210[4]
Effect of Mass Interpreted from End-Quench Hardenability Curve. Quenched in oil at 1550F, drawn as shown[1]	1 in. rd. ctr.	1000	139	116	19.5	54.4	281
		1100	127	102	21.0	57.0	255
		1200	119	93	21.9	58.4	238
	2 in. rd. ½ r.	1000	127	102	21.0	57.0	255
		1100	120	94	21.8	58.2	241
		1200	111	85	22.7	60.0	223
	3 in. rd. ½ r.	1000	112	86	22.6	59.8	226
		1100	110	83	22.9	60.3	220
		1200	106	79	23.4	61.1	212
	4 in. rd. ½ r.	1000	110	83	22.9	60.3	220
		1100	108	81	23.0	60.6	217
		1200	98	72	24.3	62.6	197

[1]Ryerson, aver.
[2]Bliss & Laughlin
[3]Max. safe tempering temp. 1250F
[4]surface of bar

(Continued on page 204)

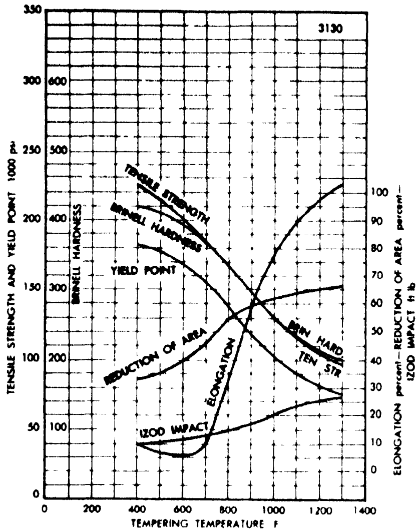
(Continued from page 203)

Water Quenched and Tempered

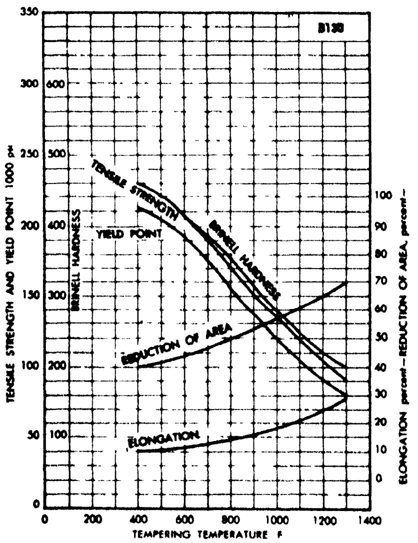


Source – International Nickel Co. Aver properties. Test conditions: 1 in. sections quenched from 1500-1550F into oil or water and drawn as shown. Tested as 0.505 in. bars.

Oil Quenched and Tempered



Quenched and Tempered



Source – Republic Steel Corp. Approx values. Test conditions: 1 in. rds normalized at 1650F, quenched from 1500F into water, drawn as indicated for 1 hr. Tested as 0.505 in. bars.

Chemical Composition[1]

C %	Mn %	P %	S %
.38-.43	.70-.90	.040 max	.040 max

Si %	Ni %	Cr %
.20-.35	1.10-1.40	.55-.75

[1] AISI

As Quenched Rockwell "C" Hardness
Treatment 1600F, A. C., 1525F, Oil Tower

Diam	Center	Half Radius	Surface
½ in.	57	57	57
1 in.	55	55	55
2 in.	40	40	46
4 in.	33½	33½	34

Characteristics. A medium deep hardening steel capable of developing good strength and toughness when oil quenched.

Uses. Spline shafts, crankshafts, propeller shafts, knuckles, rear axles, trailer axle shafts, various parts of power shovels, parts of drilling equipment such as core drills, bits, reamer bodies, tool joints, drill collars, piston rods and pump parts, parts of excavating and earth moving equipment (at 400BHN) and farm machinery for strength and abrasion resistance, and heavy duty machine tool gears.

Coef. of Thermal Expansion[1]
Quenched and Drawn

Temp Range Deg C	Temp Range Deg F	Mean Coefficient $\times 10^{-6}/^{\circ}C$	Mean Coefficient $\times 10^{-6}/^{\circ}F$
0-100	32-212	11.8	6.5
0-200	32-392	12.3	6.8
0-300	32-572	12.9	7.2
0-400	32-752	13.4	7.4
0-500	32-932	14.0	7.8

[1] ASM, Metals Handbook.

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	NBT Ft Lbs	Izod Test Ft Lbs
Bars[1]									
Hardness, Hot rolled	–	–	–	–	–	–	170-212	–	–
Hardness, Cold drawn	–	–	–	–	–	–	196-228	–	–
Aver. Prop.[7] 1 in. rds. Mean Chemistry, Cold drawn, as rolled	–	125	–	15	104	44	255[8]	–	–
Cold drawn, annealed	–	107	–	17	92	50	212[8]	–	–
Turned and Polished, as rolled	–	119	–	19	80	48	241[8]	–	–
Turned and Polished, annealed	–	93	–	25	62	56	187[8]	–	–
Annealed properties[4] 1 in. ctr.[4]	–	100	61.25	24.5		50.8	197	34	–
Normalized properties[2] 1600F, air cool, ½ in. ctr.[3]	–	148.5	–	16.4	94.75	43	302	–	21
1 in. ctr.	–	129.25	–	19.7	87	57.6	262	–	39.5
2 in. ½r.	–	119.25	–	21.7	73.5	59	248	–	44.7
4 in. ½r.	–	118	–	21	71	56.4	241	–	30
Quenched and Tempered Properties[2]									
Treatment: 1600F, air cooled, 1525F, oil tower quenched, drawn as shown; 1000F ½ in. ctr.[3]	–	150.5	–	17.4	140.5	54.8	302	–	46.3
1000F 1 in. ctr.	–	146.75	–	17.5	132	57	293	–	47.5
1000F 2 in. ½r.	–	130.25	–	19.7	102.75	60.7	269	–	64.5
1000F 4 in. ½r.	–	121.25	–	20	91.25	56.9	248	–	50.2
1100F ½ in. ctr.[3]	–	138	–	20	125.75	59.2	277	–	57
1100F 1 in. ctr.	–	131.75	–	21.2	118.87	61	269	–	65
1100F 2 in. ½r.	–	123.25	–	21.5	95.5	63.3	248	–	69.5
1100F 4 in. ½r.	–	109.25	–	23.7	78.25	65	217	–	85.5
1200F ½ in. ctr.[3]	–	128.25	–	21.7	117.25	62	255	–	72.5
1200F 1 in. ctr.	–	124.5	–	21.5	109	60.2	248	–	66.5
1200F 2 in. ½r.	–	114.5	–	23.5	85	66.7	229	–	92
1200F 4 in. ½r.	–	108	–	24.2	79	65.6	217	–	91
Effect of Mass:[7] OQ and tempered at 1000F 0.505 in. tensile specimens, 1 in. rd. ctr.	–	142	–	18	124	59	293[8]	–	–
2 in. rd. ½r.	–	129	–	19	114	55	285[8]	–	–
3 in. rd. ½r.	–	122	–	20	102	53	255[8]	–	–
Interpreted from End-Quench Hardenability Curve. Quenched in oil at 1550F, drawn as shown[6]; 1000F 1 in. rd, ctr.	–	168	–	16.1	148	48.5	341	–	–
1100 1 in. rd, ctr.	–	154	–	18.0	132	51.4	311	–	–
1200 1 in. rd, ctr.	–	138	–	19.7	114	54.6	277	–	–
1000F 2 in. rd, ½r.	–	159	–	17.2	137	50.5	321	–	–
1100 2 in. rd, ½r.	–	145	–	18.7	123	53.0	293	–	–
1200 2 in. rd, ½r.	–	130	–	20.6	106	56.3	262	–	–
1000F 3 in. rd, ½r.	–	154	–	18.0	132	51.4	311	–	–
1100 3 in. rd, ½r.	–	141	–	19.2	118	54.0	285	–	–
1200 3 in. rd, ½r.	–	125	–	21.1	100	57.2	251	–	–
1000F 4 in. rd, ½r.	–	145	–	18.7	123	53.0	293	–	–
1100 4 in. rd, ½r.	–	136	–	20.0	113	55.0	273	–	–
1200 4 in. rd, ½r.	–	124	–	21.3	99	57.5	248	–	–
Effect of Temp:[7] 0.505 in. tensile specimens cut from center of 1 in. rds. Oil quenched from about 1500F[7]	800F	188	–	12.5	162	47.5	353[8]	–	–
	900	162	–	15	145	53	331[8]	–	–
	1000	141	–	17.5	118	60	288[8]	–	–
	1100	125	–	18	105	61	262[8]	–	–
	1200	112	–	22.2	90	65	232[8]	–	–
Low Temperature Properties, Tension tests[5]	Test Temp								
	70F	146	133	14	–	60	–	–	–
	-423	243	–	4.5	–	48	–	–	–

[1] Union Drawn Steel
[2] Bethlehem Steel Co. Single heat results. Composition—Ladle: .42C, .85Mn, .33Si, 1.24Ni, .64Cr, .03Mo. Check: .40C, .90Mn, .025P, .018S, .27Si, 1.21Ni, .62Cr, .02Mo. McQuaid-Ehn grain size=100% 5-8. Test specimens: Tensile bars 0.505 in. diam, Izod 0.450 in. diam. All results are average of two tests.
[3] Tensile test bar was 0.357 in. diam.
[4] 1500F, furnace cool at 20F per hr to 1150F, air cool.
[5] ASM. Test Conditions: Steel with .35C, .56Mn, .18Si, 3.34Ni, .71Cr, oil quenched from 1560F and drawn at 1200F.
[6] Ryerson, aver.
[7] Bliss & Laughlin
[8] Max. safe tempering temp. 1250F

(Continued on page 206)

STEELS, AISI

3140

(Continued from page 205)

Critical Points

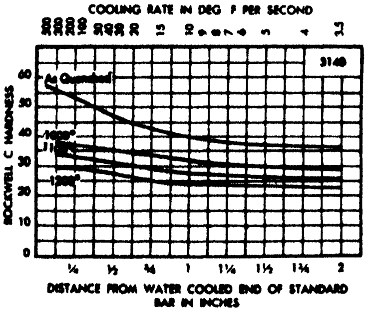
Ac_1	1350F	Ar_3	1275F
Ac_3	1420	Ar_1	1225

Treatment Temperatures[3]

Forging	1950-2250F
Annealing	1475-1550[1]
Normalizing	1550-1700[2]
Quenching	1475-1550

[1] 187BHN
[2] 250-300BHN
[3] Ryerson, Republic Steel Corp. and Bethlehem Steel Co.

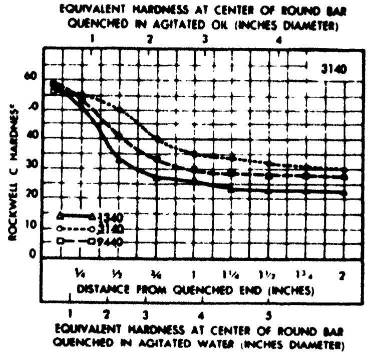
End-Quench Hardenability



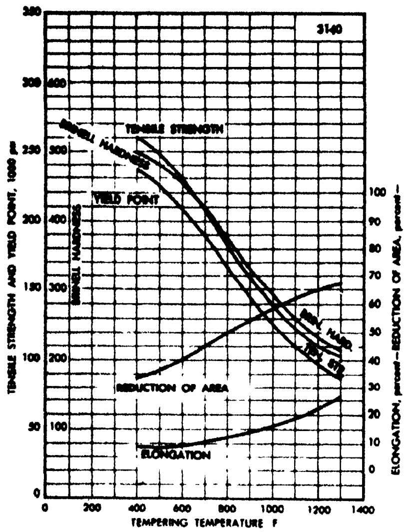
Source — Ryerson, aver results. Grain size - 5-8.

Source — Bethlehem Steel Co. Single heat results. Analysis: .40C, oil-hardening grades (1340) .43%C, 1.70%Mn, .23%Si, .03%Ni, .02%Cr, Tr. Mo. (3140) .39%C, .76%Mn, .25%Si, 1.20%Ni, .65%Cr, .08%Mo. (9440) .39%C, 1.06%Mn, .28%Si, .39%Ni, .32%Cr, .11%Mo. Grain size, carburized at 1700F, 6-8.

End-Quench Hardenability



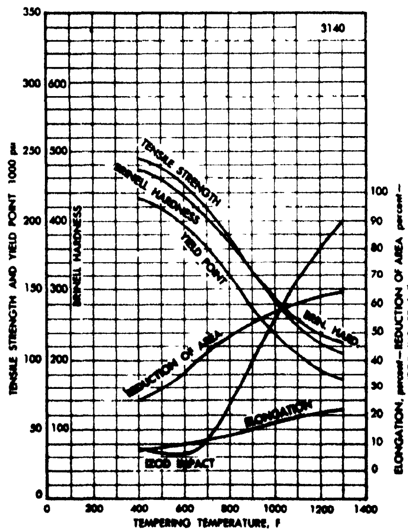
Quenched and Tempered



Source — Republic Steel Corp. Approx values. Test conditions: 1 in. rds normalized at 1600F, quenched from 1500F into oil, drawn as shown for 1 hr, tested as 0.505 in. bars.

Source — International Nickel Co. Test conditions: 1 in. sections quenched from 1475-1525F into oil and drawn as shown. Tested as 0.505 in. bars. Data are average values.

Oil Quenched and Tempered



(Continued on page 207)

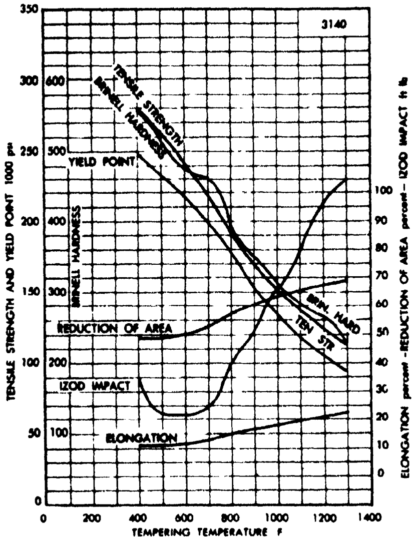
(Continued from page 206)

Technological Properties

Machinability Rating[1] (On basis of B1112 = 100) Mill annealed to 187-229BHN = 55% (A3145 = 50%) Industry values range from 36%, as rolled, to 57% mill annealed for machining.

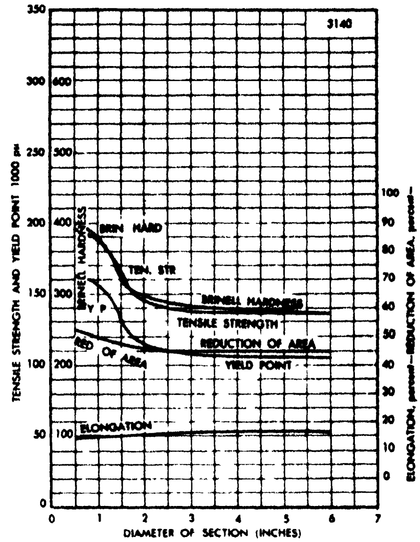
[1]ASM, Metals Handbook.

Quenched and Tempered



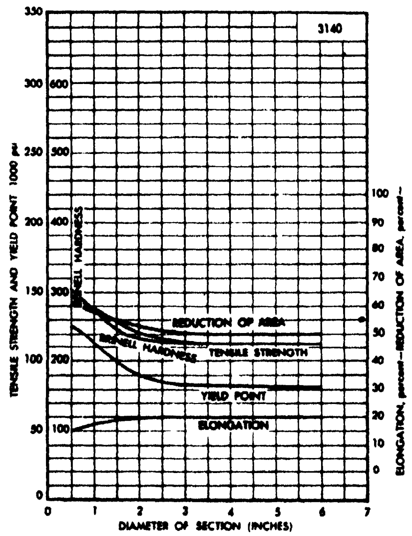
← Source – Bethlehem Steel Co. Single heat results. Test conditions: Fine grained steel (6-8) of the composition: .39C, .76Mn, .013P, .026S, .25Si, 1.20Ni, .65Cr, .08Mo. Treated as 0.530 in. rds, 1600F, air cooled, 1525F, quenched in agitated oil, drawn as shown.

Effect of Mass
Oil Quenched, Tempered at 800F

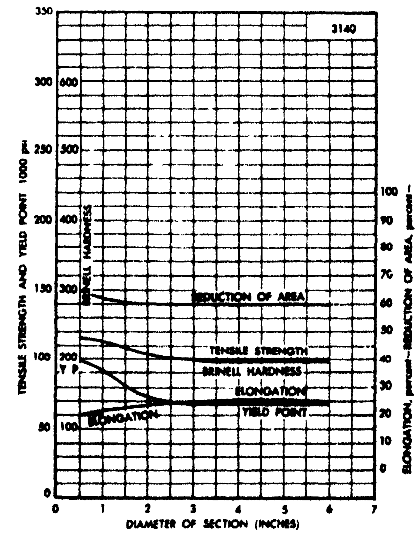


Source – International Nickel Co. Aver. values. Test conditions: Sections from ½ to 2 in. inclusive, quenched from 1475-1525F, over 2 in. to 4 in. inclusive from 1500-1550F, and over 4 in. from 1525-1575F. In sizes over 1 in. the values represent the midway position. → ←

Effect of Mass
Oil Quenched, Tempered at 1000F



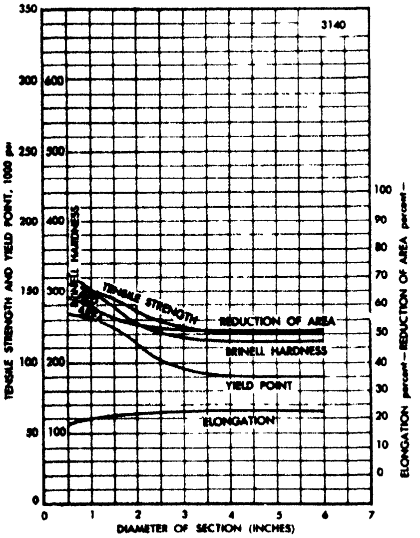
Effect of Mass
Oil Quenched, Tempered at 1200F



(Continued on page 208)

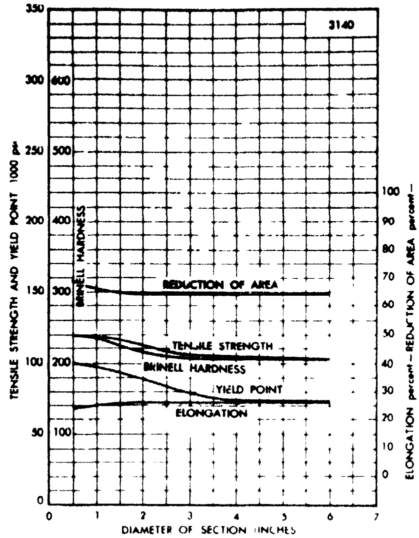
(Continued from page 207)

Effect of Mass
Water Quenched, Tempered at 1000F

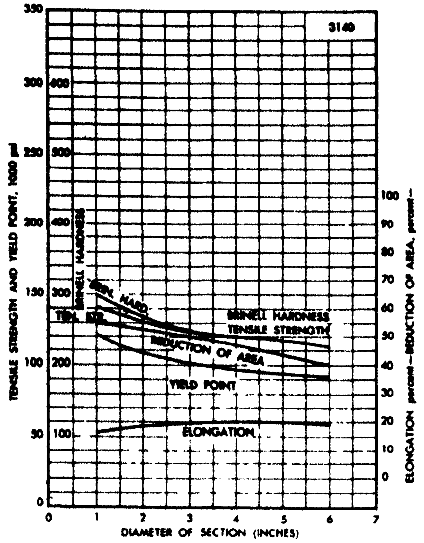


Source – International Nickel Co. Aver values. Test conditions: Sections from ½ to 2 in. inclusive, quenched from 1475-1525F, over 2 in. to 4 in. inclusive from 1500-1550F, and over 4 in. from 1525-1575F. In sizes over 1 in. the values represent the midway position.

Effect of Mass
Water Quenched, Tempered at 1200F

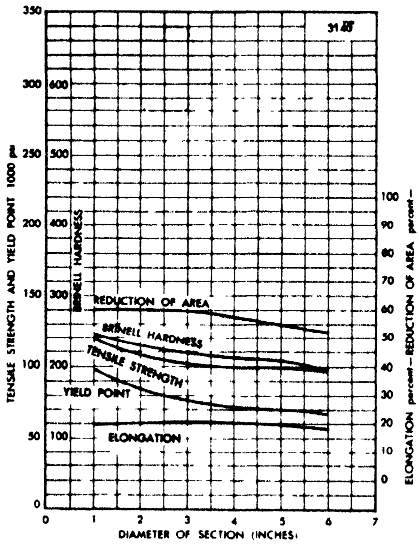


Oil Quenched, Tempered at 1000F



Source – Republic Steel Corp. Test conditions: Rds, quenched in oil, tested as 0.505 in. bars. Test bars from sizes over 1½ in. represent the midway position. Bars drawn as shown.

Oil Quenched, Tempered at 1200F



E 3310

Chemical Composition[1]

C %	Mn %	Si %	Ni %	Cr %	P %	S %
.08-.13	.45-.60	.20-.35	3.25-3.75	1.40-1.75	.025 max	.025 max

[1]Electric furnace steel.

Characteristics. This steel has exceptionally high hardenability and is well suited for heavy parts which must have high surface hardness combined with high and uniform properties when heat treated.

Typical Uses. Case-hardened gears and pinions, especially in medium large sizes up to about 6 inch sections, and for heavy heat-treated parts, and spline shafts.

Common Commercial Forms. Blooms and billets for forging or rolling, hot rolled bars.

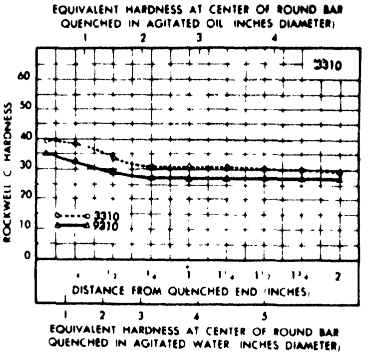
Similar Steels. The "Krupp" nickel-chromium steel is very similar but contains more nickel, or 3.80-4.30, and its strength will come on the high side as compared to 3310. Steel 9310 is very similar to 3310 -- see p.

Rockwell "C" Core Hardness[1]
Treatment - Quenched in Oil at 1700 F

Size of Round	Center	½ Radius	⅞ Radius
1 in.	36	36.5	38
2 in.	34	35	36
3 in.	32	33	34

[1]Ryerson

End-Quench Hardenability



Source — Bethlehem Steel Co. Single heat results. Analysis (3310) .10C, .55Mn, .22Si, 3.28Ni, 1.45Cr, .07Mo, Grain size 6-8, (9310) .11C, .53Mn, .29Si, 3.19Ni, 1.23Cr, .11Mo, Grain size 5-7. Carburized at 1700F.

Treatment Temperatures (collected)

Forging	1950-2200 F
Annealing	1475-1575
Normalizing	1600-1700
Carburizing	1700
Quenching	1500-1550

Coef. of Thermal Expansion[1]

Temp Range Deg C	Deg F	Coefficient α × 10^{-6}/°C	× 10^{-6}/°F
25-100	77-212	21.06	11.7
25-270	77-518	22.86	12.7

[1]P. Hidnert, see J. A. Mathews, Trans. AIME, 1922, Vol 67, p. 133) The data are for 3312 but the C was 0.32%. Steel analysis — .32C, .53Mn, .013P, .015S, .23Si, 3.53Ni, 1.37Cr. Treatment — Quenched 1525F, Drawn 1050F.

Critical Points (collected)

Ac_1	1350F[1]	1332F[2]
Ac_3	1480[1]	1440[2]
Ar_3	1210[1]	1235[3]
Ar_1	750[1]	1160[3]

[1]Bethlehem Steel Co.
[2]Average, International Nickel, Republic, Ryerson
[3]International Nickel

Rockwell "C" Hardness
Discs tested ½ in. from mid-length. Treatment 1700F for 8 hr., F.C., 1500F, quenched in agitated oil. No draw.

Size	Center	Half Radius	Surface
½ in. diam	37	37	38
1 in. diam	32	34	37
2 in. diam	29	31	32
4 in. diam	28	28	30

Mechanical Properties

Form or Condition	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red. Area %	Hard BHN	Rockwell C Hardness Core	Case[2]	Izod NBT Ft. Lbs.
Bars								
Carburized 8 hr at 1700F, OQ[1]	170	16	142	60	–	35	60	–
Cooled in box aver. Drawn as shown, 300F, reheat 1525 OQ, 1 in.	168	18	140	62	–	35	62	–
Cooled in box aver. Drawn as shown, 300F, reheat 1425F OQ, 1 in.	162	17	135	57	–	34	62	–
Cooled in box aver. Drawn as shown, 300F, reheat 1525 and 1425F, Double OQ, 1 in.	165	19	134	63	–	34	62	–
Effect of Mass[3]								
As rolled, 1 in. diam, ctr	143	16.8	100.5	53.7	285	–	–	85.3
As rolled, 2 in. diam, ½ r.	123.5	18.8	92.25	63.8	269	–	–	80.5
As rolled, 4 in. diam, ½ r.	118	20	83.75	62.2	241	–	–	39.3
Annealed[4] 1 in. diam, ctr	104	21.3	56	47.6	207	–	–	65.5
Normalized 1630F, AC, ½ in. diam, ctr[5]	133.25	19.6	89	62.6	269	–	–	84.5
Normalized 1630F, AC, 1 in. diam, ctr	131.5	20 8	88	65.3	262	–	–	86.5
Normalized 1630F, AC, 2 in. diam, ½ r.	129.75	18.5	86	64.1	262	–	–	89.5
Normalized 1630F, AC, 4 in. diam, ½ r.	121.5	19.8	76.75	62 3	248	–	–	81.8
Mock Carburized, Quenched and Drawn								
1700F for 8 hrs. F.C. 1500F quenched in agitated oil Drawn as shown, 300F, ½ in. diam, ctr[5]	172.5	15.4	142.125	63.9	341	–	–	61
300F, 1 in. diam, ctr	146.5	16.8	112.375	61.4	293	–	–	74.5
300F, 2 in. diam, ½ rd	139.5	18.5	103.25	65.9	285	–	–	86
300F, 4 in. diam, ½ r.	130.25	19 5	93.5	64.7	269	–	–	90
450F, ½ in. diam, ctr	165	15.7	131	64.3	321	–	–	55
450F, 1 in. diam, ctr	145.25	18.5	110.5	65	285	–	–	74
450F, 2 in. diam, ½ r.	136.5	18.5	100	67.8	277	–	–	83
450F, 4 in. diam, ½ r.	130	20	88.75	64.5	262	–	–	94.3

[1]Ryerson
[2]Effective case depth - 0.050 in
[3]Bethlehem Steel Co. Single heat. Composition (close to the center of the specified range): Ladle .10 C, .48 Mn, .019 P, .014 S, .28 Si, 3.52 Ni, 1.57 Cr, .06 Mo; Check .09 C, .50 Mn, .014 P, .014 S, .27 Si, 3.45 Ni, 1.55 Cr, .06 Mo. The McQuaid - Ehn grain size was 100% 7-8. All test results are averages of two tests. Test specimens .505 in. diam for tensile tests and .450 in. diam for Izod tests.
[4]1550F, F.C. at 30F/hr to 700F, then A.C.
[5].357 in. diam for tension tests.

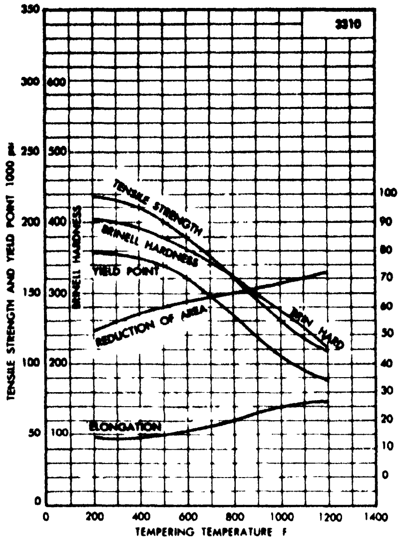
(Continued on page 210)

E 3310

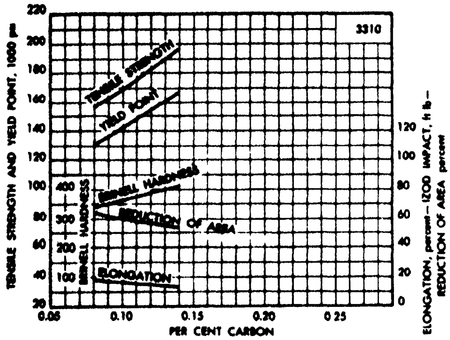
(Continued from page 209)

Size of stock treated– 1 in. diam. Size tested – .505 in. diam. Treatment – 1500-1550F – Oil quenched. Drawn as shown. (Source – International Nickel Company) ⟶

Oil Quenched and Tempered



Direct Quench



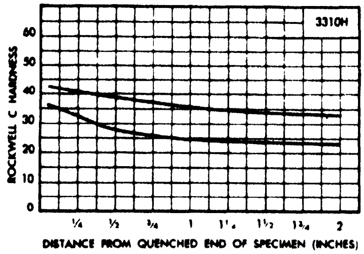
Representative core properties of 1 in. bars, pseudo-carburized at 1650-1700F, direct quenched into oil, and tempered at 300F. (Source – International Nickel Co.)

Core Properties		Draw Temp	Tensile Strength M psi	Yield Point M psi	Elong %	Red. Area %
Box cooled, reheated, oil quenched (0.12%C)	1425F	300F	170	135	15	58
	1475F		180	155	18	60
	1525F		180	160	18	60

STEELS, AISI

3310H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %	Cr %	P %	S %
.07-.14	.35-.65	.20-.35	3.20-3.80	1.35-1.75	–[1]	–[1]

[1]The P and S are 0 040 max in open hearth steel and 0 025 max in electric furnace steel. AISI

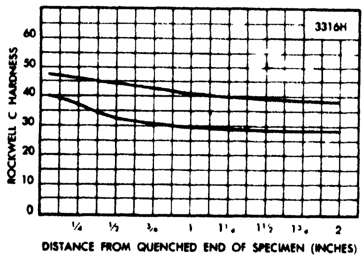
	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	42.5	42.0	41.5	41.0	41.0	40.5	40.0	39.5	39.5	39.0	38.5	38.0	37.5	37.5	37.0	36.5	35.5	35.0	34.5	34.0	34.0	34.0	34.0	34.0
Min	35.5	35.0	34.0	33.0	31.0	30.0	29.0	28.0	27.5	27.0	26.5	26.0	25.5	25.5	25.0	25.0	24.5	24.5	24.0	24.0	24.0	24.0	24.0	24.0

[1]Note - These values are to be used when points are selected and specified

STEELS, AISI

3316H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %	Cr %	P %	S %
.13-.20	.35-.65	.20-.35	3.20-3.80	1.35-1.75	–[1]	–[1]

[1]The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	47.5	47.0	47.0	46.0	45.5	45.0	44.5	44.0	43.5	43.0	43.0	42.5	42.0	41.5	41.0	40.5	40.0	39.5	39.0	39.0	39.0	39.0	38.5	38.5
Min	40.0	39.0	38.0	37.0	35.5	34.5	33.5	32.5	32.0	31.5	31.0	30.5	30.0	30.0	29.5	29.5	29.0	28.5	28.5	28.5	28.5	28.5	28.5	28.5

[1]Note - These values are to be used when points are selected and specified

STEELS, AISI

4023

Chemical Composition[1]

C %	Mn %	P %	S %	Si %	Mo %
.20-.25	.70-.90	.040 max	.040 max	.20-.35	.20-.30

[1]AISI

Treatment Temperatures[3]

Forging	2250F max
Annealing[1]	1650
Normalizing[2]	1650-1750
Quenching	1425-1575

[1] = 170 BHN
[2] = 202 BHN
[3] = Republic Steel Corp.

Technological Properties

Machinability Rating (On basis B1112 = 100)

Cold drawn to 156-207 BHN = 70% (ASM, Metals Handbook. Industry values from 73%, as rolled, to 78% cold drawn)

Critical Points

Ac_1	1350F	Ar_3	–
Ac_3	1540	Ar_1	1240

Mechanical Properties

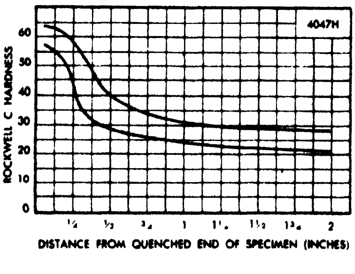
Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hardness BHN	Hardness BHN At ½r	Hardness BHN Surface	NBT Ft Lbs
Bars - Hot rolled, approx values[1]	–	–	–	–	–	–	140-170	–	–	–
Bars - Cold drawn, approx values[1]	–	–	–	–	–	–	170-196	–	–	–
Pseudo-carburized 8 hr at 1700F, direct quenched or box cooled, treated as shown drawn at 300F[6]: Direct OQ from box, 1 in. rd.	–	120	–	20	85	53	–	255	–	–
OQ 1425F, 1 in. rd.	–	105	–	19	60	48	–	223	–	–
OQ 1475F, 1 in. rd.	–	108	–	21	64	54	–	229	–	–
OQ 1575F, 1 in. rd.	–	114	–	22	72	55	–	248	–	–
Direct OQ from box, .515 in. rd.	–	152	–	15	114	43	–	–	331	–
OQ 1425F, .515 in. rd.	–	135	–	14	90	40	–	–	285	–
OQ 1475F, .515 in. rd.	–	140	–	15	95	47	–	–	293	–
OQ 1575F, .515 in. rd.	–	143	–	16	105	49	–	–	321	–
Bars: Single heat results: Box quench .530 in.[2]	–	170	120[4]	13	–	34	311	–	–	–
Box quench 1 in.[3]	–	114	–	20	89	55	217	–	–	68[5]
Reheat 1425F, quench, 1 in.[3]	–	111	–	18	87	36	228	–	–	10[5]
Reheat 1525F, quench, 1 in.[3]	–	111	–	19	91	48	217	–	–	25[5]
Low Temp Notched Bar Tests[7]: Fine grained steel, normalized at 1600F, drawn at 1000F to 156 BHN, Standard Charpy test	75F	–	–	–	–	–	–	–	–	62
	-80	–	–	–	–	–	–	–	–	34
	-180	–	–	–	–	–	–	–	–	16
	-310	–	–	–	–	–	–	–	–	4

[1]Union Drawn Steel
[2]AISI. Analysis C .20%, Mn .80%, Mo .25%.
[3]Climax Molybdenum Corp. Analysis: C .22%; Mn .80%, Mo .21%.
[4].2%
[5]Izod test
[6]Republic Steel Corp. Approx values. Tested for core prop at 0,505 in. diam.
[7]H. W. Gillett and F. T. McGuire, "Behavior of Ferritic Steels at Low Temperatures," ASTM, 1945.

STEELS, AISI

4047H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	P %	S %	Si %	Mo %
.44-.52	.60-.95	(1)	(1)	.20-.35	.20-.30

[1]The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

"J" Distance in Inches[1]

	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	64.0	63.0	61.0	58.0	54.0	48.0	43.0	40.0	38.0	36.5	35.0	34.0	33.0	32.5	32.0	31.0	30.0	29.5	29.0	29.0	29.0	29.0	29.0	29.0
Min	56.5	55.0	52.0	41.0	34.5	32.0	30.0	29.0	28.0	27.0	26.5	26.0	25.5	25.0	25.0	24.0	23.5	23.0	22.5	22.0	22.0	21.5	21.5	21.0

[1]Note – These values are to be used when points are selected and specified.

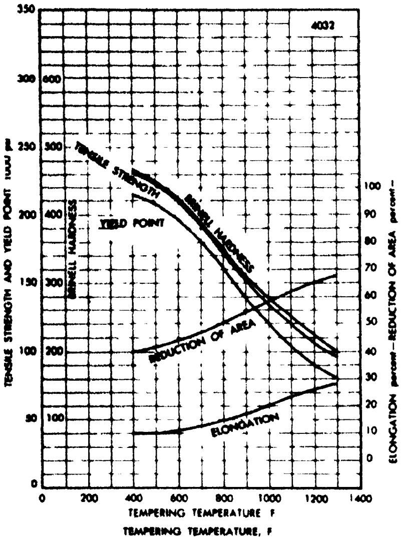
STEELS, AISI

4032

Chemical Composition[1]					
C %	Mn %	P %	S %	Si %	Mo %
.30-.35	.70-.90	.040 max	.040 max	.20-.35	.20-.30

[1]AISI

Water Quenched and Tempered



← **Source:** Republic Steel Corp. Approx values. 1 in. rds, normalized at 1600F, quenched from 1550F into water, drawn as shown for 1 hr. Tested as 0 505 in. bars

Technological Properties

Machinability Rating (On basis of B1112 = 100)

Mill annealed to 170-229 BHN = 65% (ASM, Metals Handbook. Industry values run from 55% as rolled, to 70% annealed for machining)

Treatment Temperatures[3]	
Forging	2250F max
Annealing[1]	1525-1700
Normalizing[2]	1575-1750
Quenching	1500-water

[1] = 174 BHN
[2] = 228 BHN
[3] = Republic Steel Corp.

Critical Points			
Ac_1	1350F	Ar_3	—
Ac_3	1500	Ar_1	1220

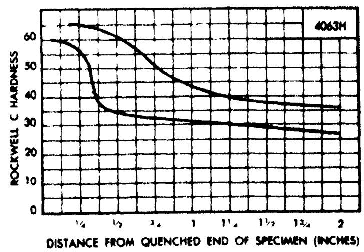
STEELS, AISI

4063H

Chemical Composition					
C %	Mn %	P %	S %	Si %	Mo %
.59-.69	.70-1.05	(1)	(1)	.20-.35	.20-.30

[1]The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

End-Quench Hardenability Band



	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	--	--	65.0	65.0	64.5	64.0	62.5	61.0	59.0	57.0	54.0	51.0	48.0	46.0	44.5	43.0	41.0	40.0	38.5	38.0	37.5	37.0	36.5	36.0
Min	60.0	59.5	58.5	56.5	50.0	39.0	36.5	34.5	33.5	33.0	32.5	32.0	31.5	31.5	31.0	31.0	30.5	30.0	29.5	29.0	28.5	28.0	27.5	27.0

[1]NOTE – These values are to be used when points are selected and specified.

STEELS, AISI
4042

Chemical Composition[1]

C %	Mn %	P %	S %	Si %	Mo %
.40-.45	.70-.90	.040 max	.040 max	.20-.35	.20-.30

[1] AISI

Technological Properties

Machinability Rating (On basis of B1112 = 100) — Mill annealed to 183-235 BHN = 60% (ASM, Metals Handbook)

Treatment Temperatures[3]

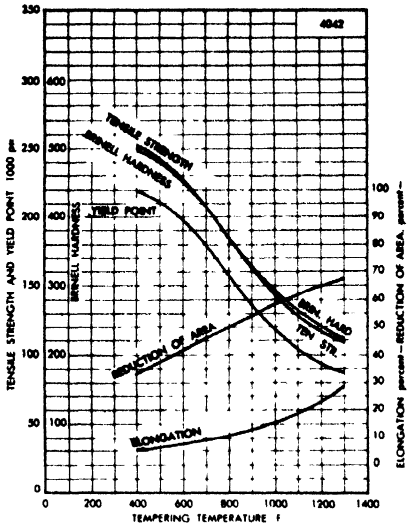
Forging	2250F max
Annealing[1]	1500-1700
Normalizing[2]	1550-1750
Quenching, oil	1475-1550

1 = 192 BHN
2 = 235 BHN
3 = Republic Steel Corp.

Critical Points

Ac_1	1320F	Ar_3	–
Ac_3	1410	Ar_1	1210

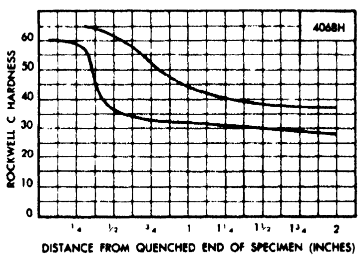
Oil Quenched and Tempered



Source: Republic Steel Corp. Approx. values. 1 in. rds. normalized at 1600F, quenched from 1500F into oil, drawn as shown for 1 hr. Tested as 0.505 in. bars.

STEELS, AISI
4068H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	P %	S %	Si %	Mo %
.62-.72	.70-1.05	(1)	(1)	.20-.35	.20-.30

[1] The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

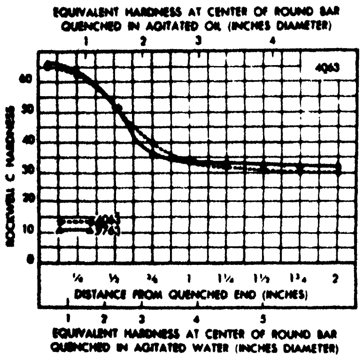
	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	—	—	—	—	65.0	64.5	63.5	62.0	60.0	58.0	55.0	52.0	49.5	47.5	45.5	44.0	42.0	40.5	39.5	39.0	38.5	38.0	37.5	37.0
Min	60.0	60.0	60.0	59.0	56.0	45.0	39.0	36.0	35.0	34.0	33.5	33.0	33.0	32.5	32.0	32.0	31.5	31.0	30.5	30.0	29.5	29.0	28.5	28.0

[1] NOTE – These values are to be used when points are selected and specified.

STEELS, AISI

4063

End-Quench Hardenability



Source – Bethlehem Steel Co. Single heat. Analysis Spring Grades: (4063) .64%C, .87%Mn, .25%Si, .04%Ni, .15%Cr, .25%Mo. Grain size 6-8. (9763) .63%C, .67%Mn, .20%Si, .59%Ni, .25%Cr, .19%Mo. Grain size, 70%, 6-8. Carburized at 1700F.

Chemical Composition[1]

C %	Mn %	P %	S %	Si %	Mo %
.60-.67	.75-1.00	.040 max	.040 max	.20-.35	.20-.30

[1]AISI

Uses. Leaf and coil springs.

Treatment Temperatures

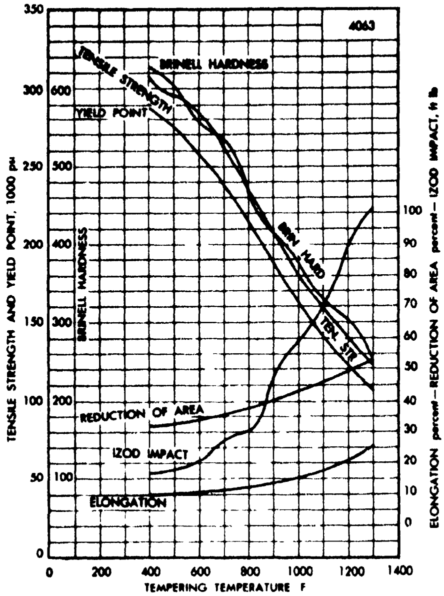
Forging	–
Annealing	1500F
Normalizing	1600
Quenching	1500

Critical Points[1]

Ac_1	1405F	Ar_3	1325
Ac_3	1460	Ar_1	1270

[1]Bethlehem Steel Co.

Quenched and Tempered



Source – Bethlehem Steel Co. Single heat results. Composition: .64%C, .87%Mn, .012%P, .027%S, .25%Si, .04%Ni, .15%Cr, .25%Mo. Grain size = 6-8. Test Conditions: 0.530 in. rds normalized at 1600F, quenched in agitated oil from 1500F, drawn as shown. Tested as 0.505 in. bars.

As Quenched Rockwell "C" Hardness

Treatment: 1600F – A.C. 1500F, Oil Tower
Tested: 1 in. discs cut from mid length

	Center	Midway	Surface
½ in. diam	64	64	65
1 in. diam	60	62	64
2 in. diam	38½	38½	43
4 in. diam	31	31	32

Mechanical Properties

Form or Condition		Draw Temp	Tensile Strength M psi	Elong 2" %	Yield Point M psi	Red Area %	Hard BHN	Izod Aver Ft Lbs
Effect of Mass[1]								
Annealed[2]	1 in. diam	–	111.5	17.7	50.75	31.5	223	9
Normalized 1600F Air cooled	½ in.[3] diam ctr.	–	145.5	14.6	101	34.7	285	12.2
	1 in. diam ctr.	–	143.75	15.2	100.75	39.9	285	10.2
	2 in. diam ½r.	–	142	16	98.75	43.1	285	10.5
	4 in. diam ½r.	–	140	14.2	96	34.7	277	12.2
Quenched & Tempered 1600F air cooled 1500F oil tower quenched drawn as shown	½ in.[3] diam ctr.	900F	204.5	11.4	189.5	42.2	401	15.2
	1 in. diam ctr.	900F	193.75	11.7	172.5	42.5	388	18.2
	2 in. diam ½r.	900F	152.25	17.2	112.5	54.2	302	20
	4 in. diam ½r.	900F	147.5	16.7	107.25	46.8	293	15.5
	½ in.[3] diam ctr.	1000F	183.75	12.8	172.5	43.2	363	24.2
	1 in. diam ctr.	1000F	175	14	162.75	45.7	352	22.7
	2 in. diam ½r.	1000F	146.5	19	104	54.1	293	22.7
	4 in. diam ½r.	1000F	137	19	97	51	277	20
	½ in.[3] diam ctr.	1100F	159	16.4	150	48.2	321	34.5
	1 in. diam ctr.	1100F	153.75	16.5	142.75	51.7	311	42.7
	2 in. diam ½r.	1100F	134.5	20.7	97.5	58.3	269	31.2
	4 in. diam ½r.	1100F	127.75	21	89.5	54.9	255	25.5

[1]Source - Bethlehem Steel Co. Single heat results. Composition. Ladle: C .64%; Mn .80%; Si .28%, Ni .17%; Cr .15%; Mo .25%. Check. C .61%; Mn .79%; P .017%; S .011%; Si .26%; Ni .15%; Cr .14%, Mo .24%. McQuaid-Ehn Grain Size: 95% 6-8; 5% 3-4. Test Conditions: Tensile test 0.505 in. diam, Izod 0.450 in. diam. Values are average of two tests.
[2]1500F F.C. 20F/hr. to 1220F – A.C.
[3]Tensile test bar was 0.357 in. diam.

4130

Chemical Composition (AISI)

C %	Mn %	P %	S %	Cr %	Mo %	Si %
.28-.33	.40-.60	.040 max	.040 max	.80-1.10	.15-.25	.20-.35

Characteristics. Similar steels, 8630, 8730.

Uses. Connecting rods in automotive industry, tubing and shapes for aircraft. The higher carbon 4135 is used for knuckles.

Common Commercial Forms. Blooms, billets, bars, forgings, strip, tubing.

Technological Properties
Machinability Rating (On basis of B1112 = 100)

As rolled	4130	51%
Annealed for machinability	4130	67
	4132	64
	4135	64
	4137	61

Rockwell "C" Hardness – As quenched
Size tested – 1 in. discs cut from mid-length.

Size	Center	Half Radius	Surface
½ in.	50	50	51
1 in.	44	50	51
2 in.	31	32	47
4 in.	24.5	25	45.5

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Izod Ft Lbs
Bars							
Hot rolled[1]	–	–	–	–	–	163-212	–
Cold drawn[1]	–	–	–	–	–	187-217	–
Aver. Prop.[9] 1 in. rd., Mean chemistry; Cold drawn, unannealed	–	122	16.0	105	45.0	248[10]	–
Cold drawn, annealed	–	98	20.0	82	53.0	201[10]	–
Turned and Polished, unannealed	–	112	21.0	72	52.0	228[10]	–
Turned and Polished, annealed	–	86	30.0	57	61.0	174[10]	–
Effect of Mass[9] OQ at 1550F and tempered at 1000F, 0.505 in tensile specimens							
1 in. rd. ctr	–	151	18.0	128	55.0	307[10]	–
2 in. rd. ½r.	–	107	20.0	83	58.0	223[10]	–
3 in. rd. ½r.	–	103	22.0	78	60.0	217[10]	–
Effect of Mass[5]							
As rolled, 1 in. diam ctr.	–	114.5	18.3	80.25	56.7	235	25.5
As rolled, 2 in. diam ½ r.	–	104.5	22	57.5	52.9	207	33
As rolled, 4 in. diam ½ r.	–	89.25	23.3	46.5	49.1	179	28.2
Annealed[6] 1 in. diam ctr.	–	81.25	28.3	52.25	55.6	156	45.5
Normalized 1600F, air cooled, ½ in.[7] diam ctr.	–	106.5	25.2	67	54.6	217	51.7
Normalized 1600F, air cooled, 1 in. diam ctr.	–	97	25.5	63.25	59.6	197	63.7
Normalized 1600F, air cooled, 2 in. diam ½ r.	–	89	28.2	61.75	65.4	167	78.7
Normalized 1600F, air cooled, 4 in. diam ½ r.	–	88.75	27	57.75	61.2	163	77.8
Quenched and drawn 1600F air cooled, 1575F quenched into water, tempered as shown, air cooled. Draw Temp 900F, ½ in.[7] diam ctr.	–	166.5	16.4	161	61	331	50.8
900F, 1 in. diam ctr.	–	161	14.8	137.5	54.4	321	41.2
900F, 2 in. diam ½ r.	–	132.75	19	110.25	63	269	76.5
900F, 4 in. diam ½ r.	–	121.5	20.5	95	63.6	241	69.7
1000F, ½ in.[7] diam ctr.	–	151	18.2	142.5	63.9	302	71.7
1000F, 1 in. diam ctr.	–	144.5	18.5	129.5	61.9	293	66.2
1000F, 2 in. diam ½ r.	–	121.75	21.3	98.75	66.3	241	88
1000F, 4 in. diam ½ r.	–	116	21.5	91.5	63.5	235	86.3
1100F, ½ in.[7] diam ctr.	–	133	20.7	122.5	69	269	79.2
1100F, 1 in. diam ctr.	–	128	21.3	113.25	67.5	262	86
1100F, 2 in. diam ½ r.	–	114.5	21.7	91.5	67.7	229	90.5
1100F, 4 in. diam ½ r.	–	101.5	24.5	77.5	69.2	197	90.5
Effect of Mass interpreted from End-Quench Hardenability curve. Quenched in oil at 1550F[8] tempered as shown. 1000F, 1 in. rd. ctr	–	141	19.2	118	54	285	–
1100, 1 in. rd. ctr	–	127	21	102	57	255	–
1200, 1 in. rd. ctr	–	114	22.4	88	59.3	229	–
1000F, 2 in. rd. ½ r.	–	125	21.1	100	57.2	251	–
1100, 2 in. rd. ½ r.	–	117	22	91	59	235	–
1200, 2 in. rd. ½ r.	–	108	23	81	60.6	217	–
1000F, 3 in. rd. ½ r.	–	114	22.4	88	59.3	229	–
1100, 3 in. rd. ½ r.	–	108	23	81	60.6	217	–
1200, 3 in. rd. ½ r.	–	100	23.9	74	62	202	–
1000F, 4 in. rd. ½ r.	–	110	22.9	83	60.3	220	–
1100, 4 in. rd. ½ r.	–	103	23.7	76	61.6	207	–
1200, 4 in. rd. ½ r.	–	98	24.3	72	62.6	197	–
Effect of Temp:[9] Oil quenched at 1600F and tempered as shown, 0.505 in. tensile specimens cut from center of 1 in. rds.	800F	179	15.0	154	57.0	370[10]	–
	900	166	17.0	141	53.0	346[10]	–
	1000	151	18.0	128	57.0	307[10]	–
	1100	136	20.0	114	61.0	276[10]	–
	1200	122	21.0	103	65.0	243[10]	–
Annealed, approx (collected)	–	–	–	–	–	174[2]	–
Annealed, single heat[4] (collected)	–	–	–	–	–	149[3]	–
Normalized, approx (collected)	–	–	–	–	–	255[2]	–
Normalized, single heat[4] (collected)	–	–	–	–	–	183[3]	–
Water quenched, single heat[4] (collected)	–	–	–	–	–	495[3]	–

[1]Union Drawn Steel. Approx values.
[2]Republic Steel Co.
[3]Bethlehem Steel Co.
[4]See Critical Point table.
[5]Bethlehem Steel Co. Single heat tests. The heat was selected to come at the middle of the range of chemical specifications. The analysis was: Ladle: .32C, .48Mn, .21Si, .14Ni, .93Cr, .21Mo. Check: .30C, .48Mn, .015P, .015S, .19Si, .12Ni, .91Cr, .20Mo. McQuaid-Ehn Grain Size 100% 6-8. Size tested: .505 in. diam. x 2 in. for tension tests and .450 in. diam. for Izod tests. All test results are averages of two tests.
[6]Treatment – 1585F, F.C. at 20F/hr to 1225F, A.C.
[7].357 in. diam for tension test.
[8]Ryerson
[9]Bliss & Laughlin
[10]Surface of bar

(Continued on page 218)

4130

(Continued from page 217)

Treatment Temperatures (collected)

	Ryerson	Beth. Steel Co	Rep Steel Co.
Forging	2000-2200F	–	2250F
Annealing	1525-1625	1585F	1525-1700
Normalizing	1575-1750	1600	1575-1750
Quenching – oil	1550-1625	–	–
Quenching – water	1525-1575	1575	1525-1750

Physical Properties[1]
Density, annealed 0.2834 lb/cu in. (7.845 S.G.)

[1]ASM, Metals Handbook. Data from Nat'l. Phys. Lab., Jour. Iron and Steel Inst., 1946, No II. Composition: .35C, .59Mn, .26Ni, .98Cr, .20Mo.

Thermal Conductivity

Temp Range Deg C	Deg F	Cal/gm/cm/cm²/°C/sec	Btu/sec/ft²/°F/in
0	32	.102	.082
100	212	.102	.082
200	392	.100	.081
300	572	.097	.078
400	752	.093	.075
500	932	.089	.072
600	1112	.081	.065
700	1292	.074	.060
800	1472	.063	.051
1000	1832	.067	.054
1200	2192	.072	.058

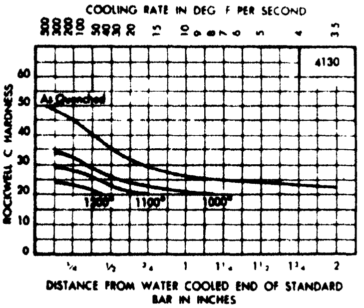
Electrical Resistivity

Temp Range Deg C	Deg F	Microhm-cm
20	68	22.3
100	212	27.1
200	392	34.2
400	752	52.9
600	1112	78.6
700	1292	94.4
800	1472	110.3
900	1652	113.8
1000	1832	117.1
1100	2012	120.0
1200	2192	122.2
1300	2372	124.2

Mean Apparent Specific Heat

Temp Range Deg C	Deg F	Cal/gm/°C
50-100	122-212	.114
150-200	302-392	.123
200-250	392-482	.126
250-300	482-572	.130
300-350	572-662	.136
350-400	662-752	.142
450-500	842-932	.157
550-600	1022-1112	.176
650-700	1202-1292	.197
700-750	1292-1382	.386
750-800	1382-1472	.211

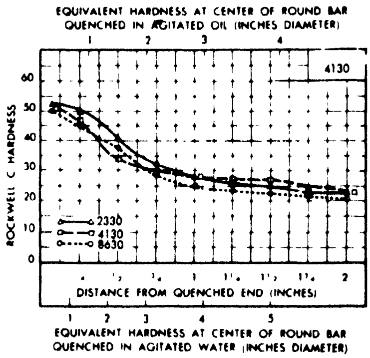
End Quench Hardenability



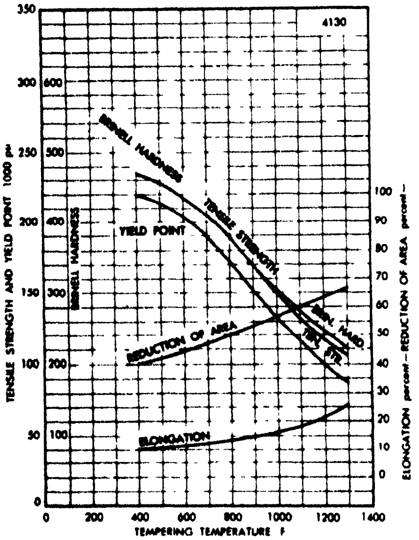
← Source – Ryerson. Test results after quenching, and after drawing at temperatures shown.

Source – Bethlehem Steel Co. Single heat results. Carburized at 1700F. Composition (2330) .31C, .70Mn, .26Si, 3.46Ni, .03Cr, .05Mo. (4130) .31C, .54Mn, .27Si, .14Ni, 1.02Cr, .17Mo. (8630) .30C, .80Mn, .27Si, .65Ni, .48Cr, .18Mo. Grain size 6-8 for all three steels. →

End Quench Hardenability



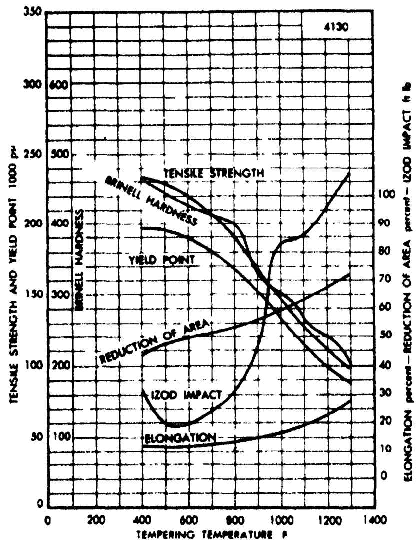
Quenched and Tempered



← Source – Republic Steel Corp. Size treated – 1 in. diam. Size tested – .505 in. diam x 2 in. Treatment – Normalized 1575F, Quenched 1550F into water, Drawn as shown for 1 hr.

Source – Bethlehem Steel Co. → Size treated .530 in. diam. Size tested: .505 in. diam x 2 in. Grain size = 6-8. Treatment: Normalized 1600F, Quenched 1575F into water. Drawn as shown.

Quenched and Tempered



(Continued on page 219)

Critical Points (collected)	Ryerson[2]	Beth. Steel Co.[1]	Rep. Steel Co.[2]	AISI
Ac_1	1395F	1400F	1395F	1380
Ac_3	1480	1510	1490	1475
Ar_3	1405	1400	–	1350
Ar_1	1250	1305	1220	1250

[1]Single heat results: .31C; .53Mn; .28Si; 1.04Cr; .20Mo.
[2]Representative data.

(Continued from page 218)

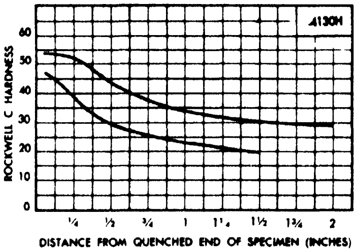
STEELS, AISI

4130

STEELS, AISI

4130H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Cr %	Mo %	P %	S %
.27-.34	.35-.65	.20-.35	.80-1.15	.15-.25	–[1]	–[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

"J" Distance in Inches[1]

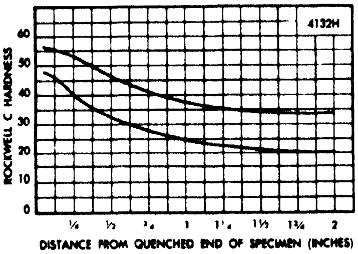
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	54.0	54.0	53.0	52.0	50.5	48.0	45.0	43.0	41.5	40.0	38.5	37.5	36.0	35.0	34.5	33.5	32.5	31.5	31.0	30.5	30.0	30.0	29.5	29.5
Min	46.5	45.0	42.0	39.0	36.0	33.5	31.5	30.0	28.5	27.5	26.5	26.0	25.0	24.0	23.5	23.0	22.0	21.0	20.5	20.0	–	–	–	–

[1]Note— These values are to be used when points are selected and specified.

STEELS, AISI

4132H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Cr %	Mo %	P %	S %
.30-.37	.35-.65	.20-.35	.80-1.15	.15-.25	–[1]	–[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

"J" Distance in Inches[1]

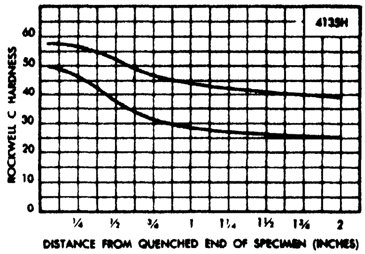
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	55.5	55.0	54.5	53.5	52.0	50.5	48.5	46.5	44.5	43.0	42.0	40.5	39.5	39.0	38.0	37.5	36.0	35.5	35.0	34.0	34.0	34.0	34.0	34.0
Min	48.0	46.0	43.5	40.5	37.5	35.5	33.5	32.0	31.0	29.5	29.0	28.0	27.0	26.5	26.0	25.0	24.0	23.0	22.5	22.0	21.0	20.5	20.5	20.0

[1]Note— These values are to be used when points are selected and specified.

STEELS, AISI

4135H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Cr %	Mo %	P %	S %
.32-.39	.60-.95	.20-.35	.80-1.15	.15-.25	—[1]	—[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

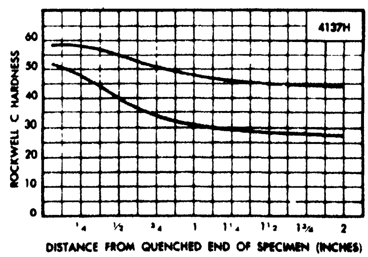
	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	57.0	57.0	57.0	56.5	55.5	54.5	53.5	52.0	51.0	49.5	48.5	47.5	46.5	45.5	45.0	44.0	43.0	42.0	41.5	41.0	40.5	40.0	40.0	39.5
Min	50.0	49.0	48.0	46.0	44.5	42.0	39.5	37.5	35.5	34.0	32.0	31.0	30.5	29.5	29.0	28.5	28.0	27.5	27.0	26.5	26.0	26.0	25.5	25.5

[1]Note—. These values are to be used when points are selected and specified.

STEELS, AISI

4137H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Cr %	Mo %	P %	S %
.35-.43	.60-.95	.20-.35	.80-1.15	.15-.25	—[1]	—[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	58.5	58.5	58.5	58.0	57.5	57.0	56.0	55.0	54.0	53.0	52.0	51.0	50.0	49.5	48.5	48.0	47.0	46.5	45.5	45.0	45.0	44.5	44.0	44.0
Min	51.5	50.5	49.0	47.5	46.0	44.0	42.0	40.0	38.0	36.5	34.5	33.5	32.5	32.0	31.0	30.5	30.0	29.0	29.0	28.5	28.0	27.5	27.5	27.0

[1]Note— These values are to be used when points are selected and specified.

4140

Chemical Composition (AISI)

C %	Mn %	P %	S %	Cr %	Mo %	Si %
.38-.43	.75-1.00	.040 max	.040 max	.80-1.10	.15-.25	.20-.35

Uses. Automotive: connecting rods, crankshafts, knuckles, rear axle and trailer axle shafts. Oil industry: bits, core drills, reamer bodies, drill collars, tool joints, piston rods and pump parts. Aircraft: shapes and tubing.

Common Commercial Forms. Blooms, billets, bars, forgings.

Characteristics. Intermediate hardenability and will give good properties in larger heat-treated sections than is possible with carbon steel of this C content. This steel can be arc welded by using pre- and post-heat. Similar steels – 8640, 8740.

Technological Properties
Machinability (On basis of B1112 = 100)

Annealed:	A4140	61%
	A4142	57%
	A4145	57%

Physical Properties[1]
Density 0.2834 lb/cu in. (7.845 S.G.)

[1]Source – ASM, Metals Handbook. Data from Natl Phys. Lab., Jour. Iron and Steel Inst., 1946, No. II. Steel – .35C, .59Mn, .88Cr, .20Mo. Annealed at 1580F, drawn at 1185F.

Coef. of Thermal Expansion[1] (mean)

Temp Range Deg C	Temp Range Deg F	$\times 10^{-6}/^{\circ}C$	$\times 10^{-6}/^{\circ}F$
0-100	32-212	11.2	6.2
0-200	32-392	11.8	6.5
0-300	32-572	12.4	6.9
0-400	32-752	13.0	7.2
0-500	32-932	13.6	7.5

[1]Steel· .39C, .51Mn, .19Si, .87Cr, .21Mo, as rolled.

As Quenched Rockwell "C" Hardness
Size tested – 1 in. discs cut from mid-length.

Diam.	Center	Half Radius	Surface
½ in.	55	56	57
1 in.	50	55	55
2 in.	38	43	49
4 in.	34	34.5	36

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Izod Ft Lbs
Bars							
Hot rolled	–	–	–	–	–	170-223	–
Cold drawn	–	–	–	–	–	196-241	–
Aver. Prop.[7] Annealed 1 in. rds. mean chem. – cold drawn	–	108	17.0	92	49.0	217[8]	–
Aver. Prop.[7] Annealed 1 in. rds. mean chem. – turned & polished	–	91	26 0	64	56.0	183[8]	–
Effect of Mass[7]							
Oil Quenched at 1550F and tempered at 1000F, 0 505 in tensile specimens – 1 in. diam. ctr.	–	165	15.0	143	50.0	335[8]	–
2 in. diam. ½r	–	133	18.0	109	55.0	302[8]	–
3 in. diam. ½r	–	125	19.0	95	55.0	293[8]	–
Effect of Mass[3]							
As rolled – 1 in. diam, ctr.	–	149.25	15	101.5	43.5	302	9.5
As rolled – 2 in. diam, ½r.	–	140	15.7	97.75	48.3	285	7.5
As rolled – 4 in. diam, ½r.	–	135.5	13	88	28.2	277	7
Annealed[4] 1 in. diam, ctr.	–	95	25.7	60.5	56.9	197	40.3
Normalized 1600F, air cooled – ½ in.[5] diam, ctr.	–	148.5	17.8	98.5	48.2	302	21.5
Normalized 1600F, air cooled – 1 in. diam, ctr.	–	148	17.7	95	46.8	302	16.7
Normalized 1600F, air cooled – 2 in. diam, ½r.	–	140.75	16.5	91.75	48.1	285	13
Normalized 1600F, air cooled – 4 in. diam, ½r.	–	117.5	22.2	69.5	57.4	241	29
Quenched and drawn, normalized at 1600F, air cooled, reheat to 1550F. Quenched in agitated oil, drawn as shown, air cooled. – ½ in.[5] diam, ctr.	1000F	171.5	15.4	161	55.7	341	43.5
1 in. diam, ctr.	1000F	156	15.5	143.25	56.9	311	54.5
2 in. diam, ½r.	1000F	139.75	17.5	115.75	59.9	285	66.8
4 in. diam, ½r.	1000F	127.75	19.2	99.25	60.4	277	37.7
½ in.[5] diam, ctr.	1100	157.5	18.1	148.75	59.4	321	66
1 in. diam, ctr.	1100	140.25	19.5	135	62.3	285	70.5
2 in. diam, ½r.	1100	127.5	21.7	102.75	65	262	84
4 in. diam, ½r.	1100	116.75	21.5	87	62.1	235	82.5
½ in.[5] diam, ctr.	1200	136.5	19.9	128.75	62.3	277	73.6
1 in. diam, ctr.	1200	132.75	21	122.5	65	269	84.5
2 in. diam, ½r.	1200	121.5	23.2	98.25	65.8	241	91.2
4 in. diam, ½r.	1200	112.5	23.2	83.5	64.9	229	86.7
Quenched in oil at 1550F. Properties interpreted from end quench tests, drawn as shown[6] – 1 in. rd. ctr.	1000	180	15	161	46.1	363	–
1 in. rd. ctr.	1100	156	17.4	135	51	316	–
1 in. rd. ctr.	1200	141	19.2	118	54	285	–
2 in. rd. ½r.	1000	174	15.5	154	47.3	352	–
2 in. rd. ½r.	1100	154	18	132	51.4	311	–
2 in. rd. ½r.	1200	139	19.5	116	54.4	281	–
3 in. rd. ½r.	1000	163	16.8	143	49.5	331	–
3 in. rd. ½r.	1100	149	18.4	127	52.3	302	–
3 in. rd. ½r.	1200	131	20.4	107	56	269	–
4 in. rd. ½r.	1000	156	17.4	135	51	316	–
4 in. rd. ½r.	1100	141	19.2	118	54	285	–
4 in. rd. ½r.	1200	127	21	102	57	255	–
Annealed – Single heat (Collected)	–	–	–	–	–	179[1]	–
Annealed – Approx (Collected)	–	–	–	–	–	197[2]	–
Normalized – Single heat (Collected)	–	–	–	–	–	311[1]	–
Normalized – Approx (Collected)	–	–	–	–	–	300[2]	–
Quenched, single heat (Collected)	–	–	–	–	–	601[1]	–
Effect of Temp[7]							
Oil Quenched at 1600F and tempered as shown, 0.505 in. tensile specimens cut from center of 1 in. rds.	800	198	12.0	174	42.0	397[8]	–
	900	181	13.0	157	45.0	367[8]	–
	1000	165	15.0	143	51.0	335[8]	–
	1100	149	16.0	128	54.0	305[8]	–
	1200	132	19.0	111	59.0	256[8]	–

[1]Bethlehem Steel Co. (See Critical Points table)
[2]Republic Steel Co.
[3]Collected. Bethlehem Steel Co. Single heat tests. The heat was selected to come at the middle of the range of chemical specifications. The analysis – Ladle: .40C, .80Mn, .27Si, .12Ni, .92Cr, .22Mo. Check: .40C, .83Mn, .012P, .009S, .26Si, .11Ni, .94Cr, .21Mo. McQuaid-Ehn Grain Size – 100% 7-8. All test results are averages of two tests.
[4]1500F, F.C. at 20F/hr to 1230F, A.C.
[5].357 in. diam for tension test.
[6]Ryerson
[7]Bliss & Laughlin
[8]Surface of bar

(Continued on page 222)

STEELS, AISI

4140

(Continued from page 221)

Treatment Temperatures (collected)

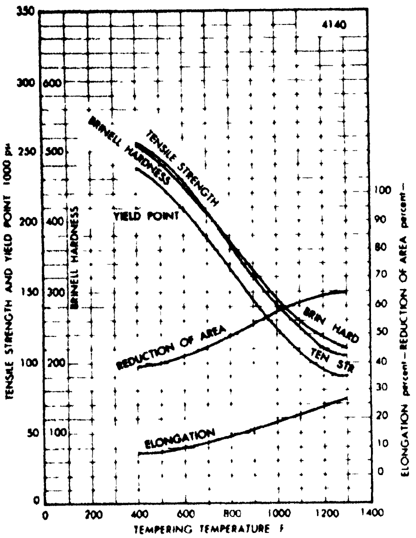
	Rep. Steel Co	Ryerson
Forging	2250F	1950-2250F
Annealing	1500-1700	1500-1550
Normalizing	1600-1725	1600-1750
Quenching – oil	1500-1550	1525-1600

Critical Points (collected)

	Ryerson[2]	Beth. Steel Co.[1]	Rep. Steel Co.[2]	AISI
Ac_1	1380F	1395F	1380F	1375
Ac_3	1460	1450	1450	1450
Ar_3	1370	1330	–	1350
Ar_1	1280	1280	1280	1250

[1]Single heat values. Analysis .41C, .85Mn, .20Si, .12Ni, 1.01Cr, .24Mo.
[2]Approx values

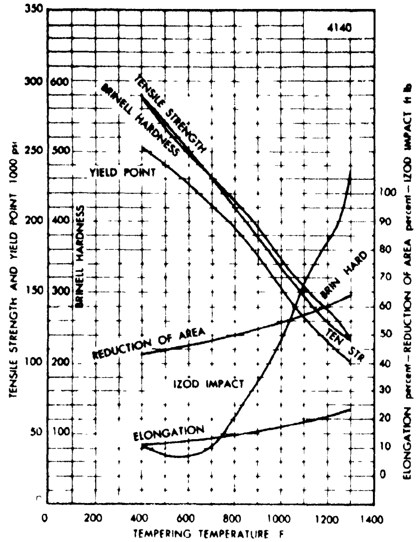
Properties as Quenched and Drawn



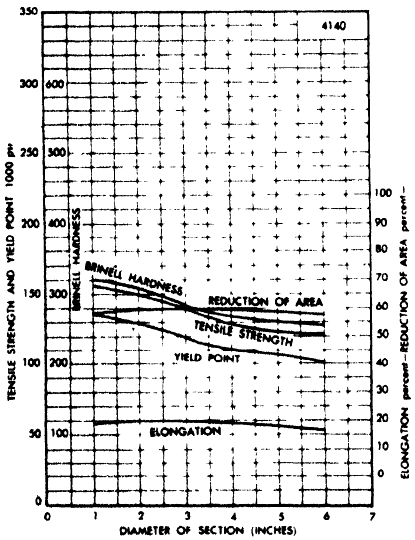
←Source – Republic Steel Co. Size treated – 1 in. diam. Size tested – .505 in. diam × 2 in. Treatment – Normalized 1600F, Quenched 1500F into oil, Drawn as shown, for 1 hr.

Source – Bethlehem Steel Co.→ Grain size – 6-8. Size treated – .530 in. diam. Size tested – .505 in. diam. Treatment – Normalized 1600F, Quenched 1550F into agitated oil, Drawn as shown.

Quenched and Tempered

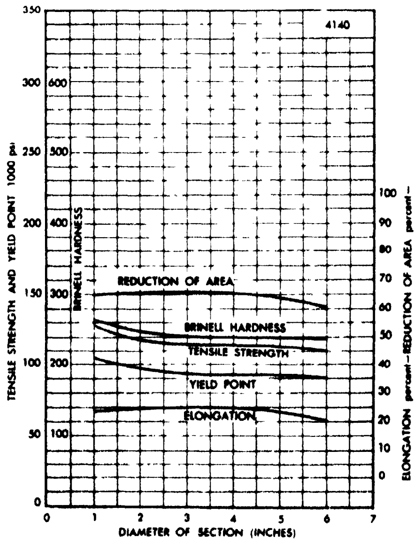


Quenched and Tempered at 1000F



Source – Republic Steel Corp. Size treated – 1 in. to 6 in. diam. Size tested – 2 in. × .505 in. diam. Tests over 1.5 in. at mid-radius. Treatment – 1500-1550F, Drawn as shown, Quenched in oil.

Quenched and Tempered at 1200F



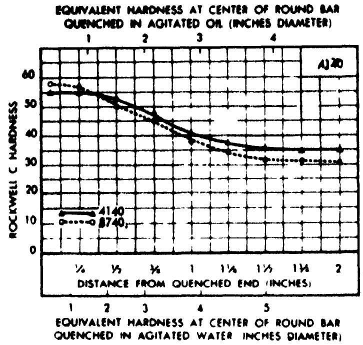
(Continued on page 223)

(Continued from page 222)

SPECIAL CASTINGS

4140

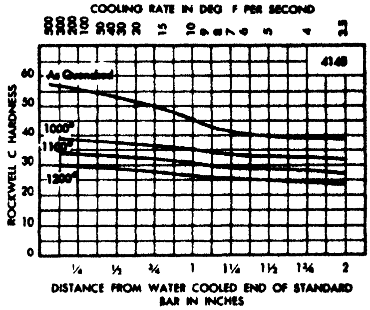
End Quench Hardenability



← Source – Bethlehem Steel Co. Single heat results. Analysis: .40C oil-hardening grades (4140) .41%C, .85%Mn, .20%Si, .12%Ni, 1.01%Cr, .24%Mo. (8740) .40%C, .95%Mn, .25%Si, .55%Ni, .55%Cr, .25%Mo. Grain size 6-8, carburized at 1700F.

Source – Ryerson. Test results → after quenching, and after drawing at temperatures shown.

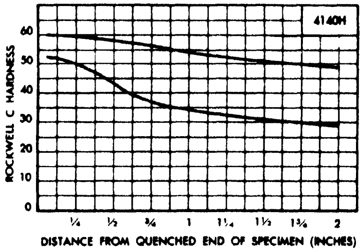
End Quench Hardenability



STEELS, AISI

4140H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Cr %	Mo %	P %	S %
.37-.45	.70-1.05	.20-.35	.80-1.15	.15-.25	–[1]	–[1]

[1] P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

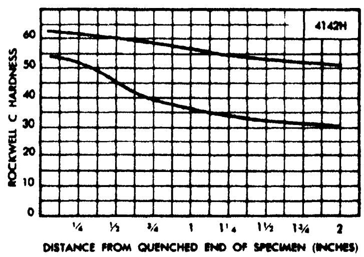
	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	60.0	60.0	60.0	59.5	59.0	59.0	58.5	58.0	58.0	57.5	57.0	56.0	55.5	55.0	54.5	54.0	53.0	52.0	51.5	51.0	50.5	50.0	49.5	49.0
Min	52.5	52.0	51.0	50.0	48.5	47.0	45.0	43.5	41.5	40.0	38.5	37.5	36.5	35.5	34.5	34.0	33.0	32.0	31.5	31.0	30.0	30.0	29.5	29.5

[1] Note – These values are to be used when points are selected and specified.

STEELS, AISI

4142H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Cr %	Mo %	P %	S %
.40-.48	.70-1.05	.20-.35	.80-1.15	.15-.25	–[1]	–[1]

[1] P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

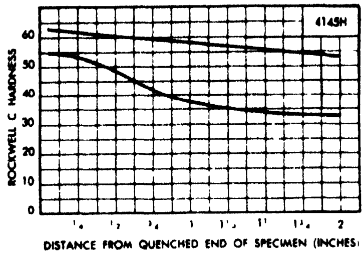
	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	62.0	62.0	61.5	61.0	61.0	60.5	60.5	60.0	59.5	59.0	58.5	58.0	57.5	57.0	56.5	56.0	55.5	54.5	54.0	53.0	52.5	52.5	52.0	51.5
Min	54.0	53.5	53.0	52.0	51.0	49.0	47.5	45.5	43.5	42.0	40.5	39.5	38.5	37.5	37.0	36.0	35.0	34.0	33.0	32.5	32.0	31.5	31.0	30.5

[1] Note – These values are to be used when points are selected and specified.

STEELS, AISI

4145H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Cr %	Mo %	P %	S %
.42-.50	.70-1.05	.20-.35	.80-1.15	.15-.25	—[1]	—[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

"J" Distance in Inches[1]

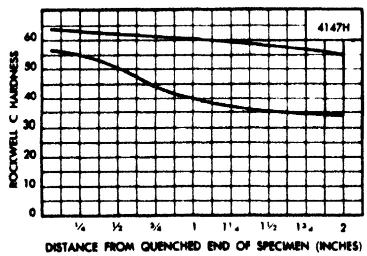
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	63.0	63.0	62.5	62.0	62.0	61.5	61.0	61.0	60.5	60.0	60.0	59.5	59.0	59.0	58.5	58.0	57.5	57.0	56.0	55.5	55.0	54.5	54.0	53.5
Min	55.0	54.5	54.0	53.0	52.5	51.0	50.0	48.5	47.0	45.0	43.5	42.0	40.5	39.5	38.5	38.0	36.5	35.5	34.5	34.0	33.5	33.0	33.0	32.5

[1]Note — These values are to be used when points are selected and specified.

STEELS, AISI

4147H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Cr %	Mo %	P %	S %
.44-.52	.70-1.05	.20-.35	.80-1.15	.15-.25	—[1]	—[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

"J" Distance in Inches[1]

	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	64.0	64.0	63.5	63.5	63.0	63.0	62.5	62.0	62.0	61.5	61.5	61.0	61.0	60.5	60.5	60.0	60.0	59.0	58.5	58.0	57.5	57.0	56.0	55.5
Min	56.5	56.5	56.0	55.0	54.5	53.5	52.0	50.5	49.0	47.5	45.5	44.5	43.0	42.0	40.5	40.0	38.0	37.0	36.0	35.5	35.0	34.5	34.0	34.0

[1]Note — These values are to be used when points are selected and specified.

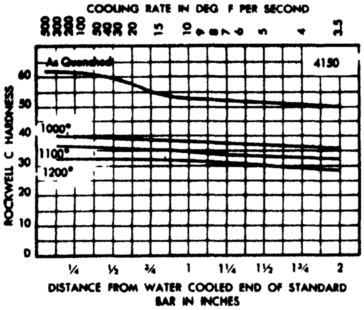
4150

Chemical Composition[1]

C %	Mn %	P %	S %	Si %	Cr %	Mo %
.48-.53	.75-1.00	.040 max	.040 max	.20-.35	.80-1.10	.18-.25

[1]AISI

End-Quench Hardenability



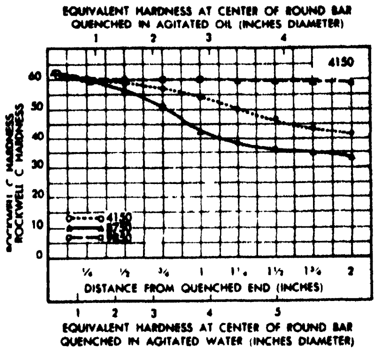
Source — Ryerson. Average results. Grain size = 5-8.

As Quenched Rockwell "C" Hardness

Diam	Center	Half Radius	Surface
½ in.	63	64	64
1 in.	62	62	62
2 in.	56	57	58
4 in.	42	43	47

Source — Bethlehem Steel Co. → Single heat results. Analysis, .50C, oil-hardening grades. (4150) .50%C, .76%Mn, .21%Si, .20%Ni, .95%Cr, .21%Mo, carburized grain size at 1700F 90% 7-8. (8750) .51%C, .80%Mn, .24%Si, .53%Ni, .52%Cr, .25%Mo, grain size 6-8. (9850) .51%C, .84%Mn, .25%Si, 1.05%Ni, .88%Cr, .24%Mo, grain size 5-8.

End-Quench Hardenability



Mechanical Properties

Form or Condition		Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hardness BHN	Hardness Rb	Izod Ft Lbs
Bars									
Hot rolled annealed[1]		–	100	21	66	51	197	93	–
Normalized[2] 0.530 in. diam.		–	–	–	–	–	311	–	–
Aver. Prop.[6] 1 in. rds., mean chemistry	annealed, cold drawn	–	116	15.0	98	45.0	235[7]	–	–
	turned & polished	–	102	22.0	70	50.0	207[7]	–	–
Effect of Mass[6] OQ at 1550F and tempered at 1000F, 0.505 in. tensile specimens	1 in. diam. ctr.	–	188	16.0	164	50.0	365[7]	–	–
	2 in. diam. ½r	–	172	14.0	151	48.0	348[7]	–	–
	3 in. diam. ½r	–	161	14.0	142	47.0	341[7]	–	–
Effect of Mass[3]									
As rolled	1 in. diam, ctr.	–	173.75	12.2	110.25	30	341	–	9.2
	2 in. diam, ctr.	–	158.75	13	110	38.2	311	–	7.7
	4 in. diam, ½r.	–	106.75	17.5	43	32.1	207	–	13
Annealed[4]	1 in. diam, ctr.	–	105.75	20.2	49.75	40.2	197	–	18.2
Normalized 1600F, air cooled	½ in.[5] diam, ctr.	–	194	10	129.5	24.8	375	–	5.5
	1 in. diam, ctr.	–	167.5	11.7	106.5	30.8	321	–	8.5
	2 in. diam, ½r.	–	158.75	13.5	109.25	40.6	311	–	9.2
	4 in. diam, ½r.	–	146	19.5	91.75	56.5	293	–	13.7
Quenched & Tempered 1600F air cooled, 1525F oil tower quenched, drawn as shown	½ in.[5] diam, ctr.	1000F	189.5	13.4	176.25	47.2	375	–	23.7
	1 in. diam, ctr.	1000F	175.25	14	159.5	46.5	352	–	31.2
	2 in. diam, ½r.	1000F	168.75	15.5	151	51	341	–	39.5
	4 in. diam, ½r.	1000F	158.75	15	127.75	46.8	311	–	21.2
	½ in.[5] diam, ctr.	1100	170	14.6	155.5	45.5	341	–	34.5
	1 in. diam, ctr.	1100	165.5	15.7	150	51.1	331	–	35
	2 in. diam, ½r.	1100	150.25	18.7	131.5	56.4	302	–	58
	4 in. diam, ½r.	1100	132.5	20	98.25	57.5	269	–	57
	½ in.[5] diam, ctr.	1200	148	17.4	137.25	53.3	302	–	48.5
	1 in. diam, ctr.	1200	141	18.7	127.5	55.7	285	–	55.7
	2 in. diam, ½r.	1200	134.75	20.5	118.25	60	269	–	73.2
	4 in. diam, ½r.	1200	124	21.5	91	61.4	255	–	73
Effect of Mass:[1] Interpreted from End-Quench Hardenability curve. Quenched in oil at 1550F, drawn as shown. Average	1 in. rd, ctr.	1000	186	14.1	167	45.0	375	–	–
		1100	168	16.1	148	48.5	341	–	–
		1200	154	18.0	132	51.4	311	–	–
	2 in. rd, ½r.	1000	186	14.1	167	45.0	375	–	–
		1100	166	16.4	145	49.0	336	–	–
		1200	151	18.2	129	52.0	306	–	–
	3 in. rd, ½r.	1000	180	15.0	161	46.1	363	–	–
		1100	163	16.8	143	49.5	331	–	–
		1200	149	18.4	127	52.3	302	–	–
	4 in. rd, ½r.	1000	171	15.9	151	48.1	346	–	–
		1100	159	17.2	137	50.5	321	–	–
		1200	145	18.7	123	53.0	293	–	–
Effect of Temp[6] Oil Quenched at 1600F and tempered as shown, 0.505 in. tensile specimens cut from center of 1 in. rds.		800	212	13.0	188	45.0	429[7]	–	–
		900	188	14.0	169	51.0	394[7]	–	–
		1000	169	15.0	150	55.0	353[7]	–	–
		1100	150	18.0	130	60.0	315[7]	–	–
		1200	139	19.0	118	65.0	273[7]	–	–

[1]Ryerson
[2]Bethlehem Steel Co. Single heat results.
[3]Bethlehem Steel Co. Single heat results. Composition — Ladle: .51C, .91Mn, .27Si, .10Ni, .96Cr, .19Mo. Check: .51C, .89Mn, .018P, .017S, .27Si, .12Ni, .87Cr, .18Mo. McQuaid-Ehn grain size = 95% 7-8; 5% 5. Test specimens — 0.505 in. diam for tensile and 0.450 in. diam. for Izod specimens.
[4]1525F, furnace cooled at 20F/hr to 1190F, air cooled.
[5]Tensile test bars were 0.357 in. diam.
[6]Bliss & Laughlin
[7]Surface of bar

(Continued on page 226)

STEELS, AISI

4150

Technological Properties

(Continued from page 225)

Machinability Rating (On basis of B1112 = 100)
Mill annealed to 187-235 BHN = 50%(ASM Metals Handbook)

Critical Points[1]

Ac_1	1375F	Ar_3	1325F
Ac_3	1425	Ar_1	1270

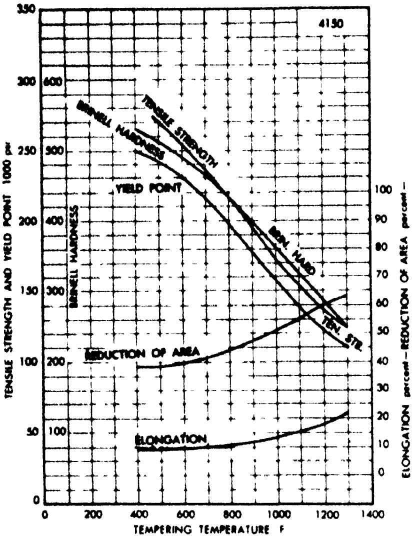
[1]Collected, principally from Ryerson.

Treatment Temperatures[1]

Forging	1950-2150F
Annealing	1450-1525
Normalizing	1500-1650
Quenching	1475-1525

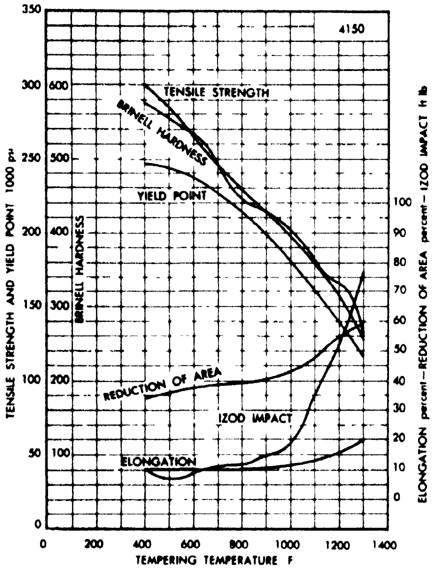
[1]Collected, principally from Ryerson

Quenched and Tempered



←Size Treated: 1 in. rd. Size Tested 2 in. × .505 in. rd. Treatment: Normalized 1600F, quenched 1500F into oil, drawn as shown for 1 hr.

Quenched and Tempered



Source – Bethlehem Steel Co.→ Single heat results. Composition: .50C, .76Mn, .015P, .012S, .21Si, .20Ni, .95Cr, .21Mo. Test Conditions: 0.530 in. rds normalized at 1600F, quenched from 1525F in agitated oil, drawn as shown. Grain size of the steel was 90% 7-8.

STEELS, AISI

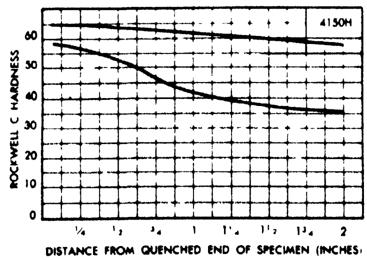
4150H

Chemical Composition

C %	Mn %	Si %	Cr %	Mo %	P %	S %
.46-.54	.70-1.05	.20-.35	.80-1.15	.15-.25	—[1]	—[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel AISI

End-Quench Hardenability Band



"J" Distance in Inches[1]																								
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	65.0	65.0	65.0	65.0	64.5	64.5	64.0	64.0	64.0	63.5	63.0	63.0	63.0	62.5	62.0	62.0	61.5	61.0	60.5	60.0	59.5	59.0	58.5	58.0
Min	58.0	58.0	57.5	57.0	56.5	55.0	54.0	53.0	51.5	50.0	48.0	46.5	45.0	44.0	42.5	42.0	40.0	39.0	38.0	37.0	36.5	36.0	36.0	35.5

[1]Note – These values are to be used when points are selected and specified.

4317

Chemical Composition[1]

C %	Mn %	P %	S %
.15-.20	.45-.65	.040 max	.040 max
Si %	**Ni %**	**Cr %**	**Mo %**
.20-.35	1.65-2.00	.40-.60	.20-.30

[1]AISI

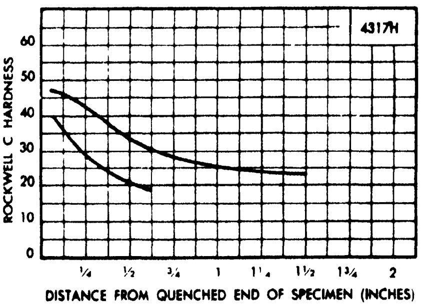
Mechanical Properties

Form or Condition			Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	BHN	Hardness Rc Core	Hardness Rc Case	Izod Ft Lbs
Aver. Prop.[5] 1 in. rds. mean chemistry	Cold Drawn	unannealed	–	113	20.0	95	53.0	228[6]	–	–	–
	Cold Drawn	annealed	–	102	22.0	85	58.0	207[6]	–	–	–
	Turned and Polished	unannealed	–	90	29.0	58	60.0	193[6]	–	–	–
	Turned and Polished	annealed	–	80	33.0	50	64.0	170[6]	–	–	–
Single heat[1] Carburized at 1700F for 8 hrs, quenched in agitated oil, heat treatment as shown.	Direct from pot		300F	180.5	14.5	139.5	50.9	375	–	61.5[2]	26
	Pot cooled, reheat 1500F		300F	130	18.5	93	58.3	269	–	61[3]	64
	Pot cooled, reheat 1500 & 1425F, DQ		300F	130.75	22	79.5	55.3	262	–	62[3]	59.5
	Direct from pot		450F	178	13	142.5	52.8	363	–	56.5[2]	29
	Pot cooled, reheat 1500F		450F	129	19	92	59.5	262	–	59[3]	58
	Pot cooled, reheat 1500 & 1425F, DQ		450F	128.75	21	85	60.7	262	–	58.5[3]	69
Carburized 8 hr at 1700F, OQ as shown, aver.[4]	Direct OQ from box	1 in. rd.	300F	181	18	154	50	–	38	64	–
	Pot cooled, reheat 1525F	1 in. rd.	300F	180	15	150	50	–	38	63	–
	Pot cooled, reheat 1425F	1 in. rd.	300F	175	15	148	48	–	37	64	–
	Pot cooled, reheat 1525 & 1425F, DQ	1 in. rd.	300F	178	17	147	51	–	38	63	–

[1]Bethlehem Steel Co.
[2].047 in. case
[3].055 in. case
[4]Ryerson
[5]Bliss & Laughlin
[6]Surface of bar

4317H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	P %	S %
.14-.21	.40-.70	—[1]	—[1]
Si %	**Ni %**	**Cr %**	**Mo %**
.20-.35	1.50-2.00	.35-.65	.20-.30

[1]The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

"J" Distance in Inches

	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	47.0	46.0	44.5	42.5	40.5	37.5	35.0	33.0	31.5	30.0	29.0	28.0	27.0	26.5	26.0	25.5	24.5	24.0	23.5	23.0	23.0	23.0	23.0	23.0
Min	40.0	35.5	31.5	28.5	26.0	24.0	22.5	21.0	20.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[1]These values are to be used when points are selected and specified.

STEELS, AISI

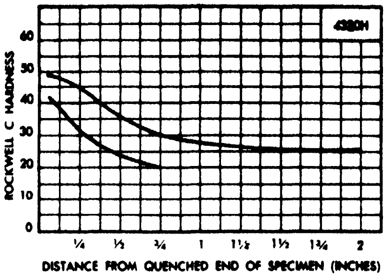
4320H

Chemical Composition

C %	Mn %	P %	S %
.16-.23	.40-.70	—[1]	—[1]
Si %	**Ni %**	**Cr %**	**Mo %**
.20-.35	1.50-2.00	.35-.65	.20-.30

[1]The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

End-Quench Hardenability Band



"J" Distance in Inches[1]

	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	49.0	48.0	46.5	44.5	42.0	40.0	37.5	35.5	34.0	32.5	31.0	30.0	29.5	29.0	28.0	27.5	27.0	26.5	26.0	26.0	25.5	25.5	25.5	25.5
Min	41.5	38.5	34.0	31.0	29.0	27.0	25.0	24.0	22.5	21.5	20.5	20.0	—	—	—	—	—	—	—	—	—	—	—	—

[1]These values are to be used when points are selected and specified.

STEELS, AISI

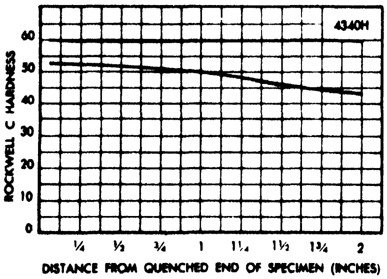
4340H

Chemical Composition

C %	Mn %	P %	S %
.37-.45	.60-.95	—[1]	—[1]
Si %	**Ni %**	**Cr %**	**Mo %**
.20-.35	1.50-2.00	.65-.95	.20-.30

[1]The P and S are 0.040 max in open hearth steel and 0.025 max in electric steel. AISI.

End Quench Hardenability Band



"J" Distance in Inches[1]

	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Min	52.5	52.5	52.5	52.5	52.5	52.5	52.5	52.0	52.0	51.5	51.5	51.0	51.0	50.5	50.5	50.0	49.0	48.0	47.0	46.0	45.0	44.5	44.0	43.0

[1]These values are to be used when points are selected and specified.

4320

Chemical Composition[1]

C	Mn	P	S
%	%	%	%
.17-.22	.45-.65	.040 max	.040 max
Si	**Ni**	**Cr**	**Mo**
%	%	%	%
.20-.35	1.65-2.00	.40-.60	.20-.30

[1] AISI

Characteristics. A high grade case hardening steel.

Uses. Used in the automotive and machinery industries for differential drive pinions, differential ring gears, transmission gears and bearings, in aircraft engine bearings and gears. The higher carbon 4325 is used for knuckles.

Technological Properties

Machinability Rating (On basis of B1112 = 100)	Mill annealed to 197-228 = 55% (ASM, Metals Handbook.)

As-Quenched Rockwell "C" Hardness

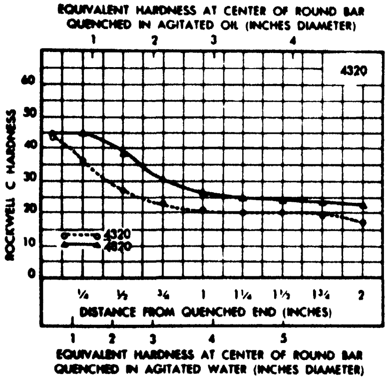
Treatment: 1700F – 8 hrs – F.C.
1500F – Quenched in Agitated Oil

	Center	Midway	Surface
½ in. diam	44½	44½	44½
1 in. diam	36	37	39
2 in. diam	27	30	35
4 in. diam	24	24	25

Rockwell "C" Core Hardness
Quenched in Oil at 1700F

Size of Round	7/8 Radius	1/2 Radius	Center
1 in. Rd.	40.5	37	36
2 in. Rd.	34	28.5	27
3 in. Rd.	28	25	22.5

End-Quench Hardenability



Source – Bethlehem Steel Co. Single heat results. Analysis: .20C, carburizing grades (4320) .17%C, .55%Mn, .25%Si, 1.75%Ni, .47%Cr, .25%Mo. (4820) .21%C, .51%Mn, .21%Si, 3.49%Ni, .18%Cr, .24%Mo. Grain size 6-8, carburized at 1700F.

Critical Points

Ac_1	1350F	Ar_3	1330
Ac_3	1485	Ar_1	900

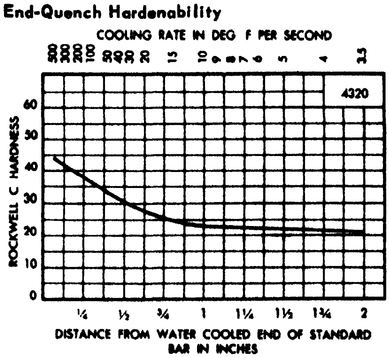
Treatment Temperatures[1]

Forging	1950-2250F
Annealing	1525-1575
Normalizing	1625-1750

[1] (Collected)

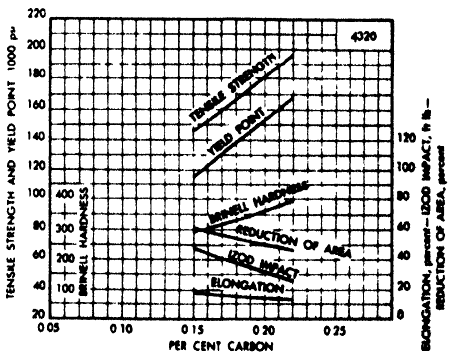
Core Properties of 4320 Condition	Reheat	Tensile Strength M psi	Yield Point M psi	Elong %	Red Area %	Izod Ft Lb
Box cooled & re-	1425F	175	147	14	48	30
heated for hard-	1475	180	125	15	49	32
ening (0.20% C)	1525	183	150	14	50	35
Drawn at 300F						

End-Quench Hardenability



Source – Ryerson. Aver results.

Direct Quench



Source – International Nickel Co. Representative core properties. Test conditions: 1 in. bars paeudo-carburized at 1650-1700F, direct quenched and drawn at 300F.

(Continued on page 230)

(Continued from page 229)

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	BHN	Hardness Rc	Case	Izod Ft Lbs	BHN Izod[16]	Impact Resistance Izod Ft Lbs
Bars: Annealed, single heat[1]	–	–	–	–	–	149	–	–	–	–	–
Bars: Annealed, approx[2]	–	–	–	–	–	197	–	–	–	–	–
Normalized, single heat[1]	–	–	–	–	–	201	–	–	–	–	–
Normalized, approx[2]	–	–	–	–	–	269	–	–	–	–	–
Aver. Prop.[14] 1 in. rds. mean chemistry: Cold drawn, unannealed	–	119	17.0	103	50.0	231[15]	–	–	–	–	–
Cold drawn, annealed	–	109	19.0	93	54.0	215[15]	–	–	–	–	–
Turned & Polished, unannealed	–	96	28.0	63	58.0	197[15]	–	–	–	–	–
Turned & Polished, annealed	–	84	32.0	52	63.0	170[15]	–	–	–	–	–
Core Properties											
1 in. rd. pseudo-carburized at 1680F for 8 hrs. at temp. and DQ, tempered at 300F for 1 hr. 0.505 in. tensile specimens and 0.394 in. sq. Izod specimen ctr.: Direct quench 1680F	–	180	13.0	160	52.0	375[15]	–	–	–	287	40.0[16]
reheat 1425	–	155	12.0	125	24.0	312[15]	–	–	–	235	28.0[16]
reheat 1475	–	180	13.0	160	45.0	375[15]	–	–	–	293	42.0[16]
reheat 1525	–	185	13.0	160	52.0	375[15]	–	–	–	293	50.0[16]
Core prop.[2] 1700F for 8 hrs in iron chips and box cooled heat treated as shown, drawn 300F, approx: 1 in. rd, Direct OQ from box	–	167	14.5	141	50	341[3]	–	–	–	–	–
1 in. rd, 1425F OQ	–	139	15	115	52	295[3]	–	–	–	–	–
1 in. rd, 1475F OQ	–	149	15.5	123	52	302[3]	–	–	–	–	–
1 in. rd, 1525F OQ	–	161	16	139	54	331[3]	–	–	–	–	–
.515 in. rd, Direct OQ from box	–	180	14.5	148	46	370[4]	–	–	–	–	–
.515 in. rd, 1425F OQ	–	151	15	126	49	321[4]	–	–	–	–	–
.515 in. rd, 1475F OQ	–	157	16	130	50	331[4]	–	–	–	–	–
.515 in. rd, 1525F OQ	–	171	16	147	53	352[4]	–	–	–	–	–
Single heat[5] Carburized at 1700F for 8 hrs, quenched in agitated oil, heat treatment as shown: Direct from pot		180.5	14.5	139.5	50.9	375	–	61.5[6]	26	–	–
Pot cooled, reheat 1500F	300F	130	18.5	93	58.3	269	–	61[6]	64	–	–
Pot cooled, reheat 1500 & 1425F, DQ		130.75	22	79.5	55.3	262	–	62[7]	59.5	–	–
Direct from pot		178	13	142.5	52.8	363	–	56.5[6]	29	–	–
Pot cooled, reheat 1500F	450	129	19	92	59.5	262	–	59[6]	58	–	–
Pot cooled, reheat 1500 & 1425F, DQ		128.75	21	85	60.7	262	–	58.5[7]	69	–	–
Carburized 8 hr at 1700F, OQ as shown aver.[8], 1 in. rd: Direct OQ from box	–	181	18	154	50	–	38	64	–	–	–
Pot cooled, reheat 1525F	300F	180	15	150	50	–	38	63	–	–	–
Pot cooled, reheat 1425F	–	175	15	148	48	–	37	64	–	–	–
Pot cooled, reheat 1525 & 1425F	–	178	17	147	51	–	38	63	–	–	–
Effect of Mass[9]											
Core Prop. 0.565 in. diam tensile and 0.510 in. diam Izod Carburized 1700F 8 hrs, quenched in agitated oil: Direct quench from pot	300	217	13	159.5	50.1	429	60.5[10]	–	32.5	–	–
Direct quench from pot	450	215.5	12.5	158.75	49.4	415	58.5[10]	–	26	–	–
Single quench Reheat to 1500F	300	218.25	13.5	178	48.2	429	62.5[11]	–	27.5	–	–
Single quench Reheat to 1500F	450	211.5	12.5	173	50.9	415	59.0[11]	–	28.8	–	–
double quench Reheat 1500 & 1425F	300	151.75	19.5	97	49.4	302	62.0[11]	–	49.3	–	–
double quench Reheat 1500 & 1425F	450	145.75	21.8	94.5	56.3	293	59.0[11]	–	48.5	–	–
As Rolled: 1 in. diam, ctr	–	120	20.3	77.75	50.6	248	–	–	77.5	–	–
As Rolled: 2 in. diam, ½r	–	111.5	21	77	56.6	229	–	–	32	–	–
As Rolled: 4 in. diam, ½r	–	105	20.3	74.25	55.2	217	–	–	16.3	–	–
Annealed[12]: 1 in. diam	–	84	29	61.625	58.4	163	–	–	81	–	–
Normalized 1640F air cooled: ½ in. diam[13] ctr.	–	121.5	23.9	74.375	54.3	248	–	–	54.5	–	–
1 in. diam ctr.	–	115	20.8	67.25	50.7	235	–	–	53.8	–	–
2 in. diam ½r.	–	102.5	23.3	58.75	59.2	212	–	–	67	–	–
4 in. diam ½r.	–	102	22.3	57	54.7	201	–	–	40	–	–
Mock carburized quenched & tempered 1700F - 8 hrs - F.C. 1500F - quenched in agitated oil: ½ in. diam[13] ctr.		212	11.8	163.25	45.5	415	–	–	28	–	–
1 in. diam ctr.	300	152.25	17	107.25	51	302	–	–	44.3	–	–
2 in. diam ½r.	–	132.5	22.5	86	56.4	255	–	–	57.5	–	–
4 in. diam ½r.	–	119.75	24	75.25	57.1	241	–	–	53.3	–	–
½ in. diam[13] ctr.	–	187.5	13.9	149.5	52.8	388	–	–	27.5	–	–
1 in. diam ctr.	450	148.75	17.8	105	55.2	285	–	–	43.8	–	–
2 in. diam ½r.	–	129.75	20.8	85	63.8	255	–	–	49	–	–
4 in. diam ½r.	–	118	22.5	75	51.9	241	–	–	59.8	–	–

[1] Bethlehem Steel Co.
[2] Republic Steel Corp. Treated 2 in. x .505 in. rd.
[3] At ¾ r.
[4] On surface
[5] Bethlehem Steel Co. Composition: .17%C, .55%Mn, .015%P, .027%S, .25%Si, 1.75%Ni, .47%Cr, .25%Mo. Grain size 6-8. Test conditions: 0.565 in. rds. carburized and heat treated as shown, tested as 0.505 in. bars.
[6] .047 in. case.
[7] .055 in. case.
[8] Ryerson.
[9] Bethlehem Steel Co. Single heat results. Analysis – Spec: .17/.23%C, .45/.65%Mn, .04%P, .04%S, .20/.35%Si, 1.65/2.00%Ni, .40/.60%Cr, .20/.30%Mo. Ladle: .19%C, .60%Mn, .023%P, .016%S, .27%Si, 1.77%Ni, .49%Cr, .24%Mo. Check: .20%C, .59%Mn, .021%P, .018%S, .25%Si, 1.77%Ni, .47%Cr, .23%Mo. McQuaid-Ehn Grain Size 100% 6-8. All test results are the average of two tests. Size tested: 0.505 in. diam tensile and 0.450 in. diam Izod specimens.
[10] 0.060 in. case.
[11] 0.075 in. case.
[12] 1560F F.C. 30F/hr to 790F – A.C.
[13] 0.357 in. diam tensile.
[14] Bliss & Laughlin
[15] Surface of bar
[16] Surface of Izod test specimen

4340

Chemical Composition (AISI)			
C %	Mn %	P %	S %
.38-.43	.60-.80	.040 max	.040 max
Si %	Ni %	Cr %	Mo %
.20-.35	1.65-2.00	.70-.90	.20-.30

Critical Points[1]			
Ac_1	1350F	Ar_3	900-1200
Ac_3	1425	Ar_1	725 +

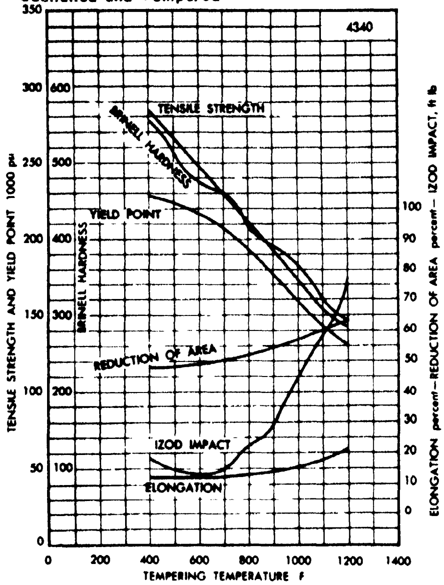
[1] Industry data.

Treatment Temperatures	
Forging	1950-2250F
Annealing	1475-1700
Normalizing	1575-1725
Quenching	1475-1550

Characteristics. This is an older "triple alloy" steel; it has high hardenability and is capable of giving good properties in large sections. It is relatively free from temper brittleness and retains useful machinability at relatively high hardness (ca 400 BHN).

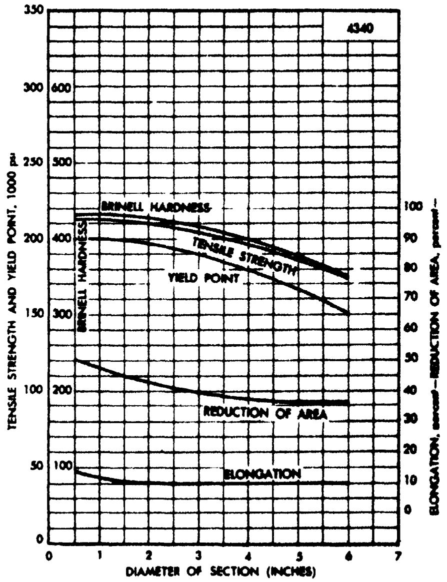
Uses. Automotive crankshafts and rear axle shafts, aircraft crankshafts, connecting rods, propeller hubs, gears, drive shafts, landing gear parts, and heavy duty parts of rock drills. A lower carbon variety (4330) is used for hollow propeller blades.

Quenched and Tempered



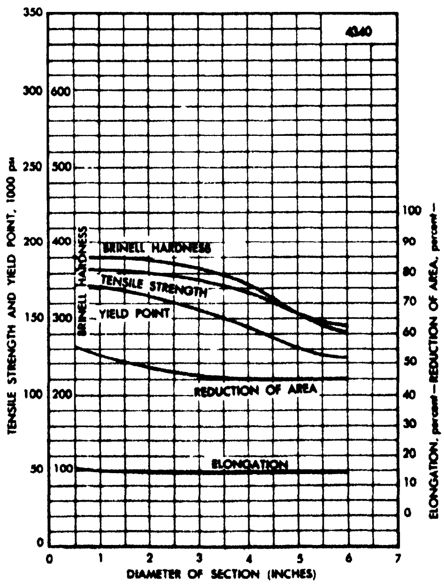
←Source—Bethlehem Steel Co. Single heat results. Composition: .41C, .67Mn, .023P, .018S, .26Si, 1.77Ni, .78Cr, .26Mo. Grain size = 6-8. Test conditions: 0.530 in. rds normalized at 1600F, quenched from 1475F in agitated oil, drawn as shown. Tested as 0.505 in. bars.

Oil Quenched, Tempered at 800F

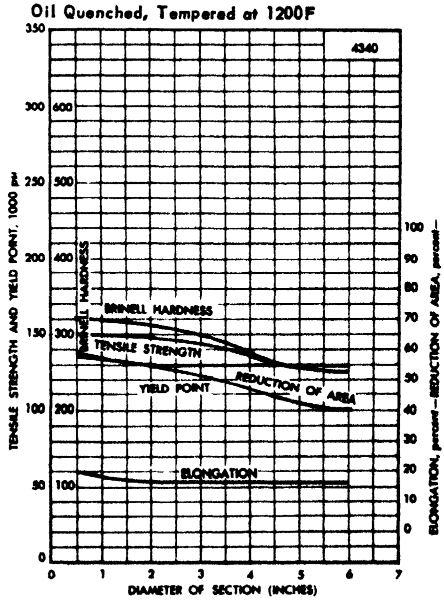


Source — International Nickel Co. Average values. Test conditions: Sections ½ to 2 in. incl. quenched in oil from 1500-1550F, over 2 in. to 4 in. incl. from 1525-1575F, and over 4 in. from 1550-1600F. In sizes over 1 in. the values represent properties at mid-radius. Tested as 0.505 in. bars.

Oil Quenched, Tempered at 1000F



Oil Quenched, Tempered at 1200F



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4340

(Continued from page 231)

As Quenched Rockwell "C" Hardness
Treatment: 1600F – A.C.
1475F Oil Tower Quenched

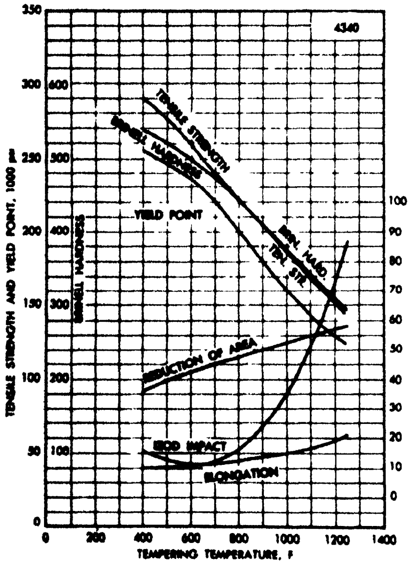
	Center	Midway	Surface
½ in. diam	56	58	58
1 in. diam	56	57	57
2 in. diam	54	55	56
4 in. diam	47	49	53

Technological Properties

Relative Machinability (On basis of B1112 = 100)

Mill annealed to 187-241 BHN 45% (ASM, Metals Handbook.)

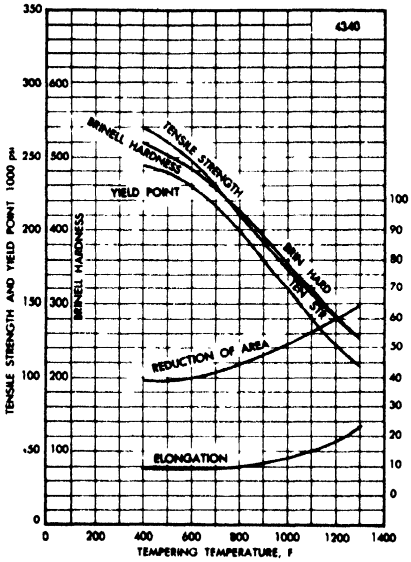
Oil Quenched and Tempered



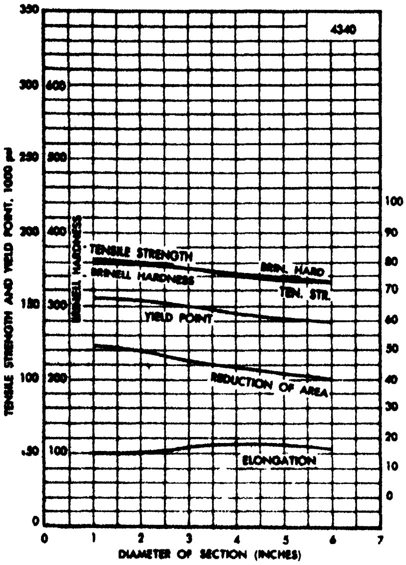
←Source—International Nickel Co. Average values. Test Conditions: 1 in. sections quenched from 1500-1550F in oil, drawn as shown, tested as 0.505 in. bars.

Source – Republic Steel→ Corp. Approx values. Test conditions: 1 in. rds, normalized at 1600F, quenched from 1525F in oil, drawn as shown for 1 hr., tested as 0.505 in. bars. Maximum section for which these properties can be expected is 4.0 in.

Quenched and Tempered

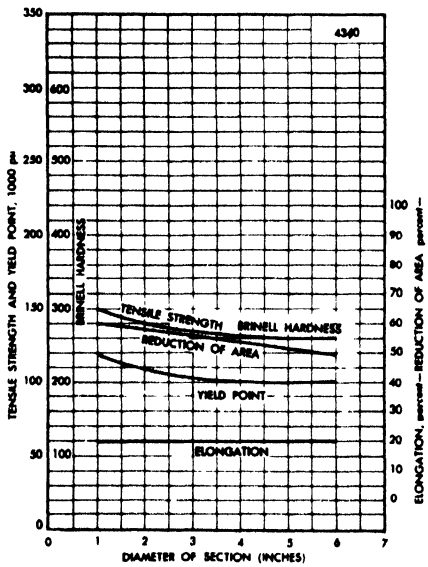


Effect of Mass
Oil Quenched, drawn at 1000F



Source – Republic Steel Corp. Test conditions: Bars, oil quenched and drawn as shown. Values for sizes over 1½ in. represent the mid-radius position. Tested as 0.505 in. bars.

Effect of Mass
Oil Quenched, drawn at 1200F



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(Continued from page 232)

Mechanical Properties

Form or Condition		Test Temp	Draw Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Izod Ft Lbs
Aver. Prop.[10] Annealed 1 in. rds. mean chem.	cold drawn		–	122	–	15.0	105	45.0	248[11]	–
	turned & polished		–	109	–	22.0	70	50.0	223[11]	–
Effect of Mass[10] OQ at 1550F and tempered at 1000F, 0.505 in. tensile specs.	1 in. diam. ctr.		–	183	–	16.0	166	48.0	375[11]	–
	2 in. diam. ½r		–	180	–	15.0	165	48.0	375[11]	–
	3 in. diam. ½r		–	175	–	14.0	155	46.0	365[11]	–
As Rolled[1]	1 in. diam. ctr		–	185	–	11.2	125.5	41.3	363	14
	2 in. diam. ½r		–	175	–	10.2	114	33.2	352	9.7
	4 in. diam. ½r		–	144.25	–	13.7	96.25	37.6	285	5.7
Annealed[2]	1 in. diam. ctr		–	108	–	22	68.5	49.9	217	37.7
Normalized 1600F air cooled	½ in.[3] diam. ctr		–	209.5	–	12.1	141	35.3	388	11.5
	1 in. diam. ctr		–	185.5	–	12.2	125	36.3	363	11.7
	2 in. diam. ½r		–	176.75	–	13.5	114.5	37.3	341	10.5
	4 in. diam. ½r		–	161	–	13.2	103	36	321	8
Normalized–Quenched–Tempered 1600F air cooled 1475F Oil Tower Quenched	½ in.[3] diam ctr		1000F	182	–	13.7	169	45	363	37.5
	1 in. diam ctr		1000F	175	–	14.2	166	45.9	352	39
	2 in. diam ½r		1000F	170	–	16	159.5	54.8	341	53
	4 in. diam ½r		1000F	164.75	–	15.5	145.25	53.4	331	46
	½ in.[3] diam ctr		1100F	165.75	–	17.1	162	57	331	55.5
	1 in. diam ctr		1100F	164.75	–	16.5	159	54.1	331	50.5
	2 in. diam ½r		1100F	147.25	–	19	139.25	60.5	293	75.5
	4 in. diam ½r		1100F	133.75	–	19.7	114.5	60.7	269	81.7
	½ in.[3] diam ctr		1200F	145	–	20	135.5	59.4	285	67.5
	1 in. diam ctr		1200F	139	–	20	128	59.7	277	72.7
	2 in. diam ½r		1200F	134.75	–	20.5	121	62.5	269	86.2
	4 in. diam ½r		1200F	124	–	21.7	105.75	63	255	91
Comparison Values[7] 4140[4] Bars, oil 4340[5] quenched	1 in. diam ctr		1000F	164	–	–	145	–	–	–
	4 in. diam ½r		1000F	166	–	–	142	–	–	–
4340[5] OQ	1 in. diam ctr		800F	212	200	12.5	–	–	–	47
	4 in. diam ½r		800F	197	178	9	–	–	–	37
1045[6] WQ	1 in. diam ctr		800F	140	103	14	–	–	–	45
	4 in. diam ½r		800F	106	76	13	–	–	–	43
Effect of Mass Interpreted from End-Quench Hardenability curve. Quenched in oil at 1550F, drawn as shown. Ryerson.	1 in. rd, ctr		1000F	188	–	13.9	169	44	379	NBT Ft Lbs
			1100F	174	–	15.5	154	47.3	352	
			1200F	156	–	17.4	135	51	316	–
	2 in. rd, ½r		1000F	188	–	13.9	169	44	379	–
			1100F	174	–	15.5	154	47.3	352	–
			1200F	156	–	17.4	135	51	316	–
	3 in. rd, ½r		1000F	186	–	14.1	167	45	375	–
			1100F	174	–	15.5	154	47.3	352	–
			1200F	156	–	17.4	135	51	316	–
	4 in. rd, ½r		1000F	186	–	14.1	167	45	375	–
			1100F	174	–	15.5	154	47.3	352	–
			1200F	154	–	18	132	51.4	311	–
Effect of Temp[10] 0.505 in. tensile specimens cut from center of 1 in rds. Oil Quenched from about 1600F.			800F	220	–	12.0	200	47.0	440[11]	–
			900	205	–	14.0	180	50.0	410[11]	–
			1000	185	–	15.0	160	53.0	380[11]	–
			1100	168	–	16.0	145	55.0	340[11]	–
			1200	150	–	19.0	130	57.0	310[11]	–
Notched Bar Impact Tests[8] 0.420 in. square bars, oil quenched & drawn to 277 BHN; tested as Charpy keyhole bars at temp shown		r.t.	–	–	–	–	–	–	–	48
		0F	–	–	–	–	–	–	–	47
		–50	–	–	–	–	–	–	–	45
		–100	–	–	–	–	–	–	–	43
		–150	–	–	–	–	–	–	–	41
		–200	–	–	–	–	–	–	–	38
		–300	–	–	–	–	–	–	–	25
Fine grained steel[9]	Normalized 1630F Charpy Vee Notch	75F	–	–	–	–	–	–	440	13
		0	–	–	–	–	–	–	440	7
		–40	–	–	–	–	–	–	440	6
		–100	–	–	–	–	–	–	440	5
	OQ 1525F, Drawn 1100F Charpy Vee Notch	75F	–	–	–	–	–	–	302	82
		0	–	–	–	–	–	–	302	82
		–40	–	–	–	–	–	–	302	82
		–100	–	–	–	–	–	–	302	77

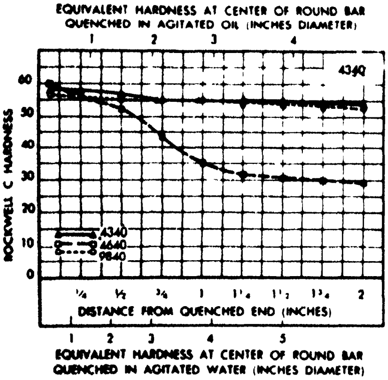
[1] Bethlehem Steel Co. Heat analysis. Ladle: .42%C, .72%Mn, .27%Si, 1.90%Ni, .79%Cr, .25%Mo. Check: .40%C, .68%Mn, .020%P, .013%S, .28%Si, 1.87%Ni, .74%Cr, .25%Mo. McQuaid-Ehn grain size 100% 7-8. Test specimens: 0.505 in. diam tensile and 0.450 in. diam Izod. All test results are average of two tests.
[2] Annealed Properties – Treatment: 1490F – F.C. 20F/hr. to 670F – A.C.
[3] .357 in. diam tensile.
[4] Analysis: .40%C, .95%Cr, .20%Mo.
[5] Analysis: .40%C, 1.85%Ni, .80%Cr, .25%Mo.
[6] .45%C
[7] International Nickel Co.
[8] H. W. Gillett and F. McGuire.
[9] H. W. Gillett Impact Resistance of Metals at Sub-Atmospheric Temperatures. ASTM, 1941.
[10] Bliss & Laughlin
[11] Surface of bar

(Continued on page 234)

4340

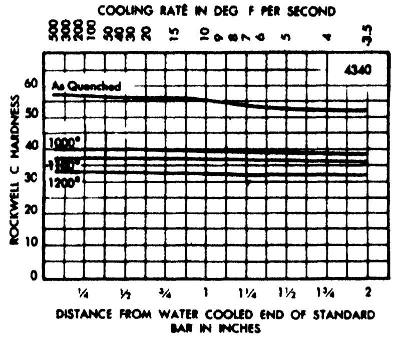
(Continued from page 233)

End-Quench Hardenability



Source – Bethlehem Steel Co. Single heat results. Analysis: .40C oil-hardening grades, (4340) .41%C, .67%Mn, .26%Si, 1.77%Ni, .76%Cr, .26%Mo. (4640) .40%C, .71%Mn, .24%Si, 1.83%Ni, .16%Cr, .28%Mo. (9840) .40%C, .90%Mn, .25%Si, 1.02%Ni, .84%Cr, .26%Mo. Grain size 6-8, carburized at 1700F.

End-Quench Hardenability



Source – Ryerson. Aver values. Grain size – 5-8.

4615

Chemical Composition[1]

C %	Mn %	P %	S %	Si %	Ni %	Mo %
.13-.18	.45-.65	.040 max	.040 max	.20-.35	1.65-2.00	.20-.30

[1] AISI

Critical Points

Ac_1	1340F
Ac_3	1525

Characteristics. This is a popular, high-grade carburizing steel for important parts where reliability and uniformity are required.

Uses. In the automotive industry it is used for differential pinions, differential pinion shafts, knuckle pins, piston pins, pump shafts and aircraft engine pins. In the oil industry it is used for rock bit cutters, pump parts to resist wear, sucker rods for corrosive wells. With a little higher nickel (2.00-2.25%) it is used as pins up to 0.318 in. diam for roller chains.

Rockwell "C" Core Hardness[1]

Treatment: Quenched in oil at 1700F

Size of Round	½ Radius	¼ Radius	Center
1 in.	29	23	21
2 in.	19	15	14
3 in.	14	12	11

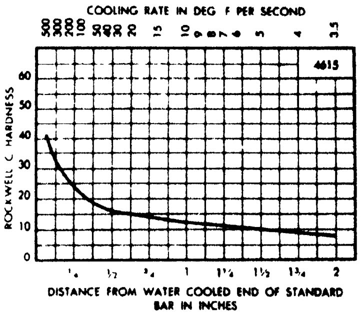
[1] Ryerson Aver values

Treatment Temperatures[1]

Forging	1950-2200F
Annealing	1575-1625
Normalizing	1675-1725
Carburizing	1650-1700
Quenching—high	1550
Quenching—low	1425

[1] Ryerson

End-Quench Hardenability



Source — Ryerson. Aver curve. Test conditions: Grain size = 5-8.

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hardness BHN	Hardness Rc Core	Rc Case	Brll Izod	Impact Resistance Ft Lbs Izod
Bars										
Hot rolled } Approx[1]	–	–	–	–	–	154-197	–	–	–	–
Cold drawn } Approx[1]	–	–	–	–	–	183-212	–	–	–	–
Aver. Prop[6] 1 in. rd Mean chemistry; Cold drawn, unannealed	–	87	79	18	56	183[7]	–	–	–	–
Cold drawn, annealed	–	81	60	24	60	163[7]	–	–	–	–
Turned and Polished, unannealed	–	79	54	31	63	163[7]	–	–	–	–
Turned and Polished, annealed	–	69	47	32	66	137[7]	–	–	–	–
Core Prop.[6] Pseudo-carburized at 1680F for 8 hrs. OQ Tempered at 300F 0.505 in. tensile specimens and 0.394 in. sq. Izod specimens; 1 in. rd. ctr.: Direct Quench	–	113	89	18	62	248[7]	–	–	228	74
Reheat and quench 1425F	–	120	93	18	46	262[7]	–	–	235	22
Reheat and quench 1475F	–	115	92	22	54	241[7]	–	–	228	46
Reheat and quench 1525F	–	115	94	24	62	248[7]	–	–	228	73
2 in. rd. ½r.: Direct Quench	–	92	77	21	74	212[7]	–	–	187	104
Reheat and quench 1425F	–	107	86	23	54	248[7]	–	–	207	37
Reheat and quench 1475F	–	101	84	25	65	235[7]	–	–	201	64
Reheat and quench 1525	–	103	86	25	72	235[7]	–	–	201	98
1 in. bars, carburized 8 hr at 1700F, drawn at 300F[2]; Direct OQ at 1700F	–	108	22	78	68	–	20	61	–	–
Box cooled Reheat OQ 1550F	–	108	23	78	68	–	20	62	–	–
Box cooled Reheat OQ 1425F	–	109	21	74	61	–	20	62	–	–
Box cooled Reheat OQ 1550 & 1425F, Double OQ	–	108	24	70	69	–	20	61	–	–
Low Temp Notched Bar Tests[3]; Normalized 1630F	75F	–	–	–	–	192	–	–	–	100[4]
	0	–	–	–	–	192	–	–	–	50
	-40	–	–	–	–	192	–	–	–	28
	-100	–	–	–	–	192	–	–	–	15
	-310	–	–	–	–	192	–	–	–	–
WQ 1525F, drawn 1100F	75	–	–	–	–	235	–	–	–	120
	0	–	–	–	–	235	–	–	–	–
	-40	–	–	–	–	235	–	–	–	120
	-100	–	–	–	–	235	–	–	–	120
	-310	–	–	–	–	235	–	–	–	8
Charpy bars carburized 4 hr at 1650F, WQ from 1425F drawn at 300F. Case depth 0.026 in. Test bars broken unnotched[5]	210	–	–	–	–	–	–	–	–	35
	70	–	–	–	–	–	–	–	–	23
	20	–	–	–	–	–	–	–	–	18
	-15	–	–	–	–	–	–	–	–	15
	-70	–	–	–	–	–	–	–	–	10

[1] Union Drawn Steel.
[2] Ryerson. Aver values. Grain size = 5-8. Case depth = 0.063 in.
[3] A. J. Herzig and R. M. Parke. Metals and Alloys, 1938, Vol. 9, p 90.
[4] Izod Vee notch.
[5] R. Sergeson. Trans ASST, 1932, Vol. 19, p 368.
[6] Bliss & Laughlin
[7] Surface of bar
[8] Surface of Izod test specimen

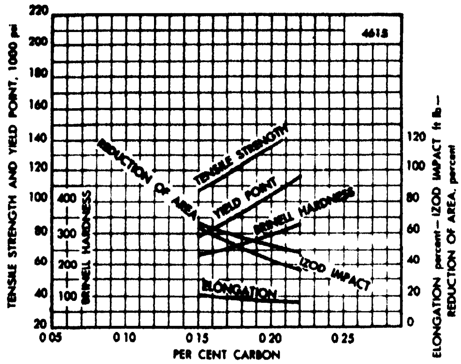
(Continued on page 236)

STEELS, AISI

4615

Source — International Nickel Co. representative properties. Test Conditions: 1 in. bars pseudo-carburized at 1650-1700F and heat treated as shown, tempered after treatment at 300F.

Direct Quench



(Continued from page 235)

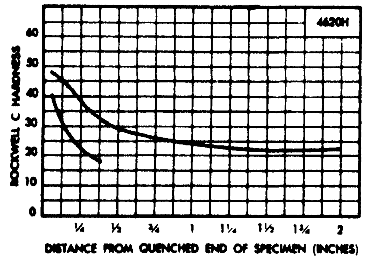
Core Properties of 4600 (.15-.22C)

Form or Condition			Tensile Strength M psi	Yield Point M psi	Elong %	Red Area %	Izod Ft Lb
Box cooled & reheated for hardening:							
Drawn at 300F	1425F, OQ	4615	110	75	20	61	48
		4620	135	90	15	46	26
	1475F, OQ	4615	110	75	22	66	66
		4620	135	95	17	52	44
	1525F, OQ	4615	110	80	24	69	76
		4620	140	103	19	56	54

STEELS, AISI

4620H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %	Mo %	P %	S %
.17-.24	.40-.70	.20-.35	1.50-2.00	.20-.30	—[1]	—[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

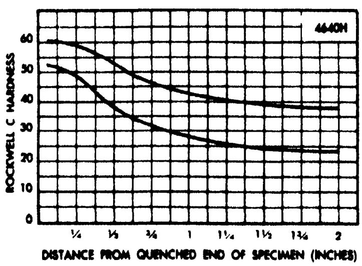
	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	48.0	45.5	43.0	39.0	35.5	33.0	31.0	29.5	28.0	27.5	26.5	26.0	25.5	25.0	24.5	24.0	23.5	23.0	22.5	22.5	22.0	22.0	22.0	22.0
Min	40.5	31.0	26.0	22.0	20.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[1]Note — These values are to be used when points are selected and specified.

STEELS, AISI

4640H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %	Mo %	P %	S %
.37-.45	.55-.85	.20-.35	1.50-2.00	.20-.30	—[1]	—[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	60.0	60.0	59.5	59.0	57.5	56.5	55.0	53.0	50.5	49.0	47.5	46.0	45.0	44.0	43.5	42.5	41.5	41.0	40.0	39.5	39.0	38.5	38.0	38.0
Min	52.5	51.5	50.5	49.0	46.0	43.0	40.0	37.5	35.0	33.5	32.0	31.0	29.5	29.0	28.0	27.5	26.5	25.5	25.0	25.0	24.5	24.0	24.0	24.0

Note.— These values are to be used when points are selected and specified.

4620

Chemical Composition[1]

C %	Mn %	P %	S %	Si %	Ni %	Mo %
.17-.22	.45-.65	.040 max	.040 max	.20-.35	1.65-2.00	.20-.30

[1] AISI

Characteristics. Very similar to 4615, though it develops greater core strength.

Uses. It is also used for spline shafts, differential and transmission gears and bearings. In aircraft engines it is used for cam shafts, bearings and gears.

Compressive Strength.[1] (Gears) The permissable compressive stress for intermittently loaded, case-hardened gears and bearings is 200 M psi. For constant mesh loading this value should be reduced by 20-25%. This assumes good practice and freedom from carbide network in the case.

[1] International Nickel Company.

Technological Properties

Machinability Rating (On basis of B1112 = 100)
As rolled = 55% (Industry value)

Critical Points

Ac_1	1325F	Ar_3	1325F
Ac_3	1480	Ar_1	1200

Treatment Temperatures

Forging	1950-2200F
Annealing	1550-1600
Normalizing	1650-1750
Carburizing	1650-1700
Quenching – high	1550
Quenching – low	1425

Rockwell "C" Core Hardness[1]

Treatment – Quenched in oil at 1700F

Size of Round	⅞ Radius	½ Radius	Center
1 in.	37	32	30.5
2 in.	27	21.5	20
3 in.	21	18	16

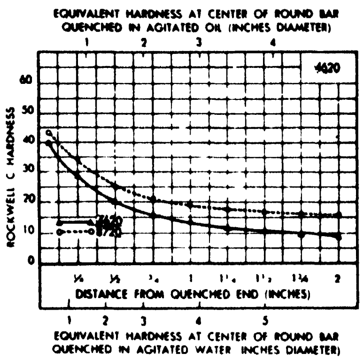
[1] Ryerson. Aver values.

As-Quenched Rockwell Hardness

Treatment – 1700F, 8 hrs, F.C.
1500F, Quenched in Agitated Oil
Size Tested – ½ in. discs cut from mid-length

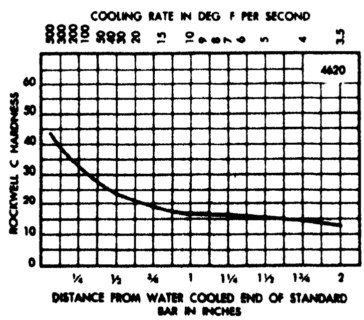
Diam	Center	Midway	Surface
½ in.	C31	C32	C40
1 in.	B97	B99	C27
2 in.	B91	B94	C24
4 in.	B88	B91	B96

End-Quench Hardenability



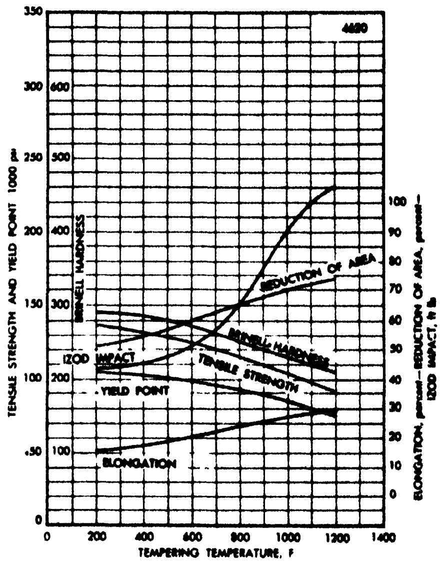
←— Source – Bethlehem Steel Co. Single heat results. Analysis: (4620) .17%C, .50%Mn, .26%Si, 1.86%Ni, .12%Cr, .28%Mo. (8720) .22%C, .90%Mn, .30%Si, .48%Ni, .52%Cr, .22%Mo. Carburized grain size at 1700F = 6-8.

End-Quench Hardenability



←— Source – Ryerson. Aver results. Grain size 5-8. Cooling rate in Deg F per second.

Quenched and Tempered Properties



Source – International Nickel Co. Aver values. Test conditions: 1 in. bars or sections quenched from 1550-1600F in oil, drawn as shown. Tested as 0.505 in. bars.

(Continued on page 238)

STEELS, AISI

4620

(Continued from page 237)

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	BHN	Hardness Izod BHN	Rc Case	Izod Ft Lbs
Aver. Prop.[12] Cold drawn unannealed	–	98	18	83	55	197[13]	–	–	–
1 in. rds. annealed	–	88	23	73	60	179[13]	–	–	–
Mean Turned and unannealed	–	90	30	58	60	179[13]	–	–	–
chemistry Polished annealed	–	75	32	47	63	152[13]	–	–	–
Core Properties[12] Direct quench 1 in.	–	136	18	104	53	321[13]	248[14]	–	45
Pseudo carburized reheat 1425F rd.	–	132	16	89	48	293[13]	269[14]	–	32
at 1680F for 8 quench 1475F ctr.	–	135	18	95	52	293[13]	262[14]	–	45
hrs, OQ tempered 1525F	–	138	19	102	54	302[13]	269[14]	–	53
at 300F, 0.505 Direct quench 2 in.	–	110	19	93	62	248[13]	229[14]	–	44
in. tensile specimens reheat 1425F rd.	–	115	21	96	54	255[13]	235[14]	–	57
and 0.394 in. sq. quench 1475F ½r	–	112	21	94	55	248[13]	241[14]	–	65
Izod specimens 1525F	–	108	22	91	57	241[13]	235[14]	–	83
Carburized 8 hrs. at 1700F. Single heat. Case .0625 quenched in agitated oil[1] Direct quench from pot	300F	145.5	16.2	130.75	53.1	–	302	59	43
Pot cooled 1500F	300F	126	17	106.5	61 7	–	262	62	75
reheat 1525 & 1475F, double OQ	300F	127.7	20 7	84 7	57 4	–	255	62	62
Direct quench from pot	450	139.75	15 5	123.75	54	–	285	57	48
Pot cooled 1500F	450	124.5	18 5	106	60 7	–	255	58	76
reheat 1525 & 1475F, double OQ	450	123.5	22 2	82 7	61 4	–	248	58	71
Heated 8 hrs at 1700F, treated as shown. Tested 0.505 in. bars Approx[2] Direct OQ from box, 1 in. rd.	300	140	15	112	52	–	293[3]	–	–
1425F, OQ, 1 in. rd.	300	128	16	100	54	–	277[3]	–	–
1475F, OQ, 1 in. rd.	300	132	16 5	105	55	–	277[3]	–	–
1525F, OQ, 1 in. rd.	300	137	17.5	109	55	–	285[3]	–	–
Direct OQ from box, .515 in. rd.	300	147	16	122	50	–	311[4]	–	–
1425F, OQ, .515 in. rd.	300	132	14	107	48	–	277[4]	–	–
1475F, OQ, .515 in. rd.	300	139	16 5	114	52	–	293[4]	–	–
1525F, OQ, .515 in. rd.	300	145	17	117	55	–	302[4]	–	–
1 in. bars carburized 8 hrs. at 1700F[5] Grain size 5-8 Direct OQ at 1700F	300	133	18	110	52	–	–	28[15], 62[9]	–
Box cooled 1550F	300	140	19	101	53	–	–	29.5[15], 64[9]	–
Reheat 1425F	300	134	16	91	47	–	–	28[15], 64[9]	–
OQ 1550 & 1425F double OQ	300	136	20	90	51	–	–	28[15], 63[9]	–
Core[6]: carburized 1700F 8 hrs, quenched in agitated oil. Specimen size 0.565 in. diam. tensile, 0.510 in. Izod. Direct quench from pot	300	148.25	17	116 5	55.7	–	311	60.5[7]	46.5
Direct quench from pot	450	147.5	16.8	115.75	57.9	–	302	58 5[8]	42.5
Pot cooled reheat 1500F	300	119.25	19.5	83.5	59.4	–	277	62.5[7]	52
Pot cooled reheat 1500F	450	115.5	20.5	80.75	63 6	–	248	59 0[9]	69
Pot cooled reheat 1525 & 1475F double OQ	300	122	22	77.25	55.7	–	248	62 0[8]	64
Pot cooled reheat 1525 & 1475F double OQ	450	115.25	22.5	77	62 1	–	235	59 0[8]	78.3
Effect of Mass[6] Single heat									
As rolled 1 in. diam. ctr.	–	86	28 3	54	63.7	–	170	–	82.5
2 in. diam. ½r	–	83.25	26 3	53.625	63.2	–	167	–	75
4 in. diam. ½r	–	75	25.3	53.5	54.8	–	149	–	14.5
Annealed[10] 1 in. diam. ctr[6]	–	74 25	31 3	54	60.3	–	149	–	69
Normalized[6] 1650F, air cooled ½ in. diam.[11] ctr.	–	87.25	30.7	54.75	68	–	192	–	92.3
1 in. diam. ctr.	–	83.25	29	53.125	66.7	–	174	–	98
2 in. diam. ½r	–	80 5	29 5	53	67.1	–	167	–	99.3
4 in. diam. ½r	–	77	30 5	51.75	65.2	–	163	–	91.8
Mock carburized, quenched and tempered 1700F, 8 hrs, furnace cooled, reheat 1500F, quenched in agitated oil ½ in. diam.[11] ctr.	300	127	20	89.5	59.8	–	255	–	43.3
1 in. diam. ctr.	300	98	25.8	67	70	–	197	–	98
2 in. diam. ½r	300	96.5	27	65.25	69.7	–	192	–	101.8
4 in. diam. ½r	300	84.75	29.5	52.5	69.2	–	170	–	100.5
½ in. diam.[11] ctr.	450	117.5	21.4	81	65.3	–	241	–	73.8
1 in. diam. ctr.	450	98	27 5	66.25	68.9	–	192	–	94.8
2 in. diam. ½r	450	95 75	26 8	62	69.2	–	187	–	100.5
4 in. diam. ½r	450	84.5	29.8	52.75	70.3	–	170	–	103.8

[1] Bethlehem Steel Co. Composition .17%C, .50%Mn, .031%P, .021%S, .26%Si, 1.86%Ni, .12%Cr, .28%Mo. Grain size = 6-8. Normalized at 1650F, air cooled = 187BHN. Annealed at 1575F, furnace cooled = 174BHN.
[2] Republic Steel Corp.
[3] At ¾ radius.
[4] On surface
[5] Ryerson. Aver results.
[6] Bethlehem Steel Co. Composition – Ladle .19%C, .53%Mn, .25%Si, 1.81%Ni, .09%Cr, .24%Mo. Check .17%C, .52%Mn, .017%P, .016%S, .26%Si, 1.81%Ni, .10%Cr, .21%Mo. McQuaid-Ehn grain size 100% = 6-8. All test results are the average of two tests. Size tested 0.505 in. diam tensile and 0.450 in. diam Izod specimens.
[7] Case depth = 0.075 in.
[8] Case depth = 0.060 in.
[9] Case depth = 0.065 in.
[10] 1575F F.C. 30F/hr to 900F A.C.
[11] 0.357 in. diam tensile on ½ in. diam stock.
[12] Bliss & Laughlin.
[13] Surface of bar.
[14] Surface of Izod test specimen.
[15] Rc – core.

4640

Chemical Composition[1]

C %	Mn %	P %	S %	Si %	Ni %	Mo %
.38-.43	.60-.80	.040 max	.040 max	.20-.35	1.65-2.00	.20-.30

[1]AISI

Critical Points

Ac_1	1350F	Ar_3	1250F
Ac_3	1400	Ar_1	1100

Treatment Temperatures[1]

Forging	2000-2250F
Annealing	1450-1550
Normalizing	1600-1750
Quenching	1450-1550

[1]Approx industry values.

Characteristics. With good mechanical properties in small and medium sizes, this steel has excellent machinability at high hardness levels and small distortion in heat treatment.

Uses. Gears which may be surface hardened in a cyanide bath, spline shafts, hand tools, and machine parts. The higher carbon, 4650, is used for railroad roller bearings and, as oil quenched and drawn to 440 BHN, as springs.

Mechanical Properties

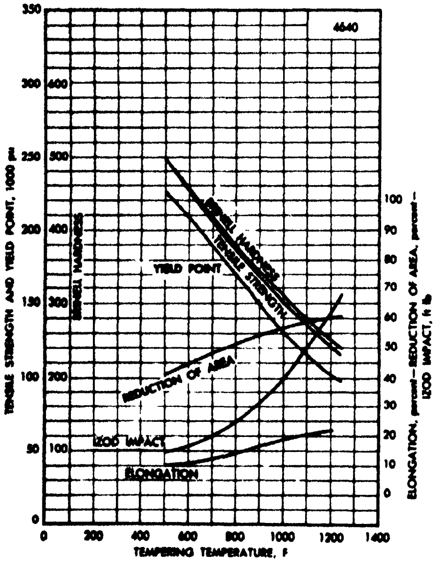
Form or Condition	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	NBT Ft Lbs	Izod Ft Lbs
Aver. Prop.[6] Annealed, 1 in. rd. Mean chemistry: cold drawn	–	117	15	95	43	235[7]	–	–
turned & polished	–	98	16	85	40	201[7]	–	–
Effect of Mass[6] OQ at 1550F and tempered at 1000F, 0 505 in. tensile specimen: 1 in. diam. ctr.	–	154	18	138	57	321[7]	–	–
2 in. diam. ½r	–	136	19	115	56	302[7]	–	–
3 in. diam. ½r	–	126	20	102	55	285[7]	–	–
Effect of Temp.[6] Oil quenched at 1550F and tempered as shown 0 505 in tensile specimens cut from center of 1 in. rds.	800F	192	13	169	51	401[7]	–	–
	900	174	16	153	54	375[7]	–	–
	1000	154	18	138	57	321[7]	–	–
	1100	139	20	123	58	302[7]	–	–
	1200	124	21	109	60	269[7]	–	–
Effect of Mass[1] Single heat								
As Rolled: 1 in. diam, ctr.	–	128.75	18	85	45.1	255	–	29.5
2 in. diam, ½r.	–	119.25	17	80.5	47.6	241	–	18.5
3 in. diam, ½r.	–	112.5	16.7	75.25	41	223	–	6
Annealed[2] 1 in. diam, ctr.	–	98	23.7	62.5	50.5	179	–	22.7
Normalized 1600F, air cooled: ½ in. diam[3] ctr.	–	130.5	17.4	88	44.3	262	–	31.6
1 in. diam, ctr.	–	123	18.7	87.25	50.7	248	–	31
2 in. diam, ½r.	–	120.5	17.7	84	49.9	241	–	22.5
4 in. diam, ½r.	–	118	18.5	79.5	46.9	235	–	18.5
Normalized, quenched and tempered· 1600F, air cooled. 1475F, oil tower quenched: ½ in. diam[3] ctr.	1000	161	17.1	147	55.7	321	–	46.7
1 in. diam, ctr.	1000	154.75	17	145.25	56.3	321	–	54.2
2 in. diam, ½r.	1000	132.25	19.2	105	58.2	269	–	64
4 in. diam, ½r.	1000	127.75	20.2	97.25	56.2	248	–	64
½ in. diam[3] ctr.	1100	148	19.2	142.5	55.5	293	–	66.7
1 in. diam, ctr.	1100	144.75	18	133	59.2	285	–	66
2 in. diam, ½r.	1100	119	22.2	94.25	63.2	235	–	81.5
4 in. diam, ½r.	1100	112.25	23.2	88.25	62.6	229	–	81.5
½ in. diam[3] ctr.	1200	129	21.7	114.5	60.6	262	–	71.7
1 in. diam, ctr.	1200	121.75	21.5	110	60.3	248	–	75.5
2 in. diam, ½r.	1200	114.75	23.2	94	65.2	229	–	88.2
4 in. diam, ½r.	1200	106	24.7	84	64.4	217	–	86.2
Effect of Mass. Interpreted from End Quench curve. Quenched in oil at 1500F and drawn as shown.[4] 1 in. rd, ctr.	1000	168	16.1	148	48.5	341	–	–
	1100	154	18.0	132	51.4	311	–	–
	1200	138	19.7	114	54.6	277	–	–
2 in. rd, ½r.	1000	159	17.2	137	50.5	321	–	–
	1100	145	18.7	123	53.0	293	–	–
	1200	131	20.4	107	56.0	269	–	–
3 in. rd, ½r.	1000	149	18.4	127	52.3	302	–	–
	1100	130	20.6	106	56.3	262	–	–
	1200	124	21.3	99	57.5	248	–	–
4 in. rd, ½r.	1000	131	20.4	107	56.0	269	–	–
	1100	120	21.8	94	58.2	241	–	–
	1200	114	22.4	88	59.3	229	–	–
Low Temp Notched Bar Tests[5]	Test Temp							
Charpy Vee Notch. Normalized 1700F	75	–	–	–	–	235	26	–
	0	–	–	–	–	235	14	–
	-40	–	–	–	–	235	10	–
	-100	–	–	–	–	235	6	–
	-310	–	–	–	–	235	–	–
Oil Quenched 1525F, drawn 1240F	75	–	–	–	–	217	110	–
	0	–	–	–	–	217	–	–
	-40	–	–	–	–	217	106	–
	-100	–	–	–	–	217	78	–
	-310	–	–	–	–	217	11	–

[1]Bethlehem Steel Co. Composition – Ladle: .42%C, .68%Mn, .33%Si, 1.89%Ni, .10%Cr, .25%Mo. Check· .39%C, .68%Mn, .019%P, .012%S, .31%Si, 1.87%Ni, .08%Cr, .24%Mo. McQuaid-Ehn grain size 100% = 7-8. All test results are the average of two tests. Size Tested· 0.505 in. diam tensile and 0.450 in. diam Izod specimens.
[2]1475F, Furnace Cooled. 20F/hr to 825F, Air Cooled.
[3]0.357 in. diam tensile.
[4]Ryerson
[5]A. J. Herzig and R. M. Parke. Metals and Alloys, 1938, Vol 9, p 90. Fine grained steel.
[6]Bliss & Laughlin
[7]Surface of bar

(Continued on page 240)

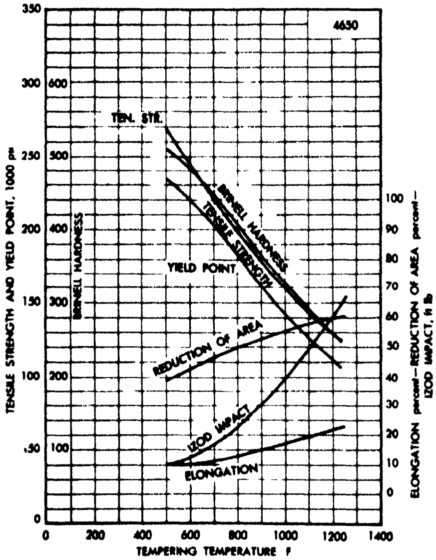
(Continued from page 239)

Quenched and Tempered Properties

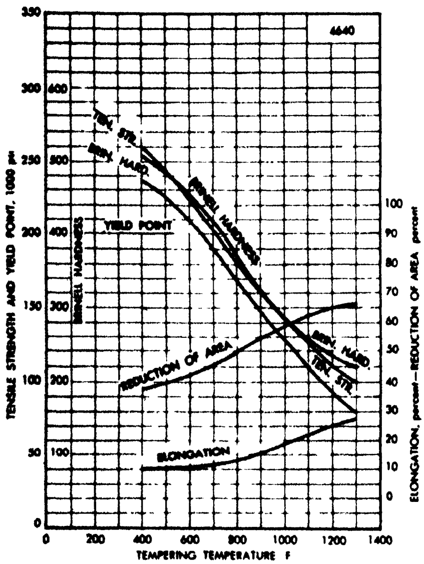


Source – International Nickel Co. Aver values. Test conditions: 1 in. bars or sections quenched in oil from 1475-1525F and drawn as shown. Tested as 0.505 in. bars. Steel 4650, shown for comparison, was quenched in oil from 1450-1500F.

Quenched and Tempered Properties



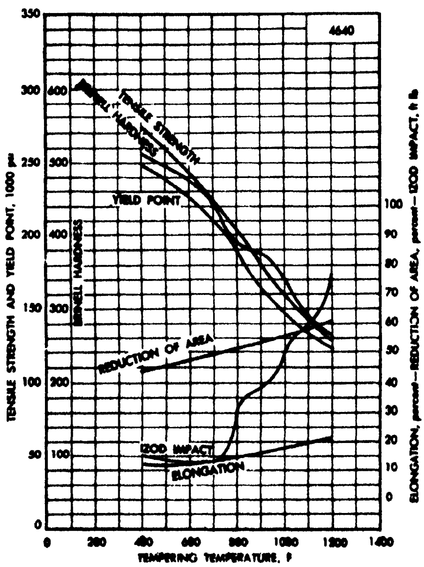
Quenched and Tempered Properties



←Source – Republic Steel Corp. Approx values. Test conditions: 1 in. rds normalized at 1600F, quenched in oil from 1500F, drawn 1 hr as shown. Tested as 0.505 in. bars. Maximum section for which these properties can be expected is 1.1 in. Maximum hardness: Annealed – 197 BHN Normalized – 225 BHN.

Source: Bethlehem Steel Co. Single heat tests. Composition: .41%C, .70%Mn, .016%P, .013%S, .24%Si, 1.83%Ni, .16%Cr, .28%Mo. Grain Size: 6 - 8. Test Conditions: 0.530 in. rds normalized at 1600F, quenched in agitated oil from 1475F, drawn as shown. Tested as 0.505 in. bars.→

Quenched and Tempered



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(Continued from page 240)

As Quenched Rockwell "C" Hardness

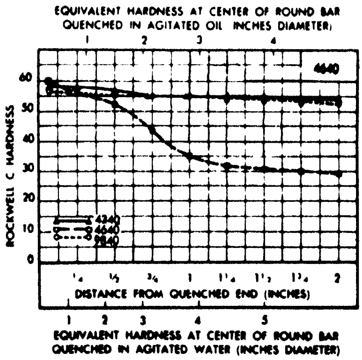
Treatment: 1600F A.C. 1475F Oil Tower Quenched
Size Tested: 1 in. discs cut from mid-length

Diam	Center	Midway	Surface
½ in.	56	57	57
1 in.	47	54	54
2 in.	32	34	39
4 in.	26	28	30

Technological Properties

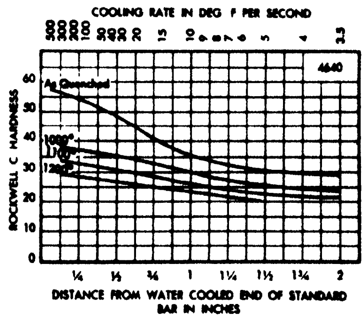
Machinability Rating (On basis B1112 = 100) Mill annealed to 187-235 BHN = 55% (ASM, Metals Handbook)

End-Quench Hardenability



Source – Bethlehem Steel Co. Single heat results. Analysis: .40C oil-hardening grades, (4340) .41%C, .67%Mn, .26%Si, 1.77%Ni, .76%Cr, .26%Mo. (4640) .40%C, .71%Mn, .24%Si, 1.83%Ni, .16%Cr, .28%Mo. (9840) .40%C, .90%Mn, .25%Si, 1.02%Ni, .84%Cr, .26%Mo. Grain size 6-8, carburized at 1700F.

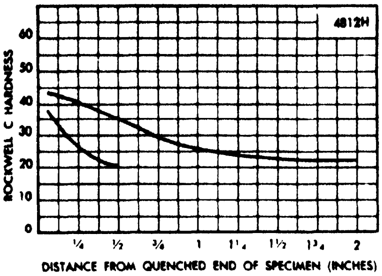
End-Quench Hardenability



Source – Ryerson. Aver results. Grain size = 5-8.

STEELS, AISI
4812H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %	Mo %	P %	S %
.10-.17	.30-.60	.20-.35	3.20-3.80	.20-.30	—[1]	—[1]

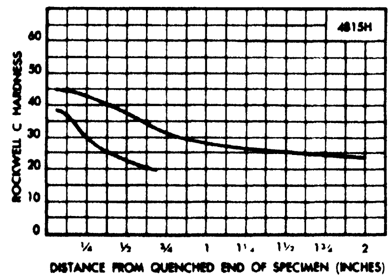
[1]The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	43.5	43.0	42.0	41.0	39.5	38.0	37.0	35.0	33.5	32.0	30.5	29.0	28.0	27.0	26.0	25.5	24.5	24.0	23.5	23.0	23.0	22.5	22.5	22.5
Min	37.0	33.0	29.5	26.5	24.5	22.5	21.0	20.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[1]Note — These values are to be used when points are selected and specified.

STEELS, AISI
4815H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %	Mo %	P %	S %
.12-.19	.35-.65	.20-.35	3.20-3.80	.20-.30	—[1]	—[1]

[1]The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	45.0	44.5	44.0	43.0	41.5	40.0	38.5	37.5	36.0	34.5	33.0	31.0	30.0	29.0	28.5	28.0	27.0	26.5	25.5	25.5	25.0	25.0	24.5	24.0
Min	38.0	37.0	34.0	30.0	27.0	25.5	24.0	22.5	21.0	20.5	20.0	—	—	—	—	—	—	—	—	—	—	—	—	—

[1]Note — These values are to be used when points are selected and specified.

4815

Chemical Composition[1]						
C %	Mn %	Si %	Ni %	Mo %	P %	S %
.13-.18	.40-.60	.20-.35	3.25-3.75	.20-.30	.040 max	.040 max

[1] AISI.

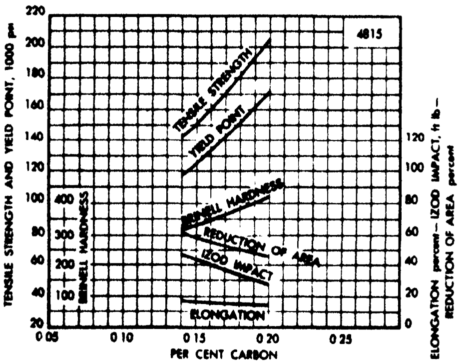
Characteristics. A case hardening steel.

Uses. Differential drive pinions, rock bit cutters, pump parts to resist wear and spline shafts. It is also used as sucker rods for corrosive wells.

Technological Properties

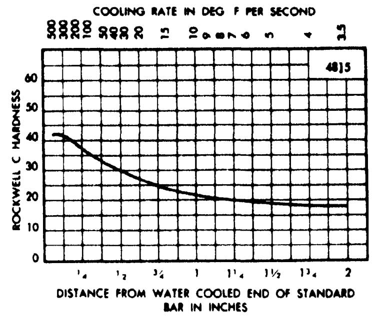
Machinability Rating (On basis of B1112 = 100): Cold drawn to 187-229 = 50%. (ASM, Metals Handbook.)

Direct Quench



Source – International Nickel Co. Representative values. 1 in. bars, pseudo-carburized at 1650-1700F, direct quenched into oil and drawn at 300F.

End-Quench Hardenability



Source – Ryerson. Aver values for fine grained steel.

Core Properties of 4815

	Reheat Temp	Tensile Strength M psi	Yield Point M psi	Elong %	Red Area %	Izod Ft Lb
Box Cooled, Reheated	1425F	145	125	17	60	44
for hardening (0.15% C)	1475F	148	125	19	60	46
OQ, drawn at 300F	1525F	149	125	18	59	44

Critical Points

Ac_1	1300F	Ar_3	–
Ac_3	1425	Ar_1	800

Treatment Temperatures[1]

Forging	1950-2200F
Annealing	1500-1575
Normalizing	1600-1700
Carburizing	1700
Quenching - high	1525
- low	1425

[1] Average industry values.

Rockwell "C" Core Hardness
Quenched in oil at 1700F

Size of Round	7/8 Radius	1/2 Radius	Center
1 in. rd.	39	36	35
2 in. rd.	32	28	26.5
3 in. rd.	27.5	23	21

Mechanical Properties

Form or Condition		Tensile Strength M psi	Elong 2" %	Yield Point M psi	Red Area %	BHN	Hardness Rockwell C Case	Hardness Rockwell C Core
Bars:[1] Annealed } approx 1 in. rds.		–	–	–	–	192	–	–
Bars:[1] Normalized } approx 1 in. rds.		–	–	–	–	235	–	–
Round Bars[1] Heated 8 hrs in iron chips at 1700F, box cooled, heat treated as shown, drawn at 300F. Tested as 0.505 in. bars. Approx	Direct OQ from box, 1 in. rds	159	16	133	50	331[4]	–	–
	OQ 1425F, 1 in. rds	149	15	124	55	311[4]	–	–
	1475F, 1 in. rds	153	14.5	129	56	321[4]	–	–
	1525F, 1 in. rds	156	15	132	55	331[4]	–	–
	Direct OQ from box, .515 in. rds	170	14.5	155	50	352[3]	–	–
	OQ 1425F, .515 in. rds	162	15	138	55	331[3]	–	–
	1475F, .515 in. rds	168	15.5	144	56	352[3]	–	–
	1525F, .515 in. rds	169	15.5	146	56	352[3]	–	–
Carburized 8 hr at 1700F, drawn at 300F. Eff. Case depth 0.041 in.[2]	OQ from 1700F, 1 in. bars	155	18	126	58	–	62	33
	Cooled in box, Reheat 1525F, OQ, 1 in. bars	149	18	125	58	–	63	32
	Cooled in box, 1425F, OQ, 1 in. bars	148	17	125	60	–	62	32
	Cooled in box, Double OQ 1525 & 1425F, 1 in. bars	148	19	120	61	–	63	32

[1] Republic Steel Corp.
[2] Ryerson. Aver values for fine grained steel.
[3] On Surface
[4] At ¼r.

4820

Chemical Composition[1]

C %	Mn %	Si %	Ni %	Mo %	P %	S %
.18-.23	.50-.70	.20-.35	3.25-3.75	.20-.30	.040 max	.040 max

[1]AISI.

Characteristics. Similar to 4815[1] but capable of developing greater strength.

[1]A case hardening steel.

Technological Properties

Machinability Rating (On basis of B1112 = 100)	Relative machinability, annealed = 45%.

Compressive Strength[1]

Permissible compressive stress for case hardened gears, bearings, and races is 215,000 psi for intermittent loading. For constant mesh loading this value should be reduced 20 to 25%. This assumes good practice and freedom from carbide network in the case.

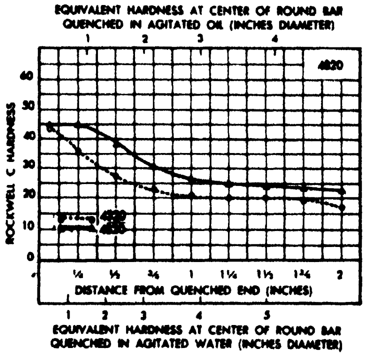
[1]International Nickel Co.

Critical Points

Ac_1	1300F
Ac_3	1430
Ar_3	1260
Ar_1	760

[1]International Nickel Co.

End-Quench Hardenability



Source – Bethlehem Steel Co. Single heat results. Analysis: .20C, carburizing grades (4320) .17%C, .55%Mn, .25%Si, 1.75%Ni, .47%Cr, .25%Mo. (4820) .21%C, .51%Mn, .21%Si, 3.49%Ni, .18%Cr, .24%Mo. Grain size 6-8, carburized at 1700F.

As Quenched Rockwell "C" Hardness

Treatment. 1700F - 8 hrs - F.C.
1475F - Quenched in Agitated Oil
Size Tested: ½ in. discs cut from mid-length

	Center	Midway	Surface
½ in. diam	44	45	45
1 in. diam	37	39	43
2 in. diam	27	31	36
4 in. diam	24	24	27

Rockwell "C" Core Hardness

Quenched in Oil at 1700F
(Source - Ryerson. Average values)

Size of Round	7/8 Radius	½ Radius	Center
1 in. rd	43	40.5	39
2 in. rd	36	32	29
3 in. rd	31	26	23

Treatment Temperatures[1]

Forging	1950-2200F
Annealing	1475-1525
Normalizing	1575-1650

[1]Industry values.

Mechanical Properties

Form or Condition			Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	BHN	Hardness Rockwell C Case	Hardness Rockwell C Core	Izod Ft Lbs
Bars: Case hardened carburized 8 hrs at 1700F, drawn at 300F Eff case depth 0.045 in.[1]	OQ from 1700F	1 in.	–	200	13	171	47	–	63	41	–
	Cooled in box, Reheat 1525F, OQ	1 in.	–	194	13	165	47	–	64	40	–
	Cooled in box, Reheat 1425F, OQ	1 in.	–	193	14	161	49	–	63	40	–
	Cooled in box, Double OQ 1525 & 1425F	1 in.	–	194	15	160	50	–	64	40	–
Normalized at 1580F			–	–	–	–	–	229	–	–	–
Annealed at 1500F			–	–	–	–	–	197	–	–	–
Single heat tests: Carburized 8 hrs at 1700F Quenched in agitated oil, tested 0.505 in.[2]	Direct Quench from Pot	0.565 in.	300F	205	13.3	165.5	53.3	415	60[4]	–	33
	Pot Cooled, Reheat 1475F	0.565 in.	300F	207.5	13.8	167	52.2	415	61[3]	–	44
	Pot Cooled, Double quench 1500 & 1450F	0.565 in.	300F	204.5	13.8	165.5	52.4	415	60[3]	–	31
	Direct Quench from Pot	0.565 in.	450F	200.5	12.8	170	53	401	56[4]	–	30
	Pot Cooled, Reheat 1475F	0.565 in.	450F	205	13	184.5	53.3	415	57.5[3]	–	47
	Pot Cooled, Double quench 1500 & 1450F	0.565 in.	450F	196.5	13	171.5	53.4	401	56.5[3]	–	29
Effect of Mass[5]											
As Rolled: tested: 0.505 in. diam tensile, 0.450 in. Izod specimens		1 in. diam ctr	–	109.5	22.5	73.25	51.7	223	–	–	46.8
		2 in. diam ½r.	–	104.75	22.5	73.25	61	212	–	–	48
		4 in. diam ½r.	–	98.75	21.3	67.5	52.7	201	–	–	30
Annealed[6]		1 in. diam ctr.	–	98.75	22.3	67.25	58.8	197	–	–	68.5
Normalized 1580F air cooled		½ in.[7] diam ctr.	–	112.5	26	72.5	57.8	235	–	–	73
		1 in. diam ctr.	–	109.5	24	70.25	59.2	229	–	–	81
		2 in. diam ½r.	–	107.25	23	69	59.8	223	–	–	81.8
		4 in. diam ½r.	–	103.5	22	68	58.4	212	–	–	79
Mock carburized quenched & tempered 1700F - 8 hrs - F.C. - 1475F quenched in Agitated oil 0.505 in diam tensile and 0.450 in. diam. Izod spec.		½ in.[7] diam ctr.	300F	209	14.2	172.75	54.3	401	–	–	35.3
		1 in. diam ctr.	300F	169.5	15	126.5	51	352	–	–	30.3
		2 in. diam ½r.	300F	135.5	19.8	93.25	56.3	277	–	–	51
		4 in. diam ½r.	300F	118.75	23	81	59.4	241	–	–	72.3
		½ in.[7] diam ctr.	450F	205	13.2	170	52.3	388	–	–	32
		1 in. diam ctr.	450F	163.25	15.5	120.5	53.1	331	–	–	32.3
		2 in. diam ½r.	450F	130	19	92.5	62.7	269	–	–	74.3
		4 in. diam ½r.	450F	117	21	80	63.8	235	–	–	81.5

[1]Ryerson. Average values for fine grained steel. (Also see 4815 for core properties of 4820.)
[2]Bethlehem Steel Co. Composition: C .21%; Mn .51%; P .021%; S .018%; Si .21%; Ni 3.50%. Cr .18%; Mo .24%.
[3].047 in. case
[4].039 in. case
[5]Effect of Mass. Source - Bethlehem Steel Co. Single heat tests. Composition. Ladle: C .20%; Mn .61%; P .021%; S .022%; Si .27%; Ni 3.60%, Cr .11%; Mo .24%. Check: C .20%; Mn .61%; P .027%; S .016%; Si .29%; Ni 3.47%; Cr .07; Mo .22%. McQuaid-Ehn grain size = 100% 6-8.
[6]1500F F.C. 30F/hr to 500F A.C.
[7]0.357 in. diam.

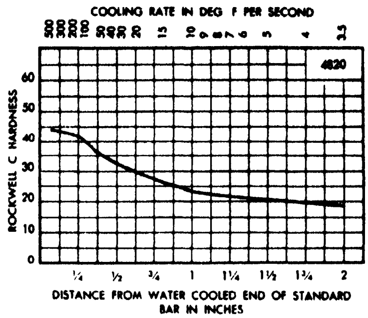
(Continued on page 246)

STEELS, AISI

4820

(Continued from page 245)

End-Quench Hardenability



Source – Ryerson. Fine grained steel.

STEELS, AISI

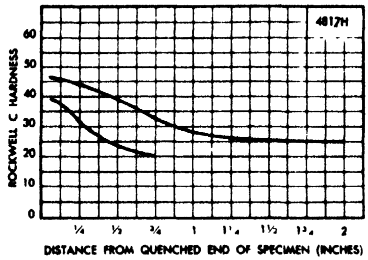
4817H

Chemical Composition

C %	Mn %	Si %	Ni %	Mo %	P %	S %
.14-.21	.35-.65	.20-.35	3.20-3.80	.20-.30	–[1]	–[1]

[1]The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

End-Quench Hardenability Band



	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	46.0	45.5	45.0	44.0	43.0	42.0	40.5	39.0	37.5	35.5	34.0	32.5	31.0	30.0	29.5	29.0	28.0	27.0	26.5	26.0	25.5	25.5	25.0	25.0
Min	39.0	38.0	35.5	32.0	29.0	27.0	25.0	23.5	22.5	21.5	20.5	20.0	—	—	—	—	—	—	—	—	—	—	—	—

[1]These values are to be used when points are selected and specified.

STEELS, AISI

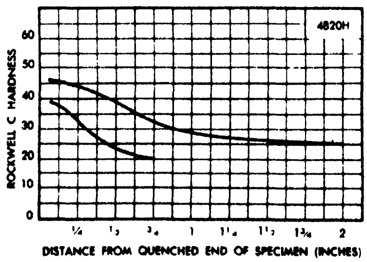
4820H

Chemical Composition

C %	Mn %	Si %	Ni %	Mo %	P %	S %
.17-.24	.45-.75	.20-.35	3.20-3.80	.20-.30	–[1]	–[1]

[1]The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

End-Quench Hardenability Band



	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	48.0	47.5	47.0	46.0	45.0	43.5	42.5	41.0	39.0	37.5	36.0	34.5	33.5	32.5	31.5	31.0	30.0	29.0	28.5	28.0	27.5	27.0	27.0	26.5
Min	40.5	39.5	37.5	35.0	32.0	30.0	28.0	26.5	25.5	24.5	23.5	23.0	22.0	21.5	21.0	20.5	20.0	—	—	—	—	—	—	—

[1]These values are to be used when points are selected and specified.

5120

Chemical Composition[1]

C %	Mn %	P %	S %	Si %	Cr %
.17-.22	.70-.90	.040 max	.040 max	.20-.35	.70-.90

[1] AISI

Critical Points

Ac_1	1410F	Ar_3	–
Ac_3	1530	Ar_1	1290

Characteristics. A relatively cheap, medium-hardening steel, especially when pot quenched.

Treatment Temperatures[1]

Forging	2250F max
Annealing	1600
Normalizing	1650-1750
Carburizing	1700

[1] Republic Steel Corp.

Technological Properties

Machinability Rating (On basis B1112 = 100): Cold drawn to 170-212 BHN = 65%. (ASM Metals Handbook.)

Mechanical Properties

Form or Condition				Test Temp	Tensile Strength M psi	Yield Point M psi	Elong 2 in. %	Red Area %	Hard BHN	BHN Izod	Impact Resistance Ft Lbs Izod
Bars:	Hot rolled[1]			–	–	–	–	–	140-170	–	–
	Cold drawn[1]			–	–	–	–	–	170-196	–	–
	Normalized[2]			–	–	–	–	–	202	–	–
Aver. Prop.[6] 1 in. rds. Mean chemistry	Cold drawn	unannealed		–	92	77	20.0	55.0	187[7]	–	–
		annealed		–	87	70	23.0	60.0	179[7]	–	–
	Turned and Polished	unannealed		–	76	60	24.0	63.0	156[7]	–	–
		annealed		–	70	42	29.0	68.0	141[7]	–	–
Core Properties[6] Pseudo-carburized at 1680F for 8 hrs. at temperature and water quenched tempered at 300F, 0.505 in. tensile specimens and 0.394 in. sq.	Direct Quench 1680F		1 in. rd. ctr.	–	130	103	20.0	45.0	321[7]	269[8]	27.0
	Pot Cool Reheat	1425F		–	116	77	16 0	27.0	241[7]	229[8]	8.0
		1475		–	122	83	18 0	29.0	269[7]	248[8]	9.0
		1525		–	124	90	20.0	41.0	331[7]	255[8]	15.0
	Direct Quench		2 in. rd. ½r	–	95	74	27.0	65.0	277[7]	192[8]	86.0
	Pot Cool Reheat	1425F		–	90	57	24.0	42.0	255[7]	163[8]	24.0
		1475		–	89	57	26.0	46.0	277[7]	167[8]	30.0
		1525		–	88	65	29.0	63.0	302[7]	179[8]	24.0
Core Prop:[2] Bars heated 8 hr in iron chips at 1700F heat treated as shown Tested as 0.505 in. Drawn 300F											NBT Ft Lbs
	Direct OQ from box		1 in. rd.	–	143	114	13.5	45	302[3]	–	–
	1425F OQ			–	121	92	14	41	260[3]	–	–
	1475F OQ			–	128	101	15	42	269[3]	–	–
	1550F OQ			–	136	110	16	45	285[3]	–	–
	Direct OQ from box		.515 in. rd	–	148	123	14	40	311[4]	–	–
	1425F OQ			–	123	94	14.5	40	269[4]	–	–
	1475F OQ			–	132	104	15	43	277[4]	–	–
	1550F OQ			–	142	114	16	50	293[4]	–	–
Low Temp Notched Bar Tests Normalized[5] 1600F				75F	–	–	–	–	149	–	103
				0	–	–	–	–	149	–	77
				-40	–	–	–	–	149	–	59
				-80	–	–	–	–	149	–	9

[1] Union Drawn Steel. Approx
[2] Republic Steel Corp. Approx
[3] At ¼r.
[4] On surface
[5] Source - H.W. Gillett. "Impact Resistance and Tensile Properties of Metals at Sub-atmospheric Temperatures." Fine grained steel. Composition - .15C, .67Mn, .83Cr, Charpy Vee-notch.
[6] Bliss & Laughlin
[7] Surface of bar
[8] Surface of Izod test specimen

STEELS, AISI

5130

Chemical Composition[1]					
C %	Mn %	P %	S %	Si %	Cr %
.28-.33	.70-.90	.040 max	.040 max	.20-.35	.80-1.10

[1]AISI

Treatment Temperatures[1]	
Forging	2250F max
Annealing	1550-1700
Normalizing	1600-1725
Quenching	1525

[1]Republic Steel Corp. Approx values.

Critical Points			
Ac_1	1370F	Ar_3	—
Ac_3	1490	Ar_1	1290

Characteristics. A relatively inexpensive alloy steel of intermediate hardenability for water hardening.

Technological Properties

Machinability Rating (On basis of B1112 = 100)	As rolled = 51%. Annealed for machining = 67%.

Mechanical Properties

Form or Condition		Draw Temp	Tensile Strength M psi	Yield Point M psi	Elong 2 in. %	Red Area %	Hard BHN
Bars, annealed, approx[1]		—	—	—	—	—	170
Aver. Prop.[2] 1 in. rds. Mean chemistry — Cold drawn	unannealed	—	115	93	18.0	53.0	228[3]
Cold drawn	annealed	—	98	80	21.0	56.0	192[3]
Turned and Polished	unannealed	—	105	66	23.0	63.0	207[3]
Turned and Polished	annealed	—	88	55	28.0	65.0	179[3]
Effect of Mass:[2]							
Quenched and Tempered at 1000F, 0.505 in. tensile specimens, WQ 1525F	1 in. diam. ctr.	—	137	119	18.0	58.0	285[3]
	2 in. diam. ½r	—	131	111	17.0	57.0	285[3]
	3 in. diam. ½r	—	112	98	17.0	56.0	269[3]
Effect of Temp[2]							
0.505 in. tensile specimens cut from center of 1 in. rds. Water quenched 1525F		800F	179	156	14.0	50.0	375[3]
		900	166	148	15.0	53.0	341[3]
		1000	137	119	18.0	58.0	285[3]
		1100	130	111	20.0	61.0	269[3]
		1200	114	95	22.0	65.0	235[3]

[1]Republic Steel Corp.
[2]Bliss & Laughlin
[3]Surface of bar

Physical Properties

Source - ASM Metals Handbook. Data from National Physical Laboratory, Jour. Iron and Steel Inst., 1946, No. II. Composition Tested - C .315%, Mn .69%; Cr 1.09%; Ni .073%; Mo .012%, Cu .07%.

Density

As annealed or oil quenched from 1650F and drawn at 1350F.	0.283 lb /cu. in. (7.84 S. G.)

Thermal Conductivity

Temp Deg C	Temp Deg F	Cal/cm/cm²/sec/°C	Btu/in/ft²/sec/°F
0	32	.116	.094
100	212	.111	.089
200	392	.106	.085
300	572	.101	.081
400	752	.092	.074
500	932	.085	.068
600	1112	.076	.061
700	1292	.069	.056
800	1472	.062	.050
1000	1832	.067	.054
1200	2192	.072	.058

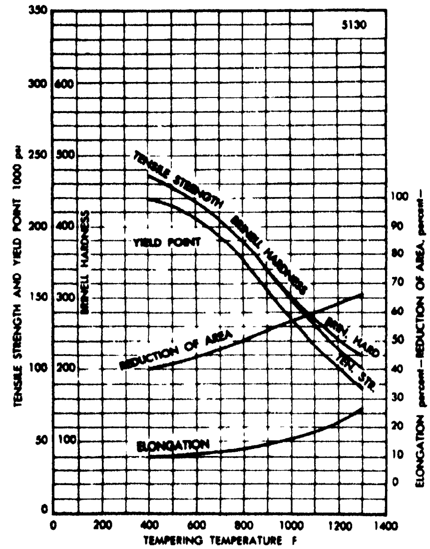
Electrical Resistivity

Temp Deg C	Temp Deg F	Microhm-cm
20	68	21.0
100	212	25.9
200	392	33.0
400	752	51.7
600	1112	77.8
700	1292	93.4
800	1472	110.6
900	1652	114.5
1000	1832	117.7
1100	2012	120.5
1200	2192	123.0
1300	2372	125.1

Mean Apparent Specific Heat

Temp Range Deg C	Temp Range Deg F	cal/gm/°C	Temp Range Deg C	Temp Range Deg F	cal/gm/°C
50-100	122-212	.118	450-500	842-932	.157
150-200	302-392	.125	550-600	1022-1112	.177
200-250	392-482	.128	650-700	1202-1292	.200
250-300	482-572	.132	700-750	1292-1382	.358
300-350	572-662	.137	750-800	1382-1472	.223
350-400	662-752	.142	850-900	1562-1652	.137

Quenched and Tempered



Source: Republic Steel Corp. Approx values. Test conditions: 1 in. bars normalized at 1600F, quenched from 1525F in water, drawn 1 hr as shown. Tested as 0.505 in. bars. Maximum section for which these properties can be expected is 1.25 in.

5140

Chemical Composition[1]

C %	Mn %	P %	S %	Si %	Cr %
.38-.43	.70-.90	.040 max	.040 max	.20-.35	.70-.90

[1]AISI

Treatment Temperatures[1]

Forging	2250F max
Annealing	1500-1725
Normalizing	1550-1750
Quenching	1500-1550-oil

[1]Republic Steel Corp. Approx

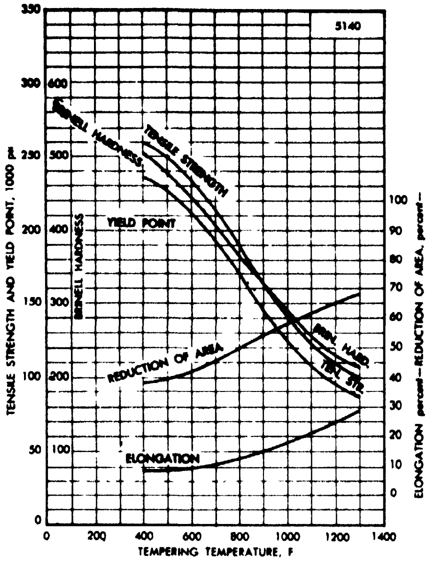
Critical Points

Ac_1	1360F	Ar_3	–
Ac_3	1450	Ar_1	1230

Characteristics. Similar to 5130 though with greater strength and hardenability.

Uses. Transmission gears, spline shafts, etc.

Quenched and Tempered Properties



← Source – Republic Steel Corp. Approx values. Test Conditions: 1 in. bars normalized at 1575F, quenched from 1500F in oil, drawn 1 hr as shown. Tested as 0.505 in. bars. Maximum section for which these properties can be expected is 1.0 in.

Technological Properties

Machinability Rating (On basis of B1112 = 100): Mill annealed to 174-229 BHN = 60% (ASM Metals Handbook.)

Coefficient of Thermal Expansion[1]

Temp Range Deg C	Deg F	Mean Coefficient Per Deg C	Per Deg F
25-100	77-212	12.8×10^{-6}	7.1×10^{-6}
25-270	77-518	13.8	7.6

[1]Source - ASM Metals Handbook, Data from National Physical Laboratory, Jour. Iron and Steel Inst., 1946, No. II. Composition tested = .40C, .78Mn, .57Si, .78Cr.

Mechanical Properties

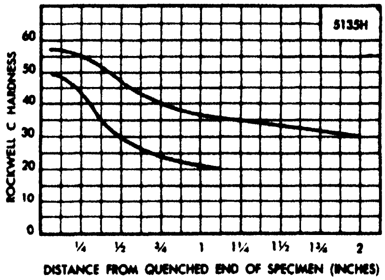
Form or Condition		Draw Temp	Tensile Strength M psi	Yield Point M psi	Elong 2 in. %	Red Area %	Hard BHN	NBT Ft Lbs Quenched	NBT Ft Lbs Slow Cool
Aver. Prop.[4] Annealed, 1 in. rds. Mean chemistry	cold drawn	–	105	88	18.0	52.0	212[5]	–	–
	turned & polished	–	90	56	27.0	62.0	183[5]	–	–
Effect of Mass[4] Quenched and tempered at 1000F, 0.505 in. tensile specimens; OQ 1550F	1 in. diam. ctr.	–	151	134	17.0	53.0	311[5]	–	–
	2 in. diam. ½r	–	135	113	18.0	52.0	285[5]	–	–
	3 in. diam. ½r	–	126	100	18.0	51.0	269[5]	–	–
Effect of Temp[4] 0.505 in. tensile specimens cut from center of 1 in. rds. Oil quenched 1550F Tempered as shown		800F	190	169	12.0	42.0	375[5]	–	–
		900	170	148	16.0	49.0	352[5]	–	–
		1000	151	134	17.0	53.0	311[5]	–	–
		1100	136	114	20.0	60.0	269[5]	–	–
		1200	123	101	22.0	63.0	241[5]	–	–
Bars approx	Hot rolled[1]	–	–	–	–	–	163-212	–	–
	Cold drawn[1]	–	–	–	–	–	187-228	–	–
	Normalized[2]	–	–	–	–	-	269 max	–	–
Low Temp Vee-notched Charpy bars:[3] Quenched and tempered to give temp martensite at 29-32 Rock C Fast vs slow cooling from the drawing temp		100F	–	–	–	–	–	84	75
		75	–	–	–	–	–	82	70
		50	–	–	–	–	–	80	56
		25	–	–	–	–	–	70	40
		0	–	–	–	–	–	50	30
		-25	–	–	–	–	–	30	24
		-50	–	–	–	–	–	23	17
		-100	–	–	–	–	–	15	10
		-150	–	–	–	–	–	10	10

[1]Union Drawn Steel.
[2]Republic Steel Corp.
[3]W.E. Jominy. Steel. Mar. 8, 1948, p. 82. Data from H.E. Hostetter, Climax Molybdenum Corp.
[4]Bliss & Laughlin
[5]Surface of bar

STEELS, AISI

5135H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Cr %	P %(1)	S %(1)
.32-.39	.55-.85	.20-.35	.75-1.10	—	—

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

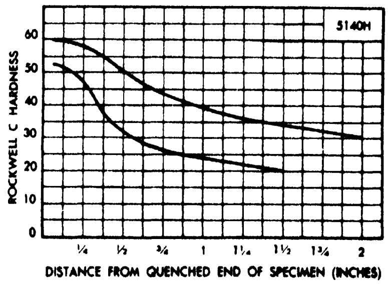
	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	56.5	56.5	56.0	55.0	53.5	52.0	49.5	47.0	44.5	43.0	41.0	40.0	49.0	38.0	37.0	36.5	35.5	35.0	34.0	33.5	32.5	31.5	31.0	30.0
Min	49.5	49.0	47.0	43.0	38.0	35.0	32.0	30.0	28.0	26.5	25.0	24.5	23.0	22.5	21.5	21.0	20.0	---	---	---	---	---	---	---

[1]These values are to be used when points are selected and specified

STEELS, AISI

5140H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Cr %	P %(1)	S %(1)
.37-.45	.60-.95	.20-.35	.65-.95	—	—

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	60.0	59.5	59.0	58.0	57.0	55.0	53.0	51.0	49.0	47.0	45.0	43.5	42.0	41.0	40.0	39.0	37.5	36.0	35.0	34.0	33.0	32.0	31.0	30.0
Min	52.5	52.0	50.0	47.0	42.0	37.0	33.5	31.5	29.5	28.0	27.0	26.0	25.5	25.0	24.5	24.0	23.0	22.0	21.0	20.0	---	---	---	---

[1]These values are to be used when points are selected and specified.

5150

Chemical Composition[1]

C %	Mn %	P %	S %	Si %	Cr %
.48-.53	.70-.90	.040 max	.040 max	.20-.35	.70-.90

[1] AISI

Characteristics. Similar to 5140 though with higher hardness, strength and elasticity.

Uses. A typical use is for coil springs and for flat springs 1/8 in. thick and heavier. The latter are oil quenched and drawn at 725 – 900F to 375 – 415 or 415 – 461 BHN.

Treatment Temperatures[1]

Forging	2250F max
Annealing	1450-1725
Normalizing	1600-1750
Quenching	1475-1525
Forming	not over 1800

[1] Republic Steel Corp. Approx values.

Critical Points

Ac_1	1340F	Ar_3	–
Ac_3	1420	Ar_1	1220

As Quenched Rockwell "C" Hardness

Treatment: 1600 F – A.C. 1525 F – Oil Tower Quenched
Size Tested: 1 in. discs cut from mid-length

	Center	Midway	Surface
½ in. diam	59	60	60
1 in. diam	50	52	59
2 in. diam	40	44	55
4 in. diam	29	31	37

Technological Properties

Machinability Rating (On basis B1112 = 100): Mill annealed to 179-235 BHN = 55% (ASM Metals Handbook.)

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Yield Point M psi	Elong 2 in. %	Red Area %	Hard BHN	Izod Aver Ft Lbs
Bars - approx: Hot rolled[1]	–	–	–	–	–	170-223	–
Bars - approx: Cold Drawn[1]	–	–	–	–	–	187-228	–
Bars - approx: Normalized[2] 1 in.	–	–	–	–	–	293	–
Aver. Prop.[6] 1 in. rds. Mean chemistry: Annealed cold drawn	–	116	100	16.0	50.0	228[7]	–
Aver. Prop.[6] 1 in. rds. Mean chemistry: turned & polished	–	102	67	22.0	57.0	202[7]	–
Effect of Temp[6] 0.505 in. tensile specimens cut from center of 1 in. rds. Oil quenched 1550F Tempered as shown	800F	210	190	11.0	29.0	429[7]	–
	900	186	165	12.0	38.0	375[7]	–
	1000	167	149	15.0	50.0	352[7]	–
	1100	148	126	16.0	51.0	302[7]	–
	1200	133	113	17.0	56.0	277[7]	–
Effect of Mass[6] Quenched and Tempered at 1000F, 0.505 in. tensile specimens, OQ 1550F: 1 in. diam. ctr.	–	167	149	15.0	50.0	352[7]	–
2 in. diam. ½r	–	155	136	16.0	49.0	331[7]	–
3 in. diam. ½r	–	143	120	17.0	48.0	293[7]	–
Effect of Mass[3] Annealed[4] 1 in. diam ctr.	–	98	51.75	22.0	43.7	197	18.5
Normalized 1600F air cooled: ½ in.[5] diam ctr.	–	131	81.5	21.0	60.6	262	25.7
1 in. diam ctr.	–	126.25	76.75	20.7	58.7	255	23.2
2 in. diam ½r.	–	123	72.5	20.0	53.3	248	19.7
4 in. diam ½r.	–	122	63	18.2	48.2	241	16.2
Normalized - Quenched & Tempered: 1600F, air cooled, 1525F oil tower quenched: ½ in.[5] diam ctr.	1000F	158.75	145.25	16.4	52.9	311	38.2
1 in. diam ctr.	1000F	153	131.75	17.0	54.1	302	38.7
2 in. diam ½r.	1000F	132	96.75	18.5	55.5	255	59.7
4 in. diam ½r.	1000F	125	85.75	20.0	57.5	248	27.0
½ in.[5] diam ctr.	1100	144	131	19.2	55.2	285	50.7
1 in. diam ctr.	1100	137	115.25	20.2	59.6	277	58.2
2 in. diam ½r.	1100	126.75	87.25	20.0	58.8	255	66.5
4 in. diam ½r.	1100	120	80.5	19.7	56.4	241	33.5
½ in.[5] diam ctr.	1200	135.5	121	21.7	59.7	269	61.0
1 in. diam ctr.	1200	128	108	21.2	61.9	255	69.5
2 in. diam ½r.	1200	118.75	88.5	22.7	63.0	241	75.0
4 in. diam ½r.	1200	115	75.5	21.5	60.8	235	38.5

[1] Union Drawn Steel.
[2] Republic Steel Corp.
[3] Source - Bethlehem Steel Co. Single heat tests. Composition. Ladle: C .49%, Mn .79%; P -%; S -%, Si .27%; Ni .14%; Cr .80%; Mo .04%. Check: C .49%; Mn .75%; P .018%; S .018%; Si .25%; Ni .11%, Cr .80%; Mo .05%. McQuaid-Ehn grain size - 100% 7-8. Test specimens: .505 in. diam tensile and 0.450 in. diam Izod.
[4] 1520 F F.C. 20 F/hr to 1190 F - A.C.
[5] .357 in. dia tensile
[6] Bliss & Laughlin
[7] Surface of bar

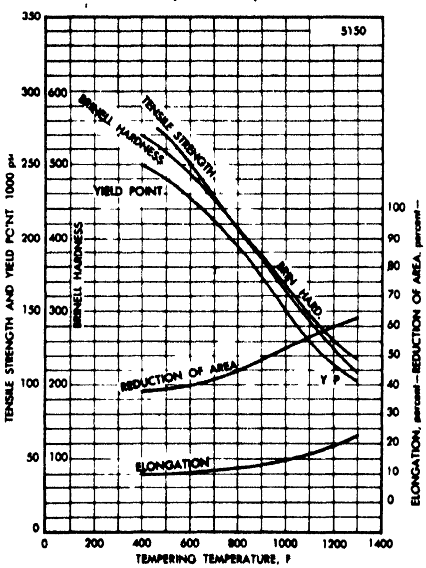
(Continued on page 252)

STEELS, AISI

5150

(Continued from page 251)

Quenched and Tempered Properties



Source: Republic Steel Corp. Approx values. Test Conditions: 1 in. bars normalized at 1600F, oil quenched from 1500F, drawn as shown for 1 hr. Tested as 0.505 in. bars. The maximum section for which these properties can be expected is 1.2 in.

STEELS, AISI

E52100

Treatment Temperatures[1]

Forging	1800-1950F
Annealing	1425-1450
Normalizing	1650-1700
Quenching-oil	1500-1550
-water	1475-1525

[1]Ryerson

Critical Points

Ac_1	1340F	Ar_3	1315
Ac_3	1415	Ar_1	1280

Chemical Composition[1]

C %	Mn %	P %	S %	Si %	Cr %
.95-1.10	.25-.45	.025 max	.025 max	.20-.35	1.30-1.60

[1]AISI

Characteristics. This is the popular bearing steel. To reduce the liability to fatigue failure it is made with a minimum of foreign inclusions.

Uses. The principal use is as electric furnace steel. Bearings.

Technological Properties

Machinability Rating (On basis B1112 = 100) Hot Rolled—Annealed 45%

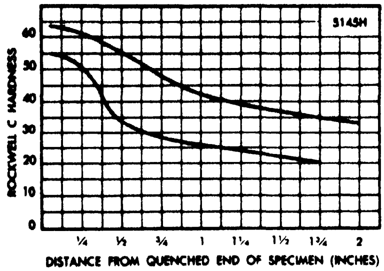
Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Rock C Approx Core
Bars: Hot Rolled aver annealed[1]	–	100	25	81	57	192	–
Bars: Hot Rolled aver normalized[1]	–	185	13	139	20	363	–
Quenched & Tempered Properties[1]	–	–	–	–	–	–	–
Heat to 1525-1550F and quench	200F	–	–	–	–	–	63-64
in oil. Aver	300F	–	–	–	–	–	62-63
Temper at 300-350F. Time held at the tempering	400F	–	–	–	–	–	60-61
temp will depend on cross section. The resultant	500F	–	–	–	–	–	58-60
hardness of from 60 to 63 Rockwell "C" is normal	600F	–	–	–	–	–	55-57
for bearings.	700F	–	–	–	–	–	50-54
In the event that E52100 is used for parts other	800F	238	–	228	–	–	–
than bearings and high hardness is not desired,	900F	190	4.0	189	30.0	–	–
these tensile prop. of a (.400 in. rd) are listed.	1000F	170	4.5	143	30.0	–	–
	1100F	146	4.3	131	36.0	–	–
[1]Ryerson	1200F	120	14.1	96	48.2	–	–

STEELS, AISI

5145H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Cr %	P %	S %
.42-.50	.60-.95	.20-.35	.65-.95	—(1)	—(1)

[1] P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

"J" Distance in Inches[1]

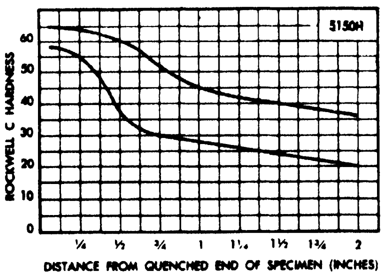
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	63.0	62.5	62.0	61.0	60.0	58.5	57.0	55.5	53.5	52.0	50.0	48.0	46.0	44.5	43.0	42.0	40.5	39.0	38.0	37.0	36.0	35.0	34.0	33.0
Min	55.0	54.5	53.0	51.0	48.0	42.0	36.5	33.5	31.5	30.0	29.0	28.0	27.5	27.0	26.5	26.0	25.0	24.0	23.0	22.0	21.0	20.0	—	—

[1] These values are to be used when points are selected and specified.

STEELS, AISI

5150H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Cr %	P %	S %
.46-.54	.60-.95	.20-.35	.65-.95	—(1)	—(1)

[1] P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

"J" Distance in Inches[1]

	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	65.0	65.0	64.5	64.0	63.5	62.5	61.5	60.0	58.5	57.0	55.0	52.0	50.0	48.0	46.5	45.0	43.5	42.0	41.0	40.0	39.0	38.0	37.0	36.0
Min	58.0	57.5	56.5	55.0	52.0	48.0	43.0	37.5	33.5	32.0	31.0	30.0	29.5	29.0	28.5	28.0	27.0	26.0	25.0	24.0	23.0	22.0	21.0	20.0

[1] These values are to be used when points are selected and specified.

6150 6152

Chemical Composition[1]

	C %	Mn %	P %	S %
6150	.48-.53	.70-.90	.040 max	.040 max
6152	.48-.55	.70-.90	.040 max	.040 max

	Si %	Cr %	V %
6150	.20-.35	.80-1.10	.15 min
6152	.20-.35	.80-1.10	.10 min

[1]AISI

Characteristics. These two steels are essentially the same and differ only in the amount of V required.

Uses. Flat springs under 1/8 in. thick, cold formed, and 1/8 in. and over, hot formed, oil quenched and drawn at 725-900F to 44-48 or 48-52 Rc, and for coil springs over 1/2 in. diam with same heat treatment. Also used for valve springs, piston rods, pump parts, spline shafts.

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	NBT Ft Lbs	Izod Aver Ft Lbs
Bars: Annealed[1]	–	–	–	–	–	183-202	–	–
Normalized[1]	–	–	–	–	–	302-363	–	–
Hot rolled[2] approx	–	–	–	–	–	163-212	–	–
Cold drawn[2] approx	–	–	–	–	–	196-228	–	–
Aver. Prop.[8] Annealed 1 in. rds, mean chem: cold drawn	–	111	14	95	44	223[9]	–	–
Aver. Prop.[8] Annealed 1 in. rds, mean chem: turned & polished	–	100	23	65	50	207[9]	–	–
Effect of Mass[8]								
OQ at 1525F, tempered at 1000F, 0.505 in. tensile specimens: 1 in. diam. ctr.	–	172	14	151	45	341[9]	–	–
2 in. diam. ½r	–	170	13	149	48	341[9]	–	–
3 in. diam. ½r	–	158	13	138	47	341[9]	–	–
Effect of Mass[3]								
As Rolled: 1 in. diam ctr.	–	179	13.2	137	45	363	–	10.5
2 in. diam ½r.	–	147.25	17.7	91	51.5	293	–	8.7
4 in. diam ½r.	–	126.75	12.2	72	22.3	255	–	4.7
Annealed[4] 1 in. diam ctr.	–	96.75	23	59.75	48.4	197	–	20.2
Normalized 1600F air cooled: ½ in.[5] diam ctr.	–	141.25	20.6	93	63	285	–	27
1 in. diam ctr.	–	136.25	21.8	89.25	61	269	–	26.2
2 in. diam ½r.	–	129.75	20.7	75.25	56.5	262	–	20.5
4 in. diam ½r.	–	128	18.2	67	49.7	255	–	17
Normalized-Quenched 1600F air cooled - 1550F Oil tower Quenched: ½ in.[5] diam ctr.	1000F	179.5	14.6	177.75	49.4	363	–	26
1 in. diam ctr.		173.5	14.5	167.75	48.2	352	–	24.7
2 in. diam ½r.		166	14.5	145.25	46.7	331	–	19.5
4 in. diam ½r.		151.5	16	127	48.7	302	–	17.5
½ in.[5] diam ctr.	1100	160	16.4	158.5	52.3	321	–	39.2
1 in. diam ctr.		158.25	16	150.5	53.2	311	–	34
2 in. diam ½r.		148.25	17.7	131.75	55.2	293	–	33.7
4 in. diam ½r.		130	19	108.5	55.4	262	–	38.5
½ in.[5] diam ctr.	1200	147	17.8	141.5	53.9	293	–	43.7
1 in. diam ctr.		141.25	18.7	129.5	56.3	293	–	56.7
2 in. diam ½r.		133.75	19.5	116.5	57.4	269	–	51.7
4 in. diam ½r.		121.5	21	94.5	59.7	241	–	45.2
Effect of Mass Interpreted from End-Quench Hardenability curve, quenched in oil at 1550F, drawn as shown[7]: 1 in. rd. ctr.	1000	188	13.9	169	44	379	–	–
	1100	171	15.9	151	48.1	346	–	–
	1200	156	17.4	135	51	316	–	–
2 in. rd. ½r.	1000	180	15	161	46.1	363	–	–
	1100	163	16.8	143	49.5	331	–	–
	1200	151	18.2	129	52	306	–	–
3 in. rd. ½r.	1000	161	17	140	50	326	–	–
	1100	154	18	132	51.4	311	–	–
	1200	143	19	120	53.5	288	–	–
4 in. rd. ½r.	1000	156	17.4	135	51	316	–	–
	1100	149	18.4	127	52.3	302	–	–
	1200	138	19.7	114	54.6	277	–	–
Effect of Temp[8] Oil quenched at 1525F and tempered as shown 0.505 in. tensile specimens cut from center of 1 in. rds.	800	228	10	210	38	461[9]	–	–
	900	199	11	175	41	401[9]	–	–
	1000	186	13	170	42	385[9]	–	–
	1100	169	15	161	48	355[9]	–	–
	1200	142	18	137	53	308[9]	–	–
Low Temperature Tests[6]								
6145: fine grained steel, Charpy vee notch: normalized, 1650F 75F	–	–	–	–	–	–	19	–
0	–	–	–	–	–	–	14	–
-40	–	–	–	–	–	–	9	–
-100	–	–	–	–	–	–	6	–
OQ 1525F, drawn at 1125F 75	–	–	–	–	–	–	77	–
0	–	–	–	–	–	–	38	–
-40	–	–	–	–	–	–	24	–
-100	–	–	–	–	–	–	15	–

[1]Industry data.
[2]Union Drawn Steel.
[3]Bethlehem Steel Co. Single heat results. Composition—Ladle: .51%C, .80%Mn, .36%Si, .12%Ni, .97%Cr, .03%Mo, .17%V. Check: .51%C, .80%Mo, .014%P, .015%S, .36%Si, .11%Ni, .95%Cr, .01%Mo, .18%V. McQuaid-Ehn grain size = 70% 5-6, 30% 2-4. All test results are the average of two tests. Size tested. 0.505 in. diam tensile and 0.450 in. diam Izod specimens.
[4]1500F, fire-cooled, 20F/hr to 1240F, air-cooled.
[5].357 in. diam tensile.
[6]H. W. Gillett, "Impact Resistance and Tensile Properties of Steel at Low Temperatures." Steel — 6145, with 0.44%C.
[7]Ryerson. Aver values.
[8]Bliss & Laughlin
[9]Surface of bar

(Continued on page 256)

6150 6152

(Continued from page 255)

Coef of Thermal Expansion Temp Range		Annealed x 10^{-6}/°C	x 10^{-6}/°F	OQ 1575, Dr 800F x 10^{-6}/°C	x 10^{-6}/°F	OQ 1575F, Dr 1200F x 10^{-6}/°C	x 10^{-6}/°F
68-212F	20-100C	12.4	6.9	11.8	6.5	12.3	6.8
392	200	12.8	7.1	12.4	6.9	12.7	7.0
572	300	13.4	7.4	13.1	7.3	13.4	7.4
752	400	13.9	7.7	13.6	7.5	13.9	7.7
932	500	14.2	7.9	13.9	7.7	14.3	7.9
1112	600	14.5	8.0	14.1	7.8	14.7	8.2

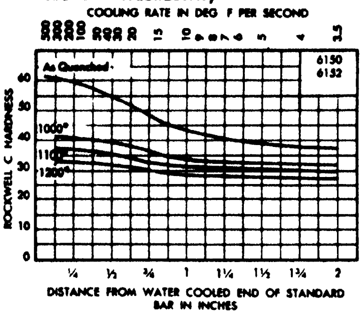
As Quenched Rockwell "C" Hardness
Treatment: 1600F – A.C. 1550F Oil Tower
Size Tested: 1 in. discs cut from mid-length

	Center	Midway	Surface
½ in. diam	60	60	61
1 in. diam	57	58	60
2 in. diam	44	47	54
4 in. diam	35	36	42

Technological Properties

Machinability Rating – Steel E 6150 (On basis B1112 = 100).
Spheroidized annealed to 183-241 BHN = 45%.
E6150 is an electric furnace steel with P and S limited to 0.025% max.

End-Quench Hardenability



Source – Ryerson, aver values.

Treatment Temperatures[1]

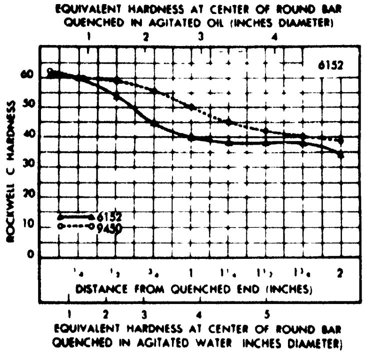
Forging	1950-2250F
Annealing	1500-1600
Normalizing	1625-1750
Quenching	1550-1600

[1] Industry data.

Critical Points

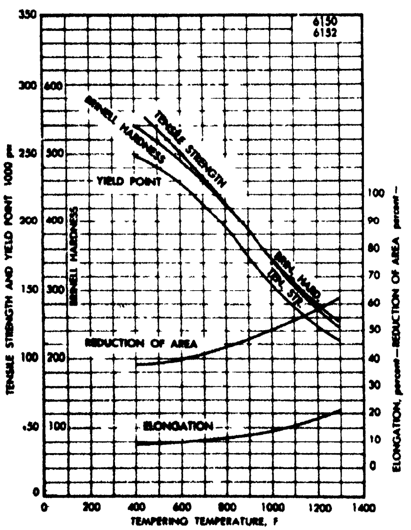
Ac_1	1390F	Ar_3	1315F
Ac_3	1445	Ar_1	1290

End-Quench Hardenability



Source – Bethlehem Steel Co. Single heat results. Analysis. .50 Carbon, oil-hardening grades (6152) .49%C, .78%Mn, .29%Si, .18%Ni, 1.00%Cr, Tr Mo, .17%V. Grain size 6-8. (9450) .51%C, 1.34%Mn, .23%Si, .47%Ni, .45%Cr, .10%Mo. Grain size 6-8. Carburized at 1700F.

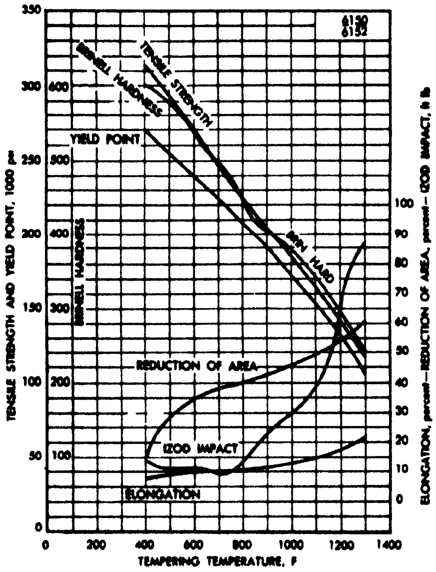
Quenched and Tempered



←Source – Republic Steel Corp. Approx values. Test Conditions: 1 in. bars, normalized at 1700F, quenched in oil from 1550F, drawn for 1 hr. as shown. Tested as 0.505 in. bars. The maximum section for which these properties can be expected is 1.6 in.

Source – Bethlehem Steel→ Co. Single heat results. Composition: .49%C, .78%Mn, .012%P, .016%S, .29%Si, .18%Ni, 1.00%Cr, Mo nil, .17%V. Test Conditions: 0.565 in. bars normalized at 1600F, quenched in agitated oil from 1550F, drawn as shown. Tested as 0.505 in. bars. Grain size =

Quenched and Tempered



Chemical Composition (AISI)						
C %	Mn %	P %	S %	Si %	Cr %	V %
.17-.22	.70-.90	.040 max	.040 max	.20-.35	.70-.90	.10 min

Characteristics. Case hardening steel of medium hardenability.

Technological Properties

Machinability Rating (On basis B1112 = 100)	Cold drawn to 179-221 BHN = 50% (ASM, Metals Handbook.)

Treatment Temperatures[1]	
Forging	2250F max
Annealing	1600
Normalizing	1700-1800
Carburizing	1700
Quenching - high	1550
low	1425

[1] Republic Steel Corp. Approx values.

Critical Points			
Ac_1	1410F	Ar_3	–
Ac_3	1530	Ar_1	1300

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hardness BHN	Hardness Brinell at ½r	Hardness Brinell on surface
Bars: Annealed[1]	–	–	–	–	–	179	–	–
Normalized[1]	–	–	–	–	–	202	–	–
Hot rolled[2] approx	–	–	–	–	–	140-170	–	–
Cold drawn[2] approx	–	–	–	–	–	187-228	–	–
Aver. Prop.[4] 1 in. rd. Mean chemistry; cold drawn, unannealed	–	108	18	91	60	217[5]	–	–
cold drawn, annealed	–	93	22	75	65	187[5]	–	–
Turned and Polished, unannealed	–	90	28	56	66	193[5]	–	–
Turned and Polished, annealed	–	74	32	52	72	153[5]	–	–
Core Properties Psuedo-carburized at 1700F for 8 hrs oil quenched, tempered at 300F, 0.505 in. tensile specimens, 0.394 in. sq. Izod specimens; 1 in. rds. ctr.: Direct quench	–	137	18	111	57	283[5]	–	–
Reheat 1425F	–	112	17	80	39	233[5]	–	–
Reheat 1475	–	125	18	100	42	265[5]	–	–
Reheat 1525	–	132	19	105	55	300[5]	–	–
2 in. rd. ½r: Direct quench	–	155	16	127	51	331[5]	–	–
Reheat 1425F	–	127	15	96	46	269[5]	–	–
Reheat 1475	–	134	15	108	44	285[5]	–	–
Reheat 1525	–	150	17	124	55	321[5]	–	–
Core Prop. Bars heated 8 hr at 1700F in iron chips, box cooled, heat treated as shown, drawn at 300F. Tested 0.505 in.; 1 in. rd.: Direct OQ from box	–	148	15	119	50	–	311	–
1425F, OQ	–	122	15.5	95	45	–	260	–
1475F, OQ	–	131	15	105	43	–	277	–
1550F, OQ	–	144	17	118	54	–	302	–
.515 in. rd.: Direct OQ from box	–	155	16	127	51	–	–	331
1425F, OQ	–	127	15.5	96	46	–	–	269
1475F, OQ	–	134	15	108	44	–	–	285
1550F, OQ	–	150	17	124	55.5	–	–	321
							Energy Ft Lb	
Low Temp Tests of Case-hardened Bars: 6115[3] Charpy bars carburized 4 hr at 1650F, quenched in water from 1450F, drawn at 300F. Case depth, 0.021 in. Tested in unnotched condition.	210F	–	–	–	–	–	42	–
	70	–	–	–	–	–	34	–
	20	–	–	–	–	–	19	–
	-15	–	–	–	–	–	15	–
	-70	–	–	–	–	–	7	–

[1] Republic Steel Corp.
[2] Union Drawn Steel.
[3] R. Sergeson, Trans. ASST, 1932, Vol. 19, p. 368. Composition: .13-.18 C.
[4] Bliss & Laughlin
[5] Surface of bar

STEELS, AISI

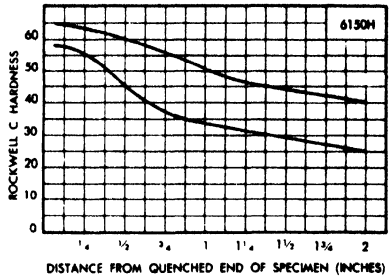
6150H

Chemical Composition

C %	Mn %	P %	S %	Si %	Cr %	V %
.46-.54	.60-.95	—[1]	—[1]	.20-.35	.80-1.15	.15 min

[1] P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

End-Quench Hardenability Band



	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	65.0	64.5	64.0	63.5	62.5	62.0	61.0	60.0	59.0	58.0	57.0	56.0	55.0	53.5	52.0	51.0	48.0	46.0	45.0	44.0	43.0	42.0	41.0	40.0
Min	58.0	57.5	57.0	56.0	54.0	51.0	48.5	45.5	42.5	40.0	38.0	36.5	35.5	35.0	34.5	34.0	33.0	31.5	30.5	29.5	28.5	27.5	26.5	25.0

[1] Note — These values are to be used when points are selected and specified.

STEELS, AISI
8615

Chemical Composition[1]

C %	Mn %	P %	S %	Si %	Ni %	Cr %	Mo %
.13-.18	.70-.90	.040 max	.040 max	.20-.35	.40-.70	.40-.60	.15-.25

[1] AISI

Characteristics. A triple alloy case-hardening steel with medium hardenability.

Uses. Automotive differential pinions, side gears and shafts, knuckle pins, piston pins, pump shafts, spline shafts, aircraft engine pins and gears.

Technological Properties

Machinability rating (On basis of B1112 = 100) Cold drawn = 70% (Union Drawn Steel. Approx value.)

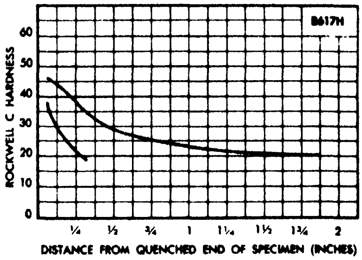
Mechanical Properties

Form or Condition		Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %
1 in. bars pseudo carburized at 1650-1700F, box cooled, reheated 1550F, OQ[6]	8615	300F	100	20	72.5	58
	8620		135	17	105	49

[1] International Nickel Co. Aver values.

STEELS, AISI
8617H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %	Cr %	Mo %	P %	S %
.14-.21	.60-.95	.20-.35	.35-.75	.35-.65	.15-.25	—[1]	—[1]

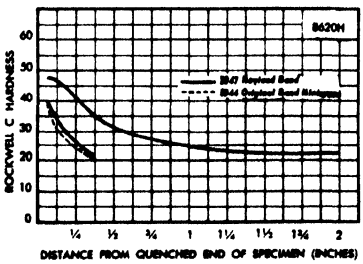
[1] P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	46.0	44.5	42.0	39.0	35.0	32.5	30.5	29.0	28.0	27.0	26.0	25.0	24.5	24.0	23.5	23.0	22.0	21.5	21.0	20.5	20.5	20.0	20.0	20.0
Min	39.0	29.5	25.0	22.0	20.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

[1] Note — These values are to be used when points are selected and specified.

STEELS, AISI
8620H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %	Cr %	Mo %	P %	S %
.17-.24	.60-.95	.20-.35	.35-.75	.35-.65	.15-.25	—[1]	—[1]

[1] P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	48.0	46.5	44.0	41.0	37.0	34.5	32.5	31.0	29.5	28.5	28.0	27.0	26.0	25.5	25.0	24.5	24.0	23.0	23.0	22.5	22.0	22.0	22.0	22.0
Min	40.5	35.0	30.0	26.0	23.5	21.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Note — These values are to be used when points are selected and specified.

STEELS, AISI

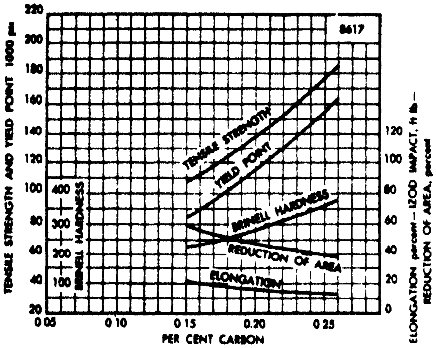
8617

Chemical Composition[1]

C	Mn	P	S	Si	Ni	Cr	Mo
%	%	%	%	%	%	%	%
.15-.20	.70-.90	.040 max	.040 max	.20-.35	.40-.70	.40-.60	.15-.25

[1] AISI

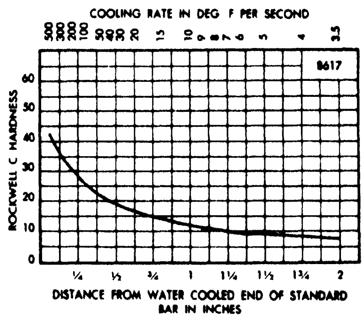
Direct Quench



Source – International Nickel Co. Representative values. Test conditions: 1 in. bars, pseudo-carburized at 1650-1700F, direct quenched in oil, drawn at 300F. Tested as 0.505 in. bars. Effect of carbon from 0.15% to 0.26%.

Characteristics. Similar to 8615 but develops a little greater strength, as shown by the line chart giving the effect of carbon on the core properties.

End-Quench Hardenability



Source – Ryerson. Aver values.

Technological Properties
Machinability Rating (On basis of B1112 = 100)
Cold drawn = 66% (Union Drawn Steel. Aver value.)

Rockwell "C" Core Hardness[1]
Treatment: Quenched in oil at 1700F.

Size of Round	¾ Radius	½ Radius	Center
1 in.	32	27	25.5
2 in.	22	17.5	16
3 in.	17	13.5	13

[1] Ryerson. Aver values.

Critical Points

Ac_1	1370F	Ar_3	1430F
Ac_3	1550	Ar_1	1260

Treatment Temperatures[1]

Forging	1950-2250F
Annealing	1575-1650
Normalizing	1650-1725
Carburizing	1700
Quenching – high	1575
Quenching – low	1475

[1] Industry values – approx.

Mechanical Properties

Form or Condition			Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hardness Rock C Core	Hardness Rock C Case
Core Prop[1] 1 in. bars carburized 8 hr at 1700F, heat treated as shown.	OQ from 1700F		300F	128	19	94	54	25	61
	Cooled in box reheat, OQ	1575F	300F	121	19	91	52	24	62
		1475F	300F	114	22	77	54	21	62
		1575 & 1475F double OQ	300F	119	23	80	56	23	62

[1] Ryerson. Aver values. Effective case depth: 0.0625 in Grain size = 5-8.

STEELS, AISI

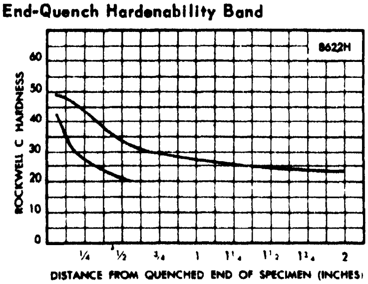
8622H

Chemical Composition

C	Mn	Si	Ni	Cr	Mo	P	S
%	%	%	%	%	%	%	%
.20-.27	.60-.95	.20-.35	.35-.75	.35-.65	.15-.25	–[1]	–[1]

[1] P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

End-Quench Hardenability Band



"J" Distance in Inches[1]

	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	49.5	48.0	46.5	43.5	40.5	38.0	35.5	34.0	32.0	31.0	30.0	29.0	28.5	28.0	27.5	27.0	26.0	25.5	25.0	24.5	24.0	24.0	24.0	24.0
Min	42.0	35.5	30.0	27.5	25.0	23.5	22.0	21.0	20.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

[1] Note – These values are to be used when points are selected and specified.

STEELS, AISI

8620

Chemical Composition[1]

C %	Mn %	P %	S %	Si %	Ni %	Cr %	Mo %
.18-.23	.70-.90	.040 max	.040 max	.20-.35	.40-.70	.40-.60	.15-.25

[1] AISI

Critical Points

Ac_1	1370F	Ar_3	–
Ac_3	1535	Ar_1	1225F

Characteristics. Similar to 8615 and 8617 though stronger.

Uses. Differential ring gears, steering worms, transmission gears, aircraft engine camshafts and gears, spline shafts for good core properties and high surface hardness after case hardening. Is also used in the heat-treated condition as chain, at about 100 Mpsi YS.

Treatment Temperatures[1]

Forging	1950-2250F
Annealing	1575-1625
Normalizing	1600-1750
Carburizing	1700
Quenching	–

[1] Industry values, approx.

Compressive Strength.[1] Permissible compressive stress to case hardened gears, bearings and races is 180 Mpsi for intermittent loading. For constant mesh loading this value should be reduced 20-25%. This assumes good practice, adequate section thickness, and freedom from carbide network in the case.

[1] International Nickel Co.

As Quenched Rockwell Hardness

Treatment: 1700F, 8 hrs, Furnace Cooled
Reheated to 1550F, Quenched in agitated oil

Size Tested: ½ in. discs cut from mid-length

Diam	Center	Midway	Surface
½ in.	C43	C43	C43
1 in.	C25	C27	C29
2 in.	B97	C22	C23
4 in.	B93	B95	C22

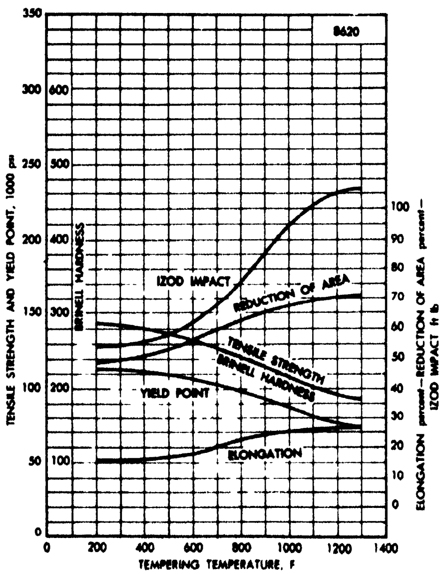
Rockwell "C" Core Hardness[1]

Treatment: Quenched in oil at 1700F

Size of Round	¾ Radius	½ Radius	Center
1 in.	36	31	30.5
2 in.	28	22.5	21
3 in.	22	18	15.5

[1] Ryerson. Aver values. Test conditions – Rounds treated as shown and tested for core hardness. Grain size = 5-8.

Oil Quenched and Tempered

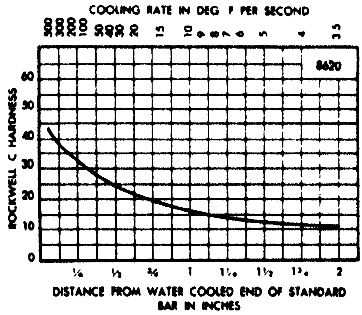


Source – International Nickel Co. Aver values. Test conditions: 1 in. bars quenched in oil from 1525-1575F, drawn as shown.

Technological Properties

Machinability Rating (On basis of B1112 = 100)
Cold drawn to 170-217 BHN = 60%. (ASM, Metals Handbook)

End-Quench Hardenability



Source – Ryerson. Aver values. Grain size = 5-8.

(Continued on page 262)

8620

(Continued from page 261)

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Hardness Rock C Core	Hardness Rock C Case	Izod Aver. Ft Lbs
Bars									
Annealed, Approx[1]	—	—	—	—	—	149-179	—	—	—
Normalized, Approx[1]	—	—	—	—	—	183-217	—	—	—
Aver. Prop.[16] 1 in. rd. Mean chemistry: Cold drawn, unannealed	—	110	15	101	55	223[17]	—	—	—
Cold drawn, annealed	—	88	18	80	60	179[17]	—	—	—
Turned and Polished, unannealed	—	96	23	69	57	192[17]	—	—	—
Turned and Polished, annealed	—	78	33	49	65	143[17]	—	—	—
Core Properties[16] Pseudo-carburized at 1700F for 8 hrs. OQ tempered at 300F, 0.505 in. tensile specimens and 0.394 in. sq. Izod specimens: Direct quench 1700F, 1 in. rd. ctr.	—	135	16	110	40	321[17]	—	—	—
Reheat 1525F, 1 in. rd. ctr.	—	126	19	108	48	302[17]	—	—	—
Reheat 1550, 1 in. rd. ctr.	—	139	19	118	48	321[17]	—	—	—
Reheat 1600, 1 in. rd. ctr.	—	142	20	119	53	341[17]	—	—	—
Direct quench 1700F, 2 in. rd. ½r	—	108	25	81	58	277[17]	—	—	—
Reheat 1525, 2 in. rd. ½r	—	95	20	70	54	262[17]	—	—	—
Reheat 1550, 2 in. rd. ½r	—	98	21	71	54	269[17]	—	—	—
Reheat 1600, 2 in. rd. ½r	—	104	23	78	56	269[17]	—	—	—
Case hardened[2] Rd. bars heated 8 hr at 1700F in iron chips, box-cooled, treated as shown, drawn 300F, tested 0.505 in. bars: Direct OQ from box, 1 in. rd.	—	156	14	127	50	321[3]	—	—	—
1425F, OQ, 1 in. rd.	—	131	15	103	52	277[3]	—	—	—
1475F, OQ, 1 in. rd.	—	139	16	111	54	293[3]	—	—	—
1550F, OQ, 1 in. rd.	—	152	17	124	55	321[3]	—	—	—
Direct OQ from box, .515 in. rd.	—	161	15	134	53	331[4]	—	—	—
1425F, OQ, .515 in. rd.	—	136	15	112	49	285[4]	—	—	—
1475F, OQ, .515 in. rd.	—	151	15.5	123	50	321[4]	—	—	—
1550F, OQ, .515 in. rd.	—	159	16.5	132	56	331[4]	—	—	—
Core Prop[5] 1 in. bars carburized 8 hr at 1700F, heat treated as shown: OQ from 1700F	300F	142	16	114	47	—	30	62	—
Cooled in box reheat, OQ 1575F	300F	131	18	107	48	—	27	63	—
Cooled in box reheat, OQ 1475F	300F	118	22	78	52	—	22	62	—
Cooled in box reheat, OQ 1575 & 1475F double OQ	300F	124	23	81	54	—	24	62	—
1 in. bars pseudo-carburized at 1650-1700F, box cooled, reheated 1550F, OQ[6]: 8615	300F	100	20	72.5	58	—	—	—	—
8620	300F	135	17	105	49	—	—	—	—
Core Prop, carburized 8 hrs, quenched in agitated oil, heat treated as shown, treated 0.565 in. tensile, 0.510 in. Izod: Direct quench from pot	300F	192	12.5	150.25	49.4	388	—	63.0[8]	27.5
Direct quench from pot	450	181.25	12.8	134.25	50.6	352	—	58.0[9]	34.3
Pot cooled reheat 1550F	300	188.5	11.5	149.75	51.6	388	—	64.0[10]	26.3
Pot cooled reheat 1550F	450	167.75	14.3	120.75	53.2	341	—	61.0[11]	29.5
Pot cooled reheat 1550 & 1475F double OQ	300	133	20	83	56.8	269	—	64.0[12]	55.8
Pot cooled reheat 1550 & 1475F double OQ	450	130.25	22.5	77.25	51.7	262	—	61.0[12]	66.3
Effect of Mass[7]									
As Rolled: 1 in. diam, ctr.	—	99.75	22.3	63	57.1	201	—	—	62.8
As Rolled: 2 in. diam, ½r.	—	91.75	23.5	62.25	59	183	—	—	34.8
As Rolled: 4 in. diam, ½r.	—	82.5	28	43	60.5	156	—	—	44.3
Annealed[13] 1 in. diam, ctr.	—	77.75	31.3	55.875	62.1	149	—	—	82.8
Normalized, 1675F, air cooled: ½ in. diam[14] ctr.	—	96.5	26.3	54.25	62.5	197	—	—	62.5
Normalized, 1675F, air cooled: 1 in. diam, ctr.	—	91.75	26.3	51.75	59.7	183	—	—	73.5
Normalized, 1675F, air cooled: 2 in. diam, ½ r.	—	87.25	27.8	52	62.1	179	—	—	81.3
Normalized, 1675F, air cooled: 4 in. diam, ½ r.	—	81.75	28.5	51.5	62.3	163	—	—	74
Mock carburized, quenched and tempered, 1700F 8 hrs, furnace cooled, reheat to 1550F, quenched in agitated oil: ½ in. diam[14] ctr.	300	199.25	13.2	157	49.4	388	—	—	13.5
1 in. diam ctr.	300	126.75	20.8	83.75	52.7	255	—	—	42.3
2 in. diam ½ r.	300	117.25	23	73	57.8	235	—	—	48.8
4 in. diam ½ r.	300	98.5	24.3	57.75	57.6	207	—	—	49.5
½ in. diam[14] ctr.	450	178.5	14.6	139.5	53.9	352	—	—	11.5
1 in. diam ctr.	450	124.25	19.5	80.75	54.2	248	—	—	33
2 in. diam ½ r.	450	114.5	22	72.25	59	229	—	—	38
4 in. diam ½ r.	450	98	25.5	55.5	57.8	201	—	—	43.3

Form or Condition	Draw Temp	Test Temp	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Rock C Core	NBT Ft Lbs	Izod Aver. Ft Lbs
Low temp notched bar tests[15] Charpy keyhole notch, Normalized 1600F	1000F	75F	—	—	—	217	—	57	—
	1000F	-40	—	—	—	217	—	35	—
	1000F	-100	—	—	—	217	—	22	—
	1000F	-180	—	—	—	217	—	7	—
	1000F	-310	—	—	—	217	—	—	—
Oil quenched 1600F	900F	75F	—	—	—	352	—	45	—
	900F	-40	—	—	—	352	—	42	—
	900F	-100	—	—	—	352	—	—	—
	900F	-180	—	—	—	352	—	26	—
	900F	-310	—	—	—	352	—	19	—

[1] Industry values.
[2] Republic Steel Corp. Approx values.
[3] At ¾ radius.
[4] On surface.
[5] Ryerson. Aver values. Grain size = 5-8 Effective case depth = 0.065 in.
[6] International Nickel Co. Aver values.
[7] Bethlehem Steel Co. Single heat results. Composition — Ladle: .22C, .90Mn, .024P, .024S, .30Si, .48Ni, .52Cr, .22Mo. Check: .23C, .81Mn, .025P, .016S, .28Si, .56Ni, .43Cr, .19Mo. McQuaid-Ehn Grain Size = 90% 7-8, 10% 4. Size Tested: 0.505 in. diam tensile and 0.450 in. diam Izod specimens.
[8] Case depth 0.056 in.
[9] Case depth 0 050 in.
[10] Case depth 0.075 in.
[11] Case depth 0.076 in.
[12] Case depth 0.070 in
[13] 1600F, fire cooled 30F/hr to 1150F, air cooled.
[14] 0.357 in. diam tensile.
[15] H. W. Gillett and F. T. McGuire. "Behavior of Ferritic Steels at Low Temperatures."
[16] Bliss & Laughlin
[17] Surface of bar

8630

Chemical Composition[1]

C %	Mn %	P %	S %	Si %	Ni %	Cr %	Mo %
.28-.33	.70-.90	.040 max	.040 max	.20-.35	.40-.70	.40-.60	.15-.25

[1]AISI

Technological Properties

Machinability Rating (On basis B1112 = 100) Mill annealed to 179-229 BHN = 65% (ASM Metals Handbook)

Characteristics. Very similar to steel 4130.

Uses. Is used for aircraft engine mounts on account of good properties when normalized in light sections and its air hardening after welding. Is used for connecting rods, engine bolts and studs, shapes and tubing.

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Izod Ft Lbs
Bars[1]							
Annealed	–	–	–	–	–	174	–
Normalized	–	–	–	–	–	217	–
Aver. Prop.[6] 1 in. rds. Mean chemistry; Cold drawn, unannealed	–	119	13	111	48	241[7]	–
Cold drawn, annealed	–	98	16	86	52	197[7]	–
Turned and Polished, unannealed	–	101	23	57	54	207[7]	–
Turned and Polished, annealed	–	83	28	49	52	156[7]	–
Effect of Temp[6]							
Oil quenched at 1525F and tempered at various temperatures, 0.505 in. tensile specimens cut from center of 1 in. rds.	800F	171	14	125	57	363[7]	–
	900	151	16	132	59	321[7]	–
	1000	142	19	128	60	311[7]	–
	1100	122	20	105	67	262[7]	–
	1200	113	22	100	69	269[7]	–
Effect of Mass[6] OQ at 1525F and tempered at 1000F, 0.505 in. tensile specimens; 1 in. diam. ctr.	–	142	19	128	60	311[7]	–
2 in. diam. ½r	–	114	20	95	62	255[7]	–
3 in. diam. ½r	–	110	21	90	62	241[7]	–
Effect of Mass[2] Single heat							
As Rolled; 1 in. diam, ctr.	–	104.75	20.5	70.5	56.2	212	67.7
2 in. diam, ½r.	–	99.25	22	62	58.2	207	41.2
4 in. diam, ½r.	–	94.5	21.5	59.5	49.9	197	22.7
Annealed[3] 1 in. diam, ctr.	–	81.75	29	54	59	156	70.2
Normalized 1600F, air cooled; ½ in.[4] diam, ctr.	–	95	25.3	61.75	60.3	201	63
1 in. diam, ctr.	–	94.25	23.5	62.25	53.5	187	69.8
2 in. diam, ½r.	–	93	26.2	62	59.2	187	76.7
4 in. diam, ½r.	–	93.5	24.5	56.25	57.3	187	63.5
Normalized, quenched and drawn 1600F, air cooled, 1550F water quenched, drawn as shown, air cooled; ½ in. diam[4] ctr.	900F	152.25	16.4	150.5	59.4	302	53.7
1 in. diam, ctr.	900F	146.75	16.2	131.75	56.5	293	55.3
2 in. diam, ½r.	900F	129.75	19.3	107.25	63.7	269	73.5
4 in. diam, ½r.	900F	113	21.3	86	64.7	235	87.3
½ in. diam[4] ctr.	1000F	139.25	18.9	132.5	58.1	285	60
1 in. diam, ctr.	1000F	134.75	18.7	123	59.6	269	62.7
2 in. diam, ½r.	1000F	120.25	21.3	100	65.6	235	90.2
4 in. diam, ½r.	1000F	107.25	23	82.5	63	217	95
½ in. diam[4] ctr.	1100F	134.5	19.2	132	61	269	66.7
1 in. diam, ctr.	1100F	118	18.7	101.25	58.2	241	76
2 in. diam, ½r.	1100F	111.25	22.5	89	68.6	223	95.7
4 in. diam, ½r.	1100F	96	25.5	72.25	68.1	197	104
Effect of Mass Interpreted from End-Quench Hardenability curve. Quenched in oil at 1550F, drawn as shown[5]; 1 in. rd. ctr.	1000F	143	19.0	120	53.5	288	–
	1100	127	21.0	102	57.0	255	–
	1200	114	22.4	88	59.3	229	–
2 in. rd. ½r.	1000	127	21.0	102	57.0	255	–
	1100	117	22.0	91	59.0	235	–
	1200	108	23.0	81	60.6	217	–
3 in. rd. ½r.	1000	119	21.9	93	58.4	238	–
	1100	111	22.7	85	60.0	223	–
	1200	106	23.4	79	61.1	212	–
4 in. rd. ½r.	1000	114	22.4	88	59.3	229	–
	1100	110	22.9	83	60.3	220	–
	1200	103	23.4	79	61.1	207	–

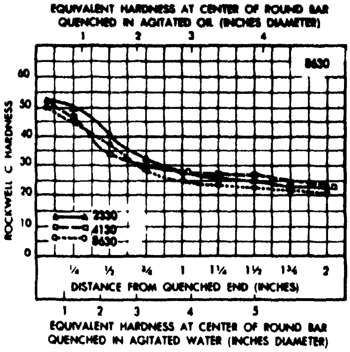
[1]Bethlehem Steel Co. Single heat values.
[2]Bethlehem Steel Co. Composition – Ladle: .30%C, .87%Mn, .26%Si, .57%Ni, .46%Cr, .22%Mo. Check .29%C, .85%Mn, .012%P, .021%S, .25%Si, .62%Ni, .44%Cr, .19%Mo. McQuaid-Ehn Grain Size = 100% 6-8. All test results are the average of two tests Size Tested .505 in. diam tensile and 0.450 in. diam Izod specimens.
[3]1550F, furnace-cooled 20F/hr to 1155F, air-cooled.
[4].357 in. diam tensile.
[5]Ryerson, aver values.
[6]Bliss & Laughlin.
[7]Surface of bar.

(Continued on page 264)

8630

(Continued from page 263)

End-Quench Hardenability



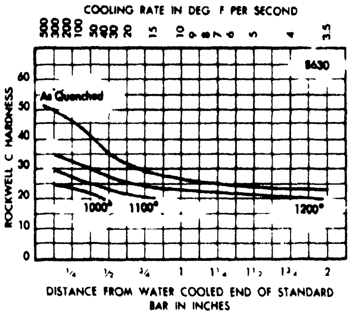
Source – Bethlehem Steel Co. Single heat results. Carburized at 1700F. Composition: (2330) .31C, .70Mn, .26Si, 3.46Ni, .03Cr, .05Mo. (4130) .31C, .54Mn, .27Si, .14Ni, 1.02Cr, .17Mo. (8630) .30C, .80Mn, .27Si, .65Ni, .48Cr, .18Mo. Grain size: 6-8 for all three steels. ⟶

As Quenched Rockwell "C" Hardness

Treatment: 1600F, air cooled, 1550F, water quench
Size Tested: 1 in. discs cut from mid-length

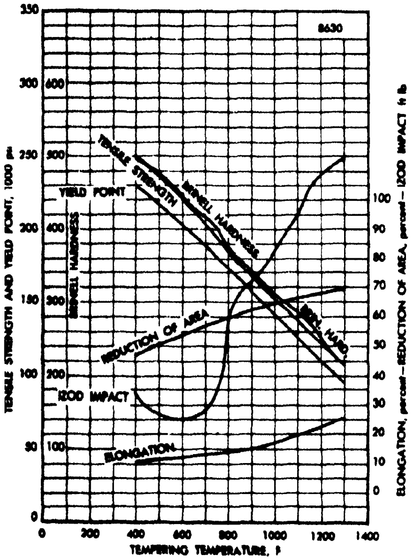
Diam	Center	Midway	Surface
½ in.	47	49	52
1 in.	43	48	52
2 in.	30	31	51
4 in.	22	25	47

End-Quench Hardenability



Source – Ryerson. Aver values. Grain Size – 5-8

Quenched and Tempered



⟵ Source: Bethlehem Steel Co. Single heat values. Composition: .30%C, .80%Mn, .018%P, .024%S, .27%Si, .65%Ni, .48%Cr, .18%Mo. Grain Size: 6 — 8. Test Conditions: 0.530 in. bars normalized at 1600F, quenched in water from 1550F, drawn as shown. Tested as 0.505 in. bars.

Critical Points

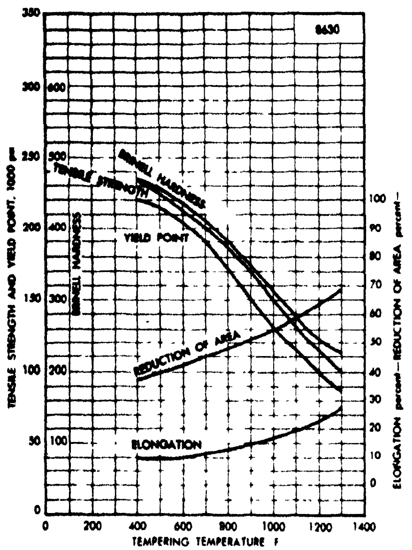
Ac_1	1355F	Ar_3	1335F
Ac_3	1445	Ar_1	1210

Treatment Temperatures[1]

Forging	2000-2250F
Annealing	1500-1600
Normalizing	1550-1650
Quenching	1500-1550

[1]Industry values, approx.

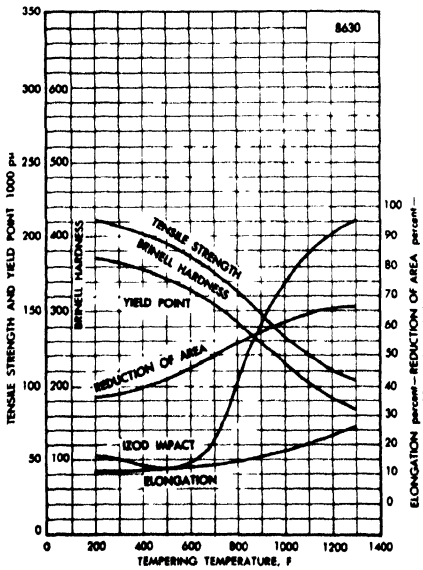
Water Quenched and Tempered



⟵Source – Republic Steel Corp. Approx values. Test conditions: 1 in. bars normalized at 1600F, quenched from 1525F in water, drawn 1 hr as shown. Tested as 0.505 in. bars. The maximum section for which these properties can be expected is 1.5 in.

Source – International Nickel⟶ Co. Aver values. Test conditions: 1 in. bars quenched from 1525-1575F in oil, drawn as shown.

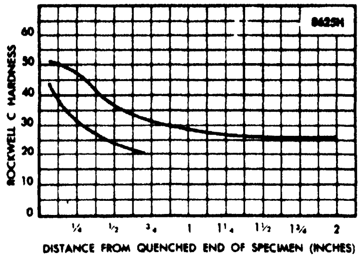
Oil Quenched and Tempered



STEELS, AISI

8625H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %	Cr %	Mo %	P %	S %
.22-.29	.60-.95	.20-.35	.35-.75	.35-.65	.15-.25	—[1]	—[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

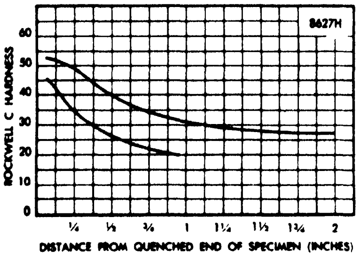
	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	50.5	50.0	48.5	46.5	44.0	41.0	38.5	37.0	35.0	34.0	32.5	32.0	31.0	30.0	29.5	29.0	28.0	27.0	26.5	26.0	26.0	26.0	26.0	26.0
Min	43.5	38.5	34.0	31.0	28.5	26.5	25.0	23.5	22.5	21.5	20.0	—	—	—	—	—	—	—	—	—	—	-	—	—

[1]Note — These values are to be used when points are selected and specified.

STEELS, AISI

8627H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %	Cr %	Mo %	P %	S %
.25-.32	.60-.95	.20-.35	.35-.75	.35-.65	.15-.25	—[1]	—[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

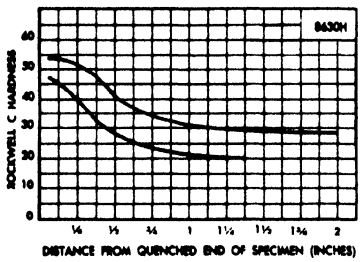
	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	52.5	52.0	50.0	49.0	47.0	44.5	42.0	40.0	38.0	36.5	35.0	34.0	33.0	32.5	31.5	31.0	30.0	29.0	28.0	28.0	27.5	27.5	27.5	27.5
Min	45.5	42.0	37.5	35.0	32.0	30.0	28.0	26.5	25.0	24.0	23.0	22.0	21.5	21.0	20.0	—	—	—	—	—	—	—	—	—

[1]Note — These values are to be used when points are selected and specified.

STEELS, AISI

8630H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %	Cr %	Mo %	P %	S %
.27-.34	.60-.95	.20-.35	.35-.75	.35-.65	.15-.25	—[1]	—[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

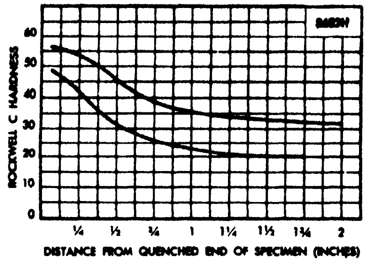
	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	54.0	54.0	53.0	51.5	50.0	47.0	44.0	41.0	38.5	37.0	35.0	34.0	33.0	32.5	32.0	31.5	30.5	30.0	29.5	29.0	29.0	29.0	29.0	29.0
Min	46.5	45.0	42.5	39.5	35.0	31.5	29.5	28.0	27.0	25.5	25.0	24.0	23.0	22.5	22.0	21.5	21.0	20.5	20.0	—	—	—	—	—

[1]Note — These values are to be used when points are selected and specified.

STEELS, AISI

8632H

End-Quench Hardenability Band



Chemical Composition

C	Mn	Si	Ni	Cr	Mo	P	S
%	%	%	%	%	%	%	%
.30-.37	.60-.95	.20-.35	.35-.75	.35-.65	.15-.25	–[1]	–[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

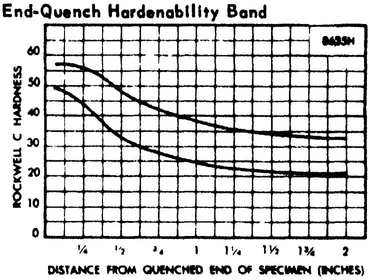
	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	55.5	55.5	55.0	54.0	52.5	50.5	48.0	45.5	43.5	42.0	40.5	39.0	38.0	37.0	36.5	35.5	34.5	33.5	33.0	32.5	32.0	32.0	31.5	31.5
Min	48.0	47.0	45.0	42.0	38.5	35.5	33.0	31.0	29.0	28.0	27.0	26.0	25.0	24.5	23.5	23.0	22.0	21.5	21.0	20.5	20.0	20.0	–	–

[1]Note – These values are to be used when points are selected and specified.

STEELS, AISI

8635H

End-Quench Hardenability Band



Chemical Composition

C	Mn	Si	Ni	Cr	Mo	P	S
%	%	%	%	%	%	%	%
.32-.39	.70-1.05	.20-.35	.35-.75	.35-.65	.15-.20	–[1]	–[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

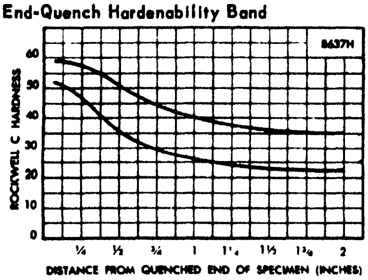
	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	57.0	57.0	57.0	56.0	55.0	53.0	51.0	48.0	46.0	44.5	43.0	42.0	40.5	39.5	39.0	38.0	37.0	36.0	35.0	34.5	34.0	33.5	33.0	33.0
Min	49.5	48.5	47.0	44.5	42.0	38.0	35.5	33.5	31.5	30.0	28.5	27.5	26.5	26.0	25.0	24.5	24.0	23.0	22.5	22.0	21.5	21.5	21.0	21.0

[1]Note – These values are to be used when points are selected and specified.

STEELS, AISI

8637H

End-Quench Hardenability Band



Chemical Composition

C	Mn	Si	Ni	Cr	Mo	P	S
%	%	%	%	%	%	%	%
.35-.43	.70-1.05	.20-.35	.35-.75	.35-.65	.15-.25	–[1]	–[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	58.5	58.5	58.0	57.5	56.5	55.0	53.0	50.5	49.0	47.0	45.5	44.0	43.0	42.0	41.0	40.0	39.0	38.0	37.0	36.5	36.0	35.5	35.5	35.0
Min	51.5	50.5	49.0	47.0	44.0	40.5	37.5	35.5	33.5	32.0	30.5	29.5	28.5	28.0	27.0	26.5	25.0	24.5	24.0	23.5	23.0	22.5	22.5	22.5

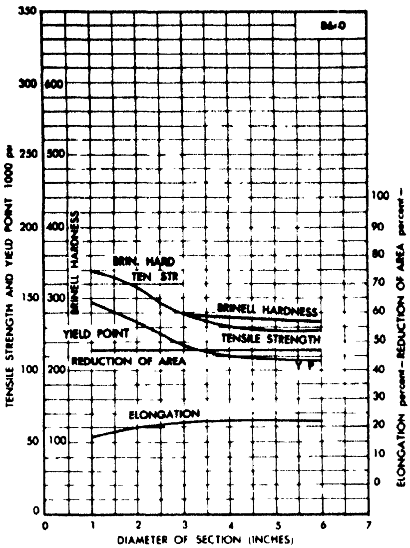
[1]Note – These values are to be used when points are selected and specified.

8640

Chemical Composition (AISI)

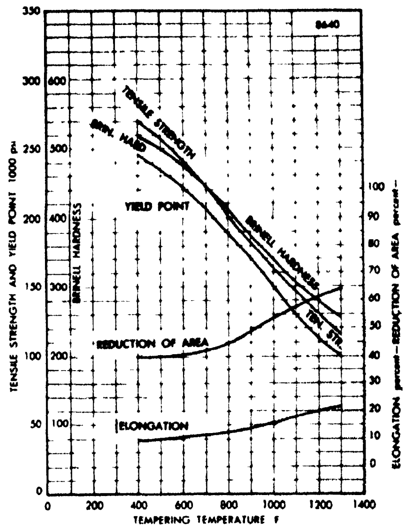
C %	Mn %	P %	S %	Si %	Ni %	Cr %	Mo %
.38-.43	.75-1.00	.040 max	.040 max	.20-.35	.40-.70	.40-.60	.15-.25

Effect of Mass **Tempered at 1000F**



Test Conditions: Sizes shown were quenched in oil and drawn as shown. Tested as 0.505 in. bars. Above 1½ in. the test bars were taken from the mid-radius position.

Effect of Mass **Tempered at 1200F**



Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	NBT Ft Lbs
Bars[1]							
Annealed	–	–	–	–	–	197	–
Normalized	–	–	–	–	–	302	–
Aver. Prop.[4] 1 in. rds. Mean chemistry — Cold drawn — unannealed	–	140	11	120	38	277[5]	–
Cold drawn — annealed	–	107	14	90	45	217[5]	–
Turned and Polished — unannealed	–	124	17	94	42	255[5]	–
Turned and Polished — annealed	–	99	24	58	46	183[5]	–
Effect of Mass[4] OQ at 1525F and tempered at 1000F, 0.505 in. tensile specimens — 1 in. diam. ctr.	–	155	17	137	56	331[5]	–
2 in. diam. ½r	–	132	18	112	57	293[5]	–
3 in. diam. ½r	–	125	19	103	58	277[5]	–
Effect of Mass Interpreted from End-Quench Hardenability curve. Quenched in oil at 1550F, drawn as shown[2] — 1 in. rd. ctr.	1000F	174	15.5	154	47.3	352	–
	1100	156	17.4	135	51.0	316	–
	1200	143	19.0	120	53.5	285	–
2 in. rd. ½r.	1000	156	17.4	135	51.0	316	–
	1100	145	18.7	123	53.0	293	–
	1200	130	20.6	106	56.3	262	–
3 in. rd. ½r.	1000	141	19.2	118	54.0	285	–
	1100	130	20.6	106	56.3	262	–
	1200	120	21.8	94	58.2	241	–
4 in. rd. ½r.	1000	131	20.4	107	56.0	269	–
	1100	122	21.6	96	57.9	244	–
	1200	111	22.7	85	60.0	223	–
Effect of Temp[4] Oil quenched at 1525F and tempered as shown 0.505 in. tensile specimens cut from center of 1 in. rds.	800F	200.5	10	179	46	415[5]	–
	900	181	13	162	51	388[5]	–
	1000	155	17	137	56	331[5]	–
	1100	148.5	16	132	57	302[5]	–
	1200	125.5	20	110.5	61	269[5]	–
	Test Temp						
Low Temp Notched Bar Tests[3] 0.420 in. sq. bars quenched and drawn to 255 BHN. Tested as Charpy bars with keyhole notch.	70F	–	–	–	–	–	45
	0	–	–	–	–	–	40
	-50	–	–	–	–	–	36
	-100	–	–	–	–	–	31
	-200	–	–	–	–	–	22
	-270	–	–	–	–	–	15
	-300	–	–	–	–	–	11

[1]Republic Steel Corp. Approx values.
[2]Ryerson. Aver values.
[3]H. W. Gillett and F. T. McGuire. "Behavior of Ferritic Steels at Low Temperatures."
[4]Bliss & Laughlin
[5]Surface of bar

(Continued on page 268)

STEELS, AISI

8640

(Continued from page 267)

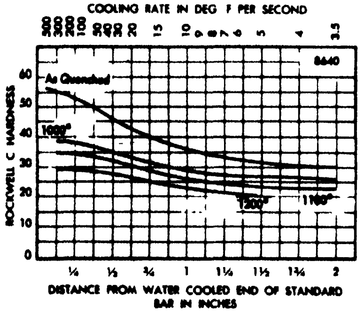
Characteristics. Compares favorably with most low alloy, 0.40%C steels and develops greater hardness and strength than 8130.

Uses. Knuckles, propeller shafts, transmission gears, spline shafts.

Technological Properties

Machinability Rating (On basis B1112 = 100)
Mill annealed to 179-229 BHN = 60%

End-Quench Hardenability



Source — Ryerson. Aver values. Grain Size = 5-8

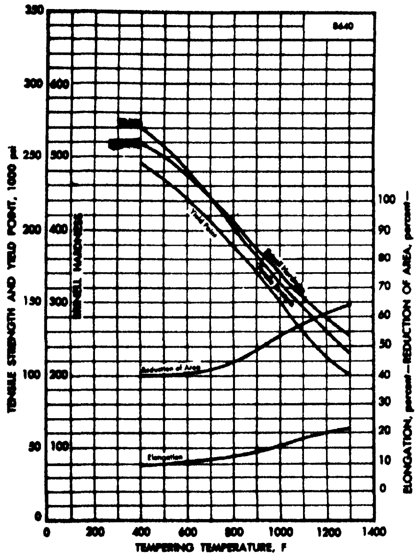
Source — Republic Steel Corp. Approx values. Test Conditions: 1 in. bars normalized at 1600F, quenched from 1525F in oil, drawn 1 hr as shown. Tested as 0.505 in. bars. The maximum section for which these properties can be expected is 1.4 in.

Treatment Temperatures[1]	
Forging	2000-2250F
Annealing	1475-1575
Normalizing	1550-1650
Quenching	1475-1550

[1]Industry values. Approx

Critical Points			
Ac_1	1360F	Ar_3	1270F
Ac_3	1430	Ar_1	1200

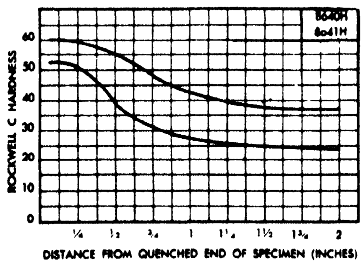
Quenched and Tempered



STEELS, AISI

8640H 8641H

End-Quench Hardenability Band



Chemical Composition	C %	Mn %	S %	Si %	Ni %	Cr %	Mo %	P %
8640H	.37-.45	.70-1.05	—[1]	.20-.35	.35-.75	.35-.65	.15-.25	—[1]
8641H	.37-.45	.70-1.05	.040-.060	.20-.35	.35-.75	.35-.65	.15-.25	—[1]

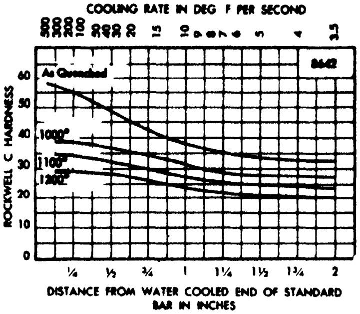
[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	60.0	60.0	60.0	59.5	58.5	58.0	56.5	55.0	53.5	52.0	50.5	48.5	46.5	45.0	43.5	42.5	40.5	39.5	38.5	37.5	37.5	37.0	37.0	37.0
Min	52.5	52.5	52.0	51.0	49.0	46.0	42.0	39.0	36.5	34.0	32.5	31.0	30.0	29.0	28.0	27.5	26.5	26.0	25.0	25.0	24.5	24.5	24.0	24.0

[1]Note — These values are to be used when points are selected and specified.

8642

End-Quench Hardenability



Source — Ryerson. Aver values. Grain size = 5-8.

Treatment Temperatures[1]

Forging	2000-2200F
Annealing	1475-1525
Normalizing	1575-1625
Quenching	1500-1525

[1] Ryerson. Aver. Grain size, 5-8

Critical Points

Ac_1	1370F	Ar_3	1265F
Ac_3	1425	Ar_1	1120

Chemical Composition[1]

C %	Mn %	P %	S %	Si %	Ni %	Cr %	Mo %
.40-.45	.75-1.00	.040 max	.040 max	.20-.35	.40-.70	.40-.60	.15-.25

[1] AISI

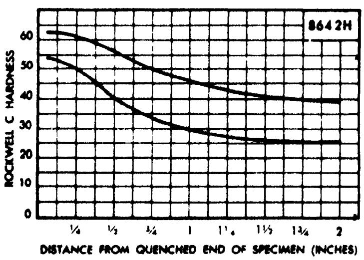
Mechanical Properties

Form or Condition		Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN
Effect of Mass Interpreted from End-Quench Hardenability curve. Quenched in oil at 1550F, drawn as shown[1]	1 in. rd. ctr.	1000F	180	15.0	161	46.1	363
		1100	159	17.2	137	50.5	321
		1200	141	19.2	118	54.0	385
	2 in. rd. ½r.	1000	163	16.8	143	49.5	331
		1100	151	18.2	129	52.0	306
		1200	131	20.4	107	56.0	269
	3 in. rd. ½r.	1000	151	18.2	129	52.0	306
		1100	138	19.7	114	54.6	277
		1200	124	21.3	99	57.5	248
	4 in. rd. ½r.	1000	141	19.2	118	54.0	285
		1100	130	20.6	106	56.3	262
		1200	117	22.0	91	59.0	235

[1] Ryerson, aver values.

8642H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %	Cr %	Mo %	P %	S %
.40-.48	.70-1.05	.20-.35	.35-.75	.35-.65	.15-.25	—[1]	—[1]

[1] P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

"J" Distance in Inches

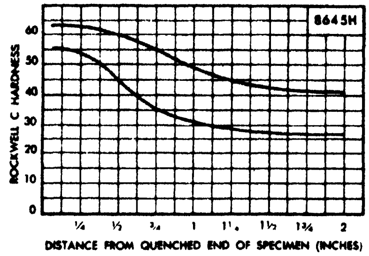
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	62.0	62.0	62.0	61.0	60.0	59.0	57.5	56.0	54.0	52.5	51.0	50.0	48.5	47.5	46.5	46.0	44.5	43.0	42.0	41.5	40.5	40.0	39.5	39.0
Min	54.0	53.0	52.0	50.5	48.0	45.5	42.5	40.5	38.0	36.5	35.0	33.5	32.0	31.0	30.0	29.5	28.5	27.5	27.0	26.0	26.0	25.5	25.5	25.5

NOTE — These values are to be used when points are selected and specified.

STEELS, AISI

8645H

End-Quench Hardenability Band



Chemical Composition

C	Mn	Si	Ni	Cr	Mo	P	S
%	%	%	%	%	%	%	%
.42-.50	.70-1.05	.20-.35	.35-.75	.35-.65	.15-.25	—[1]	—[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

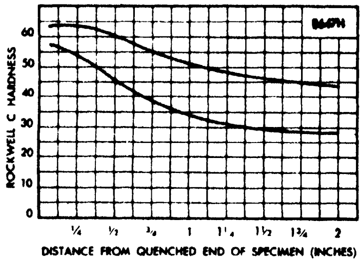
	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	63.0	63.0	63.0	62.5	62.0	61.5	60.5	59.5	58.5	57.5	56.0	55.0	54.0	52.0	50.5	49.0	46.5	45.0	43.5	42.5	41.5	41.5	41.0	41.0
Min	55.0	55.0	55.0	54.0	52.5	50.5	48.0	45.0	41.5	39.0	37.0	35.5	34.0	33.0	32.0	31.0	30.0	29.0	28.5	28.0	27.5	27.5	27.0	27.0

[1]Note — These values are to be used when points are selected and specified.

STEELS, AISI

8647H

End-Quench Hardenability Band



Chemical Composition

C	Mn	Si	Ni	Cr	Mo	P	S
%	%	%	%	%	%	%	%
.44-.52	.70-1.05	.20-.35	.35-.75	.35-.65	.15-.25	—[1]	—[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

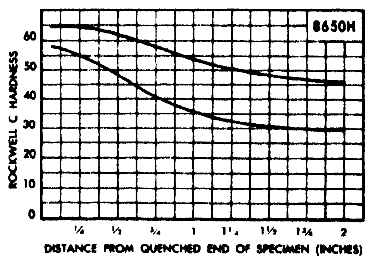
	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	64.0	64.0	64.0	64.0	63.5	62.5	61.5	60.5	59.0	57.5	56.5	55.0	54.0	93.0	52.0	51.0	49.5	48.0	47.0	46.0	45.5	45.0	44.0	43.5
Min	56.5	56.0	55.0	53.5	52.0	50.0	48.0	45.5	43.5	41.5	40.0	38.5	37.0	35.5	34.5	33.5	32.0	31.0	30.0	29.0	29.0	28.5	28.0	28.0

[1]Note — These values are to be used when points are selected and specified

STEELS, AISI

8650H

End-Quench Hardenability Band



Chemical Composition

C	Mn	Si	Ni	Cr	Mo	P	S
%	%	%	%	%	%	%	%
.46-.54	.70-1.05	.20-.35	.35-.75	.35-.65	.15-.25	—[1]	—[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	65.0	65.0	65.0	65.0	64.5	63.5	63.0	62.0	61.0	60.0	59.0	58.0	57.0	56.0	55.0	54.0	52.0	51.0	49.5	48.5	48.0	47.0	46.5	46.0
Min	58.0	57.5	56.5	55.0	53.5	52.0	50.0	48.5	46.5	44.5	42.5	41.0	39.5	38.0	37.0	36.0	34.0	32.5	31.5	31.0	30.5	30.0	29.5	29.5

[1]Note — These values are to be used when points are selected and specified.

8650

Chemical Composition[1]

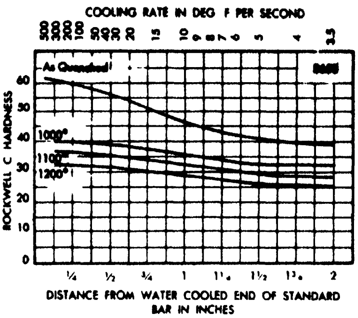
C %	Mn %	P %	S %	Si %	Ni %	Cr %	Mo %
.48-.53	.75-1.00	.040 max	.040 max	.20-.35	.40-.70	.40-.60	.15-.25

[1]AISI

Characteristics. A popular alloy spring steel of good properties with high hardness and good surface.

Uses. For sections from 1 to 2 in. the higher carbon 8660 is used. Also used for rear axle shafts.

End-Quench Hardenability



Source — Ryerson. Aver values. Grain size = 5-8.

Treatment Temperatures[1]

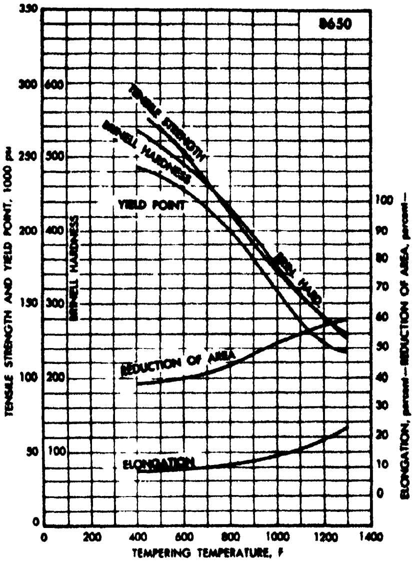
Forging	2000-2250F
Annealing	1450-1550
Normalizing	1575-1650
Quenching	1475-1525

[1]Industry values. Approx.

Critical Points

Ac_1	1340F	Ar_3	1240F
Ac_3	1400	Ar_1	1100

Quenched and Tempered



Source — Republic Steel Corp. Approx. Test conditions: 1 in. bars normalized at 1600F, quenched from 1500F in oil, drawn as shown. Tested as 0.505 in. bars. The maximum section for which these properties can be expected is 2.0 in.

Technological Properties

Machinability Rating (On basis B1112 = 100)

Mill annealed to 183-241 BHN = 50% (ASM, Metals Handbook)

Mechanical Properties

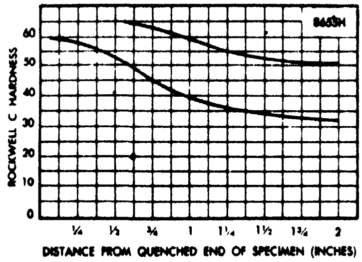
Form or Condition	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN
Bars[1]						
Annealed	–	–	–	–	–	212
Normalized	–	–	–	–	–	355
Aver. Prop.[3] Annealed 1 in. rds, Mean chemistry — Cold drawn	–	110	13	92	45	217[4]
Turned and Polished	–	112	22	69	42	223[4]
Effect of Mass[3] OQ at 1525F and tempered at 1000F; 0.505 in. tensile specimens — 1 in. diam. ctr.	–	178	14	162	50	363[4]
2 in. diam. ½r	–	159	15	142	49	341[4]
3 in. diam. ½r	–	155	16	130	48	331[4]
Effect of Mass Interpreted from End-Quench Hardenability curve. Quenched in oil at 1550F, drawn as shown[2] — 1 in. rd. ctr.	1000F	186	14.1	167	45.0	375
	1100	166	16.4	145	49.0	336
	1200	151	18.2	129	52.0	306
2 in. rd. ½r.	1000	180	15.0	161	46.1	363
	1100	161	17.0	140	50.0	326
	1200	145	18.7	123	53.0	293
3 in. rd. ½r.	1000	166	16.4	145	49.0	336
	1100	154	18.0	132	51.4	311
	1200	139	19.5	116	54.4	285
4 in. rd. ½r.	1000	156	17.4	135	51.0	316
	1100	145	18.7	123	53.0	293
	1200	131	20.4	107	56.0	269
Effect of Temp[3] Oil quenched at 1525 and Tempered as shown 0.505 in. tensile specimens cut from center of 1 in. rd.	800	228	10	206.5	37	444[4]
	900	205	12	183.5	41	415[4]
	1000	178	14	162	50	363[4]
	1100	167.5	16	146.5	50	341[4]
	1200	145	17	127.5	53	311[4]

[1]Republic Steel Corp. Approx
[2]Ryerson, aver values.
[3]Bliss & Laughlin
[4]Surface of bar

STEELS, AISI

8655H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %	Cr %	Mo %	P %	S %
.50-.60	.70-1.05	.20-.35	.35-.75	.35-.65	.15-.25	—[1]	—[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

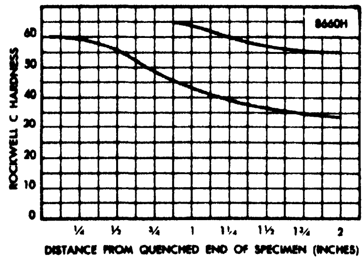
	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	–	–	–	–	–	–	–	–	65.0	64.5	64.0	63.0	62.0	61.0	60.0	59.0	57.0	55.5	54.0	53.0	52.0	51.5	51.0	50.5
Min	60.0	59.5	59.0	58.0	57.0	55.5	54.0	52.0	50.5	48.5	47.0	45.0	43.5	42.0	40.5	39.5	37.5	36.0	35.0	34.0	33.0	32.5	32.0	31.5

[1]Note – These values are to be used when points are selected and specified.

STEELS, AISI

8660H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %	Cr %	Mo %	P %	S %
.55-.65	.70-1.05	.20-.35	.35-.75	.35-.65	.15-.25	—[1]	—[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	–	–	–	–	–	–	–	–	–	–	–	–	–	65.0	64.5	64.0	62.0	60.0	58.5	57.5	56.5	56.0	55.5	55.0
Min	60.0	60.0	60.0	59.5	59.0	58.0	57.0	55.5	54.0	52.0	50.0	48.5	47.0	45.5	44.5	43.0	41.0	39.0	38.0	37.0	35.5	35.0	34.0	33.5

[1]Note – These values are to be used when points are selected and specified.

8720

Chemical Composition[1]

C %	Mn %	P %	S %
.18-.23	.70-.90	.040 max	.040 max
Si %	**Ni %**	**Cr %**	**Mo %**
.20-.35	.40-.70	.40-.60	.20-.30

[1] AISI

Technological Properties

Machinability Rating (On basis of B1112 = 100)	Cold drawn to 170-217 BHN = 60% (ASM Metals Handbook.)

Characteristics. Very similar to 8620 though its greater hardenability makes it better suited to larger sized parts.

Uses. Differential pinions, ring gears, side gears, steering worms, transmission gears in the automotive industry, (in pump parts to resist wear) rock bit cutters, etc. Another use is for spline shafts.

Compressive Strength[1]

The permissable compressive stress for case-hardened gears, bearings and races is 180M psi for intermittent loading. For constant mesh loading this value should be reduced 20-25%. This assumes good practice, adequate section thickness, and freedom from carbide network in the case.

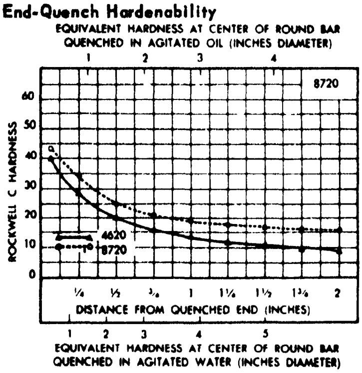
[1] International Nickel Co.

Rockwell "C" Core Hardness[1]
Quenched in Oil at 1700 F

Size of Round	7/8 Radius	1/2 Radius	Center
1 in. rd	37	33	32
2 in. rd	29	23	21
3 in. rd	22	19	16.5

[1] Ryerson, Aver values.

End-Quench Hardenability



Source — Bethlehem Steel Co. Single heat results. Analysis: (4620) .17%C, .50%Mn, .26%Si, 1.86%Ni, .12%Cr, .28%Mo. (8720) .22%C, .90%Mn, .30%Si, .48%Ni, .52%Cr, .22%Mo. Carburized grain size at 1700F = 6-8.

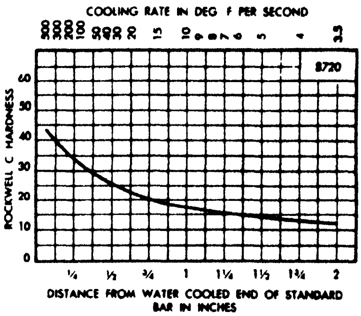
Treatment Temperatures

Forging	1950-2250F
Annealing	1575-1625
Normalizing	1650-1750
Carburizing	1650-1700
Quenching	—

Critical Points

Ac_1	1375F	Ar_3	1400
Ac_3	1535	Ar_1	1200

End-Quench Hardenability



Source: Ryerson. Aver results.

Mechanical Properties

Form or Condition			Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	BHN	Hardness Rock C core	Rock C case	Izod Ft Lbs
Bars,[1] Annealed			—	—	—	—	—	163	—	—	—
Normalized			—	—	—	—	—	202	—	—	—
Case hardened, single heat[2]											
Carburized at 1700F for 8 hrs quenched in agitated oil	direct quench from pot		300F	205.5	14.5	168.5	49.7	415	—	58.5[5]	23
	pot cooled	1550F	300F	191.5	13.5	170.25	51.1	388	—	63[4]	26
	reheat	1550 and 1475, double OQ	300F	142.25	20.5	81.25	46.4	293	—	61[4]	41
	direct quench from pot		450	199	14	166	52	415	—	58[3]	23
	pot cooled	1550F	450	187	14	162.5	49.1	388	—	61[4]	28
	reheat	1550 and 1475, double OQ	450	130.5	23.5	83	58	269	—	60[4]	62
Carburized at 1700F for 8 hrs treated as shown, 1 in. bars	direct quench from pot		300	150	16	120	46	—	32	62	—
	box cooled	1575F	300	134	18	107	48	—	28	63	—
	reheat	1475F	300	129	22	79	52	—	22	62	—
		1575 and 1475, double OQ	300	126	23	82	54	—	25	62	—

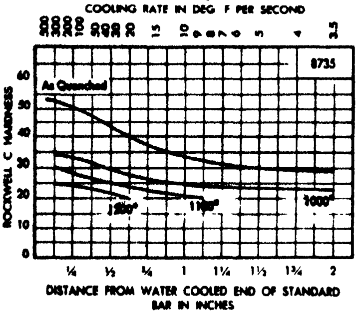
[1] Bethlehem Steel Co. Single heat results for 0.565 in. diam.
[2] Bethlehem Steel Co. Composition: .22%C, .90%Mn, .024%P, .024%S, .30%Si, .48%Ni, .52%Cr, .22%Mo. Grain Size : 6-8. Test Conditions 0.565 in. rds treated as shown. Tested as 0.505 in. bars. Normalized at 1675F., Air cooled to 202 Brinell. Annealed at 1600F. Furnace cooled to 163 Brinell.
[3] .0625 in. case depth.
[4] .055 in. case depth.
[5] Ryerson, Aver values. Grain Size: 5-8.

STEELS, AISI
8735

Chemical Composition[1]			
C %	Mn %	P %	S %
.33-.38	.75-1.00	.040 max	.040 max
Si %	Ni %	Cr %	Mo %
.20-.35	.40-.70	.40-.60	.20-.30

[1] AISI

End-Quench Hardenability



Source: Ryerson, aver values. Grain size 5-8.

Characteristics. Similar to 8630 and 8640.

Uses. Knuckles, aircraft engine bolts and studs, shapes, tubing.

Technological Properties

Machinability Rating (On basis of B1112 = 100)	Mill annealed to 179-229 = 65% (ASM Metals Handbook.)

Treatment Temperatures[1]	
Forging	2000-2200F
Annealing	1475-1525
Normalizing	1575-1625
Quenching -oil	1500-1575

[1] Ryerson

Critical Points			
Ac_1	1370F	Ar_3	1300
Ac_3	1450	Ar_1	1180

Mechanical Properties

Form or Condition		Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN
Effect of Mass Interpreted from End-Quench hardenability curve. Quenched in oil at 1550F drawn as shown[1]	1 in. rd. ctr.	1000F	149	18.4	127	52.3	302
		1100	131	20.4	107	56.0	269
		1200	119	21.9	93	58.4	238
	2 in. rd. ½r	1000	138	19.7	114	54.6	277
		1100	122	21.6	96	57.9	244
		1200	111	22.7	85	60.0	223
	3 in. rd. ½r	1000	127	21.0	102	57.0	255
		1100	114	22.4	88	59.3	229
		1200	106	23.4	79	61.1	212
	4 in. rd. ½r	1000	122	21.6	96	57.9	244
		1100	110	22.9	83	60.3	220
		1200	103	23.7	76	61.6	207

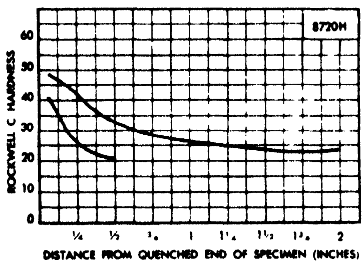
[1] Ryerson, aver values

STEELS, AISI
8720H

Chemical Composition			
C %	Mn %	P %[1]	S %[1]
.17-.24	.60-.95	—	—
Si %	Ni %	Cr %	Mo %
.20-.35	.35-.75	.35-65	.20-.30

[1] The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

End-Quench Hardenability Band



	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	48.0	46.5	44.5	41.5	38.0	36.0	34.0	33.0	31.5	30.0	29.5	28.5	28.0	27.0	26.5	26.5	25.5	25.0	24.5	24.0	23.5	23.5	23.5	23.5
Min	40.5	35.5	29.0	25.5	23.5	22.0	21.0	20.5	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

[1] These values are to be used when points are selected and specified.

8740

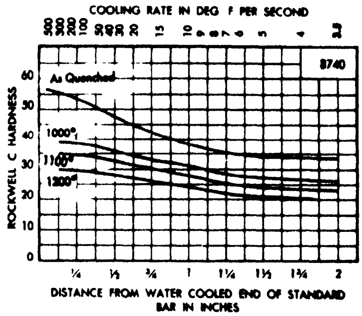
Chemical Composition[1]			
C %	Mn %	P %	S %
.38-.43	.75-1.00	.040 max	.040 max
Si %	Ni %	Cr %	Mo %
.20-.35	.40-.70	.40-.60	.20-.30

[1] AISI

Characteristics. Similar to 4140.

Uses. Knuckles, connecting rods, propeller shafts, transmission gears, rear axle and trailer shafts, tool joints, bits, core drills, reamer bodies, drill collars, piston rods, pump parts, aircraft engine bolts and studs, shapes and tubing.

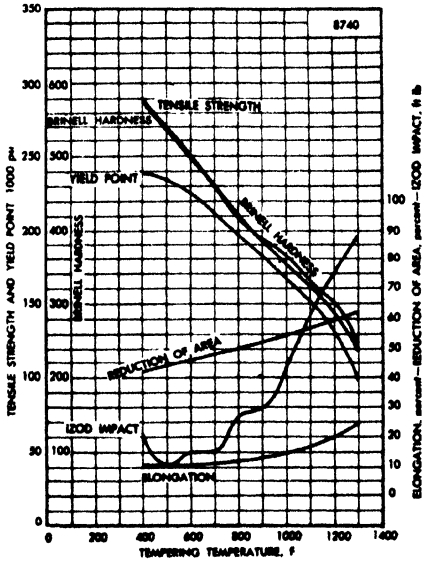
End-Quench Hardenability



Source: Ryerson, aver values. Grain size 5-8.

Quenched and Tempered

Source: Bethlehem Steel Co. Single heat values. Composition: .39%C, 1.00%Mn, .012%P, .017%S, .25%Si, .53%Ni, .52%Cr, .28%Mo. Grain Size: 6 - 8. Test Conditions: 0.565 in. bars normalized at 1600F, quenched from 1525F in agitated oil, drawn as shown. Tested as 0.505 in. bars.



Mechanical Properties

Form or Condition		Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Izod Ft Lbs
Bars,[1] Annealed		–	–	–	–	–	207	–
Normalized		–	–	–	–	–	302	–
Effect of Mass:[2] Single heat		–	–	–	–	–	–	–
Annealed[3]	1 in. diam ctr	–	100.75	22.2	60.25	46.4	201	29.5
Normalized 1600F, Air cooled	½ in.[4] diam ctr	–	135.5	16	89.5	47.2	269	9.2
	1 in. diam ctr	–	134.75	16	88	47.9	269	13
	2 in. diam ½r	–	132	16.7	87.5	50.2	262	12
	4 in. diam ½r	–	132	15.5	87	46.2	255	10
Normalized, Quenched, Tempered								
1600F air cooled, 1525F Oil Tower quenched	½ in.[4] diam ctr	1000	179	15.5	165	47.4	352	34
	1 in. diam ctr		178.5	16	164.25	53	352	35.5
	2 in. diam ½r		170.75	15.7	153.5	52.8	331	40.5
	4 in. diam ½r		138.75	18	108.5	55.6	277	36.2
	½ in.[4] diam ctr	1100	153.5	17.4	139.5	55	311	55.5
	1 in. diam ctr		149.25	18.3	134.5	59.9	302	67.5
	2 in. diam ½r		142.5	18.5	122.5	62	277	77.7
	4 in. diam ½r		123.75	20.5	96.75	59.8	248	75
	½ in.[4] diam ctr	1200	140	19.9	127.25	60.7	285	70.5
	1 in. diam ctr		138	20	123	60.7	285	75.7
	2 in. diam ½r		127.25	21.5	105.75	65.4	255	89.7
	4 in. diam ½r		115.5	22.7	88.25	62.9	229	85.2
Effect of Mass Interpreted from End-Quench Hardenability curve Quenched in oil at 1550F drawn as shown[5]	1 in. rd. ctr	1000F	174	15.5	154	47.3	352	–
		1100	159	17.2	137	50.5	321	–
		1200	141	19.2	118	54.0	285	–
	2 in. rd. ½r	1000	163	16.8	143	49.5	331	–
		1100	149	18.4	127	52.3	302	–
		1200	131	20.4	107	56.0	269	–
	3 in. rd. ½r	1000	149	18.4	127	52.3	302	–
		1100	138	19.7	114	54.6	277	–
		1200	124	21.3	99	57.5	248	–
	4 in. rd. ½r	1000	136	20.0	113	55.0	273	–
		1100	127	21.0	102	57.0	255	–
		1200	114	22.4	88	59.3	229	–

[1] Bethlehem Steel Co.
[2] Bethlehem Steel Co. Composition: Ladle: .41%C, .87%Mn, .24%Si, .65%Ni, .55%Cr, .27%Mo, Check: .41%C, .90%Mn, .016%P, .010%S, .25%Si, .63%Ni, .53%Cr, .29%Mo, McQuaid-Ehn Grain Size – 100% 7-8, Size Tested: 0.505 in. diam tensile and 0.450 in. diam Izod specimens.
[3] 1500F, Furnace Cooled – 20F/hr to 1100F, Air Cooled.
[4] 0.357 in. diam tensile.
[5] Ryerson, aver values.

(Continued on page 276)

STEELS, AISI
8740

Critical Points

Ac_1	1370F	Ar_3	1265
Ac_3	1435	Ar_1	1160

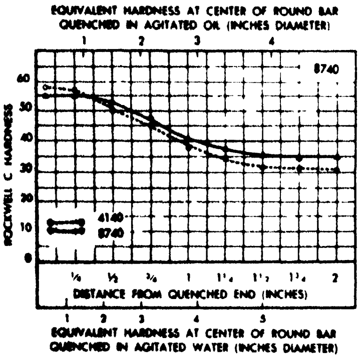
(Continued from page 275)

Oil Quenched Rockwell "C" Hardness

Treatment: 1600F, Air Cooled 1525F, Oil Tower Quenched.
Size Tested: 1 in. discs cut from midlength.

	Center	Midway	Surface
(½ in. diam)	56	56	57
(1 in. diam)	54	55	56
(2 in. diam)	45	49	52
(4 in. diam)	36	37	43

End-Quench Hardenability



Treatment Temperatures[1]

Forging	2000-2200F
Annealing	1475-1525
Normalizing	1575-1625
Quenching -oil	1500-1575

[1] Ryerson

Source – Bethlehem Steel Co. Single heat results. Analysis: .40C oil-hardening grades (4140) .41%C, .85%Mn, .20%Si, .12%Ni, 1.01%Cr, .24%Mo. (8740) .40%C, .95%Mn, .25%Si, .55%Ni, .55%Cr, .25%Mo. Grain size 6-8, carburized at 1700F.

Technological Properties

Machinability Rating (On basis of B1112 = 100)	Mill annealed to 179-229 BHN = 60% (ASM Metals Handbook.)

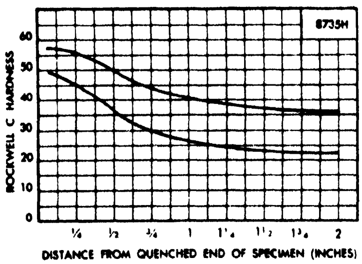
STEELS, AISI
8735H

Chemical Composition

C %	Mn %	P %	S %
.32-.39	.70-1.05	—[1]	—[1]
Si %	**Ni %**	**Cr %**	**Mo %**
.20-.35	.35-.75	.35-.65	.20-.30

[1] The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

End-Quench Hardenability Band



"J" Distance in Inches[1]	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	57.0	57.0	56.5	56.0	55.0	53.5	52.0	50.0	48.0	47.0	45.5	44.5	43.0	42.5	41.5	41.0	39.5	38.5	38.0	37.5	37.0	36.5	36.0	36.0
Min	49.5	48.5	47.5	45.5	43.5	41.0	38.5	36.0	34.0	32.0	31.0	29.5	28.5	28.0	27.0	26.5	25.5	24.5	24.0	23.5	23.0	23.0	22.5	22.5

[1] These values are to be used when points are selected and specified.

8742

Mechanical Properties

Form or Condition		Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN
Effect of Mass Interpreted from End-Quench Hardenability curve Quenched in oil at 1550F, drawn as shown[1]	1 in. rd ctr	1000	180	15.0	161	46.1	363
		1100	161	17.0	140	50.0	326
		1200	141	19.2	118	54.0	285
	2 in. rd ½r	1000	168	16.1	148	48.5	341
		1100	156	17.4	135	51.0	316
		1200	138	19.7	114	54.6	277
	3 in. rd ½r	1000	156	17.4	135	51.0	316
		1100	145	18.7	123	53.0	293
		1200	130	20.6	106	56.3	262
	4 in. rd ½r	1000	149	18.4	127	52.3	302
		1100	141	19.2	118	54.0	285
		1200	125	21.1	100	57.2	251

[1] Ryerson, aver values

Critical Points

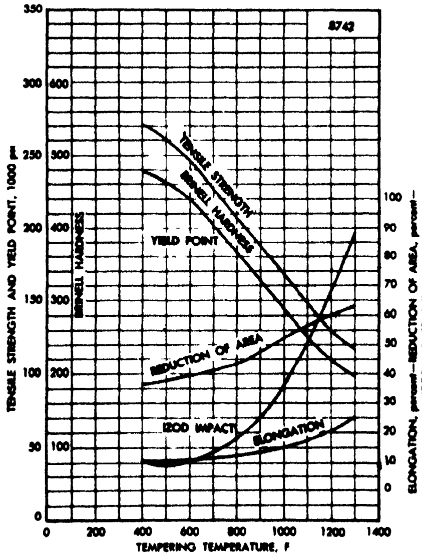
Ac_1	1370F
Ac_3	1425
Ar_3	1255
Ar_1	1110

Treatment Temperatures[1]

Forging	2000-2200F
Annealing	1475-1525
Normalizing	1575-1625
Quenching -oil	1500-1575

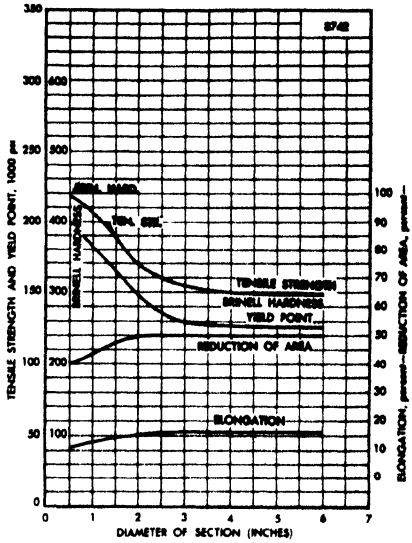
[1] Ryerson

Oil Quenched and Tempered



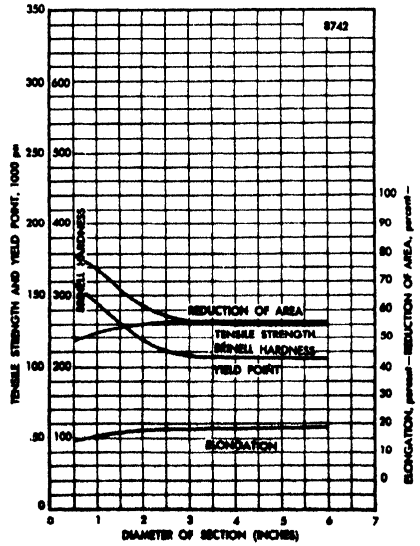
← Source: International Nickel Co. Aver values. Test conditions: 1 in. sections quenched from 1500-1550F in oil, drawn as shown.

Oil Quenched, Tempered at 800F

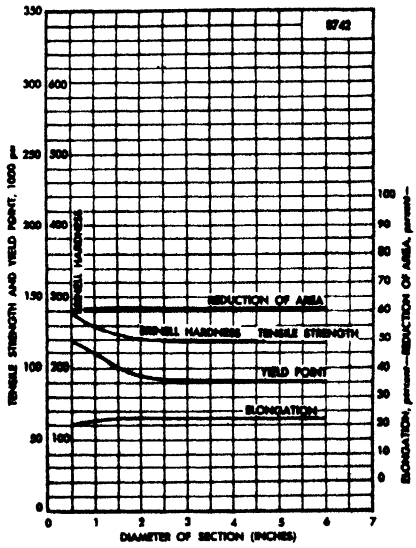


Effect of Mass. Source: → International Nickel Co., aver values. Test conditions: sections ½ to 2 in. inclusive quenched from 1500-1550F in oil, over 2 in. to 4 in. inclusive quenched from 1525-1575F in oil, sections over 4 in. quenched from 1550-1600F in oil, drawn as shown. For sizes over 1 in. the properties represent the ← half radius position. →

Oil Quenched, Tempered at 1000F



Oil Quenched, Tempered at 1200F



(Continued on page 278)

STEELS, AISI

8742

(Continued from page 277)

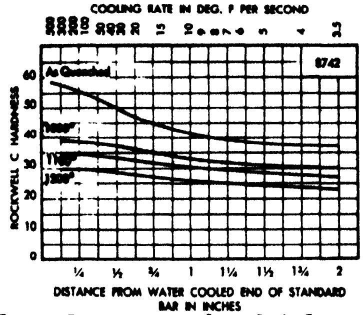
Chemical Composition[1]

C %	Mn %	P %	S %
.40-.45	.75-1.00	.040 max	.040 max
Si %	**Ni %**	**Cr %**	**Mo %**
.20-.35	.40-.70	.40-.60	.20-.30

[1]non-standard

Characteristics. Similar to 8740 with greater strength and hardness. In smaller sizes, similar to 8642.

End-Quench Hardenability



Source: Ryerson, aver values. Grain Size 5-8

STEELS, AISI

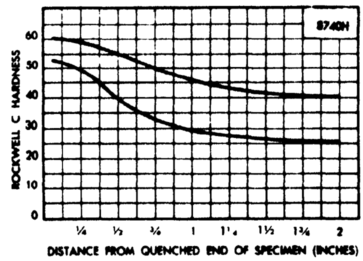
8740H

Chemical Composition

C %	Mn %	P %	S %
.37-.45	.70-1.05	—[1]	—[1]
Si %	**Ni %**	**Cr %**	**Mo %**
.20-.35	.35-.75	.35-.65	.20-.30

[1]The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

End-Quench Hardenability Band



	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	60.0	60.0	60.0	59.0	58.5	57.5	56.5	55.0	54.0	52.5	51.5	50.0	49.0	48.0	47.0	46.0	44.5	43.0	42.5	42.0	41.5	41.0	40.5	40.5
Min	52.5	52.0	51.0	49.5	47.5	45.0	42.5	40.0	37.5	36.0	34.0	33.0	32.0	31.0	30.0	29.5	28.0	27.5	27.0	26.5	26.0	25.5	25.5	25.5

[1]These values are to be used when points are selected and specified

STEELS, AISI

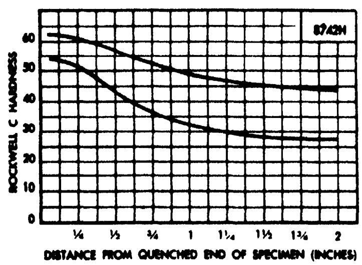
8742H

Chemical Composition

C %	Mn %	P %	S %
.40-.48	.70-1.05	—[1]	—[1]
Si %	**Ni %**	**Cr %**	**Mo %**
.20-.35	.35-.75	.35-.65	.20-.30

[1]The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

End-Quench Hardenability Band



	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	62.0	62.0	61.5	61.0	60.0	59.0	58.0	57.0	56.0	55.0	54.0	53.0	52.0	51.0	50.0	49.0	48.0	47.0	46.0	45.5	45.0	44.5	44.0	44.0
Min	54.0	53.5	53.0	51.5	50.0	48.0	45.5	43.0	41.5	39.5	37.5	36.0	35.0	34.0	33.0	32.0	30.5	29.5	29.0	28.5	28.0	28.0	28.0	28.0

[1]These values are to be used when points are selected and specified.

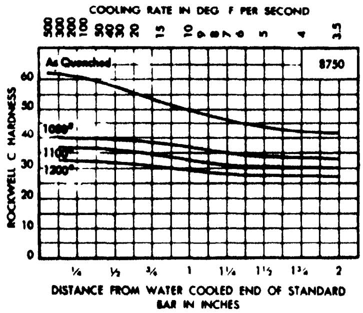
8750

Chemical Composition[1]

C %	Mn %	P %	S %
.48-.53	.75-1.00	.040 max	.040 max
Si %	**Ni %**	**Cr %**	**Mo %**
.20-.35	.40-.70	.40-.60	.20-.30

[1] AISI

End-Quench Hardenability



Source: Ryerson, aver values. Grain size 5-8.

Treatment Temperatures[1]

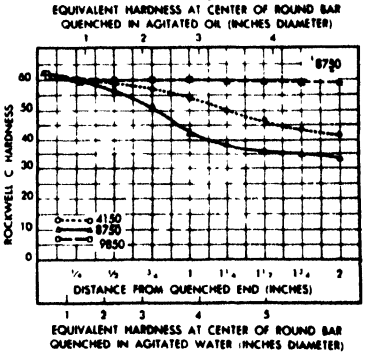
Forging	2000-2200F
Annealing	1450-1500
Normalizing	1575-1625
Quenching -oil	1500-1575

[1] Ryerson

Critical Points

Ac_1	1325F	Ar_3	1230
Ac_3	1390	Ar_1	1000

End-Quench Hardenability



Source: Bethlehem Steel Co. Single heat results. Analysis, .50C, oil-hardening grades. (4150) .50%C, .76%Mn, .21%Si, .20%Ni, .95%Cr, .21%Mo, carburized grain size at 1700F 90% 7-8. (8750) .51%C, .80%Mn, .24%Si, .53%Ni, .52%Cr, .25%Mo, grain size 6-8. (9850) .51%C, .84%Mn, .25%Si, 1.05%Ni, .88%Cr, .24%Mo, grain size 5-8.

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Izod Ft Lbs
Bars,[1] Annealed	–	–	–	–	–	201	–
Normalized	–	–	–	–	–	293	–
Effect of Mass[2] single heat	–	–	–	–	–	–	–
Annealed 1 in. diam ctr.	–	103.75	22.5	56	46.4	212	21.7
Normalized ½ in.[3] diam ctr.	–	182	10.3	131.25	25.3	363	7.5
1600F air cooled 1 in. diam ctr.	–	148.5	14	99.75	40.4	302	10
2 in. diam ½r.	–	144.25	15.5	95.75	44.8	293	10.2
4 in. diam ½r.	–	139.25	15	93.25	40.5	285	7
Normalized-Quenched-Tempered							
1600F air cooled 1475F oil tower quenched ½ in.[3] diam ctr.	1000F	177.5	14.6	168.75	48.2	363	30.2
1 in. diam ctr.	1000F	172.5	14.5	159.75	49.2	352	36
2 in. diam ½r.	1000F	165.25	17	148.5	55.6	331	47.5
4 in. diam ½r.	1000F	143.25	18.7	113	54.9	285	30
½ in.[3] diam ctr.	1100F	154.5	17.8	151	55	321	51
1 in. diam ctr.	1100F	153.5	17.7	142.75	57.3	311	52.2
2 in. diam ½r.	1100F	145	20	131	61	293	68.7
4 in. diam ½r.	1100F	126.25	22	98.5	61.2	255	51
½ in.[3] diam ctr.	1200F	148	18.5	137	54.8	293	52.2
1 in. diam ctr.	1200F	141	19.5	132	59.8	285	61.2
2 in. diam ½r.	1200F	135.25	21.2	121	62.3	277	78.7
4 in. diam ½r.	1200F	121.75	22.5	94	59.8	241	74.5
Effect of Mass Interpreted from End-Quench Hardenability curve Quenched in oil at 1550F, drawn as shown[4] 1 in. rd. ctr.	1000F	188	13.9	169	44.0	379	–
	1100	171	15.9	151	48.1	346	–
	1200	151	18.2	129	52.0	306	–
2 in. rd. ½r.	1000	186	14.1	167	45.0	375	–
	1100	166	16.4	145	49.0	336	–
	1200	149	18.4	127	52.3	302	–
3 in. rd. ½r.	1000	174	15.5	154	47.3	352	–
	1100	159	17.2	137	50.5	321	–
	1200	143	19.0	120	53.5	288	–
4 in. rd. ½r.	1000	163	16.8	143	49.5	331	–
	1100	149	18.4	127	52.3	302	–
	1200	138	19.7	114	54.6	277	–

[1] Bethlehem
[2] Bethlehem Steel Co. Composition Ladle: .48%C, .88%Mn, .27%Si, .59%Ni, .53%Cr, .25%Mo, Check: .48%C, .86%Mn, .020%P, .016%S, .31%Si, .58%Ni, .53%Cr, .24%Mo. Mc Quaid-Ehn Grain Size- 100% 6-8. All test results are the average of two tests. 0.505 in. diam tensile and 0.450 in. diam Izod specimens.
[3] Size Tested: .357 in. diam tensile
[4] Ryerson, aver values.

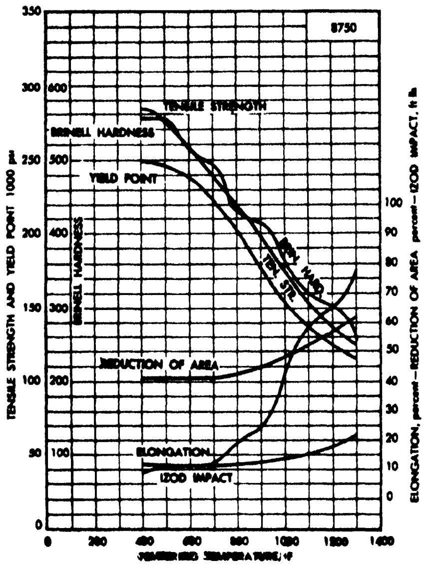
(Continued on page 280)

STEELS, AISI

8750

(Continued from page 279

Quenched and Tempered



Technological Properties

Machinability Rating (On basis B1112 = 100)	Mill annealed to 183-241 = 50% (ASM Metals Handbook.)

As Quenched Rockwell "C" Hardness

Treatment: 1600 F, Air Cooled 1475 F, Oil Tower Quenched
Size Tested: 1 in. discs cut from mid-length.

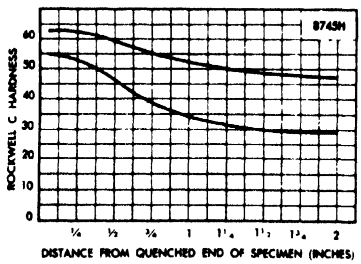
	Center	Midway	Surface
(½ in. diam)	61	61	61
(1 in. diam)	57	58	58
(2 in. diam)	52	53	53
(4 in. diam)	38	39	42

Source: Bethlehem Steel Co. Single heat results. Composition: .51%C, .80%Mn, .018%P, .019%S, .24%Si, .53%Ni, .52%Cr, .25%Mo. Grain Size: 6 - 8. Test Conditions: 0.530 in. bars normalized at 1600F, quenched from 1475F in agitated oil, drawn as shown. Tested as 0.505 in. bars.

STEELS, AISI

8745H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	P %	S %
.42-.50	.70-1.05	—[1]	—[1]

Si %	Ni %	Cr %	Mo %
.20-.35	.35-.75	.35-.65	.20-.30

[1]The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

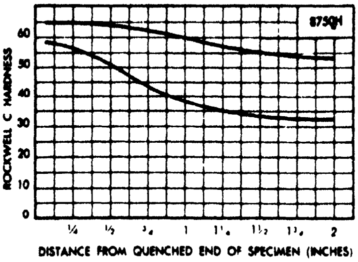
"J" Distance in Inches[1]	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	63.0	63.0	63.0	62.5	62.0	61.0	60.0	59.5	58.5	58.0	57.0	56.0	55.0	54.5	53.5	52.5	51.5	50.0	49.5	48.5	48.0	47.5	47.0	47.0
Min	55.0	55.0	54.5	53.5	52.0	50.0	48.0	45.5	43.5	41.5	40.0	38.5	37.0	36.0	35.0	34.0	32.5	31.5	30.5	30.0	30.0	29.5	29.5	29.5

[1]These values are to be used when points are selected and specified

STEELS, AISI

8747H

End-Quench Hardenability Band



Chemical Composition

C	Mn	P	S
%	%	%[1]	%[1]
.44-.52	.70-1.05	—	—
Si	**Ni**	**Cr**	**Mo**
%	%	%	%
.20-.35	.35-.75	.35-.65	.20-.30

[1] The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

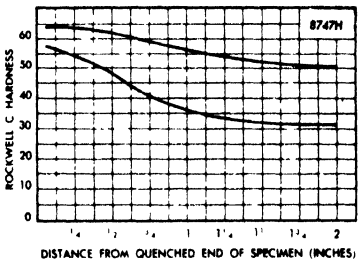
	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	64.0	64.0	64.0	63.5	63.0	63.0	62.5	62.0	61.0	60.5	59.5	59.0	58.5	58.0	57.0	56.5	55.0	54.0	53.0	52.0	51.5	51.0	50.5	50.5
Min	56.5	56.0	55.5	54.5	53.0	52.0	50.0	48.0	46.0	44.0	42.5	41.0	39.5	38.5	37.5	36.0	34.5	33.0	32.5	32.0	31.5	31.0	31.0	31.0

[1] These values are to be used when points are selected and specified.

STEELS, AISI

8750H

End-Quench Hardenability Band



Chemical Composition

C	Mn	P	S
%	%	%[1]	%[1]
.46-.54	.70-1.05	—	—
Si	**Ni**	**Cr**	**Mo**
%	%	%	%
.20-.35	.35-.75	.35-.65	.20-.30

[1] The P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	65.0	65.0	65.0	65.0	65.0	65.0	64.5	64.0	64.0	63.5	63.0	62.5	62.0	61.5	61.0	60.0	59.0	57.5	56.5	55.5	55.0	54.5	54.0	54.0
Min	58.0	58.0	57.5	56.5	55.5	54.5	53.0	51.0	49.0	47.0	45.0	43.5	42.0	40.5	39.5	38.5	37.0	35.0	34.0	33.5	33.0	33.0	32.5	32.5

[1] These values are to be used when points are selected and specified.

9255

Chemical Composition[1]				
C %	Mn %	P %	S %	Si %
.50-.60	.70-.95	.040 max	.040 max	1.80-2.20

[1]AISI

Critical Points[1]

Ac_1	1410F	Ar_3	1330
Ac_3	1480	Ar_1	1270

[1]Bethlehem Steel Co.

Characteristics and Uses: Similar to 9261 though with slightly less hardenability.

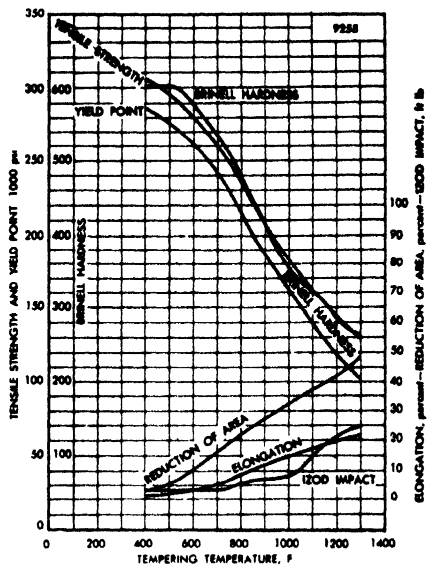
As Quenched Rockwell "C" Hardness

Treatment: 1650 F, Air Cooled, 1625 F Oil Tower Quenched
Size Tested: 1 in. discs cut from mid-length

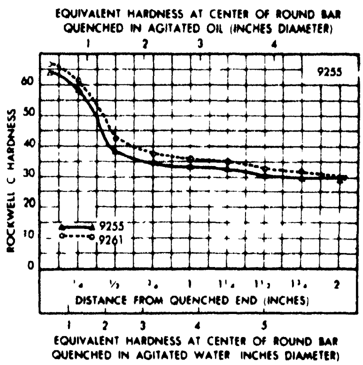
	Center	Midway	Surface
½ in. diam	58	59	61
1 in. diam	48	55	57
2 in. diam	33	37	52
4 in. diam	27½	31½	35½

Source: Bethlehem Steel Co. Single heat results. Composition: .58%C, .78%Mn, .020%P, .024%S, 2.00%Si, .08%Ni, .08%Cr, Mo nil. Grain Size: 6 - 8. Test Conditions: 1 in. bars normalized at 1650F, quenched from 1625F in agitated oil, drawn as shown. Tested as 0.505 in. bars.

Quenched and Tempered



End Quench Hardenability



Source: Bethlehem Steel Co. Single heat results. Analysis: (9255) .55%C .70%Mn, 1.95%Si, .08%Ni, .08%Cr, Tr Mo, (9261) .59%C, .80%Mn, 1.96%Si, .02%Ni, .23%Cr, Tr Mo. Carburized grain size at 1700F: (9255) 6-7, (9261) 6-8.

Mechanical Properties

Form or Condition		Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Izod Ft Lbs
Bars[1] Annealed		–	–	–	–	–	223	–
Normalized		–	–	–	–	–	277	–
Effect of Mass[2] single heat		–	–	–	–	–	–	–
Annealed[3]	1 in. diam ctr.	–	112.75	21.7	70.5	41.2	229	6.5
Normalized 1650F, air cooled	½ in. diam[4] ctr.	–	137.5	20	85.25	45.5	277	8.5
	1 in. diam ctr.	–	135.25	19.7	84	43.4	269	10
	2 in. diam ½r.	–	135	19.5	82	39.5	269	6
	4 in. diam ½r.	–	133	18.7	79.5	36.2	269	6
Normalized-Quenched-Tempered 1650F, air cooled, 1625F, oil tower quenched drawn as shown air cooled	½ in. diam[4] ctr.	1000F	170	14.9	146.5	40	331	13
	1 in. diam ctr.	1000F	164.25	16.7	133.75	38.3	321	11.5
	2 in. diam ½r.	1000F	154.75	18	102.5	45.6	302	9.5
	4 in. diam ½r.	1000F	149	19.2	94	43.7	293	5.2
	½ in. diam[4] ctr.	1100F	155	18.1	132.25	45.3	302	27.7
	1 in. diam ctr.	1100F	150	19.2	118	44.8	293	20.2
	2 in. diam ½r.	1100F	145.5	20	91.75	48.7	293	8.7
	4 in. diam ½r.	1100F	137	21	83	46	277	8.5
	½ in. diam[4] ctr.	1200F	144.75	21	123	50.4	285	33
	1 in. diam ctr.	1200F	138	21.2	106.5	48.2	277	23.7
	2 in. diam ½r.	1200F	137.5	21	87.25	50.7	277	12.2
	4 in. diam ½r.	1200F	132.25	21.7	81.75	48.3	262	11.5

[1]Bethlehem Steel Co.
[2]Bethlehem Steel Co. Composition-Ladle: .53%C, .78%Mn, 2.18%Si, .07%Ni, .12%Cr, .03%Mo. Check: .51%C, .75%Mn, .024%P, .016%S, 2.20%Si, .07%Ni, .12%Cr, .01%Mo. Grain Size. 100% 6-8. All test results are the average of two tests. Size Tested: 0.505 in. diam tensile and 0.450 in. diam Izod specimens
[3]1550F, Furnace Cooled 20F/hr to 1220F, Air Cooled.
[4].357 in. diam tensile.

STEELS, AISI

9260 9261 9262

Chemical Composition[1]

	C %	Mn %	P %	S %	Si %	Cr %
9260	.55-.65	.70-1.00	.040 max	.040 max	1.80-2.20	—
9261	.55-.65	.75-1.00	.040 max	.040 max	1.80-2.20	.10-.25
9262	.55-.65	.75-1.00	.040 max	.040 max	1.80-2.20	.25-.40

[1]AISI

Treatment Temperatures

Steel 9260

Forging		2000-2200F
Annealing	<Ac_1,	1525-1575
Normalizing		1600-1650
Quenching	Oil -	1575-1625

Critical Points[1] Steel 9261

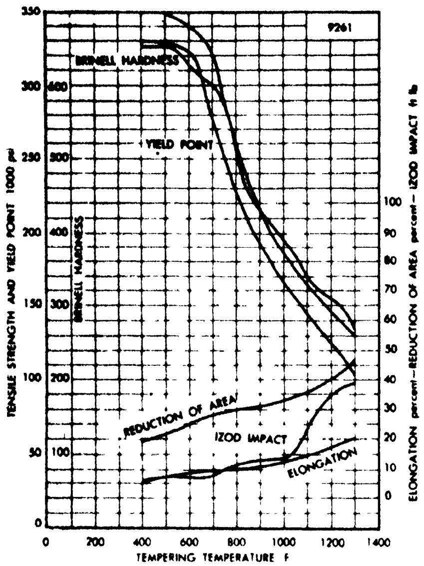
Ac_1	1440F	Ar_3	1345F
Ac_3	1490	Ar_1	1330

[1]Bethlehem Steel Co.

Characteristics. These are alloy steel spring steels, oil-hardening type. The chromium additions give greater hardenability for heavier sections.

Uses. These steels are used for heavy duty service.

Quenched and Tempered



Technological Properties

Machinability Rating
(On basis B1112=100)

9260- mill annealed to 187-255 BHN=45%
(ASM Metals Handbook.)

← Source: Bethlehem Steel Co. Single heat results. Composition: .59%C, .80%Mn, .012%P, .020%S, 1.96%Si, .02%Ni, .23%Cr, Mo nil. Grain Size: 6 - 8. Test Conditions: 0.565 in. bars normalized at 1600F, quenched from 1575F in agitated oil, drawn as shown. Tested as 0.505 in. bars.

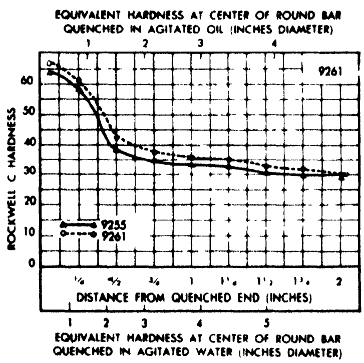
Source: Bethlehem Steel Co. Single heat results. Analysis: (9255) .55%C .70%Mn, 1.95%Si, .08%Ni, .08%Cr, Tr Mo, (9261) .59%C, .80%Mn, 1.96%Si, .02%Ni, .23%Cr, Tr Mo. Carburized grain size at 1700F: (9255) 6-7, (9261) 6-8. →

As Quenched Rockwell "C" Hardness

Treatment: 1600 F, Air Cooled 1575 F Oil Tower quenched
Size Tested 1 in. discs cut from mid-length

	Center	Midway	Surface
½ in. diam	63	63	63
1 in. diam	62	62	62
2 in. diam	50	55	60
4 in. diam	37	38	42

End Quench Hardenability



Mechanical Properties

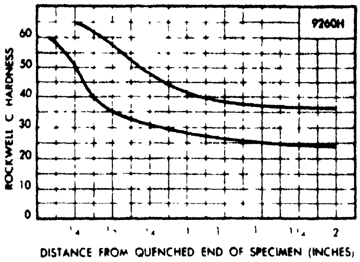
Form or Condition		Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Izod Ft Lbs
Bars[1] Annealed		—	—	—	—	—	241	—
Normalized		—	—	—	—	—	311	—
9261 Effect of Mass[2] single heat								
Annealed[3]	1 in. diam ctr.	—	132.25	14.5	67.25	20.2	262	2.5
Normalized 1600F air cooled	½ in. diam[4] ctr.	—	166.75	15.3	98.25	35.8	331	4
	1 in. diam ctr.	—	161	12.7	90.75	25.3	321	4
	2 in. diam ½r.	—	159.5	13.7	87.25	30.3	311	4
	4 in. diam ½r.	—	144	4.2	86.75	3.9	293	3
Normalized-Quenched-Tempered								
1600F air cooled 1575F oil tower quenched, drawn as shown, air cooled	½ in. diam[4] ctr.	900F	230.5	10.7	207	25.7	444	5.7
	1 in. diam ctr.	900F	224.5	9.2	200.75	24.6	444	6
	2 in. diam ½r.	900F	202	9.5	168.25	22.7	401	6.5
	4 in. diam ½r.	900F	173.25	4.5	105.5	4.6	341	3.5
	½ in. diam[4] ctr.	1000F	200	12.1	177.5	26	401	3.2
	1 in. diam ctr.	1000F	197.75	11.5	173	27.5	388	5.5
	2 in. diam ½r.	1000F	180.25	12.2	145.5	27.1	363	6.5
	4 in. diam ½r.	1000F	164.5	3	108	3.9	331	3.5
	½ in. diam[4] ctr.	1100F	177.75	14.2	155	30.5	352	5
	1 in. diam ctr.	1100F	174.25	14.7	147.5	34.5	341	8.7
	2 in. diam ½r.	1100F	160.25	16	130.5	36	321	8.2
	4 in. diam ½r.	1100F	159.75	10.5	94.25	19.2	321	3.2

[1]Bethlehem Steel Co.
[2]Bethlehem Steel Co. Composition - Ladle .61%C, .83%Mn, .013%P, .020%S, 2.14%Si, .11%Ni, .27%Cr, .02%Mo. Check: .61%C, .82%Mn, .014%P, .020%S, 2.11%Si, .08%Ni, .23%Cr, .02%Mo. Grain Size - 100% 5-7. All test results are the average of two tests. Size tested 0.505 in. diam tensile and 0.450 in. diam Izod specimens.
[3]1575F Furnace Cooled 20F/hr to 1280F, Air Cooled.
[4].357 in. diam tensile.

STEELS, AISI

9260 H

End Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	P %	S %
.55-.65	.70-1.05	1.70-2.20	—[1]	—[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

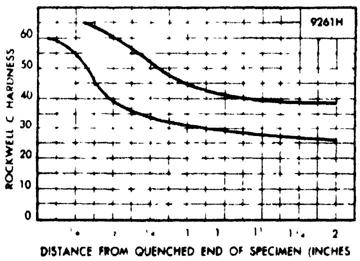
"J" Distance in Inches[1]																								
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	---	---	---	65.0	63.5	62.0	60.0	58.0	56.0	53.0	50.0	48.0	46.0	44.0	43.0	41.5	40.0	38.5	37.5	37.0	37.0	36.5	36.0	36.0
Min	60.0	58.0	55.0	50.5	44.0	39.5	37.0	35.0	33.5	32.5	32.0	31.0	30.0	29.5	29.0	28.5	27.5	26.5	26.0	25.5	25.0	24.5	24.0	24.0

[1]These values are to be used when points are selected and specified.

STEELS, AISI

9261 H

End Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Cr %	P %	S %
0.55-0.65	0.70-1.05	1.70-2.20	.05-.35	—[1]	—[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

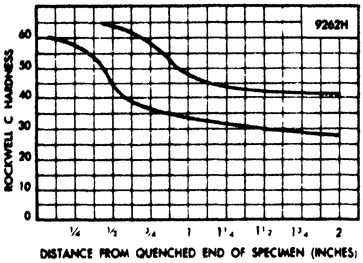
"J" Distance in Inches[1]																								
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	---	---	---	---	65.0	64.0	62.5	60.5	59.0	57.0	54.5	52.0	50.0	48.0	46.0	44.5	42.5	41.0	40.5	40.0	39.5	39.5	39.0	39.0
Min	60.0	59.0	57.0	55.0	51.0	46.0	42.0	39.0	37.5	36.0	35.0	34.0	33.0	32.0	31.5	31.0	30.0	29.5	28.5	28.0	27.5	27.0	26.5	26.0

[1]These values are to be used when points are selected and specified.

STEELS, AISI

9262 H

End Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Cr %	P %	S %
.55-.65	.70-1.05	1.70-2.20	.20-.50	—[1]	—[1]

[1] P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI

	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	---	---	---	---	---	---	65.0	64.0	63.0	62.0	60.0	58.5	56.5	53.5	50.5	48.0	45.0	43.5	43.0	42.5	42.0	41.5	41.5	41.0
Min	60.0	60.0	59.0	57.5	56.0	53.5	50.0	44.0	41.0	38.5	37.5	36.5	36.0	35.0	34.0	33.5	32.5	31.5	30.5	30.0	29.5	29.0	28.5	28.0

[1] These values are to be used when points are selected and specified

E 9310

Chemical Composition (AISI)

C %	Mn %	P %	S %	Si %	Ni %	Cr %	Mo %
.08-.13	.45-.65	.025 max	.025 max	.20-.35	3.00-3.50	1.00-1.40	.08-.15

Characteristics. An electric furnace steel for case hardening, similar to the 3300 grades and is a deep hardening steel.

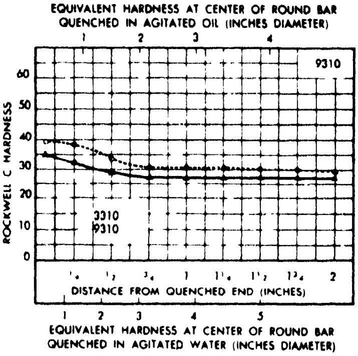
Uses. Typical use is aircraft gears.

Treatment Temperatures[1]

Forging	2200F max
Annealing	1525-1575
Normalizing	1625-1725
Carburizing	1700

[1]Collected.

End Quench Hardenability Band (Tentative)



← Source – Bethlehem Steel Co. Single heat results. Analysis: (3310) .10%C, .55%Mn, .22%Si, 3.28%Ni, 1.45%Cr, .07%Mo, Grain size 6-8; (9310) .11%C, .53%Mn, .29%Si, 3.19%Ni, 1.23%Cr, .11%Mo, Grain size 5-7. Carburized at 1700F.

Critical Points[1]

Ac_1	1325F	Ar_3	1200-1300
Ac_3	1490	Ar_1	850-1000

[1]Collected

As Quenched Rockwell "C" Hardness

Treatment: 1700 F, 8 hrs Fire cooled
1450 F Quenched in Agitated Oil - No Draw

	Center	Midway	Surface
½ in. diam	38	40	40
1 in. diam	37	38	40
2 in. diam	32	35	38
4 in. diam	29	30	31

Mechanical Properties

Form or Condition			Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	BHN	Hardness BHN ¼r	BHN Surface	Izod Ft Lbs
Bars	Annealed[1]		–	–	–	–	–	207-217	–	–	–
	Normalized[1]		–	–	–	–	–	277-285	–	–	–
Heated 8 hrs in iron chips at 1700F, heat treated as shown, drawn 300F, tested 0.505 in. bars[2]	Direct quench from box	1 in. bars	–	174	15	150	53	–	363	–	–
	1425F, OQ		–	145	15.5	118	54	–	302	–	–
	1475F, OQ		–	156	15.5	133	54	–	331	–	–
	1525F, OQ		–	171	15.5	148	54	–	352	–	–
	Direct quench from box	.515 in. bars	–	187	15	162	51	–	–	375	–
	1425F, OQ		–	155	15.5	130	52	–	–	331	–
	1475F, OQ		–	164	16	140	53	–	–	341	–
	1525F, OQ		–	174	16	153	53	–	–	363	–
										Rc Case	
Carburized at 1700F for 8 hrs, quenched in agitated oil core prop.[3] single heat	Direct quench from pot		300F	179.5	15.3	144	59.1	375	–	59.5[4]	57
	Pot cooled reheated	1450F	300F	173	15.5	135	60	363	–	62[5]	61
		1475 and 1425F double OQ	300F	174.5	15.3	139	62.1	363	–	60.5[6]	54
	Direct quench from pot		450F	178	15	146.5	59.7	363	–	54.5[4]	46
	Pot cooled reheated	1450F	450F	168	15.5	137.5	60	341	–	59.5[5]	39
		1475 and 1425F double OQ	450F	169.5	14.8	138	61.8	352	–	58[6]	63
Effect of Mass[7] Single heat											
As Rolled	1 in. diam, ctr.		–	131	19	88	61.5	269	–	–	88.3
	2 in. diam, ½r.		–	132.75	19.5	91	62.3	269	–	–	96.3
	4 in. diam, ½r.		–	117.5	18.8	84	59.2	241	–	–	29.8
Annealed[8]	1 in. diam, ctr.		–	119	17.3	63.75	42.1	241	–	–	58
Normalized 1630F, air cooled	½ in. diam,[9] ctr.		–	133	20	87.75	63.7	285	–	–	88.5
	1 in. diam, ctr.		–	131.5	18.8	82.75	58.1	269	–	–	88
	2 in. diam, ½r.		–	131.25	19.5	84.5	60.5	262	–	–	94.8
	4 in. diam, ½r.		–	125.25	19.5	81.75	61.7	255	–	–	63.5
Mock Carburized, Quenched & Tempered											
1700F, 8 hrs, Furnace cooled reheated to 1450F Quenched in Agitated oil	½ in diam,[9] ctr.		300F	178.75	15.7	143	58.9	363	–	–	61.5
	1 in. diam, ctr.		300F	159	15.5	122.75	57.5	321	–	–	68.3
	2 in. diam, ½r.		300F	145.25	18.5	108	66.7	293	–	–	93
	4 in. diam, ½r.		300F	136	19	94.75	62.3	277	–	–	93.3
	½ in. diam,[9] ctr.		450F	178.25	15	141.5	60.3	363	–	–	66
	1 in. diam, ctr.		450F	157.5	16	123	61.7	321	–	–	78.3
	2 in. diam, ½r.		450F	143.5	17.8	105.5	68.1	293	–	–	91.5
	4 in. diam, ½r.		450F	131.5	20.5	96.5	67	269	–	–	105.5

[1]Collected.
[2]Republic Steel Corp. Approx values.
[3]Bethlehem Steel Co. Composition: C .11%; Mn .53%, P .013%; S .014%, Si .29%, Ni 3.19%; Cr 1.23%; Mo .11%. Grain Size: 5-7. Test Conditions: 0.565 in. bars carburized and treated as shown. Tested as 0.505 in. bars.
[4]Case depth .039 in.
[5]Case depth .047 in.
[6]Case depth .055 in.
[7]Bethlehem Steel Co. Composition: Ladle: C .11%; Mn .59%; .59%; Si .32%; Ni 3.12% Cr 1.28%; Mo .13%. Check: C .09%, Mn .57%; P .012%; S .010%; Si .32%, Ni 3.11%; Cr 1.23%, Mo .13%. McQuaid-Ehn Grain Size: 80% 5, 20% 2-4. All test results are the average of two tests. Size Tested: 0.505 in. diam tensile and 0.450 in. diam Izod Specimens.
[8]1550F, Furnace Cooled 30F/hr to 760F, Air Cooled.
[9]0.357 in. diam tensile.

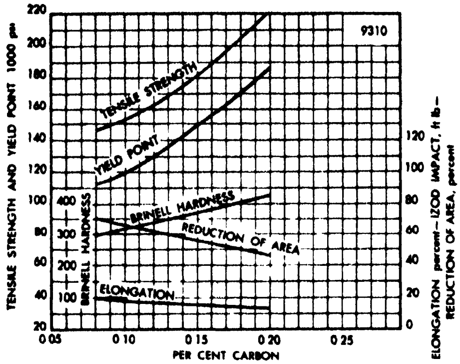
(Continued on page 288)

STEELS, AISI

E 9310

(Continued from page 287)

Direct Quench



Source: International Nickel Co. Representative values. Steels – 9310, 9315, 9317. Test Conditions. 1 in. bars, psuedo-carburized at 1650-1700F, direct quench into oil, drawn at 300F.

Core Properties

		Draw Temp	Tensile Strength M psi	Yield Point M psi	Elong %	Red of Area %
Box cooled Reheated for hardening	0.15%C:					
	1420F, OQ	300F	150	125	14	54
	1470F, OQ		172	145	14	56
	1520F, OQ		182	147	14	56
	0.20%C:					
	1420F, OQ		185	160	12	46
	1470F, OQ		212	185	12	46
	1520F, OQ		220	185	12	46

STEELS, AISI

E 9315 E 9317

Chemical Composition (AISI)

	C %	Mn %	P %	S %	Si %	Ni %	Cr %	Mo %
9315	.13-.18	.45-.65	.025 max	.025 max	.20-.35	3.00-3.50	1.00-1.40	.08-.15
9317	.15-.20	.45-.65	.025 max	.025 max	.20-.35	3.00-3.50	1.00-1.40	.08-.15

Critical Points[1] **9317**

Ac_1	1300F	Ar_3	1290
Ac_3	1455	Ar_1	800

[1] International Nickel Co.

Characteristics. Similar to 3315, for heavy duty service.

Uses. Used for shafts, spline shafts, differential drive pinions etc.

Case Hardened Properties: See 9310 (above) for core properties for 0.15 and 0.20%C.

Technological Properties

Machinability Rating (On basis B1112 = 100)	Cold drawn to 179-229 BHN = 40%. (ASM Metals Handbook.)

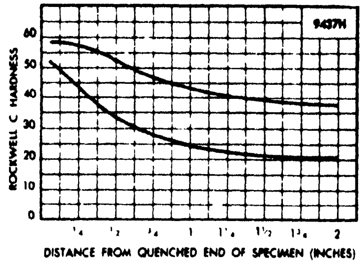
Compressive Strength

Permissible compressive stress for gears, bearings, and races is 215M psi for intermittent loading. This value should be reduced by 20-25% for constant mesh loading. Good practice is assumed, with adequate section thickness and freedom from carbide network in the case.

STEELS, AISI

9437 H

End-Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %	Cr %	Mo %	P %	S %
.35-.43	.85-1.25	.20-.35	.25-.65	.25-.55	.08-.15	–[1]	–[1]

[1]P and S are 0 040 max in open hearth steel and 0 025 max in electric furnace steel. AISI.

"J" Distance in Inches[1]

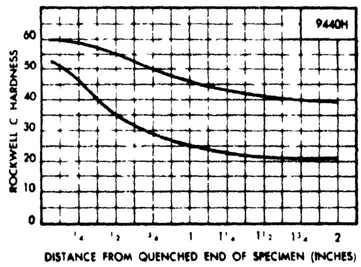
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	58.5	58.5	58.0	57.5	56.5	55.5	54.5	53.0	51.5	49.5	48.0	47.0	45.5	44.5	43.5	43.0	42.0	41.0	40.0	39.0	38.5	38.0	38.0	37.5
Min	51.5	49.5	47.0	43.5	40.0	37.5	35.0	33.0	31.5	30.0	28.5	27.5	26.5	26.0	25.0	24.0	23.0	22.0	21.5	21.0	21.0	20.5	20.5	20.5

[1]These values are to be used when points are selected and specified

STEELS, AISI

9440 H

End Quench Hardenability Band



Chemical Composition

C %	Mn %	Si %	Ni %	Cr %	Mo %	P %	S %
.37-.45	.85-1.25	.20-.35	.25-.65	.25-.55	.08-.15	–[1]	–[1]

[1]P and S are 0.040 max in open hearth steel and 0 025 max in electric furnace steel. AISI.

"J" Distance in Inches[1]

	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	60.0	60.0	60.0	59.5	58.5	57.5	56.5	55.0	53.5	52.5	51.0	50.0	49.0	48.0	47.0	46.0	44.5	43.0	42.0	41.5	40.5	40.0	40.0	39.5
Min	52.5	51.0	49.0	46.5	43.0	40.0	37.5	35.0	33.5	32.0	30.0	29.0	28.0	27.0	26.0	25.0	24.0	23.0	22.5	22.0	21.5	21.5	21.0	21.0

[1]These values are to be used when points are selected and specified.

STEELS, AISI

NE 9450

Critical Points

Ac_1	1365F	Ar_3	1245F
Ac_3	1430	Ar_1	1225

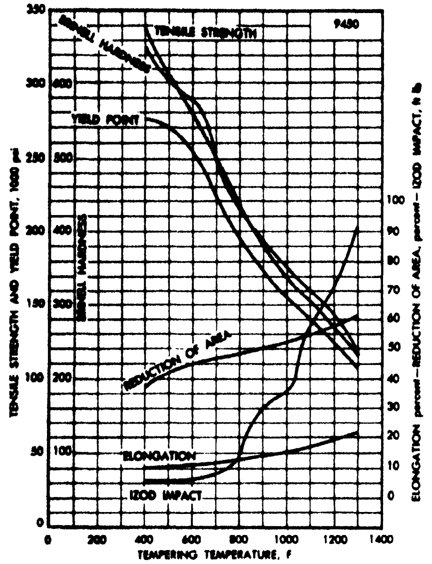
Chemical Composition[1]

C %	Mn %	P %	S %
.48-.53	1.20-1.50	.040 max	.040 max
.51[2]	1.34[2]	.024[2]	.020[2]

Si %	Ni %	Cr %	Mo %
.20-.35	.30-.60	.30-.50	.08-.15
.23[2]	.47[2]	.45[2]	.10[2]

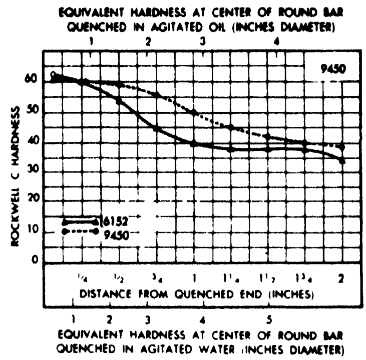
[1]This is not an AISI steel.
[2]Bethlehem Steel Co. Single heat results. Grain size 6-8.

Quenched and Tempered



Test Conditions: 0.530 in. bars normalized at 1600F, quenched in agitated oil from 1500F, drawn as shown. Tested as 0.505 in. bars.

End-Quench Hardenability Band (Tentative)



Source – Bethlehem Steel Co. Single heat results. Analysis, .50 Carbon, oil-hardening grades (6152) .49%C, .78%Mn, .29%Si, .18%Ni, 1.00%Cr, Tr Mo, .17%V. Grain size 6-8. (9450) .51%C, 1.34%Mn, .23%Si, .47%Ni, .45%Cr, .10%Mo. Grain size 6-8. Carburized at 1700F.

STEELS, AISI

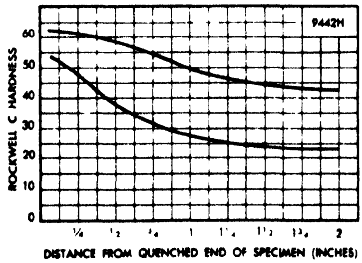
9442H

Chemical Composition

C %	Mn %	Si %	Ni %	Cr %	Mo %	P %	S %
.40-.48	.95-1.35	.20-.35	.25-.65	.25-.55	.08-.15	–[1]	–[1]

[1]P and S are 0.040 max in open hearth steel and 0.025 max in electric furnace steel. AISI.

End Quench Hardenability Band



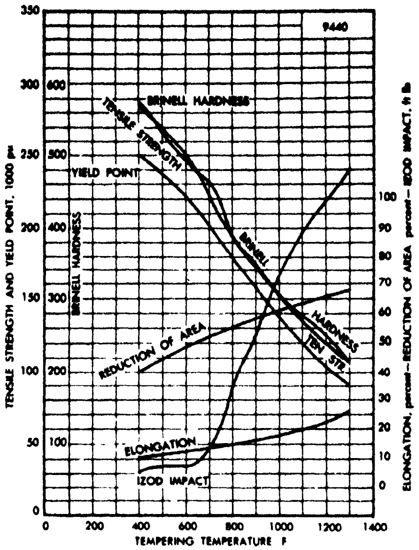
"J" Distance in Inches[1]

	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	62.0	62.0	62.0	61.0	60.5	60.0	59.5	58.5	57.5	56.5	55.0	54.0	53.0	52.0	51.0	50.0	48.5	47.0	45.5	44.5	44.0	43.0	43.0	42.5
Min	54.0	52.5	50.5	48.5	45.0	43.0	40.5	38.0	36.0	34.0	32.5	31.0	30.0	29.0	28.0	27.0	26.0	25.5	25.0	24.5	24.0	24.0	24.0	23.5

[1]These values are to be used when points are selected and specified.

9440 9442

Quenched and Tempered



Source: Bethlehem Steel Co. Single heat values. Composition: .39%C, 1.06%Mn, .017%P, .018%S, .28%Si, .39%Ni, .32%Cr, .11%Mo. Grain Size – 6 - 8. Test Conditions: 0.530 in. bars normalized at 1600F, quenched from 1525F in agitated oil, drawn as shown. Tested as 0.505 in. bars.

Critical Points[1]

Ac_1	1360F	Ar_3	1290
Ac_3	1450	Ar_1	1215

[1]Bethlehem Steel Co.

Chemical Composition[1]

	C %	Mn %	P %	S %
9440	.38-.43	.90-1.20	.040 max	.040 max
9442	.40-.45	1.00-1.30	.040 max	.040 max

	Si %	Ni %	Cr %	Mo %
9440	.20-.35	.30-.60	.30-.50	.08-.15
9442	.20-.35	.30-.60	.30-.50	.08-.15

[1]AISI

As Quenched Rockwell "C" Hardness

Treatment: 1600F, Air Cooled 1525F, Oil Tower Quenched
Size Tested: 1 in. discs cut from mid-length

	Center	Midway	Surface
½ in. diam	53	54	56
1 in. diam	39	45	51
2 in. diam	26	33	41
4 in. diam	21	23	28

Mechanical Properties

Form or Condition			Test Temp	Draw Temp	Tensile Strength M psi	Elong 2 in. %	Yield Point M psi	Red Area %	Hard BHN	Izod Ft Lbs
9440 Bars Annealed[1]				–	–	–	–	–	192	–
Normalized[1]				–	–	–	–	–	235	–
Effect of Mass[2]				–	–	–	–	–	–	–
As Rolled	1 in. diam ctr			–	123	18	80	46.7	241	19.7
	2 in. diam ½r.			–	113	21.5	67.5	57	229	26.5
	4 in. diam ½r.			–	110	17.2	61.25	38.6	223	17.7
Annealed[3]	1 in. diam ctr.			–	92.75	26	59.25	53.3	183	36
Normalized 1600F air-cooled	½ in. diam ctr.[4]			–	124	20.7	83	55.3	248	59
	1 in. diam ctr.			–	110.25	24.7	71.5	57.7	223	46.7
	2 in. diam ½r.			–	106.75	24	68.5	59.2	217	61.5
	4 in. diam ½r.			–	103.75	24	60.5	55.8	212	40.5
Normalized - Quenched - Tempered										
1600F air cooled 1525F Oil Tower quenched drawn as shown	½ in. diam ctr.[4]				155	18.1	142.75	56.7	311	51
	1 in. diam ctr.			1000F	135	19.3	107	59.8	269	68
	2 in. diam ½r.				113	22	87.25	63.4	229	81.5
	4 in. diam ½r.				108.5	23.2	76.25	59.9	223	74.7
	½ in. diam ctr.[4]				132.5	21.4	117.5	63	262	67
	1 in. diam ctr.			1100F	124.5	20.2	100.5	59.4	248	71
	2 in. diam ½r.				110.75	23.2	82.75	64.6	229	88.7
	4 in. diam ½r.				101.5	26.2	72.5	65.2	207	85.5
	½ in. diam ctr.[4]				122	23.1	108.75	62.8	241	73.7
	1 in. diam ctr.			1200F	110.5	23.5	90.25	63.6	229	83.5
	2 in. diam ½r.				102.75	25.7	78.25	68.2	207	97.7
	4 in. diam ½r.				97.5	26.5	64.75	65.4	201	88.7
			Test Temp							NBT Ft Lbs
9440	Low temp properties	Normalized 1525F	75F		–	–	–	–	269	25
			-100	1000F	–	–	–	–	269	15
			-180		–	–	–	–	269	14
			-310		–	–	–	–	269	6
		Oil Quenched 1525F	75F		–	–	–	–	375	26
			-100	900F	–	–	–	–	375	15
			-180		–	–	–	–	375	14
			-310		–	–	–	–	375	8

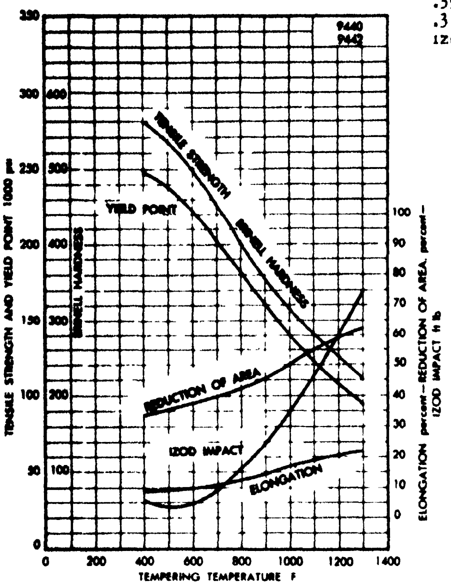
[1]Bethlehem Steel Co.
[2]Source: Bethlehem Steel Co. Single heat results. Composition: Ladle .39% C, .92% Mn, .28% Si, .46% Ni, .38% Cr, .11% Mo. Check .39% C, .89% Mn, .022% P, .016% S, .25% Si, .46% Ni, .41% Cr, .10% Mo. McQuaid-Ehn Grain Size· 100% 6-8 Size tested: 0.505 in. diam tensile and 0.450 in. diam Izod. All test results are the average of two tests.
[3]1525F Furnace Cooled 20F/hr to 1165F, Air Cooled.
[4].357 in. diam tensile specimens.
[5]Source: H. W. Gillett and F. T. McGuire. "Behavior of Ferritic Steels at Low Temperatures."

(Continued on page 292)

9440 9442

(Continued from page 291)

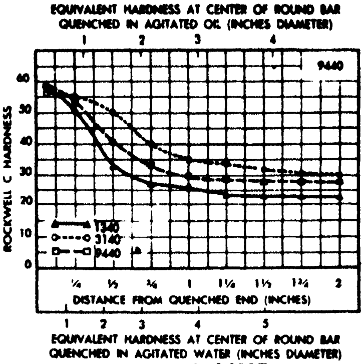
Oil Quenched and Tempered



Source: International Nickel Co. Aver values. Test Conditions: 1 in. sections quenched from 1525-1575F in oil, drawn as shown.

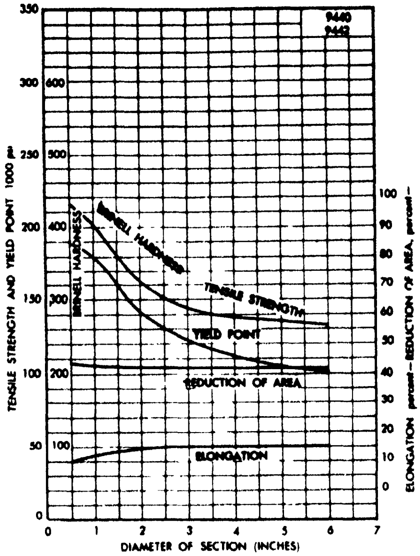
End-Quench Hardenability

Source – Bethlehem Steel Co. Single heat results. Analysis: .40C, oil-hardening grades (1340) .43%C, 1.70%Mn, .23%Si, .03%Ni, .02%Cr, Tr. Mo. (3140) .39%C, .76%Mn, .25%Si, 1.20%Ni, .65%Cr, .08%Mo. (9440) .39%C, 1.06%Mn, .28%Si, .39%Ni, .32%Cr, .11%Mo. Grain size, carburized at 1700F, 6-8.

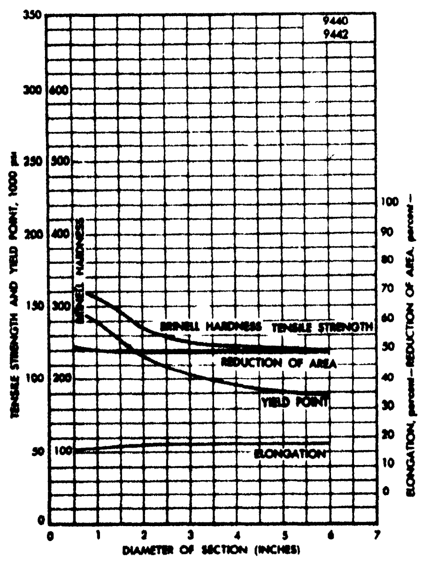


Effect of Mass Source: ⟶ International Nickel Co. Aver values. Test Conditions: Sections to 2 in. inclusive quenched from 1525-1575F, over 2 in. to 4 in. inclusive from 1550-1600F, and over 4 in. from 1575-1625F in oil, drawn as shown. In sizes over 1 in. the values represent ⟵ the midway position. ⟶

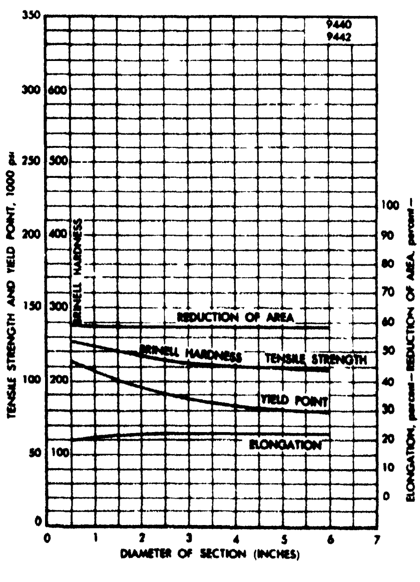
Oil Quenched, Tempered at 800F



Oil Quenched, Tempered at 1000F



Oil Quenched, Tempered at 1200F



94T40

Chemical Composition[1]

C	Mn	P	S
%	%	%	%
.42	1.06	.017	.024
Si	**Ni**	**Cr**	**Mo**
%	%	%	%
.46	.34	.30	.11

[1]Source: SAE Report on Investigation of Boron Treated Steels, January 1948.

Characteristics[1]. Boron Treated 94T40. Fine grained and normal.

[1]Source: SAE Report on Investigation of Boron Treated Steels, January 1948.

Hardenability. The depth of hardening was 1.8 times that of 9440.

Field Tests. Axle shafts made of 94T40 were found in field tests to compare favorably with the steels regularly specified, 2345 and 8645.

Experience in Fabrication. Steel 94T40 was found to forge satisfactorily and to respond properly to an annealing cycle of heating to 1500F, holding 2 hr, cooling to 1180-1200F, holding 5 hr, and air cooling. The hardness was 207-217 BHN. In machining 94T40 was comparable to the production steels 4145, 8645, and 9445.

Notched Bar Tests

Draw Temp	Hard Rc	Izod Test Ft Lbs 70F	Izod Test Ft Lbs -20F	Draw Temp	Hard Rc	Charpy Test Ft Lbs 70F	Charpy Test Ft Lbs 70F[3]
760F[1]	44	19	16	425F[1]	52	20	16
800[2]	43	25	–	800[2]	43	23	18
1000[1]	35	44	40	1000[2]	34	34	27
1200[2]	23	88	–	1200[2]	23	–	38

[1]Oil quenched as oversized bars from 1550F.
[2]Oil quenched as oversized bars from 1525F.
[3]Check tests by a second laboratory.

Mechanical Properties

Form or Condition	Draw Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Red Area %	Hard Rc	End Limit M psi Plain	End Limit M psi Notch[1]
Bars: 1.25 in. normalized 1650F, oversize 0.357 in. taken ½r, quenched 1550F in oil at 100-120F, drawn as shown, tested 0.357 in.	450F	271.5	231	9.7	43.1	52	110	60
	800	194.5	181	10.9	55.6	41	90	45
	950	160.5	146	15.2	57.9	35	80	31
	1100	136	119.5	17.7	61.4	28	70	33

[1]Notch radius 0.010 in

Torsional Fatigue Tests[1]

Cycles to Failure

Stress M psi	94T40	Steel 3240	8949	6150	4340
35	135,415	113,000	–	143,500	47,000
40	62,884	40,000	191,000	101,000	29,000
45	43,911	37,000	101,000	53,000	24,000
50	41,432	27,500	80,000	27,500	22,500
60	24,959	19,000	37,000	9,000	11,000
70	12,571	–	14,000	–	–
BHN	444	415-444	401-444	388-415	402-430

[1]Test Conditions: 1¾ in. diam shafts, oil quenched and drawn at 900F to 444 BHN. Torsional fatigue tests were run at 30 complete reversals per minute; the values are the averages of three tests. Typical values are given for other steels for comparison.

Impact Tests[1]

Steel	Number Tested	Aver No. of Blows to Failure	Rc Hard Surface	Rc Hard Center
94T40	3	13	36.3	37.2
94T40	4	10.5	38.4	39.7
4145	2	13.5	40	39
8640	3	11	37.7	36.7
9445	3	10.7	39.2	39.5

[1]Test Conditions: Torque rod end pins were tested with a 40-pound hammer falling 7 feet onto the ball end. This produced a shock load through the threaded section nearest the shoulder of the pin.

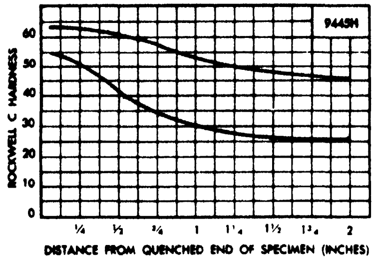
STEELS, AISI

9445H

Chemical Composition

C	Mn	Si	Ni
%	%	%	%
.42-.50	.95-1.35	.20-.35	.25-.65
Cr	**Mo**	**P**	**S**
%	%	%	%
.25-.55	.08-.15	—[1]	—[1]

End Quench Hardenability Band



	"J" Distance in Inches[1]																							
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2
Max	63.0	63.0	63.0	62.5	62.5	62.0	61.5	61.0	60.0	59.0	58.0	57.0	56.0	55.0	54.0	53.0	51.5	50.0	49.0	48.0	47.5	46.5	46.0	45.5
Min	55.0	54.0	52.5	51.0	49.0	46.0	43.0	41.0	39.0	37.0	35.5	34.0	33.0	32.0	31.0	30.0	28.5	28.0	27.0	26.5	26.0	26.0	26.0	26.0

[1] These values are to be used when points are selected and specified.

9840

Chemical Composition[1]

C %	Mn %	P %	S %
.38-.43	.70-.90	.040 max	.040 max
Si %	**Ni %**	**Cr %**	**Mo %**
.20-.35	.85-1.15	.70-.90	.20-.30

[1]AISI

Critical Points[1]

Ac_1	1360F	Ar_3	1250
Ac_3	1425	Ar_1	800-1100

[1]Industry values.

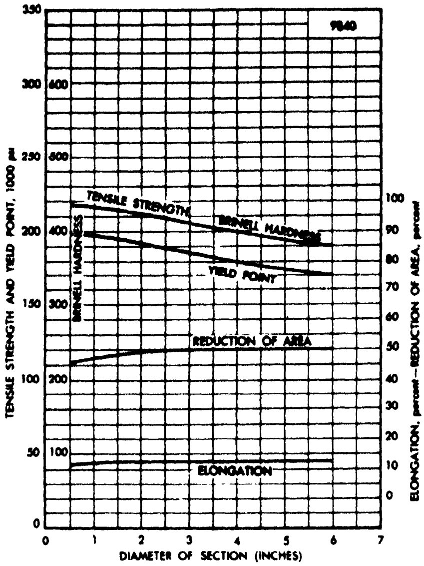
Mechanical Properties

Form or Condition		Hard BHN
Bars	Annealed[1] 1500F	207
	Normalized[1] 1600F	331

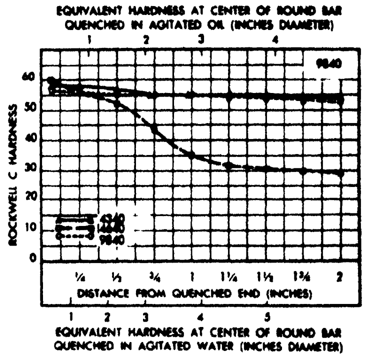
[1]Bethlehem Steel Co.

Characteristics and Uses. Very similar to 4340 with lower nickel and slightly higher manganese.

Oil Quenched, Tempered at 800F



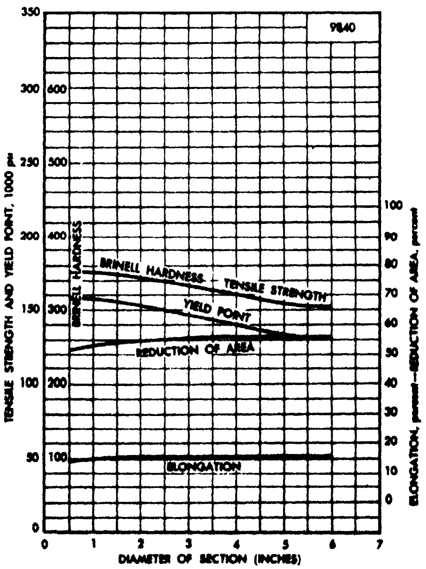
End-Quench Hardenability



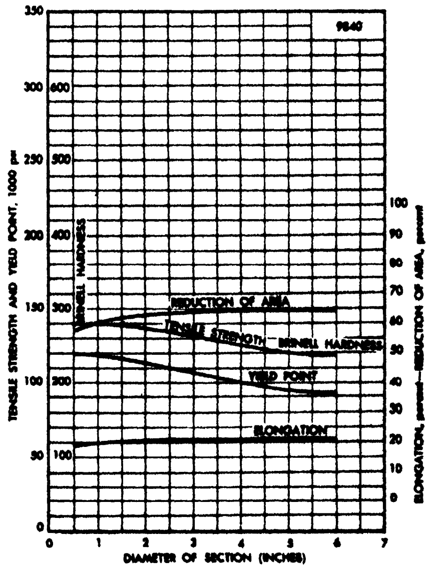
Source – Bethlehem Steel Co. Single heat results. Analysis: .40C oil-hardening grades, (4340) .41%C, .67%Mn, .26%Si, 1.77%Ni, .76%Cr, .26%Mo. (4640) .40%C, .71%Mn, .24%Si, 1.83%Ni, .16%Cr, .28%Mo. (9840) .40%C, .90%Mn, .25%Si, 1.02%Ni, .84%Cr, .26%Mo. Grain size 6-8, carburized at 1700F.

← Effect of Mass. Source: International Nickel Co. Average values. Test Conditions: Sections to 2 in. inclusive quenched from 1525-1575F, over 2 in. to 4 in. inclusive quenched from 1550-1600F, over 4 in. quenched from 1575-1625F in oil, drawn as shown. For sizes over 1 in. the values represent the midway position. →

Oil Quenched, Tempered at 1000F



Oil Quenched, Tempered at 1200F



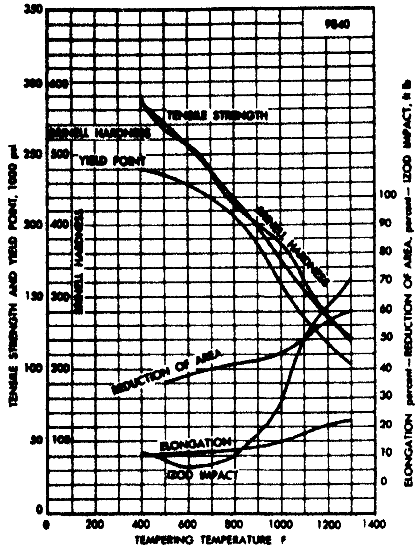
(Continued on page 296)

(Continued from page 295)

Technological Properties

Machinability Rating (On basis of B1112 = 100)	Annealed for machining = 57%

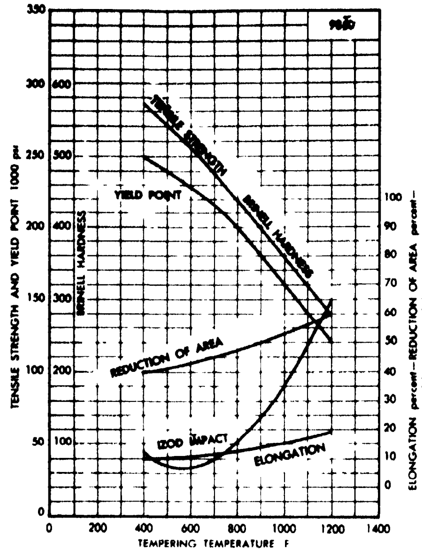
Quenched and Tempered



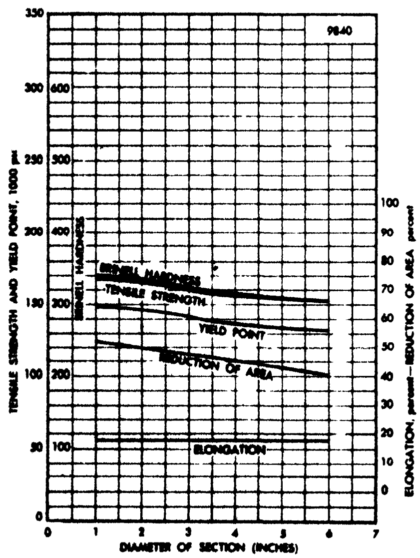
←Source: Bethlehem Steel Co. Single heat results. Composition: .40%C, .90%Mn, .036%S, .25%Si, 1.02%Ni, .84%Cr, .26%Mo. Grain Size – 6 - 8. Test Conditions: 1¼ in. bars normalized at 1600F, quenched from 1525F in agitated oil, drawn as shown. Tested as 0.505 in. bars.

Source: International Nickel Co. Average values. Test Conditions: 1 in. sections quenched from 1525-1575F in oil, drawn as shown.→

Oil Quenched and Tempered

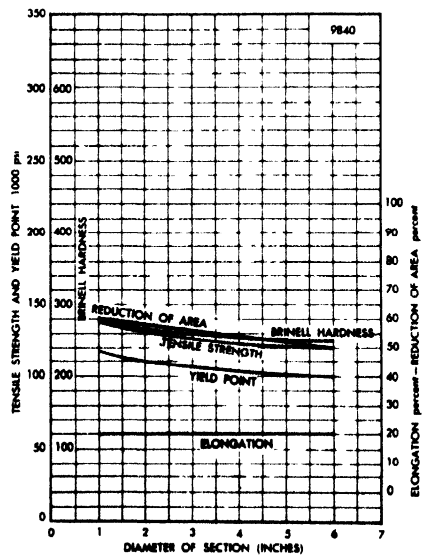


Tempered at 1000F



Source: Republic Steel Co. Approximate values. Test Conditions: Bars in sizes shown, oil quenched and drawn as shown. For sizes over 1½ in. the values represent the mid-radius position. Tested as 0.505 in. bars.

Tempered at 1200F



9850

Chemical Composition[1]

C	Mn	P	S
%	%	%	%
.48-.53	.70-.90	.040 max	.040 max
Si	Ni	Cr	Mo
%	%	%	%
.20-.35	.85-1.15	.70-.90	.20-.30

[1]AISI

Critical Points[1]

Ac_1	1360F	Ar_3	1290
Ac_3	1450	Ar_1	1215

[1]Bethlehem Steel Co.

Treatment Temperatures[1]

Forging	2250F max
Annealing	1475-1700
Normalizing	1575-1700
Quenching	1475-1525

[1]Republic Steel Corp.

Technological Properties

Machinability Rating (On basis of B1112 = 100)	Annealed for machinability = 50% (Industry value — approximate)

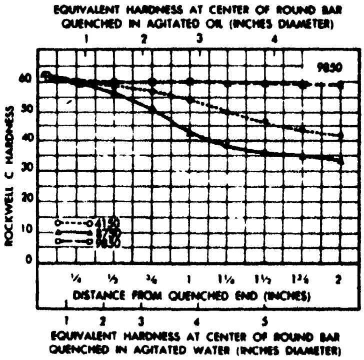
Mechanical Properties

Form or Condition		Hard BHN
Bars	Annealed[1]	223
	Normalized[1]	400

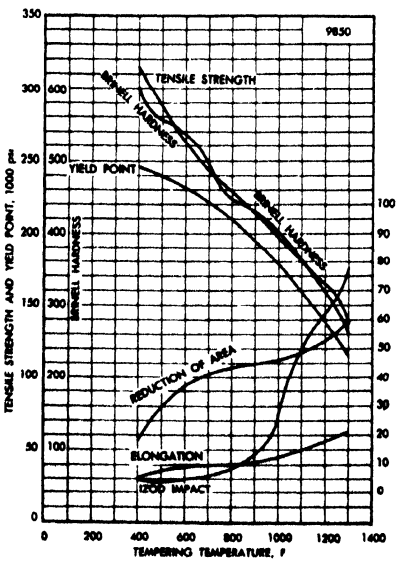
[1]Industry values.

End-Quench Hardenability

Source: Bethlehem Steel Co. Single heat results. Analysis, .50C, oil-hardening grades: (4150) .50%C, .76%Mn, .21%Si, .20%Ni, .95%Cr, .21%Mo. Carburized grain size at 1700F, 90%, 7-8. (8750) .51%C, .80%Mn, .24%Si, 53%Ni, .52%Cr, .25%Mo. Grain size 6-8. (9850) .51%C, .84%Mn, .25%Si, 1.05%Ni, .88%Cr, .24%Mo. Grain size 5-8.



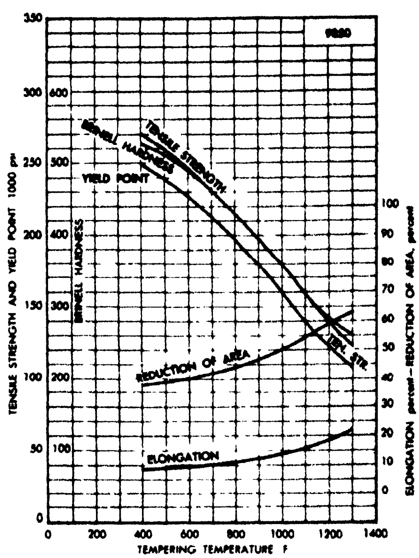
Quenched and Tempered



Source: Bethlehem Steel Co. Single heat results. Composition: .51%C, .86%Mn, .022%P, .020%S, .22%Si, 1.06%Ni, .90%Cr, .24%Mo. Grain Size – 5 - 8. Test Conditions: 0.530 in. bars normalized at 1600F, quenched from 1475F in agitated oil, drawn as shown. Tested as 0.505 in. bars.

Oil Quenched and Tempered

Source: Republic Steel Corp. Approximate values. Test Conditions: 1 in. bars normalized at 1600F, quenched from 1500F in oil, drawn as shown. Tested as 0.505 in. bars. The maximum section for which these properties can be expected is 3.5 in.



9763

Critical Points			
Ac_1	1355F	Ar_3	1250
Ac_3	1400	Ar_1	1220

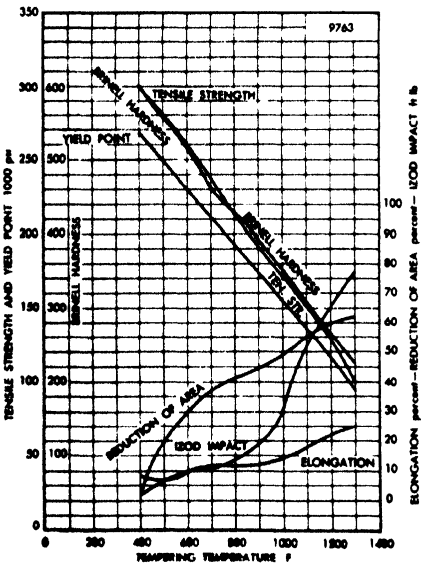
Chemical Composition[1]

C %	Mn %	P %	S %
.60-.67	.50-.80	.040 max	.040 max
.63[2]	.67[2]	.02[2]	.027[2]

Si %	Ni %	Cr %	Mo %
.20-.35	.40-.70	.10-.25	.15-.25
.20[2]	.59[2]	.25[2]	.20[2]

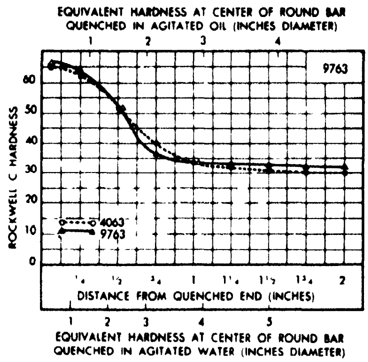
[1] AISI
[2] Bethlehem Steel Co. Single heat results. Grain size: 70% 6-8.

Quenched and Tempered



Test Conditions: 0.530 in. bars normalized at 1600F, quenched from 1475F in agitated oil, drawn as shown. Tested as 0.505 in. bars.

End-Quench Hardenability



Source – Bethlehem Steel Co. Single heat. Analysis Spring Grades (4063) .64%C, .87%Mn, .25%Si, .04%Ni, .15%Cr, .25%Mo. Grain size 6-8. (9763) .63%C, .67%Mn, .20%Si, .59%Ni, .25%Cr, .19%Mo. Grain size, 70%, 6-8. Carburized at 1700F.

PURE Copper

Chemical Composition [1]

	%		%		%		%
Fe	.0005	Ni	.0001 max	Te	.0001 max	O	nil
Sb	.0001 max	Bi	.0001 max	Se	.0001 max		
Pb	.00005 max	Ag	.00003 max	S	.0001 max		
Sn	.00005 max	As	.0001 max	C	.0008 max		

[1] Example of high purity copper

(These data relate to spectrographically pure copper or to copper which is equal to or higher in purity than commercial electrolytic copper)

Technological Properties

Melting point 1083.0 ±0.1 °C or 1981.4 ±0.2 °F [1]
Boiling point 2595C or 4700F

[1] Values for spectrographically pure copper.

Physical Properties

Density, at 20C or 68F	0.324 lb/cu in. (8.96 S.G.)[1] The density decreases 0.028% by 50% reduction in drawing.
Specific heat, cal/gm at 20C or 68F	0.092 The specific heat increases linearly to 0.115 at the melting point.
Volume conductivity, % of standard copper	103.06% [1]
Mass conductivity, % of standard copper	102.3%
Electrical resistivity, microhm/cm³ at 20C or 68F	1.6730 [1,2]
Electrical resistivity, ohms/meter gm at 20C or 68F	0.14983 [1,2]
Temp coef of electrical resistivity, microhm/cm³/°C at 20C or 68F	0.0068
Temp coef of electrical resistivity, ohms/meter gm/°C at 20C or 68F	0.00060

[1] Values for spectrographically pure copper.
[2] The electrical resistivity increases about linearly to about 11 microhm/cm³ at the m.p.

Thermal Conductivity

Cal/cm²/cm/°C/ sec	at 20C	0.941 ± 0.005 [1]
Btu/ft²/ft/hr/°F	or 68F	228

[1] The thermal conductivity decreases linearly to about 0.75 at the m.p.

Coef of Thermal Expansion

Temp Range	
20C or 68F	$16.5 \times 10^{-6}/°C$ $9.16 \times 10^{-6}/°F$
0-300C or 32-572F	$L_t = L_0[1 + (16.23t + 0.00483t^2) \times 10^{-6}]$

Mechanical Properties [1]

Form or Condition	Tensile Strength M psi	Elong 2" %
Values are approximate	32	45

[1] For properties of copper of commercial purity, see Electrolytic Tough Pitch Copper and Deoxidized Copper.

YELLOW Brass

Chemical Composition [1]

	Cu %	Zn %	Pb %	Fe %
Sheet	64.0/67.5	rest	.30 max	.05 max
Wire	63.0/67.5	rest	.10 max	.05 max

[1] ASTM

Characteristics. Yellow Brass has the combination of high strength and ductility, and has excellent cold working properties with fair hot working properties.

Uses. Cartridge cases and ammunition components, and is also used for radiator cores and tanks, reflectors, flashlight shells, lamp fixtures, bases for incandescent lamps, sockets and screw shells, eyelets, fasteners, pins, rivets, springs, various stampings, tubes, etc.

Technological Properties

Melting point	solidus 1660F or 905C liquidus 1710F or 930C
Hot working temp	usually hot extruded
Annealing temp	800-1300F or 425-700C

Physical Properties

Density, at 68F	0.306 lb/cu in. (8.47 S.G.)
Specific heat, cal/gm at 68F	0.09/°C
Volume conductivity, % of Cu, annealed	27%
Electrical resistivity, microhm/cm³ at 68F	6.4
Electrical resistivity, ohms/mil ft, at 68F	38

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Rock Hard	Shear S M psi	End Lt[2] M psi	E 10^6 psi
Flat Rolled							
Annealed	49	17	57	F68	34	12	15
1/4 hard	54	40	43	B55	36	—	15
1/2 hard	61	50	23	B70	40	—	15
hard	74	60	8	B80	43	14	15
spring	91	62	3	B90	47	20	15

[1] 0.5% extension under load
[2] At 10^8 cycles

Thermal Conductivity

Cgs units	at 20C	0.28
Btu/ft²/ft/hr/°F	at 68F	67.7

Coef of Thermal Expansion

Temp Range	
20-300C or 68-572F	$20.3 \times 10^{-6}/°C$ $11.3 \times 10^{-6}/°F$

ELECTROLYTIC TOUGH PITCH Copper

Chemical Composition

This grade is specified as 99.9% Cu + Ag. By agreement silver may be specified up to 30 oz/ton, 0.102%, silver being counted as copper in the analysis. Additional notes follow:

O = 0.01 – 0.07%, with nominal, 0.04%
Pb = should be under 0.005% for hot rolling
Others may be present in small amounts

Technological Properties

Melting point	solidus 1949F or 1065C liquidus 1981F or 1083C
Hot working temp	1400-1600F or 750-875C
Annealing temp	700-1200F or 375-650C, in neutral or oxidizing atmosphere
Recrystallization temp	Varies considerably with composition, grain size, amount of cold reduction, and time of holding at temperature. As an example, a pure copper which had been cold reduced 75% required 350F to recrystallize in 15 min. and only 225F for 24 hr. A tough pitch copper, reduced 69% recrystallized in 30 min. at about 435F. The first effects of softening are observed 25-50 degrees F lower. No simple value can be given but the usual annealing treatment results in the soft condition.
Weldability	Not too satisfactory though it is done by electrical fusion and resistance methods.
Soldering	Good
Brazing	Good
Riveting	Use copper

Characteristics. Copper combines very good conductivity for electricity and heat, and corrosion resistance with good ductility, formability, and moderate strength.

Uses. Electrical wiring, transmission lines, bus bars, contacts, switches and electrical equipment, roofing, building fronts, down spouts and gutters, flashing, screens, gaskets, radiators, ball floats, burrs, cotter pins, nails, rivets, tacks, soldering coppers, copper plating anodes, kettles, pans, chemical equipment, printing rolls, rotating bands, etc.

Physical Properties

Density	0.321-0.323 lb/cu in. (8.89-8.94 S.G.)
Specific heat, cal/gm at 68F	0.092 (also see pure copper)
Volume conductivity, at 68F, referred to copper standard	101% annealed
Electrical resistivity, microhm/cm³ at 68F	1.71, annealed
Temp coef of electrical resistivity, at 68F	0.00392/°C
Electrical conductivity vs cold work, at 68F	Drops from about 102% to about 98% for 95% reduction in area
Velocity of sound, in ft/sec at 68F	12,700
Latent heat of fusion, cal/gm	50.6

Thermal Conductivity

Cal/cm²/cm/°C/sec at 20C 0.934, for copper of 101% electrical conductivity. Also see pure copper
Btu/ft²/ft/hr/°F at 68F 226

Coef of Thermal Expansion

Temp Range	
20-300C or 68-572F	$17.7 \times 10^{-6}/°C$ $9.82 \times 10^{-6}/°F$

$L_t = L_0 \left[1 + (1623 \times 10^{-8} t + 483 \times 10^{-11} t^2)\right]$

Mechanical Properties[8]

Form or Condition	Test Temp	Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Red. Area %	Rock F Hard	Shear S M psi	End Lt[2] M psi
Soft G. S. = 0.050mm		32	10	45-55	70	40	22	–
Soft G. S. = 0.025mm		34	11	45-55	70	45	23	11
1/8 hard		36	28	30-40	–	60	25	–
1/4 hard		38	30	25-35	–	70	25	–
1/2 hard		42	36	14	–	84	26	13
Hard		50	45	6-12	–	90	28	13
Spring temper		55	50	4	–	94	29	14
Extra spring temper		57	53	4	–	95	29	–
Soft wire		35	–	35[3]	–	–	24	–
Hard wire		55	–	1.5[4]	–	–	29	–
Spring wire		66	–	1.5[4]	–	–	33	–
Soft tube[8]		32	10	45	–	40	22	–
Soft tube, mild drawn		34	11	45	–	45	23	–
Light drawn tube (15%)		40	32	25	–	77	26	–
Hard drawn tube (40%)		55	50	8	–	95	29	–
Hard shape (15%)		40	32	30	–	35[5]	26	–
Effect of temp[7]	Room	30	8.6[6]	45	70±	–	–	–
	–20C	34	9[6]	42	70±	–	–	–
	–60	38	9.5[6]	47	70±	–	–	–
	–100	40	10.5[6]	50	70±	–	–	–
	–140	48	11[6]	50	75	–	–	–
	–200	60	11.5[6]	58	78	–	–	–

[1] 0.5% extension under load
[2] At 10^8 cycles
[3] In 10 in.
[4] In 60 in.
[5] Rockwell B
[6] .1%
[7] These are approximate values for annealed 99.985% Cu. At temperatures below normal the mechanical properties of copper and copper alloys tend to improve.
[8] Selected, typical

Modulus of elasticity, E in M psi	17,000 (Probably decreases with cold work)
Poisson's ratio	0.33 ±.01
Dampening capacity	Relatively high

Creep Strength (Minimum)

Temp	Stress M psi	Estimated Creep Rate per 1000 hr
400F or 205C	5	0.042%
	6.7	0.10%
	9	0.21%

DEOXIDIZED Copper

Chemical Composition[1]

	Cu (+ Ag) %	P %	Others %
Sheet	99.90 min	.015/.040	–
Tubing	99.90 min	.015/.040	–
Condenser tubing	99.90 min	.035 max	–
Water tubes	99.90 min	.040 max	–
Boiler tubes	99.90 min	–	.100 max
Pipes	99.90 min	.04 max	–

[1] These limits established by ASTM

Characteristics. Phosphorus deoxidized copper contains a small residual of P. This improves its properties and characteristics for hot and cold working but detracts from its electrical conductivity.

Uses. Household gas lines, heater lines, oil burner tubes, plumbing lines, refrigerators, condenser, evaporator, and heat exchanger tubes, steam and water lines, tubes for the dairy, distilling, brewing, and paper industries, air, gas, oil, and hydraulic lines and oil coolers for engines and machinery, rotating bands, etc.

Physical Properties

Density, at 68F	0.323 lb/cu in. (8.94 S.G.)
Specific heat, cal/gm at 68F	0.092
Volume conductivity, % of standard copper	85%
Electrical resistivity, microhm/cm² at 68F	2.03
Electrical resistivity, ohms/mil ft at 68F	12.2
Temp coef of electrical resistivity, 20-200C or 68-392F	0.002198/°C for 0.042% P 0.003/°C for 0.02% P
Electrical resistivity vs cold work	about 1% increase with 84% reduction

Technological Properties

Melting point	1981F or 1083C
Recrystallization temp	See comments under tough pitch copper. See Fig 2, p 908, Metals Handbook.
Machinability index, free cutting brass = 100	20
Hot working temp	1400-1600F or 750-875C
Annealing temp	700-1200F or 375-650C
Workability	Excellent, hot or cold
Weldability	Satisfactory by oxyacetylene and carbon-arc methods. Resistance methods are used under special conditions.
Soldering	Good
Brazing	Good
Riveting	Use copper rivets

Thermal Conductivity

Cal/cm²/cm/°C/sec at 20C	0.81
Btu/ft²/ft/hr/°F at 68F	196

Coef of Thermal Expansion

Temp Range	
20-300C or 68-572F	17.7×10^{-6}/°C 9.82×10^{-6}/°F

Mechanical Properties

Form or Condition	Tensile Strength M psi	Tensile Strength, M psi Angle to Rolling Direction 0°	45°	90°	Yield Strength M psi[1]	Elong 2" %	Elong, % Angle to Rolling Direction 0°	45°	90°	Rock F Hard	Shear S M psi	End Lt[2] M psi	Stress[8] M psi
Soft, 0.050 mm G.S.	32	–	–	–	10	45	–	–	–	40	22	11	–
Tubing, light drawn (15%)	40	–	–	–	32	25	–	–	–	77	26	14	–
Tubing, hard drawn (40%)	55	–	–	–	50	8	–	–	–	95	29	19	–
Pipe, hard drawn, (30%)	50	–	–	–	45	10	–	–	–	90	28	–	–
Directional Properties[3]													
Cold rolled, 50%	–	53.35	53.4	55.35	–	–	6.0	5.2	5.7	–	–	–	–
Annealed at 600C	–	33.3	33.075	32.5	–	–	57.0	53.0	56.2	–	–	–	–
Annealed at 800C	–	31.625	31.15	30	–	–	50.2	52.2	54.5	–	–	–	–
Cold rolled, 89.8%	–	64.4	63	67.35	–	–	5.7	5.0	4.0	–	–	–	–
Annealed at 600C	–	35.75	33.1	33.1	–	–	48	54.5	56.5	–	–	–	–
Annealed at 800C	–	35.5	29.2	30.75	–	–	42.7	55	59.5	–	–	–	–
Effect of Temp													
300F Annealed, G.S. = 0.013 mm													
10^4 hr	–	–	–	–	–	–	–	–	–	–	–	–	10.5
10^5 hr	–	–	–	–	–	–	–	–	–	–	–	–	8
300F Cold drawn, 84%													
10^4 hr	–	–	–	–	–	–	–	–	–	–	–	–	> 30
10^5 hr	–	–	–	–	–	–	–	–	–	–	–	–	22
400F Annealed, G.S. = 0.013 mm													
10^4 hr	–	–	–	–	–	–	–	–	–	–	–	–	5.2
10^5 hr	–	–	–	–	–	–	–	–	–	–	–	–	2.1
400F Cold drawn, 84%													
10^4 hr	–	–	–	–	–	–	–	–	–	–	–	–	10±[4]
10^5 hr	–	–	–	–	–	–	–	–	–	–	–	–	5.2[4]
500F Annealed, G.S. = 0.013 mm													
10^4 hr	–	–	–	–	–	–	–	–	–	–	–	–	1.95
10^5 hr	–	–	–	–	–	–	–	–	–	–	–	–	.7
500F Cold drawn, 84%													
10^4 hr	–	–	–	–	–	–	–	–	–	–	–	–	2.3[5]
10^5 hr	–	–	–	–	–	–	–	–	–	–	–	–	.6[5]

[1] 0.5% extension under load
[2] Rotating beam tests on rod, at 20×10^6 cycles
[3] Plate 0.102 in. thick. P = 0.0089%; O = 0.005%
[4] Slightly recrystallized
[5] Recrystallization well advanced
[6] 1% creep

Modulus of elasticity, nominal value of E, M psi 17,000

COPPER ALLOYS, WROUGHT

WROUGHT Brass

Technological Properties

Melting point	solidus 1920F or 1050C liquidus 1950F or 1065C
Recrystallization temp	700F or 370C, approx., for material reduced 50% and grain size 0.015-0.070 mm initially.
Machinability index	20, with free-cutting brass = 100
Hot working temp	1400-1600F or 750-875C
Annealing temp	800-1450F or 425-800C
Weldability	Fair, by carbon arc Good, by oxyacetylene welding
Soldering	Good
Brazing	Good

Chemical Composition[1]

	Cu %	Zn %	Pb %	Fe %
Sheet	94.0/96.0	rest	.03 max	.05 max
Wire	94.0/96.0	rest	.05 max	.05 max

[1]ASTM

Characteristics. Gilding metal has excellent forming properties, both hot and cold, with a yellow color.

Uses. For coins, medals, novelties, jewelry, bullet jackets, firing pin supports, base for enamel, etc.

Physical Properties

Density, at 68F	0.320 lb/cu in. (8.86 S.G.)
Specific heat, cal/gm at 68F	0.09 per °C
Volume conductivity, % of Cu, at 68F	56%
Electrical resistivity, microhm/cm³ at 68F	3.1
Electrical resistivity, ohms/mil ft at 68F	18.5
Temp coef of electrical resistivity, at 68F	.00231/°C

Thermal Conductivity
Cgs units at 20C
Btu/ft²/ft/hr/°F 135

Coef of Thermal Expansion

Temp Range	
25-300C or 77-572F	$18.1 \times 10^{-6}/°C$ $10.0 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Rock 30-T Hard	Rock Hard	Shear S M psi
Hot rolled strip .050mm[2]	34	10	45	–	F46	–
Hot rolled strip .035mm[2]	35	11	45	4	F52	28
Hot rolled strip .015mm[2]	38	14	42	15	F60	30
1/4 hard strip	42	32	25	44	B38	32
1/2 hard strip	48	40	12	54	B52	34
Hard strip	56	50	5	60	B64	37
Extra hard strip	61	55	4	64	B70	39
Spring temper	64	58	4	66	B73	40

[1]0.5% extension under load
[2]Grain size values

Modulus of elasticity, E in M psi 17,000

COMMERCIAL Bronze

Chemical Composition[1]

	Cu %	Zn %	Pb %	Fe %	Others %
Sheet	89.0/91.0	rest	.05 max	.05 max	–
Strip	89.0/91.0	rest	.05 max	.05 max	.13 max
Bullet-jacket cups	89.0/91.0	rest	.05 max	.05 max	.13 max
Wire	89.0/91.0	rest	.05 max	.05 max	–

[1] ASTM

Characteristics. Commercial bronze has very good working properties, especially cold.

Uses. Grill work, screen cloth, weather stripping, etching bronze, escutcheons, kick plates, line clamps, marine hardware, rivets, screws, primer caps, rotating bands, costume jewelry, compact cases and the like, ornamental trim, base for enamel, etc.

Technological Properties

Melting point	solidus 1870F or 1020C liquidus 1910F or 1045C
Recrystallization temp	About 700F or 370C, for 37% cold reduction with 0.050mm initial grain size
Hot working temp	1400-1600F or 750-875C
Annealing temp	800-1450F or 425-800C
Weldability	Fair, by carbon arc Good by oxyacetylene
Soldering	Good
Brazing	Good
Machinability index	20, with free cutting brass=100

Physical Properties

Density, at 68F	0.318 lb/cu in. (8.80 S.G.)
Specific heat, cal/gm at 68F	0.09
Volume Conductivity, % of Cu, at 68F, annealed	44%
Electrical resistivity, microhm/cm³ at 68F	3.9
Electrical resistivity, ohms/mil ft, at 68F	23.5
Temp coef of electrical resistivity, at 68F	0.00186/°C

Thermal Conductivity

Cgs units at 20C	0.45
Btu/ft²/ft/hr/°F at 68F	109

Coef of Thermal Expansion

Temp Range	
25-300C or 77-572F	18.2×10^{-6}/°C 10.1×10^{-6}/°F

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Rock 30-T Hard	Rock Hard	Shear S M psi
Flat Products						
.040 in. G. S.=.050mm	37	10	45	6	F53	28
.040 in. G. S.=.035mm	38	12	45	12	F57	30
.040 in. G. S.=.025mm	39	14	44	16	F60	31
.040 in. G. S.=.015mm	41	15	42	26	F65	32
.040 in. 1/4 hard	45	35	25	44	B42	33
.040 in. 1/2 hard	52	45	11	56	B58	35
.040 in. hard	61	54	5	63	B70	38
.040 in. extra hard	67	58	4	67	B75	40
.040 in. spring	72	62	3	69	B78	42
.040 in. as hot rolled	39	14	44	–	B60	31
.250 in. G. S.=.035mm	38	12	50	–	F57	30
.250 in. 1/2 hard	52	45	15	–	B58	35
.250 in. as hot rolled	37	10	45	–	F53	28
Wire						
.080 in. G. S.=.035mm	40	–	50	–	–	30
.080 in. G. S.=.015mm	42	–	48	–	–	32
.080 in. 1/8 hard	44	–	27	–	–	33
.080 in. 1/4 hard	50	–	13	–	–	34
.080 in. 1/2 hard	60	–	6	–	–	37
.080 in. hard	74	–	4	–	–	42
.080 in. extra hard	83	–	3	–	–	–
.080 in. spring	90	–	3	–	–	–
Tube						
1 in. od × .065 G. S.=.035mm	38	12	50	12	F57	–
1 in. od × .065 hard drawn	60	53	6	62	B69	–
Rod						
.500 in. G. S.=.035mm	40	–	50	–	F55	32
.500 in. 1/8 hard	45	–	25	–	B42	33

[1] 0.5% extension under load

Endurance limit, spring temper, 0.040 in. thick	21 M psi, 15×10^{8} cycles
Endurance limit, hard wire at 0.080 in.	23 M psi, 10×10^{7} cycles
Modulus of elasticity, E in M psi	17,000

COPPER ALLOYS, WROUGHT

RED Brass

Chemical Composition[1]	Cu %	Zn %	Pb %	Fe %	Sn %
Sheet	84.0/86.0	rest	.05 max	.05 max	–
Wire	84.0/86.0	rest	.05 max	.05 max	–
Tubes	83.0/86.0	rest	.06 max	.05 max	–
Condenser tubes	84.0 min	rest	.075 max	.06 max	–
Pipe	83.0/86.0	rest	.06 max	.05 max	.15 max

[1] ASTM

Technological Properties

Melting point	solidus 1810F or 990C liquidus 1880F or 1025C
Recrystallization temp	About 660F or 350C for sheet of 0.035 initial grain size, reduced 50%
Machinability index	30, basis of free cutting brass = 100
Hot working temp	1450-1650F or 800-900C
Annealing temp	800-1350F or 425-725C
Weldability	Fair, with carbon arc Good, with oxyacetylene
Soldering	Good
Brazing	Good

Characteristics. Red Brass has good hot working properties. and excellent cold working properties.

Uses. Architectural trim, weather strip, and etching parts, electrical conduit, sockets, etc., fire extinguishers, eyelets and fasteners, condenser and heat exchanger tubes, flexible hose, pickling crates, plumbing pipe, pump lines, radiator cores, plumbing traps, etc., costume jewelry, compact cases, etc., tags, dials, etc.

Physical Properties

Density, at 68F	0.316 lb/cu in. (8.75 S.G.)
Specific heat, cal/gm at 68F	0.09/ °C
Volume conductivity, % of Cu, at 68F, annealed	37%
Electrical resistivity, microhm/cm³ at 68F annealed	4.7
Electrical resistivity, ohms/mil ft, at 68F annealed	28
Temp coef of electrical resistivity, at 68F	0.0016/ °C

Thermal Conductivity

Cgs units at 20C	0.38
Btu/ft²/ft/hr/°F at 68F	92

Coef of Thermal Expansion Temp Range	
25-300C or 77-572F	18.7×10^{-6}/°C 10.4×10^{-6}/°F

Mechanical Properties Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Rock 30-T Hard	Rock Hard	Shear S M psi
Flat Rolled (0.040 in. thick)						
G. S. = .070mm	39	10	48	10	F56	31
G. S. = .050mm	40	12	47	14	F59	31
G. S. = .035mm	41	14	46	22	F63	31
G. S. = .025mm	43	16	44	28	F66	32
G. S. = .015mm	45	18	42	38	F71	33
1/4 in. hard	50	39	25	54	B55	35
1/2 in. hard	57	49	12	60	B65	37
hard	70	57	5	68	B77	42
extra hard	78	61	4	72	B83	44
spring	84	63	3	74	B86	46
Wire (0.080 in. diam)						
G. S. = .035mm	41	–	48	–	–	31
G. S. = .025mm	43	–	–	–	–	32
G. S. = .015mm	45	–	–	–	–	33
1/8 in. hard	50	–	25	–	–	35
1/4 in. hard	59	–	11	–	–	38
1/2 in. hard	72	–	8	–	–	43
hard	88	–	6	–	–	48
spring	105	–	–	–	–	54
Tube (1.0 in. o.d.)						
G. S. = .050mm	40	12	55	15	F60	–
G. S. = .015mm	44	18	45	38	F71	–
light drawn	50	40	30	54	B55	–
hard drawn	70	58	8	68	B77	–
Pipe (.750 in. SPS)						
G. S. = .015mm	44	18	45	–	F71	–

[1] 0.5% extension under load

Endurance limit, 1/8 hard rod	20 M psi, 30×10^7 cycles
Modulus of elasticity, E in M psi	17,000
Creep Strength (See Fig 3, p 913 Metals Handbook	

Low Brass

Chemical Composition[1]

	Cu %	Zn %	Pb %	Fe %
Sheet, strip	78.5/81.5	rest	.05 max	.05 max
Wire	78.5/81.5	rest	.05 max	.05 max

[1] ASTM

Characteristics. Low Brass has excellent hot working properties, with fair cold working properties.

Uses. Ornamental metal work, spandrels, etc., battery caps, musical instruments, bellows, clock dials, flexible hose, pump lines, tokens, etched articles, etc.

Technological Properties

Melting point	solidus 1770F or 965C liquidus 1830F or 1000C
Recrystallization temp	About 750F or 400C for strip of 0.060mm initial grain size, after 37% reduction.
Machinability index	30, on basis of free cutting brass = 100
Hot working temp	1500-1650F or 825-900C
Annealing temp	800-1300F or 425-700C
Weldability	Fair, by carbon arc Good, by oxyacetylene
Soldering	Good
Brazing	Good

Physical Properties

Density, at 68F	0.313 lb/cu in. (8.67 S.G.)
Specific heat, cal/gm at 68F	0.09/°C
Volume conductivity, % of Cu, at 68F, annealed	32%
Electrical resistivity, microhm/cm³ at 68F	5.4
Electrical resistivity, ohms/mil ft, at 68F	32
Temp coef of electrical resistivity, at 68F	0.00154/°C

Thermal Conductivity

Cgs units at 20C	0.33
Btu/ft²/ft/hr/°F at 68F	81

Coef of Thermal Expansion

Temp Range	
25-300C or 68-572F	$19.1 \times 10^{-6}/°C$ $10.6 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Rock 30-T Hard	Rock Hard	Shear S M psi	End Lt M psi
Flat Products								
0.040 in.	G.S.=.070mm	42	12	52	8	F57	–	–
0.040 in.	G.S.=.050mm	44	14	50	16	F61	32	–
0.040 in.	G.S.=.035mm	46	15	48	28	F66	–	–
0.040 in.	G.S.=.025mm	48	17	47	32	F69	–	–
0.040 in.	G.S.=.015mm	50	20	46	42	F75	33	–
0.040 in. 1/4 hard		53	40	30	54	B55	36	–
0.040 in. 1/2 hard		61	50	18	64	B70	39	–
0.040 in. hard		74	59	7	71	B82	43	–
0.040 in. spring		91	65	3	77	B91	48	24[2]
Wire								
0.080 in.	G.S.=.050mm	44	–	55	–	–	32	–
0.080 in.	G.S.=.035mm	46	–	50	–	–	–	–
0.080 in.	G.S.=.015mm	50	–	47	–	–	33	–
0.080 in. 1/8 hard		56	–	27	–	–	37	–
0.080 in. 1/4 hard		68	–	12	–	–	42	–
0.080 in. 1/2 hard		82	–	8	–	–	47	–
0.080 in. hard		107	–	5	–	–	53	23[3]
0.080 in. extra hard		116	–	4	–	–	–	–
0.080 in. spring		125	–	3	–	–	60	26[3]

[1] 0.5% extension under load
[2] At 20×10^6 cycles
[3] At 10^8 cycles

Modulus of elasticity, E in M psi 16,000

COPPER ALLOYS, WROUGHT

LEADED COMMERCIAL Bronze

Chemical Composition	Cu %	Zn %	Pb %	Fe %
Rod	87.50/90.50	rest	1.25/2.25	.10 max

Technological Properties

Melting point	solidus 1850F or 1010C liquidus 1900F or 1040C
Hot working temp	Usually hot extruded
Annealing temp	800-1200F or 425-650C
Machinability	80 on basis of free cutting brass=100

Characteristics. Leaded Commercial Bronze has greatly improved machinability.

Uses. Screw machine parts, screws, pickling crates, etc.

Physical Properties

Density, at 68F	0.319 lb/cu in. (8.83 S.G.)
Specific heat, cal/gm at 68F	0.09/°C
Volume conductivity, % of Cu, annealed	42%
Electrical resistivity, microhm/cm³ at 68F	4.1
Electrical resistivity, ohms/mil ft, at 68F	25

Thermal Conductivity

Cgs units at 20C	0.43
Btu/ft²/ft/hr/°F at 68F	104

Coef of Thermal Expansion Temp Range	
20-300C or 68-572F	$18.4 \times 10^{-6}/°C$ $10.2 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Rock Hard	Shear S M psi	E 10^6 psi
Rod							
Annealed	37	12	45	70	F55	24	17
1/2 hard	52	45	18	60	B58	30	17

[1] At 0.5% extension under load

COPPER ALLOYS, WROUGHT

LOW LEADED Brass

Chemical Composition	Cu %	Zn %	Pb %	Fe %
Sheet	62.5/66.5	rest	.30/.70	.10 max

Characteristics. Low leaded brass has very good machinability.

Uses. Various hardware parts, watch hooks, etc.

Technological Properties

Melting point	solidus 1650F or 900C liquidus 1760F or 925C
Hot working temp	Usually hot extruded
Annealing temp	800-1300F or 425-700C
Machinability	60 on basis of free cutting brass=100

Physical Properties

Density, at 68F	0.306 lb/cu in. (8.47 S.G.)
Specific heat, cal/gm at 68F	0.09/°C
Volume conductivity, % of Cu, annealed	26%
Electrical resistivity, microhm/cm³ at 68F	6.6
Electrical resistivity, ohms/mil ft, at 68F	40

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Rock Hard	Shear S M psi	E 10^6 psi
Flat Products						
Annealed	49	17	57	F68	34	15
1/4 hard	54	40	43	B55	36	15
1/2 hard	61	50	23	B70	40	15
hard	74	60	8	B80	43	15

[1] At 0.5% extension under load

Thermal Conductivity

Cgs units at 20C	0.28
Btu/ft²/ft/hr/°F at 68F	67.5

Coef of Thermal Expansion Temp Range	
20-300C or 68-572F	$20.3 \times 10^{-6}/°C$ $11.3 \times 10^{-6}/°F$

CARTRIDGE Brass

Chemical Composition	Cu %	Zn %	Pb %	Fe %	Others %
Sheet and strip	68.5/71.5	rest	.07 max	.05 max	–
Sheet and strip, etc.	68.5/71.5	rest	.07 max	.05 max	0.15
Cups	68.5/71.5	rest	.07 max	.05 max	+
Wire	68.5/71.5	rest	.07 max	.05 max	–
Tubes	68.5/71.5	rest	.075 max	.06 max	–

Characteristics. Cartridge brass has the combination of high strength and ductility, and has excellent cold working properties with fair hot working properties.

Uses. Cartridge cases and ammunition components, and is also used for radiator cores and tanks, reflectors, flashlight shells, lamp fixtures, bases for incandescent lamps, sockets and screw shells, eyelets, fasteners, pins, rivets, springs, various stampings, tubes, etc.

Technological Properties

Melting point	solidus 1680F or 915C liquidus 1750F or 955C
Recrystallization temp	About 660F or 350C for 0.045mm initial grain size and 50% reduction
Machinability index	30 on basis of free cutting brass = 100
Hot working temp	1350-1550F or 725-850C
Annealing temp	800-1400F or 425-750C
Weldability	Fair, by carbon arc Fair, by electric resistance Good, by oxyacetylene
Soldering	Good
Brazing	Good

Mechanical Properties

Form or Condition	Test Temp Deg C	Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Red. Area %	Rock 30-T Hard	Rock Hard	Shear S M psi	End Lt[2] M psi
Flat Products 0.040 in.									
G. S. .100 mm	–	44	11	66	–	11	F54	–	13
.070 mm	–	46	14	65	–	15	F58	32	13
.050 mm	–	47	15	62	–	26	F64	–	–
.035 mm	–	49	17	57	–	31	F68	34	14
.025 mm	–	51	19	55	–	36	F72	–	–
.015 mm	–	53	22	54	–	43	F78	35	15
¼ hard	–	54	40	43	–	54	B55	36	–
½ hard	–	62	52	23	–	65	B70	40	18
Hard	–	76	63	8	–	73	B82	44	21
Extra hard	–	86	65	5	–	76	B88	46	–
Spring	–	94	65	3	–	77	B91	48	23
Extra spring	–	99	65	3	–	78	B93	–	–
Wire 0.080 in.									
G. S. .050 mm	–	48	–	64	–	–	–	–	–
.035 mm	–	50	–	60	–	–	–	34	–
.025 mm	–	52	–	58	–	–	–	–	–
.015 mm	–	54	–	56	–	–	–	–	–
1/8 hard	–	58	–	35	–	–	–	38	–
¼ hard	–	70	–	20	–	–	–	–	–
Extra hard	–	124	–	4	–	–	–	–	–
Spring	–	130	–	3	–	–	–	60	22
Tube 1.0 in. O.D. × 0.065 in.									
G. S. .050 mm	–	47	15	65	–	26	F64	–	–
.025 mm	–	52	20	55	–	40	F75	–	–
Hard drawn	–	78	64	8	–	73	B82	–	–
Rod 1.0 in.									
G. S. .050 mm	–	48	16	65	–	–	F65	34	–
1/8 hard	–	55	40	48	–	–	B60	36	–
½ hard	–	70	52	30	–	–	B80	42	22[3]
Effect of Temp[4]									
	20	51	28[5]	48	77	–	–	–	–
	-10	53	29[5]	48	77	–	–	–	–
	-40	54	26[5]	58	76	–	–	–	–
	-80	57	27[5]	60	79	–	–	–	–
	-120	62	28[5]	55	78	–	–	–	–
	-180	74	30[5]	75	74	–	–	–	–
Directional Properties[6]									
// to rolling	–	48	–	59	–	–	–	–	–
45° to rolling	–	44	–	66	–	–	–	–	–
Transverse to rolling	–	47	–	61	–	–	–	–	–

[1] 0.5% extension under load
[2] At 10^8 cycles, except (3)
[3] At 50×10^6 cycles
[4] Approximate values from Colbeck and MacGillivray, Trans. Inst. Chem. Eng., 1933, 11, p. 107
[5] .1%
[6] Example for material with ready-to-finish anneal of 400C, cold rolled 70%, and annealed 1 hr at 575C — from Palmer and Smith, Trans. AIME, 1942, 147, p. 69

Modulus of elasticity, E in M psi 16,000

(Continued on page 308)

COPPER ALLOYS, WROUGHT

CARTRIDGE Brass

(Continued from page 307)

Thermal Conductivity

Cgs units at 20C	0.29
Btu/ft²/ft/hr/°F at 68F	70

Coef of Thermal Expansion

Temp Range	
25-300C or 77-572F	$19.9 \times 10^{-6}/°C$
	$11.1 \times 10^{-6}/°F$

Equation, 20-300C

$L_t = L_0\,[1 + (17.75t + 0.00653t^2) \times 10^{-6}]$

Physical Properties

Density, at 68F	0.308 lb/cu in. (8.53 S.G.)
Specific heat, cal/gm at 68F	0.09/°C
Volume conductivity, % of Cu, at 68F, annealed	28%
Electrical resist, microhm/cm³ at 68F, annealed	6.2
Electrical resist, ohms/mil ft at 68F, annealed	37
Temp coef of electrical resistivity, at 68F	0.001484/°C

COPPER ALLOYS, WROUGHT

Muntz Metal

Chemical Composition[1]

	Cu %	Zn %	Pb %	Fe %
Sheet	59/63	rest	.20 max	.15 max

[1] ASTM

Technological Properties

Melting point	solidus	1650F or 900C
	liquidus	1660F or 905C
Hot working temp		1150-1450F or 625-800C
Annealing temp		800-1100F or 425-600C

Characteristics. Muntz Metal has good resistance to corrosion and hot working properties.

Uses. Architectural trim, nuts and bolts, condenser plates, tubing for condensers, evaporators, and heat exchangers, valves, hot forgings, brazing rod, etc.

Physical Properties

Density, at 68F	0.303 lb/cu in (8.39 S.G.)
Specific heat, cal/gm at 68F	0.09/°C
Volume conductivity, % of Cu, annealed	28%
Electrical resistivity, microhm/cm³ at 68F	6.2
Electrical resistivity, ohms/mil ft, at 68F	37

Thermal Conductivity

Cgs units at 20C	0.29
Btu/ft²/ft/hr/°F at 68F	70.3

Coef of Thermal Expansion

Temp Range	
20-300C or 68-572F	$20.8 \times 10^{-6}/°C$
	$11.6 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Rock 30-T Hard	Rock Hard	Shear S M psi	E 10^6 psi
Flat Products							
Annealed	54	21	45	46	F80	40	15
1/2 hard	70	50	10	67	B75	44	15

[1] At 0.5% extension under load

COPPER ALLOYS, WROUGHT

LOW LEADED Brass (Tube)

Chemical Composition	Cu %	Zn %	Pb %	Fe %
Tube	65.0/68.0	rest	.3/.8	.07 max

Characteristics. Low Leaded Brass (Tube) has improved machinability over non-leaded brass with moderate cold working properties.

Uses. Primers for ammunition, pump lines, J-bends, etc.

Technological Properties

Melting point	solidus 1660F or 905C
	liquidus 1720F or 940C
Annealing temp	800-1200F or 425-650C
Hot working temp	Is usually extruded
Machinability	60 on basis of free cutting brass = 100

Thermal Conductivity

Cgs units	at 20C	0.28
Btu/ft²/ft/hr/°F	at 68F	67.7

Physical Properties

Density, at 68F	0.307 lb/cu in. (8.50 S.G.)
Volume conductivity, % of Cu, annealed	26%
Electrical resistivity, microhm/cm³ at 68F	6.6
Electrical resistivity, ohms/mil ft, at 68F	40

Coef of Thermal Expansion Temp Range	
20-300C or 68-572F	$20.2 \times 10^{-6}/°C$
	$11.2 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Rock Hard
Tube				
Annealed	47	15	60	F64
Hard	75	60	7	B80

[1]At 0.5% extension under load

COPPER ALLOYS, WROUGHT

MEDIUM LEADED Brass

Chemical Composition	Cu %	Zn %	Pb %	Fe %
Sheet	62.5/66.5	rest	.75/1.25	.10 max

Technological Properties

Melting point	solidus 1630F or 885C
	liquidus 1700F or 925C
Hot working temp	Usually hot extruded
Annealing temp	800-1200F or 425-650C
Machinability	70, on basis of free cutting brass = 100

Uses. Hardware, butts, gears, nuts, rivets, screws, dials on instrument plates, engravings, etc.

Thermal Conductivity

Cgs units	at 20C	0.28
Btu/ft²/ft/hr/°F	at 68F	67.7

Physical Properties

Density, at 68F	0.306 lb/cu in. (8.47 S.G.)
Specific heat, cal/gm at 68F	0.09
Volume conductivity, % of Cu, annealed	26%
Electrical resistivity, microhm/cm³ at 68F	6.6
Electrical resistivity ohms/mil ft, at 68F	40

Coef of Thermal Expansion Temp Range	
20-300C or 68-572F	$20.3 \times 10^{-6}/°C$
	$11.3 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Rock Hard	Shear S M psi	E 10^6 psi
Flat Products						
Annealed	49	17	54	F68	34	15
1/4 hard	54	40	41	B55	36	15
1/2 hard	61	50	21	B70	40	15
Hard	74	60	7	B80	43	15

[1]At 0.5% extension under load

COPPER ALLOYS, WROUGHT

HIGH LEADED Brass

Chemical Composition (Nominal)		
Cu %	Zn %	Pb %
62.5	33.75	1.75

Uses. Clock plates, nuts, clock and watch backs, gears, wheels, and channel plates.

Technological Properties

Melting point	solidus 1630F or 885C liquidus 1670F or 910C
Hot working temp	Usually hot extruded
Annealing temp	800-1100F
Machinability	90, on basis of free cutting brass = 100

Physical Properties

Density, at 68F	0.306 lb/cu in. (8.47 S.G.)
Electrical resistivity, microhm/cm³ at 68F	6.6
Electrical resistivity, ohms/mil ft, at 68F	40

Thermal Conductivity

Cgs units at 20C	0.28
Btu/ft²/ft/hr/°F at 68F	67

Coef of Thermal Expansion

Temp Range	
20-300C or 68-572F	$20.3 \times 10^{-6}/°C$ $11.3 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Rock 30-T Hard	Rock Hard	Shear S M psi	E 10^6 psi
Flat Products							
Annealed	49	17	52	31	F68	34	–
1/4 hard	54	40	38	54	B55	36	–
1/2 hard	61	50	20	65	B70	40	–
Hard	74	60	7	69	B80	43	15
Extra hard	85	62	5	74	B87	45	–
Rod							
1/2 hard	58	45	25	–	B75	–	–

[1] At 0.5% extension under load

COPPER ALLOYS, WROUGHT

FREE CUTTING Brass

Chemical Composition (Nominal)		
Cu %	Zn %	Pb %
61.5	35.5	3

Characteristics. Free Cutting Brass has the highest machinability rating of the brasses and bronzes.

Uses. Gears and pinions, hardware, and parts made on high speed screw machines.

Technological Properties

Melting point	solidus 1630F or 885C liquidus 1650F or 900C
Hot working temp	1300-1450F
Annealing temp	800-1100F

Physical Properties

Density, at 68F	0.307 lb/cu in. (8.50 S.G.)
Electrical resistivity, microhm/cm³ at 68F	6.6
Electrical resistivity, ohms/mil ft, at 68F	40

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Rock Hard	Shear S M psi
Flat Products					
1/4 hard	56	45	20	–	33
Rod					
Annealed	49	18	53	F68	30
1/8 hard	55	44	32	B75	32
1/4 hard	58	45	25	B78	34
1/2 hard	68	52	18	B80	38
Shapes					
Extruded	49	18	50	F68	30
1/4 hard	56	45	20	B62	33

[1] At 0.5% extension under load

Modulus of elasticity, E in M psi 14,000

Thermal Conductivity

Cgs units at 20C	0.28
Btu/ft²/ft/hr/°F at 68F	67

Coef of Thermal Expansion

Temp Range	
20-300C or 68-572F	$20.5 \times 10^{-6}/°C$ $11.4 \times 10^{-6}/°F$

COPPER ALLOYS, WROUGHT

Naval Brass

Chemical Composition

	Cu %	Zn %	Sn %	Fe %	Pb %	Others %
Rod, bar	59.00/62.00	rest	.50/1.00	.10 max	.20 max	.10 max
Forgings	59.00/61.00	rest	.50/1.00	.10 max	.20 max	–
Tube plates	59.00/61.00	rest	.50/1.00	.10 max	.20 max	.10 max

Characteristics. Naval Brass is well suited to forming operations, both hot and cold.

Uses. Condenser plates, marine hardware, propeller shafts, piston rod and valve stems, airplane turnbuckle barrels, and welding rod.

Technological Properties

Melting point	solidus 1630F or 885C
	liquidus 1650F or 900C
Hot working temp	1200-1500F or 650-825C
Annealing temp	800-1100F or 425-600C
Machinability	30, on basis of free cutting brass = 100

Physical Properties

Density, at 68F	0.304 lb/cu in. (8.41 S.G.)
Specific heat, cal/gm at 68F	0.09/°C
Volume conductivity, % of Cu, at 68F, annealed	26%
Electrical resistivity, ohms/mil ft, at 68F	42

Thermal Conductivity

Cgs units at 20C	0.28
Btu/ft²/ft/hr/°F at 68F	67

Coef of Thermal Expansion

Temp Range	
20-300C or 68-572F	$21.2 \times 10^{-6}/°C$
	$11.8 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Section In.	Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Rock B Hard	Shear S M psi
Flat Products						
Light anneal	.040	62	30	40	60	41
1/4 hard	.040	70	58	17	75	43
Soft anneal	.250	58	25	49	56	40
Light anneal	.250	60	28	45	58	41
Hot rolled	1.0	55	25	50	55	40
Rod						
Soft anneal	.250	58	27	45	56	40
Light anneal	.250	63	30	40	60	42
1/4 hard	.250	70	48	25	80	43
1/2 hard	.250	80	57	20	85	45
Soft anneal	1.0	57	25	47	55	40
Light anneal	1.0	63	30	40	60	42
1/4 hard	1.0	69	46	27	78	43
1/2 hard	1.0	75	53	20	82	44
Soft anneal	2.0	56	25	47	55	40
Light anneal	2.0	62	28	43	60	42
1/4 hard	2.0	67	40	35	75	43
Tube 0.375 in. O.D. × 0.097 in.						
Hard drawn	–	88	66	18	95	–

[1] At 0.5% extension under load

End. Lt., as rod, cold drawn 11.5%	15 M psi at 30 × 10⁷ cycles
Modulus of elasticity, E in M psi	15,000

COPPER ALLOYS, WROUGHT

LEADED Muntz Metal

Chemical Composition (Nominal)

Cu %	Zn %	Pb %
60	39.5	0.5

Uses. Condenser tube plates.

Physical Properties

Density, at 68F	0.304 lb/cu in. (8.41 S.G.)
Electrical resistivity, microhm/cm² at 68F	6.2
Electrical resistivity, ohms/mil ft, at 68F	38

Technological Properties

Melting point	solidus 1630F or 885C
	liquidus 1650F or 900C
Hot working temp	1150-1450F or 625-800C
Annealing temp	800-1100F or 425-600C

Thermal Conductivity

Cgs units at 20C	0.29
Btu/ft²/ft/hr/°F at 68F	71

Coef of Thermal Expansion

Temp Range	
20-300C or 68-572F	$20.8 \times 10^{-6}/°C$
	$11.6 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Rock Hard	Shear S M psi	E 10^6 psi
Hot rolled plate 1 in. section	54	20	45	F80	40	15

COPPER ALLOYS, WROUGHT

Forging Brass

Chemical Composition (Nominal)		
Cu %	Zn %	Pb %
60	38	2

Characteristics. Forging Brass has very good machinability.

Uses. Forgings and pressings.

Physical Properties

Density, at 68F	0.305 lb/cu in. (8.44 S.G.)
Electrical resistivity, microhm/cm³ at 68F	6.4
Electrical resistivity, ohms/mil ft, at 68F	38

Technological Properties

Melting point	solidus 1620F or 882C
	liquidus 1640F or 893C
Hot working temp	1200-1500F or 650-825C
Annealing temp	800-1100F or 425-600C
Machinability	80, on basis of free cutting brass = 100

Thermal Conductivity

Cgs units at 20C	0.28
Btu/ft²/ft/hr/°F at 68F	69

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Rock Hard	E 10^6 psi
Rods and Shapes					
As extruded	52	20	45	F78	15

Coef of Thermal Expansion

Temp Range	
20-300C or 68-572F	$20.7 \times 10^{-6}/°C$
	$11.5 \times 10^{-6}/°F$

COPPER ALLOYS, WROUGHT

ARCHITECTURAL Bronze

Chemical Composition (Nominal)		
Cu %	Zn %	Pb %
57	40	3

Uses. Architectural trim, for hardware such as butts, hinges, and lock bodies, and for industrial forgings.

Physical Properties

Density, at 68F	0.306 lb/cu in. (8.47 S.G.)
Electrical resistivity, microhm/cm³ at68F, annealed	6.2
Electrical resistivity, ohms/mil ft, at 68F, annealed	37

Technological Properties

Melting point	solidus 1610F or 875C
	liquidus 1630F or 890C
Hot working temp	1150-1350F or 625-725C
Annealing temp	800-1100F or 425-600C
Machinability	90, on basis of free cutting brass = 100

Thermal Conductivity

Cgs units at 20C	0.29
Btu/ft²/ft/hr/°F at 68F	71

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Rock Hard	Shear S M psi
As extruded 1 in	60	20	30	B65	35

Coef of Thermal Expansion

Temp Range	
20-300C or 68-572F	$20.9 \times 10^{-6}/°C$
	$11.6 \times 10^{-6}/°F$

COPPER ALLOYS, WROUGHT

LEADED Naval Brass

Chemical Composition

	Cu %	Zn %	Sn %	Pb %	Fe %	Others %
Rod, bar	59/62	rest	.5/1.0	1.25/2.25	.10 max	.10 max

Characteristics. Leaded Naval Brass is suited to forming by hot extrusion, hot forging, pressing, and machine.

Uses. Marine hardware and screw machine products.

Technological Properties

Melting point	solidus 1630F or 885C
	liquidus 1650F or 900C
Hot working temp	1200-1400F or 650-750C
Annealing temp	800-1100F or 425-600C
Machinability	70, on basis of free cutting brass = 100

Physical Properties

Density, at 68F	0.305 lb/cu in. (8.44 S.G.)
Specific heat, cal/gm at 68F	0.09/°C
Volume conductivity, % of Cu, at 68F, annealed	26%
Electrical resistivity, ohms/cir mil ft, at 68F, annealed	40

Thermal Conductivity

Cgs units at 20C	0.28
Btu/ft²/ft/hr/°F at 68F	67

Coef of Thermal Expansion

Temp Range	
20-300C or 68-572F	$21.4 \times 10^{-6}/°C$
	$11.8 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Rock B Hard	Shear S M psi	E 10^6 psi
Rod 1.0 in.						
Soft anneal	57	25	40	55	36	15
1/4 hard	69	46	20	78	39	–
1/2 hard	75	53	15	82	40	–

[1] At 0.5% extension under load

COPPER ALLOYS, WROUGHT

FREE CUTTING Muntz Metal

Characteristics. A free machining brass.

Uses. Screw machine products.

Chemical Composition (Nominal)

Cu %	Zn %	Pb %
60.5	38.4	1.1

Technological Properties

Melting point	solidus 1630F or 885C
	liquidus 1650F or 900C
Hot working temp	1150-1450F or 625-800C
Annealing temp	800-1100F or 425-600C
Machinability	70, on basis of free cutting brass = 100

Physical Properties

Density, at 68F	0.304 lb/cu in. (8.41 S.G.)
Electrical resistivity, microhm/cm³ at 68F, annealed	6.4
Electrical resistivity, ohm/mil ft, at 68F, annealed	38

Thermal Conductivity

Cgs units at 20C	0.28
Btu/ft²/ft/hr/°F at 68F	69

Coef of Thermal Expansion

Temp Range	
20-300C or 68-572F	$20.8 \times 10^{-6}/°C$
	$11.6 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Rock 30-T Hard	Rock Hard	E 10^6 psi
Tubing							
Light anneal	1.5 in. O.D.	54	20	40	43	F80	–
Hard	1.0 in. O.D.	80	60	6	74	B85	15
Hard	2.0 in. O.D.	70	45	10	67	B75	–

COPPER ALLOYS, WROUGHT

MANGANESE Bronze

Chemical Composition[1]	Cu %	Fe %	Sn %	Mn %	Zn %	Pb %	Al %
Rod	57.00/60.00	.80/2.00	.50/1.50	.5 max	rest	.20 max	—
Forging rod	57.00/60.00	.80/2.00	.50/1.50	.5 max	rest	.20 max	.25 max

[1] ASTM

Technological Properties

Melting point	solidus 1590F or 865C
	liquidus 1630F or 890C
Hot working temp	1150-1450F or 625-750C
Annealing temp	800-1100F or 425-600C
Machinability	30, on basis of free cutting brass = 100

Characteristics. Manganese bronze is suited to forming by hot forging, pressing, hot heading, and upsetting.

Uses. Clutch discs, pump rods, shafting, valve stems, welding rod, etc. It has good resistance to corrosion.

Physical Properties

Density, at 68F	0.308 lb/cu in. (8.53 S.G.)
Specific heat, cal/gm at 68F	0.09/°C
Volume conductivity, % of Cu, at 68F, annealed	24%
Electrical resistivity, ohms/cir mil ft, at 68F, annealed	43

Thermal Conductivity

Cgs units at 20C	0.26
Btu/ft²/ft/hr/°F at 68F	61

Coef of Thermal Expansion

Temp Range	
20-300C or 68-572F	$21.2 \times 10^{-6}/°C$
	$11.8 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Rock B Hard	Shear S M psi	E 10^6 psi
Rod 1.0 in.						
Soft anneal	65	30	33	65	42	15
1/4 hard	77	45	23	83	47	—
1/2 hard	84	60	19	90	48	—
Rod 2.0 in.						
1/4 hard	72	42	27	77	44	—

[1] At 0.5% extension under load

COPPER ALLOYS, WROUGHT

ALUMINUM Brass

Chemical Composition[1]	Cu %	Zn %	Al %	Pb %	Fe %	Others %
Tube	76.00 min	rest	1.75/2.50	.075 max	.06 max	.10 max

[1] ASTM

Technological Properties

Melting point	solidus 1710F or 935C
	liquidus 1780F or 975C
Hot working temp	1400-1600F or 750-875C
Annealing temp	800-1100F or 425-600C
Machinability	30, on basis of free cutting brass = 100

Characteristics. Aluminum Brass is suited to forming by hot extrusion, cold drawing and cold rolling. It has good corrosion resistance.

Uses. Condenser, evaporator, and heat exchanger tubes, distiller tubes and ferrules.

Physical Properties

Density, at 68F	0.301 lb/cu in. (8.33 S.G.)
Specific heat, cal/gm at 68F	0.09/°C
Volume conductivity, % of Cu, at 68F, annealed	25%
Electrical resistivity, ohms/mil ft, at 68F, annealed	45

Thermal Conductivity

Cgs units at 20C	0.24
Btu/ft²/ft/hr/°F at 68F	58

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Rock Hard	Apparent El. Lt. M psi
Tube 1 in. O.D. × .065 in. G.S. = 0.025mm	60	27	55	F77	16

Coef of Thermal Expansion

Temp Range	
20-300C or 68-572F	$18.5 \times 10^{-6}/°C$
	$10.3 \times 10^{-6}/°F$

5% – GRADE A
Phosphor Bronze

Chemical Composition[1]

	Cu %	Sn %	P %	Pb %	Fe %	Zn %	Sb %
Sheet, Wire or Rod	rest	3.5/5.8	.03/.35	.05 max	.10 max	.30 max	.01 max

[1]ASTM

Characteristics. Phosphor Bronze is relatively strong and corrosion resistant and is well suited to various cold forming operations.

Uses. Beater bars, bridge bearing plates, bellows, Bourdon tubing, clutch discs, cotter pins, diaphragms, fuse clips, fasteners, lock washers, sleeve bushings, springs, switch parts, truss wire, wire brushes, chemical hardware, perforated sheets, textile machinery, welding rods, etc. This alloy is hot short.

Physical Properties

Density, at 68F	0.320 lb/cu in. (8.86 S.G.)
Specific heat, cal/gm at 68F	0.09/°C
Volume conductivity, % of standard copper at 68F	18%
Electrical resistivity, microhm/cm³ at 68F	9.6

Technological Properties

Melting point	solidus 1750F or 950C liquidus 1920F or 1050C
Annealing temp	900-1250F or 475-675C
Machinability	20, on basis of free cutting brass = 100
Weldability	Good by oxyacetylene, carbon arc, and electric resistance
Soldering	Good
Brazing	Good

Thermal Conductivity

Cgs units	at 20C	0.19
Btu/ft²/ft/hr/°F	at 68F	46

Coef of Thermal Expansion

Temp Range	
20-300C or 68-572F	17.8×10^{-6}/°C 9.9×10^{-6}/°F

Mechanical Properties

Form or Condition	Section In.	Tensile Strength M psi	Yield Strength M psi	Elong %	Rock B Hard	E 10^6 psi
Flat Products						
Annealed	.040	47	19	64	26	15
1/2 hard	.040	68	55	28	78	15
Hard	.040	81	75	10	87	–
Spring	.040	100	80	4	95	–
Extra Spring	.040	107	80	3	97	–
Wire						
Annealed	.080	50	20	58	–	–
1/4 hard	.080	68	60	24	–	–
1/2 hard	.080	85	80	8	–	–
Hard	.080	110	–	5	–	–
Spring	.080	140	–	2	–	–
Rod						
1/2 hard	0.5	75	65	25	80	–
1/2 hard	1.0	70	58	25	78	–

Admiralty Metal

Chemical Composition

	Cu %	Zn %	Sn %	Fe %	Pb %	Add. Agents[1] %
Tube	70.00/73.00	rest	.90/1.20	.06 max	.075 max	.10 max
Plate	70.00/73.00	rest	.75/1.20	.06 max	.075 max	.10 max

[1] As, Sb, or P, added to inhibit dezincification

Technological Properties

Melting point	solidus 1650F or 900C
	liquidus 1720F or 935C
Hot working temp	1200-1450F or 650-800C
Annealing temp	800-1100F or 425-600C
Machinability	30, on basis of free cutting brass = 100

Characteristics. Admiralty Metal is suited to hot rolling and extrusion, and to cold rolling and drawing, and is superior to brass in certain corrosive conditions.

Uses. Condenser and heat exchanger tubes, condenser tube plates, distiller tubes and ferrules.

Physical Properties

Density, at 68F	0.308 lb/cu in. (8.53 S.G.)
Specific heat, cal/gm at 68F	0.09/°C
Volume conductivity, % of Cu, annealed	24.65%
Electrical resistivity, ohms/mil ft, at 68F, annealed	42

Thermal Conductivity

Cgs units at 20C	0.26
Btu/ft²/ft/hr/°F at 68F	64

Coef of Thermal Expansion

Temp Range	
20-300C or 68-572F	$20.2 \times 10^{-6}/°C$
	$11.2 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Rock Hard	End Lt M psi
Tube – 1" O.D. × 0.065"						
Annealed	G.S.=.025mm	53	22	65	F75	–
Plate 1" Thick						
Hot rolled		48	18	65	F70	–
Wire 0.080"						
Annealed	G.S.=.015mm	55	–	60	–	–
Rod						
Annealed	G.S.=.035mm	–	–	–	–	18±1

[1] At 0.5% extension under load

Creep Strength

Rod, hot rolled to 0.875 in., cold drawn to 0.750 in.

Temp Deg C	Temp Deg F	No Creep M psi	Stress in M psi for creep of .01% per 1000 hr	.10% per 1000 hr	1.0% per 1000 hr
200	400	10	13	19	27
315	600	~zero	1	1.95	3.8
425	800	~zero	.054	.160	.500

Modulus of elasticity, E in M psi 15,000

COPPER ALLOYS, WROUGHT

8% – GRADE C Phosphor Bronze

Chemical Composition*

	Cu %	Sn %	P %	Pb %
Sheet, Wire or Rod	rest	7.0/9.0	.03/.35[1]	.05 max

	Fe %	Zn %	Sb %
Sheet, Wire or Rod	.10 max	.20 max	.01 max[2]

*ASTM
[1]For sheet = .03/ 25 [2]Sheet only

Characteristics and Uses. Same as Grade A, but stronger.[1]

[1]Phosphor Bronze is relatively strong and corrosion resistant and is well suited to various cold forming operations.
It is used for beater bars, bridge bearing plates, bellows, Bourdon tubing, clutch discs, cotter pins, diaphragms, fuse clips, fasteners, lock washers, sleeve bushings, springs, switch parts, truss wire, wire brushes, chemical hardware, perforated sheets, textile machinery, welding rods, etc. This alloy is hot short.

Technological Properties

Melting point	solidus	1620 F or 880 C
	liquidus	1880 F or 1020 C
Annealing temp		900-1250 F or 475-675 C
Machinability index		20 (Free cutting brass = 100)
Weldability		Good by oxyacetylene, carbon arc, and electrical resistance
Soldering		Good
Brazing		Good

Physical Properties
Density, at 68 F 0.318 lb/cu in. (8.80 S.G.)
Specific heat, cal/gm at 68 F 0.09/°C
Volume conductivity, % of standard Cu 13%
Electrical resistivity, microhm/cm³ at 68 F 13

Thermal Conductivity

Cgs units	at 20C	0.15
Btu/ft²/ft/hr/°F	at 68F	36.3

Coef. of Thermal Expansion

Temp Range	
20-300C or 68-572F	$18.2 \times 10^{-6}/°C$
	$10.1 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Sect. in.	Tensile Strength M psi	Yield Strength M psi	Elong %	Rock Hard	End Lt M psi[1]	E 10^6 psi
Flat Products							
Annealed	.040	55	–	70	F75	–	16
½ hard	.040	76	55	32	B84	–	16
hard	.040	93	72	10	B93	22	–
Spring	.040	112	–	3	B98	–	–
Extra spring	.040	120	–	2	B100	–	–
Wire							
Annealed	.080	60	24	65	–	–	–
¼ hard	.080	81	–	–	–	–	–
½ hard	.080	105	–	–	–	–	–
Hard	.080	130	–	–	–	–	–
Spring	.080	140	–	–	–	–	–
Rod							
½ hard	.500	80	65	33	B85	–	–

[1]At 10^8 cycles

10% – GRADE D Phosphor Bronze

Chemical Composition*	Cu %	Sn %	P %	Pb %
Sheet, Wire or Rod	rest	9.0/11.0	.03/.25	.05 max

	Fe %	Zn %	Sb %
Sheet, Wire or Rod	.10 max	.20 max	.01 max

*ASTM

Technological Properties

Melting point solidus	1550 F or 845 C
liquidus	1830 F or 1000 C
Annealing temp	900-1250 F or 475-675 C
Machinability index	20 (Free cutting brass = 100)
Weldability	Good by oxyacetylene, carbon arc, or resistance
Soldering	Good
Brazing	Good

Characteristics and Uses. Grade D Phosphor Bronze is limited in cold-forming properties but is used for parts requiring good resistance to wear and corrosion, heavy bars and plates subjected to severe compression, bridge plates, expansion plates and fittings, and parts requiring extra spring qualities, resiliency, and fatigue strength.

Physical Properties

Density, at 68 F 0 317 lb/cu in. (8.78 S.G)
Specific heat, cal/gm at 68 F 0.09/°C
Volume conductivity, % of Cu 11% (free cutting brass = 100)
Electrical resistivity, microhm/cm³ at 68 F 16

Thermal Conductivity

Cgs units	at 20C	0.12
Btu/ft²/ft/hr/°F	at 68F	29

Coef. of Thermal Expansion

Temp Range	
20-300C or 68-572F	18.4×10^{-6}/°C
	10.2×10^{-6}/°F

Mechanical Properties

Form or Condition	Sect. in.	Tensile Strength M psi	Yield Strength M psi	Elong %	Rock B Hard	E 10^6 psi
Flat Products						
Annealed	.040	66	28	68	55	16
½ hard	.040	83	–	32	92	16
Hard	.040	100	–	13	97	–
Spring	.040	122	–	4	101	–
Extra spring	.040	128	–	3	103	–
Wire						
Annealed	.080	66	–	70	–	–
¼ hard	.080	93	–	–	–	–
½ hard	.080	118	–	–	–	–
Hard	.080	147	–	–	–	–

COPPER ALLOYS, WROUGHT

1.25% – GRADE E
Phosphor Bronze

Chemical Composition*

	%		%		%
Cu	98.5 min	Sn	1.0/1.5	P	trace

*Commercial grade

Characteristics. The 1.25% Sn bronze is suited to many cold-forming operations.

Uses. Electrical contacts, flexible hose, pole line hardware, trolley wire.

Technological Properties

Melting point	solidus	1900 F or 1035 C
	liquidus	1970 F or 1075 C
Annealing temp		900-1200 F or 475-650 C
Machinability index		20 (Free cutting brass = 100)
Hot working temp		1450-1600 F or 800-875 C
Weldability		Good by oxyacetylene, carbon arc and resistance methods
Soldering		Good
Brazing		Good

Physical Properties

Density, at 68 F 0.321 lb/cu in. (8.89 S.G.)
Specific heat, cal/gm at 68 F 0.09/°C
Volume conductivity, % of Cu 48%
Electrical resistivity, microhm/cm³ at 68 F 3.6

Mechanical Properties

Form or Condition	Section in.	Tensile Strength M psi	Yield Strength M psi	Elong %	Hard Rock	End Lt M psi[1]	E 10^6 psi
Flat Products							
Annealed	.040	40	14	48	F60	–	17
½ hard	.040	55	45	16	B64	–	17
Hard	.040	65	50	8	B75	–	–
Spring	.040	75	–	4	B79	–	–
Wire							
Hard	.08	79	–	–	–	32	–
Hard	.46	72	–	–	–	–	–

[1]At 10^8 cycles

Thermal Conductivity

Cgs units	at 20C	0.49
Btu/ft²/ft/hr/°F	at 68F	118.5

Coef. of Thermal Expansion

Temp Range	
20-300C or 68-572F	$17.8 \times 10^{-6}/°C$
	$9.9 \times 10^{-6}/°F$

COPPER ALLOYS, WROUGHT

30%
Cupro-Nickel

Chemical Composition*

	Cu %	Ni %	Fe %	Mn %
Sheet Tube	rest	29.0/33.0	.6 max	1.0 max
	Zn %	**Sn %**	**Pb %**	
Sheet Tube	1.0 max	1.50 max	.05 max	

*ASTM

Characteristics. Cupro-Nickel has very good corrosion resistance and good mechanical and forming properties.

Uses. Condensers, condenser plates, evaporator and heat exchanger tubes, condenser tubes, distiller tubes, ferrules.

Technological Properties

Melting point	solidus	2140 F or 1170 C
	liquidus	2260 F or 1240 C
Hot working temp		1700-1900 F or 925-1050 C
Annealing temp		1200-1500 F or 650- 825 C
Machinability index		20 (Free cutting brass = 100)
Weldability		Good by oxyacetylene, carbon arc and electric resistance methods
Soldering		Good
Brazing		Good

Physical Properties

Density, at 68 F 0.323 lb/cu in. (8.94 S.G.)
Specific heat, cal/gm at 68 F 0.09/°C
Volume conductivity, % of Cu 4.6%
Electrical resistivity, microhm/cm³ at 68 F 37

Mechanical Properties

Form or Condition	Sect. in.	Tensile Strength M psi	Yield Strength M psi	Elong %	Rock B Hard
Flat Products					
Hot rolled	1.0	55	20	45	35
Tubes					
Annealed	1.0 × .065	60	25	45[1]	36
Rod					
½ hard	1.0	75	70	15[1]	80

[1]On 2 in.

Modulus of elasticity, E in M psi 22,000

Thermal Conductivity

Cgs units	at 20C	0.07
Btu/ft²/ft/hr/°F	at 68F	16.9

Coef. of Thermal Expansion

Temp Range	
20-300C or 68-572F	$16.2 \times 10^{-6}/°C$
	$9.8 \times 10^{-6}/°F$

COPPER ALLOYS, WROUGHT

18% – ALLOY A
Nickel Silver

Technological Properties

Melting point	solidus	1960 F or 1070 C
	liquidus	2030 F or 1110 C
Annealing temp		1100-1500 F or 600-825 C
Machinability index		20 (Free cutting brass = 100)
Weldability		Good by oxyacetylene, carbon arc, and electric resistance methods
Soldering		Good
Brazing		Good

Physical Properties

Density, at 68 F 0.316 lb/cu in. (8.73 S.G.)
Specific heat, cal/gm at 68 F 0.09/°C
Volume conductivity, % of Cu 6%
Electrical resistivity, microhm/cm³ at 68 F 29

Thermal Conductivity

Cgs units	at 20C	0.08
Btu/ft²/ft/hr/°F	at 68F	19.3

Coef. of Thermal Expansion

Temp Range	
20-300C or 68-572F	16.2×10^{-6}/°C
	9.0×10^{-6}/°F

Chemical Composition*

	Cu %	Ni %	Zn %
Sheet	63.0/66.5	17.0/19.5	rest
Wire, rod, bar	63.0/66.5	17.0/19.5	rest
Wire	63.0/66.5	16.5/19.5	rest
	Pb %	**Fe %**	**Mn %**
Sheet	.10 max	.25 max	.50 max
Wire, rod, bar	.05 max	.25 max	.50 max
Wire	.10 max	.25 max	.50 max

*ASTM

Characteristics. Nickel Silver is well suited to cold-forming operations, is tarnish- and corrosion-resistant, and has a pleasing white color.

Uses. Table flat ware, base for silver plate, optical goods, rivets, screws, truss wire, zippers, costume jewelry, etching stock, hollow ware, name plates, radio dials, etc.

Mechanical Properties

Form or Condition	Sect. in.	Tensile Strength M psi	Yield Strength M psi	Elong %	Rock B Hard	E 10^6 psi
Flat Products						
Annealed	.040	58	25	40	40	18
¼ hard	.040	65	50	20	73	–
½ hard	.040	74	62	8	83	18
Hard	.040	85	74	3	87	–
Rod						
Annealed	.5	56	25	42	–	–
Hard	.5	70	60	20	78	–
Wire						
Annealed	.080	58	25	45	–	–
¼ hard	.080	73	65	16	–	–
½ hard	.080	86	80	7	–	–
Hard	.080	103	90	3	–	–

COPPER ALLOYS, WROUGHT

18% – ALLOY B
Nickel Silver

Technological Properties

Melting point	solidus	–
	liquidus	1930 F or 1055 C
Annealing temp		1100-1500 F or 600-825 C
Machinability index		30 (Free cutting brass = 100)
Weldability		Good by oxyacetylene, carbon arc and electrical resistance methods
Soldering		Good
Brazing		Good

Physical Properties

Density, at 68 F 0.314 lb/cu in. (8.70 S.G.)
Specific heat, cal/gm at 68 F 0.09/°C
Volume conductivity, % of Cu 5.5%
Electrical resistivity, microhm/cm³ at 68 F 31

Thermal Conductivity

Cgs units	at 20C	0.07
Btu/ft²/ft/hr/°F	at 68F	16.9

Coef. of Thermal Expansion

Temp Range	
20-300C or 68-572F	16.7×10^{-6}/°C
	9.3×10^{-6}/°F

Chemical Composition*

	Cu %	Ni %	Zn %
Sheet	53.5/56.5	16.5/19.5	rest
Wire	53.5/56.5	16.5/19.5	rest
Rod, bar, wire	53.5/56.5	17.0/19.5	rest
	Pb %	**Fe %**	**Mn %**
Sheet	.10 max	.25 max	.50 max
Wire	.10 max	.25 max	.50 max
Rod, bar, wire	.05 max	.25 max	.50 max

*ASTM

Characteristics. Alloy B is stronger and harder than Alloy A and is somewhat limited in cold-forming properties.

Uses. Springs, resistance wire, optical goods, etc.

Mechanical Properties

Form or Condition	Sect. in.	Tensile Strength M psi	Yield Strength M psi	Elong %	Rock B Hard	E 10^6 psi
Flat Products						
Annealed	.040	60	27	40	55	18
Hard	.040	100	85	3	91	18
Spring	.040	115	93	2.5	99	–
Wire						
Annealed	.080	60	–	40	–	–
Spring	.080	145	–	2	–	–

5% Aluminum Bronze

Chemical Composition*

	Cu %	Al %	Fe %	Cu + Al + Fe %	As %	Pb %
Sheet, strip, plate, rods, forgings	92/96	4.0/7.0	.50 max	99.50 min	–	–
Tubes, condenser	rest	5.0/6.5	.10 max	–	.35 max	.10 max

*ASTM

Characteristics. Suited to forming, hot and cold, but is limited in drawing and stamping.

Physical Properties

Density, at 68 F 0.295 lb/cu in. (8.17 S.G.)
Volume conductivity, % of Cu, annealed 17.5%
Electrical resistivity, microhm/cm^3 at 68 F 9.8
Temp coef. of elect. resistivity, 20-200 C 0.00160/°C

Thermal Conductivity

Cgs units at 20C 0.198
Btu/ft^2/ft/hr/°F at 68F 48.0

Technological Properties

Melting point solidus	1920 F or 1050 C
liquidus	1940 F or 1060 C
Hot working temp	1500-1600 F or 815-870 C
Annealing temp	800-1400 F or 425-750 C
Machinability index	20 (Free cutting brass = 100)
Recrystallization temp	About 660 F or 350 C, for 44% reduction and initial grain size of 0.075 mm
Weldability	Good by metal arc with suitable flux-coated electrodes. Fair with oxyacetylene, carbon-arc and resistance methods
Soldering	Good with silver soldering. Soft solder not used.
Brazing	Not used

Mechanical Properties

Form or Condition	Sect. in.	Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Rock B Hard	Hard BHN	End Lt M psi[2]
Sheet							
Annealed, 400C	.015	65.2	34.1	41.8	–	–	–
Cold rolled, 37%	.015	80.5	62.5	8.0	–	–	–
Annealed, 400C	.020	65	32.5	50	–	–	–
Cold rolled, 37%	.020	88.9	66.5	6.8	–	–	–
Annealed, 500C	.041	60.3	25.6	65.8	48.5	–	–
Cold rolled, 44%	.041	100	63.9	8.0	93.5	–	–
Rod							
Annealed, 650C	<1.0	55	20	60	45	79	–
Cold drawn, 50%	<1.0	110	65	15	92	163	–
Tube							
Annealed, 705C	.75 × .049	55	–	65	–	–	–
Cold drawn	.75 × .049	71	–	30	85	–	–
Fatigue Strength							
Rolled rod	–	72	–	43	–	–	19

[1] At 0.5% extension under load
[2] At 10^8 cycles

COPPER ALLOYS, WROUGHT

TYPE A
Silicon Bronze

Technological Properties

Melting point solidus	1780 F or 970 C
liquidus	1880 F or 1025 C
Hot working temp	1300-1600 F or 700-875 C
Annealing temp	900-1300 F or 475-700 C
Machinability index	30 (Free cutting brass = 100)

Chemical Composition[1]

	Cu %	Si %	Mn Optional %	Zn Optional %
Plate, sheet, strip, rod, bar, wire, plate or forging rod	94.80 min	2.75/3.50[2]	1.50 max	1.50 max[3]

	Fe Optional %	Sn Optional %	Ni Optional %	Pb Optional %
Plate, sheet, strip, rod, bar, wire, plate or forging rod	1.60 max	.75 max	.60 max[4]	.05 max[5]

[1]One or more of the optional elements may be present to the amounts indicated.
[2]For plate = 2.70/3.75
[3]For plate = 1.75 max
[4]Plate, sheet and strip only.
[5]Plate and sheet only.

Creep Strength

Condition	Temp Deg C	Temp Deg F	Stress in M psi for creep of .01% per 1000 hr	Stress in M psi for creep of .10% per 1000 hr
Annealed	205	400	10.5	22.5
Cold drawn 0.750 in. round bar; annealed at 842F, to BHN of 119, TS of 70.3 M psi, and Elong in 2 in. of 52%	205	400	8.1	14.9
Cold drawn 0.750 in. round bar; annealed at 842F, to BHN of 119, TS of 70.3 M psi, and Elong in 2 in. of 52%	290	550	3.75	6.4

Characteristics. Silicon Bronze is well suited to both hot and cold-forming operations and combines good mechanical properties and corrosion resistance.

Uses. Hydraulic pressure lines, marine hardware, pole line hardware, nails, screws, nuts, rivets, burrs, hot water tanks, bearing plates, shafting, bushings, channels, heat exchanger tubes, Fourdrinier wire, kettles, screens, piston rings, chemical equipment.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Hardness Rock B	Hardness Rock 30-T	Shear S M psi	End Lt M psi[2]
Flat Products .040 in.							
Grain size = .070mm	56	21	63	40	–	42	–
Grain size = .035mm	60	25	60	62	–	43	–
Grain size = .015mm	63	30	55	66	–	45	–
1/4 hard	68	35	30	75	67	47	–
1/2 hard	78	45	17	87	75	50	–
Hard	94	58	8	93	78	57	–
Extra hard	104	60	6	96	80	60	–
Spring	110	62	4'	97	81	63	–
Rod 1 in.							
Grain size = .050mm	58	22	60	60	–	43	–
1/2 hard	78	45	35	85	–	52	–
Hard	92	55	22	90	–	58	–
Extra hard	108	60	13	95	–	62	–
Wire .080 in.							
Grain size = .035mm	60	25	60	–	–	43	–
1/8 hard	70	40	35	–	–	48	–
1/4 hard	80	48	20	–	–	52	–
1/2 hard	98	57	8	–	–	58	–
Hard	125	65	5	–	–	65	29
Spring	145	70	3	–	–	70	30
Tube 1.0 in. OD × .065 in.							
Grain size = .050mm	57	–	70	45	–	–	–
Hard	93	–	22	92	78	–	–

[1]At 0.5% extension under load
[2]For 10^8 cycles

Modulus of elasticity, E in M psi 15,000

(Continued on page 323)

TYPE A Silicon Bronze

(Continued from page 322)

Physical Properties
Density, at 68 F 0.308 lb/cu in. (8.53 S.G.)
Specific heat, cal/gm at 68 F 0.09/°C
Volume conductivity, % of Cu at 68 F annealed, 7%
Electrical resistivity, ohms/mil-ft at 68F, annealed 150

Thermal Conductivity
Cgs units at 20C .09
Btu/sq ft/ft/hr/°F at 68 F 21

Coef. of Thermal Expansion

Temp Range	
20-300 C or 68-572 F	18.0×10^{-6}/°C
	10.0×10^{-6}/°F

Fatigue Strength

Form or Condition	Ready-to-finish Grain Size	Cold Reduction in Area	Cu %	Si %	Mn %	Sn %	Fe %	End Strength M psi	10^6 cycles
Strip	–	50%	96.42	3.12	–	–	.16	29	50
	–	Annealed	95.89	3.00	1.00	–	–	16	100
	–	37%	95.89	3.00	1.00	–	–	23	100
	–	60%	95.89	3.00	1.00	–	–	20.5	100
Rod	.125mm	39%	95.49	3.20	1.07	–	.15	33.6	300
	.065mm	20%	96.13	2.91	.95	–	.16	30.5	300
	.085mm	8%	96.13	2.91	.95	–	.16	31.5	300
	.085mm	Ann., 1300F, ½ hr	95.49	3.20	1.07	–	.15	18.8	300
	.100mm	20%	96.29	3.19	–	.42	.10	30	100
	–	Ann., 1300F, 1 hr	96.29	3.19	–	.42	.10	18	100

TYPE B Silicon Bronze

Chemical Composition[1]*

%		Optional %		Optional %		Optional %	
Cu	96 min	Mn	.75 max	Fe	.80 max	Pb	.05 max
Si	.75/2 00	Zn	1.50 max	Sn	1.60 max		

[1]One or more of the optional elements may be present to the amounts indicated.
*ASTM

Technological Properties

Melting point solidus	1890 F or 1030 C
liquidus	1940 F or 1060 C
Hot working temp	1300-1600 F or 700-875 C
Annealing temp	900-1250 F or 475-675 C
Machinability index	30 (Free cutting brass = 100)

Characteristics. Type B Silicon Bronze is similar to Type A[1] in forming characteristics, and is also corrosion-resistant.

Uses. Hydraulic pressure lines, marine hardware, bolts, nuts, rivets, V bolts, cap screws, machine screws, pole line hardware, electrical conduit, heat exchanger tubes, welding rod, etc.

[1]Silicon Bronze is well suited to both hot and cold-forming operations and combines good mechanical properties and corrosion resistance.

Fatigue Strength

Form or Condition	Cu %	Si %	Mn %	Sn %	Fe %	End Strength M psi	10^6 cycles
Cold drawn 72%	98.17	1.41	.21	–	.06	30.4	300
Extruded	97.97	1.74	–	.21	.08	20	50
Hot rolled	98.06	1.70	–	.18	.06	19	60

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Rock Hard	Shear S M psi	End L[2] M psi
Rod 1 in.							
Soft	G. S. = .035mm	40	15	50	F55	–	–
Hard		70	55	15	B80	45	–
Extra hard		90	67	12	B90	50	–
Wire .080 in.							
1/8 hard		50	35	40	–	36	–
1/4 hard		57	45	25	–	40	–
1/2 hard		70	55	15	–	45	–
Hard		90	67	12	–	50	25
Extra hard		95	69	11	–	53	28
Wire .440 in.							
1/4 hard		53	–	30	–	–	–
1/2 hard		63	–	20	–	–	–
Hard		80	–	12	–	–	–
Tube 1.0 in. OD × .065 in.	G. S. = .015mm	45	20	55	F68	–	–
Hard		65	40	20	B75	–	–

[1]At 0.5% extension under load
[2]At 10^8 cycles

Modulus of elasticity, E in M psi 15,000

Physical Properties

Density, at 68F	0.316 lb/cu in. (8.75 S.G.)
Specific heat, cal/gm at 68F	0.09/°C
Volume conductivity, % of Cu at 68F	12% annealed
Electrical resistivity, ohms/mil-ft at 68F	86

Thermal Conductivity
Cgs units at 20C 0.14
Btu/sq ft/ft/hr/°F at 68 F 33

Coef. of Thermal Expansion

Temp Range	
20-300 C or 68-572 F	17.9×10^{-6}/°C
	9.9×10^{-6}/°F

10% Aluminum Bronze

Chemical Composition*

	Cu %	Al %	Fe %	Ni[1] %	Si[1] %
Rods, bars, shapes	80/93	6.50/11	4 max	1 max	2.25 max
Rods, forgings	78/93	6.50/11	4 max	5.50 max	2.25 max
	Mn %	**Sn %**	**Zn %**	**Te %**	**Others[2] %**
Rods, bars, shapes	1.50 max	.60 max	1 max	.65 max	.50 max
Rods, forgings	2 max	.60 max	–	–	–

*ASTM

[1]When both Ni and Si are present, only one may be in excess of 0.25%.

[2]Analysis is made only for elements specified. If other elements are suspected or indicated, further analysis shall be made to determine that the total of such other elements is not in excess of 0.50%.

Technological Properties

Melting point solidus	1890 F or 1030 C
liquidus	1905 F or 1040 C
Transformation temp, on cooling	1060 F or 570 C
Recrystallization temp	About 800-1000 F
Machinability index	Machining is difficult but is done commercially, especially with carbide tools
Hot working temp	1470-1695 F or 800-925 C
Heat treatment	Alloys of this classification are heat treatable. Common commercial usage is to quench from 1200 F or 650 C. The alpha alloys can be precipitation-hardened.
Cold forming	Quite limited
Weldability	Good by metal arc with special flux coated electrodes. Only fair with oxy-acetylene, carbon arc, and electric resistance methods
Soldering	Only with silver solder
Brazing	Not used

Physical Properties

Density, at 68 F 0.274 lb/cu in. (7.58 S.G.)
Specific heat, cal/gm at 68-212 F soft 0.104
Volume conductivity, % of Cu annealed 12.6%
Electrical resistivity, microhm/cm^3 at 68 F 13.67
Temp coef. of electr. resist., at 68 F 0.000829/°C

Thermal Conductivity

Cgs units at 20C	annealed	0.144
Btu/ft^2/ft/hr/°F at 68F		34.8

Characteristics. Aluminum Bronze has very good mechanical properties and other properties which suit it to applications which require resistance to corrosion, wear, and heat. It also has a pleasing appearance and resists tarnishing.

Uses. *Corrosion-resistant parts* – marine pumps, shafts, propellers, trim, valves, nuts, etc., pickling crates, chains, hooks, impeller blades in chemical equipment, beater bars and blades in paper-making equipment, tubing of alpha alloys with simple structure.

Heat-resistant parts – parts for internal combustion engines, jaws and clamps for electric welding equipment, gas stove grill plates, and searchlight components, which require strength and resistance to corrosion.

Parts requiring toughness, wear resistance, low coefficient of friction, and damping capacity – spindle bearings, bushings, gear wheels, pinions, worm wheels, roller bearing cages, bearing material, wear and aligning plates for machines and bridges, cam rollers, locking nuts, cam supports, damping bushings in airplanes.

Parts requiring hardness and low friction – forming and drawing dies for both ferrous and nonferrous metals.

Decorative usage – coins, medallions, plaques, statues, grills, fireplace fittings, vanity sets, imitation jewelry, "gold" pigment.

Coef. of Thermal Expansion

Ref.		Composition-% Al	Fe	Other	Coefficient × 10^{-6} per Deg C 20C to 100	200	300	500	700	per Deg F 68F to 212	392	572	932	1292
27	Hot roll	7.34	–	.40Zn, .09Si	16.6	17.4	18.2	–	–	9.2	9.6	10.1	–	–
28	Hard dr.	9.29	.44	.38Sn, .18Ni	16.2	16.3	16.8	18.5	18.9	9.0	9.0	9.3	10.3	10.5
36	As cast	10.8	6.0	3.5Mn	17.6	17.9	19.2	–	–	9.8	9.9	10.6	–	–
36	As cast	10.0	1.0	–	16.5	17.3	18.5	–	–	9.2	9.6	10.3	–	–

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Hard BHN
Annealed rod	80	40	22	–
Commercial temper	95	55	16	–
Sand cast	75	28	40	126
Sand cast, extruded	82	37.5	25	140
Sand cast	90	37	14	175
Sand cast, extruded	95	47	12	195
Forged	86	35	28	143-156
Extruded	91	52	28	179-187
Hot rolled	100	60	20	170-187

Effect of temp

The TS begins to drop rapidly at 350C at which temperature the rolled alloy is about 70 M psi. The TS then falls off to about 20 M psi at 550C. The elongation increases generally to values from 40-60% at 400-500C.

[1]At 0.5 extension under load.

Modulus of elasticity, E in M psi 17,500 to 19,000

Fatigue Strength

Form or Condition	Cu %	Al %	Ni %	Fe %	Other %	TS M psi	Elong 2" %	End Strength M psi	10^6 Cycles
Hard, 11.5% red.	89.71	8.74	.51	.64	Sn = .38	97.5	14.5	22	300
Extruded, light draw	89.5	8.89	–	.15	Zn = 1.40	80	37	31.3	52.5+
Extruded, heat treat.	89.91	10.06	–	.13	–	77.5	36	34	70
Annealed	90.52	10.01	–	tr	–	83	38	28	80

SPECIAL Aluminum Bronze

Chemical Composition*

	Cu %	Al %	Fe %	Ni %
Condenser-tube plates	rest	8.0/11.0	1.5/3.5	4.0/7.0
Rods, bars, shapes	78/85	9 /11	2 /4	4 /5.50
Forging rods, bars, shapes	78/93	6.5/11	4 max	5.50 max[1]

	Si %	Mn %	Sn %	Others %
Condenser-tube plates	–	.5/2.0	–	.50 max
Rods, bars, shapes	.25 max	1.50 max	.20 max	.50 max[3]
Forging rods, bars, shapes	2.25 max[2]	2.0 max	.60 max	.50 max

*ASTM
[1] With this Ni limit, Si shall not exceed .25%.
[2] With this Si limit, Ni shall not exceed .25%.
[3] The analysis is made only for elements specified. If other elements are suspected or indicated, further analysis shall be made to determine that the total of these other elements is not in excess of .50%.

Characteristics and Uses. Similar to 10% Aluminum Bronze but is especially adapted to hot-rolled plates, bars, forgings and marine shafting.

Technological Properties

Melting point solidus	1895 F or 1035 C
liquidus	1930 F or 1055 C
Transformation temp, cooling	1380 to 1470 F or 750 to 800 C
Recrystallization temp	1380 + F or 750 + C, approx
Hot working temp	1470-1740 F or 800-950 C
Heat treatment	See examples under Mechanical Properties
Welding	Good by metal arc with special flux-coated electrodes. Only fair with oxyacetylene, carbon arc, and electric resistance methods
Soldering	Only with silver solder
Brazing	Not used

Fatigue Strength

Condition	Tensile Strength M psi	Elong %
Cold reduced rod, 11.5% = 32 M psi at 30 × 10^7 cycles	125	14.2
Forged rod = 50.4 M psi at 56.8 × 10^6 cycles	116	10.8

Physical Properties
Density, at 68 F 0.274 lb/cu in. (7.58 S.G.)
Specific heat, cal/gm at 68 F 0.104, approx
Volume conductivity, % of Cu, annealed 7.5%
Electrical resistivity, microhm/cm^2 at 68 F 22.9

Thermal Conductivity
Cgs units at 20C 0.091
Btu/sq ft/ft/hr/°F at 68 F 22

Coef. of Thermal Expansion

Ref.		Composition-% Al	Fe	Other	Coefficient × 10^{-6} per Deg C, Range 20C to 100	200	300	500	700	per Deg F, 68F to 212	392	572	932	1292
27	Hot roll	7.34	–	.40Zn, .09Si	16.6	17.4	18.2	–	–	9.2	9.6	10.1	–	–
28	Hard dr.	9.29	.44	.38Sn, .18Ni	16.2	16.3	16.8	18.5	18.9	9.0	9.0	9.3	10.3	10.5
36	As cast	10.8	6.0	3.5Mn	17.6	17.9	19.2	–	–	9.8	9.9	10.6	–	–
36	As cast	10.0	1.0	–	16.5	17.3	18.5	–	–	9.2	9.6	10.3	–	–

Mechanical Properties

Cu %	Al %	Fe %	Ni %	Others %	Form or Condition	Yield Strength M psi	Tensile Strength M psi	Elong 2" %	Rock Hard	Results
82	9.5	2.5	5	Mn = 1.0	Soft plate	–	90	12	–	
–	–	–	–	–	Hard rod	60[1]	105	12	B105	
81.7	13.4	4.4	–	Mn = .5	Cast	37-45[2]	85-100	1-4	C35-38	
81.8	9.1	–	–	Pb = 9.1	Cast	18-20[2]	45-50	32-35	B36-39	
81.1	9.78	3.74	5.38	–	Forged, Annealed 845C	61.6	104.8	17.3	B96	
78.66	8.17	3.39	–	Mn = 9.78	Forged, Annealed 815C	45.0	100.2	26.2	B93	
–	–	–	–	–	Forged, Quenched and Annealed 425C	67.5	118.8	6.3	B104	
82.9	7.15	–	8.12	Mn = 1.83	Forged, Annealed 845C	60.1	94.5	28	B90	
81.3	10.7	4.0	4.0	–	Forged, Ht. Tr.	55-60	96-102	10-15	–	
					Effect of Heat Treatment[3] (Treatment Deg C)					
					Quench 850, reheat to 600	63[1]	109	25	G76	High YS with good Elong
					Air cooled from 850	57[1]	107	21	G76	Fair properties
					Furnace cooled 850-550, hold 2 hr, quench	48[1]	101	30	G67	High ductility
					Quench from 950, reheat to 450	80[1]	132	1.5	G98	Maximum strength without cold work
					Quench from 850, cold draw 23%, reheat to 450	94.1[1]	151	0.5	G100	Maximum hardness and strength

[1] At .5% extension under load
[2] At .01% extension under load
[3] Size is a factor which limits the effectiveness of heat treatment (82.5 Cu, 10 Al, 5 Ni, 2.5 Fe)

Modulus of elasticity, E in M psi probably about 16,000

Beryllium Copper

Chemical Composition*	Cu %	Be %	Ni,Co,Fe %	Others %
Strip, wire	rest	1.90/2.15	.15/.50	.50 max

*ASTM

Technological Properties

Melting point solidus	1587 F or 864 C	
liquidus	1750 F or 955 C	
Recrystallization temp, minimum temp for complete recrystallization in 1 hr	For 50% reduction = 900 F or 480 C	
	For 75% reduction = 810 F or 430 C	
	For 90% reduction = 700 F or 370 C	
Solution temp	1390-1450 F or 755-790 C	
Precipitation temp	From A temper	600 ±5°F or 316 ±3°C, 3 hr
	From ½H temper	600 ±5°F or 316 ±3°C, 2 hr
	From H temper	600 ±5°F or 316 ±3°C, 2 hr

For stock thicker than 0.75 in., allow 1 hr. more for ½H and H. Higher temperatures, with shorter times, for more accurate springs with lesser drift.

Characteristics. Beryllium Copper is a malleable alloy that is capable of being strengthened and hardened by heat treatment. It is used for numerous applications in spite of its relatively high price.

Uses. Parts which require good formability for fabrication and high proportional limit, fatigue strength, and creep strength for service — springs for special or severe conditions.

Parts which require corrosion resistance, high conductivity or non-magnetic qualities, with high strength — springs, diaphragms, contact bridges, surgical instruments, bolts and screws.

Hard parts that wear well against steel — firing pins, dies, aircraft engine counterweight bushings, small tools, and non-sparking tools and parts.

Physical Properties

Density, at 70 F 0.297 ±0.01 lb/cu in. (8.23 ±0.02 S.G.)
increase during aging 0.6%
linear contraction during aging 0.2%

Specific heat, cal/gm at 30-100 C 0.1/°C

Volume conductivity, % of Cu 17% for A
21% for AT

Electrical resistivity, microhm/cm³ at 68 F 10 for A
6.8-9.8 for AT

Thermal Conductivity

Condition	Cgs units	Btu/ft²/ft/hr/°F
A	0.20 at 20C	48.5 at 68F
AT	0.25	60.5
H, HT	0.18 -0.20	43.6

Coef. of Thermal Expansion

Temp Range	per Deg C	per Deg F
20-100C or 68-212F	16.6×10^{-6}	9.2×10^{-6}
100-200C or 212-392F	17.2×10^{-6}	9.5×10^{-6}
200-300C or 392-572F	19.0×10^{-6}	10.5×10^{-6}

Mechanical Properties

Form	Condition[1]	Sect. in.	PL M psi	Tensile Strength M psi	Yield[2] Strength M psi	Elong %	Hard BHN	Rock Hard	End Lt M psi	E 10^6 psi
Strip	A	.032	17	72	25	50	–	B60	32.5[8]	17
	½H	.032	50	95	62	12	–	B93	35.6[8]	17
	H	.032	58	107	70	6	–	B97.5	36.8[8]	17
	AT	.032	75[4]	175	80	5	–	C41	35.2[8]	19.5
	½HT	.032	90[4]	188	105	4	–	C42	39.1[8]	20
	HT	.032	88[4]	195	110	3	–	C42.5	40.7[8]	20
	½HT[6]	.020	107[4]	188.1	126	2.5	–	30T90.8	–	18.3
	7	.020	113.7[4]	196.5	139	1.4	–	30T91.3	–	18.4
Rod	AT	.75	55[5]	190	140[3]	4	380	–	–	18.4
	HT	.75	100[5]	200	171[3]	3	400	–	47-61.5[9]	18.4

[1]
A = Solution treated, quenched
AT = Solution treated, quenched, precipitation hardened
½H = Solution treated, quenched, cold rolled 20.7% or cold drawn 37 1%
½HT = ½H, precipitation hardened
H = Solution treated, quenched, cold rolled 37.1% or cold drawn 60.5%
HT = H, precipitation hardened

[2] 0.01% offset

[3] True stress, for 0.1% offset

[4] Not corrected for true stress and strain. The traditional method for determining the PL may lead to considerable error with heat treated Be-Cu alloys

[5] Corrected for true stress and strain (C. S. Smith and R. W. Van Wagner, Proc. ASTM, 1941, 41, 825)

[6] Regular ½HT treatment, to compare with the heavier reduction of Condition 7

[7] 78% reduction T

[8] Cross milled specimens tested in flexure for 10^8 cycles

[9] Rotating beam test on polished specimens

Temperature coefficient of E, at 0° C minus $35.0 \times 10^{-5}/°C$

COPPER ALLOYS, CAST

LEADED TIN Bronze

Chemical Composition

	Cu %	Sn %	Pb %	Zn %	Ni %
Sand cast	86.00/90.00	5.50/6.50	1.00/2.00	3.0/5.0	1.00 max
Ingot	86.00/89.00	5.75/6.50	1.00/1.75	3.5/5.0	.75 max

	Fe %	Sb %	S %	Si %	P %	Al %
Sand cast	.25 max	—	—	—	.05 max	—
Ingot	.20 max	.25 max	.05 max	.005 max	.03 max	—

Technological Properties
Melting point solidus, 1800-1830F or 980-1000C

Physical Properties
Density, at 68F 0.315 lb/cu in. (S. G. 8.7)
Volume conductivity, 14% of Cu

Characteristics. High grade steam or valve bronze for use up to 550F.

Uses. Valve bodies (medium pressures), oil pumps, gears, high duty bearings, bushings, backings for babbitted bearings, etc.

Coef. of Thermal Expansion

Temp Range	
70-500F or 21-260C	$18.5 \times 10^{-6}/°C$
	$10.3 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN	Shear S[3] M psi	Comp YS[2] M psi	E 10^6 psi
Sand cast	38	16	35	35	66	34	13	13

[1] At 0.5% elongation under load, 0.505 in. test bar
[2] 0.001 in. set
[3] 0.1 in. set

COPPER ALLOYS, CAST

LEADED TIN BEARING Bronze

Chemical Composition

	Cu %	Sn %	Pb %	Zn %	Ni %
Sand cast	85.00/89.00	7.50/9.0	1.0 max	3.0/5.0	1.00 max
Ingot	85.00/89.00	7.75/9.0	.9 max	3.5/5.0	.75 max

	Fe %	Sb %	S %	Si %	P %	Al %
Sand cast	.25 max	—	—	—	.05 max	—
Ingot	.20 max	.25 max	.05 max	.005 max	.03 max	—

Technological Properties
Melting point solidus 1570F or 855C
liquidus 1830F or 1000C

Characteristics. Strong, general utility structural bronze for severe conditions.

Uses. High duty, wear resistant bearings, bolts, nuts, gears, high pressure bearings and bushings against hardened steel, valves, expansion points, pump pistons, electrical equipment, automotive bushings.

Physical Properties
Density, at 68F 0.318 lb/cu in. (S. G. 8.80)
Volume conductivity, 11% of Cu

Thermal Conductivity
12% of Cu

Coef. of Thermal Expansion

Temp Range	
70-350F or 21-177C	$18 \times 10^{-6}/°C$
	$10 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard[4] BHN	Shear S[3] M psi	Comp YS[2] M psi	E 10^6 psi
Sand cast	36	18	30	25	68	43	13	14

[1] 0.5% elongation under load
[2] 0.001 in. set
[3] 0.1 in. set
[4] 500 kg load

COPPER ALLOYS, CAST

HIGH LEADED TIN Bronze

Chemical Composition

	Cu[1] %	Sn %	Pb %	Zn %	Ni[1] %
Sand cast	83.0/86.0	4.50/6.0	8.00/10.00	.00/2.00	.50 max
Ingot	83.0/85.0	4.50/5.5	8.5/9.75	.5/1.50	.50 max

	Fe %	Sb %	S %	Si %	P %	Al %
Sand cast	.20 max	.30 max	–	–	–	–
Ingot	.15 max	.25 max	.08 max	.003 max	.02 max	–

[1]Minimum Cu may be calculated as Cu + Ni

Technological Properties
Melting point solidus, 1750F or 955C

Physical Properties
Density, at 68F 0.320 lb/cu in. (S. G. 8.87)

Uses. Small bearings and bushings, bronze backings for babbitted automotive bearings.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN	Comp YS[2] M psi
Sand cast	30	15	15	16	60	13

[1]At 0.5% elongation under load
[2]0.001 in. set

COPPER ALLOYS, CAST

HIGH LEADED TIN Bronze

Chemical Composition

	Cu[1] %	Sn %	Pb %	Zn %	Ni[1] %
Sand Cast	81.0/85.0	6.25/7.50	6.00/8.00	2.00/4.00	.50 max
Ingot	82.0/84.0	6.50/7.50	6.50/7.75	2.50/4.00	.50 max

	Fe %	Sb %	S %	Si %	P %	Al %
Sand Cast	.20 max	.35 max	–	–	–	–
Ingot	.15 max	.30 max	.08 max	.003 max	.02 max	–

[1]Minimum Cu may be calculated Cu + Ni

Technological Properties
Melting point solidus, 1750F or 955C

Physical Properties
Density, at 68F 0.322 lb/cu in. (S. G. 8.93)

Characteristics. General utility alloy.

Uses. Bearings, bushings, and automobile fittings.

Coef. of Thermal Expansion

Temp Range	
30-200F or -1-93C	$18. \times 10^{-6}/°C$ $10 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN	E 10^6 psi
Sand cast	34	17	20	18	60	14.5

[1]At 0.5% elongation under load, 0.505 in. test bar

COPPER ALLOYS, CAST

HIGH LEADED TIN Bronze

Chemical Composition

	Cu[1] %	Sn %	Pb %	Zn %	Ni[1] %
Sand Cast	78.00/82.00	9.00/11.00	8.00/11.00	.75 max	.50 max
Ingot	78.00/81.00	9.25/10.75	8.25/10.75	.75 max	.50 max

	Fe %	Sb %	S %	Si %	P %	Al %
Sand Cast	.15 max	.55 max	–	–	–	–
Ingot	.10 max	.50 max	.08 max	.003 max	.03 max	–

[1]Minimum Cu may be calculated as Cu + Ni

Uses. Bearings for high speeds and heavy pressures, such as roll-neck bearings, lathe bearings, babbitt-lined armature bearings on electric locomotives, and bearings in contact with mineral waters or paper mill sulphite liquor.

Physical Properties
Density, at 70F 0.320 lb/cu in. (S. G. 8.80)

Thermal Conductivity
At 70F, 12% of Cu

Coef. of Thermal Expansion	
Temp Range	
21-204C	$18.4 \times 10^{-6}/°C$
70-400F	$10.2 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN	Shear S[3] M psi	Comp YS[2] M psi	E 10^6 psi
Sand cast	32	17	12	10	65	43	14.5	11

[1]At 0.5% elongation under load
[2]0.001 in. set
[3]0.1 in. set

COPPER ALLOYS, CAST

HIGH LEADED TIN Bronze

Chemical Composition

	Cu[1] %	Sn %	Pb %	Zn %	Ni[1] %
Sand Cast	75.0/79.0	6.25/7.50	13.0/16.0	.75 max	.75 max
Ingot	76.0/79.0	6.5/7.5	14.0/16.0	.75 max	.50 max

	Fe %	Sb %	S %	Si %	P %	Al %
Sand Cast	.15 max	.75 max	.05 max	–	.05 max	–
Ingot	.10 max	.75 max	.08 max	.003 max	.03 max	–

[1]Minimum Cu may be calculated as Cu + Ni

Uses. Locomotive castings and general service bearings for moderate pressure; general purpose wearing metal for rod bushings, shoes, and wedges; freight and streetcar bearings; backs for lined journal bearings for locomotive tenders and passenger cars.

Physical Properties
Density, at 68F 0.334 lb/cu in. (S. G. 9.25)

Technological Properties
Melting point solidus, 1700F or 925C

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN	Shear S[3] M psi	Comp YS[2] M psi	E 10^6 psi
Sand cast	30	16	15	15	55	42	15	10.5

[1]0.5% extension under load
[2]0.001 in. set
[3]0.1 in. set

COPPER ALLOYS, CAST

HIGH LEADED TIN Bronze

Chemical Composition	Cu[1] %	Sn %	Pb %	Zn %	Ni[1] %
Sand Cast	68.5/73.5	4.50/6.0	22.00/25.00	.05 max	.05 max
Ingot	69.0/73.0	4.50/5.75	22.00/24.50	.05 max	.05 max

	Fe %	Sb %	S %	Si %	P %	Al %
Sand Cast	.15 max	.75 max	–	–	.05 max	–
Ingot	.10 max	.75 max	.08 max	–	.03 max	–

[1]Minimum Cu may be calculated as Cu + Ni

Technological Properties
Melting point solidus, 1650F or 899C

Physical Properties
Density, at 68F 0.336 lb/cu in. (S. G. 9.30)

Uses. Bearings under light loads and high speeds such as driving boxes and railroad bearings.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Elong %	Red. Area %	Hard BHN	Shear S[2] M psi	Comp YS[1] M psi	E 10^6 psi
Sand cast	21	10	8	48	23	13	10

[1]At 0.001 in. set
[2]At 0.1 in. set

COPPER ALLOYS, CAST

85-5-5-5

Chemical Composition	Cu[1] %	Sn %	Pb %	Zn %	Ni[1] %
Sand Cast	84.00/86.00	4.0/6.0	4.0/6.0	4.0/6.0	1.0 max
Ingot	84.00/86.00	4.25/6.0	4.0/5.75	4.50/6.0	.75 max

	Fe %	Sb %	S %	Si %	P %	Al %
Sand Cast	.3 max	–	–	–	.05 max	–
Ingot	.25 max	.25 max	.08 max	.003 max	.03 max	–

[1]Minimum Cu may be calculated as Cu + Ni

Technological Properties
Melting point solidus, 1810-1840F or 990-1005C

Physical Properties
Density, at 68F 0.318 lb/cu in. (S. G. 8.80)
Volume conductivity, 15% of Cu

Coef. of Thermal Expansion Temp Range	
70-400F or 21-204C	$19.1 \times 10^{-6}/°C$
	$10.9 \times 10^{-6}/°F$

Characteristics. This alloy has fair strength, soundness, and good machining properties.

Uses. Low pressure valves, pipe fittings, small gears, fire equipment fittings, small pump castings, ornamental fixtures, etc.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN	Shear S[3] M psi	Comp YS[2] M psi	E 10^6 psi
Sand cast	34	17	25	25	60	31	11	13.5

[1]At 0.5% elongation under load
[2]At 0.001 in. set
[3]At 0.1 in. set

COPPER ALLOYS, CAST

LEADED RED Brass

Chemical Composition	Cu[1]	Sn	Pb	Zn	Ni[1]
	%	%	%	%	%
Sand Cast	82.0/83.75	3.25/4.25	5.00/7.00	5.00/8.00	1.00 max
Ingot	82.0/83.5	3.5/4.25	5.25/6.75	5.50/8.00	.75 max

	Fe	Sb	S	Si	P	Al
	%	%	%	%	%	%
Sand Cast	.30 max	–	–	–	–	–
Ingot	.25 max	.25 max	.08 max	.003 max	.01 max	–

[1]Minimum Cu may be calculated as Cu + Ni

Technological Properties
Melting point solidus, 1800F or 980C

Characteristics. This is a general purpose, free machining alloy.

Uses. Air, gas, and water fittings; plumbing supplies and fittings; pumps and pump bodies; hardware, carburetors; injectors; railroad catenary and overhead fittings.

Physical Properties
Density, at 68F 0.312 lb/cu in. (S. G. 8.6)

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN	Shear S[3] M psi	Comp YS[2] M psi
Sand cast	32	15	24	20	55	29	11.5

[1]At 0.5% extension under load
[2]0.001 in. set
[3]0.1 in. set

COPPER ALLOYS, CAST

LEADED SEMI-RED Brass

Chemical Composition	Cu[1]	Sn	Pb	Zn	Ni[1]
	%	%	%	%	%
Sand Cast	78.00/82.00	2.25/3.5	6.00/8.00	7.00/10.00	1.00 max
Ingot	78.00/82.00	2.5/3.5	6.25/7.75	7.50/10.00	.75 max

	Fe	Sb	S	Si	P	Al
	%	%	%	%	%	%
Sand Cast	.40 max	–	–	–	.02 max	–
Ingot	.35 max	.20 max	.08 max	.003 max	.01 max	–

[1]Minimum Cu may be calculated as Cu + Ni

Technological Properties
Melting point solidus, 1750F or 955C

Physical Properties
Density, at 68F 0.314 lb/cu in. (S. G. 8.70)
Volume conductivity, 18% of Cu

Uses. Low pressure valves and fittings, general hardware fittings, plumbing supplies and fixtures, ornamental fixtures.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN	E 10^6 psi
Sand cast	32	15	22	20	55	13

[1]At 0.5% elongation under load

COPPER ALLOYS, CAST

LEADED YELLOW Brass

Chemical Composition	Cu	Sn	Pb	Zn	Ni	Fe	Al
	%	%	%	%	%	%	%
Sand Cast	60.00/65.00	.5/1.50	.75/1.50	rest	–	.75 max	.50 max
Ingot	59.00/63.00	.5/1.50	.75/1.25	rest	.5 max	.5 max	.1/.5

Uses. Spring bushings, hardware fittings, ornamental castings, ship trimmings, etc.

Technological Properties
Melting point solidus, 1675-1725F or 915-940C

Physical Properties
Density, at 68F 0.304 lb/cu in. (S. G. 8.40)
Volume conductivity, 20-26% of Cu

Coef. of Thermal Expansion	
Temp Range	
70-500F or 21-260C	$21.6 \times 10^{-6}/°C$
	$12 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN	E 10^6 psi
Sand cast	40	14	25	25	65	14

[1]At 0.5% elongation under load

COPPER ALLOYS, CAST

LEADED SEMI-RED Brass

Chemical Composition

	Cu[1] %	Sn %	Pb %	Zn %	Ni[1] %
Sand Cast	75.00/76.75	2.50/3.50	5.25/6.75	13.00/17.00	1.00 max
Ingot	75.00/76.75	2.75/3.25	5.50/6.50	14.00/17.00	.50 max

	Fe %	Sb %	S %	Si %	P %	Al %
Sand Cast	.4 max	–	–	–	.02 max	–
Ingot	.35 max	.20 max	.07 max	.005 max	.01 max	–

[1] Minimum Cu may be calculated as Cu + Ni

Technological Properties
Melting point solidus, 1725F or 940C

Physical Properties
Density, at 68F 0.310 lb/cu in. (S. G. 8.6)

Uses. Plumbing fixtures, cocks, faucets, stops, wastes, air and gas fittings, general hardware fittings, low pressure valves and fittings.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN	Shear S[3] M psi	Comp YS[2] M psi	E 10^6 psi
Sand cast	32	15	30	30	55	31	9	12

[1] At 0.5% elongation under load
[2] At 0.001 in. set
[3] At 0.1 in. set

COPPER ALLOYS, CAST

LEADED YELLOW Brass

Chemical Composition

	Cu %	Sn %	Pb %	Zn %	Ni %
Sand Cast	70.00/74.00	.75/2.00	1.5/3.75	rest	–
Ingot	70.00/73.00	.75/1.75	1.5/3.50	rest	.5 max

	Fe %	Sb %	S %	Si %	P %	Al %
Sand Cast	.6 max	–	–	–	–	–
Ingot	.5 max	.1 max	.05 max	.05 max	.01 max	–

Technological Properties
Melting point solidus, 1700F or 925C

Physical Properties
Density, at 68F 0.307 lb/cu in. (S. G. 8.50)
Volume conductivity, 25% of Cu

Uses. Plumbing fixtures, fittings and trimmings; valves; chandeliers; irons; hardware; and ornamental work.

Coef. of Thermal Expansion

Temp Range	
70-200F or 21-93C	$20.7 \times 10^{-6}/°C$
	$11.5 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN	Shear S[3] M psi	Comp YS[2] M psi	E 10^6 psi
Sand cast	35	12	35	30	48	30	9	13

[1] At 0.5% elongation under load, 0.505 in. bar
[2] 0.001 in. set
[3] 0.1 in. set

COPPER ALLOYS, CAST

LEADED YELLOW Brass

Chemical Composition

	Cu %	Sn %	Pb %	Zn %	Ni %	Fe %
Sand Cast	65.00/70.00	1.50 max	1.50/3.75	rest	–	.75 max
Ingot	65.00/69.00	1.50 max	1.50/3.50	rest	.5 max	.5 max

	Sb %	S %	Si %	P %	Al %
Sand Cast	.10 max	.05 max	–	.01 max	.30 max
Ingot	–	–	.05 max	–	none

Technological Properties
Melting point solidus, 1700F or 925C

Characteristics. This is a general purpose, yellow casting alloy.

Uses. Light castings not subjected to high internal pressure, furniture hardware, ornamental castings, radiator fittings; ship trimmings, gas cock and light fixtures.

Physical Properties
Density, at 68F 0.303 lb/cu in. (S. G. 8.4)
Volume conductivity, 18-25% of Cu

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN	Shear S[3] M psi	Comp YS[2] M psi	E 10^6 psi
Sand cast	34	13	35	30	50	30	9	13

[1] At 0.5% elongation under load. 0.505 in. bar
[2] 0.001 in. set
[3] 0.1 in. set

Coef. of Thermal Expansion

Temp Range	
70-200F or 21-93C	$20.2 \times 10^{-6}/°C$
	$11.2 \times 10^{-6}/°F$

COPPER ALLOYS, CAST

ASTM Alloy A

Chemical Composition

	%		%		%
Cu	57.0 min	Pb	1.50 max	Si	.25 max
Zn	30.00 min	Fe	.25 max	Al	.25 max
Sn	1.50 max	Mn	.25 max	Others	.50 max
Ni	–	S	–		
Sb	–	P	–		

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi .2% offset	Elong on 2" %
Specified minimum	45	25	10
Average values[1]	>60	>37	–

[1] J. C. Fox, Doehler-Jarvis Corp.

Characteristics. This is a low cast, general purpose alloy with wide limits on composition.

Uses. Die castings.

COPPER ALLOYS, CAST

ASTM Alloy B

Chemical Composition

	%		%		%
Cu	63.0/67.0	Pb	.25 max	Sn	.25 max
Zn	rest	Fe	.15 max	Al	.15 max
Si	.75/1.25	Mn	.15 max	Others	.50 max
Ni	–	S	–		
Sb	–	P	–		

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi .2% offset	Elong 2" %
Specified minimum	58	30	15
Average values[1]	>80	>50	–

[1] J. C. Fox, Doehler-Jarvis Corp.

Characteristics. This alloy has excellent castability and mechanical properties as a die casting.

COPPER ALLOYS, CAST

SILICON Brass

Chemical Composition[1]	%		%		%
Cu	80/81.5	Fe	–	P	–
Ni	–	Si	3.5/4.5	Al	–
Sb	–	Sn	–	Zn	rest
Pb	–	S	–	Mn	–

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong on 2" %
	85-95	45-50	16-18

Characteristics. This die casting alloy has high strength, hardness, and resistance to wear and corrosion.

[1] J. C. Fox, Doehler-Jarvis Corp.

COPPER ALLOYS, CAST

HIGH STRENGTH MANGANESE Bronze

Technological Properties
Melting point liquidus, 1650F or 900C

Physical Properties
Density, at 68F 0.285 lb/cu in. (S. G. 7.9)
Volume conductivity, 12% of Cu

Thermal Conductivity
13% of Cu

Chemical Composition

	Cu %	Sn %	Pb %	Zn %	Ni %
Sand cast	60.00/68.00	.5 max	.2 max	rest	–
Ingot	60.00/68.00	.5 max	.1 max	rest	1.00 max

	Fe %	Sb %	S %	Si %	P %	Al %	Mn %
Sand cast	2.00/4.00	–	–	–	–	3.00/7.50	2.50/5.00
Ingot	2.00/4.00	–	–	–	–	3.00/7.50	2.50/5.00

Coef. of Thermal Expansion

Temp Range	
70-500F or 21-260C	$19.8 \times 10^{-6}/°C$
	$11.0 \times 10^{-6}/°F$

Characteristics. This is an alloy for extra heavy duty service.

Uses. Large valve stems, gears, cams; bearings for slow speeds and heavy loads; screw down nuts, bridge parts; hydraulic cylinder parts.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard[2] BHN	Shear S[4] M psi	Comp YS[3] M psi	E 10^6 psi
Sand cast	115	70	15	15	210	100	60	15.5

[1] At 0.5% elongation under load
[2] 3000 kg load
[3] 0.001 in. set
[4] 0.1 in. set

COPPER ALLOYS, CAST

MANGANESE Bronze

Chemical Composition

	Cu %	Sn %	Pb %	Sb %	Zn %	Ni %
Sand cast	55.00/60.00	1.00 max	.40 max	–	rest	.50 max
Ingot	55.00/60.00	1.00 max	.30 max	–	rest	.50 max

	S %	Fe %	Si %	P %	Al %	Mn %
Sand cast	–	.4/2.00	–	–	.50/1.50	1.50 max
Ingot	–	.4/2.00	–	–	.50/1.50	1.50 max

Technological Properties
Melting point liquidus, 1660F or 905C

Physical Properties
Density, at 68F 0.296 lb/cu in. (S. G. 8.2)
Volume conductivity, 18% of Cu

Characteristics. This is a strong, corrosion-resistant alloy.

Uses. Propeller hubs, blades, and parts in contact with fresh and salt water; gears; liners; valve stems; complicated lever arms requiring strength and toughness.

Coef. of Thermal Expansion

Temp Range	
70-200F or 21-93C	$21.6 \times 10^{-6}/°C$
	$12.0 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN	Shear S[3] M psi	Comp YS[2] M psi	E 10^6 psi
Sand cast	70	28	30	30	125	87	24	15

[1] At 0.5% elongation under load
[2] 0.001 in. set
[3] 0.1 in. set

COPPER ALLOYS, CAST

LEADED MANGANESE Bronze

Chemical Composition

	Cu %	Sn %	Pb %	Sb %	Zn %	Ni %
Sand cast	56.00/62.00	1.50 max	.50/1.50	–	rest	–
Ingot	56.00/62.00	.5/1.00	.5/1.00	–	rest	.5 max

	S %	Fe %	Si %	P %	Al %	Mn %
Sand cast	–	2.00 max	–	–	1.50 max	1.5 max
Ingot	–	.75/1.50	–	–	.25/1.00	.10/.50

Technological Properties
Melting point solidus, 1675-1725F or 915-940C

Physical Properties
Density, at 68F 0.296 lb/cu in. (S. G. 8.2)

Characteristics. This is a free machining manganese bronze.

Uses. Valve stems, marine castings and fittings, pump bodies, gas engine bases, lever arms, brackets, gears, etc.

Coef. of Thermal Expansion

Temp Range	
70-400F or 21-204C	$20.5 \times 10^{-6}/°C$
	$11.4 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN	Shear S[3] M psi	Comp YS[2] M psi	E 10^6 psi
Sand cast	65	30	18	20	85	87	23	15

[1] At 0.5% elongation under load
[2] 0.001 in. set
[3] 0.1 in. set

COPPER ALLOYS, CAST

Nickel Silver-25%

Physical Properties
Density, at 68F 0.318-0.322 lb/cu in. (S. G. 8.8-8.9)
Volume conductivity, 4-5% of Cu

Thermal Conductivity
6.5% of Cu

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN
Sand cast	50	24	15	15	130

[1]At 0.5% extension under load

Chemical Composition

	Cu %	Sn %	Pb %	Zn %	Ni %
Sand cast	64.00/67.00	4.00/5.50	1.00/2.50	rest	24.00/27.00
Ingot	64.00/67.00	4.50/5.50	1.00/2.00	rest	24.00/26.00

	Fe %	Sb %	S %	Si %	Mn %	Al %
Sand cast	1.50 max	—	—	—	1.00 max	—
Ingot	1.00 max	.25 max	.05 max	.10 max	1.00 max	—

Characteristics. This is a silvery white alloy which is corrosion- and tarnish-resistant.

Uses. Dairy and soda fountain equipment, hardware, musical instruments, keys, and valve seats for elevated temperatures.

COPPER ALLOYS, CAST

Nickel Silver-20%

Physical Properties
Density, at 68F 0.320 lb/cu in. (S. G. 8.85)
Volume conductivity, 5% of Cu

Thermal Conductivity
6% of Cu

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN
Sand cast	40	25	15	14	105

[1]At 0.5% extension under load

Chemical Composition

	Cu %	Sn %	Pb %	Zn %	Ni %
Sand cast	63.00/67.00	3.50/4.50	3.00/5.00	rest	19.50/21.50
Ingot	63.00/65.00	3.50/4.50	3.50/5.00	rest	19.50/21.00

	Fe %	Sb %	S %	Si %	Mn %	Al %
Sand cast	1.50 max	—	—	—	1.00 max	—
Ingot	1.00 max	.25 max	.05 max	.05 max	1.00 max	—

Uses. This analysis of Nickel Silver is used for marine castings, ship trimmings, furniture trim, hardware, valves, ornamental castings.

COPPER ALLOYS, CAST

LEADED Nickel Silver-12%

Physical Properties
Density, at 68F 0.323 lb/cu in. (S. G. 8.95)

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN
Sand cast	34	15	20	20	60

[1]At 0.5% extension under load

Chemical Composition

	Cu %	Sn %	Pb %	Zn %	Ni %
Sand cast	53.00/58.00	1.50/3.00	8.00/11.00	rest	11.00/14.00
Ingot	53.00/58.00	1.50/3.00	8.00/11.00	rest	11.00/14.00

	Fe %	Sb %	S %	Si %	Mn %	Al %
Sand cast	1.50 max	—	—	—	.50 max	—
Ingot	1.00 max	.25 max	.05 max	—	.50 max	—

Characteristics. This is a free machining Nickel Silver.

Uses. Hardware fittings, valves, valve trimmings, plumbing fixtures, statuary, ornamental castings, and free machining work.

COPPER ALLOYS, CAST

LEADED NICKEL Silver-16%

Chemical Composition

	Cu %	Sn %	Pb %	Zn %	Ni %
Sand cast	58.00/61.00	2.5/3.5	4.50/5.50	rest	15.5/17.0

	Fe %	Sb %	S %	Si %	Mn %	Al %
Sand cast	1.00 max	.25 max	.05 max	–	.50 max	–

Physical Properties
Density, at 68F 0.320 lb/cu in. (S. G. 8.95)
Volume conductivity, 5-6% of Cu

Characteristics. This is a free machining alloy.

Uses. Valves, hardware, boat and railroad car fittings, pipe fittings, etc.

Thermal Conductivity
7% of Cu

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard BHN
Sand cast	38	17	25	25	75

[1]At 0.5% extension under load

COPPER ALLOYS, CAST

ALUMINUM Bronze

Chemical Composition

	Sn %	Cu %	Pb %	Zn %	Ni %	S %
Sand cast	–	86.9 min	–	–	–	–
Ingot	–	–	–	–	–	–

	Fe %	Sb %	Si %	Mn %	Al %
Sand cast	.75/1.50	–	–	–	9.0/11.0
Ingot	–	–	–	–	–

Technological Properties

Heat treatment, A	Solution treatment; 1600-1650F or 870-900C, quench in agitated water bath, age 1 hr at 1100-1150F or 595-620C, quench in water.
Heat treatment, B	Solution treatment, same as A, age 1 hr at 1000F or 540C, quench in water.

Characteristics. This is a strong, heat-treatable alloy of good resistance to wear and corrosion.

Uses. Pickling baskets, steel mill slippers, nuts, internal gears, marine equipment and welding jaws.

Coef. of Thermal Expansion

Temp Range	
70-500F or 21-260C	$17.1 \times 10^{-6}/°C$
	$9.5 \times 10^{-6}/°F$

Physical Properties
Volume conductivity, 14% of Cu

Thermal Conductivity
14% of Cu

Mechanical Properties

Form or Condition	Al %	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard[2] BHN
SC, cooled in sand	9.5	62	26	25	25	122
SC, shaken out of mold in ½ hr	9.5	70	25	32	30	120
Heat treatment A	9.5	80	32	25	25	145
Heat treatment B	9.5	82	40	22	20	160
SC, cooled in sand	10.00	67	32	15	15	140
SC, shaken out of mold in ½ hr	10.00	76	28	22	20	135
Heat treatment A	10.00	90	40	15	15	180
Heat treatment B	10.00	92	50	9	8	195
SC, cooled in sand	10.75	65	32	15	15	165
SC, shaken out of mold in ½ hr	10.75	72	28	10	10	160
Heat treatment A	10.75	85	38	8	6	180
Heat treatment B	10.75	90	55	5	4	240

[1]At 0.5% elongation under load
[2]3000 kg load

COPPER ALLOYS, CAST

ALUMINUM Bronze

Physical Properties
Density, at 68F 0.267 lb/cu in. (S. G. 7.4)
Volume conductivity, 13% of Cu

Coef. of Thermal Expansion	
Temp Range	
70-500F or 21-260C	$17.1 \times 10^{-6}/°C$
	$9.5 \times 10^{-6}/°F$

Thermal Conductivity
15% of Cu

Chemical Composition

	Sn %	Cu %	Pb %	Zn %	Ni %	S %
Sand cast	–	86.00 min	–	–	–	–
Ingot	–	86.00 min	–	–	–	–

	Fe %	Sb %	Si %	Mn %	Al %
Sand cast	2.50/4.00	–	–	–	8.50/9.50
Ingot	2.50/4.00	–	–	–	8.50/9.50

Characteristics. This alloy is relatively resistant to acids and mild alkalies, with good strength.

Uses. Mine pumps for acid waters, valve seats, guides, stems, propellers, worm wheels, bearings, bushings, etc.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard[2] BHN	Shear S[4] M psi	Comp YS[3] M psi	E 10^6 psi
Sand cast[5]	75	27	35	32	120	67	29	17

[1] At 0.5% extension under load
[2] 3000 kg load
[3] 0.001 in. set
[4] 0.1 in. set
[5] Shaken out of mold after ½ hr

COPPER ALLOYS, CAST

NICKEL ALUMINUM Bronze

Technological Properties
Heat treatment, A Solution temperature, 1600-1650F or 870-900C, quench in water, age 1 hr at 1100-1200F or 595-650C, quench in water.

Chemical Composition

	Sn %	Cu %	Pb %	Zn %	Ni %	S %
Sand cast	–	78.0 min	–	–	3.0/5.5	–
Ingot	–	–	–	–	–	–

	Fe %	Sb %	Si %	Mn %	Al %
Sand cast	3.0/5.0	–	–	3.5 max	10.0/11.5
Ingot	–	–	–	–	–

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard[2] BHN	E 10^6 psi
Sand cast	95	45	7	7	195	17
Heat treatment A	115	70	5	6	235	17

[1] At 0.5% elongation in 2" under load
[2] 3000 kg load

Characteristics. Hard, strong, and resistant to wear and corrosion.

Uses. Valve guides and seats in airplane engines, bearing plates under heavy loads, gun mounts and slides, and for corrosion resistant parts. Propeller bushings and bearing retainers.

ALUMINUM Bronze

Chemical Composition

	Sn %	Cu %	Pb %	Zn %	Ni %
Sand cast	–	83.00 min	–	–	2.5 max
Ingot	–	–	–	–	–

	Fe %	Sb %	Si %	Mn %	S %	Al %
Sand cast	3.0/5.0	–	–	.5 max	–	10.0/11.5
Ingot	–	–	–	–	–	–

Technological Properties

Heat treatment, A — Solution temp, 1600-1650F or 870-900C, quench in oil or water.

Heat treatment, B — Treatment A, plus aging 1 hr at 1000F or 540C, quench in water.

Characteristics. Good strength, ductility, and resistance to shrinkage as well as resistance to wear and corrosion.

Uses. Bearings, gears, worm gears, bushings, etc.

Coef. of Thermal Expansion

Temp Range	
70-500F or 21-260C	$16.2 \times 10^{-6}/°C$
	$9.0 \times 10^{-6}/°F$

Physical Properties

Density, at 68F 0.271 lb/cu in. (S. G. 7.5)

Volume conductivity, 13% of Cu

Thermal Conductivity

15% of Cu

Mechanical Properties

Form or Condition	Al %	Tensile Strength M psi	Yield[1] Strength M psi	Elong %	Red. Area %	Hard[2] BHN	E 10^6 psi
SC, cooled in sand	10	75	35	18	15	155	18
SC, shaken out of mold in ½ hr	10	85	29	25	22	150	18
Heat treatment A	10	100	40	15	13	190	15
Heat treatment B	10	105	52	10	8	230	15
SC, cooled in sand	10.75	80	37	10	8	170	15
SC, shaken out of mold in ½ hr	10.75	90	32	15	14	160	15
Heat treatment A	10.75	105	45	10	10	200	17
Heat treatment B	10.75	110	65	5	4	250	18

[1] At 0.5% elongation under load
[2] 3000 kg load

ALUMINUM ALLOYS, WROUGHT

AP

Chemical Composition §

%			%		%
Al	99.996	Mn	–	Pb	–
Fe	–	Zn	–	Mg	–
Si	–	Bi	–	Cr	–
Cu	–	Ni	–	Ti	–

Characteristics. § High purity Al is more resistant to corrosion than other forms.

Uses. § Cladding on stronger alloys.

Technological Properties §
Melting point 1220.4F or 660.2C
Boiling point 3740F or 2060C

Mechanical Properties §

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %[1]	Hard BHN[2]
Annealed	6.875	1.775	48.8	17
Cold rolled, 75%	16.300	15.425	5.5	27

[1] Sheet, 1/16 in. thick
[2] 500 kg load, 10 mm ball

§ *Metals Handbook, ASM*

Physical Properties §

Density, at 68F	0.09751 lb/cu in. (2.6989 S.G.)
Specific heat, cal/gm at 100C	0.226
Latent heat of fusion, cal/gm	94.6
Heat of combustion, cal/gm	7389
Electrical resistivity, micro/cm³ at 20C	2.6548
Temperature coefficient, 20C	0.00429
Volume conductivity, % of Cu	64.94%
Emissivity, 25C	0.030 (air)
Reflectivity	90%

Coef. of Thermal Expansion §

Temp Range Deg C	Deg F	per Deg C $\times 10^{-6}$	per Deg F $\times 10^{-6}$
-60-20	-76-68	–	–
20-100	68-212	23.86	13.26
-200	-392	24.58	13.66
-300	-572	25.45	14.14
-400	-752	26.49	14.71
-500	-932	27.68	15.38

ALUMINUM ALLOYS, WROUGHT

11S

Chemical Composition

%			%		%
Al	–	Mn	1.0 max	Pb	.20/.70
Fe	1.00 max	Zn	.30 max	Mg	.80 max
Si	.80 max	Bi	.20/.70	Cr	.25 max
Cu	3.5/6.0	Ni	–	Others	.20 max

Characteristics. ♦ Combines machinability and strength.

Uses. Screw machine parts and forgings which require considerable machining.

Physical Properties

Density, at 68F	0.102 lb/cu in. (2.82 S.G.)
Specific heat, cal/gm at 212F or 100C	0.23
Electrical resistivity, microhm/cm³ 20C or 68F	4.310 for T3
Volume conductivity, % of Cu	40% for T3

Thermal Conductivity
Cal/sq cm/cm/°C/sec,
25C or 77F 0.37 for T3

Coef. of Thermal Expansion

Temp Range Deg C	Deg F	per Deg C $\times 10^{-6}$	per Deg F $\times 10^{-6}$
-60-20	-76-68	21.2	11.8
20-100	68-212	22.9	12.7
-200	-392	–	–
-300	-572	–	–
-400	-752	–	–
-500	-932	–	–

♦ *Free Machining*

Technological Properties

Melting point	solidus, 995F or 535C
	liquidus, 1190F or 643C
Hot working temp	900 to 500F or 480 to 260C
Annealing temp, (O)[1]	800 to 750F or 430 to 400C
To soften after cold work[2]	650F or 340C
Solution temp, (T4)[3]	930 to 980F or 500 to 530C
Precipitation temp, (T8)[4]	320 to 340F or 160 to 170C
Weldability, light sections	Good by flash welding
Riveting	Use 24S-T4 or 17S-T4

[1] 2 hrs, furnace cool to 500F (50 deg max/hr)
[2] No holding time, quench not critical
[3] ½ to 1 hr (salt bath), water quench
[4] 12 to 18 hrs, quench not critical

Mechanical Properties

Form or Condition	Test Temp[2]	Tensile Strength M psi	Yield Strength M psi	Elong %	Hard BHN	Shear S M psi	End Lt[1] M psi
Solution ht tr. cold worked, T3		53	47	15[3]	95	30	12.5
Effect of temp	75F	53	47	15	–	–	–
	300	27	18	25	–	–	–
	400	19	13	34	–	–	–
	500	8.5	4.5	44	–	–	–
	600	4	2	90	–	–	–
	700	2.5	1	125	–	–	–
Ht tr, cold worked, aged, T8		57	44	14[3]	100	33	–

[1] At 5 × 10⁸ cycles
[2] After prolonged exposure to test temp
[3] ½ in. rd.

Modulus of elasticity, E, M psi	10,300
Modulus of rigidity, M psi	3,850
Poisson's ratio	0.33
Compressive YS	Same as tensile YS, approx
Torsional YS	0.55 times tensile YS, approx
Torsional TS	0.65 times tensile TS, approx

ALUMINUM ALLOYS, WROUGHT

R317

Chemical Composition	%		%		%
Al	–	Mn	.4/1.0	Pb	.3/.7
Fe	1.0 max	Zn	.2 max	Mg	.2/.8
Si	1.0 max	Bi	.3/.7	Cr	.25 max
Cu	3.5/4.5	Ni	–	Others	.20 max

Technological Properties

Hot working temp	750 to 675F or 400 to 355C
Annealing temp	750 to 800F or 425 to 400C
Formability	Good by forging or machining
Solution temp	930 to 950F or 498 to 509C
Aging temp	Room temp, 4 days
Riveting	24S-T4 or 17S-T4
Welding, brazing, soldering	Not recommended

Characteristics.♦ Combines good machinability with strength.

Uses. Free-machining stock and forgings.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Hard BHN	Hard R_b	E 10^6 psi
As quenched, T	61	35	22	100	73	10.5

Physical Properties

Density, at 68F 0.101 lb/cu in. (2.81 S.G.)

Volume conductivity, % of Cu 30

♦ *Free Machining*

ALUMINUM ALLOYS, WROUGHT

17S

Technological Properties

Melting point	solidus, 955F or 513C liquidus, 1185F or 641C
Recrystallization temp, after 50% reduction	650F or 345C
Hot working temp	900 to 500F or 480 to 260C
Annealing temp, O	750 to 800F or 400 to 425C
to remove cold work	650F or 345C
Solution temp	925 to 950F or 495 to 510C (+ quench)
Precipitation temp	Room temp, 2-4 days
Weldability	Good, by resistance welding
Riveting, T4	A17S-T4; 17S-T4; 24S-T4; or steel

Chemical Composition

	Si %	Cu %	Mn %	Mg %
Bar, rod, shapes, wire	.80 max	3.5/4.5	.40/1.00	.20/.80
Forgings	.75 max	3.5/4.7	.40/1.00	.20/.75

	Fe %	Cr %	Zn %	Ti %
Bar, rod, shapes, wire	1.00 max	.25 max	.10 max	–
Forgings	1.00 max	.25 max	.25 max	.15 max

	Others %
Bar, rod, shapes, wire	.15 max
Forgings	.15 max

Characteristics. Relatively high strength and good formability and corrosion resistance.

Uses. Used in the construction and transportation industries in structures and for rivets, hardware, screw-machine parts, aircraft fittings, etc.

Physical Properties

Density, at 68F or 20C	0.101 lb/cu in. (2.79 S.G.)
Electrical resistivity, microhm/cm³ at 68F or 20C	3.831 for O; 5.747 for T4
Volume conductivity, % of Cu	45% for O; 30% for T4
Specific heat, cal/gm at 212F	0.23

Mechanical Properties

Form or Condition	Test Temp[3]	Tensile Strength M psi	Yield Strength M psi	Elong %	Hard BHN[1]	Shear S M psi	End Lt[2] M psi
Annealed, O		26	10	22	45	18	11
Treated, T4		62	40	22	105	38	18
Effect of temp	75F	62	40	22	–	–	–
	300	41	35	18	–	–	–
	400	17	11	33	–	–	–
	500	10	7	50	–	–	–
	600	6	4	80	–	–	–
	700	4	3	100	–	–	–

[1] 500 kg load, 10 mm ball
[2] Rotating beam test at 5 × 10^8 cycles
[3] After long holding at test temp

Thermal Conductivity

Cal/sq cm/cm/°C/sec O 0.41; T4 0.29

Coef. of Thermal Expansion

Temp Range Deg C	Temp Range Deg F	per Deg C × 10^{-6} Cond O	per Deg C × 10^{-6} Cond T6	per Deg F × 10^{-6} Cond O	per Deg F × 10^{-6} Cond T6
-60-20	-76-68	–	21.6	–	12.0
20-100	68-212	23.0	23.5	12.8	13.0
-200	-392	24.0	–	13.3	–
-300	-572	25.0	–	13.8	–
-400	-752	–	–	–	–
-500	-932	–	–	–	–

Modulus of elasticity, E, M psi	10,400
Modulus of rigidity, M psi	3,850
Poisson's ratio	0.33
Compressive YS	Same as tensile YS, approx
Torsional YS	0.55 times tensile YS, approx
Torsional TS	0.65 times tensile TS, approx

2S

Chemical Composition

	Si[1] %	Cu %	Mn %
Sheet, plate	—	—	—
Bar, rod, shapes, wire	1.00 max	.20 max	.05 max
Tubing	1.00 max	.20 max	.10 max

	Zn %	Al %	Others %
Sheet, plate	—	99.0 min	—
Bar, rod, shapes, wire	.10 max	99.0 min	.15 max
Tubing	.03 max	99.0 min	.10 max

[1]Fe & Si

Technological Properties

Melting point	solidus, 1190F or 643C liquidus, 1215F or 657C
Hot working temp	950 to 500F or 510 to 260C
Annealing temp	650F or 345C
Cold working	Excellent
Welding	Excellent in light sections
Formability	

Temper	Bend Classification
O	A
H12	B
H14	B
H16	D
H18	F

Characteristics. 2S has good formability and resistance to corrosion, with low strength. It also has good conductivity for its density.

Uses. For cooking utensils, food and chemical equipment, bottle and jar tops, architectural trim, many small parts.

Physical Properties

Density, at 68F	0.098 lb/cu in. (2.71 S.G.)
Specific heat, cal/gm	0.2297
Electrical resistivity, microhm/cm[3] at 68F	condition O, 2.922 condition H18, 3.025
Temperature coefficient, 50-86F	0.0115
Volume conductivity, % of Cu	condition O, 59 condition H18, 57
Reflectivity — as high as 97% at λ =	20,000A
as high as 90% at λ =	5,000A

Thermal Conductivity

Cal/sq cm/cm/°C/sec condition O, 0.53
condition H18, 0.52

Coef. of Thermal Expansion

Temp Range Deg C	Temp Range Deg F	per Deg C $\times 10^{-6}$	per Deg F $\times 10^{-6}$
-60-20	-76-68	21.7	12.0
20-100	68-212	23.5	13.0
-200	-392	24.6	13.7
-300	-572	25.6	14.2
-400	-752	—	—
-500	-932	—	—

Mechanical Properties

Form or Condition	Test Temp[2]	Tensile Strength M psi	Yield Strength M psi	Elong %	Elong 1/16 in. sheet %	Hard BHN 500/10	Shear S M psi	End Lt[1] M psi	E, % of E at 75F
O, Annealed		13	5	45[3]	35	23	9.5	5	—
Effect of temp	75F	13	5	45	—	—	—	—	100
	300	7.5	3.5	65	—	—	—	—	95
	400	6	3	70	—	—	—	—	90
	500	3.5	2	85	—	—	—	—	85
	600	2.5	1.5	90	—	—	—	—	65
	700	1.5	1	95	—	—	—	—	40
H12, Cold worked		15	13	25[3]	12	28	10	6	—
H14, Cold worked		17	14	20[3]	9	32	11	7	—
Effect of temp	75	17	14	20	—	—	—	—	—
	300	13	10	22	—	—	—	—	—
	400	9.5	6.5	25	—	—	—	—	—
	500	3.5	2	85	—	—	—	—	—
	600	2.5	1.5	90	—	—	—	—	—
	700	1.5	1	95	—	—	—	—	—
H16, Cold worked		20	17	17[3]	6	38	12	8.5	—
H18, Cold worked		24	21	15[3]	5	44	13	8.5	—
Effect of temp	75	24	21	15	—	—	—	—	—
	300	17.5	14	16	—	—	—	—	—
	400	6	3	70	—	—	—	—	—
	500	3.5	2	85	—	—	—	—	—
	600	2.5	1.5	90	—	—	—	—	—
	700	1.5	1	95	—	—	—	—	—

[1]Rotating beam test, at 5×10^8 cycles.
[2]After long exposure to test temp
[3]½ in. rd.

Modulus of Elasticity, E, M psi	10,000
Modulus of Rigidity, M psi	3,850
Poisson's Ratio, μ	0.33
Compressive YS	Same as tensile YS, approx.
Torsional YS	0.55 times tensile YS, approx.
Torsional TS	0.65 times tensile TS, approx.

ALUMINUM ALLOYS, WROUGHT

18S

Chemical Composition	%		%		%
Al	–	Mn	.20 max	Ti	.15 max
Fe	1.00 max	Zn	.25 max	Mg	.45/.90
Si	.90 max	Bi	–	Cr	.10 max
Cu	3.5/4.5	Ni	1.7/2.3	Others	.15 max

Technological Properties

Melting point	solidus, 945F or 507C liquidus, 1180F or 638C
Hot working temp	900 to 500F or 480 to 260C
Annealing temp, O	750 to 800F or 400 to 425C
Solution temp, T61	950 to 970F or 510 to 520C, quench
Precipitation temp, T61	335 to 345F or 168 to 175C

Characteristics. High strength up to 400F.

Uses. Forged cylinder heads and pistons, etc.

Physical Properties

Density, at 68F	0.101 lb/cu in. (2.80 S.G.)
Electrical resistivity, microhm/cm³ at 68F	3.448 for O; 4.310 for T61
Volume conductivity, % of Cu	50% for O; 40% for T61
Specific heat, cal/gm at 212F	0.23 approx

Coef. of Thermal Expansion

Temp Range Deg C	Deg F	per Deg C × 10^{-6} Cond O	Cond T6	per Deg F × 10^{-6} Cond O	Cond T6
-60-20	-76-68	–	20.9	–	11.6
20-100	68-212	22.4	22.6	12.4	12.6
-200	-392	23.3	–	12.9	–
-300	-572	24.2	–	13.4	–
-400	-752	–	–	–	–
-500	-932	–	–	–	–

Mechanical Properties

Form or Condition	Test Temp[3]	Tensile Strength M psi	Yield Strength M psi	Elong %	Hard BHN[1]	Shear S M psi	End Lt[2] M psi
T61		63	47	17[5]	130	39	17
Effect of temp	75F	63	47	17[5]	–	–	–
	300	49	44	10	–	–	15[4]
	400	22	17	15	–	–	9.5[4]
	500	11	7	32	–	–	6.5[4]
	600	6	4	55	–	–	–
	700	4	2.5	85	–	–	–

[1] 500 kg load, 10 mm ball
[2] Rotating beam at 5 × 10^8 cycles
[3] After long exposure to test temp
[4] At 10^8 cycles
[5] ½ in. bar.

Thermal Conductivity

Cal/sq cm/cm/°C/sec, 77F

O 0.46

T61 0.37

Modulus of elasticity, E, M psi	10,600, T61
Modulus of rigidity, M psi	3,850, T61
Poisson's ratio	0.33
Compressive YS	Same as tensile YS, approx
Torsional YS	0.55 times tensile YS, approx
Torsional TS	0.65 times tensile TS, approx

ALUMINUM ALLOYS, WROUGHT

56S

Chemical Composition — Wire	%		%		%
Al	–	Mn	.05/.20	Ti	–
Fe	.30 max	Zn	–	Mg	4.5/5.6
Si	.30 max	Bi	–	Cr	.05/.20
Cu	.10 max	Ni	–	Others	.15 max

Technological Properties

Melting point	solidus, 1055F or 568C liquidus, 1180F or 638C
Hot working temp	950 to 500F or 510 to 260C
Annealing temp	650F or 345C
Weldability	Good with fusion methods but limited. Good with resistance methods
Riveting	With 56S, if used

Uses. 56S is used for wire and wire products where good resistance to corrosion is required. Rivets for use with magnesium alloy and cable sheathing are typical.

Physical Properties

Density, at 68F	0.095 lb/cu in. (2.64 S.G.)
Electrical resistivity, microhm/cm³ at 68F	5.945 for O; 6.386 for H38
Volume conductivity, % of Cu	29% for O; 27% for H38
Specific heat, cal/gm at 212F	0.23, approx

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong ½ in. rd. %	End Lt[1] M psi
Annealed, O	42	20	35	20
Hard drawn, H38	58	48	7	22

[1] Rotating beam at 5 × 10^8 cycles

Coef. of Thermal Expansion

Deg C	Deg F	per Deg C × 10^{-6}	per Deg F × 10^{-6}
-60-20	-76-68	22.3	12.4
20-100	68-212	24.3	13.5
-200	-392	25.4	14.1
-300	-572	26.3	14.6
-400	-752	–	–
-500	-932	–	–

Modulus of elasticity, E in M psi	10,300
Modulus of rigidity, M psi	3,850
Poisson's ratio	0.33
Compressive YS	Same as tensile YS, approx
Torsional YS	0.55 times tensile YS, approx
Torsional TS	0.65 times tensile TS, approx

Thermal Conductivity

Cgs units at 77F

O 0.28

H38 0.26

3S

Chemical Composition
(1.2% Mn)

	Si %	Cu %	Mn %
Sheet, plate	.60 max	.20 max	1.00/1.50
Bar, rod, shapes, wire	.60 max	.20 max	1.00/1.50
Tubing	.60 max	.20 max	1.00/1.50

	Zn %	Fe %	Others %
Sheet, plate	.10 max	.70 max	.15 max
Bar, rod, shapes, wire	.10 max	.70 max	.15 max
Tubing	—	.70 max	.10 max

Characteristics. Stronger than 2S but has good workability, weldability, and corrosion resistance.

Uses. Cooking utensils, food and chemical equipment, tanks, trim for transportation equipment, etc.

Technological Properties

Melting point	solidus, 1190F or 643C
	liquidus, 1210F or 654C
Hot working temp	950 to 500F or 510 to 260C
Annealing temp	750F or 400C
Weldability	Good
Formability	

Temper	Bend Classification
O	A
H12	B
H14	C
H16	E
H18	G

Physical Properties

Density, at 68F	0.099 lb/cu in. (2.73 S.G.)
Specific heat, 212F, cal/gm	0.23
Electrical resistivity, micro/cm³	O 3.448
	H12, 4.105
	H14, 4.205
	H18, 4.310
Volume conductivity, % of Cu	O 50
	H12, 42
	H14, 41
	H18, 40

Thermal Conductivity
Cal/sq cm/cm/°C/sec

O	0.46
H12	0.39
H14	0.38
H18	0.37

Coef. of Thermal Expansion, Annealed

Temp Range Deg C	Deg F	per Deg C $\times 10^{-6}$	per Deg F $\times 10^{-6}$
-60-20	-76-68	21.4	11.9
20-100	68-212	23.2	12.9
-200	-392	24.2	13.4
-300	-572	25.1	13.9
-400	-752	—	—
-500	-932	—	—

Mechanical Properties

Form or Condition	Test Temp²	Tensile Strength M psi	Yield Strength M psi	Elong 1/16 in. sheet %	Elong %	Hard BHN 500/10	Shear S M psi	End Lt¹ M psi
Annealed, O		16	6	30	40³	28	11	7
Effect of temp	75F	16	6	—	40	—	—	—
	300	11	5	—	47	—	—	—
	400	8	4.5	—	50	—	—	—
	500	5.5	3.5	—	60	—	—	—
	600	4	2.5	—	60	—	—	—
	700	3	2	—	60	—	—	—
Cold worked, H12		18	15	10	20³	35	12	8
Cold worked, H14		21	18	8	16³	40	14	9
Effect of temp	75	21	18	—	16	—	—	—
	300	18	15	—	17	—	—	—
	400	14	9	—	22	—	—	—
	500	10.5	5	—	25	—	—	—
	600	6	3	—	40	—	—	—
	700	3	2	—	60	—	—	—
Cold worked, H16		25	21	5	14³	47	15	9.5
Cold worked, H18		29	25	4	10³	55	16	10
Effect of temp	75	29	25	—	10	—	—	—
	300	23	16	—	12	—	—	—
	400	17	8	—	15	—	—	—
	500	10.5	5	—	25	—	—	—
	600	4.5	3	—	55	—	—	—
	700	3	2	—	60	—	—	—

¹Rotating beam test at 5 × 10⁸ cycles ³½ in. rd.
²After prolonged exposure to test temp

Modulus of Elasticity, E M psi	10,000
Modulus of Rigidity, M psi	3,850
Poisson's Ratio	0.33
Compressive YS	Same as tensile YS, approx
Torsional YS	0.55 times tensile YS, approx
Torsional TS	0.65 times tensile TS, approx

ALUMINUM ALLOYS, WROUGHT	
14S	**R301**

R301 is similar to 14S and is supplied on the same specification, Government AN-A-22.

Chemical Composition (Plain and Clad)

	Cu %	Si %	Mn %	Mg %
Clad Sheet – core	3.9/5.0	.50/1.2	.40/1.2	.20/.80
– cladding	.10 max	.35/1.0	.75 max	.80/1.50
Extrusions	3.9/5.0	.50/1.2	.40/1.2	.20/.80
Forgings	3.9/5.0	.50/1.2	.40/1.2	.20/.75

	Fe %	Cr %	Zn %	Ti %
Clad sheet – core	1.00 max	.25 max	.25 max	–
– cladding	.60 max	.35 max	.20 max	.10 max
Extrusions	1.00 max	.10 max	.25 max	–
Forgings	1.00 max	10 max	.25 max	.15 max

	Others[1] %
Clad sheet – core	.15 max
– cladding	.15 max
Extrusions	.15 max
Forgings	.15 max

[1]Each .05%

Technological Properties

Melting point	solidus, 950F or 510C liquidus, 1180F or 638C
Recrystallization temp, 50% reduction	650F or 345C
Hot working temp	900 to 500F or 480 to 260C
Annealing temp, O[3]	750 to 800F or 400 to 430C
to remove cold work[4]	650F or 345C
Solution temp, T4[5]	925 to 950F or 495 to 515C
Precipitation temp, T6[6]	335 to 345F or 168 to 174C
Precipitation temp, T4	315 to 325F or 157 to 163C
Weldability	Good by fusion and resistance methods
Riveting, T6	Use A17S-T4; 17S-T4; 24S-T4; or steel
Formability	Good in O temper, fair in quenched condition, W

Temper	Bend Classification
O	B[1]
T4	H[1,2]
T6	K[1]

[1]Alclad is slightly better.
[2]Freshly quenched—appreciably better.
[3]2 hrs, furnace cool to 500F (50 deg max/hr).
[4]No time required, cooling not critical.
[5]10 min to 1 hr (salt bath), cold water quench.
[6]8 to 12 hrs, cooling not critical.

Characteristics. Strength and hardness combined with relatively good formability.

Uses. Heavy-duty forgings, boils for power shovels, aircraft parts, etc.

Physical Properties

Density, at 68F or 20C	0.101 lb/cu in. (2.80 S.G.)
Electrical resistivity, microhm/cm³	3.448 for O; 4.310 for T6
Volume conductivity, % of Cu	50% for O; 40% for T6
Specific heat, 212F or 100C, cal/gm	0.23 approx

Thermal Conductivity

Cal/sq cm/cm/°C/sec, 77F or 25C O 0.46
T6 0.37

Coef. of Thermal Expansion

Temp Range Deg C	Deg F	per Deg C $\times 10^{-6}$ Cond O	Cond T6	per Deg F $\times 10^{-6}$ Cond O	Cond T6
-60-20	-76-68	–	21.4	–	11.9
20-100	68-212	22.5	23.0	12.5	12.8
-200	-392	23.6	–	13.1	–
-300	-572	24.5	–	13.6	–
-400	-752	–	–	–	–
-500	-932	–	–	–	–

Mechanical Properties

Form or Condition	Test Temp[4]	Tensile Strength M psi	Yield Strength M psi	Elong 1/16 in. sheet %	%	Hard BHN[1]	Shear S M psi	End Lt[2] M psi
Bare[3]								
Annealed, O		27	14	–	18[5]	45	18	11
Treated, T4		56	40	–	25[5]	100	34	18
Treated, T6		70	60	–	13[5]	135	42	18
Effect of temp	75F	70	60	–	13	–	–	–
	300	43	39	–	16	–	–	–
	400	17	13	–	33	–	–	–
	500	10	8	–	50	–	–	–
	600	6	4.5	–	65	–	–	–
	700	4	3.5	–	75	–	–	–
Clad Sheet								
Annealed, O		25	10	21	–	–	18	–
Treated, T4		59	38	18	–	–	39	–
Treated, T6		65	58	9	–	–	41	–

[1]500 kg load and 10 mm ball
[2]Values for 5×10^8 cycles
[3]Transverse elongation is 70% at longitudinal, approx
[4]After long holding at test temp
[5]½ in. rd.

Modulus of elasticity, E, M psi	10,600, bare 10,500, clad
Modulus of rigidity M psi	3,850
Torsional YS	0.55 times tensile YS, approx
Torsional TS	0.65 times tensile TS, approx

24S

Chemical Composition	Cu %	Si %	Mn %	Mg %
Sheet	3.8/4.9	.50 max	.30/.90	1.2/1.8
Bar, rods, shapes, wire	3.8/4.9	.50 max	.30/.90	1.2/1.8
Tubing	3.8/4.9	.50 max	.30/.90	1.2/1.8
Clad sheet, core	3.8/4.9	.50 max	.30/.90	1.2/1.8
Clad sheet, cladding[2]	.20 max	.70 max[1]	.05 max	–

	Fe %	Cr %	Zn %	Others %
Sheet	.50 max	.25 max	.10 max	.10 max
Bar, rods, shapes, wire	.50 max	.25 max	.10 max	.15 max
Tubing	.50 max	.25 max	.10 max	.15 max
Clad sheet, core	.50 max	.25 max	.03 max	.10 max
Clad sheet, cladding[2]	–	–	.20 max	

[1] Fe & Si [2] Al-99 3 min.

Characteristics. 24S is a stronger alloy than 17S.

Uses. Aircraft structures, rivets, etc.

Technological Properties

Melting point	solidus, 935F or 502C liquidus, 1180F or 638C
Recrystallization temp, 50% reduction	650F or 345C
Hot working temp	900 to 500F or 480 to 260C
Annealing temp, O	750 to 800F or 400 to 425C
remove cold work	650F or 345C
T4 treatment	910 to 930F or 488 to 499C, WQ, precipitation at r. t.
T81 treatment	Precipitate T4 at 370 to 380F or 188 to 193C
T84 treatment	Stretch T4 3%, precipitate at 370 to 380F or 188 to 193C
T36 treatment	Solution treated (T4) and cold worked
T86 treatment	T36 precipitated at 370 to 380F or 188 to 193C
Weldability	Good by resistance methods
Riveting, T4 condition	Use A17S-T4; 17S-T4; 24S-T4; or steel

Formability

Temper	Bend Classification
O	B[1]
T4	J[1,2]
T36	K[1]

[1] Alclad is slightly better
[2] Freshly quenched = appreciably better

Physical Properties

Density, at 68F	0.100 lb/cu in. (2.77 S.G.)
Electrical resistivity, microhm/cm[3] at 68F	3.448 for O, 5.747 for T4
Volume conductivity, % of Cu	50% for O; 30% for T4
Specific heat, cal/gm at 212F	0.23 approx

Thermal Conductivity

Cgs at 77F O 0.45
T4 0.29

Coef. of Thermal Expansion

Temp Range Deg C	Deg F	per Deg C × 10^{-6} Cond O	Cond T4	per Deg F × 10^{-6} Cond O	Cond T4
-60-20	-76-68	–	21.5	–	11.9
20-100	68-212	22.8	23.2	12.7	12.9
-200	-392	23.9	–	13.3	–
-300	-572	24.7	–	13.7	–
-400	-752	–	–	–	–
-500	-932	–	–	–	–

Mechanical Properties

Form or Condition	Test Temp[3]	Tensile Strength M psi	Yield Strength M psi	Elong 1/16 in. sheet %	%	Hard BHN[1]	Shear S M psi	End Lt[2] M psi
Bare								
Annealed, O		27	11	19	22[4]	42	18	12
Treated, T4		68	46	19	22[4]	120	41	18
Effect of temp	75F	68	46	–	22	–	–	–
	300	42	37	–	20	–	–	–
	400	20	16	–	26	–	–	–
	500	12	10	–	40	–	–	–
	600	7	5.5	–	70	–	–	–
	700	5	3.5	–	100	–	–	–
Treated + cold worked, T36		73	57	13	–	130	42	–
Clad Sheet								
T4		64	43	18	–	–	40	–
T36		67	53	11	–	–	41	–
T81		66	60	7	–	–	–	–
T86		70	66	6	–	–	–	–

[1] 500 kg load, 10 mm ball
[2] At 5 × 10^8 cycles
[3] After long holding at test temp
[4] ½ in. rd.

Modulus of elasticity, E in M psi	0.064 in. clad sheet and thicker	10,000
	Clad sheet under 0.064 in.	9,600
	Other bare and clad sheet	10,600
Modulus of rigidity, bare products in M psi	3,850	
Poisson's ratio	0.33	
Compressive YS	Same as tensile YS, approx	
Torsional YS	0.55 times tensile YS, approx	
Torsional TS	0.65 times tensile TS, approx	

52S

Chemical Composition

	Cu %	Mn %	Mg %	Fe[1] %
Sheet	.10 max	.10 max	2.20/2.80	.45 max
Bar, rods, shapes, wire	.10 max	.10 max	2.20/2.80	.45 max
Tubing	.10 max	.10 max	2.20/2.80	.45 max

	Cr %	Zn %	Others %
Sheet	.15/.35	.03 max	.10 max
Bar, rods, shapes, wire	.15/.35	.10 max	.15 max
Tubing	.15/.35	.03 max	.10 max

[1] Fe & Si

Characteristics. Combines good workability with good fatigue strength and corrosion resistance and moderate strength.

Uses. Aircraft fuel and oil lines, fuel tanks, and marine and transportation applications.

Technological Properties

Melting point	solidus, 1100F or 593C liquidus, 1200F or 649C
Recrystallization temp, after 50% reduction	550F or 290C
Hot working temp	950 to 500F or 510 to 260C
Annealing temp, O	650F or 345C
Weldability	Good with fusion methods but limited, good with resistance methods
Soldering, brazing	Good
Riveting	Condition O, use 2S. For H tempers, use A17S-T4; 53S-T61; 53S-T4

Formability

Temper	Bend Classification
O	B
H32	C
H34	D
H36	F
H38	G

Physical Properties

Density, at 68F	0.097 lb/cu in. (2.68 S.G.)
Electrical resistivity, microhm/cm², at 68F	4.926 for O; 4.926 for H38
Volume conductivity, % of Cu	35% for O and H38
Specific heat, cal/gm at 212F	0.23, approx

Coef. of Thermal Expansion

Temp Range Deg C	Temp Range Deg F	per Deg C 10^{-6} Cond O	per Deg F $\times 10^{-6}$ Cond O
-60-20	-76-68	22.0	12.2
20-100	68-212	23.8	13.3
-200	-392	24.9	13.8
-300	-572	25.8	14.3
-400	-752	–	–
-500	-932	–	–

Thermal Conductivity

Cal/sq cm/cm/°C/sec, 77F 0.33 for O and H38

Mechanical Properties

Form or Condition	Test Temp[4]	Tensile Strength[3] M psi	Yield Strength M psi	Elong 1/16 in. sheet %	Elong %	Hard BHN[1]	Shear S M psi	End Lt[2] M psi
Annealed, O		29	14	25	30[5]	45	18	17
Effect of temp	75F	29	14	–	30	–	–	–
	300	23	13.5	–	55	–	–	–
	400	18	11	–	65	–	–	–
	500	12	8	–	100	–	–	–
	600	7.5	4	–	105	–	–	–
	700	5	2.5	–	120	–	–	–
H32 ¼ in. hard		34	26	12	18[5]	62	20	17.5
H34 ½ in. hard		37	29	10	14[5]	67	21	18
H36 ¾ in. hard		39	34	8	10[5]	74	23	18.5
Effect of temp	75	39	34	–	10	–	–	–
	300	32	27	–	16	–	–	–
	400	25	11	–	35	–	–	–
	500	12	8	–	80	–	–	–
	600	8	4.5	–	100	–	–	–
	700	5	2.5	–	120	–	–	–
H38 full hard		41	36	7	8[5]	85	24	19

[1] 500 kg load, 10 mm ball
[2] Rotating beam at 5×10^8 cycles
[3] Transverse values are slightly lower for H conditions
[4] After long holding at test temp
[5] ½ in. rd.

Modulus of elasticity, E in M psi	10,200
Modulus of rigidity, M psi	3,850
Poisson's ratio	0.33
Compressive YS	Same as tensile YS, approx
Torsional YS	0.55 times tensile YS, approx
Torsional TS	0.65 times tensile TS, approx

ALUMINUM ALLOYS, WROUGHT
32S

Chemical Composition (Forgings)					
	%		%		%
Al	—	Mn	.20 max	Ti	.15 max
Fe	1.00 max	Zn	.25 max	Mg	.80/1.3
Si	11.5/13.5	Bi	—	Cr	.10 max
Cu	.50/1.3	Ni	.50/1.3	Others	.15 max

Characteristics. Relatively low expansion and good forgeability.

Uses. Useful for applications such as forged pistons.

Physical Properties

Density, at 68F	0.097 lb/cu in. (2.69 S.G.)
Electrical resistivity, microhm/cm[3] at 68F	4.310 for O; 4.926 for T6
Volume conductivity, % of Cu	40% for O; 35% for T6
Specific heat, cal/gm at 212F	0.23, approx

Thermal Conductivity

Cal/sq cm/cm/°C/sec, 77F O 0.37
T6 0.33

Coef. of Thermal Expansion					
		per Deg C × 10^{-6}		per Deg F × 10^{-6}	
Temp Range Deg C	Temp Range Deg F	Cond O	Cond T6	Cond O	Cond T6
-60-20	-76-68	—	18.4	—	10.2
20-100	68-212	19.4	19.9	10.8	11.0
-200	-392	20.3	—	11.3	—
-300	-572	21.1	—	11.7	—
-400	-752	—	—	—	—
-500	-932	—	—	—	—

Technological Properties

Melting point	solidus, 990F or 532C; liquidus, 1060F or 571C
Hot working temp	900 to 500F or 480 to 260C
Annealing temp, O[1]	750 to 800F or 400 to 425C
Solution treatment, T6[2]	950 to 970F or 510 to 520C
Precipitation treatment, T6[3]	335 to 345F or 168 to 174C

[1] 2 hrs, furnace cool to 500F (50 deg max/hr)
[2] 4 hrs (min), water quench
[3] 6 to 10 hrs, quench not critical

Mechanical Properties Form or Condition	Test Temp[4]	Tensile Strength M psi	Yield Strength M psi	Elong[3] %	Hard BHN[1]	Shear S M psi	End Lt[2] M psi
T6		56	46	8	125	38	16
Effect of temp	75F	56	46	8	—	—	—
	300	39	33	9	—	—	—
	400	16	11	30	—	—	—
	500	8.5	6.5	50	—	—	—
	600	6	3.5	60	—	—	—
	700	3.5	2	120	—	—	—

[1] 500 kg load, 10 mm ball
[2] Rotating beam at 5 × 10^8 cycles
[3] Transverse elongation is approx 70% of the longitudinal
[4] After long exposure to test temp
[5] ½ in. rd.

Modulus of elasticity, E in M psi	10,300
Modulus of rigidity, E in M psi	3,850
Poisson's ratio	0.33
Compressive YS	Same as tensile YS, approx
Torsional YS	0.55 times tensile YS, approx
Torsional TS	0.65 times tensile TS, approx

ALUMINUM ALLOYS, WROUGHT
A51S

Chemical Composition					
	%		%		%
Al	—	Mn	.20 max	Ti	.15 max
Fe	1.00 max	Zn	.25 max	Mg	.45/.80
Si	.60/1.20	Bi	—	Cr	.15/.35
Cu	.35 max	Ni	—	Others	.15 max

Characteristics. Combines good forgeability, strength, and resistance to corrosion.

Uses. Crankcases, fuse parts, machine and automotive parts.

Physical Properties

Density, at 68F	0.097 lb/cu in. (2.69 S.G.)
Electrical resistivity, microhm/cm[3] at 68F	3.135 for O; 3.831 for T4 and T6
Volume conductivity, % of Cu	55% for O; 45% for T4 and T6
Specific heat, cal/gm at 212F	0.23, approx

Thermal Conductivity

Cal/sq cm/cm/°C/sec, 77F O 0.50
T4 and T6 0.41

Coef. of Thermal Expansion					
		per Deg C × 10^{-6}		per Deg F × 10^{-6}	
Temp Range Deg C	Temp Range Deg F	Cond O	Cond T6	Cond O	Cond T6
-60-20	-76-68	—	21.6	—	12.0
20-100	68-212	23.1	23.3	12.8	12.9
-200	-392	24.2	—	13.4	—
-300	-572	25.0	—	13.8	—
-400	-752	—	—	—	—
-500	-932	—	—	—	—

Technological Properties

Melting point	solidus, 1025F or 552C; liquidus, 1200F or 649C
Hot working temp	900 to 500F or 480 to 260C
Annealing temp, O[1]	750 to 800F or 400 to 425C
Solution treatment, T4[2]	960 to 980F or 515 to 525C, WQ
Precipitation treatment, T6,[3] applied to T4	335 to 345F or 168 to 174C
Weldability	Good with fusion methods but limited; good with resistance methods
Soldering, brazing	Good
Riveting	Use 53S-T61; 53S-T4; 53S-T6

[1] 2 hrs, furnace cool to 500F (50 deg max/hr)
[2] 4 hrs (min), water quench
[3] 6 to 10 hrs, quench not critical

Mechanical Properties Form or Condition	Test Temp[4]	Tensile Strength M psi	Yield Strength M psi	Elong[3] %	Hard BHN[1]	Shear S M psi	End Lt[2] M psi
T6		47	40	20[6]	100	32	11
Effect of temp	75F	47	40	20	—	—	—
	300	19	15	28	—	—	—
	400	7.5	5.5	58	—	—	3.5[5]
	500	5.5	4.5	59	—	—	3.5[5]
	600	4.5	3.5	60	—	—	—
	700	3.5	3	65	—	—	—

[1] 500 kg load, 10 mm ball
[2] Rotating beam at 5 × 10^8 cycles
[3] Transverse elongation is approx 70% of the longitudinal
[4] After long holding at test temp
[5] At 10^8 cycles
[6] ½ in. rd.

Modulus of elasticity, E in M psi	10,200
Modulus of rigidity, M psi	3,850
Poisson's ratio	0.33
Compressive YS	Same as tensile YS, approx
Torsional YS	0.55 times tensile YS, approx
Torsional TS	0.65 times tensile TS, approx

ALUMINUM ALLOYS, WROUGHT

61S

Technological Properties

Melting point	solidus, 1080F or 582C
	liquidus, 1205F or 652C
Hot working temp	950 to 500F or 510 to 260C
Recrystallization temp for 75% reduction	650F or 345C
Annealing temp, O[2]	750 to 800F or 400 to 425C
to remove cold work[3]	650F or 343C
Solution temp, T4[4]	960 to 980F or 516 to 527C, WQ
Precipitation temp, T6[5]	315 to 325F or 157 to 163C
Precipitation temp, start with T4, T6[6]	345 to 355F or 174 to 179C
Weldability	Same as A51S
Riveting, for T4 and T6	53S-T61; 53S-T4; 53S-T6; or steel

Formability

Temper	Bend Classification
O	B
T4	E[1]
T6	F

[1]Freshly quenched - appreciably better
[2]2 hrs, furnace cool to 500F (50 deg max/hr)
[3]No holding time, quench not critical
[4]½ to 1 hr, cold water quench
[5]18 to 20 hrs, cooling not critical
[6]6 to 10 hrs, cooling not critical

Chemical Composition

	Cu %	Si %	Mn %	Mg %	Fe %
Sheet	.15/.40	.40/.80	.15 max	.80/1.2	.70 max
Bar, rod, shapes, wire	.15/.40	.40/.80	.15 max	.80/1.2	.70 max
Tubing	.15/.40	.40/.80	.15 max	.80/1.2	.70 max

	Cr %	Zn %	Ti %	Others %
Sheet	.35 max	.20 max	.15 max	.10 max
Bar, rod, shapes, wire	.15/35	.20 max	.15 max	.15 max
Tubing	.35 max	.20 max	.15 max	.10 max

Characteristics. Good strength, workability, and corrosion resistance.

Uses. Aircraft landing mats, pontoon boats, canoes, furniture, vacuum cleaner tubing, and transportation equipment.

Physical Properties

Density, at 68F	0.098 lb/cu in. (2.70 S.G.)
Electrical resistivity, microhm/cm³ at 68F	3.831 for O; 4.310 for T4 and T6
Volume conductivity, % of Cu	45% for O; 40% for T4 and T6
Specific heat, cal/gm at 212F	0.23, approx

Thermal Conductivity

Cgs units at 77F O 0.41
T4 and T6 0.37

Coef. of Thermal Expansion

Temp Range Deg C	Temp Range Deg F	per Deg C $\times 10^{-6}$ Cond O	per Deg C $\times 10^{-6}$ Cond T6	per Deg F $\times 10^{-6}$ Cond O	per Deg F $\times 10^{-6}$ Cond T6
-60-20	-76-68	–	21.6	–	12.0
20-100	68-212	23.5	23.5	13.0	13.0
-200	-392	24.3	–	13.5	–
-300	-572	25.4	–	14.1	–
-400	-752	–	–	–	–
-500	-932	–	–	–	–

Mechanical Properties

Form or Condition	Test Temp[4]	Tensile Strength[3] M psi	Yield Strength M psi	Elong 1/16 in. sheet %	%	Hard BHN[1]	Shear S M psi	End Lt[2] M psi
Annealed, O		18	8	22	30[5]	30	12.5	9
Treated, T4		35	21	22	28[5]	65	24	13.5
Treated, T6		45	40	12	15[5]	95	30	13.5
Treated, T6, Test temp	75F	45	40	–	15	–	–	–
	300	31	29	–	23	–	–	–
	400	19	15	–	29	–	–	–
	500	7.5	5	–	55	–	–	–
	600	3.5	2.5	–	90	–	–	–
	700	3	2	–	105	–	–	–

[1]500 kg load, 10 mm ball
[2]Rotating beam at 5×10^8 cycles
[3]Transverse values for sheet are approximately the same
[4]After long holding at test temp
[5]½ in. rd.

Modulus of elasticity, E in M psi	10,000
Modulus of rigidity, in M psi	3,850
Poisson's ratio	0.33
Compressive YS	Same as tensile YS, approx
Torsional YS	0.55 times tensile YS, approx
Torsional TS	0.65 times tensile TS, approx

53S

Chemical Composition

	Cu %	Si %	Mg %	Fe %
Bar, rod, shapes, wire	.10 max	.45/.65 × % Mg	1.10/1.40	.35 max
Forgings	.10 max	.45/.65 × % Mg	1.10/1.40	.35 max

	Cr %	Zn %	Ti %	Others %
Bar, rod, shapes, wire	.15/.35	.10 max	.15 max	.15 max
Forgings	.15/.35	.25 max	.15 max	.15 max

Characteristics. Good workability and corrosion resistance with moderate strength.

Uses. Petroleum refining equipment, beer barrels and in naval and architectural construction.

Physical Properties

Density, at 68F	0.097 lb/cu in. (2.69 S.G.)
Electrical resistivity, microhm/cm³ at 68F	3.831 for O; 4.310 for T4 and T6
Volume conductivity, % of Cu	45% for O; 40% for T4 and T6
Specific heat, cal/gm at 212F	0.23, approx

Thermal Conductivity

Cal/sq cm/cm/°C/sec, 77F O 0.41
T4 and T6 0.37

Technological Properties

Melting point solidus,	1075F or 579C
liquidus,	1205F or 652C
Hot working temp	950 to 500F or 510 to 260C
Recrystallization temp, for 75% reduction	650F or 345C
Annealing temp, O[1]	750 to 800F or 400 to 425C
to remove cold work	650F or 345C
Solution treatment, T4[2]	960 to 980F or 516 to 527C
Precipitation treatment, T6[3]	315 to 325F or 157 to 163C
Precipitation treatment, T4, T6[4]	345 to 355F or 174 to 179C
Weldability	Good with fusion methods but limited; good with resistance methods
Soldering, brazing	Good
Riveting, conditions T4 and T6	Use 53S-T61; 53S-T4; 53S-T6 or steel

[1] 2 hrs, furnace cool to 500F (50 deg max/hr)
[2] ½ to 1 hr, water quench
[3] 16 to 20 hrs, quench not critical
[4] 6 to 10 hrs, quench not critical

Coef. of Thermal Expansion

Temp Range Deg C	Temp Range Deg F	per Deg C × 10^{-6} Cond O	per Deg C × 10^{-6} Cond T6	per Deg F × 10^{-6} Cond O	per Deg F × 10^{-6} Cond T6
-60-20	-76-68	–	21.7	–	12.0
20-100	68-212	22.9	23.5	12.7	13.0
-200	-392	24.1	–	13.4	–
-300	-572	25.1	–	13.9	–
-400	-752	–	–	–	–
-500	-932	–	–	–	–

Mechanical Properties

Form or Condition	Test Temp[4]	Tensile Strength[3] M psi	Yield Strength M psi	Elong %	Hard BHN[1]	Shear S M psi	End Lt[2] M psi
O		16	7	35[5]	26	11	8
T4		33	20	30[5]	65	20	13
T6		39	33	20[5]	80	24	13
Effect of temp	75F	39	33	20	–	–	–
	300	25	22	17	–	–	–
	400	13	10	30	–	–	–
	500	6	3.5	70	–	–	–
	600	3.5	2.5	75	–	–	–
	700	2.5	2	90	–	–	–

[1] 500 kg load, 10 mm ball
[2] Rotating beam at 5 × 10^8 cycles
[3] Transverse values same as longitudinal, approx
[4] After long exposure to test temp
[5] ½ in. rd.

Modulus of elasticity, E in M psi	10,000
Modulus of rigidity, in M psi	3,850
Poisson's ratio	0.33
Compressive YS	Same as tensile YS, approx
Torsional YS	0.55 times tensile YS, approx
Torsional TS	0.65 times tensile TS, approx

ALUMINUM ALLOYS, WROUGHT

25S

Chemical Composition

	%		%		%
Al	–	Mn	.40/1.2	Ti	.15 max
Fe	1.00 max	Zn	.25 max	Mg	.05 max
Si	.50/1.2	Bi	–	Cr	.10 max
Cu	3.9/5.0	Ni	–	Others	.15 max

Technological Properties

Melting point	solidus, 970F or 521C liquidus, 1185F or 641C
Annealing temp, O[1]	750 to 800F or 400 to 425C
Hot working temp[2]	900 to 500F or 480 to 260C
Heat treatment, T6[3]	
solution treatment	950 to 970F or 510 to 520C
precipitation treatment	335 to 345F or 168 to 174C
Riveting	Use A17S-T4; 17S-T4; or 24S-T4

[1]2 hrs, furnace cool to 500F
[2]4 hrs, water quench
[3]8 to 12 hrs, quench not critical

Characteristics. A forging alloy; also has fairly high strength.

Uses. Aircraft propellers, link rods, radial engine crankcases.

Physical Properties

Density, at 68F	0.101 lb/cu in. (2.79 S.G.)
Electrical resistivity, microhm/cm[3] at 68F	4.310 for T6
Volume conductivity % of Cu	40% for T6
Specific heat, cal/gm at 212F	0.23

Mechanical Properties

Form or Condition	Test Temp[4]	Tensile Strength M psi	Yield Strength M psi	Elong %	Hard BHN[1]	Shear S M psi	End Lt[3] M psi
T6		57	35	18[5]	110	35	18[2]
Effect of temp	75F	57	35	18	–	–	–
	300	57	28	20	–	–	9.5
	400	19	13.5	35	–	–	6.5
	500	9	6	45	–	–	3.5
	600	4.5	4	50	–	–	–
	700	3.5	3	55	–	–	–

[1]500 kg load 10 mm ball
[2]Rotating beam at 5 × 10^8 cycles
[3]At 10^8 cycles
[4]After long holding at test temp
[5]½ in rd.

Thermal Conductivity
Cal/sq cm/cm/°C/sec, 77F T6 0.37

Modulus of elasticity, E in M psi	10,400
Modulus of rigidity, M psi	3,850
Poisson's ratio	0.33
Compressive YS	Same as tensile YS, approx
Torsional YS	0.55 times tensile YS, approx
Torsional TS	0.65 times tensile TS, approx

Coef. of Thermal Expansion

Deg C	Deg F	per Deg C × 10^{-6} Cond O	per Deg C × 10^{-6} Cond T6	per Deg F × 10^{-6} Cond O	per Deg F × 10^{-6} Cond T6
-60-20	-76-68	–	21.6	–	12.0
20-100	68-212	22.8	23.3	12.7	12.9
-200	-392	23.7	–	13.2	–
-300	-572	24.5	–	13.6	–

ALUMINUM ALLOYS, WROUGHT

R303

Chemical Composition

	%		%		%
Al	–	Mn	–	Pb	–
Fe	–	Zn	6.4	Ti	–
Si	–	Bi	–	Mg	2.5
Cu	1.2	Ni	–	Cr	–

Technological Properties

Hot working temp	800 to 700F or 425 to 370C
Annealing temp	675 to 700F or 355 to 370C cool to 450F, 4 hr
Formability	Good, as annealed or freshly quenched
Solution treatment	810 to 840F or 430 to 450C, WQ
Precipitation treatment, T275	270 to 280F or 132 to 138C
Precipitation treatment, T315	310 to 320F or 154 to 160C
Incubation period at r. t.	24 hr
Weldability	Only spot welding clad sheet is recommended
Riveting	Use 24S-T4; 17S-T4

Characteristics. Exceptionally high strength and otherwise good properties.

Uses. Components of aircraft structures. Heat treatment must be carefully controlled to minimize tendency to stress-corrosion cracking.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Hard Rock	Shear S M psi	End Lt M psi
0.064" sheet, annealed	30	15	18	57-62Re	–	–
0.064" sheet, WQ, T275	79	73	9	89-93Rb	–	–
0.064" sheet, WQ, T315	75	69	9	87-91Rb	–	–
Extrusions, WQ, T275	85	80	9	–	48	23[1]
Extrusions, WQ, T315	79	73	9	–	47	23

[1] 5 × 10^8

Physical Properties
Density, at 68F 0.102 lb/cu in. (2.82 S.G.)

Modulus of elasticity, E in M psi	10,400
Shear modulus, M psi	3,900
Bearing YS—for edge distance 1.50D	= 1.4 × YS
for edge distance 2.00D	= 1.6 × YS

75S

Chemical Composition

	Cu %	Si %	Mn %	Mg %	Fe %
Bare sheet	1.2/2.0	.50 max	.10/.30	2.1/2.9	.70 max
Clad sheet, core	1.2/2.0	.50 max	.10/.30	2.1/2.9	.70 max
Clad sheet, cladding	.10 max	.70 max[1]	.10 max	.10 max	.70 max[1]

	Cr %	Zn %	Ti %	Others[2] %
Bare sheet	.15/.40	5.10/6.10	.20 max	.15 max
Clad sheet, core	.15/.40	5.10/6.10	.20 max	.15 max
Clad sheet, cladding	–	.75/1.25	–	.15 max

[1]Fe & Si [2]Each .05% max

Characteristics. 75S is a very high strength alloy, with good corrosion resistance.

Uses. Structural parts for aircraft.

Technological Properties

Melting point	solidus, 890F or 476C liquidus, 1180F or 638C
Hot working temp	850 to 500F or 455 to 260C
Annealing temp, to remove cold work	775F or 415C, 50% reduction
Annealing temp, O	775 to 850F, AC, followed by 450F or 415 to 455C, AC, followed by 230C
Solution treatment, W	860 to 930F[1], WQ or 460 to 500C, WQ
Precipitation treatment, T6	Heat W to 245 to 255F or 118 to 124C; or heat to 205 to 215F (96 to 102C), cool to r.t., and reheat to 310 to 320F (154 to 160C)
Weldability	Good by resistance methods
Riveting	Use A17S-T4; 17S-T4; 24S-T4; or steel
Formability	

Temper	Bend Classification
O	D[2]
W	E[2,3]
T6	K[2]

[1]Heat extrusions to 860-880F
[2]Alclad is slightly better
[3]As long as 2 hr after quenching

Physical Properties

Density, at 68F	0.101 lb/cu in. (2.80 S.G.)
Electrical resistivity, microhm/cm³ at 68F	5.747 for T6
Volume conductivity, % of Cu	30% for T6
Specific heat, cal/gm at 212F	0.23, approx

Coef. of Thermal Expansion

Temp Range Deg C	Temp Range Deg F	per Deg C × 10^{-6} Cond O	per Deg C × 10^{-6} Cond T6	per Deg F × 10^{-6} Cond O	per Deg F × 10^{-6} Cond T6
-60-20	-76-68	–	21.6	–	12.0
20-100	68-212	23.2	23.6	12.9	13.1
-200	-392	24.2	–	13.4	–
-300	-572	26.0	–	14.4	–
-400	-752	–	–	–	–
-500	-932	–	–	–	–

Thermal Conductivity

Cgs units at 77F 0.29 for T6

Mechanical Properties

Form or Condition	Test Temp[3]	Tensile Strength M psi	Yield Strength M psi	Elong 1/16 in. sheet %	Elong %	Hard BHN[1]	Shear S M psi	End Lt[2] M psi
Extrusions, O		40	20	–	12[4]	–	–	–
Extrusions, T6		88	80	–	10[4]	150	47	22.5
Other Bare Products, O		33	15	17	12[4]	–	–	–
Other Bare Products, T6		82	72	11	10[4]	150	–	–
Clad Sheet, O		32	14	16	–	–	–	–
Clad Sheet, T6		76	66	11	–	–	46	–
Effect of temp	75F	88	80	–	10	–	–	–
	300	25	22	–	32	–	–	–
	400	15	12	–	55	–	–	–
	500	12	8	–	60	–	–	–
	600	8.5	6	–	68	–	–	–
	700	6.5	5	–	75	–	–	–

[1]500 kg load, 10 mm ball [4]½ in. rd.
[2]Rotating beam at 5 × 10^8 cycles
[3]After long holding at test temp

Modulus of elasticity, E in M psi	10,400 (primary) 9,600 (secondary)
Modulus of rigidity, M psi	3,850
Poisson's ratio	0.33
Directional properties	Transverse and longitudinal properties approximately equal
Compressive YS	Same as tensile YS, approx
Torsional YS	0.55 times tensile YS, approx
Torsional TS	0.65 times tensile TS, approx

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Chemical Composition	%		%		%
Si	11.0/13.0	Mg	.10 max	Ni	.50 max
Fe	2.0 max	Mn	.30 max	Sn	.10 max
Cu	.60 max	Zn	.50 max	Others	.20 max

Al remainder

Characteristics. Excellent castability and good corrosion resistance.

Uses. Thin-walled and intricately designed castings.

Physical Properties
Density, at 68 F 0.096 lb/cu in. (2.66 S.G.)
Electrical resistivity, microhm/cm^3 at 68 F 4.421
Volume conductivity, % of Cu 39%
Specific heat, cal/gm at 212 F 0.23, approx

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	11.1	20.0
-392	-200	11.4	20.5
-572	-300	11.9	21.5

Technological Properties

Melting point	solidus 1065 F or 574 C liquidus 1085 F or 585 C
Castability	excellent
Weldability	good by flash welding
Soldering	plate with copper, then solder as for copper
Riveting	use 53S-T4; 53S-T6; 53S-T61

Thermal Conductivity
Cgs units at 77 F 0.37

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong ¼" round %	End Lt M psi
Die cast	37	18	1.8	15[1]

[1] Rotating beam at 50 × 10^7 cycles

Modulus of elasticity, E in M psi — 10,300
Modulus of rigidity, in M psi — 3,850
Poisson's ratio — 0.33

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Chemical Composition

	Si %	Fe %	Cu %	Mg %
Die Cast	4.5/6.0	2.00 max	.60 max	.10 max
Sand Cast	4.5/6.0	.80 max	.10 max	.05 max
Permanent mold	4.5/6.0	.80 max	.10 max	.05 max
	Mn %	**Zn %**	**Ti %**	**Others %**
Die Cast	.30 max	.50 max	–	.20 max
Sand Cast	.10 max	.20 max	.20 max	.10 max
Permanent mold	.10 max	.10 max	.20 max	.10 max

Physical Properties
Density, at 68 F 0.097 lb/cu in. (2.69 S.G.)
Electrical resistivity, microhm/cm^3 at 68 F 4.660 as cast; 4.105 annealed
Volume conductivity, in % of Cu 37% as cast; 42% annealed
Specific heat, cal/gm at 212 F 0.23, approx

Uses. Die castings which require above average ductility and excellent corrosion resistance. It is also used for sand and permanent mold castings for good castability and corrosion resistance with moderate strength, such as cooking utensils, food handling equipment, marine fittings, and thin-section castings.

Technological Properties

Melting point	solidus 1070 F or 577 C liquidus 1165 F or 629 C
Castability	very good
Weldability	good by fusion and resistance methods, but check welding manuals for details
Soldering	can be soldered
Brazing	can be brazed

Thermal Conductivity
Cgs units at 77 F
0.35 as cast
0.39 annealed

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	12.2	22.0
-392	-200	12.8	23.0
-572	-300	13.3	24.0

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong % ¼" diam	Elong % ½" diam	Hard, BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi
Die cast	30	14	7	–	–	–	–	–
Sand cast	19	9	–	6	40	14	6.5	10
Permanent mold cast	24	9	–	9	45	18	–	9

[1] 500 kg load, 10 mm ball
[2] Rotating beam at 50 × 10^7 cycles

Modulus of elasticity, E in M psi 10,300
Modulus of rigidity, in M psi 3,850
Poisson's ratio 0.33

ALUMINUM ALLOYS, CAST

85

Chemical Composition					
	%		%		%
Cu	3.5/4.5	Mg	.10 max	Ni	.50 max
Si	4.5/5.5	Mn	.30 max	Sn	.30 max
Fe	2.3 max	Zn	1.00 max	Others	.20 max

Technological Properties

Melting point	solidus 970 F or 521 C liquidus 1135 F or 613 C
Weldability	Good by flash welding
Soldering	Plate with copper, then solder as for copper
Riveting	Use 53S-T4; 53S-T6; 53S-T61

Characteristics. General purpose die-casting alloy which permits relatively large amounts of impurities.

Physical Properties
Density, at 68 F 0.101 lb/cu in. (2.78 S.G.)
Electrical resistivity, microhm/cm³ at 68 F 6.158
Volume conductivity, in % of Cu 28%
Specific heat, cal/gm at 212 F 0.23, approx

Mechanical Properties Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong ¼" diam %	End Lt M psi
Die cast	40	22	3.5	17[1]

[1] Rotating beam at 50 × 10⁷ cycles

Thermal Conductivity
Cgs units at 77 F 0.27

Modulus of elasticity, E in M psi 10,300
Modulus of rigidity, in M psi 3,850
Poisson's ratio 0.33

Coef. of Thermal Expansion Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	11.7	21
-392	-200	12.2	22
-572	-300	12.8	23

ALUMINUM ALLOYS, CAST

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Chemical Composition					
	%		%		%
Cu	3.5/4.5	Mg	.03 max	Ti	.20 max
Si	2.5/3.5	Mn	.30 max	Others	.30 max
Fe	1.00 max	Zn	.20 max		

Technological Properties

Melting point	solidus 970 F or 521 C liquidus 1170 F or 632 C
Weldability	Good with electric fusion and resistance methods
Soldering	Good
Brazing	Good
Riveting	Use A17S-T4; 17S-T4

Characteristics. Good castability, weldability, pressure tightness and moderate strength.

Uses. Manifolds, valve bodies, etc.

Physical Properties
Density, at 68 F 0.101 lb/cu in. (2.79 S.G.)
Electrical resistivity, micronm/cm³ at 68 F 5.562
Volume conductivity, in % of Cu 31%
Specific heat, cal/gm at 212 F 0.23, approx

Mechanical Properties Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong ½" round %	Hard BHN	Shear S M psi	End Lt M psi	Comp YS M psi
Sand cast	21	14	2.5	55.[1]	20	8[2]	14

[1] 500 kg load, 10 mm ball
[2] Rotating beam at 50 × 10⁷ cycles

Thermal Conductivity
Cgs units at 77 F 0.29

Modulus of elasticity, E in M psi 10,300
Modulus of rigidity, M psi 3,850
Poisson's ratio 0.33

Coef. of Thermal Expansion Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	12.2	22
-392	-200	12.8	23
-572	-300	13.3	24

ALUMINUM ALLOYS, CAST

Allcast

Chemical Composition

	%		%		%
Cu	2.5/3.5	Fe	1.2 max	Ni	.5 max
Si	4.5/6.0	Mg	.15 max	Zn	1.0 max
Ti	.2 max	Mn	.8 max	Others	1.0 max

Characteristics. A general-purpose alloy with good as-cast properties, which can also be improved by heat treatment.

Physical Properties
Density, at 68 F 0.100 lb/cu in. (2.76 S.G.)
Volume conductivity,
in % of Cu 27% as cast
30% stress relieved
30% quenched and aged
36% quenched and stress relieved

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	12.2	21.9

Mechanical Properties

Form or Condition	Yield Strength 2% M psi	Tensile Strength M psi	Elong ½" diam %	Hard Rock E	End Lt M psi	Comp YS M psi
Sand cast						
As cast	14	27	2.5	65	–	–
Stress relieved	18	29	2.0	67	–	19
Quenched and aged	20	35	4.0	80	10.5[1]	25
Quenched and stress relieved	23	37	2.5	81	–	30
Permanent mold cast						
As cast	18	35	3.0	80	–	–
Stress relieved	22	37	2.0	82	–	24
Quenched and aged	22	42	5.0	85	–	24
Quenched and stress relieved	23	42	3.0	86	–	24

[1]Rotating beam at 50 × 10^7 cycles

Thermal Conductivity
Cgs units at 68 F:
0.25 as cast
0.28 stress relieved
0.28 quenched and aged
0.33 quenched and stress relieved

Coef. of Thermal Expansion

Temp Range Deg C	per Deg C
20-100	21.9 x 10^{-6}
-200	–
-300	–
-400	–

ALUMINUM ALLOYS, CAST

A108

Chemical Composition

	%		%		%
Si	5.0/6.0	Mn	.30 max	Ti	.20 max
Cu	4.0/5.0	Mg	.10 max	Others	.50 max
Fe	1.00 max	Zn	.50 max		

Characteristics. Good castability, weldability, and soundness, and moderate strength.

Uses. Ornamental grilles, reflectors, and general-purpose castings.

Technological Properties

Melting point	solidus 960 F or 516 C
	liquidus 1140 F or 616 C
Weldability	Good with electric fusion and resistance methods
Soldering	Good
Brazing	Good
Riveting	Use A17S-T4; 17S-T4

Physical Properties
Density, at 68 F 0.101 lb/cu in. (2.79 S.G.)
Electrical resistivity,
microhm/cm^2 at 68 F 4.660
Volume conductivity, in % of Cu 37%
Specific heat, cal/gm at 212 F 0.23, approx

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong ½" round %	Hard BHN	Shear S M psi	Comp YS M psi
Permanent mold cast	28	16	2.0	70[1]	25	16

[1]500 kg load and 10 mm ball

Modulus of elasticity, E in M psi 10,300
Modulus of rigidity, M psi 3,850
Poisson's ratio 0.33

Thermal Conductivity
Cgs units at 77 F 0.34

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	11.9	21.5
-392	-200	12.5	22.5
-572	-300	12.8	23.0

ALUMINUM ALLOYS, CAST

113

Chemical Composition

%		%		%	
Cu	6.0/8.0	Fe	1.4 max	Ti	.20 max
Si	1.0/3.0	Mn	.50 max	Mg	.07 max
Zn	2.5 max	Ni	.30 max	Others	.50 max

Technological Properties

Melting point	solidus 975 F or 524 C liquidus 1165 F or 629 C
Weldability	Good with electric fusion and resistance methods
Soldering	Good
Brazing	Good
Riveting	Use A17S-T4; 17S-T4

Characteristics. Good castability, machinability, and pressure tightness.

Uses. Castings which must be dense.

Physical Properties
Density, at 68 F 0.105 lb/cu in. (2.91 S.G.)
Electrical resistivity,
microhm/cm³ at 68 F 5.747
Volume conductivity, in % of Cu 30%
Specific heat, cal/gm at 212 F 0.23, approx

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong ½" round %	Hard BHN	Shear S M psi	End Lt M psi	Comp YS M psi
Sand cast	24	15	1.5	70[1]	20	9[2]	17

[1] 500 kg load, 10 mm ball
[2] Rotating beam at 50 × 10⁷ cycles

Thermal Conductivity
Cgs units at 77 F 0.28

Modulus of elasticity, E in M psi 10,300
Modulus of rigidity, M in psi 3,850
Poisson's ratio 0.33

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	12.2	22.0
-392	-200	12.8	23.0
-572	-300	13.3	24.0

ALUMINUM ALLOYS, CAST

C113

Chemical Composition

%		%		%	
Cu	6.0/8.0	Mn	.30 max	Ti	.20 max
Si	4.0 max	Mg	.10 max	Others	1.00 max
Fe	1.4 max	Zn	2.5 max		

Technological Properties

Melting point	solidus 975 F or 524 C liquidus 1165 F or 629 C
Weldability	Good with electric fusion and resistance methods
Soldering	Good
Brazing	Good
Riveting	Use A17S-T4; 17S-T4

Physical Properties
Density, at 68 F 0.105 lb/cu in. (2.91 S.G.)
Electrical resistivity,
microhm/cm³ at 68 F 6.386
Volume conductivity, in % of Cu 27%
Specific heat, cal/gm at 212 F 0.23, approx

Mechanical Properties

Form or condition	Tensile Strength M psi	Yield Strength M psi	Elong ½" round %	Hard BHN	Shear S M psi	End Lt M psi	Comp YS M psi
Permanent mold cast	30	24	1	80[1]	22	9.5[2]	24

[1] 500 kg load and 10 mm ball
[2] Rotating beam at 50 × 10⁷ cycles

Thermal Conductivity
Cgs units at 77 F 0.26

Modulus of elasticity, E in M psi 10,300
Modulus of rigidity, M in psi 3,850
Poisson's ratio 0.33

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	12.2	22.0
-392	-200	12.8	23.0
-572	-300	13.3	24.0

Chemical Composition

	Cu %	Mg %	Fe[1] %	Si %	Mn %
Sand Cast	9.2/10.8	.15/.35	1.5 max	2.0 max[1]	.10 max
Permanent mold cast	9.2/10.7	.15/.35	1.5 max	1.00 max	.30 max

	Zn %	Ni %	Ti %	Others %
Sand Cast	.10 max	–	.20 max	.10 max
Permanent mold cast	.40 max	.30 max	.20 max	.30 max

[1]Fe & Si

Characteristics. Good high-temperature strength, high hardness and resistance to wear, and good machinability.

Uses. For air-cooled cylinder heads, automotive pistons, bushings, and tappet guide clusters.

Physical Properties

Density, at 68 F 0.105 lb/cu in. (2.95 S.G.)

Electrical resistivity, microhm/cm[3] at 20 C: 4.205, sand cast, T2; 5.225, sand cast, T61; 5.071, perm. mold, as cast

Volume conductivity, % of Cu: 41%, sand cast, T2; 33%, sand cast, T61; 34%, perm. mold, as cast

Specific heat, cal/gm at 212 F 0.23, approx

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	12.2	22.0
-392	-200	12.8	23.0
-572	-300	13.0	23.5

Thermal Conductivity

Cgs units at 77 F

0.38 sand cast, T2

0.31 sand cast, T61

0.32 perm. mold, as cast

Technological Properties

Melting point	solidus 1005 F or 541 C
	liquidus 1160 F or 627 C
Annealing temp, T2[1]	595-605 F or 313-318 C
Solution temp[6]	945-955 F or 507-513 C, WQ
Sand castings, precipitation temp following solution treatment, T61[2]	305-315 F or 152-157 C
Permanent mold castings, precipitation temp, T52[3]	305-315 F or 152-157 C
Permanent mold castings, precipitation temp, T551[4]	335-345 F or 168-174 C
Permanent mold castings, precipitation temp for solution heat-treated material, T65[5]	335-345 F or 168-174 C
Weldability	Good with electric fusion and resistance methods
Soldering	Good
Riveting	Use A17S-T4; 17S-T4

[1]2 to 4 hrs, quench not critical
[2]10 to 14 hrs, quench not critical
[3]5 to 7 hrs, quench not critical
[4]18 to 22 hrs, quench not critical
[5]7 to 9 hrs, quench not critical
[6]12 hrs, water at 150-212F

Mechanical Properties

Form or Condition	Test Temp[3]	Tensile Strength M psi	Yield Strength M psi	Elong ½" round %	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi
Sand cast								
T2, Annealed		27	20	1.0	80	21	9.5	20
T2, Effect of temp	75	27	20	1.0	–	–	–	–
	300	25	17	1.0	–	–	–	–
	400	22	14	1.5	–	–	–	–
	500	17	11	3.0	–	–	–	–
	600	8	4.5	14.0	–	–	–	–
T61, Heat treatment		40	30	<0.5	115	29	8.5	43
T61, Effect of temp	75	40	30	0.5	–	–	–	–
	300	35	30	1.0	–	–	–	–
	400	22	16	2.0	–	–	–	–
	500	10	5	6.0	–	–	–	–
	600	8	4.5	14.0	–	–	–	–
Permanent mold cast								
T52, Heat treatment		35	31	1.0	100	25	–	31
T551, Heat treatment		37	35	<0.5	115	27	8.5	40
T551, Effect of temp	75	37	35	0.5	–	–	–	–
	300	33	29	0.5	–	–	–	–
	400	26	20	1.0	–	–	–	–
	500	18	12.5	3.0	–	–	–	–
	600	10	6	10.0	–	–	–	–
T65, Heat treatment		48	36	<0.5	140	30	9	36

[1]500 kg load, 10 mm ball
[2]Rotating beam at 50 × 10^7 cycles
[3]After long holding at test temp

Modulus of elasticity, E in M psi	10,300
Modulus of rigidity, in M psi	3,850
Poisson's ratio	0.33

ALUMINUM ALLOYS, CAST

A132

Chemical Composition					
	%		%		%
Si	11.0/13.0	Ni	2.0/3.0	Zn	.10 max
Cu	.5/1.5	Fe	1.3 max	Ti	.20 max
Mg	.70/1.3	Mn	.10 max	Others	.20 max

Technological Properties

Melting point	solidus	1000 F or 538 C
	liquidus	1095 F or 591 C
Precipitation temp as cast, T551[1]		335-345 F or 168-174 C
Solution temp[2]		955-965 F or 513-518 C, WQ
Precipitation temp after solution heat treatment, T65[3]		335-345 F or 168-174 C
Weldability	Good with electric fusion and resistance methods	
Soldering	Good	
Riveting	Use 53S-T4; 53S-T6; 53S-T61	

[1]14 to 18 hrs, quench not critical
[2]8 hrs, water at 150-212F
[3]12 to 16 hrs, quench not critical

Characteristics. Good high-temperature strength, relatively low expansion, and good wear resistance.

Uses. Automotive and Diesel pistons, pulleys and sheaves.

Physical Properties
Density, at 68 F 0.097 lb/cu in. (2.68 S.G.)
Electrical resistivity, microhm/cm[3] at 68 F 5.945 for T551
Volume conductivity, in % of Cu 29% for T551
Specific heat, in cal/gm at 212F 0.23, approx

Mechanical Properties

Form or Condition	Test Temp[2]	Tensile Strength M psi	Yield Strength M psi	Elong ½" round %	Hard BHN[1]	Shear S M psi	Comp YS M psi
Permanent mold cast							
T551		36	28	0.5	105	24	30
T551, Effect of temp	75	36	28	0.5	–	–	–
	300	31	22	1.0	–	–	–
	400	23	13.5	2.0	–	–	–
	500	17.5	9.5	2.0	–	–	–
	600	11	5	8.0	–	–	–
T65		47	–	0.5	125	27	–

[1]500 kg load, 10 mm ball
[2]After long holding at test temp

Thermal Conductivity
Cgs units at 77 F 0.28 for T551

Modulus of elasticity, E in M psi 10,300
Modulus of rigidity, in M psi 3,850
Poisson's ratio 0.33

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	10.6	19.0
-392	-200	11.1	20.0
-572	-300	11.7	21.0

ALUMINUM ALLOYS, CAST

Red X-13

Chemical Composition					
	%		%		%
Cu	1.0/2.0	Si	11.0/13.0	Ni	.05 max
Mg	.4/1.0	Ti	.2 max	Zn	.4 max
Mn	.5/.9	Fe	.9 max	Others	.5 max

Technological Properties
Treatment for pistons Heat 8 hr at 400 F for dimensional stability

Characteristics. Combines high strength at elevated temperatures with a relatively low coefficient of expansion.

Uses. For pistons for internal combustion engines.

Physical Properties
Density, at 68 F 0.098 lb/cu in. (2.7 S.G.)

Thermal Conductivity
Cgs units at 77 F 0.33 for T4
0.35 for T62

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	11.2	20.1
-392	-200	11.6	20.8
-572	-300	12.0	21.7
-752	-400	12.4	22.3

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength .2% M psi	Elong ½" round %	Hardness Rock E	BHN[1]
Permanent mold cast					
Stress relieved	36	–	0.5	92	100
Treated 8 hr at 400 F	40	–	–	97	115
Solution heat treated, aged	43	38	1.0	92	100

[1]500 kg load, 10 mm ball

Chemical Composition

	Cu %	Mg %	Ni %	Fe %	Si %
Sand Cast	3.5/4.5	1.2/1.8	1.7/2.3	1.00 max	.80 max
Permanent mold	3.5/4.5	1.2/1.8	1.7/2.3	1.00 max	.70 max

	Mn %	Zn %	Ti %	Others %
Sand Cast	.10 max	.03 max	.20 max	.30 max
Permanent mold	.30 max	.10 max	.20 max	.30 max

Characteristics. Excellent high-temperature strength.

Uses. Motorcycle, Diesel and aircraft pistons, air-cooled cylinder heads, aircraft generator housings, etc.

Physical Properties

Density, at 68 F 0.101 lb/cu in. (2.81 S.G.)

Electrical resistivity, microhm/cm^3 at 68 F
- 3.918, sand cast, T21
- 5.071, sand cast, T571
- 4.660, sand cast, T77
- 5.338, perm. mold cast, T61

Volume conductivity, % of Cu
- 44%, sand cast, T21
- 34%, sand cast, T571
- 37%, sand cast, T77
- 32%, perm. mold cast, T61

Specific heat, cal/gm at 212 F 0.23, approx.

Thermal Conductivity

Cgs units at 77 F
- 0.40 sand cast, T21
- 0.32 sand cast, T571
- 0.36 sand cast, T77
- 0.31 perm. mold, T61

Coef. of Thermal Expansion

Temp Range Deg F	Temp Range Deg C	Coefficient × 10^{-6} per Deg F	Coefficient × 10^{-6} per Deg C
68-212	20-100	12.5	22.5
-392	-200	13.0	23.5
-572	-300	13.6	24.5

Technological Properties

Melting point solidus 995 F or 535 C
liquidus 1165 F or 629 C

Sand Castings

Annealing temp, T21[1]	645-655 F or 341-346 C
Precipitation temp, as cast, T571[2]	335-345 F or 168-174 C
Solution temp[3]	965-975 F or 518-524 C, AC
Precipitation temp, after solution treatment, T77[4]	645-655 F or 341-346 C

Permanent Mold Castings

Precipitation temp, as cast, T571[5]	335-345 F or 168-174 C
Solution temp[6]	955-965 F or 513-518 C, WQ
Precipitation temp, after solution treatment, T61[7]	395-405 F or 202-207 C
Weldability	Good with electric fusion and resistance methods
Soldering	Good
Riveting	Use A 17S-T4; 17S-T4

[1] 2 to 4 hrs, quench not critical
[2] 40 to 48 hrs, quench not critical
[3] 6 hrs, still air
[4] 1 to 3 hrs, quench not critical
[5] 40 to 48 hrs, quench not critical
[6] 4 hrs, water at 150-212F
[7] 3 to 5 hrs, quench not critical

Mechanical Properties

Form or Condition	Test Temp[2]	Tensile Strength M psi	Yield Strength M psi	Elong ½" round %	Hard BHN[1]	Shear S M psi	End Lt M psi[3]	Comp YS M psi
Sand cast								
T21		27	18	1.0	70	21	6.5	18
T21, Effect of temp	75	27	18	1.0	–	–	–	–
	300	27	18	1.0	–	–	–	–
	400	21	14	1.5	–	–	–	–
	500	16	8	3.0	–	–	–	–
	600	8	4	9.0	–	–	–	–
T571		32	28	0.5	85	27	8	34
T77		28	25	2.0	75	24	9.5	–
Permanent mold cast								
T571		40	34	1.0	105	26	10.5	34
T571, Effect of temp	75	40	34	1.0	–	–	–	–
	300	37	33	1.0	–	–	–	–
	400	28	22	2.0	–	–	–	–
	500	15	9	10.0	–	–	–	–
	600	9	5	30.0	–	–	–	–
T61		47	42	0.5	110	31	9.5	46

[1] 500 kg load, 10 mm ball
[2] After long holding at test temp
[3] Rotating beam at 50 × 10^7 cycles

Modulus of elasticity, E in M psi	10,300
Modulus of rigidity, in M psi	3,850
Poisson's ratio	0.33

ALUMINUM ALLOYS, CAST

195

Chemical Composition

%		%		%	
Cu	4.0/5.0	Mg	.03 max	Others	.10 max
Fe	1.0 max	Zn	.10 max		
Si	1.20 max	Ti	.20 max		

Characteristics. Combines high tensile properties with good machinability.

Uses. Flywheel housings, rear axle housings, bus wheels, aircraft wheels, crankcases and fittings.

Technological Properties

Melting point solidus	1020 F or 549 C
liquidus	1195 F or 646 C
Solution temp, T4[1]	955-965 F or 513-518 C, WQ
Precipitation temp for solution treated material, T6[2]	305-315 F or 152-157 C[1]
Precipitation temp for solution-treated material, T62[3]	305-315 F or 152-157 C[1]
Weldability	Good by fusion and electric resistance methods
Soldering	Good
Riveting	Use A17S-T4; 17S-T4

[1]12 hrs, water at 150-212F
[2]3 to 5 hrs, quench not critical
[3]12 to 16 hrs, quench not critical

Mechanical Properties

Form or Condition	Test Temp[3]	Tensile Strength M psi	Yield Strength M psi	Elong ½" round %	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi
Sand cast								
T4		32	16	8.5	60	24	6	16
T4, Effect of temp	75	32	16	8.5	–	–	–	–
	300	24	13	9.0	–	–	–	–
	400	15	9	20.0	–	–	–	–
	500	9.5	6	25.0	–	–	–	–
	600	4	3	80.0	–	–	–	–
T6		36	24	5.0	75	30	6.5	25
T6, Effect of temp	75	36	24	5.0	–	–	–	–
	300	24	13	9.0	–	–	–	–
	400	15	9	20.0	–	–	–	–
	500	9.5	6	25.0	–	–	–	–
	600	4	3	80.0	–	–	–	–
T62		40	30	2.0	95	31	7	38

[1]500 kg load, 10 mm ball
[2]Rotating beam at 50 × 10^7 cycles
[3]After long holding at test temp

Physical Properties
Density, at 68F 0.101 lb/cu in. (2.81 S.G.)
Electrical resistivity, microhm/cm[3] at 68F 4.926 for T4; 4.660 for T62
Volume conductivity, in % of Cu 35% for T4; 37% for T62
Specific heat, cal/gm at 212F 0.23, approx.

Thermal Conductivity
Cgs units at 77F 0.33 for T4
0.35 for T62

Modulus of elasticity, E in M psi	10,300
Modulus of rigidity, M psi	3,850
Poisson's ratio	0.33

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	12.8	23.0
-392	-200	13.3	24.0
-572	-300	13.9	25.0

ALUMINUM ALLOYS, CAST

218

Chemical Composition

%		%		%	
Mg	7.5/8.5	Si	.30 max	Ni	.10 max
Fe	1.8 max	Mn	.30 max	Sn	.10 max
Cu	.20 max	Zn	.10 max	Others	.20 max

Technological Properties

Melting point solidus	1005 F or 541 C
liquidus	1150 F or 621 C
Weldability	Good by flash welding
Soldering	Good after copper plating
Riveting	Use 53S-T4; 53S-T6; 53S-T61

Uses. 218 is used where exceptional mechanical properties, corrosion resistance, and finishing characteristics are required, such as marine and aircraft fittings.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong ¼" round %	End Lt M psi[1]
Die cast	42	23	7.0	18

[1]For rotating beam at 50 × 10^7 cycles

Physical Properties
Density, at 68 F 0.091 lb/cu in. (2.53 S.G.)
Electrical resistivity, microhm/cm[3] at 68 F 7.184
Volume conductivity, in % of Cu 24%
Specific heat, in cal/gm at 212 F 0.23, approx

Modulus of elasticity, E in M psi	10,300
Modulus of rigidity, in M psi	3,850
Poisson's ratio	0.33

Thermal Conductivity
Cgs units at 77 F 0.24

355

Chemical Composition	Si %	Cu %	Mg %	Fe %
Sand Cast	4.5/5.5	1.00/1.5	.40/.60	.60 max
Permanent mold cast	4.5/5.5	1.00/1.5	.40/.60	.60 max

	Mn %	Zn %	Ti %	Others %
Sand Cast	.10 max	.10 max	.20 max	.10 max
Permanent mold cast	.10 max	.10 max	.20 max	.10 max

Characteristics. Good castability, weldability, and pressure tightness.

Uses. Aircraft supercharger covers, fuel pump bodies, air compressor pistons, liquid cooled cylinder heads, liquid cooled aircraft engine crankcases, water jackets and blower housings.

Physical Properties

Density, at 68 F 0.098 lb/cu in. (2.70 S.G.)

Electrical resistivity, microhm/cm^3 at 68 F
- 4.010, sand cast, T51
- 4.789, sand cast, T6
- 4.660, sand cast, T61
- 4.105, sand cast, T7
- 4.421, perm. mold cast, T6

Volume conductivity, in % of Cu
- 43%, sand cast, T51
- 36%, sand cast, T6
- 37%, sand cast, T61
- 42%, sand cast, T7
- 39%, perm. mold cast, T6

Specific heat, cal/gm at 212 F 0.23, approx

Thermal Conductivity

Cgs units at 77 F
- 0.40, sand cast, T51
- 0.34, sand cast, T6
- 0.35, sand cast, T61
- 0.39, sand cast, T7
- 0.36, perm. mold cast, T6

Coef. of Thermal Expansion			
Temp Range Deg F	Temp Range Deg C	Coefficient × 10^{-6} per Deg F	Coefficient × 10^{-6} per Deg C
68-212	20-100	12.2	22.0
-392	-200	12.8	23.0
-572	-300	13.3	24.0

Technological Properties

Melting point solidus 1075 F or 580 C
liquidus 1160 F or 625 C

Heat treatment

Sand Castings

Precipitation temp,[1] T51[3] 435-445 F or 224-230 C
Solution temp[4] 975-985 F or 524-529 C, WQ
Precipitation temp,[2] T6[5] 305-315 F or 152-157 C
Precipitation temp,[2] T61[6] 305-315 F or 152-157 C
Precipitation temp,[2] T7[7] 435-445 F or 224-230 C
Precipitation temp,[2] T71[8] 470-480 F or 243-249 C

Permanent Mold Castings

Precipitation temp,[1] T51[9] 435-445 F or 224-230 C
Solution temp[10] 975-985 F or 524-529 C, WQ
Precipitation temp,[2] T6[11] 305-315 F or 152-157 C
Precipitation temp,[2] T62[12] 335-345 F or 168-174 C
Precipitation temp,[2] T7[13] 435-445 F or 224-230 C
Precipitation temp,[2] T71[14] 470-480 F or 243-249 C

Weldability: Good with fusion and electric resistance methods
Soldering: Good
Brazing: Good
Riveting: Use 53S-T4; 53S-T6; 53S-T61

[1] Start with material as cast
[2] Start with solution-treated material
[3] 7 to 9 hrs, quench not critical
[4] 12 hrs, water at 150-212F
[5] 3 to 5 hrs, quench not critical
[6] 8 to 10 hrs, quench not critical
[7] 7 to 9 hrs, quench not critical
[8] 4 to 6 hrs, quench not critical
[9] 7 to 9 hrs, quench not critical
[10] 8 hrs, water at 150-212F
[11] 3 to 5 hrs, quench not critical
[12] 14 to 18 hrs, quench not critical
[13] 7 to 9 hrs, quench not critical
[14] 4 to 6 hrs, quench not critical

Mechanical Properties

Form or Condition	Test Temp[3]	Tensile Strength M psi	Yield Strength M psi	Elong ½" round %	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi
Sand cast								
T51		28	23	1.5	65	22	7	24
T51, Effect of temp	75	28	23	1.5	–	–	–	–
	300	22	17	2.5	–	–	–	–
	400	13	9	12.0	–	–	–	–
	500	8	5	22.0	–	–	–	–
	600	6	3.5	30.0	–	–	–	–
T6		35	25	2.5	80	30	8.5	29
T6, Effect of temp	75	35	25	2.5	–	–	–	–
	300	30	25	1.5	–	–	–	–
	400	13	9	12.0	–	–	–	–
	500	8	5	22.0	–	–	–	–
	600	6	3.5	30.0	–	–	–	–
T61		39	35	1.0	90	32	–	37
T7		38	36	0.5	85	26	8.5	35
T71		35	29	1.5	75	–	10	–
Permanent mold cast								
T51		30	24	2.0	75	24	–	24
T6		43	27	4.0	90	30	9	26
T6, Effect of temp	75	43	27	4.0	–	–	–	–
	300	33	29	2.0	–	–	–	–
	400	12	9	20.0	–	–	–	–
	500	8	6	25.0	–	–	–	–
	600	4.5	3	50.0	–	–	–	–
T62		45	40	1.5	105	36	–	–
T7		40	30	2.0	85	30	–	–
T71		36	31	3.0	85	26	–	–

[1] 500 kg load, 10 mm ball
[2] Rotating beam at 50 × 10^7 cycles
[3] After long holding at test temp

Modulus of elasticity, E in M psi - 10,300
Modulus of rigidity, in M psi 3,850
Poisson's ratio 0.33

ALUMINUM ALLOYS, CAST

A214

Chemical Composition			
%	%	%
Mg 3.5/4.3	Si .30 max	Others .05 max[1]
Zn 1.4/2.2	Fe .40 max	
Cu .10 max	Mn .30 max	

[1]Each element

Technological Properties

Melting point	solidus 1050 F or 566 C
	liquidus 1180 F or 638 C
Weldability	Good with electric fusion and resistance methods
Soldering	Good
Brazing	Good
Riveting	Use 53S-T4; 53S-T6; 53S-T61

Characteristics. Good resistance to corrosion and tarnishing.

Uses. Typical use is for cooking utensils.

Physical Properties

Density, at 68 F 0.096 lb/cu in. (2.65 S.G.)
Electrical resistivity, microhm/cm³ at 68 F 5.225
Volume conductivity, in % of Cu 33%
Specific heat, cal/gm at 212 F 0.23, approx

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong ½" round %	Hard BHN[1]	Shear S M psi	Comp YS M psi
Permanent mold cast	27	16	7.0	60	22	17

[1]500 kg load, 10 mm ball

Thermal Conductivity

Cgs units at 77 F 0.31

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	13.3	24.0
-392	-200	13.9	25.0
-572	-300	14.4	26.0

Modulus of elasticity, E in M psi 10,300
Modulus of rigidity, in M psi 3,850
Poisson's ratio 0.33

ALUMINUM ALLOYS, CAST

214

Chemical Composition		
%	%	%
Mg 3.2/4.3	Si .30 max	Ti .20 max
Cu .10 max	Mn .60 max	Others .10 max
Fe .60 max	Zn .10 max	

Technological Properties

Melting point	solidus 1075 F or 579 C
	liquidus 1185 F or 641 C
Weldability	Good with fusion and electric resistance methods
Soldering	Good
Brazing	Good
Riveting	Use 53S-T4; 53S-T6; 53S-T61

Characteristics. Moderate strength, but excellent resistance to corrosion and tarnishing.

Uses. For dairy and food handling equipment, cooking utensils, fittings for chemical and sewage equipment.

Physical Properties

Density, at 68 F 0.096 lb/cu in. (2.65 S.G.)
Electrical resistivity, microhm/cm³ at 68 F 4.926
Volume conductivity, in % of Cu 35%
Specific heat, cal/gm at 212 F 0.23, approx

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	13.3	24.0
-392	-200	13.9	25.0
-572	-300	14.4	26.0

Mechanical Properties

Form or Condition	Test Temp[3]	Tensile Strength M psi	Yield Strength M psi	Elong ½" round %	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi
Sand cast		25	12	9.0	50	20	5.5	12
Effect of temp	75	25	12	9.0	–	–	–	–
	300	23	15	7.0	–	–	–	–
	400	18.5	12.5	9.0	–	–	–	–
	500	13.5	8	12.0	–	–	–	–
	600	9	4	17.0	–	–	–	–

[1]500 kg load, 10 mm ball
[2]Rotating beam at 50 × 10^7 cycles
[3]After long holding at test temp

Thermal Conductivity

Cgs units at 77 F 0.33

Modulus of elasticity, E in M psi 10,300
Modulus of rigidity, in M psi 3,850
Poisson's ratio 0.33

Red X-8

Chemical Composition					
	%		%		%
Cu	1.0/2.0	Ti	.3 max	Cr	.3 max
Mg	.20/.60	Fe	1.0 max	Others	.5 max
Mn	.20/.60	Ni	.2 max		
Si	7.0/8.6	Zn	.5 max		

Characteristics. General-purpose, heat-treatable alloy with good high-temperature properties.

Uses. For parts for internal combustion engines, etc., which are highly stressed at elevated temperatures.

Physical Properties
Density, at 68 F 0.099 lb/cu in. (2.73 S.G.)
Volume conductivity,
in % of Cu 26%, as cast
29%, stress relieved

Coef. of Thermal Expansion

Temp Range Deg F	Temp Range Deg C	Coefficient $\times 10^{-6}$ per Deg F	Coefficient $\times 10^{-6}$ per Deg C
68-212	20-100	11.9	21.4

Thermal Conductivity
Cgs units at 68 F 0.24, as cast
0.24, stress relieved

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi[2]	Elong ½" round %	Rockwell E Hardness
Sand cast					
Stress relieved[1]		30	21	1.5	76
Stress relieved, Effect of temp	75	31	–	1.5	81
	200	30	–	1.5	84
	300	27	–	2.0	80
	400	23	–	3.0	80
	500	19	–	3.5	78
	600	13	–	7.0	71
Solution treated, aged		39	30	1.5	88
Solution treated, aged, Effect of temp	75	38	–	2.5	88
	200	36	–	2.5	89
	300	34	–	3.0	88
	400	31	–	3.5	92
	500	20	–	5.5	83
	600	11	–	13	68
Solution treated, stress relieved		36	28	2.0	82
Permanent mold cast					
Stress relieved[1]		36	–	1.0	88
Stress relieved, Effect of temp	75	41	–	2.0	89
	200	39	–	2.5	89
	300	34	–	3.0	88
	400	28	–	4.5	88
	500	22	–	6.5	85
	600	14	–	14	75
Solution treated, aged		44	27	4.0	91
Solution treated, aged, Effect of temp	75	45	–	4.5	92
	200	43	–	5.0	92
	300	39	–	6.0	92
	400	33	–	6.5	95
	500	23	–	11	87
	600	11	–	23	71
Solution treated, stress relieved		41	28	3.0	88

[1] Castings heated 5 hr at 450 F for dimensional stability.
[2] .2%

ALUMINUM ALLOYS, CAST

356

Chemical Composition					
	%		%		%
Si	6.5/7.5	Fe	.60 max	Ti	.20 max
Mg	.20/.40	Mn	.10 max	Others	.10 max
Cu	.20 max	Zn	.10 max		

Technological Properties

Melting point solidus 1075 F or 580 C
liquidus 1130 F or 610 C

Heat treatment

Sand Castings

Precipitation temp,[1] T51[3] 435-445 F or 224-230 C
Solution temp[4] 995-1005 F or 535-541 C, WQ
Precipitation temp, [2]T6[5] 305-315 F or 152-158 C
Precipitation temp, [2]T7[6] 435-445 F or 224-230 C
Precipitation temp, [2]T71[7] 470-480 F or 243-249 C

Permanent Mold Castings

Solution temp[8] 995-1005 F or 535-541 C, WQ
Precipitation temp, [2]T6[9] 305-315 F or 152-157 C
Precipitation temp, [2]T7[10] 435-445 F or 224-230 C

Weldability: Good with fusion and electric resistance methods
Soldering: Good
Brazing: Good
Riveting: Use 53S-T4; 53S-T6; 53S-T61

[1]No solution treatment
[2]Start with solution-treated material
[3]7 to 9 hrs, quench not critical
[4]12 hrs, water at 150-212F
[5]2 to 5 hrs, quench not critical
[6]7 to 9 hrs, quench not critical
[7]2 to 4 hrs, quench not critical
[8]8 hrs, water at 150-212F
[9]3 to 5 hrs, quench not critical
[10]7 to 9 hrs, quench not critical

Physical Properties

Density, at 68 F 0.097 lb/cu in. (2.68 S.G.)

Electrical resistivity, microhm/cm^3 at 68F
4.010, sand cast, T51
4.421, sand cast, T6
4.310, sand cast, T7
4.205, perm. mold cast, T6

Volume conductivity, in % of Cu
43%, sand cast, T51
39%, sand cast, T6
40%, sand cast, T7
41%, perm. mold cast, T6

Specific heat, in cal/gm at 212 F 0.23, approx

Thermal Conductivity

Cgs units at 77 F
0.40, sand cast, T51
0.36, sand cast, T6
0.37, sand cast, T7
0.38, perm. mold cast, T6

Coef. of Thermal Expansion

Temp Range Deg F	Temp Range Deg C	Coefficient × 10^{-6} per Deg F	Coefficient × 10^{-6} per Deg C
68-212	20-100	11.9	21.5
-392	-200	12.8	23.0
-572	-300	13.0	23.5

Mechanical Properties

Form or Condition	Test Temp[3]	Tensile Strength M psi	Yield Strength M psi	Elong ½" round %	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi
Sand cast								
T51		25	20	2.0	60	18	7.5	22
T6		33	24	4.0	70	27	8	22
T6, Effect of temp	75	33	24	4.0	–	–	–	–
	300	21	16	5.0	–	–	–	–
	400	13	9	8.0	–	–	–	–
	500	8	5.5	20.0	–	–	–	–
	600	4.5	3	45.0	–	–	–	–
T7		34	30	2.0	75	18	–	29
T71		28	21	4.5	60	16	–	–
Permanent mold cast								
T6		40	27	5.0	90	–	–	24
T7		33	–	5.0	70	–	–	–

[1]500 kg load, 10 mm ball
[2]Rotating beam at 50 × 10^7 cycles
[3]After long holding at test temp

Modulus of elasticity, E in M psi 10,300
Modulus of rigidity, in M psi 3,850
Poisson's ratio 0.33

ALUMINUM ALLOYS, CAST

220

Chemical Composition					
	%		%		%
Mg	9.5/10.6	Si	.20 max	Others	.15 max
Cu	.20 max	Mn	.10 max		
Fe	.30 max	Zn	.10 max		

Technological Properties
Melting point solidus 840 F or 500 C
liquidus 1150 F or 620 C
Weldability Good with electric resistance methods
Soldering Good
Riveting Use 53S-T4; 53S-T6; *53S-T61

Characteristics. 220 has the best tensile properties of the sand cast alloys, as well as excellent machinability and corrosion resistance.

Uses. Aircraft fittings, railroad passenger car frames, and miscellaneous castings which must be strong and resistant to shock loads.

Physical Properties
Density, at 68 F 0.093 lb/cu in. (2.58 S.G.)
Electrical resistivity, microhm/cm³ at 68 F 8.210 for T4
Volume conductivity, in % of Cu 21% for T4
Specific heat, cal/gm at 212 F 0.23, approx

Mechanical Properties

Form or Condition	Test Temp[3]	Tensile Strength M psi	Yield Strength M psi	Elong ½" round %	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi
Sand cast								
T 4		46	25	14	75	33	7	26
T 4, Effect of temp	75	46	25	14	–	–	–	–
	300	35	19	16	–	–	–	–
	400	22	11.5	40	–	–	–	–
	500	15	7.5	55	–	–	–	–
	600	10.5	3	70	–	–	–	–

[1] 500 kg load, 10 mm ball
[2] Rotating beam at 50 × 10⁷ cycles
[3] After long holding at test temp

Thermal Conductivity
Cgs units at 77 F 0.21 for T4

Modulus of elasticity, E in M psi 10,300
Modulus of rigidity, in M psi 3,850
Poisson's ratio 0.33

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	13.6	24.5
-392	-200	14.2	25.5
-572	-300	14.7	26.5

ALUMINUM ALLOYS, CAST

360

Chemical Composition					
	%		%		%
Si	9.0/10.0	Cu	.60 max	Ni	.50 max
Mg	.40/.60	Mn	.30 max	Sn	.10 max
Fe	2.0 max	Zn	.50 max	Others	.20 max

Physical Properties
Density, at 68 F 0.097 lb/cu in. (2.68 S.G.)
Electrical resistivity, microhm/cm³ at 68 F 4.660
Volume conductivity, in % of Cu 37%
Specific heat, cal/gm at 212 F 0.23, approx

Characteristics. Excellent castability and resistance to corrosion.

Uses. For thin-walled and intricate castings.

Technological Properties
Melting point solidus 1050 F or 565 C
liquidus 1095 F or 590 C
Weldability Good by flash welding
Soldering Good after copper plating
Riveting Use 53S-T4; 53S-T6; 53S-T61

Thermal Conductivity
Cgs units at 77 F 0.35

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong ¼" round %
Die cast	42	23	1.8

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	10.8	19.5
-392	-200	11.4	20.5
-572	-300	11.9	21.5

Modulus of elasticity, E in M psi 10,300

ALUMINUM ALLOYS, CAST

40E

Chemical Composition

	%		%		%
Zn	5.0/6.0	Ti	.10/.30	Si	.25 max
Mg	.50/.65	Cu	.30 max	Mn	.30 max
Cr	.40/.60	Fe	1.00 max	Others	.05 max[1]

[1] Each element

Technological Properties

Melting point solidus	1060 F or 572 C
liquidus	1140 F or 760 C
Precipitation temp	356 F or 180 C (or 21 days aging at room temp)
Weldability	Good by oxyacetylene or elec. resistance methods
Soldering	Good
Brazing	Good

Characteristics. 40E gives a good combination of mechanical properties without heat treatment and has good resistance to shock and corrosion, machinability, dimensional stability, and freedom from distortion caused by heat treatment.

Uses. Stressed parts of airplanes, turret housings, air compressor pistons, instrument parts, and machine parts subjected to shock.

Physical Properties

Density, at 77 F 0.101 lb/cu in. (2.81 S.G.)
Electrical resistivity, microhm/cm^3 at 68 F 4.926
Volume conductivity, in % of Cu 35%
Specific heat, cal/gm at 212 F 0.23, approx

Thermal Conductivity

Cgs units at 77 F 0.33

Coef. of Thermal Expansion

Temp Range Deg F	Temp Range Deg C	Coefficient × 10^{-6} per Deg F	Coefficient × 10^{-6} per Deg C
68-199	21-93	13.7	24.7

Mechanical Properties

Form or Condition	Test Temp[3]	Tensile Strength M psi	Yield Strength M psi	Elong ½" round %	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp PL M psi
Sand cast		35	25	5	80	28	9	14
Effect of temp	175 F	33.8	30.7	3	–	–	–	–
	250	29.5	25.2	2	–	–	–	–
	350	19.7	17	6	–	–	–	–

[1] 500 kg load, 10 mm ball
[2] Rotating beam at 50 × 10^7 cycles
[3] After 1000 hr at test temp

Modulus of elasticity, E in M psi 10,300
Poisson's ratio 0.33

ALUMINUM ALLOYS, CAST

B195

Chemical Composition					
	%		%		%
Cu	4.0/5.0	Mn	.30 max	Ti	.20 max
Si	2.0/3.0	Mg	.05 max	Others	.30 max
Fe	1.00 max	Zn	.20 max		

Characteristics. Combines relatively high strength and good machinability.

Uses. Aircraft fittings, aircraft gun control parts, aircraft wheels, railroad car seat frames, and fuel pump bodies.

Technological Properties

Melting point solidus	980 F or 527 C
liquidus	1160 F or 627 C
Solution temp, T4[1]	945-955 F or 507-513 C, WQ
Precipitation temp for solution-treated material, T6[2]	305-315 F or 152-157 C
Precipitation temp for solution-treated material, T7[3]	495-505 F or 257-263 C
Weldability	Good by fusion and electric resistance methods
Soldering	Good
Riveting	Use A17S-T4; 17S-T4

[1]8 hrs, water at 150-212F
[2]5-7 hrs, quench not critical
[3]5-7 hrs, quench not critical

Physical Properties
Density, at 68 F 0.101 lb/cu in. (2.78 S.G.)
Electrical resistivity, microhm/cm[3] at 68 F 4.926 for T4; 4.789 for T6
Volume conductivity, in % of Cu 35% for T4; 36% for T6
Specific heat, in cal/gm at 212 F 0.23, approx

Coef. of Thermal Expansion

Temp Range Deg F	Temp Range Deg C	Coefficient × 10^{-6} per Deg F	Coefficient × 10^{-6} per Deg C
68-212	20-100	12.2	22
-392	-200	12.8	23
-572	-300	13.3	24

Thermal Conductivity
Cgs units at 77 F 0.33 for T4
0.34 for T6

Mechanical Properties

Form or Condition	Test Temp[3]	Tensile Strength M psi	Yield Strength M psi	Elong ½" round %	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi
Permanent mold cast								
T4		40	22	10.0	75	30	9.5	22
T4, Effect of temp	70	40	22	10.0	–	–	–	–
	300	33	20	11.0	–	–	–	–
	400	17	9	15.0	–	–	–	–
	500	8.5	5	25.0	–	–	–	–
	600	4	2.5	65.0	–	–	–	–
T6		45	23	5.0	90	32	10	33
T6, Effect of temp	70	45	23	5.0	–	–	–	–
	300	33	20	11.0	–	–	–	–
	400	17	9	15.0	–	–	–	–
	500	8.5	5	25.0	–	–	–	–
	600	4	2.5	65.0	–	–	–	–
T7		39	20	4.5	80	–	–	–

[1]500 kg load, 10 mm ball
[2]Rotating beam at 50 × 10^7 cycles
[3]After long holding at test temp

Modulus of elasticity, E in M psi 10,300
Modulus of rigidity, in M psi 3,850
Poisson's ratio 0.33

ALUMINUM ALLOYS, CAST

380

Chemical Composition					
	%		%		%
Si	7.5/9.5	Mg	.10 max	Ni	.50 max
Cu	3.0/4.0	Mn	.50 max	Others	.50 max
Fe	2.0 max	Zn	1.0 max		

Technological Properties

Melting point solidus	970 F or 520 C
liquidus	1090 F or 588 C
Weldability	Good by flash welding
Soldering	Good after copper plating
Riveting	Use 53S-T4; 53S-T6; 53S-T61

Characteristics. General-purpose alloy.

Uses. Used where greater castability is required than that of 85 alloy.

Physical Properties
Density, at 68 F 0.099 lb/cu in. (2.76 S.G.)
Electrical resistivity, microhm/cm[3] at 68 F 6.386
Volume conductivity, in % of Cu 27%
Specific heat, cal/gm at 212 F 0.23, approx

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong ¼" round %
Die cast	45	25	2.0

Modulus of elasticity, E in M psi 10,300

Thermal Conductivity
Cgs units at 77 F 0.2

ALUMINUM ALLOYS, CAST

319

Chemical Composition

	%		%		%
Cu	2.5/4.5	Mg	.50 max	Ni	.50 max
Si	5.0/7.0	Mn	.80 max	Ti	.20 max
Fe	1.20 max	Zn	1.00 max	Others	1.00 max

Technological Properties

Melting point solidus 950 F or 510 C
liquidus 1120 F or 605 C

Heat treatment

Sand Castings[1]

Solution temp	935-945 F or 501-507 C, WQ
Precipitation temp, after solution treatment, T6[2]	305-315 F or 152-157 C
Weldability	Good with flash welding method
Soldering	Good after copper plating
Riveting	Use 53S-T4; 53S-T6; 53S-T61

[1]Precision mold castings same as above except sand castings solutions are held 12 hrs, permanent mold solutions are held 8 hrs, water at 150-212F
[2]2 to 5 hrs, quench not critical

Characteristics. Good casting characteristics, weldability, and pressure tightness, with moderate strength.

Uses. For automotive cylinder heads, crankcases for internal combustion engines, typewriter frames, piano plates, etc.

Physical Properties

Density, at 68 F 0.100-lb/cu in. (2.77 S.G.)
Electrical resistivity, microhm/cm³ at 68 F 6.386 for sand castings
6.158 for perm. mold castings
Volume conductivity, in % of Cu 27% (sand); 28% (permanent mold)
Specific heat, cal/gm at 212 F 0.23, approx.

Thermal Conductivity

Cgs units at 77 F 0.26

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	11.9	21.5
-392	-200	12.5	22.5
-572	-300	13.0	23.5

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong ½" round %	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi
Sand cast							
As cast	27	18	2.0	70	24	10	18
T6	36	24	2.0	80	–	10	–
Permanent mold cast							
As cast	34	19	2.5	85	24	–	19
T6	40	27	3.0	95	–	–	–

[1]500 kg load, 10 mm ball
[2]Rotating beam at 50 x 10^7 cycles

Modulus of elasticity, E in M psi 10,300
Modulus of rigidity, in M psi 3,850
Poisson's ratio 0.33

ALUMINUM ALLOYS, CAST

750

Chemical Composition

	%		%		%
Sn	5.5/7.0	Si	.70 max	Ti	.20 max
Cu	.70/1.3	Fe	.70 max	Others	.30 max
Ni	.70/1.3	Mn	.10 max		

Technological Properties

Melting point solidus 450 F or 230 C
liquidus 1200 F or 650 C

Characteristics. Excellent bearing qualities.

Uses. For bearings and bushings.

Physical Properties

Density, at 68 F 0.104 lb/cu in. (2.89 S.G.)
Electrical resistivity, microhm/cm³ at 68 F 3.831
Volume conductivity, in % of Cu 45%
Specific heat, cal/gm at 212 F 0.23, approx

Thermal Conductivity

Cgs units at 77 F 0.42

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
68-212	20-100	12.8	23.1
-392	-200	13.5	24.3

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong ½" round %	Hard, BHN[1]	Shear S M psi	End Lt M psi[2]	Comp. YS M psi
Permanent mold cast	22	10	12	45	14	9	10

[1]500 kg load, 10 mm ball
[2]Rotating beam at 50 x 10^7 cycles

Modulus of elasticity, E in M psi 10,300
Modulus of rigidity, in M psi 3,850
Poisson's ratio 0.33

Pure Nickel

Chemical Composition
Nominal
Ni + Co = 99.95%

Characteristics. This is electrolytic nickel.

Uses. Plating surfaces and in electronic devices.

Technological Properties

Melting point	2651 F or 1455 C
Annealing temp	See Fig 10, p 1046, Metals Handbook

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong %	Hard VHN
Annealed	46	8.5	30	45

Modulus of elasticity, E in M psi 30,000 at room temp. For additional information see Fig 9, p 1046, Metals Handbook.

Physical Properties
Density, at 77 F 0.322 lb/cu in. (8.902 S.G.)
Specific heat, cal/gm at 212 F 0.1123/°C. The specific heat rises to 0.16 at the Curie point (353 C) where it drops abruptly to 0.135 and is 0.1265 at 500 C or 932 F.
Volume conductivity, in % of Cu 25.2%
Electrical resistivity, microhm/cm³ at 68 F 6.84
Temperature coefficient of electrical resistivity, microhm/cm³/°C, 0-100 C 0.0069
Magnetic properties See Figs 4 and 6, p 1046, Metals Handbook
Magnetostriction, cm/cm/gauss -32×10^{-6}
Curie point 665 F or 353 C

Thermal Conductivity

Temp Range Deg F	Deg C	Cgs Units	Btu/ft²/hr/in./°F
77	25	0.22	637.24
212	100	0.198	573.52
572	300	0.152	440.28
932	500	0.148	428.69

Coef. of Thermal Expansion

Temp Range	
32-212F	7.4×10^{-6}/°F
0-100C	13.3×10^{-6}/°C

GRADE "D" Nickel

Chemical Composition

%	%	%	%	%	%
Mn 4.25-5.25	Fe .75 max	C .2 max	Cu .25 max	Si .15 max	S .015 max

"E" Nickel is similar, with 2% Mn

Characteristics. Manganese gives better resistance to sulphur compounds at elevated temperatures in both oxidizing and reducing atmospheres.

Uses. Spark plug wires.

Technological Properties

Hot working temp	2150-1200 F or 1175-650 C
Annealing temp	1400-1500 F or 760-815 C
Workability	Good both hot and cold
Weldability	Good by oxyacetylene and resistance methods
Brazing	Good
Soldering	Good, with soft solder and silver solder

Mechanical Properties

Form or Condition	Deg/in.	Tensile Strength M psi	Yield Strength M psi	Elong %	Red. Area %	Hard BHN	Rock B Hard
Hot rolled, tension	—	86	34[1]	40	60	147	70
Torsional strength	380	68	26	—	—	—	—

[1] .2%

Modulus of elasticity, E in M psi 30,000

Physical Properties
Density, at 68 F 0.317 lb/cu in. (8.78 S.G.)
Specific heat, cal/gm at 32-212 F 0.13
Electrical resistivity, microhm/cm³ at 68 F 19.
Magnetic transformation temp (Curie point) 665 F or 352 C

Thermal Conductivity

Temp Range Deg F	Deg C	Cgs Units	Btu/ft²/hr/in./°F
32-212	0-100	0.115	333.1

NICKEL ALLOYS

GRADE "A"
Nickel

Chemical Composition

	Ni %	Cu %	Fe %	Mn %	Si %	C %	S %
Wrought	99 min	.25 max	.4 max	.35 max	.35 max	.15 max	.01 max

Technological Properties

Melting point solidus	2615 F or 1435 C
liquidus	2635 F or 1446 C
Recrystallization temp	1110 F or 600 C
Annealing temp	1200-1400 F or 650-760 C
Hot working temp	2300-1200 F or 1260-650 C
Workability	Good both hot and cold
Weldability	Good by oxyacetylene, metal arc, and resistance methods.
Brazing	Good
Soldering	Good with soft and silver solders

Uses. Nickel plating and in the chemical industries at normal and elevated temperatures, especially for handling caustic soda.

Thermal Conductivity

Temp Range Deg F	Deg C	Cgs Units	Btu/ft²/hr/in./°F
32-212	0-100	0.145	420

Physical Properties

Density, at 68 F 0.321 lb/cu in. (8.885 S.G.)
Specific heat, cal/gm at 32-212 F 0.13
Volume conductivity, % of Cu 18%
Electrical resistivity, microhm/cm³ at 68 F 9.5
Temperature coefficient of electrical resistivity, microhm/cm³/°C at 68-212 F 0.00474
Magnetic properties, initial permeability 110 gausses
maximum permeability 600 gausses
coercive force 3.4 oersteds
saturation magnetization (B-H) 6100 gausses
hysteresis loss at saturation 3000 ergs/cm³/cycle
Magnetic transformation temp, (Curie point) 680 F or 360 C

Coef. of Thermal Expansion

Temp Range	
77-212F	$7.4 \times 10^{-6}/°F$
25-100C	$13.3 \times 10^{-6}/°C$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength .2% M psi	Elong 2" %	Red Area %	Hard BHN	Rock B Hard
Rod and Bar						
Cold drawn, annealed	50-80	10-30	50-40	75-60	90-120	40-65
Cold drawn, as drawn	65-110	40-100	35-10	70-50	140-230	76-100
Hot rolled	55-80	15-45	65-30	75-60	90-120	40-65
Forged	65-105	20-80	40-25	70-50	90-200	40-95
Cold drawn wire						
Annealed	50-80	10-30	50-30	–	–	–
No. 1 Temper	90-105	75-90	20-5	–	–	–
Regular temper	105-140	90-130	15-4	–	–	–
Spring temper	135-165	130-155	10-2	–	–	–
Hot rolled plate						
Annealed	55-80	15-40	60-40	–	90-140	40-75
As rolled	55-85	20-50	55-35	–	100-150	50-80
Special cold rolled sheet & strip						
Annealed	55-75	15-30	55-40	–	–	70 max
Hard sheet	90-115	70-105	15-2	–	–	90 min
Full hard strip	90-130	70-115	15-2	–	–	95 min
Cold drawn tubing						
Annealed	55-75	15-30	60-40	–	–	70 max
As drawn	65-110	40-90	35-15	–	–	75-98
Sand castings						
As cast	45-60	20-30	30-15	–	80-125	–

Modulus of elasticity, E in M psi	21,500, sand cast 30,000, annealed
Strength in double shear, in M psi	52.3, annealed 57.55, ½ hard 75.3, hard
Endurance limit, at 10⁸ cycles in M psi	24, annealed 30, hot rolled 42.5, cold drawn
Effect of temp	
Minimum creep rate, at 750F or 400C, M psi, stress for 0.0001%/hr	10, hot rolled
Minimum creep rate, at 800F or 425C, M psi, stress for 0.0001%/hr	24, cold drawn

NICKEL ALLOYS

Cast Nickel

Chemical Composition				
%	%	%	%	%
Ni rest	Si 2 max	Mn 1.5 max	C 1 max	Fe 1.25 max

Characteristics. Nickel in this cast form has corrosion resistance similar to wrought nickel.

Uses. Equipment for handling corrosives, such as caustics, and for avoiding contamination from metals such as copper and iron.

Technological Properties

Melting temp	2450-2600 F or 1345-1425 C
Weldability	Good with oxyacetylene and metal arc methods
Brazing	Good
Soldering	Good with soft solder and silver solder

Physical Properties
Density, at 68 F 0.301 lb/cu in. (8.34 S.G.)
Electrical resistivity, microhm/cm^3 at 68 F 21
Magnetic properties Slightly magnetic

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield[1] Strength M psi	Elong 2" %	Hard BHN	Comp YS M psi 0.00%	0.01%	0.2%	E 10^6 psi
	45-60	20-30	30-15	80-125	10	14	23	21.5

[1] 0.05% elongation under load

Coef. of Thermal Expansion

Temp Range	
77-212F	$7.2 \times 10^{-6}/°F$
25-100C	$13.0 \times 10^{-6}/°C$

NICKEL ALLOYS

GRADE "Z"

Duranickel

Chemical Composition		
%	%	%
Ni 93 min	Cu .25 max	Mn .5 max
S .01 max	Si 1 max	Al 4-4.75
Fe .6 max	Ti .25-1	

Characteristics. Duranickel is used for parts for high strength and resistance to corrosion, especially in large sections.

Uses. Pump rods, springs, shafts, plastic molding equipment.

Technological Properties

Melting point solidus	2615 F or 1435 C
liquidus	2635 F or 1445 C
Hot working temp	2150-1300 F or 1175-700 C
Annealing temp	1600 F or 870 C, 1 hr, WQ
Workability	Good, hot or cold
Hardening treatment	1100 F or 595 C, 8-16 hr, FC
Weldability	Good by oxyacetylene or metal arc
Brazing	Good
Soldering	Good, with soft solder or silver solder

Physical Properties
Density, at 68 F 0.298 lb/cu in. (8.26 S.G.)
Specific heat, cal/gm at 32-212 F 0.13/°C
Electrical resistivity, microhm/cm^3 at 68 F 43.3
Magnetic properties Annealed, only very slightly magnetic
Age hardened, slightly magnetic

Coef. of Thermal Expansion

Temp Range	
32-212F	$7.2 \times 10^{-6}/°F$
0-100C	$13.0 \times 10^{-6}/°C$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength .2% M psi	Elong 2" %	Red. Area %	Hard BHN	Rock. Hard	Shear S M psi	End Lt M psi[1]	Comp YS M psi .01%	.2%	E 10^6 psi
Cold drawn rod and bar											
Annealed	90-120	30-60	55-35	65-45	135-190	B75-90	–	–	–	–	–
As drawn	110-150	60-130	35-15	60-40	185-300	C 8-31	–	–	–	–	–
As drawn, age hardened	170-210	125-175	25-15	30-15	300-380	C31-40	–	–	–	–	–
Hot rolled rod and bar											
As rolled	90-130	35-90	55-30	65-45	140-240	C 0-22	–	–	–	–	–
As rolled, age hardened	160-200	115-150	30-15	30-15	300-375	C31-40	–	–	–	–	–
Cold drawn wire											
Annealed	90-120	30-60	40-25	–	–	–	–	–	–	–	–
Annealed, age hardened	160-190	–	15-7	–	–	–	–	–	–	–	–
Spring, as drawn	150-200	–	5-2	–	–	–	–	–	–	–	–
Spring, age hardened	190-250	–	10-5	–	–	–	–	–	–	–	–
Cold rolled strip											
Soft	90-120	30-60	50-30	–	–	B-90 max	–	–	–	–	–
Soft, age hardened	160-190	–	50-10	–	–	C30-40	–	–	–	–	–
1/2 hard	130-155	–	15-3	–	–	C25-34	–	–	–	–	–
1/2 hard, age hardened	170-210	–	20-7	–	–	C33-42	–	–	–	–	–
Full hard	155-190	–	10-2	–	–	C30-40	–	–	–	–	–
Full hard, age hardened	180-230	–	15-5	–	–	C36-46	–	–	–	–	–
Hot rolled	–	–	–	–	–	–	67.5	53.5	40	51	30
Hot rolled, age hardened	–	–	–	–	–	–	116	52.0	126	148	–
Cold drawn	–	–	–	–	–	–	89	52.5-54.5	67	103	–
Cold drawn, age hardened	–	–	–	–	–	–	104	53.5-65.5	140	166	–

[1] At 10^8 cycles

"K" Monel

Chemical Composition

	Ni %	Cu %	Al %	Fe %	Ti %
QQ-N-286, 46N5	63.0/70.0	rest	2.0/4.0	2.0 max	.25-1
"KR" Monel	63.0/70.0	rest	2.0/4.0	2.0 max	.25-1

	Si %	Mn %	C %	S %
QQ-N-286, 46N5	1.0 max	1.5 max	.25 max	–
"KR" Monel	1.0 max	1.5 max	.2-.3	.01 max

Technological Properties

Melting point solidus	2400 F or 1315 C
liquidus	2460 F or 1350 C
Hot working temp	2150-1350 F or 1175-730 C
Hot shortness temp	1000-1350 F or 540-730 C
Annealing temp	1600 F or 870 C, 1 hr, WQ
Hardening treatment	1100 F or 595 C, 8-16 hr, FC
Formability	Good, either hot or cold
Weldability	Good by oxyacetylene, resistance, or metal arc
Brazing	Good
Soldering	Good, with soft solder or silver solder

Characteristics. Grade "K" is an age-hardenable, extra high strength, Monel with high resistance to corrosion.

Uses. Nonmagnetic parts for aircraft, pump rods, springs, shafts, valve stems. Like Monel, it should not be used above 600 F or 315 C in sulfidizing atmospheres.

Physical Properties

Density, at 68 F 0.306 lb/cu in. (8.47 S.G.)
Specific heat, cal/gm at 77-750 F or 25-400 C 0.127/°C
Electrical resistivity, microhm/cm^3 at 68 F 58.3
Temperature coefficient of electrical resistivity, microhm/cm^3/°C at 68-212 F 0.00018
Magnetism Nonmagnetic to –150 F
Maximum permeability 1.0015 cgs (air, 1.02 max)
Magnetic transformation temp, age hardened –150 F or –101 C
soft –200 F or –129 C

Thermal Conductivity

Cgs units at 32-212 F	0.045
Btu/sq ft/in/hr/°F	130

Coef. of Thermal Expansion

Temp Range	
77-212F	$7.8 \times 10^{-6}/°F$
25-100C	$14.0 \times 10^{-6}/°C$

Mechanical Properties

Form or Condition	Test Temp Deg C	Test Temp Deg F	Proof Strength M psi[1]	Tensile Strength M psi	Yield Strength M psi .01%	Yield Strength M psi .2%	Elong 2" %	Red Area %	Hard BHN	Rock Hard	Shear S M psi	End Lt M psi[2]
Cold Drawn Rod and Bar												
Annealed	–	–	–	90-110	–	40-60	45-25	70-50	140-185	B75-90	–	–
Annealed, age hardened	–	–	70-100	130-160	–	90-110	30-20	50-30	250-280	C21-28	–	–
As drawn	–	–	–	100-135	–	70-100	35-13	65-45	175-260	C8-26	–	–
As drawn, age hardened	–	–	80-125	135-180	–	95-130	30-15	50-25	255-340	C27-33	–	–
Hot Finished Rod and Bar												
As rolled	–	–	–	90-135	–	40-110	45-20	70-50	140-260	B75-C20	–	–
As rolled, age hardened	–	–	80-110	140-170	–	100-125	30-17	50-25	265-330	C27-33	–	–
Cold Drawn Wire												
Annealed	–	–	–	90-110	–	40-60	45-30	–	–	–	–	–
Annealed, age hardened	–	–	–	130-150	–	90-110	30-15	–	–	–	–	–
Spring	–	–	–	145-175	–	130-155	4-2	–	–	–	–	–
Spring, age hardened	–	–	–	160-200	–	150-175	8-3	–	–	–	–	–
Cold Rolled Strip												
Soft	–	–	–	90-105	–	40-65	45-25	–	–	B85 max	–	–
Soft, age hardened	–	–	–	130-170	–	90-120	25-15	–	–	C24-33	–	–
1/2 hard	–	–	–	115-140	–	90-130	20-5	–	–	C20-28	–	–
1/2 hard, age hardened	–	–	–	145-190	–	110-165	15-8	–	–	C30-38	–	–
Full hard	–	–	–	145-165	–	105-160	8-3	–	–	C25-32	–	–
Full hard, age hardened	–	–	–	170-200	–	130-180	10-5	–	–	C34-40	–	–
Hot rolled	–	–	–	–	34	40	–	–	–	–	65.3	38.5-45.5
Hot rolled, age hardened	–	–	–	–	96	121	–	–	–	–	96.475	45-53
Cold drawn	–	–	–	–	55	76	–	–	–	–	71	40.5-43.5
Cold drawn, age hardened	–	–	–	–	102	121	–	–	–	–	98.75	42-53
Directional Properties[3]												
// to rolling direction	–	–	–	152.8	–	–	23.1	–	–	–	–	–
⊥ to rolling direction	–	–	–	151.35	–	–	20.6	–	–	–	–	–
Effect of temp												
	480[4]	900[4]	–	–	–	–	–	–	–	–	–	–
	540[5]	1000[5]	–	–	–	–	–	–	–	–	–	–

[1] Proof stress at 0.01% offset
[2] At 10^8 cycles
[3] Age hardened bar, 10.5 in. diam by 74.5 in. long
[4] Minimum Creep Rate, 0.0001% per hr 48 M psi
[5] Minimum Creep Rate, 0.0001% per hr 21 M psi
[6] E, 10^6 psi 26

Monel

Physical Properties

Density, at 68 F 0.319 lb/cu in. (8.84 S.G.)
Specific heat, cal/gm at 2300 F or 1260 C 0.127
Volume conductivity, % of Cu 3.58%
Electrical resistivity, microhm/cm[3] at 68 F 48.2
ohm/cir mil-ft 290
Temperature coefficient of electrical resistivity,
microhm/cm[3] at 68-212 F 0.0011/°C
0.0019/°F

Magnetism Slightly magnetic
Permeability 2,000-10,000 gauss/oersted
Saturation 1,000-2,000 gausses at 200 oersteds
Curie point 43-60 C

Thermal Conductivity

Temp Range Deg F	Temp Range Deg C	Cgs Units	Btu/ft²/hr/in./°F
32-212	0-100	0.062	173.5

Coef. of Thermal Expansion

Temp Range	
77-212F	7.8×10^{-6}/°F
25-100C	14.0×10^{-6}/°C

(See Fig 1, p 1049, Metals Handbook)

Mechanical Properties

Form or Condition	Temp Deg F 3 hr	Proof Strength M psi[1]	Tensile Strength M psi	Yield Strength .2% M psi	Elong 2" %	Red. Area %	Hard BHN	Rock B Hard	End Lt M psi[6]	E 10^6 psi	PL M psi
Rod and Bar											
Annealed	–	20-30	70-85	25-40	50-35	75-60	110-140	60-75	–	–	–
Hot rolled	–	30-55	80-95	40-65	45-30	75-60	130-175	75-88	–	–	–
Forged	–	25-65	80-110	60-85	30-20	70-60	160-220	84-98	–	–	–
Forged, high tensile	–	45-95	85-125	55-120	35-17	70-50	160-250	B85-C23	–	–	–
Cold drawn, No. 1 temper, < .5 in.	–	–	95-110	50-85	20-5	–	–	–	–	–	–
Cold Drawn Wire											
Annealed	–	–	70-85	25-40	50-30	–	–	–	–	–	–
No. 1 temper	–	–	95-110	50-85	20-5	–	–	–	–	–	–
Regular temper	–	–	110-140	85-130	15-4	–	–	–	–	–	–
Spring temper, < 5/16 in.	–	–	140-170	130-160	10-2	–	–	–	–	–	–
Hot Rolled Plate											
Annealed	–		70-85	28-50	50-35	–	110-150	62-80	–	–	–
As rolled	–		75-90	40-60	45-30	–	140-170	75-87	–	–	–
Cold Rolled Sheet and Strip											
Annealed	–	–	70-85	25-45	50-35	–	–	73 max	–	–	–
Cold rolled sheet, std.	–	–	70-85	25-45	50-35	–	–	73 max	–	–	–
No. 35 sheet	–	–	78-85	45-65	40-20	–	–	74-89	–	–	–
1/4 hard, strip	–	–	78-85	45-65	40-20	–	–	74-82	–	–	–
Hard sheet	–	–	100-120	90-110	15-2	–	–	93 min	–	–	–
Full hard strip	–	–	100-140	90-130	15-2	–	–	98 min	–	–	–
Seamless Drawn Tubing											
Annealed	–	–	70-85	25-45	50-35	–	–	75 max	–	–	–
As drawn	–	–	85-125	65-120	30-10	–	–	90-105	–	–	–
Rod, annealed	–	–	–	–	–	–	–	60-75	31-36	26	–
Rod, hot rolled	–	–	–	–	–	–	–	75-90	39-44	26	–
Forged	–	–	–	–	–	–	–	75-98	–	26	–
Cold drawn, as drawn	–	–	–	–	--	–	–	B85-C23	39.5-47.5	26	–
Effect of Annealing Monel[2]											
	as drawn	–	108.5	99.425[3]	20.5	–	–	98	–	–	45
Stress equalizing	390	–	111.2	103.2[3]	20.0	–	–	100	–	–	62.5
Stress equalizing	480	–	113.25	103.75[3]	20.0	–	–	100	–	–	67.5
Stress equalizing	570	–	112.625	101.15[3]	20.8	–	–	99	–	–	69.825
	660	–	111.575	97.85[3]	22.2	–	–	98	–	–	66.5
Temper annealing	750	–	110	91.1[3]	25.2	–	–	97	–	–	60
Temper annealing	930	–	103.35	81[3]	27	–	–	95	–	–	58
Temper annealing	1110	–	99.25	73.125[3]	30.8	–	–	91	–	–	52.5
	1290	–	84.625	34[3]	44.2	–	–	69	–	–	22.5
Soft annealing	1380	–	83.625	33.75[3]	43.5	–	–	66	–	–	20
Effect of Mass[4]											
Longitudinal	–	62[7]	95.3	70.1	33.5	70.6	–	–	–	–	55.7
Transverse	–	60.9[7]	93.8	69.6	28.2	53.0	–	–	–	–	54.4
Effect of Orientation[5]											
Angle of test specimen to forging direction											
0 longitudinal	–	55.75[7]	89.06	61.875	35.6	67.5	–	–	–	–	–
15 deg	–	54.2[7]	88.025	61	37.8	67.6	–	–	–	–	–
30 deg	–	54.1[7]	86.325	60.65	36.3	68.7	–	–	–	–	–
45 deg	–	55[7]	88.125	62.05	35.5	66.5					
60 deg	–	55.8[7]	89.875	63.4	30	59.4	–	–	–	–	–
75 deg	–	54.5[7]	90.75	63.35	27.8	52.9	–	–	–	–	–
90 transverse	–	53.8[7]	91	62.95	26.5	53.7	–	–	–	–	–

Effect of Temp (See Figs. 3 and 5, p. 1051, Metals Handbook)

[1] .01% offset
[2] Material Rod, 1½ in. diam drawn 20%
[3] .5%
[4] Average values of tests on each end of 17 rods, 9-5/8 in. diam by 22 ft long by 6000 lb.
[5] Tests of high-tensile forged rods
[6] At 10^8 cycles
[7] .01%

Shear modulus, M psi 9,500

(Continued on page 376)

NICKEL ALLOYS

Monel

(*Continued from page 375*)

Chemical Composition

	Ni[2] %	Cu %	Fe %	Al %
Nominal	67	30	1.4	–
"R" Monel[2]	63.0/70.0	rest	2.50 max	.50 max
	Mn %	**C %**	**Si %**	**S %**
Nominal	1	.15	.1	.01
"R" Monel[2]	2.00 max	.30 max	.50 max	.025-.06

[1]Includes a small amount of Co
[2]"R" Monel is a free-cutting grade

Technological Properties

Melting temp	2370-2460F or 1300-1350C
Recrystallization temp	1220F or 660C, for 10% reduction 1110F or 600C, for 50% reduction
Hot working temp	Forging, 2150-1700F or 1175-925C High tensile forging, 1200-1000 F or 650-540C Hot forming, 2150-1850F or 1175-1010C
Hot shortness temp	1700-1200F or 925-650C
Annealing temp	Stress-equalizing, 390-570F Temper annealing, 750-1100F Full anneal, 1400F
Welding	Good by oxyacetylene, resistance, and metal arc methods
Brazing	Good
Soldering	Good with soft solder or silver solder
Riveting	Use Monel rivets

Characteristics. Monel has excellent corrosion resistance and moderate strength, and is available in many shapes and sizes.

Uses. It is used in many corrosive environments, such as sea water, dilute sulphuric acid, and strong caustic solutions, in the chemical, paper, power industries, etc., and in marine equipment; and in architectural applications. It is also used at elevated temperatures up to about 1000 F in simple oxidizing conditions, sometimes even up to 1500 F, but in sulfidizing atmospheres should not be used above 700 F.

NICKEL ALLOYS

"S" Monel

Chemical Composition

	Ni %	Cu %	Mn %	Si %	Fe %	C %
Navy 46N7, class B	62/68	rest	.5/1.5	3.5/5.0	3.5 max	.25 max

Technological Properties

Melting temp	2300-2350 F or 1260-1290 C
Annealing treatment	1600 F or 870 C, 1 hr, AC to 1200 F, WQ
Hardening treatment	1100 F or 595 C, 4-6 hr, AC or FC
Brazing	Good
Soldering	Good with soft solder or silver solder

Characteristics. "S" Monel is a heat-treatable, casting alloy for applications requiring high strength, pressure tightness, and high resistance to corrosion and galling.

Uses. Valve seats and moving components.

Physical Properties
Density, at 68 F 0.302 lb/cu in. (8.36 S.G.)
Electrical resistivity, microhm/cm^3 at 68 F 63.3
Magnetism Nonmagnetic at room temp
Magnetic transformation point −70 F or −57 C

Coef. of Thermal Expansion

Temp Range Deg F	Temp Range Deg C	in./in. per Deg F	in./in. per Deg C
70-212	21-100	6.8×10^{-6}	12.2×10^{-6}
-600	-316	8.2×10^{-6}	14.8×10^{-6}
-850	-454	8.4×10^{-6}	15.1×10^{-6}
-1000	-538	8.7×10^{-6}	15.7×10^{-6}

Mechanical Properties

Form or Condition	Test Temp Deg F	Test Temp Deg C	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Hard BHN	Comp YS M psi .00%	Comp YS M psi .01%	Comp YS M psi .2%	E 10^6 psi
Sand cast	–	–	110-145	80-115	4-1	275-350	65	80	111	21.0
Quenched	–	–	–	–	–	225-260	30	41	61	20.5
Aged	–	–	110-145	80-115	4-1	300-375	67	91	125	21.5
Effect of temp										
As cast	room	room	–	–	–	321	–	–	–	–
	700	370	–	–	–	321	–	–	–	–
	800	425	–	–	–	311	–	–	–	–
	900	480	–	–	–	311	–	–	–	–
	1000	540	–	–	–	321	–	–	–	–
	1050	565	–	–	–	355	–	–	–	–
	1100	595	–	–	–	293	–	–	–	–

NICKEL ALLOYS

Cast Monel

Chemical Composition

%	%	%	%	%	%
Ni 62.0/68.0	Cu rest	Fe 2.5 max	C 0.35 max	Si 1-2.24	Mn .5-1.5

Uses. For various applications requiring strength with high resistance to corrosion and wear, with pressure tightness in castings.

Technological Properties

Melting temp	2400-2450 F or 1315-1345 C
Weldability	Good with metal arc
Brazing	Good
Soldering	Good with soft solder and silver solder

Physical Properties
Density, at 68 F 0.312 lb/cu in. (8.63 S.G.)
Electrical resistivity, microhm/cm³ at 68 F 53.3
Magnetism Slightly magnetic

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Hard BHN	Comp YS M psi 0.00%	0.01%	0.2%	E 10⁶ psi
	65-90	32-40	45-25	125-150	19	23	29	18.5

Coef. of Thermal Expansion

Temp Range	
77-212F	$7.2 \times 10^{-6}/°F$
25-100C	$12.9 \times 10^{-6}/°C$

NICKEL ALLOYS

Hastelloy A

Chemical Composition

%	%	%	%	%	%	%
Mo 20/22	Fe 18/20	C 0.12 max	Mn 3 max	Cr 1 max	Si 1 max	Ni rest

Characteristics. Hastelloy A is a corrosion-resisting alloy which is useful for applications in which stainless steel is susceptible to attack, such as phosphoric acid, sulphuric acid in concentrations up to 50%, hydrochloric acid and reducing chloride salts. It is susceptible to attack under oxidizing conditions and to hot hydrochloric acid. It also has good high temperature properties. See Section on Super Alloys, p000.

Physical Properties
Density, at 77 F 0.318 lb/cu in. (8.80 S.G.)
Specific heat, cal/gm 0.094
Volume conductivity, % of Cu 1.4%
Electrical resistivity, microhm/cm³ at 77 F 126.7
Temperature coefficient of electrical resistivity, 68-1472 F or 20-800 C zero
Magnetic permeability 5 cgs

Thermal Conductivity

Temp Range Deg F	Deg C	Cgs Units	Btu/ft²/hr/in./°F
77	25	0.04	115.9

Coef. of Thermal Expansion

Temp Range	
32-212F	$6.2 \times 10^{-6}/°F$
0-100C	$11.0 \times 10^{-6}/°C$
32-1832F	$8.5 \times 10^{-6}/°F$
0-1000C	$15.4 \times 10^{-6}/°C$

Technical Properties

Melting point solidus	2370 F or 1300 C
liquidus	2425 F or 1330 C
Hot working temp	2250-1900 F or 1230-1035 C
Hot shortness temp	1110-1600 F or 600- 870 C
Annealing temp	2150 F or 1175 C
Workability	Good, hot or cold
Full anneal	2100-2150 F or 1150-1180 C, ½-1½ hr, WQ or AC
Detrimental temp (corrosion resistance)	1200-1900 F or 650-1140 C
Stabilizing anneal	1925-1950 F or 1050-1065 C, 2-4 hr, AC
Hardening treatment	1375-1400 F or 745- 760 C, 168 hr, AC
Weldability	Good by oxyacetylene, resistance, and metal arc methods

Mechanical Properties

Form or Condition	Section in.	Test Temp Deg F	Deg C	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Red. Area %	Hard BHN	Rock B Hard	E 10⁶ psi
Sand cast	.505	–	–	69-77.5	42.5-45	8-12	16-18	155-200	85-94	–
Annealed	.505	–	–	110-120	47.0-52	40-48	40-54	200-215	94-97	27
Precision cast	.250	–	–	75-80	43.8-48.4	10-20	11-30	–	80-85	–
Effect of Low Temp										
Rolled and		-58	-50	125	59	52	49	–	–	–
annealed material		-148	-100	130	61	49	49	–	–	–
		-328	-200	149	70	51	48	–	–	–
Effect of Temp										
Precision cast bars										
0.250 in. diam		70	20	75-80	43.8-48.4	10-20	11-30	–	–	–
		1000	540	63-72	–	15-30	12-30	–	–	–
		1200	650	57.7-66.0	–	20-28	12-26	–	–	–
		1500	815	41-52	–	11-27	11-22	–	–	–

Creep rate at 1650F or 900C at 1500 psi, under 1% per yr

NICKEL ALLOYS

Hastelloy B

Characteristics. Similar to Hastelloy A but more resistant to mineral acid compositions, and particularly to boiling hydrochloric acid and wet hydrogen chloride gas. High temperature properties are good to 1500F.

Chemical Composition

	%	%	%	%
Specified	Mo 26/30	Fe 4/7	C 0.12 max	Si 1 max
	Mn 1 max	Cr 1 max	Ni rest	

Physical Properties
Density, at 77 F 0.334 lb/cu in. (9.24 S.G.)
Specific heat, cal/gm 0.091
Volume conductivity, % of Cu 1.3%
Electrical resistivity, microhm/cm³ at 77 F 135
Magnetic permeability 4 cgs

Technological Properties

Melting point solidus	2410 F or 1320 C
liquidus	2460 F or 1350 C
Magnetic permeability	4 cgs
Hot working temp	2250-1900 F or 1250-1035 C
Hot shortness temp	1110-1600 F or 600-870 C
Annealing temp	2150 F or 1175 C
Hardening treatment	1375-1400 F, 168 hr, AC
Forming and heat treatment	Same as Hastelloy A
Weldability	Good by oxyacetylene, resistance and metal arc methods

Thermal Conductivity

Temp Range Deg F	Deg C	Cgs Units	Btu/ft²/hr/in./°F
77	25	0.027	78.21

Coef. of Thermal Expansion

Temp Range	
32-212F	5.5×10^{-6}/°F
0-100C	10.0×10^{-6}/°C
32-1832F	8.1×10^{-6}/°F
0-1000C	14.6×10^{-6}/°C

Mechanical Properties

Form or Condition	Section in.	Test Temp Deg F	Test Temp Deg C	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Red. Area %	Hard BHN	Rock B Hard	E 10^6 psi
Sand cast	.505	–	–	75-85	55-60	6-10	9-13	179-235	92-99	26.5
Rolled, annealed	.505	–	–	130-140	56-63	50-55	40-50	177-225	92-98	30.75
Precision cast	.250	–	–	80-90	58-63	10-17	12-18	197-235	92-99	28.5
Effect of Low Temp										
		-58	-50	142	59	66	54	–	–	–
		-148	-100	144	61	63	53	–	–	–
		-328	-200	172	83	58	45	–	–	–
Effect of Temp										
Precision cast specimens		70	20	80-90	58-63	10-17	12-18	197-235	92-99	28.5
0.250 in. diam		1000	540	74.5-80	–	13-17	11-19	–	–	–
		1200	650	65-69	–	10-25	10-30	–	–	–
		1500	815	55-61	–	11-30	10-30	–	–	–

Compressive PL, M psi 25-36
YS, 0.2% offset 61-68
Min. Creep Rate, 1% in 10,000 hr., at 1350F is 7500 psi (wrought sheet)

NICKEL ALLOYS

Hastelloy D

Characteristics. This is a casting alloy which is resistant to all concentrations of hot sulphuric acid, hydrochloric acid under mild conditions, and to other nonoxidizing acids and salts. It has excellent wearing properties and freedom from galling against both hard and soft alloys.

Chemical Composition

	%	%	%	%	%	%
Specified	Si 8.5/10	Cu 3.85/4.25	C 0.12 max	Mn 0.8/1.25	Cr 1 max	Ni rest

Physical Properties
Density, at 77 F 0.282 lb/cu in. (7.8 S.G.)
Specific heat, cal/gm 0.109
Volume conductivity, % of Cu 1.5%
Electrical resistivity, microhm/cm³ at 77 F 113
Temperature coefficient of electrical resistivity, 68-1470 F or 20-800 C nearly zero

Technological Properties

Melting point solidus	2030 F or 1110 C
liquidus	2050 F or 1120 C
Machinability	Limited, by machining and grinding
Weldability	Suitable by oxyacetylene
Heat treatment, for moderate softening and toughening	1925-1950 F or 1050-1065 C, 2-4 hr, FC

Thermal Conductivity

Temp Range Deg F	Deg C	Cgs Units	Btu/ft²/hr/in./°F
77	25	0.05	144.83

Coef. of Thermal Expansion

Temp Range	
32-212F	6.1×10^{-6}/°F
0-100C	11.0×10^{-6}/°C
32-1832F	10.0×10^{-6}/°F
0-1000C	18.1×10^{-6}/°C

Mechanical Properties

Form or Condition	Section	Tensile Strength M psi	Elong %	Red Area %	Rock C Hard[2]	Trans Load	Test[1] Defl., in	Mod Rupt M psi	E 10^6 psi
Sand cast	0.505 in.	110-125	0.2	–	31-47	5000	.07-.08	78	28.85

[1] 1 in. cross section × 12 in. span
[2] Inversely proportional to section thickness.

NICKEL ALLOYS

Hastelloy C

Chemical Composition

	%	%	%	%	%
Specified	Mo 16/18	Cr 15.5/17.5	C 0.12 max	W 3.75/4.75	Mn 1 max
	Si 1 max	P 0.04 max	S 0.03 max	Ni rest	

Characteristics. Similar to A and B except for the chromium addition which confers resistance to corrosion under oxidizing conditions. It is resistant to wet chlorine, ferric chloride, nitric acid, hydlochloric and sulphuric acids at moderate temperatures or under oxidizing conditions, acetic acid, sea water, etc. High temperature properties are exceptionally high up to 2000F.

Technological Properties

Melting point solidus	2320 F or 1270 C
liquidus	2380 F or 1305 C
Harmful temp (corrosion)	930-1470 F or 500-800 C
Hot working temp	2200-1900 F or 1205-1035 C
Hot shortness temp	1200-1700 F or 650- 925 C
Annealing temp	2225 F or 1220 C, 2-3 hr, AC
Formability	Good, hot or cold
Stabilizing anneal	2050-2075 F or 1120-1135 F, 2-4 hr, AC
Hardening treatment	1575-1600 F or 860- 870 C, 16 hr, AC
Weldability	Good by oxyacetylene, resistance, and metal arc methods
Scaling in air	Resistant up to 2000 F

Physical Properties

Density, at 77 F 0.323 lb/cu in. (8.94 S.G.)
Specific heat, cal/gm 0.092
Volume conductivity, % of Cu 1.3%
Electrical resistivity, microhm/cm³ at 77 F 133.0
Temperature coefficient of electrical resistivity, 68-1470 F or 20-800 C zero
Magnetic permeability, cgs units 4

Thermal Conductivity

Temp Range Deg F	Deg C	Cgs Units	Btu/ft²/hr/in./°F
77	25	0.03	86.9

Coef. of Thermal Expansion

Temp Range	
32-212F	6.3×10^{-6}/°F
0-100C	11.3×10^{-6}/°C
32-1832F	8.5×10^{-6}/°F
0-1000C	15.3×10^{-6}/°C

Mechanical Properties

Form or Condition	Section in.	Test Temp Deg F	Deg C	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Red. Area %	Hard BHN	Rock B Hard	E 10^6 psi
Sand cast	.505	—	—	73-83	55-60	5-10	8-12	181-248	B90-C23	26
Annealed plate	.250	—	—	120-130	55-65	40-50	35-40	195-226	92-98	28.5
Precision cast	.250	—	—	75-85	57-62	4-10	5-12	201-248	B93-C23	24.5
Effect of Low Temp										
		- 58	-50	134	65	38	33	—	—	—
		-148	-100	143	79	25	25	—	—	—
		-328	-200	160	96	24	22	—	—	—
Effect of Temp										
Precision cast specimens, 0.250 in. diam		70	20	75-85	57-62	4-10	5-12	—	—	—
		1000	540	63-73	—	10-17	10-20	—	—	—
		1200	650	56-62	—	10-16	10-20	—	—	—
		1500	815	50-61	—	11-28	10-20	—	—	—
		—	900	42	—	—	—	—	—	—
		—	1000	22	—	—	—	—	—	—

Compressive PL, M psi 41
YS, 0.2% offset, M psi 75-79
Min Creep rate, 1% in 10,000 hr, at 1350F is 12,000 psi (wrought sheet)

NICKEL ALLOYS

Illium "G"

Chemical Composition

Nominal[1]

%	%	%	%
Ni 56	Cu 6.5	Fe 6.5	Si .65
Cr 22.5	Mo 6.4	Mn 1.25	C .2

[1] As given by The Ilium Corp

Technological Properties

Melting point solidus	2290F or 1254C
liquidus	2440F or 1338C
Weldability	Good, by oxyacetylene, inert gas and arc.
Soldering	Fair, with soft solder. Good with silver solder.
Heat treatment	Improves corrosion resistance in certain applications.

Physical Properties

Density, 0.31 lb/cu in. (8.58 S.G.)
Specific heat, 0.105 cal/ °C
Electrical resistivity, 123.5 microhms/cm²/cm.
Magnetic permeability, 26C, 1.0011
-30C, 1.0011
Coefficient of linear thermal expansion, 0-100C, 0.00001219
0-500C, 0.00001403
Contraction in casting, ¹⁄₄ in./ft.

Characteristics. A machinable, corrosion-resistant alloy for use with sulphuric, nitric, phosphoric, and mixed acids, salt and acid mixtures, and sea water and saline atmospheres; available in centrifugal or sand cast forms.

Uses. It is useful at elevated temperatures where severe corrosion is encountered. In general, it is not used with halogen acids.

Thermal Conductivity

Temp Range Deg F	Deg C	Cgs Units	Btu/ft²/hr/in./°F
70	21	0.029	84

Mechanical Properties

	Tensile Strength M psi	Yield Strength M psi	Elong %	Red Area %	Hard BHN	E 10^6 psi
Sand cast	68	38.9	7.5	11.3	159-177	24.3

Inconel

Chemical Composition			
%	%	%	%
Ni 72.0 min	Fe 6-10	Mn 1.0 max	C .15 max
Cr 14.0/17.0	Cu .5 max	Si .5 max	S .015 max

Technological Properties

Melting point	solidus	2540 F or 1395 C
	liquidus	2600 F or 1425 C
Hot working temp		2300-1600 F or 1260-870 C
Hot shortness range		1200-1600 F or 650-870 C
Annealing temp		1600 F or 870 C, for 3 hr to 1800 F or 980 C for 7-15 min
Formability		Good, hot or cold
Weldability		Good by oxyacetylene, resistance and metal arc methods
Brazing		Good
Soldering		Good, with soft solder or silver solder

Characteristics. Inconel is an excellent material for high temperature service under oxidizing conditions, but should not be used above 1500 F or 815 C in sulphidizing atmospheres. It can be worked either cold or hot.

Thermal Conductivity			
Temp Range Deg F	Temp Range Deg C	Cgs Units	Btu/ft²/hr/in./°F
32-212	0-100	0.036	104

Physical Properties

Density, at 68 F 0.307 lb/cu in. (8.51 S.G.)
Specific heat, cal/gm at 77-212 F 0.109
Electrical resistivity, microhm/cm³ at 68 F 98.1
Temperature coefficient of electrical resistivity, microhm/cm³/°C at 68-930 F or 20-500 C 0.000125
Magnetism Nonmagnetic at room temp
Maximum permeability Cgs 1.005 1.02 max
Magnetic transformation temp Minus 40 C

Coef. of Thermal Expansion	
Temp Range	
68-212F	$6.4 \times 10^{-6}/°F$
20-100C	$11.5 \times 10^{-6}/°C$

Mechanical Properties

Form or Condition	Test Temp Deg F	Creep Strength M psi[2]	Tensile Strength M psi	Yield Strength .2% M psi	Elong 2" %	Hard BHN	Rock Hard	Shear S M psi	End Lt M psi[1]	Comp YS M psi .01%	Comp YS M psi .2%
Cold Drawn Rod and Bar											
Annealed	–	–	80-100	25-50	55-35	120-170	B65-85	60.8	31-45	23	28
As drawn	–	–	105-150	80-125	30-10	180-290	C8-30	66.2	40-51	90	105
Hot Rolled Rod and Bar											
As rolled or forged	–	–	85-120	35-90	50-30	140-210	B75-95	–	38-51	31	42
Annealed	–	–	80-100	25-50	55-35	120-170	B65-85	–	–	–	–
Cold Drawn Wire											
Annealed	–	–	80-105	25-50	50-25	–	–	–	–	–	–
Regular temper	–	–	130-175	115-165	12-3	–	–	–	–	–	–
Spring	–	–	165-185	150-175	10-2	–	–	–	–	–	–
Hot Rolled Plate											
Annealed	–	–	80-110	30-50	55-35	120-180	B65-90	–	–	–	–
As rolled	–	–	85-110	35-65	50-30	140-210	B76-95	–	–	–	–
Cold Rolled Sheet and Strip											
Annealed	–	–	80-110	30-45	55-35	–	B88 max	–	–	–	–
Hard sheet	–	–	125-150	90-125	15-2	–	C24 min	–	–	–	–
Full hard strip	–	–	145-170	120-160	10-2	–	C30 min	–	–	–	–
Cold Drawn Tubing											
Annealed	–	–	80-100	30-50	55-35	–	B88 max	–	–	–	–
As drawn	–	–	110-160	65-140	20-2	–	C8-35	–	–	–	–
Creep Strength											
Hot rolled rod	900	40	–	–	–	–	–	–	–	–	–
	1000	25	–	–	–	–	–	–	–	–	–
	1100	12	–	–	–	–	–	–	–	–	–
	1200	9.5	–	–	–	–	–	–	–	–	–
	1300	6.2	–	–	–	–	–	–	–	–	–
	1400	3.6	–	–	–	–	–	–	–	–	–
	1500	1.5	–	–	–	–	–	–	–	–	–
	1600	.75	–	–	–	–	–	–	–	–	–
	1800	.42	–	–	–	–	–	–	–	–	–

[1] At 10^8 cycles
[2] Stress for secondary creep rate of 0.0001% per hr

Modulus of elasticity, E in M psi 31,000

NICKEL ALLOYS

Cast Inconel

Chemical Composition					
%	%	%	%	%	%
Ni rest	Fe 11.0 max	Mn 1.5 max	C .4 max	Cr 14.0/17.0	Si 3.0 max

Technological Properties

Melting point	2500-2550 F or 1370-1400 C
Weldability	Good by fusion and resistance methods
Soldering and brazing	Good

Characteristics. A casting alloy with high strength, pressure tightness, and resistance to wear, corrosion, and oxidation at high temperatures.

Physical Properties
Density, at 68 F 0.30 lb/cu in. (8.3 S.G.)
Magnetic transformation temp Minus 150 F or Minus 100 C

Coef. of Thermal Expansion	
Temp Range	
77-212F	$6.4 \times 10^{-6}/°F$
25-100C	$11.5 \times 10^{-6}/°C$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Hard BHN	Comp YS M psi .00%	.01%	.2%	E 10^6 psi
Sand cast	70-95	30-45	30-10	160-190	17	23	36	22.7

NICKEL ALLOYS

Nickel-Chromium

Chemical Composition[1]			
%	%	%	%
Ni 77/79	Fe 1.0 max	C .25 max	S .03 max
Cr 19/20	Mn 2.5 max	Si .75/1.5	

[1]ASTM

Characteristics. A standard alloy for heating elements with high electrical resistivity, resistance to oxidation, and good working characteristics. It is sensitive to sulphur, especially in reducing atmospheres.

Technological Properties

Melting point	2550 F or 1400 C
Hot working temp	2200 F or 1200 C
Annealing temp	1600-1900 F or 870-1040 C
Formability	Good, hot or cold
Weldability	Good by fusion and resistance methods
Brazing	Good
Soldering	Good, with soft solder and silver solder

Physical Properties
Density 0.30 lb/cu in. (8.4 S.G.)
Specific heat, cal/gm 0.107
Volume conductivity, % of Cu 1.6%
Electrical resistivity, microhm/cm³ at 68 F 107.9
Temperature coefficient of electrical resistivity,
See Fig 1, p 1060, Metals Handbook

Thermal Conductivity
Watts/sq cm/cm/°C at 212 F 0.134

Coef. of Thermal Expansion	
Temp Range	
158-1830F	$9.8 \times 10^{-6}/°F$
70-1000C	$17.6 \times 10^{-6}/°C$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Elong %	Red. Area %	Rock B Hard	E 10^6 psi
Annealed	95	25-35	55	85-90	31
Hard	165	0-1	0-1	100-105	–
Extra spring	200	0	0	–	–

NICKEL ALLOYS

Nickel-CHROMIUM-IRON

Chemical Composition[1]

	%		%		%		%
Ni + Co	57 min	Fe	rest	Si	.75/1.5	S	.03 max
Cr	14/18	Mn	3 max	C	.25 max		

[1]ASTM

Technological Properties

Hot working temp	2300-1800 F or 1260-980 C
Annealing temp	1200-2000 F or 650-1100 C
Formability	Good, hot or cold
Weldability	Good, by oxyacetylene
Brazing	Good
Soldering	Good, with soft solder or silver solder

Characteristics. A satisfactory heating element for various domestic and industrial appliances, carburizing and annealing containers, dipping baskets for acid pickling and cyanide hardening, pickling machine parts, filters, enameling racks, salt bath containers, and for high-resistance rheostats.

Mechanical Properties

Form or Condition	Test Temp Deg F	Tensile Strength M psi	Elong %	Red. Area %	Rock Hard
Sand cast	–	65	2	2	C9
Annealed	–	105	30	47	B83
Effect of temp					
Cast samples	68	65	2	–	–
	1000	47	2.1	–	–
	1200	42.7	2.3	–	–
	1400	37	2.5	–	–
	1600	22	3.7	–	–
	1800	15	6.0	–	–
Wrought samples	68	105	30	–	–
	1000	52.5	12	–	–
	1200	38	13	–	–
	1400	28.5	23	–	–
	1600	19	32	–	–
	1800	9	45	–	–

Physical Properties

Density, at 68 F 0.298 lb/cu in. (8.247 S.G.)
Specific heat, cal/gm at 68 F 0.107
Volume conductivity, % of Cu 1.5%
Electrical resistivity, microhm/cm^3 at 68 F 112
Temperature coefficient of electrical resistivity, See Fig 1, p 1060, Metals Handbook, lower fig.

Thermal Conductivity

Temp Range Deg F	Temp Range Deg C	Cgs Units	Btu/ft^2/hr/in./°F
68	20	0.0325	94.14

Coef. of Thermal Expansion

Temp Range	
68-1830 F	9.4×10^{-6}/°F
20-1000 C	17×10^{-6}/°C

NICKEL ALLOYS

Iron-Nickel CHROMIUM ALLOY

Chemical Composition
Nominal

Ni %	Fe %	Cr %
35	50	15

Technological Properties

Hot working temp	2300-1800 F or 1260-980 C
Annealing temp	1200-2000 F or 650-1100 C
Scaling temp	1500 F or 815 C
Formability	Good, hot or cold
Weldability	Good, by oxyacetylene
Brazing	Good
Soldering	Good, with soft solder or silver solder

Characteristics. This is a relatively inexpensive heat-resistant alloy with good electrical resistance and relatively high temperature coefficient.

Uses. Heavy duty rheostats and resistors for service in cracked gas atmospheres and for low-priced electrical resistors.

Physical Properties

Density, at 68 F 0.287 lb/cu in. (7.95 S.G.)
Specific heat, cal/gm at 68 F 0.110/°C
Volume conductivity, % of Cu 1.7%
Electrical resistivity, microhm/cm^3 at 68 F 100
Temperature coefficient of electrical resistivity, See Fig 1, p 1061, Metals Handbook

Thermal Conductivity

Temp Range Deg F	Temp Range Deg C	Cgs Units	Btu/ft^2/hr/in./°F
68	20	0.031	89.79

Coef. of Thermal Expansion

Temp Range	
68-930 F	8.8×10^{-6}/°F
20-500 C	15.8×10^{-6}/°C

Mechanical Properties

Form or Condition	Test Temp Deg F	Tensile Strength M psi	Elong %	Red. Area %	Rock Hard
Sand cast	–	62	2	2	C18
Annealed	–	102	30	45	B83
Effect of temp[1]					
Cast samples	68	62	2	–	–
	1000	43	4	–	–
	1200	36	6	–	–
	1400	34	8.5	–	–
	1600	19	20	–	–
	1800	12	25	–	–
Wrought samples	68	102	32	–	–
	1000	50	22	–	–
	1200	36	20	–	–
	1400	26.5	26	–	–
	1600	17.5	28	–	–
	1800	8.5	30	–	–

[1]Approximate values

NICKEL ALLOYS

Constantan

Chemical Composition
(Nominal, 45-55% Cu modified by additions of Mn and Fe)

Characteristics. Constantan has an excellent combination of high electrical resistivity and low temperature coefficient, and high thermal emf against platinum. It is used for electrical resistors (which operate at room or moderately low temperatures) and for thermocouples.

Uses. It is generally used as wire but is also used in cast form.

Technological Properties

Melting point	solidus	2230 F or 1220 C
	liquidus	2355 F or 1290 C

Thermal Conductivity

Temp Range Deg F	Temp Range Deg C	Cgs Units	Btu/ft²/hr/in./°F
–	–	0.0546	158.25

Physical Properties
Density, wrought 0.32 lb/cu in. (8.9 S.G.)
cast 0.31 lb/cu in. (8.6 S.G.)
Specific heat, cal/gm 0.094
Electrical resistivity, microhm/cm³ 49
ohm/cir mil-ft 294
ohm/sq mil-ft 231
Temperature coefficient of electrical resistivity,
68-212 F or 20-100 C, wrought ± 0.00002
68-930 F or 20-500 C, wrought ± 0.000025
32-300 F or 0-150 C, cast ± 0.0001

Coef. of Thermal Expansion

Temp Range	
68-212F	$8.3 \times 10^{-6}/°F$
20-100C	$14.9 \times 10^{-6}/°C$
68-930F	$9.0 \times 10^{-6}/°F$
20-500C	$16.3 \times 10^{-6}/°C$
68-1830F	$10.4 \times 10^{-6}/°F$
20-1000C	$18.8 \times 10^{-6}/°C$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength .2% M psi	Elong 2" %	Red. Area %	Hard BHN	Rock B Hard
Wrought, annealed	60	–	–	–	–	–
Wrought, cold worked	135	–	–	–	–	–
Cast, .505 in.	55	21	32	4	75-85	48-54

NICKEL ALLOYS

Illium "R"

Chemical Composition – Nominal[1]

%	%	%	%
Ni 64	Cu 2.5	Fe 6	Si 0.15
Cr 22	Mo 5	Mn 0.3	C 0.05

[1]As given by the Illium Corp.

Characteristics. A machinable, heat and corrosion-resisting alloy available in wrought form for use where a wrought form of Illium is desirable. Withstands high temperature fluorine conditions better than Illium "G."

Physical Properties
Density, 0.31 lb/cu in (8.31 S.G.)
Specific heat, 0.110 cal. per Deg C
Electrical resistivity, 119.6 microhms/cm²/cm
Magnetic permeability, 26C, 1.0012
-30C, 1.0018
Coefficient of linear thermal expansion, 0-100C, 0.1202×10^{-4}
0-500C, 0.1398×10^{-4}

Technological Properties

Melting point	solidus	2415F or 1323C
	liquidus	2500F or 1371C
Weldability		Excellent with inert gas, arc or oxyacetylene
Soldering		Fair, with soft solder Good, with silver solder
Heat treatment		2150F water quench desirable for optimum corrosion resistance 2150F anneal for maximum softness and ductility.

Mechanical Properties

	Tensile Strength M psi	Yield Strength M psi	Elong %	Red Area %	Hard BHN	E 10^6 psi
Annealed	112.8	50.2	50	61	162-178	31.1
20% cold work	142.3	128.1	13	50	238-304	27.9

ZINC ALLOYS

Pure Zinc

Chemical Composition
This is spectroscopically pure zinc.

Characteristics. This is a special grade of zinc.

Uses. Research investigations.

Technological Properties

Melting point	787.03 F or 419.46 C
Boiling point	1663 F or 906 C

Physical Properties

Density, at 77F	0.258 lb/cu in. (7.133 S.G.)
Effect of temp	See Fig 1, P 1087 Metals Handbook
Specific heat, cal/gm at 68F	0.0915/°C
Volume conductivity, % of Cu	28.27%
Electrical resistivity, microhm/cms at 68F	5.916
Temp coefficient of electrical resistivity, microhm/cm³/°C at 32-212F	0.00419 (See Fig 5, p 1087 Metals Handbook)
Coefficient of friction, against zinc	0.21

Thermal Conductivity

Cgs units at 25C	0.27
Btu/ft²/ft/hr/°F at 77F	65.4

Coef. of Thermal Expansion

Temp Range	
68-482F	$22.0 \times 10^{-6}/°F$
20-250C	$39.7 \times 10^{-6}/°C$

$L_t = L_o(1 + 35.4 \times 10^{-6}t + 1 \times 10^{-6}t^2)$

ZINC ALLOYS

Zamak 3

Chemical Composition*

	%		%		%
Al	3.5 /4.3	Pb	.007 max	Fe	.100 max
Mg	.03/ .08	Cd	.005 max		
Cu	.1 max	Sn	.005 max		

*ASTM, B86, No. XXIII
Special high grade zinc is required

Technological Properties

Melting point	solidus	717.1 F or 380.6 C
	liquidus	727.9 F or 386.6 C
Weldability		Good with oxyacetylene
Soldering		Good with soft solder over nickel-plated surface

Characteristics. A popular zinc die casting alloy. Close chemical control is needed to avoid dimensional changes and intergranular attack.

Uses. Automotive parts such as carburetors, fuel pump bodies, speedometer frames, horns, heaters, grilles, brackets, hardware, instrument panels, etc., in numerous electrical appliances, business machines, oil burners, washing machines, kitchen equipment, various small tools, projectors, vending machines, hardware, toys, padlocks, etc.

Physical Properties
Density, at 70 F 0.24 lb/cu in. (6.6 S.G.)
Specific heat, cal/gm at 68-212 F 0.10
Volume conductivity, % of Cu 27%
Electrical resistivity, microhm/cm³ at 68 F 6.3694
Temperature coefficient of electrical resistivity, microhm/cm³/°C at 32-212 F 0.003774

Thermal Conductivity

Cgs units at 70-140C	0.27
Btu/ft²/ft/hr/°F at 158-284F	65.4

Mechanical Properties

Form or Condition	Tensile Strength M psi	Elong %	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp S M psi
Die cast, ¼ in.	41	10	82	31	6.875	60

[1] 500 kg load, 10 mm ball, 30 sec
[2] At 10^8 cycles

Coef. of Thermal Expansion

Temp Range	
68-212F	$15.2 \times 10^{-6}/°F$
20-100C	$27.4 \times 10^{-6}/°C$

ZINC ALLOYS

Zamak 5

Chemical Composition*	%		%		%
Al	3.5 /4.3	Pb	.007 max	Fe	.100 max
Cu	.75/1.25	Cd	.005 max		
Mg	.03/ .08	Sn	.005 max		

*ASTM, B86, Alloy XXV
Special high purity zinc is required.

Technological Properties

Melting point	solidus	716.7 F or 380.4 C
	liquidus	727 F or 386.1 C
Weldability		Good with oxyacetylene
Soldering		Good with soft solder over nickel-plated surface

Uses.[1] As sand castings this alloy is used for drop hammer dies.

[1]For die castings, see also Alloy XXIII, Zamak 3. Automotive parts such as carburetors, fuel pump bodies, speedometer frames, horns, heaters, grilles, brackets, hardware, instrument panels, etc., in numerous electrical appliances, business machines, oil burners, washing machines, kitchen equipment, various small tools, projectors, vending machines, hardware, toys, padlocks, etc.

Physical Properties
Density, at 70 F 0.24 lb/cu in. (6.7 S.G.)
Specific heat, cal/gm at 68-212 F 0.10
Volume conductivity, % of Cu 26%
Electrical resistivity, microhm/cm^3 at 68 F 6.5359
Temperature coefficient of electrical resistivity, microhm/cm^3/°C at 32-212 F 0.003527

Thermal Conductivity
Cgs units at 70-140C 0.26
Btu/ft^2/ft/hr/°F at 158-284F 63.0

Mechanical Properties

Form or Condition	Tensile Strength M psi	Elong %	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp S M psi
Die cast, ¼ in.	47.6	7	91	38	8.175	87

[1]500 kg load, 10 mm ball, 30 sec
[2]At 10^8 cycles

Coef. of Thermal Expansion

Temp Range	
68-212F	15.2×10^{-6}/°F
20-100C	27.4×10^{-6}/°C

ZINC ALLOYS

Zamak 2

Chemical Composition*	%		%		%
Al	3.5 /4.5	Pb	.007 max	Fe	.100 max
Cu	2.5 /3.5	Cd	.005 max		
Mg	.02/ .10	Sn	.005 max		

*ASTM, B86, Alloy XXI
Special high grade zinc is required.

Technological Properties

Melting point	solidus	714.7 F or 379.3 C
	liquidus	733.6 F or 389.8 C
Weldability		Good with oxyacetylene
Soldering		Good with soft solder over nickel-plated surface

Uses[1]. Sand castings for drop hammer dies.

[1]For die castings see Alloy XXIII, Zamak 3 and Alloy XXV, Zamak 5.

Physical Properties
Density, at 70 F 0.24 lb/cu in. (6.7 S.G.)
Specific heat, cal/gm at 68-212 F 0.10
Volume conductivity, % of Cu 25%
Electrical resistivity, microhm/cm^3 at 68 F 6.8493

Thermal Conductivity
Cgs units at 70-140C 0.25
Btu/ft^2/ft/hr/°F at 158-284F 60.5

Mechanical Properties

Form or Condition	Tensile Strength M psi	Elong %	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp S M psi
Die cast, ¼ in.	52.1	8	100	46	8.5	93

[1]500 kg load, 10 mm ball, 30 sec
[2]At 10^8 cycles

Coef. of Thermal Expansion

Temp Range	
68-212F	15.4×10^{-6}/°F
20-100C	27.7×10^{-6}/°C

ZINC ALLOYS

SLUSH CASTING ALLOY Zinc

Chemical Composition*					
	%		%		%
Al	4.50/5.00	Pb	.007 max	Sn	.005 max
Cu	.2 / .3	Cd	.005 max	Fe	.100 max

*Customary
Special high grade zinc is required

Technological Properties
Melting point solidus 716 F or 380 C
liquidus 734 F or 390 C

Characteristics. Its composition must be closely controlled to avoid warping, cracking, and intergranular attack.

Uses. Slush and permanent mold castings for lighting fixtures, etc.

Mechanical Properties Form or Condition	Tensile Strength M psi
Chill cast, ½ in. section	28

ZINC ALLOYS

SLUSH CASTING ALLOY Zinc

Chemical Composition*					
	%		%		%
Al	5.25/5.75	Pb	.007 max	Sn	.005 max
Cu	.1 max	Cd	.005 max	Fe	.100 max

*Customary
Special high grade zinc is needed.

Technological Properties
Melting point solidus 716 F or 380 C
liquidus 743 F or 395 C

Uses. For slush and permanent mold castings.

Mechanical Properties Form or Condition	Tensile Strength M psi	Elong %
Chill cast, ½ in. section	25	1

ZINC ALLOYS

Rolled Zinc

Chemical Composition					
	%		%		%
Pb	.10 max	Cd	.005 max	Sn	.001 max
Fe	.012 max	Cu	.001 max	Al	.001 max

Technological Properties

Melting point	786 F or 419 C
Hot working temp	525-250 F or 275-120 C
Hot shortness temp	570-786 F or 300-419 C
Formability	Good, by drawing, bending, roll forming, spinning, swaging, impact extrusion, above 70F
Soldering	Good

Characteristics. This is commercial rolled zinc of deep drawing quality. It is subject to slow creep under load, particularly at 212 F and above.

Uses. Battery cans, eyelets, grommets, laundry tags, address plates, flashing, etc. where strength and stiffness are not critical.

Physical Properties
Density, at 70 F 0.258 lb/cu in. (7.14 S.G.)
Specific heat, cal/gm at 68-212 F 0.094
Volume conductivity, % of Cu, hot rolled 28.44%
cold rolled 28.27%
Electrical resistivity, microhm/cm³ at 68 F
hot rolled 6.06
cold rolled 6.10

Thermal Conductivity
Cgs units at 18C, with grain 0.26
Btu/ft²/ft/hr/°F at 64F 60.5

Mechanical Properties

Form or Condition	Tensile Strength M psi Long.	Trans.	Elong % Long.	Trans.	Hard BHN	End Lt M psi[1]
Hot rolled strip	–	–	–	–	38	2.5
Directional Properties						
Hot rolled strip at 0.024 in.	19.5	23	65	50	–	–
Cold rolled strip at 0.024 in.	21	27	50	40	–	–

[1]At 10^8 cycles

Coef. of Thermal Expansion

Temp Range	
68-104F	18.0×10^{-6}/°F with grain
	12.8×10^{-6}/°F across grain
20-40C	32.5×10^{-6}/°C with grain
	23×10^{-6}/°C across grain

ZINC ALLOYS

Rolled Zinc

Chemical Composition	Pb %	Cd %	Fe %	Cu %
Strip	.05/.10	.05/.08	.012 max	.005 max
	Sn %	Al %		
Strip	.001 max	.001 max		

Technological Properties

Melting point	786 F or 419 C
Hot working temp	525-250 F or 275-120 C
Hot shortness temp	570-786 F or 300-419 C
Formability	Good, by drawing, bending, roll forming, spinning, swaging, and impact extrusion
Soldering	Good

Characteristics. Same as Zn:.08 Pb when parts require some rigidity.

Physical Properties
Density, at 70 F 0.258 lb/cu in. (7.14 S.G.)
Specific heat, cal/gm at 68-212 F 0.094 approx

Thermal Conductivity
Cgs units at 18C, with grain 0.26 approx
Btu/ft²/ft/hr/°F at 64F 60.5

Mechanical Properties

Form or Condition	Tensile Strength M psi Long.	Tensile Strength M psi Trans.	Elong % Long.	Elong % Trans.	Hard BHN	End Lt M psi[1]
Hot rolled strip	–	–	–	–	43	3.8
Directional Properties						
Hot rolled strip at 0.024 in.	21	25	52	30	–	–
Cold rolled strip at 0.024 in.	22	29	40	30	–	–

[1]At 10^8 cycles

Coef. of Thermal Expansion

Temp Range	
68-104F	$18.0 \times 10^{-6}/^{\circ}F$ with grain
	$12.8 \times 10^{-6}/^{\circ}F$ across grain
20-40C	$32.5 \times 10^{-6}/^{\circ}C$ with grain
	$23 \times 10^{-6}/^{\circ}C$ across grain

ZINC ALLOYS

Rolled Zinc

Chemical Composition	Pb %	Cd %	Fe %	Cu %
Strip	.25/.50	.25/.45	.02 max	.005 max
	Sn %	Al %		
Strip	.001 max	.001 max		

Technological Properties

Melting point	786 F or 419 C
Hot working temp	435-250 F or 225-120 C
Hot shortness temp	525-786 F or 275-419 C
Annealing temp	220 F or 105 C
Formability	Good, by drawing, bending, roll forming, swaging, and impact extrusion
Soldering	Good

Characteristics. It deforms under continuous load, particularly above 125 F.

Uses. Soldered battery cans, made of plate or strip, and for photoengraver's and lithographer's sheet.

Physical Properties
Density, at 70 F 0.258 lb/cu in. (7.14 S.G.)
Specific heat, cal/gm at 68-212 F 0.094 approx

Mechanical Properties

Form or Condition	Tensile Strength M psi Long.	Tensile Strength M psi Trans.	Elong % Long.	Elong % Trans.	Hard BHN	End Lt M psi[1]
Hot rolled strip	–	–	–	–	47	4.1
Directional Properties						
Hot rolled strip at 0.024 in.	23	29	50	32	–	–
Cold rolled strip at 0.024 in.	25	31	45	28	–	–

[1]At 10^8 cycles

Coef. of Thermal Expansion

Temp Range	
68-208F	$18.8 \times 10^{-6}/^{\circ}F$ with grain
	$13.0 \times 10^{-6}/^{\circ}F$ across grain
20-98C	$33.9 \times 10^{-6}/^{\circ}C$ with grain
	$23.4 \times 10^{-6}/^{\circ}C$ across grain

ZINC ALLOYS

COPPER HARDENED Rolled Zinc

Chemical Composition[1]

	%		%		%
Cu	.85/1.25	Fe	.012 max	Sn	.001 max
Pb	.10 max	Cd	.005 max	Al	.001 max

[1] Zilloy-40

Technological Properties

Melting point solidus	786 F or 419 C
liquidus	792 F or 422 C
Hot working temp	570-445 F or 300-175 C
Hot shortness temp	570-786 F or 300-419 C
Annealing temp	345 F, or 175 C
Formability	Good, by drawing, bending, roll forming, spinning, and swaging.
Soldering	Good

Characteristics. This is a stronger and stiffer alloy. It deforms under heavy, continuous loads, particularly at 125 F or higher.

Uses. Weatherstrip, name plates, ferrules, and drawn, formed, or spun articles requiring stiffness.

Physical Properties

Density, at 70F 0.259 lb/cu in. (7.18 S.G.)
Specific heat, cal/gm at 68-212F 0.0957 approx
Volume conductivity, % of Cu 28% approx
Electrical resistivity, microhm/cm³ at 68F, hot rolled 6.22

Mechanical Properties

Form or Condition	Tensile Strength M psi Long.	Trans.	Elong % Long.	Trans.	Hard BHN	End Lt M psi[1]
Hot rolled strip	–	–	–	–	52	6.1
Cold rolled strip	–	–	–	–	60	–
Directional Properties						
Hot rolled strip at 0.024 in.	24	32	20	15	–	–
Cold rolled strip at 0.024 in.	32	40	5	3	–	–

[1] At 10^8 cycles

ZINC ALLOYS

Rolled Zinc Alloy

Chemical Composition[1]

	Cu %	Mg %	Pb %	Fe %
Strip	.85/1.25	.006/.016	.15 max	.015 max
	Sn %	**Al %**	**Cd %**	
Strip	.001 max	.001 max	.04 max	

[1] Zilloy-15

Technological Properties

Melting point solidus	786 F or 419 C
liquidus	792 F or 422 C
Hot working temp	570-445 F or 300-175 C
Hot shortness temp	570-786 F or 300-419 C
Annealing temp	345 F or 175 C
Formability	Good, by drawing, bending, roll forming
Soldering	Good

Characteristics. A relatively strong zinc alloy. It deforms under heavy, continuous load, particularly at 125 F and above.

Uses. Corrugated roofing and flat, drawn, or mildly formed articles requiring maximum stiffness.

Physical Properties

Density, at 70 F 0.259 lb/cu in. (7.18 S.G.)
Specific heat, cal/gm at 68-212 F 0.0957
Volume conductivity, % of Cu 27%
Electrical resistivity, microhm/cm³ at 68 F, hot rolled 6.31

Thermal Conductivity

Cgs units at 18C, with grain 0.25
Btu/ft²/ft/hr/°F at 64F 60.5

Mechanical Properties

Form or Condition	Tensile Strength M psi Long.	Trans.	Elong % Long.	Trans.	Hard BHN	End Lt M psi[1]
Hot rolled strip	–	–	–	–	61	6.8
Cold rolled strip	–	–	–	–	80	–
Directional Properties						
Hot rolled strip at 0.024 in.	28	36	20	10	–	–
Cold rolled strip at 0.024 in.	37	48	20	2	–	–

[1] At 10^8 cycles

Coef. of Thermal Expansion

Temp Range	
68-212F	19.3×10^{-6}/°F with grain
	11.7×10^{-6}/°F across grain
20-100C	34.8×10^{-6}/°C with grain
	21.1×10^{-6}/°C across grain

LEAD ALLOYS

COMMERCIAL Pure Lead

Chemical Composition

	Ag %	Cu %	Ag + Cu %	As %	Sb + Sn %
Corroding Lead	.0015 max	.0015 max	.0025 max	.0015 max	.0095 max
Common Desilverized Lead A	.002 max	.0025 max	–	–	–
Common Desilverized Lead B	.002 max	.0025 max	–	–	–
Soft Undersilverized Lead	.002 max	.04 max	–	–	–
Acid Lead	.002 max	.040/.080	–	–	–
Copper Lead	.002 max	.040/.080	–	–	–

	As + Sb + Sn %	Zn %	Fe %	Bi %	Pb %
Corroding Lead	–	.0015 max	.002 max	.05 max	99.94 min
Common Desilverized Lead A	.015 max	.002 max	.002 max	–	–
Common Desilverized Lead B	.015 max	.002 max	.002 max	.25 max	99.73 min
Soft Undersilverized Lead	.015 max	.002 max	.002 max	.005 max	99.93 min
Acid Lead	.002 max	.001 max	.002 max	.025 max	99.90 min
Copper Lead	.015 max	.002 max	.002 max	.10 max	99.85 min

Technological Properties
Melting point 621F or 327.4C
Joining Good by soldering or "lead burning"

Physical Properties
Density, at 68-77F 0.4097 lb/cu in. (11.340 S.G.)

Uses. Storage batteries, cable sheath, ammunition, sheet, foil, gaskets, alloys, caulking, pipe and traps.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength[1] M psi	Elong %	Hard Rock[2]
Rolled sheet, longitudinal test	2.63	–	52[3]	75
Rolled sheet, longitudinal test	2.51	1.32	27[4]	75
Extruded sheet, longitudinal test	2.575	–	57[3]	78
Rolled sheet, longitudinal test	2.385	1.18	29[4]	71

[1] 0.5% offset
[2] ½ in. ball, 30 kg load, 30 sec special scale
[3] 2 in. gage length
[4] 8 in. gage length

Endurance Limit 520 psi at 10^8 cycles in flexure at 860 cycles/min, ⅛ in. sheet

LEAD ALLOYS

Calcium Lead

Chemical Composition

	%		%		%
Pb	rest	Sn	.005 max	Fe	–
Ag	.002/.02	Sb + Sn	–	Bi	.005 max
Cu	.02/.1	Ca	.023/.033		
Ag + Cu	–	Zn	–		

Technological Properties
Melting point solidus 621.3F or 327.4C
liquidus 621.5F or 327.5C
Joining Good with soft solder

Characteristics. The addition of a small amount of calcium hardens lead and increases its resistance to creep.

Uses. Cable sheath, battery grids.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Elong %	End Lt M psi[1]
Extruded	3	40	–
Extruded, aged 1 yr at r.t.	4.5	25	1.7

[1] 700 cycles/min

Physical Properties
Density, at 68F 0.409 lb/cu in. (11.34 S.G.)
Volume conductivity, in % of Cu 8.2%
Electrical resistivity, microhm/cm³ at 68F 21.1

Minimum creep rate at 80F 0.1% per yr at 360 psi

LEAD ALLOYS

Chemical Lead

Chemical Composition	%		%		%
Pb	99.90 min	As	–	Fe	.002 max
Ag	.002/.02	Sb + Sn	–	Bi	.025 max
Cu	.040/.080	As + Sb + Sn	.002 max		
Ag + Cu	–	Zn	.001 max		

Technological Properties

Melting point	618F or 325.6C
Recrystallization temp	About room temp but varies with the purity
Joining	By "lead burning", or by soft solder.

Characteristics. Relatively pure and is satisfactorily resistant to many corrosives, principally sulfuric acid. It is a general purpose lead.

Uses. Used principally in the construction of chemical equipment, and as pipe and sheet in building construction.

Coef. of Thermal Expansion

Temp Range	per Deg F	per Deg C
-310 to 66F or -190 to 19C	14.7×10^{-6}	26.5×10^{-6}
63 to 212F or 17 to 100C	16.3×10^{-6}	29.3×10^{-6}

Physical Properties

Density, at 68F	Cast	0.4092 lb/cu in. (11.34 S.G.)
	Rolled	0.41 lb/cu in. (11.36 S.G.)
Specific heat, cal/gm at 32F		0.0309/°C
Volume conduct., in % of Cu		8.3%
Electrical resistiv., microhm/cm³ at 68F		20.648
Temp coef. of electrical resistivity, microhm/cm³/°C, at 68-104F		0.00336

Thermal Conductivity

Temp Deg C	Deg F	Cgs units	Btu/ft²/ft/hr/°F
100	212	0.081	0.065
200	392	0.077	0.062
400	752	0.038	0.031
500	932	0.037	0.030
600	1112	0.036	0.029
700	1292	0.036	0.029

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong %	Red Area %	Hard BHN	Shear S M psi	End Lt M psi[1]	E 10^6 psi
Sand cast	1.8 ±	.8	30	100	4±	1.825	4.7	2
Chill cast	2	–	47	100	4	1.825	–	–

[1]At 10^8 cycles

Poisson's ratio 0.40 to 0.45

LEAD ALLOYS

Wiping Solder

Chemical Composition[1]	%		%		%
Pb	rest	Fe	–	Sb	0/2
Ag	–	Al	–	As	–
Bi	–	Sn	38/42		
Cu	–	Zn	–		

[1]Nominal

Characteristics. This is plumber's wiping solder.

LEAD ALLOYS

Antimonial Lead

Chemical Composition (Nominal)	
Pb%	Sb%
96	4

Technological Properties
Melting point solidus 495F or 260C
liquidus 578F or 300C

Characteristics. This addition of Sb materially hardens lead. Often referred to as hard lead.

Thermal Conductivity
Cgs units at 20-100C 0.073
Btu/ft²/ft/hr/°F at 68-212F 17.67

Physical Properties
Density, at 64F 0.398 lb/cu in. (11.04 S.G.)
Specific heat, cal/gm at 68-212F 0.0318/°C
Volume conductivity,
in % of Cu 7.7%, quenched from 235C, aged 150 days
Electrical resistivity,
microhm/cm³ at 68F 24.0

Coef. of Thermal Expansion

Temp Range	per Deg F	per Deg C
68 to 212F or 20 to 100C	15.4×10^{-6}	27.8×10^{-6}

Mechanical Properties

Form or Condition	Tensile Strength M psi	Elong %	Hard BHN[1]	End Lt M psi[2]
Commercially cold rolled, 95% red.	4.02	48.3	8.1	1.5
Heated to 235C, Q, aged 1 day	11.67	6.3	24	–

[1] 1/16 in. ball, 9.85 kg, 30 sec
[2] At 20×10^6 cycles

Minimum creep rate, cold rolled, at 86F 210 psi for 1%/10,000 hr

LEAD ALLOYS

Antimonial Lead

Chemical Composition (Nominal)	
Pb%	Sb%
94	6

Technological Properties
Melting point solidus 495F or 260C
liquidus 552F or 290C

Characteristics. This grade of antimonial lead has about the same corrosion resistance as soft lead but has greater strength. Often referred to as hard lead.

Uses. Rolled sheet and extruded pipe in building construction.

Thermal Conductivity
Cgs units at 20-100C 0.069
Btu/ft²/ft/hr/°F at 68-212F 16.70

Physical Properties
Density, at 64F 0.393 lb/cu in. (10.88 S.G.)
Specific heat, cal/gm at 68-212F 0.0322/°C
Volume conductivity,
in % of Cu 7.6%, quenched from 235C, aged 150 days
Electrical resistivity,
microhm/cm³ at 68F 25.3

Coef. of Thermal Expansion

Temp Range	per Deg F	per Deg C
68 to 212F or 20 to 100C	15.1×10^{-6}	27.2×10^{-6}

Mechanical Properties

Form or Condition	Test Temp Deg C	Tensile Strength M psi	Elong 2" %	Hard BHN	End Lt M psi[1]
Chill cast		6.84	24	13.0	2.5
Commercially cold rolled, 95%		4.1	47	–	1.5
Extruded		3.3	65	10.7	1.2
Effect of temp chill cast	100	3.5	–	6.8	–
	200	.85	–	2.0	–
Effect of temp cold rolled	100	1.85	–	3.9	–
	200	.6	–	1.6	–

[1] At 20×10^6 cycles

Minimum creep rate, cold rolled, at 86F 400 psi for 1%/10,000 hr
Minimum creep rate, cold rolled, at 212F 50 psi for 1%/10,000 hr

LEAD ALLOYS

8% Antimonial Lead

Technological Properties
Melting point solidus 486F or 252C
liquidus 520F or 271C

Chemical Composition (Nominal)	
Pb%	Sb%
92	8

Physical Properties
Density, at 64F 0.388 lb/cu in. (10.74 S.G.)
Specific heat, cal/gm at 68-212F 0.0326/°C
Volume conductivity,
in % of Cu 7.5%, quenched from 235C, aged 150 days
Electrical resistivity,
microhm/cm³ at 68F 26.5

Coef. of Thermal Expansion

Temp Range	per Deg F	per Deg C
68 to 212F or 20 to 100C	14.8×10^{-6}	26.7×10^{-6}

Mechanical Properties

Form or Condition	Tensile Strength M psi	Elong %	Hard BHN[1]	End Lt M psi[2]
Commercially rolled, 95%	4.65	31.3	9.5	1.75
235C, Q, aged 1 day	12.35	4.7	26.3	–

[1] 1/16 in. ball, 9.85 kg, 30 sec
[2] At 20×10^6 cycles

Thermal Conductivity
Cgs units at 20-100C 0.065
Btu/ft²/ft/hr/°F at 68-212F 15.73

Minimum creep rate, cold rolled, at 86F 425 psi for 1%/10,000 hr

LEAD ALLOYS

Grid Metal

Chemical Composition [1]

	%		%		%
Pb	rest	Cu	.05 max	Ag	.002 max
Sb	7/12	Bi	.05 max	Fe	.01 max
Sn	.10/.50	Ni	.005 max	Mn	.001 max
As	.05 max	Zn	.005 max		

[1] Typical

Technological Properties
Melting point solidus 486F or 252C
(10% Sb) liquidus 509F or 265C

Uses. Battery grids.

Physical Properties
Density, at 64F 0.385 lb/cu in. (10.66 S.G.)
Specific heat, cal/gm at 68-212F 0.0328/°C
Volume conductivity,
in % of Cu 7.4%, quenched from 235C, aged 150 days
Electrical resistivity,
microhm/cm³ at 68F 27.1

Mechanical Properties

Form or Condition	Tensile Strength M psi	Elong %	Hard BHN	End Lt M psi[1]
Chill cast	7.5	17	15.4	2.7

[1] At 20×10^6 cycles

Coef. of Thermal Expansion
26.4×10^{-6}/°C
14.6×10^{-6}/°F

Thermal Conductivity
Cgs units at 20-100C 0.064
Btu/ft²/ft/hr/°F at 68-212F 15.49

LEAD ALLOYS

5-95
Soft Solder

Chemical Composition[1]

	%		%		%
Pb	95	Bi	.25 max	Zn	.005 max
Sn	4.5/5.5	Cu	.08 max	Others	.08 max
Ag	–	Fe	.02 max		
Sb	.50 max	Al	.005 max		

[1] ASTM

Technological Properties
Melting point solidus 518F or 270C
liquidus 594F or 312C

Characteristics. This is a low tin alloy.

Uses. Coating metals and joining.

Physical Properties
Density, at 68F 0.397 lb/cu in. (11 S.G.)
Volume conductivity, in % of Cu 8.8%
Electrical resistivity, microhm/cm[3] 19.5

Thermal Conductivity

Cgs units at 54C	0.085
Btu/ft²/ft/hr/°F at 129F	20.57

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong %	Red. Area %	Hard BHN
	3.4	1.5	50	80	8

Coef. of Thermal Expansion

Temp Range	per Deg F	per Deg C
59 to 230F or 15 to 110C	15.9×10^{-6}	28.7×10^{-6}

LEAD ALLOYS

20-80
Soft Solder

Chemical Composition[1]

	%		%		%
Pb	80	Bi	.25 max	Zn	.005 max
Sn	20	Cu	.08 max	Others	.08 max
Ag	–	Fe	.02 max		
Sb	.50 max	Al	.005 max		

[1] ASTM

Technological Properties
Melting point solidus 361F or 183C
liquidus 531F or 277C

Characteristics. A relatively low tin solder.

Uses. Coating and joining metals and as body solder to fill dents and seams in automobile bodies. With less Sn (10%±) is used for Terne plate.

Physical Properties
Density, at 68F 0.368 lb/cu in. (10.20 S.G.)
Volume conductivity, in % of Cu 9.8%
Electrical resistivity, microhm/cm[3] 17.5

Thermal Conductivity

Cgs units at 54C	0.089
Btu/ft²/ft/hr/°F at 129F	21.54

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong %	Red. Area %	Hard BHN	Shear S M psi
	5.8	3.65	16	50	11.3	4.74

Coef. of Thermal Expansion

Temp Range	per Deg F	per Deg C
59-230F or 15-110C	14.7×10^{-6}	26.5×10^{-6}

LEAD ALLOYS

SILVER
Lead Solder

Chemical Composition[1]

	%		%		%
Pb	97.5	Bi	.25 max	Zn	.005 max
Sn	.75/1.25	Cu	.08 max	Others	.08 max
Ag	1.3/1.7	Fe	.02 max		
Sb	.40 max	Al	.005 max		

[1] ASTM

Technological Properties
Melting point 589F or 310C

Characteristics. This is a new solder composition with greatly reduced tin content.

Uses. Coating.

Mechanical Properties
Brinell Hardness No 13.0

LEAD ALLOYS

HALF & HALF Soft Solder

Technological Properties
Melting point solidus 361F or 183C
liquidus 421F or 216C

Chemical Composition[1]	Pb %	Sn %	Sb %	Bi %	Cu %
Grade 50A	50	50	.12 max	.25 max	.08 max
Grade 50B	50	50	.50 max	.25 max	.08 max

	Fe %	Al %	Zn %	Others %
Grade 50A	.02 max	.005 max	.005 max	.08 max
Grade 50B	.02 max	.005 max	.005 max	.08 max

[1]ASTM

Physical Properties
Density, at 68F 0.321 lb/cu in. (8.89 S.G.)
Specific heat, cal/gm at 60F 0.041/°C
Volume conductivity, in % of Cu 11%
Electrical resistivity, microhm/cm³ 15.6
Surface tension, at 662F or 350C in dynes/cm 472

Characteristics. This is the widely used soft solder.

Thermal Conductivity
Cgs units at 54C 0.111
Btu/ft²/ft/hr/°F at 129F 19.36

Coef. of Thermal Expansion

Temp Range	per Deg F	per Deg C
59-230F or 15-110C	19.7×10^{-6}	23.4×10^{-6}

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong %	Red. Area %	Hard BHN	Shear S M psi
	6.1	4.8	60	70	14.5	5.87

LEAD ALLOYS

LEAD BASE Babbitt

Chemical Composition[1]	Pb %	Sn %	Sb %	Cu %	As %
No. 13	rest	4.50/5.50	9.25/10.75	.5 max	.60 max

[1]SAE

Technological Properties
Melting point solidus 464F or 240C
liquidus 493F or 256C

Uses. For light loads and lower speeds, in car journal bearings.

Physical Properties
Density, 0.38 lb/cu in. (10.24 S.G.)
Specific heat, cal/gm at
68-459F or 20-237C 0.036/°C
Volume conductivity, in % of Cu 6.0%[1]
Electrical resistivity, microhm/cm³ 28.7[1]
[1]These values vary with the thermal treatment

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Elong %	Hard BHN	End Lt M psi[1]	E 10^6 psi
Chill cast	68F	10	5	19	3.7	4.2
Chill cast	212	4.9	30	8.5	–	–

[1]At 20×10^6 cycles

LEAD ALLOYS

ARSENICAL LEAD BASE Babbitt

Chemical Composition

	%		%		%
Pb	–	Bi	–	Cu	.6 max
Sn	.75/1.25	Al	–	Fe	–
Ag	–	As	.8/1.4		
Sb	14.5/17.5	Zn	–		

Technological Properties
Melting point solidus 595F or 247C
liquidus 667F or 353C

Characteristics. This Babbitt Metal has greater strength at elevated temperatures.

Uses. High loads and speeds, as in diesel engines, automotive engines, steamships, steel mills and machinery.

Mechanical Properties

Form or Condition	Test Temp Deg C	Tensile Strength M psi	Elong %	Hard BHN	End Lt M psi[1]	E 10^6 psi
Chill cast	25	10.35	2	20	4.3	4.2
Chill cast	100	6.4	9	12.5	–	–
Chill cast	150	3.74	26	7.4	–	–

[1]At 20×10^6 cycles

Physical Properties
Density, at 68F 0.365 lb/cu in. (10.1 S.G.)

LEAD ALLOYS

LEAD BASE Babbitt

Chemical Composition

	%		%		%
Pb	rest	Fe	—	As	.20 max
Ag	—	Sb	14/16	Zn	—
Sn	4.5/5.5	Al	—		
Bi	—	Cu	.5 max		

Technological Properties
Melting point solidus 464F or 240C
liquidus 522F or 272C

Physical Properties
Density, at 68F 0.36 lb/cu in. (10.04 S.G.)
Specific heat, cal/gm at 68-212F 0.036/°C
Volume conductivity, in % of Cu 6.1%[1]
Electrical resistivity, microhm/cm³ at 68F 28.2[1]

[1]These values vary with the thermal treatment

Uses. For light loads and moderate speeds — mining machinery, transmission machinery, car journals, etc.

Mechanical Properties

Form or Condition	Test Temp Deg C	Tensile Strength M psi	Elong %	Hard BHN	End Lt M psi[1]	E 10^6 psi
Chill cast .125 in.	25	10	5	20	3.9	4.2
Chill cast .125 in.	100	5.4	27	10	—	—
Chill cast .125 in.	150	2.9	55	7.3	—	—

[1]At 20 × 10^6 cycles

Thermal Conductivity
Cgs units at 20C 0.058
Btu/ft²/ft/hr/°F at 68F 14.04

Coef. of Thermal Expansion

Temp Range	per Deg F	per Deg C
68-212F or 20-100C	13.3×10^{-6}	24×10^{-6}

LEAD ALLOYS

LEAD BASE Babbitt

Chemical Composition

	%		%		%
Pb	rest	Cu	.5 max	Zn	—
Sn	9.3/10.7	Bi	—	Fe	.10 max
Ag	—	As	.60 max		
Sb	14/16	Al	—		

Technological Properties
Melting point solidus 464F or 240C
liquidus 514F or 268C

Physical Properties
Density, at 68F 0.35 lb/cu in. (9.73 S.G.)
Specific heat, cal/gm at 68-212F 0.038/°C
Volume conductivity, in % of Cu 6.0%[1]
Electrical resistivity, microhm/cm³ 28.6[1]

[1]These values vary with the thermal treatment

Uses. For moderate loads and speeds as in blowers, pumps, electric motors, and machine tools.

Mechanical Properties

Form or Condition	Test Temp Deg C	Tensile Strength M psi	Elong %	Hard BHN	End Lt M psi[1]	E 10^6 psi
Chill cast	25	10.5	4	22	4	4.2
Chill cast	100	5.5	25	10.5	—	—
Chill cast	150	3	52	8	—	—

[1]At 20 × 10^6 cycles

Thermal Conductivity
Cgs units at 20C 0.057
Btu/ft²/ft/hr/°F at 68F 13.79

Coef. of Thermal Expansion

Temp Range	per Deg F	per Deg C
68-212F or 20-100C	10.9×10^{-6}	19.6×10^{-6}

LEAD ALLOYS

ARSENICAL LEAD BASE Babbitt

Chemical Composition

	%		%		%
Pb	rest	Bi	—	Cu	.1 max
Sn	.6/1.0	Al	—	Fe	—
Ag	—	As	1.5/3.0		
Sb	12.0/13.5	Zn	—		

Technological Properties
Melting point solidus 477F or 247C
liquidus 595F or 313C

Characteristics. Retains strength and hardness exceptionally well at elevated temperatures.

Uses. Diesel, truck, and tractor engines and in heavy machinery.

Mechanical Properties

Form or Condition	Test Temp Deg C	Tensile Strength M psi	Elong %	Hard BHN	End Lt M psi[1]	E 10^6 psi
Chill cast	25	9.8	1.5	22	4.4	4.2
Chill cast	100	6.7	4	13.5	—	—
Chill cast	150	4.2	10	10.0	—	—

[1]At 20 × 10^6 cycles

Physical Properties
Density, at 68F 0.365 lb/cu in. (10.1 S.G.)

Pure Tin

Chemical Composition

	Sn %	Pb %	Sb %	Zn %	As %
Federal, QQ-7-371	99.75 min	.10 max	.10 max	nil	.10 max
Chempur tin[1]	99.9918	.0025	.0031	–	nil

	Cu %	Cr %	S %	Fe %	Bi %
Federal, QQ-7-371	nil	.10 max	.01 max	.01 max	.01 max
Chempur tin[1]	.0004	–	.0002	.0016	.0004

[1] Ag = nil, Co = nil

Technological Properties

Melting point	449.4 F or 231.9 C
Boiling point	4120 F or 2270 C
Transformation point (equilibrium)	55.8 F or 13.2 C
Recrystallization temp	Below room temp

Characteristics. Very soft and malleable, and highly resistant to water, the atmosphere, milk, and to numerous packaged products.

Uses. Pure tin is used for electrotinning, foil, collapsible tubes, tin plate, pipe.

Physical Properties

Density, alpha or gray tin at 33.8 F or 1 C 0.208 lb/cu in. (5.765 S.G.)
beta or white tin at 59 F or 15 C 0.2637 lb/cu in. (7.2984 S.G.)
Density of liquid tin
Volume change on transformation of white to gray tin + 27%
Specific heat, cal/gm at 32-212 F 0.0534 + 0.0000348 × t
(Also see Fig. 2, pg 1071, Metals Engineering Handbook)
Volume conductivity, % of Cu 15.0%
Electrical resistivity, microhm/cm^3 at 68 F 11.5
, liquid at m.p. in microhm/cm^3 48.1
Temperature coefficient of electrical resistivity, microhm/cm^3/°C at 32-212 F 0.00447

Thermal Conductivity

Cgs units at OC 0.16
Btu/ft^2/ft/hr/°F at 32F 38.72
(Also see Fig. 3, pg 1071, Metals Handbook)

Coef. of Thermal Expansion (White tin)

Temp Range	per Deg F	per Deg C
32-212F or 0-100C	12.8×10^{-6}	23×10^{-6}
68-448F or 20-231C	13.3×10^{-6}	24×10^{-6}

Effect of Temperature

(Use Figs. 4, 5 and 6, pg 1071, Metals Engineering Handbook)

Creep at Room Temperature

Wire 0.1 in. diam							
Applied stress, psi	75	155	230	310	390	540	775
Time, days	28	28	28	28	28	28	3
Elong., %	0	0	0.78	3.0	8.5	10.5	failed
Rolled strip 0.1 in. thick							
Applied stress, psi	160	195	325	400	470	610	1025
Time, days	551	551	173	79	21	4.6	0.5
Elong, %	3.5	7.0	101	132	119	105	78
Failure	No	No	Yes	Yes	Yes	Yes	Yes

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength .2% M psi	Elong %	Hard BHN	Hard VPN	Shear S M psi
Cast	2.1	–	55 (4 in.)	5.3	–	2.9
Chill cast	2.1	–	69 (2 in.)	–	–	–
Sheet, 0.1 in. annealed	2.4	–	96	–	–	–
Sheet, 0.040 in., 370F, 1 hr	2.2	1.3	45 (2 in.)	–	7.2	–
Sheet, 0.040 in., 30% red	2.8	2.0	35 (2 in.)	–	8.4	–
Foil, 0.0016 in.	2.0	–	6.5	–	–	–

Modulus of elasticity, E in 10^6 psi	6.0-6.5
Modulus of rigidity, in M psi	2,400
Poisson's ratio	0.33

TIN ALLOYS

Hard Tin

Chemical Composition (Nominal)	
Sn%	Cu%
99.6	0.4

Technological Properties
Melting point solidus 441 F or 227 C
liquidus 446 F or 230 C

Characteristics. Hard tin is harder than pure tin.

Uses. Collapsible tubes and foil.

Mechanical Properties Form or Condition	Tensile Strength M psi
Strip, 0.1 in., annealed 3 hr at 100C	3.3
Strip, 0.1 in., annealed 3 hr at 200C	3.1
Strip, cold reduced 80%	4.0

Bursting pressure of collapsible tube, 1 in. × 0.004 in. wall 46 psi

TIN ALLOYS

ANTIMONIAL Tin Solder

Chemical Composition (Nominal)	
Sn%	Sb%
95	5

Technological Properties
Melting point solidus 452 F or 233 C
liquidus 464 F or 240 C

Characteristics. This is a higher melting tin solder with better conductivity than high lead alloys.

Uses. Solder for electrical equipment, copper tubing, cooling coils for refrigerators, and avoids lead for service in contact with foodstuffs.

Physical Properties
Volume conductivity, % of Cu 11.9%
Electrical resistivity, microhm/cm³ at 77 F 14.5

Mechanical Properties Form or Condition	Tensile Strength M psi	Elong 4" %	Shear S M psi
Cast	5.9	38	6.0
Soldered copper joint	14.2	–	11.1

TIN ALLOYS

Tin Foil

Technological Properties
Melting point solidus 390 F or 199 C

Chemical Composition (Nominal)	
Sn%	Zn%
92	8

Uses. Packaging food products.

Physical Properties
Volume conductivity, % of Cu 14%
Electrical resistivity, microhm/cm³ 12.1

Thermal Conductivity
Cgs units at 0-200C 0.14
Btu/ft²/ft/hr/°F at 32-392F 33.88

Mechanical Properties Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong %
Foil	8.7	6	40

TIN ALLOYS

Tin-Silver Solder

Chemical Composition (Nominal)	
Sn%	Ag%
95	5

Uses. This is a solder for electrical work and high temperature service.

Technological Properties
Melting point solidus 430 F or 221 C
liquidus 473 F or 245 C

Mechanical Properties Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Shear S M psi
Sheet, 0.040 in., aged 14 d	4.6	3.6	49	–
Soldered copper joint	14	–	–	10.6

Physical Properties
Volume conductivity, % of Cu 16.6%
Electrical resistivity, microhm/cm^3 at 32 F 10.4
Temperature coefficient of electrical resistivity, microhm/cm^3/°C at 32-212 F 0.00423

TIN ALLOYS

Soft Solder

Chemical Composition*

	Sn %	Sb %	Bi %	Cu %	Fe %
Grade 70A	(1)	.12 max	.25 max	.08 max	.02 max
Grade 70B	(1)	.50 max	.25 max	.08 max	.02 max

	Zn %	Al %	Others %	Pb %
Grade 70A	.005 max	005 max	.08 max	rest
Grade 70B	.005 max	.005 max	.08 max	rest

*ASTM, B32-46T
[1] 69.00% min in composite sample, 68 50% min in random sample

Uses. A solder for joining and coating metals.

Technological Properties
Melting point solidus 361 F or 183 C
liquidus 378 F or 192 C

Physical Properties
Density, 0.300 lb/cu in. (8.32 S.G.)
Volume conductivity, % of Cu 11.8%
Electrical resistivity, microhm/cm^3 14.6

Mechanical Properties Form or Condition	Tensile Strength M psi	Hard BHN
Cast	6.8	12

Coef. of Thermal Expansion Temp Range	per Deg F	per Deg C
59-230F or 15-110C	12.0×10^{-6}	21.6×10^{-6}

TIN ALLOYS

Soft Solder

Chemical Composition*	Sn %	Sb %	Bi %	Cu %	Fe %
Grade 60A	(1)	.12 max	.25 max	.08 max	.02 max
Grade 60B	(1)	.50 max	.25 max	.08 max	.02 max

	Zn %	Al %	Others %	Pb %
Grade 60A	.005 max	.005 max	.08 max	rest
Grade 60B	.005 max	.005 max	.08 max	rest

*ASTM, B32-46T

[1] For fabricated metal, random sample = 61.50 min and composite sample = 62.00 min, for cast metal, composite sample = 62.50 min.

Technological Properties
Melting point 361 F or 183 C

Physical Properties
Density, 0.304 lb/cu in. (8.42 S.G.)
Volume conductivity, % of Cu 11.9%
Electrical resistivity, microhm/cm^3 · 14.5

Uses. Solder for electrical work.

Coef. of Thermal Expansion

Temp Range	per Deg F	per Deg C
59-230F or 15-110C	13.7×10^{-6}	24.7×10^{-6}

Thermal Conductivity
Cgs units at 0-180C 0.12
Btu/ft^2/ft/hr/°F at 32-356F 29.04

Creep Strength (Minimum)

Temp	0.0001 in /day
room	335 psi
176F or 80C	68 psi

Mechanical Properties

Form or Condition	Tensile Strength M psi	Elong 4" %	Hard BHN	Shear S M psi
Cast	7.5	32	14	6.2
Soldered copper joint	29	—	—	8.0

TIN ALLOYS

Tin Babbitt

Chemical Composition*	Sn %	Sb %	Cu %	Pb %
Chill cast	90/92	4/5	4/5	.35 max
Sand cast B23[1]	90/92	4/5	4/5	.35 max
Die cast B102	90/92	4/5	4/5	.35 max

	Fe %	As %	Zn %	Al %
Chill cast	.08 max	.10 max	none	none
Sand cast B23[1]	.08 max	.10 max	none	none
Die cast B102	.08 max	.08 max	.01 max	.01 max

*ASTM, B23 and B102

[1] Also Bi = .08% max

Technological Properties
Melting point solidus 433 F or 223 C
liquidus 700 F or 371 C

Physical Properties
Density, 0.265 lb/cu in. (7.34 S.G.)

Uses. Bearings and die castings.

Mechanical Properties

Form or Condition	Test Temp Deg F	Test Temp Deg C	Tensile Strength M psi	Hard BHN	End Lt M psi[1]	E 10^6 psi	Comp S M psi 25%	Comp YS M psi 0.125%	Comp YS M psi 0.3%
Chill cast	—	—	9.3	17	3.8	7.3	—	—	—
Effect of temp									
Chill cast	68	20	—	17	—	—	12.8	4.4	6.3
	140	60	—	—	—	—	—	—	5.2
	212	100	—	8	—	—	6.9	2.6	—
	302	150	—	—	—	—	—	—	—
	392	200	—	—	—	—	—	—	1.0

[1] At 20×10^6 cycles

TIN ALLOYS

Tin Babbitt

Chemical Composition*

	Sn %	Sb %	Cu %	As %	Fe %
Sand cast	88/90	7/8	3/4	.10 max	.08 max

	Pb %	Zn %	Al %	Bi %
Sand cast	.35 max	none	none	.08 max

*ASTM, B23-46T

Uses. This is an excellent bearing metal.

Technological Properties
Melting point solidus 466 F or 241 C
liquidus 669 F or 354 C

Physical Properties
Density, 0.267 lb/cu in. (7.39 S.G.)

Mechanical Properties

Form or Condition	Test Temp Deg F	Test Temp Deg C	Tensile Strength M psi	Yield Strength M psi[1]	Elong 2" %	Red. Area %	Hard BHN[1]	Comp S M psi 25%	Comp YS M psi .125%	E 10^6 psi[1]	End Lt M psi[2]
Chill cast	68	20	11.2	1.46	18	25	22	14.9	6.1	7.6	–
	120	49	9.2	–	24	27	–	–	–	–	–
	212	100	6.5	–	23	28	–	8.7	3	–	–
	300	149	4	–	32	38	–	–	–	–	–
	345	175	2.9	–	38	44	–	–	–	–	–
Chill cast from 600F into mold at 300F	–	–	12.6	–	–	–	24	–	–	–	4.8

[1] Cast from 750F into mold at 212F
[2] At 20 × 10^6 cycles

TIN ALLOYS

Tin Babbitt

Chemical Composition*

	%		%		%
Sn	82.5/84.5	Pb	.35 max	Bi	.08 max
Sb	7.5/ 9.0	Fe	.08 max	Zn	.005 max
Cu	7.5/ 9.0	As	.10 max	Al	.005 max

*ASTM, B23-46T

Uses. Used for bearings.

Technological Properties
Melting point solidus 464 F or 240 C
liquidus 792 F or 422 C

Physical Properties
Density, 0.269 lb/cu in. (7.46 S.G.)

Mechanical Properties

Form or Condition	Test Temp Deg F	Test Temp Deg C	Tensile Strength M psi	Elong %	Hard BHN	Comp S M psi 25%	Comp YS M psi .125%	Comp YS M psi .3%
Die cast	–	–	10	1	30	–	–	–
Chill cast	–	–	–	–	27	–	–	–
Effect of temp								
	68	20	–	–	27	17	6.6	8
	140	60	–	–	–	–	–	6.8
	212	100	–	–	14	9.9	3.1	5.1
	392	200	–	–	–	–	–	1

TIN ALLOYS

Tin Babbitt

Technological Properties
Melting point solidus 358 F or 181 C
liquidus 565 F or 296 C

Physical Properties
Density, 0.280 lb/cu in. (7.75 S.G.)

Chemical Composition*	Sn %	Sb %	Pb %	Cu %
Sand cast, B23	64/66	14/16	17/19	1.75/2.25
Chill cast	64/66	14/16	17/19	1.75/2.25
Die cast, B102	64/66	14/16	17/19	1.5 /2.5
	Fe %	**As %**	**Zn %**	**Al %**
Sand cast, B23	.08 max	.15 max	none	none
Chill cast	.08 max	.15 max	none	none
Die cast, B102	.08 max	.15 max	.01 max	.01 max

*ASTM, B23, B102

Uses. Bearings and die castings.

Mechanical Properties

Form or Condition	Test Temp Deg F	Test Temp Deg C	Hard BHN	Comp S M psi 25%	Comp YS M psi .125%
Chill cast	68	20	22.5	15	5
	212	100	10	6.7	2.1

TIN ALLOYS

Soft Solder

Technological Properties
Melting point solidus 361F or 183C
liquidus 421F or 216C

Chemical Composition[1]	Pb %	Sn %	Sb %	Bi %	Cu %
Grade 50A	50	50	.12 max	.25 max	.08 max
Grade 50B	50	50	.50 max	.25 max	.08 max
		Fe %	**Al %**	**Zn %**	**Others %**
Grade 50A		.02 max	.005 max	.005 max	.08 max
Grade 50B		.02 max	.005 max	.005 max	.08 max

[1]ASTM

Physical Properties
Density, at 68F 0.321 lb/cu in. (8.89 S.G.)
Specific heat, cal/gm at 60F 0.041/°C
Volume conductivity, in % of Cu 11%
Electrical resistivity, microhm/cm³ 15.6
Surface tension, at 662F or 350C in dynes/cm 472

Thermal Conductivity
Cgs units at 54C 0.111
Btu/ft²/ft/hr/°F at 129F 26.86

Coef. of Thermal Expansion

Temp Range	per Deg F	per Deg C
59-230F or 15-110C	13.0×10^{-6}	23.4×10^{-6}

Characteristics. This is the widely used soft solder.

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong %	Red. Area %	Hard BHN	Shear S M psi
	6.1	4.8	60	70	14.5	5.87

Pure Magnesium

Chemical Composition*

	Mg %	Cu %	Ni %
Sheet, wire, extrusions, ribbon, ingot	99.80 min	.02 max	.001 max
Powder – Grade C[1]	96. min	–	–

	Al, Cu, Fe, Mn, Ni, Si %
Sheet, wire, extrusions, ribbon, ingot	.20 max
Powder, Grade C[1]	–

*ASTM

[1]Fe = .05 max; insoluble residue = .25 max, Si = .10 max, grease and oil = .020 max, Fe and Al as oxides = .40 max.

Characteristics. Pure magnesium is chemically active.

Uses. Deoxidizer and getter, in pyrotechnics, and for dry electric current rectifiers. Grignard reaction, alloying ingredient in aluminum, lead and zinc alloys, deoxidizing and desulfurizing copper and nickel alloys, debismuthizing lead, reducing agent in production of metallic titanium and zirconium.

Physical Properties[1]

Density, at 68 F 0.0628 lb/cu in. (1.74 S.G.)
Specific heat, cal/gm at 78 F or 25 C 0.25/°C
Heat of combustion 5995 cal/gm
Volume conductivity, % of Cu 38.6%
Electrical resistivity, microhm/cm³ at 68 F 4.46
Temperature coefficient of electrical resistivity, microhm/cm³/°C at 68 F 0.01784

[1]50% cold reduction lowers the conductivity about 6%

Technological Properties

Melting point	1202 F or 650 C
Recrystallization temp	1 hr anneal after 30% red. 350 F, 99.85% Mg; 200 F, 99.99% Mg
Hot working temp	900-450 F or 480-230 C
Annealing temp	650 F or 345 C
Machinability index	500, with free cutting brass = 100
Weldability	Good with oxyacetylene, resistance welding, and particularly with helium arc
Riveting	Use aluminum alloy 56S-H12

Thermal Conductivity

Cgs units at 18C	0.376 approx
Btu/ft²/ft/hr/°F at 64F	91.3 approx

Coef. of Thermal Expansion

Temp Range	
40C	$26 \times 10^{-6}/°C^{1}$
104F	$14.4 \times 10^{-6}/°F$

[1]$L_t = L_0\,[1 + (24.80t + 0.00961t^2) \times 10^{-6}]$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength .2% M psi	Elong %	Rock E Hard	Hard BHN[1]	Shear S M psi	End Lt M psi[2]
Sand cast, ½ in.	12	3	6	-16	30	–	–
Sheet, annealed	27	14	16	36	40	17	9
Sheet, hard rolled	37	27	9	59	50	–	–

[1]500 kg load, 10 mm ball
[2]At 50 × 10⁷ cycles with cantilever specimen

Modulus of elasticity, E in M psi 6,500
Modulus of rigidity, in M psi 2,400
Poisson's ratio 0.35

MAGNESIUM ALLOYS

Mazlo AM244

Chemical Composition

	%		%		%
Mg	rest	Zn	.3 max	Ni	.01 max
Al	3.5/5.0	Si	.3 max	Others	.3 max
Mn	.20 min	Cu	.05 max		

Technological Properties

Melting point	solidus	1045 F or 565 C
	liquidus	1165 F or 630 C
Machinability index		500, with free cutting brass = 100
Weldability		Good with oxyacetylene, resistance welding, and helium arc

Characteristics. This is not a strong alloy.

Uses. Low-stressed, pressure-tight castings.

Physical Properties

Density, at 68 F 0.064 lb/cu in. (1.76 S.G.)
Specific heat, cal/gm at 78 F or 25 C 0.25 approx
Volume conductivity, % of Cu 17.2%
Electrical resistivity, microhm/cm³ at 68 F 10.0

Thermal Conductivity

Cgs units, 100-300C	0.23 approx
Btu/ft²/ft/hr/°F, 212-572F	55.7 approx

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength .2% M psi	Elong %	Rock. E Hard	Hard BHN	Shear S M psi	Comp YS M psi
Sand cast, 1/2 in.	24	9	6	46	44	14	9

Coef. of Thermal Expansion

Temp Range	
40C	$26 \times 10^{-6}/°C$
104F	$14.4 \times 10^{-6}/°F$

Modulus of elasticity, E in M psi 6,500
Modulus of rigidity, in M psi 2,400
Poisson's ratio 0.35

MAGNESIUM ALLOYS

AM11

Chemical Composition

	Al %	Mn %	Fe %	Ni %
Die cast	1.0/1.5	.5/1.5	.005 max	.005 max

	Cu %	Si %
Die cast	.05 max	.30 max

Technological Properties

Melting point	solidus	1165 F or 630 C
	liquidus	1190 F or 645 C
Aging treatment		475 F or 245 C, 4 hr, air cool
Machinability index		500, with free cutting brass = 100

Characteristics. General die casting alloy, particularly for parts requiring ductility and toughness.

Physical Properties

Density, at 68 F 0.062 lb/cu in. (1.705 S.G.)
Specific heat, cal/gm at 68-662 F or 20-350 C 0.25

Coef. of Thermal Expansion

Temp Range	
18-100C	$26 \times 10^{-6}/°C$
65-212F	$14.4 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong %	Rock. E Hard	Hard BHN
Section tested 0.061 sq in. Die cast, aged	32	21	9	65	60

Modulus of elasticity, E in M psi 6,500
Modulus of rigidity, in M psi 2,400
Poisson's ratio 0.35

A8

Chemical Composition*

	Al %	Mn %	Zn %	Si %
Sand cast	7.8/9.2	.15 min	.3 max	.3 max
Ingot	8.0/9.0	.18 min	.2 max	.2 max

	Cu %	Ni %	Others %
Sand cast	.10 max	.01 max	.3 max
Ingot	.08 max	.01 max	.3 max

*ASTM

Characteristics. Alloy A8 produces tough, leak-proof castings.

Technological Properties

Melting point solidus	918 F or 492 C
liquidus	1125 F or 607 C
Solution treatment, HT	800 F or 425 C, 14 hr, cool in strong air blast
Aging treatment, HTA	400 F or 205 C, 16 hr, cool in air
Weldability	Good with oxyacetylene, resistance welding, and helium arc
Machinability index	500, with free cutting brass = 100

Physical Properties
Density, at 68 F 0.065 lb/cu in. (1.80 S.G.)
Specific heat, cal/gm at 78 F or 25 C 0.25 approx
Volume conductivity, HT condition, % of Cu 11.5% approx
Electrical resistivity, microhm/cm³ at 68 F 15.0 as HT

Thermal Conductivity
Cgs units at 100-300C 0.18 approx
Btu/ft²/ft/hr/°F at 212-572F 43.5 approx

Coef. of Thermal Expansion

Temp Range	
40C	$26 \times 10^{-6}/°C$
104F	$14.4 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Test Temp Deg F	Test Temp Deg C	Tensile Strength M psi	Yield Strength .2% M psi	Elong %	Rock. E Hard	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi
Sand cast			29	14	6	51	46	–	6	14
Sand cast, HT			39	12	14	55	48	18	8	12
Sand cast, HTA			39	15	9	–	–	–	–	15
Effect of Temp[3]										
Sand cast, HT	300	150	21	10	16	–	–	–	–	–
	400	205	14	8	22	–	–	–	–	–
	500	260	9	5	40	–	–	–	–	–

[1] 500 kg load, 10 mm ball
[2] Rotating beam, at 50×10^7 cycles
[3] After long holding at test temperature

Modulus of elasticity, E in M psi 6,500
Modulus of rigidity, in M psi 2,400
Poisson's ratio 0.35

MAGNESIUM ALLOYS

A10

Chemical Composition*

		Al %	Mn %	Zn %	Si %
Sand cast,	A10	9.0/11.0	.10 min	.3 max	.3 max
Permanent mold,	A10	9.3/10.7	.10 min	.3 max	.3 max
Extrusions,	A10X	9.5/10.5	.10 min	.3 max	.3 max
Ingot,	A10	9.4/10.6	.13 min	–	.2 max

		Cu %	Ni %	Fe %	Others %
Sand cast,	A10	.10 max	.01 max	–	.3 max
Permanent mold,	A10	.10 max	.01 max	–	.3 max
Extrusions,	A10X	.05 max	.005 max	.005 max	.3 max
Ingot,	A10	.08 max	.01 max	–	.3 max

*ASTM

Technological Properties

Melting point solidus	867 F or 464 C
liquidus	1101 F or 594 C
Hot working temp	750-450 F or 400-230 C (hot short above 810 F or 430 C)
Annealing temp, wrought	650 F or 345 C
Solution treatment, HT	790 F or 420 C, 20 hr, cool in strong air blast
Aging treatment, partial, A	325 F or 165 C, 12 hr, air cool
Aging treatment, complete, A	350 F or 175 C, 20 hr, air cool
Stabilizing treatment, S[1]	500 F or 260 C, 4 hr, air cool
Machinability index	500, with free cutting brass = 100
Weldability	Good by oxyacetylene or helium arc
Riveting	Use Aluminum Alloy 56S-H12 rivets

[1]Used on castings (AC or HT) to minimize growth at elevated temp

Characteristics. Alloy A10 has a good combination of strength and ductility. It also produces high strength bars and shapes by extrusion and can be strengthened by heat treatment.

Uses. Sand and permanent mold castings which are pressure-tight.

Physical Properties

Density, at 68 F 0.066 lb/cu in. (1.81 S.G.)
Specific heat, cal/gm at 78 F or 25 C 0.25, approx

Volume conductivity, % of Cu	
AC	11.5%, approx
HT	9.9%, approx
HTA	12.3%, approx
Wrought	9.7%, approx

Electrical resistivity, microhm/cm³, at 68 F	
AC	15.0%, approx
HT	17.5%, approx
HTA	14.0%, approx
Wrought	18.0%, approx

Coef. of Thermal Expansion

Temp Range	
40C	26 × 10^{-6}/°C
104F	14.4 × 10^{-6}/°F

Thermal Conductivity

Cgs units at 100-300C	0.17 approx
Btu/ft²/ft/hr/°F at 212-572F	41.1 approx

Mechanical Properties

Form or Condition	Test Temp Deg F	Test Temp Deg C	Tensile Strength M psi	Yield [6] Strength M psi	Elong %	Rock. E Hard	Hard, BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi
1/2 in. bars[3]										
Sand cast, (SC) AC			22 (20)	12 (20)[6]	2 (1)	64	53	18	10	12
Perm. mold, (PM) AC			22	12[6]	2	64	53	18	10	12
PM or SC, HT			40 (32)	13 (10)[6]	10 (6)	62	52	20	11	13
PM or SC, HTA			40 (34)	19 (17)[6]	1 (–)	80	69	22	10	19
PM or SC, S			22	16[6]	2	70	58	–	–	16
PM or SC, HTS			38	18[6]	1	78	67	–	–	18
Extruded bar			51	38[6]	9	81	70	23	18	27
Bearing strength										
PM or SC, HT 3/16" pin diam			69	45[4]	–	–	–	–	–	–
PM or SC, HTA 3/16" pin diam			81	68[4]	–	–	–	–	–	–
Effect of temp[5]										
Sand cast	-108	-78	22	18	1	–	63	–	–	–
Sand cast, HT	-108	-78	38	18	7	–	60	–	–	–
Sand cast, HT	200	93	34	–	1.5	–	–	–	–	–
Sand cast, HT	300	149	23	–	9	–	–	–	–	–
Sand cast, HT	500	260	12	–	22	–	–	–	–	–
Sand cast, HTA	-108	-78	39	26	2	–	85	–	–	–
Sand cast, HTA	300	149	24	9	4	–	–	–	–	–
Sand cast, HTA	400	204	17	6.5	25	–	–	–	–	–
Sand cast, HTA	500	260	12	4	45	–	–	–	–	–
Sand cast, HTA	600	316	8.5	2.5	60	–	–	–	–	–
Sand cast, HTA	700	371	5.5	1.5	100	–	–	–	–	–

[1]500 kg load, 10 mm ball
[2]Rotating beam test at 50 × 10^7 cycles
[3]Values in parentheses are specified minimum values
[4]2.0%
[5]Properties of quenched and aged material determined after long holding at test temp
[6]0.2%

Modulus of elasticity, E in M psi	6,500
Modulus of rigidity, in M psi	2,400
Poisson's ratio	0.35

M1

Chemical Composition

	Mn %	Co %	Si %	Cu %
Sand cast[1]	1.20 min	—	.3 max	.05 max
Ingot[1]	1.30 min	—	.3 max	.05 max
Wrought[2]	1.20 min	.3 max	.3 max	.05 max

	Ni %	Others %
Sand cast[1]	.01 max	.3 max
Ingot[1]	.01 max	.3 max
Wrought[2]	.01 max	.3 max

[1]Government — AN-M-36.
[2]Government — AN-M-26, sheet, welding wire, extrusions and forgings.

Characteristics. M1 is a low-cost alloy of moderate mechanical properties with the best weldability, and hot formability.

Uses. Castings to be welded to M1 wrought products.

Physical Properties

Density, at 68 F 0.064 lb/cu in. (1.76 S.G.)
Specific heat, cal/gm at 78 F or 25 C 0.25, approx
Volume conductivity, % of Cu 25.7% as cast
34.5% wrought
Electrical resistivity, microhm/cm^3 at 68 F
6.7 as cast
5.0 wrought

Technological Properties

Melting point solidus	1198 F or 648 C
liquidus	1200 F or 649 C
Hot working temp	1000-560 F or 540-295 C
Annealing temp	700 F or 370 C
Stress relieving, annealed sheet	500 F for 15 min
Stress relieving, hard-rolled sheet	400 F for 60 min
Stress relieving, extrusions	500 F for 15 min
Recrystallization temp	500 F or 260 C, 60 min, for 20% reduction
Machinability index	500, with free cutting brass = 100
Weldability	Good by oxyacetylene, resistance, and helium arc methods
Riveting	Use aluminum alloy rivets 56S-H12

Thermal Conductivity

Cgs units at 100-300C 0.30 Approx
Btu/ft^2/ft/hr/°F at 212-572F 72.6 approx

Coef. of Thermal Expansion

Temp Range	
20-100C	26 $\times 10^{-6}$/°C
68-212F	14.4 $\times 10^{-6}$/°F

Mechanical Properties

Form or Condition	Test Temp Deg F	Test Temp Deg C	Tensile Strength M psi	Yield Strength M psi	Elong %	Rock. E Hard	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi	Bear. YS M psi	Bear. TS M psi
Sheet, annealed[3]			33 (28)	18 (12)[5]	17 (12)	55	48	17	9	12	29	51
Sheet, hard			35 (32)	26 (22)[5]	7 (4)	65	54	17	10	20	39	57
Forgings			36 (30)	23 (18)[5]	7 (5)	54	47	16	—	—	—	—
Extrusions, bars			38 (30)	28 (20)[5]	10 (3)	41	42	16	9	13	—	—
Extrusions, shapes			36 (29)	25 (17)[5]	11 (3)	50	46	16	—	12	35	56
Extrusions, tubing			35 (28)	23 (13)[5]	8 (3)	41	42	—	—	10	—	—
Sand cast			14 (12)	4.5 (4)[5]	5 (3)	3	33	11	—	4.5	—	—
Directional Properties, M1 sheet												
Annealed, longitudinal			33	18[5]	17	—	—	—	—	—	—	—
transversal			32	17[5]	17	—	—	—	—	—	—	—
Hard rolled, longitudinal			35	26[5]	7	—	—	—	—	—	—	—
transversal			37	27[5]	13	—	—	—	—	—	—	—
Effect of Temp												
Forgings	95	35	33.6	18.8	11.6[4]	—	—	—	—	—	—	—
	200	93	23.1	13.8	25.7[4]	—	—	—	—	—	—	—
	250	121	22.4	16	25.5[4]	—	—	—	—	—	—	—
	300	149	19.9	12	30.7[4]	—	—	—	—	—	—	—
	400	204	17.2	9.1	34.2[4]	—	—	—	—	—	—	—
	500	260	10.1	5.9	87.5[4]	—	—	—	—	—	—	—
	600	316	6	3.8	140.0[4]	—	—	—	—	—	—	—
Extrusions	95	35	39.6	30.9	7.6[4]	—	—	—	—	—	—	—
	200	93	27	21.3	15.0[4]	—	—	—	—	—	—	—
	250	121	24.4	18.8	20.2[4]	—	—	—	—	—	—	—
	300	149	21.3	15.7	18.7[4]	—	—	—	—	—	—	—
	400	204	18.8	11.7	25.0[4]	—	—	—	—	—	—	—
	500	260	13	7.5	60.0[4]	—	—	—	—	—	—	—
	600	316	9	5.4	93.0[4]	—	—	—	—	—	—	—
Sheet, Annealed	95	35	33	20.2	17.7[4]	—	—	—	—	—	—	—
	200	93	24.2	16.2	31.0[4]	—	—	—	—	—	—	—
	250	121	21.6	14.7	40.5[4]	—	—	—	—	—	—	—
	300	149	19.3	12.7	44.0[4]	—	—	—	—	—	—	—
Sheet, hard rolled	95	35	36	27	10.0[4]	—	—	—	—	—	—	—
	200	93	29.7	26.7	7.7[4]	—	—	—	—	—	—	—
	250	121	27.3	24.5	11.7[4]	—	—	—	—	—	—	—
	300	149	25	21.2	16.0[4]	—	—	—	—	—	—	—

[1]500 kg load, 10 mm ball
[2]At 50 × 10^7 cycles
[3]Values in parentheses are specified minimum values
[4]2 in.
[5].2%

Modulus of elasticity, E in M psi 6,500
Modulus of rigidity, in M psi 2,400
Poisson's ratio 0.35

AZ92

Chemical Composition

	Al %	Mn %	Zn %	Si %
Sand cast	8.3/9.7	.10 min	1.6/2.4	.3 max
Permanent mold	8.3/9.7	.10 min	1.7/2.3	.3 max
Welding wire	8.3/9.7	.10 min	1.7/2.3	.3 max
Ingot	8.5/9.5	.13 min	1.7/2.3	.2 max

	Cu %	Ni %	Others %
Sand cast	.25 max	.01 max	.03 max
Permanent mold	.25 max	.01 max	.03 max
Welding wire	.25 max	.01 max	.03 max
Ingot	.20 max	.01 max	.03 max

Technological Properties

Melting point	solidus	830 F or 445 C
	liquidus	1100 F or 595 C
Solution treatment,	HT	760 F or 405 C, 20 hr, strong air blast cool
Artificial aging,	A	420 F or 215 C, 14 hr, air cool
Stabilizing treatment,[1]	S	500 F or 260 C, 4 hr, air cool
Machinability index		500, with free cutting brass = 100
Weldability		Satisfactory with resistance methods

[1]Used on AC or HT conditions to minimize growth at elevated temp

Characteristics. AZ92 has high strength and is a very versatile alloy for sand and permanent mold castings.

Physical Properties

Density, at 68 F 0.066 lb/cu in. (1.82 S.G.)
Specific heat, cal/gm at 78 F 0.25 approx
Volume conductivity, % of Cu AC 12.3%, approx
HT 10.5%, approx
HTA 12.3%, approx
Electrical resistivity, microhm/cm^2 at 68 F
AC 14.0%
HT 16.5%
HTA 14.0%

Thermal Conductivity

Cgs units, 100-300C 0.17 approx
Btu/ft^2/ft/hr/°F, 212-572F 41.1 approx

Coef. of Thermal Expansion

Temp Range	
40C	26 × 10^{-6}/°C
104F	14.4 × 10^{-6}/°F

Mechanical Properties

Form or Condition	Test Temp Deg F	Test Temp Deg C	Tensile Strength M psi	Yield Strength .2% M psi	Elong %	Rock. E Hard	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS .2% M psi	Bear. YS M psi[3]	Bearing Ult. Str. M psi[3]
1/2 in. bars[4]												
Sand cast (SC)			25 (20)	14 (10)	2 (–)	76	65	18	12	14	–	–
Perm. mold (PM)			25	14	2	76	65	18	12	14	–	–
PM or SC, HT			40 (34)	14 (10)	10 (6)	75	63	20	13	14	–	–
PM or SC, HTA			40 (34)	22 (18)	3 (1)	88	81	22	12	22	–	–
PM or SC, S			25 (20)	17 (11)	1 (–)	80	69	19	11	17	52	57
PM or SC, HTS			40 (34)	21 (16)	3 (1)	86	78	21	13	21	63	78
Effect of temp												
Sand cast[6]	200	93	25	–	2	–	–	–	–	–	–	–
Sand cast[7]	300	149	22	–	3	–	–	–	–	–	–	–
Sand cast[7]	400	204	16	–	36	–	–	–	–	–	–	–
Sand cast[5]	500	260	12	–	34	–	–	–	–	–	–	–
Sand cast, HT[7]	200	93	40	–	8	–	–	–	–	–	–	–
Sand cast, HT[7]	300	149	26	–	40	–	–	–	–	–	–	–
Sand cast, HT[7]	400	204	17	–	41	–	–	–	–	–	–	–
Sand cast, HT[5]	500	260	11	–	52	–	–	–	–	–	–	–
Sand cast, HTA[7]	200	93	38	–	7	–	–	–	–	–	–	–
Sand cast, HTA[7]	300	149	25	–	40	–	–	–	–	–	–	–
Sand cast, HTA[7]	400	204	17	–	43	–	–	–	–	–	–	–
Sand cast, HTA[5]	500	260	12	–	47	–	–	–	–	–	–	–

[1]500 kg load, 10 mm ball
[2]Rotating beam at 50 × 10^7 cycles
[3]3/16 in. pin diam.
[4]Values in parentheses are specified minimum values
[5]Held at test temp 40 days
[6]Held at test temp 80 days
[7]Held at test temp 160 days

Modulus of elasticity, E in M psi	6,500
Modulus of rigidity, in M psi	2,400
Poisson's ratio	0.35

AZ63

Chemical Composition*

	Al %	Zn %	Mn %	Si %
Sand cast; welding wire	5.3/6.7	2.5/3.5	.15 min	.3 max
Ingot	5.5/6.5	2.7/3.3	.18 min	.2 max

	Cu %	Ni %	Others %
Sand cast; welding wire	.25 max	.01 max	.3 max
Ingot	.20 max	.01 max	.3 max

*ASTM

Technological Properties

Melting point	solidus	850 F or 455 C
	liquidus	1130 F or 610 C
Solution treatment	HT	730 F or 388 C, 10 hr, air cool
Aging treatment,	A	375 F or 190 C, 18 hr, air cool
Stabilizing treatment,[1]	S	500 F or 260 C, 4 hr, air cool
Machinability index		500, with free cutting brass = 100

[1]Used to minimize growth at elevated temp

Characteristics. General purpose sand casting alloy with good strength and best ductility and toughness.

Physical Properties

Density, at 68 F 0.066 lb/cu in. (1.84 S.G.)

Specific heat, cal/gm at 78 F or 25 C 0.25/°C, approx

Volume conductivity, % of Cu	AC	15.0%
	HT	12.3%
	HTA	13.8%
Electrical resistivity, microhm/cm³ at 68 F	AC	11.5%
	HT	14.0%
	HTA	12.5%

Thermal Conductivity

Cgs units at 100-300C	0.18 approx
Btu/ft²/ft/hr/°F at 212-572F	43.5 approx

Coef. of Thermal Expansion

Temp Range	
20-100C	26 $\times 10^{-6}$/°C
68-212F	14.4 $\times 10^{-6}$/°F

Mechanical Properties

Form or Condition	Test Temp Deg F	Test Temp Deg C	Tensile Strength M psi	Yield Strength M psi	Elong %	Rock. E Hard	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi	Comp S M psi	Bear. S M psi	Bear. YS M psi
1/2 in. bars[3]													
Sand cast			29 (24)	14 (10)	6 (4)	59	50	18	11	14	45	–	–
Sand cast, HT			40 (34)	14 (10)	12 (7)	66	55	19	14	14	46	–	–
Sand cast, HTA			40 (34)	19 (16)	5 (3)	83	73	20	13	19	50	–	–
Sand cast, S			29 (24)	14 (10)	5 (2)	–	–	19	11	14	–	66	45
Sand cast, HTS			40 (34)	17 (13)	7 (4)	71	59	20	13	17	–	70	47
Effect of temp													
AC	75	24	28.6	13.7	4.5	–	–	–	–	–	–	–	–
	150	66	30.5	–	3.0	–	–	–	–	–	–	–	–
	200	93	30.1	–	4.5	–	–	–	–	–	–	–	–
	250	121	27.7	–	7.5	–	–	–	–	–	–	–	–
	300	149	24.1	–	20	–	–	–	–	–	–	–	–
	400	204	15.3	–	50	–	–	–	–	–	–	–	–
	500	260	10.3	–	38	–	–	–	–	–	–	–	–
HT	75	24	36.8	13.6	10.0	–	–	–	–	–	–	–	–
	150	66	36.7	–	9.0	–	–	–	–	–	–	–	–
	200	93	34.3	–	7.0	–	–	–	–	–	–	–	–
	250	121	30.0	–	9.0	–	–	–	–	–	–	–	–
	300	149	22.4	–	33	–	–	–	–	–	–	–	–
	400	204	14.6	–	38	–	–	–	–	–	–	–	–
	500	260	10.9	–	26	–	–	–	–	–	–	–	–
HTA	95	35	38.7	17.7	5.5	–	–	–	–	–	–	–	–
	200	93	36.0	17.3	11	–	–	–	–	–	–	–	–
	250	121	32.4	16.5	11	–	–	–	–	–	–	–	–
	300	149	24.5	15.0	15	–	–	–	–	–	–	–	–
	400	204	17.5	12.0	17	–	–	–	–	–	–	–	–
	500	260	12.0	8.8	15	–	–	–	–	–	–	–	–
	600	316	8.2	5.6	20	–	–	–	–	–	–	–	–

[1]500 kg load, 10 mm ball
[2]Rotating beam at 50 × 10^7 cycles
[3]Values in parentheses are specified minimum values

Modulus of elasticity, E in M psi	6,500
Modulus of rigidity, in M psi	2,400
Poisson's ratio	0.35

MAGNESIUM ALLOYS

AZ31X

Chemical Composition*

	Al %	Mn %	Zn %	Ca %	Si %
Sheet	2.5/3.5	.2 min	.6/1.4	.3 max	.3 max
Welding wire	2.5/3.5	.2 min	.6/1.4	.3 max	.3 max
Extrusions	2.5/3.5	.2 min	.6/1.4	.3 max	.3 max

	Cu %	Ni %	Fe %	Others %
Sheet	.05 max	.005 max	.005 max	.3 max
Welding wire	.05 max	.005 max	.005 max	.3 max
Extrusions	.05 max	.005 max	.005 max	.3 max

*ASTM

Technological Properties

Melting point solidus	1050 F or 565 C
liquidus	1170 F or 630 C
Hot working temp	800-450 F or 425-230 C
Hot shortness temp	Above 820 F or 440 C
Annealing temp	650 F or 345 C
Recrystallization temp	400 F or 205 C, 1 hr, after 15% reduction
Heat treatment, stress relief—annealed sheet	500 F in 15 min
Heat treatment, stress relief—hard-rolled sheet	300 F in 60 min
Heat treatment, stress relief—extrusions	500 F in 15 min
Machinability index	500, with free cutting brass = 100
Weldability	Good with oxyacetylene, resistance, and helium arc methods
Riveting	Use aluminum alloy 56S-H12

Characteristics. AZ31X has good strength and high resistance to corrosion, good weldability, and best forming properties as sheet and plate.

Uses. Low-cost extruded bars, rods, shapes, structural sections, and tubing with good mechanical properties and the highest % elongation.

Physical Properties

Density, at 68 F 0.064 lb/cu in. (1.78 S.G.)
Specific heat, cal/gm at 78 F or 25 C 0.25, approx
Volume conductivity, % of Cu 18.5%
Electrical resistivity, microhm/cm^3 at 68 F 9.3

Thermal Conductivity

Cgs units at 100-300C	0.23 approx
$Btu/ft^2/ft/hr/°F$ at 212-572F	55.7 approx

Coef. of Thermal Expansion

Temp Range	
40C	26 $\times 10^{-6}/°C$
104F	14.4 $\times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Test Temp Deg F	Test Temp Deg C	Tensile Strength M psi	Yield Strength M psi	Elong %	Rock. E Hard	Hard BHN[1]	Shear S M psi	End Lt M psi	Comp YS M psi	Bear. YS M psi[2]	Bearing Ult. Str. M psi[2]
Annealed sheet[5]			37 (32)	22 (15)[3]	21 (12)	66	55	21	11	16	37	76
Hard sheet			42 (38)	33 (26)[3]	11 (4)	82	72	23	13	29	54	79
Extruded, bar			40 (35)	30 (22)[3]	17 (10)	59	50	19	15[4]	17	–	–
Extruded, shape			39 (33)	26 (20)[3]	15 (8)	59	50	19	–	15	–	–
Extruded, tubing			35 (32)	22 (16)[3]	18 (8)	59	50	–	–	15	–	–
Press forged			38	25	15	59	50	19	–	–	–	–
Directional Properties, AZ31X Sheet												
Annealed, longitudinal			37	22	21	–	–	–	–	–	–	–
transversal			39	25	19	–	–	–	–	–	–	–
Hard rolled, longitudinal			44	34	11	–	–	–	–	–	–	–
transversal			46	36	15	–	–	–	–	–	–	–
Effect of temp												
Sheet, hard rolled[6]	-112	-80	48	34	–	–	–	–	–	–	–	–
	-18	-28	45	34	–	–	–	–	–	–	–	–
	212	100	30	21	30	–	–	–	–	–	–	–
	300	149	22	13	45	–	–	–	–	–	–	–
	400	204	15	8.5	55	–	–	–	–	–	–	–
	500	260	11	4.5	75	–	–	–	–	–	–	–
	600	316	6	3	125	–	–	–	–	–	–	–
	700	371	4	2	140	–	–	–	–	–	–	–
Extruded bar	200	93	31	20	33	–	–	–	–	–	–	–
	300	149	26	14	50	–	–	–	–	–	–	–
	400	204	17	9.5	65	–	–	–	–	–	–	–
	500	260	15	5.5	55	–	–	–	–	–	–	–
	572	300	–	3.1	–	–	–	–	–	–	–	–
	600	316	10	–	90	–	–	–	–	–	–	–

[1] 500 kg load, 10 mm ball
[2] 3/16 in. pin diam
[3] .2%
[4] At 50×10^7 cycles
[5] The values in parentheses are specified minimum values
[6] Tests at elevated temperatures, after long holding at test temp

Modulus of elasticity, E in M psi	6,500
Modulus of rigidity, in M psi	2,400
Poisson's ratio	0.35

AZ80X

Chemical Composition*

	Al %	Zn %	Mn %	Si %
Extrusions, forgings	7.8/9.2	.2/.8	.10 min	.3 max

	Cu %	Ni %	Fe %	Others %
Extrusions, forgings	.05 max	.005 max	.005 max	.3 max

*QQ-M-40

Characteristics. Alloy AZ80X is a high strength wrought alloy. Its strength can be increased by heat treatment.

Uses. Extruded products and press forgings.

Physical Properties

Density, at 68 F	0.066 lb/cu in. (1.80 S.G.)
Specific heat, cal/gm at 78 F	0.25/°C, approx
Volume conductivity, % of Cu	10.6% extruded 14.6% aged
Electrical resistivity, microhm/cm³ at 68 F	16.2 extruded 11.8 aged

Technological properties

Melting point solidus	900 F or 480 C
liquidus	1115 F or 600 C
Recrystallization temp	650 F or 345 C, 1 hr anneal after 10% reduction
Machinability index	500, with free machining brass = 100
Hot working temp	750-600 F or 400-315 C
Hot shortness temp	Above 775 F or 420 C
Annealing temp	725 F or 385 C
Solution heat treatment	750 F or 400 C, 2-4 hr, air cool
Aging treatment	350 F or 175 C, 16-24 hr, air cool
Stress relieving, extrusions	400 F or 205 C, 1 hr
HTA, extrusions	600 F or 315 C, ¼ hr
Weldability	Good by oxyacetylene, resistance, and helium arc methods
Riveting	Use aluminum alloy 56S-H12

Thermal Conductivity

Cgs units at 100-300C	0.18
Btu/ft²/ft/hr/°F at 212-572F	43.5

Coef. of Thermal Expansion

Temp Range	
20-100C	26×10^{-6}/°C
68-212F	14.4×10^{-6}/°F

Mechanical Properties

Form or Condition	Test Temp Deg F	Test Temp Deg C	Tensile Strength M psi	Yield Strength M psi	Elong %	Rock. E Hard	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi	Bear. YS M psi	Bearing Ult. S M psi
Forgings, as forged[3]			46 (42)	31 (26)[4]	8 (5)	80	69	22	18	25	–	–
Aged			50 (42)	34 (28)[4]	6 (2)	82	72	23	16	28	–	–
Extrusions, as extruded			49 (43)	35 (28)[4]	12 (9)	75	63	21	19	26	–	–
Aged			50	36[4]	7	87	80	22	19	34	–	–
Heat treated, aged			53 (48)	40 (33)[4]	7 (4)	87	80	22	–	36	–	–
Shapes, as extruded			48 (41)	32 (25)[4]	12 (6)	78	67	21	–	21	51	80
Aged			50	34[4]	10	87	80	22	–	33	–	–
Heat treated, aged			52 (47)	37 (30)[4]	9 (5)	90	85	22	–	35	62	92
Effect of temp												
Forgings, heat treated, aged	95	35	52.9	39.5	4.5	–	–	–	–	–	–	–
	300	150	31	20.7	30	–	–	–	–	–	–	–
Extrusions, heat treated, aged	95	35	56.5	40.5	4.5	–	–	–	–	–	–	–
	200	93	48.5	32.1	20	–	–	–	–	–	–	–
	250	120	42	26.6	33	–	–	–	–	–	–	–
	300	150	33.6	21.4	41	–	–	–	–	–	–	–
	400	205	21.6	14.7	49	–	–	–	–	–	–	–
	500	260	13.6	7.8	83	–	–	–	–	–	–	–
	600	315	8.7	4.7	123	–	–	–	–	–	–	–

[1] 500 kg load, 10 mm ball
[2] At 50×10^7 cycles
[3] Values in parentheses are specified minimum values
[4] .2%

Modulus of elasticity, E in M psi	6,500
Modulus of rigidity, in M psi	2,400
Poisson's ratio	0.35

AZ61X

Chemical Composition*

	Al %	Mn %	Zn %	Si %
Welding wire	5.8/7.2	0.15 min	.4/1.5	.3 max
Extrusions	5.8/7.2	0.15 min	.4/1.5	.3 max
Forgings	5.8/7.2	0.15 min	.4/1.5	.3 max

	Cu %	Ni %	Fe %	Others %
Welding wire	.05 max	.005 max	.005 max	.3 max
Extrusions	.05 max	.005 max	.005 max	.3 max
Forgings	.05 max	.005 max	.005 max	.3 max

*Government

Technological properties

Melting point solidus	950 F or 510 C
liquidus	1140 F or 615 C
Recrystallization temp	550 F or 290 C, 1 hr anneal after 20% reduction
Machinability index	500, with free cutting brass = 100
Hot working temp	750-450 F or 400-230 C
Hot shortness temp	Above 780 F or 415 C
Annealing temp	650 F or 345 C
Stress relief, extrusions	500 F for 15 min
Weldability	Good by oxyacetylene, resistance, and helium arc methods
Riveting	Use aluminum alloy 56S-H12

Characteristics. Alloy AZ61X has good mechanical properties and resistance to corrosion.

Uses. Good general purpose alloy for extrusions and forgings of intermediate cost.

Physical Properties

Density, at 68 F 0.065 lb/cu in. (1.80 S.G.)
Specific heat, cal/gm at 78 F 0.25, approx
Volume conductivity, % of Cu 11.6%
Electrical resistivity, microhm/cm³ at 68 F 14.9

Thermal Conductivity

Cgs units at 100-300C	0.19 approx
Btu/ft²/ft/hr/°F at 212-572F	46.0 approx

Coef. of Thermal Expansion

Temp Range	
40C	26 × 10^{-6}/°C
104F	14.4 × 10^{-6}/°F

Mechanical Properties

Form or Condition	Test Temp Deg F	Test Temp Deg C	Tensile Strength M psi	Yield Strength M psi	Elong %	Rock. E Hard	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi	Bear. YS M psi[3]	Bearing Ult. S M psi[3]
Press forged[4]			43 (38)	26 (22)[7]	12 (6)	66	55	21	16	18	–	–
Extruded bar			45 (40)	32 (26)[7]	15 (11)	67	56	21	17	21	–	–
Extruded shape			44 (40)	29 (22)[7]	16 (9)	72	60	20	–	18	45	76
Extruded tubing			40 (36)	22 (16)[7]	15 (7)	66	55	–	–	15	–	–
Effect of temp												
Extruded bar[5]	-112[6]	-80[6]	47	37	14	–	–	–	–	–	–	–
	-18	-28	45	33	14	–	–	–	–	–	–	–
	212	100	35	25	35	–	–	–	–	–	–	–
	300	149	22	17	50	–	–	–	–	–	–	–
	400	204	16	12	60	–	–	–	–	–	–	–
	500	260	12	7	100	–	–	–	–	–	–	–
	572	300	–	2	–	–	–	–	–	–	–	–
	600	316	9.5	–	45	–	–	–	–	–	–	–

[1] 500 kg load, 10 mm ball
[2] Rotating beam at 50 × 10^7 cycles
[3] 3/16 in. pin diam
[4] Values in parentheses are specified minimum values
[5] Values for elevated temperatures determined after prolonged holding at test temp
[6] 70 BHN or 80 Rock E; E = 6,800 M psi
[7] .2%

Modulus of elasticity, E in M psi	6,500
Modulus of rigidity, in M psi	2,400
Poisson's ratio	0.35

AZ91

Chemical Composition*

	Al %	Zn %	Mn %	Si %
Sand cast	8.3/9.7	.4/1.0	.13 min	.3 max
Ingot	8.5/9.5	.5/ .9	.15 min	.2 max

	Cu %	Ni %	Others %
Sand cast	.10 max	.01 max	.3 max
Ingot	.08 max	.01 max	.3 max

*ASTM

Technological Properties

Melting point	solidus	875 F or 468 C
	liquidus	1105 F or 596 C
Hot shortness temp		Above 750 F or 400 C
Machinability index		500, with free cutting brass = 100

Characteristics. The most generally used magnesium die casting alloy.

Physical Properties
Density, at 68 F 0.066 lb/cu in. (1.81 S.G.)
Specific heat, cal/gm at 78 F 0.25 approx
Volume conductivity, % of Cu 10.1%
Electrical resistivity, microhm/cm^3 at 68 F 17.0

Thermal Conductivity
Cgs units at 100-300C 0.17
Btu/ft^2/ft/hr/°F at 212-572F 41.1

Coef. of Thermal Expansion

Temp Range	
20-100C	26 × 10^{-6}/°C
68-212F	14.4 × 10^{-6}/°F

Mechanical Properties

Form or Condition	Test Temp Deg F	Test Temp Deg C	Tensile Strength M psi	Yield Strength .2% M psi	Elong %	Rock. E Hard	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi	Comp S M psi
			33	22	3	72	60	20	14	22	58
Effect of temp	95	35	34.2	21.9	4.0[3]	–	–	–	–	–	–
	200	93	32.7	21.1	5.0[3]	–	–	–	–	–	–
	300	149	27.6	16.2	14.7[3]	–	–	–	–	–	–
	450	232	14.6	9.8	17.0[3]	–	–	–	–	–	–
	600	316	7	3.6	20.7[3]	–	–	–	–	–	–

[1] 500 kg load, 10 mm ball
[2] At 50 × 10^7 cycles
[3] 2 in.

Modulus of elasticity, E in M psi 6,500
Modulus of rigidity, in M psi 2,400
Poisson's ratio 0.35

AZ51X

Chemical Composition*

	%		%		%
Al	4.1/5.5	Si	.3 max	Ni	.005 max
Zn	.4/1.3	Ca	.3 max	Fe	.005 max
Mn	.15 min	Cu	.05 max	Others	.3 max

* (AN-M-28)

Characteristics. Alloy AZ51X is used only for sheet.
Uses. It has good properties and forms readily hot.

Technological properties

Melting point solidus	990 F or 530 C
liquidus	1150 F or 620 C
Recrystallization temp	550 F or 290 C, 1 hr anneal after 20% reduction
Machinability index	500, with free cutting brass = 100
Hot working temp	785-500 F or 420-260 C
Hot shortness temp	Above 800 F or 425 C
Annealing temp	650 F or 345 C
Stress relieving, annealed sheet	500 F, 15 min
Stress relieving, hard-rolled sheet	375 F, 60 min
Weldability	Good by oxyacetylene and resistance methods but helium arc is preferred
Riveting	Use aluminum alloy 56S-H12

Physical Properties
Density, at 68 F 0.065 lb/cu in. (1.79 S.G.)
Specific heat, cal/gm at 78 F 0.25, approx
Volume conductivity, % of Cu 12.8%
Electrical resistivity, microhm/cm^3 at 68 F 13.5

Thermal Conductivity
Cgs units at 100-300C 0.21
Btu/ft^2/ft/hr/°F at 212-572F 50.8

Coef. of Thermal Expansion

Temp Range	
20-100C	26 × 10^{-6}/°C
68-212F	14.4 × 10^{-6}/°F

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong %	Rock. E Hard	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi	Bear. YS M psi	Bearing Ult. S M psi
Sheet, annealed[3]	40 (37)	21 (19)[4]	19 (8)	68	57	20	13	16	—	–
Sheet, hard	45 (42)	34 (32)[4]	10 (3)	81	71	22	14	26	54	79
Directional Properties, Sheet										
Annealed, // to rolling direction	40	21	19	–	–	–	–	–	–	–
Annealed, ⊥ to rolling direction	41	25	18	–	–	–	–	–	–	–
Hard rolled, // to rolling direction	45	34	10	–	–	–	–	–	–	–
Hard rolled, ⊥ to rolling direction	49	39	14	–	–	–	–	–	–	–

[1] 500 kg load, 10 mm ball
[2] At 50 × 10^7 cycles
[3] Values in parentheses are specified minimum values
[4] .2%

Modulus of elasticity, E in M psi	6,500
Modulus of rigidity, in M psi	2,400
Poisson's ratio	0.35

TA54

Chemical Composition*

	%		%		%
Al	3.0/4.0	Si	.3 max	Others	.3 max
Mn	.40 min	Cu	.05 max		
Sn	4.0/6.0	Ni	.005 max		

*Government

Characteristics. Alloy TA54 has intermediate strength.

Uses. General purpose hammer-forging alloy.

Technological properties

Hot working temp	820-450 F or 440-230 C
Hot shortness temp	Above 850 F or 455 C
Annealing temp	650 F or 345 C
Machinability index	500, with free cutting brass = 100
Riveting	Use aluminum alloy 56S-H12

Physical Properties

Density, at 68 F 0.067 lb/cu in. (1.84 S.G.)
Specific heat, cal/gm at 78 F 0.25 approx
Volume conductivity, % of Cu 12.5%
Electrical resistivity, microhm/cm^3 at 68 F 13.8

Coef. of Thermal Expansion

Temp Range	
40C	$26 \times 10^{-6}/°C$
104F	$14.4 \times 10^{-6}/°F$

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength .2% M psi	Elong %	Rock. E Hard	Hard BHN[1]	Shear S M psi	End Lt M psi[2]	Comp YS M psi
Forged[3]	40 (36)	28 (22)	12 (7)	62	52	16	11	21

[1] 500 kg load, 10 mm ball
[2] At 50×10^7 cycles
[3] Values in parentheses are specified minimum values

Modulus of elasticity, E in M psi	6,500
Modulus of rigidity, in M psi	2,400
Poisson's ratio	0.35

SUPER ALLOY, WROUGHT

19-9 W Mo

Chemical Composition (Typical)

	%		%		%
C	.12 max	Cr	19	Cb	.50
Mn	.50	Ni	8.5	Co	–
Si	.60	Mo	.35	N	–
P		W	1.25	Al	–
S		Ti	.35	Fe	–

Characteristics. A moderately strong alloy, more comparable to 316.

Fatigue Strength !

Condition	Temp	10^8 cycles M psi	2.5×10^8 cycles M psi
2000F, WQ, 4 hr at 1200F	1200F	37	35

! *Westinghouse Research Laboratory*

Stress-Rupture Strength[1] (M psi)

Temp	100 hr	1000 hr
1000 F	–	–
1100	–	–
1200	54.5	42
1300	–	–
1350	28.5	–
1400	–	–
1500	–	–
1600	–	–
1700	–	–
1800	–	–

[1] Wrought alloy, 26% reduction at 1200 F, stress relieved at 1200 F

Creep Strength[1] (M psi)

Stress for 1% creep in

Temp	100 hr	1000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	6.6
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	–	–	–
1600	–	–	–

! Hot rolled, stress relieved at 1200F

SUPER ALLOY, WROUGHT

19-9 DL

Chemical Composition (Typical)

	%		%		%
C	.25	Cr	19	Cb	.30
Mn	.50	Ni	9	Co	–
Si	.60	Mo	1.25	N	–
P		W	1.20	Al	–
S		Ti	.20	Fe	–

Physical Properties

Density, at 70F or 21C
0.287 lbs/cu in. (7.933 S.G.)

Coef. of Thermal Expansion

Temp Range Deg F	Temp Range Deg C	Coefficient $\times 10^{-6}$* per Deg F	Coefficient $\times 10^{-6}$* per Deg C
70-600	21-315	9.31	16.76
-800	-426	9.59	17.26
-1000	-537	9.78	17.60
-1200	-648	9.97	17.95
-1500	-815	10.01	18.02

Fatigue Strength

Condition	Temp	10^8 cycles M psi
2100F, 1 hr, AC, cold worked 15% at 1200F, aged 4hr at 1200F	1200F	43
	1500	17

* *Grant*

Stress-Rupture Strength (M psi)

Temp	100 hr	1000 hr
1000F	–	–
1100	–	–
1200	43[1], 42[2], 62[3]	36[1], 34.5[2], 50[3]
1300	–	–
1350	35[3]	20.5[3]
1400	–	–
1500	11[4]	10[5]
1600	–	–
1700	–	–
1800	–	–

[1] Hot rolled
[2] Annealed 2100F, AC
[3] Hot forged, reduced 21% at 1200F
[4] Hot worked, aged at 1500F
[5] 2250F, ½ hr, OQ, 50 hr at 1500F (Grant)

Creep Strength! (M psi)

Stress for 1% creep in

Temp	1000 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	13	–
1400	–	–	–
1500	10.4	6.5	<5
1600	–	–	–

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Red. Area %
2100F, 1 hr, AC Finish roll 1200F, SR at 1200F, AC	70F	141	115	30	48
	1200F	91	–	–	–

SUPER ALLOY, WROUGHT

234-A-5

Chemical Composition (Typical)

	%		%		%
C	.38	Cr	18.5	Cb	.60
Mn	4.2	Ni	4.5	Co	–
Si	.30	Mo	1.35	N	–
P		W	1.3	Al	–
S		Ti		Fe	–

Stress-Rupture Strength (M psi)

Temp	100 hr	1000 hr
1000F	–	–
1100	–	–
1200	50[1], 47.5[2], 53[3]	39[1], 37[2], 32[3]
1300	–	–
1350	22.5[1]	12.5[1]
1400	–	–
1500	–	–
1600	–	–
1700	–	–
1800	–	–

1 Hot forged
2 Annealed 2050F, WQ
3 Annealed 2050F, WQ, reduced 20% at 1200F, stress relieved at 1200F

SUPER ALLOY, WROUGHT

TIMKEN
16-25-6

Creep Strength (M psi)*

Temp	1000 hr *	10,000 hr	100,000 hr
	Stress for 1% creep in		
1000F	–	–	–
1100	–	–	–
1200	21.5	20[1]	12.8[1]
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	8.4	6.6[1], 7[2]	4.5[1], 5[2]
1600	–	–	–

1 2150F, WQ
2 2150F, WQ, 50 hr at 1500F

Stress-Rupture Strength (M psi)

Temp	100 hr	1000 hr
1000F	–	–
1100	–	–
1200	52[1], 49[2], 57[3]	39[1], 35[2], 42[3]
1300	–	–
1350	28.5[1], 25.5[2], 28[3]	19[3]
1400	–	–
1500	12.9[4]	<10[4]
1600	–	–
1700	–	–
1800	–	–

1 Hot rolled, stress relieved at 1200F
2 2100F, AC
3 2100F, AC, reduced 22.5% at 1200F, stress relieved at 1200F
4 Stress relieved 50 hr at 1500F

Chemical Composition (Typical)

	%		%		%
C	.10	Cr	16.7	Cb	–
Mn	1.35	Ni	25.2	Co	–
Si	.70	Mo	6.25	N	.15
P		W	–	Al	–
S		Ti	–	Fe	–

Physical Properties

Density at 70F or 21C
0.291 lbs/cu in. (8.059 S.G.)

Coef. of Thermal Expansion *

Temp Range Deg F	Temp Range Deg C	Coefficient × 10⁻⁶ per Deg F	Coefficient × 10⁻⁶ per Deg C
70-600	21-315	9.28	16.70
-800	-426	9.29	16.72
-1000	-537	9.36	16.85
-1200	-648	9.52	17.14
-1500	-815	9.69	17.44

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Red. Area %
2100F, 1 hr, AC	70F	162*	143.5	15.5	34
Roll to 1200F, stress relieve at 1200F, AC	1200F	107.5*	94	13	28

* *Grant*
† *Westinghouse Research Laboratory*

Fatigue Strength †

Condition	Temp	10⁸ cycles M psi	25 x 10⁸ cycles M psi
2000F, WQ, 4 hr 1200F	1200F	46	–
2150F, WQ, 50 hr 1500F	1500	19	18

SUPER ALLOY, WROUGHT

LOW C
N-155

Creep Strength[1] (M psi)

Temp	1000 hr	10,000 hr	100,000 hr
	Stress for 1% creep in		
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	16	12.5
1400	–	–	–
1500	9.8	9	6.5
1600	–	–	–

1 2200F, WQ, 50 hr at test temp

Stress-Rupture Strength (M psi)

Temp	100 hr	1000 hr
1000F	–	–
1100	–	–
1200	58[1], 49[2], 47[3], 51[4]	48[1], 38[2], 37[3], 46[4]
1300	–	–
1350	36[1], 30[3]	27.5[1], 22.5[3]
1400	–	–
1500	20[1], 18.8[3]	12.5[1]
1600	–	–
1700	5.1[5], 7.6[6] 4.9[6]	2.5[5], 4.8[6] 2.8[6]
1800		

1 Hot forged
2 Hot rolled
3 2200F, WQ, 50 hr at 1350F
4 Hot rolled, reduced 20% at 1200F, stress relieved at 1200F
5 Stress relieved at 1200F
6 The condition = 2280F, AC

Chemical Composition (Typical)

	%		%		%
C	.15	Cr	21.5	Cb	1.0
Mn	1.5	Ni	20	Co	20
Si	.50	Mo	3.0	N	.15
P	–	W	2.0	Al	–
S	–	Ti	–	Fe	Rest

Physical Properties

Density at 70F or 21C
0.296 lbs/cu in. (8.199 S.G.)

Coef. of Thermal Expansion *

Temp Range Deg F	Temp Range Deg C	Coefficient × 10⁻⁶ per Deg F	Coefficient × 10⁻⁶ per Deg C
70-600	21-315	8.70	15.66
-800	-426	8.89	16.00
-1000	-537	9.10	16.38
-1200	-648	9.40	16.92
-1500	-815	9.77	17.59

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Red. Area %
Reduced 10% at 1200F	70F	147*	121	25	47
	1200F	116*	–	13	23
Hot worked	1350F	80*	68	24	37
2300F, ¾ hr, WQ 1500F, 4 hr, FC	1500F	50*	29	34	35

* *Grant*

Fatigue Strength

Condition	Temp	10⁸ cycles M psi	2.5 x 10⁸ cycles M psi
Aged 50 hr at 1200F	1200F	66	–
Aged 50 hr at 1500F	1500	33	32

SUPER ALLOY, WROUGHT

N-155

Chemical Composition (Typical)

	%		%		%
C	.36	Cr	21	Cb	1
Mn	1.5	Ni	21	Co	20.5
Si	.60	Mo	3	N	.1
P	–	W	2	Al	–
S	–	Ti	–	Fe	Rest

Stress-Rupture Strength (M psi)

Temp	100 hr	1000 hr
1000F	–	–
1100	–	–
1200	59[1], 52[2]	46[1], 39[2]
1300	–	–
1350[5]	28[1]	20[1]
1400	–	–
1500	21.5[3]	16.5[3]
1600	15.5[4]	11.4[4]
1700	–	–
1800	–	–

1 Hot rolled, stress relieved at 1200F
2 2100F, AC
3 2200F, WQ, 50 hr at 1500
4 Hot worked, 2300F, 1 hr, WQ; 1500F, 4 hr, AC - Estimated values. (Grant)
5 Grant reports 6000 - 8000 psi higher stresses for 2320F, WQ; 50 hr at 1500F

Creep Strength (M psi)

Temp	Stress for 1% creep in 1000 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	25[2]	16[1], 18.4[2]	12.5[1], 13.5[2]
1400	–	–	–
1500	13.8[2]	8.5-10[1], 10.3[2]	7[1], 7.8[2]
1600	–	–	–

1 2200 WQ, aged 50 hr at test temp
2 Values from Grant

Physical Properties

Density at 70F or 21C
0.299 lbs/cu in. (8.269 S.G.)

Coef. of Thermal Expansion *

Temp Range Deg F	Deg C	Coefficient $\times 10^{-6}$ per Deg F	per Deg C
70-500	21-260	8.5	15.3
-1000	-537	8.7	15.7
-1600	-870	9.9	17.8

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi	Elong. 2" %	Red. Area %
2200F, 1 hr, WQ	70F	138	70	16	13
1500F, 4 hr, FC	1500F	58	29	34	29

SUPER ALLOY, WROUGHT

S-495

Chemical Composition (Typical)

	%		%		
C	.40-.50	Cr	13.0-15.0	Cb	3.50-4.50
Mn	1.0 max	Ni	19.0-21.0	Co	–
Si	1.0 max	Mo	3.50-4.50	N	–
P	–	W	3.50-4.50	Al	–
S	–	Ti	–	Fe	Rest

Stress-Rupture Strength (M psi)

Temp	100 hr	1000 hr
1000F	–	–
1100	–	–
1200	35[1]	26[1], 36[3]
1300	–	–
1350	28[4]	24[4]
1400	–	–
1500	18[2]	14[2]
1600	13.3[2]	9.2[2]
1700	–	–
1800	–	–

1 Hot worked
2 2250F, WQ, 50 hr at test temp
3 Aging treatment - 16 hr at 1400F
4 Values from Grant, estimated, for 2250F, 2 hr, WQ; 50 hr at 1400F.

Creep Strength [1] (M psi)

Temp	Stress for 1% creep in 1000 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	22.4[2]	15.5	11.7[2]
1400	–	–	–
1500	12.9[2]	10	7.5 & 8.3[2]
1600	7.9[2]	<6.5, 5.3[2]	3.5[2]

1 2250F, WQ, 50 hr at test temp
2 Values from Grant

Physical Properties

Density at 70F or 21C
0.298 lbs/cu in. (8.260 S.G.)

Fatigue Strength †

Condition	Temp	10^8 cycles M psi	2.5×10^8 cycles M psi
2000F, 1 hr, WQ; 1300F, 16 hr	1200F	42	41

Coef. of Thermal Expansion *

Temp Range Deg F	Deg C	Coefficient $\times 10^{-6}$ per Deg F	per Deg C
70-600	21-315	8.94	16.09
-800	-426	9.00	16.20
-1000	-537	9.11	16.40
-1200	-648	9.29	16.72
-1500	-815	9.46	17.03

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi 0.2%	Elong 2" %	Red. Area %
Forged, finished at 1400F	70F	148	136	6	22
	1200F	88	72	24	34

* *Grant*
† *Westinghouse Research Laboratory*

SUPER ALLOY, WROUGHT

S-497

Creep Strength[1] (M psi)

Temp	Stress for 1% creep in 1000 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	19.7[2]	15.5	12.0
1400	–	–	–
1500	12.4[2]	10.5[2]	8.5[2]
1600	7.8[2]	6.2[2]	5[2]

1 2250F, WQ, 50 hr at test temp
2 Values from Grant

Stress-Rupture Strength (M psi)

Temp	100 hr	1000 hr
1000F	–	–
1100	–	–
1200	45[1]	33.5[1]
1300	–	–
1350	29[3]	23[3]
1400	–	–
1500	18[2]	14.5[2]
1600	11.5[2]	8.6[2]
1700	–	–
1800	–	–

1 Hot worked
2 2250F, WQ, 50 hr at test temp
3 Values from Grant, 2250F, 12 hr, WQ, 4-50 hr at 1500F

Chemical Composition (Typical)

	%		%		%
C	.40-.50	Cr	–	Cb	–
Mn	–	Ni	–	Co	19.0-21.0
Si	–	Mo	–	N	
P	–	W	–	Al	
S	–	Ti	–	Fe	Rest

Physical Properties

Density at 70F or 21C
0.310 lbs/cu in. (8.570 S.G.)

Coef. of Thermal Expansion *

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
70-600	21-315	7.92	14.26
-800	-426	8.08	14.54
-1000	-537	8.26	14.87
-1200	-648	8.50	15.30
-1500	-815	8.80	15.84

Mechanical Properties*

Form or Condition		Tensile Strength M psi	Yield Strength M psi 0.2%	Elong 2" %	Red. Area %
Forged, finished at 1400F	70F	155	138	10	25
	1200F	104	90	22	26
2100F, 1 hr, WQ, 1500F 4 hr, FC	1350F	64	36	35	32
	1500F	63	40	6	9
	1700F	28	16	20	18

Fatigue Strength !

Condition	Temp	10^8 cycles M psi	2.5×10^8 cycles M psi
2000F, 1 hr, WQ; 1300F, WQ	1200F	50	49

* *Grant*
! *Westinghouse Research Laboratory*

SUPER ALLOY, WROUGHT

S-590

Creep Strength (M psi)

Temp	Stress for 1% creep in 1000 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	20[1]	13.5[1]
1400	–	–	–
1500	12.7*	11[2], 9.6*	9[2], 7.3*
1600	–	7.4[1]	5.5[1]

1 2300F, WQ, 50 hr at test temp
2 2300F, WQ, 50 hr at 1350F

Stress-Rupture Strength (M psi)

Temp	100 hr	1000 hr
1000F	–	–
1100	–	–
1200	52[4]	40[4]
1300	–	–
1350	32[1]	26[1]
1400	–	–
1500	19/21[2]	14/15.5[2]
1600	12.5[3]	9[3]
1700	9.4[3]	6.6[3]
1800	5.6[3]	3.5[3]

1 2270F, WQ, 16 hr at 1400F
2 Range for material aged 50 hr at 1350 or 1500F
3 Aged 16hr at test temp, after 2300F, 1 hr, WQ
4 2325F, 1 hr, WQ; 1400F, 16 hr, AC-Grant

Chemical Composition (Typical)

	%		%		%
C	.40-.50	Cr	18.5-20.5	Cb	3.50-4.00
Mn	2.0 max	Ni	19.0-21.0	Co	19.0-21.0
Si	1.0 max	Mo	3.50-4.00	N	–
P	–	W	3.50-4.00	Al	–
S	–	Ti	–	Fe	rest

Physical Properties

Density at 70F or 21C
0.300 lbs/cu in. (8.313 S.G.)

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi 0.2%	Elong 2" %	Red. Area %
2270F, 1 hr, WQ, 1400F, 16 hr	70F	160*	90	10	10
2270F, 1 hr, WQ, 1400F, 16 hr, AC	1200F	82*	49	27	31
2270F, 1 hr, WQ, 1400F, 16 hr	1300F	67*	58	27	33

Coef. of Thermal Expansion *

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
70-600	21-315	8.47	15.25
-800	-426	8.43	15.17
-1000	-537	8.54	15.37
-1200	-648	8.61	15.50
-1500	-815	8.97	16.15
-1600	-870	9.20	16.56

* *Grant*
! *Westinghouse Research Laboratory*

SUPER ALLOY, WROUGHT

S-816

Chemical Composition (Typical)

	%		%		%
C	.35-.45	Cr	18.5-20.5	Cb	3.50-4.00
Mn	1.0 max	Ni	19.0-21.0	Co	42.0-44.0
Si	1.0 max	Mo	3.50-4.00	N	–
P	–	W	3.50-4.00	Al	–
S	–	Ti		Fe	Rest

Stress-Rupture Strength (M psi)

Temp	100 hr	1000 hr
1000F	–	–
1100	–	–
1200	64[4]	49[4]
1300	–	–
1350	35[1]	30[1]
1400	–	–
1500	24/25[2]	17/18[2]
1600[5]	14[3]	9.5[3]
1700[5]	9.5[3]	6.1[3]
1800[5]	5.3[3]	3[3]

1 2300F, WQ; 16 hr at 1400F
2 2300F, WQ. Range for material aged 50 hr at 1350 or 1500F.
3 2300F, WQ; 16 hr at test temp
4 2250-2300F, 1 hr, WQ; 1400F, 6-16 hr. AC. (Grant)
5 Values in Metal Handbook for castings are 3000 psi higher at 1600F and 5000 psi higher at 1700 and 1800F

Creep Strength (M psi)

Temp	Stress for 1% creep in 1000 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	27[3]	>20[1]	14[1]
1400	–	–	–
1500	16[3]	>10[2]	8[2]
1600	8.5[3]	6.5[2]	5[2]

1 2300F, WQ; 50 hr at 1350F
2 2300F, WQ; 16 hr at 1400F
3 Values from Grant

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi 0.2%	Elong 2" %	Red. Area %	End Limit M psi[1]
As rolled	70F	175*	73	39	45	–
2300F, 1 hr, WQ, 1400F, AC	1200F	120*	–	–	–	–
	1350F	100*	–	–	–	–
	1500F	78*	–	–	–	–
	1600F	60*	–	–	–	–
	1700F	46*	–	–	–	–
As cast	Room	100.0	44.45	6.0	7.4	–
Aged 100 hr at 1500F	Room	104.4	56.2	1.0	1.5	–
2300F, 1 hr, WQ, plus 1400F, 6 hr, AC-"A"	Room	122.3	–	0.5	1.5	–
Treat as in "A"	1200F	100.5	–	3.5	10.5	69[2]
As cast	1500F	61.78	–	17.0	18.0	33[3]
Aged 100 hr at 1500F	1500F	70.5	–	8.0	15.0	–
Treat as in "A"	1500F	71	–	3.5	14.0	–

1 At 10^8 cycles; alternate bending, at 120 cycles/sec
2 2350F, 1 hr, WQ; 1500F, 16 hr (Westinghouse Research Laboratory)
3 Condition not given

* *Grant*

Physical Properties

Density at 70F or 21C
0.310 lbs/cu in. (8.587 S.G.)

Coef. of Thermal Expansion *

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
70-500	21-260	7.6	13.7
-1000	-537	8.0	14.4
-1600	-870	9.4	16.9

SUPER ALLOY, WROUGHT

K-42 B

Chemical Composition (Typical)

	%		%		%
C	.06	Cr	18	Cb	
Mn	.70	Ni	42	Co	22
Si	.35	Mo	–	N	–
P	–	W	–	Al	0.6
S	–	Ti	2.5	Fe	13

Physical Properties

Density at 70F or 21C
0.295 lbs/cu in. (8.152 S.G.)

Coef. of Thermal Expansion *

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
70-500	21-260	8.0	14.4
-1000	-537	8.4	15.1
-1600	-870	10.0	18.0

Fatigue Strength 1

Condition	Temp	10^8 cycles M psi	2.5×10^8 cycles M psi
2100F, 1 hr, WQ; 1350F, 20 hr	1200F	54	48
2100F, 1 hr, WQ; 1500F, 20 hr	1350	48	–

Stress-Rupture Strength * (M psi)

Temp	100 hr	1000 hr
1000F	–	–
1100	–	–
1200	62[1]	39.5[1]
1300	–	–
1350	36.5[1]	26.5[1]
1400	–	–
1500	22.5[2]	15[2]
1600	–	–
1700	–	–
1800	–	–

1 1950F, WQ; 1350F, 20 hr
2 2100F, WQ; 1500F, 20-50 hr

Creep Strength * (M psi)

Temp	Stress for 1% creep in 1000 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	29	18.8	12
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	14	7.4	3.9
1600	–	–	–

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Red. Area %
1750F, 2 hr, WQ; 1200F, 72 hr, FC	70F	162	97[1]	31	39
	1200F	128	–	–	–
	1350F	101	–	–	–
	1500F	71	–	–	–
	1700F	24	–	–	–

1 .1%

SUPER ALLOY, WROUGHT

Inconel X

Creep Strength[1] **(M psi)**

	Stress for 1% creep in		
Temp	100 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	60, 63[2]	48, 54[2]
1300	–	–	–
1350	–	37, 38[2]	30, 30[2]
1400	–	–	–
1500	–	18, 18[2]	15, 14[2]
1600	–	9[2]	7[3]

1 Normalized, aged 24 hr at 1550F plus 20 hr at 1300F
2 International Nickel Co data
3 Inconel X is liable to fracture in 1000 hr at this stress — see Stress-Rupture

Stress Rupture Strength* (M psi)

	100 hr		1000 hr	
Temp	International Nickel	Grant	International Nickel	Grant
1000F	115[3]	115	110[3]	110
1100F	100[3]	–	90[3]	–
1200F	72[3,4]	59[1]	60[3]	55[1]
1300F	–	–	–	–
1350F	45[3,4]	48[1]	35[3]	40[1]
1500F	25[3,4]	29[2]	17[3]	18.5[2]
1600F	10[3]	12	7[3]	7
1700F	–	–	–	–
1800F	–	3.3	–	2.3

1 2100F, 24 hr, AC, 1300F, 6-20 hr, AC.
2 2100F, 4-24 hr, AC; 1300F, 6-20 hr, AC.
3 2100F, 4 hr, AC, 1550F 24 hr, AC; 1300F 20 hr, AC.
4 Acceptance test specification minimum values.

Chemical Composition (Typical)

	%		%		
C	.08 max	Cr	14.0-16.0	Cb	.70-1.20
Mn	.30-1.00	Ni	70.0 min	Cu	.20 max
Si	.50 max	Mo	–	N	–
P	–	W	–	Al	.40-1.00
S	.01 max	Ti	2.25-2.75	Fe	5.0-9.0

Characteristics. This is a nickel base alloy for high temperature service, with good resistance to scaling. Its properties are developed by heat treatment, rather than by working, for service at 1100-1500F.

Uses. Gas turbine rotors, blades, bolts, forming tools, jet and rocket components, and as wire and strip for springs. It is available in a wide variety of commercial shapes and sizes.

Physical Properties

Density at 70F 0.300 lb/cu in. (8.3 S.G.)
Specific heat cal/gm, 20-100C 0.10-0.11
cal/gm, 20-900C(1650F) 0.13
Specific resistivity microhm/cm³ 122
Magnetism μ=1.0028

Technological Properties

Forging temp	2225-1900F
Annealing temp	1900-2000F, Quench
Solution temp	2100F, 2-4 hr, AC
Aging temp	High = 1550F; Low = 1300F
Stress relief temp	1625F
Melting range	2450-2600F
Machinability	Satisfactory, though tough
Weldability	Satisfactory
Scaling temp oxidizing	Over 1800F
Drawability	Good

Coef. of Thermal Expansion *

Temp Range Deg F	Temp Range Deg C	Coefficient × 10^{-6} per Deg F	Coefficient × 10^{-6} per Deg C
70-500	21-260	7.8	14.0
-1000	-537	8.2	14.7
-1200	-648	8.4	15.1
-1500	-815	9.0	16.2
-1600	-870	9.2	16.6

Modulus of Elasticity – E, psi [1] †

Temp	Tension x 10^6	Torsion x 10^6
80F	31	11
500	29	10
1000	25	9
1200	23	8
1350	21	–
1500	18.5	–

1 Poisson's ratio = 0.29 at 80F.

Thermal conductivity

Temp	cal/cm²/cm/sec/°C	Btu/ft²/hr/in/°F
50C	.035	102
100	.038	110
300	.048	140
500	.060	174
900	.089	258

Fatigue Strength †

Temp	10^8 cycles M psi	10^7 cycles M psi	10^8 cycles M psi
1200F	67.5	59	55
1350	54	49.5	48.5
1500	47.5	39.5	36

NOTE: Specimens were fully heat treated and tested as 0.350 in. rounds on a Krouse rotating beam testing machine at 3450 RPM.

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Red Area %	Hardness BHN	Hardness Rock	Izod ft-lb
Hot rolled-aged	70F	192	136[1]	26	45	313-400	34-44C†	38†
		184†	132†	24†	37†	–	–	–
	1200F	118	82†	9†	11†	–	–	–
Hot rolled aged		120†	–	–	–	–	–	–
solution treat.	1500F	70	44†	22†	34†	–	–	–
		52†	–	–	–	–	–	–
	1600F	34†	24†	47†	63†	–	–	–
	1700F	15†	9.5†	106†	95†	–	–	–
Aged for service >1200F	1800F	9†	5.5†	89†	95†	262-340	26-37C†	37†

1 .2%

* *Grant*
† *International Nickel Company*

SUPER ALLOY, WROUGHT

Refractaloy 26

Chemical Composition (Typical)

	%		%		%
C	.03	Cr	18	Cb	–
Mn	.70	Ni	37	Co	20
Si	.65	Mo	3	N	–
P		W	–	Al	.25
S		Ti	3	Fe	Rest

Stress-Rupture Strength[1] **(M psi)**

Temp	100 hr	1000 hr
1000F	–	–
1100	–	–
1200	74[2]	–
1300	–	–
1350	48[2]	–
1400	–	–
1500	28.5	18
1600	–	–
1700	–	–
1800	–	–

1 2100F, OQ; 20 hr at 1500F, AC; 20 hr at 1350F
2 Values from Grant; condition unknown

Creep Strength (M psi)

	Stress for 1% creep in		
Temp	1000 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	> 20[1]	> 20[1]
1400	–	–	–
1500	15.7[2]	9.5[2]	5.7[2]
1600	–	–	–

1 2100F, OQ; 20 hr at 1500F; AC, 20 hr at 1350F
2 Values from Grant

SUPER ALLOY, WROUGHT

Refractaloy-70

Chemical Composition

	%		%		%
C	.1	Cr	20.3	Cb	–
Mn	2	Ni	20.1	Co	30.2
Si	.2	Mo	8.3	N	–
P	–	W	3.8	Al	–
S	–	Ti	–	Fe	15.3

Physical Properties

Density at 70F 0.298 lb/cu in. (8.259 S.G.)

Stress-Rupture Strength * (M psi)

Temp	100 hr	1000 hr
1000F	–	–
1100	–	–
1200	–	–
1300	–	–
1350	–	–
1400	–	–
1500	19[1]	15[1]
1600	12.5[1]	9.6[1]
1700	–	–
1800	–	–

[1] 2350F, 4 hr, OQ, 1500F, 24 hr

Creep Strength (M psi)

	Stress for 1% creep in		
Temp	1000 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	15.2	12.8	11
1600	–	–	–

**Grant*

SUPER ALLOY, WROUGHT

N-153

Chemical Composition

	%		%		%
C	.4	Cr	16	Cb	1
Mn	1.8	Ni	15	Co	13
Si	.5	Mo	3	N	.07
P	–	W	2.2	Al	
S	–	Ti	–	Fe	Rest

Physical Properties

Density at 70F 0.294 lb/cu in. (8.145 S.G.)

Stress-Rupture Strength * (M psi)

Temp	100 hr	1000 hr
1000F	–	–
1100	–	–
1200	–	–
1300	–	–
1350	–	–
1400	–	–
1500	19[1]	13.4[1]
1600	–	–
1700	–	–
1800	–	–

[1] Preheat 1550F, ½ hr, 2200F, ½ hr, OQ, 1500F, 50 hr

**Grant*

SUPER ALLOY, WROUGHT

Nimonic-80

Chemical Composition

	%	%◆		%	%◆		%	%◆
C	.04	.10	Mo	–	–	N	–	–
Mn	.6	1.0	W	–	–	Al	.63	.7
Si	.5	1.0	Ti	2.4	2.3	Fe	Rest	2.0
Cr	21.2	19	Cb	–	–	P	–	–
Ni	74.2	75	Co	–	–	S	–	–

Stress Rupture Strength (M psi)

Temp, Deg F		100 hr		1000 hr	
1000*	1000◆	–		–	
1100*	1112◆	–	75.0◆[4]	–	66.1◆[4]
1200*	1202◆	60[1]*	62.7◆[4]	45[1]*	50.4◆[4]
1300*	1292◆	–	49.3◆[4]	–	35.8◆[4]
1350*	1382◆	36[2]*	33.6◆[4]	23.3[2]*	21.3◆[4]
1400*		–		–	
1500*		16.3[3]*		11.8[3]*	
1600*		–		–	
1700*		–		–	
1800*		–		–	

[1] 1950F, WQ; 1290F, 16 hr
[2] 1950F, 4 hr, WQ, 1400F, 50 hr
[3] 1950F, 4 hr, WQ, 1500F, 50 hr
[4] 1975F, 8 hr, AC, 1290F, 16 hr, AC

Creep Strength◆ (M psi)

		Stress for 1% Creep in		
	Temp, Deg	1000 hr	10,000 hr	100,000 hr
1000*	–	–	–	–
1100*	1112◆	66.0◆	49.3◆	38.0◆
1200*	1202◆	47.0◆	37.0◆	26.9◆
1300*	1292◆	37.0◆	24.6◆	–
1350*	1382◆	22.4◆	13.5◆	–
1400*	–	–	–	–
1500*	1500◆	15.7*	9.5*	5.7*
1600*	–	–	–	–
1700*	–	–	–	–
1800*	–	–	–	–

*Grant
◆Mond Nickel Co.

Physical Properties

Density at 70F 0.296 lbs/cu in. (8.192 S.G.)
0.298 lbs/cu in. (8.259 S.G.)

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength 0.2% M psi	Elong 2 in. %	Red Area %
	70F	147◆	90◆	45◆	36◆
1950F, 2 hr, WQ, 1300F	70F	153*	84*	36*	34*
16 hr	1200F	97.5*	–	–	–
1975F, 8 hr, AC	1292F	85◆	86◆	7◆	12◆
1300F, 16 hr, AC	1472F	71◆	63◆	8◆	10◆

◆*Mond Nickel Co.*

Coef. of Thermal Expansion

Temp Range Deg F	Temp Range Deg C	Coefficient $\times 10^{-6}$ per Deg F		Coefficient $\times 10^{-6}$ per Deg C	
70-600	21-315	7.33*	7.20◆	13.19	12.96
-800	-426	7.42*	7.50◆	13.36	13.50
-1000	-537	7.47*	7.60◆	13.45	13.69
-1200	-648	7.56*	7.91◆	13.61	14.24
-1500	-815	–	–	–	–
-1600	-870	7.99*	8.40◆	14.38	15.12
-1650	-900	–	–	–	–
-1800	-981	8.28*	8.78◆	14.90	15.80

**Grant*

SUPER ALLOYS, WROUGHT

Nimonic 80A

Stress-Rupture Strength[1] (M psi)

Temp	100 hr	1,000 hr
1000F	–	–
1100F	–	–
1202F	67.2	54.9
1292F	57.1	40.3
1382F	39.2	25.8

[1] 1975F, 8 hr, AC, 1290F, 16 hrs, AC. Mond Nickel Co. Tables are terminated at highest temp for which data are available.

Creep Strength[1]◆ (M psi)

Temp	Stress in 1% Creep in 1000 hr	10,000 hr
1000F	–	–
1100F	–	–
1202F	58.2	44.8
1292F	42.6	25.8
1350F	–	–
1382F	32.5	19.0
1500F	–	–
1600F	–	–

[1] 1975F, 8 hr, AC, 1290F, 16 hrs, AC.

Chemical Composition◆

	%		%		%
C	.10	Cr	19	Cb	–
Mn	1.0	Ni	75	Co	–
Si	1.0	Mo	–	N	–
P	–	W	–	Al	1.2
S	–	Ti	2.3	Fe	2.0

Physical Properties◆

Density at 70 F. 0.298 lb/cu in. (8.25 S.G.)

Mechanical Properties◆

Form or Condition		Tensile Strength M psi	Yield Strength M psi	Elong 2 in. %	Red Area %
	70F	147	90	45	36
1975F, 8 hr, AC.	1292F	85	80	7	12
1300F, 16 hr, AC.	1472F	71	63	8	10

◆Mond Nickel Co.

Coef. of Thermal Expansion◆

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
70-600	21-315	7.20	12.96
-800	-426	7.50	13.50
-1000	-537	7.60	13.69
-1200	-648	7.91	14.24
-1500	-815	8.40	15.12
-1650	-900	8.78	–

◆Mond Nickel Co.

SUPER ALLOYS, WROUGHT

Nimonic 90

Stress Rupture Strength (M psi)[1]

Temp	100 hr	1,000 hr
1000F	–	–
1100F	–	–
1202F	76.1	63.9
1292F	61.6	48.2
1350F	–	–
1382F	44.8	33.6
1500F	28.0	17.9

[1] 1975F, 8 hr, AC. 1290F, 16 hr, AC. Mond Nickel Co. Tables are terminated at highest temp for which data are available.

Creep Strength[1] (M psi)

Temp	Stress for 1% Creep in 1,000 hr	10,000 hr
1000F	–	–
1100F	–	–
1202F	69.5	58.2
1292F	53.8	42.5
1350F	–	–
1382F	38.0	26.9
1500F	22.4	13.4

[1] 1975F, 8 hr, AC. 1290F, 16 hr, AC. Mond Nickel Co.

Chemical Composition◆

	%		%		%
C	.10	Cr	19	Cb	–
Mn	1.0	Ni	55	Co	20
Si	1.5	Mo	–	N	–
P	–	W	–	Al	1.2
S	–	Ti	2.4	Fe	2.0

Physical Properties◆

Density at 70F 8.27 gm/cc 0.298 lb/cu in. (8.27 S.G.)

Mechanical Properties◆

Form or Condition		Tensile Strength M psi	Yield Strength* M psi	Elong 2 in. %	Red Area %
1975F. 8 hr, AC. 1300F. 16 hr, AC.	70F	165	101	39	20
	1202F	132	89	26	21
	1292F	116	83	20	7
	1382F	103	72	15	5
	1500F	76	58	8	4

*0.1 per cent proof stress.
◆Mond Nickel Co.

Coef. of Thermal Expansion◆

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
70-600	21-315	7.05	12.69
-800	-426	7.50	13.50
-1000	-537	7.60	13.69
-1200	-648	8.10	14.58
-1500	-815	8.90	16.02
-1650	-900	9.45	17.01

◆Mond Nickel Co.

SUPER ALLOYS, CAST

Hastelloy A

Chemical Composition					
	%		%		%
C	.04/.15	Ni	55.5/59.5	Co	–
Mn	–	Mo	18/22	N	–
Si	–	W	–	Se	–
P	–	Ti	–	Al	–
Cr	–	Ta	–	Fe	18/22

Characteristics. This is an intermediate high temperature alloy for casting by gravity or centrifugal methods and is particularly suited to precision casting.

Uses. Fixtures for cyanide baths, where the heating is followed by quenching.

Technological Properties
Scaling temp 1400 F (oxidizing)

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength .2% M psi	Elong 1" %	Red. Area %
Room temp and hot tensile strength[1]	70F	75/80	44/48	10/20	11/33
	1000	63/72.5	–	15/32	12/32
	1200	57.5/66	–	20/28	13/27
	1500	41/52	–	11/27	11/22

[1]Precision cast test bars, 0.250 in. diam, as cast

Stress-Rupture Strength[1] (M psi)

Temp	10 hr	100 hr	1000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	19.5	11.6	8.8
1600	–	–	–
1700	–	–	–
1800	–	–	–

[1]Precision cast test bars, 0.160 in. diam, 2125F, ½ hr, AC; 1700F, 72 hr, AC.

SUPER ALLOYS, CAST

Hastelloy B

Chemical Composition					
	%		%		%
C	.04/.15	Ni	62.5/66.5	Co	–
Mn	.60	Mo	26/30	N	–
Si	.20	W	–	Se	–
P	–	Ti	–	Al	–
Cr	–	Ta	–	Fe	4/7

Creep Strength* (M psi)

Temp	Stress for 1% creep in 1000 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	20	7.4	2.6
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	4.8	2.8	1.6
1600	–	–	–

Characteristics. Similar to Hastelloy A, but stronger.

Technological Properties
Scaling temp 1400 F (oxidizing)

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Red. Area %	End Lt M psi[2]
1950F, 2 hr, AC	70F	139	–	–	–	–
Room temp and hot tensile strength[5]	70F	80/83.5	56.5/61.5[1]	9.5/15	9.8/23.2	–
	1100	74.5/80	–	13/17	11.3/19.6	–
	1200	62.9/68.7	–	10/25	9.5/31.2	66[3]
	1500	55.4/61.4	–	11/32	8.9/29.5	34[4]
1950F, 2 hr, AC	1500	77	–	–	–	–
	1600	52	–	–	–	–
	1700	39	–	–	–	–
	1800	32	–	–	–	–
	1900	18	–	–	–	–
	2000	13	–	–	–	–
	–	139	57[6]	50	50	–

[1].2%
[2]At 10^8 cycles—Westinghouse Research Laboratory
[3]2000F, WQ; 1200F, 4 hr
[4]2050F, AC; 1900F, 24 hr
[5]Precision castings, 0.250 in. diam, as cast
[6]1%

* N.J. Grant, A.F. Frederickson, & M.E. Taylor, Iron Age, Mar. 18, Apr. 8, 15, 1948, hereafter referred to as "Grant"

Stress-Rupture Strength* (M psi)

Temp	10 hr	100 hr	1000 hr
1000F	–	–	–
1100	–	–	–
1200	–	58[2]	33[2]
1300	–	–	–
1350	–	34[3,6]	25[3,6]
1400	–	–	–
1500	–	17[4]	11.3[4,6]
1500	29[1]	17.6[1]	10.7[1]
1600	–	11.7[5]	8.3[5]
1700	–	–	–
1800	–	–	–

[1]From Metals Handbook—Precision castings, 0.160 in. diam, 2125F, ½ hr, AC; 1700F, 72 hr, AC
[2]2000F, 1 hr, WQ; 1200F, 4 hr, FC
[3]1950F, 2 hr, AC
[4]1900F, 24 hr, AC
[5]Condition unknown
[6]Estimated

Physical Properties
Density at 70F or 21C
0.334 lb/cu in (9.24 S.G.)

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
70-600	21-315	6.18	11.12
-800	-426	6.39	11.50
-1000	-537	6.52	11.74
-1200	-648	6.90	12.42
-1600	-870	7.49	13.48
-1800	-981	7.83	14.09

SUPER ALLOYS, CAST

Hastelloy C

Chemical Composition

	%		%		%
C	.04/.15	Ni	54.5/59.5	Co	–
Mn	–	Mo	15/19	N	–
Si	–	W	3.5/5.5	Se	–
P	–	Ti	–	Al	–
Cr	13/16	Ta	–	Fe	4/7

Characteristics. Similar to Hastelloy A but is stronger and is resistant to oxidizing conditions.

Uses. Parts for heat-treating furnaces operating up to 2000 F, and for conveyors operating up to 1750 F.

Stress-Rupture Strength[1] (M psi)

Temp	10 hr	100 hr	1000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	18.8	14.1	10.7
1600	–	–	–
1700	–	–	–
1800	–	–	–

[1]Precision cast, 0.160 in. diam, 2225F, ½ hr, AC; 2100F, 8 hr, AC

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength .2% M psi	Elong 1" %	Red. Area %
Room temp and hot tensile strength[1]	70F	76.7/88.5	44.5/56.4	8/12	9/15
	1000	63.0/73.1	–	10/17	7/24
	1200	56.2/67.2	–	8/16	10/24
	1500	50.4/61.4	–	11/28	9/22
	1750	30/34	–	12/15	41/56
	1950	13/16	–	23/30	53/66

[1]Precision castings, 0.250 in. diam, as cast

SUPER ALLOYS, CAST

Vitallium Stellite 21

Stress-Rupture Strength* (M psi)

Temp	10 hr	100 hr	1000 hr
1000F	–	–	–
1100	–	–	–
1200	68	54[1]	43[1]
1300	–	–	–
1350	48	36.5[2]	28[2]
1400	–	–	–
1500	31	22[3]	16[3]
1600	23.8	18.4[2]	14.5[2]
1700	16.4	13.1[1]	10.5[1]
1800	12.2	8.8[1]	6.4[1]

[1]As cast
[2]1500F, 50 hr
[3]1350-1500F, 50 hr

Creep Strength* (M psi)

Temp	Stress for 1% creep in 100 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	11.7[1]	7.6[1]	4.9[1]
1600	11.2[1]	7.9[1]	5.6[1]

[1]These values are thought to be inconsistent

Chemical Composition – Typical

	%		%		%
C	.22	Ni	2.8	Co	62.2
Mn	.66	Mo	5.5	N	–
Si	.53	W	–	Se	–
P	–	Ti	–	Al	–
Cr	27.4	Ta	–	Fe	.7

Technological Properties

Annealing temp	2100 F +
Hardening temp	1300-1700 F, by age-hardening
Melting point	2550 F
Machinability	Difficult – use carbide tools, annealed condition
Weldability	Commercial with manual arc and submerged melt

Physical Properties

Density at 70F or 21C
0.229 lb/cu in (8.298 S.G.)

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
70-600	21-315	7.83	14.09
-800	-426	7.96	14.33
-1000	-537	8.18	14.72
-1200	-648	8.38	15.08
-1500	-815	8.68	15.62
-1600	-870	8.72	15.70
-1800	-981	8.90	16.02

Thermal Conductivity §

Watts per cm/°C at	
200C	0.145
300	0.160
400	0.175
500	0.190
600	0.205

§*Metals Handbook*
**Grant*

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi[3]	Elong 2" %	Red. Area %	E 10^6 psi	End Lt M psi[1]
As cast	Room	101.3	82.3	8.2	9.0	36.0	35/40[2]
	1000F	69.1	39.1	16.4	25.3	33.3	–
	70	110	65	10	12	–	–
1350F, 48 hr	70	120	–	5	7	–	–
1350F, 50 hr	1000	86.2	74.4	1.2	4.3	35.0	–
As cast	1200	74.2	38.0	5.7	36.9	33.7	44[2]
1350F, 50 hr	1200	89.3	71.3	2.0	6.0	23.9	–
	1200	93*	71.5	2	6	–	–
	1350	80*	–	–	–	–	–
	1350	79.3	61.5	3.8	9.0	24.2	–
	1500	59.0	49.0	6.8	19.7	16.8	33[2]
	1500	60*	–	–	–	–	–
	1600	42*	–	–	–	–	–
	1600	41.6	32.8	19.3	23.6	15.4	–
As cast	1700	42.5	–	27	52.4	–	–
	1800	33.3	–	35	52.4	–	–
1700F, 16 hr	1800	32.9	–	49	63.1	–	–
	1800	33*	–	–	–	–	–

[1]At 10^8 cycles; alternate bending at 120 cycles/sec.
[2]Condition not given
[3].2%

SUPER ALLOYS, CAST

73 J

Chemical Composition – Typical

	%		%		%
C	.73	Ni	6	Co	60
Mn	1	Mo	6	N	–
Si	–	W	–	Se	–
P	–	Ti	–	Al	–
Cr	23	Ta	2	Fe	–

Creep Strength (M psi)

Temp	Stress for 1% creep in 100 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	20.4	14.3	10.1
1600	–	–	–

Stress-Rupture Strength* [1] (M psi)

Temp	10 hr	100 hr	1000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	52.5	40.5
1400	–	–	–
1500	–	34.8	28.2
1600	–	26.4	21.0
1700	–	17.2	12.3
1800	–	12.8	9.3

[1] Condition 1350F, 48 hr

* *Grant*

SUPER ALLOYS, CAST

STELLITE 31
X40

Chemical Composition – Typical

	%		%		%
C	.5	Ni	10	Co	55
Mn	.6	Mo	–	N	–
Si	.7	W	7	Se	–
P	–	Ti	–	Al	–
Cr	25	Ta	–	Fe	1

Physical Properties

Density at 70F or 21C
0.311 lb/cu in (8.608 S.G.)

Thermal Conductivity

Watts per cm/°C at	
200C	0.148
300	0.175
400	0.183
500	0.194
600	0.219

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient $\times 10^{-6}$ per Deg F	per Deg C
70-600	21-315	7.97	14.35
-800	-426	7.88	14.18
-1000	-537	7.98	14.36
-1200	-648	8.18	14.72
-1500	-815	8.43	15.17
-1600	-870	8.79	15.82
-1800	-981	–	–

Creep Strength* (M psi)

Temp	Stress for 1% creep in 1000 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	18.5	13.7	10.2
1600	15.7	11.7	8.7

Stress-Rupture Strength* (M psi)

Temp	10 hr	100 hr	1000 hr
1000F	–	–	–
1100	–	–	–
1200	66	55[1]	46[1]
1300	–	–	–
1350	59[2]	44.8[2]	34[2]
1400	–	–	–
1500	34[3]	28[3]	23.2[3]
1600	25[4]	21.3[4]	18.5[4]
1700	21[5]	17.3[5]	14.4[5]
1800	13[5]	11.3[5]	9.8[5]

[1] Not known
[2] 1350F, 50 hr
[3] 1350-1500F, 50 hr
[4] 1600F, 50 hr
[5] As cast

Mechanical Properties

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Red. Area %	E 10^6 psi	End Lt M psi[3]
As cast §	Room	101.0	74.1[1]	11.0	14.0	28.0	–
	1000	80.1	40.2[1]	20.0	33.5	33.5	–
	1200	77.0	37.6[1]	19.0	28.4	22.8	56[2]
As cast	1200	77*	38	20	29	–	–
Aged 50 hr at 1350F §	1350	75.7	53.6[1]	4.6	7.6	23.9	–
	1500	59.6	44.5[1]	10.3	14.1	19.3	–
	1600	48.6	36.2[1]	14.3	18.1	19.0	–
As cast	1350	75*	–	–	–	–	–
	1500	59*	–	–	–	–	–
	1600	48*	–	–	–	–	–

[1] .2%
[2] Condition not given
[3] At 10^8 cycles; alternate bending at 120 cycles/sec.

§ *Metals Handbook*
* *Grant*

SUPER ALLOYS, CAST

111 VT 2-2

Creep Strength* (M psi)

Temp	Stress for 1% creep in 1000 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	20.4	15	11
1600	15.1	10.3	7.2

Chemical Composition – Typical

	%		%		%
C	1.11	Ni	–	Co	67
Mn	–	Mo	6	N	–
Si	–	W	–	Se	–
P	–	Ti	–	Al	–
Cr	23	Ta	2	Fe	–

Stress-Rupture Strength* [1] (M psi)

Temp	10 hr	100 hr	1000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	43	33.2	25.8
1600	37	27.3	20
1700	22.4	16.8	12.1
1800	15.3	11.1	8

[1] As cast

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
70-1200	21-648	8.8	15.8
-1350	-732	8.9	16.0
-1500	-815	9.0	16.2
-1600	-870	9.0	16.2
-1800	-981	–	–

Mechanical Properties

Form or Condition		Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Red. Area %
As cast	70F	120	–	4	1

*Grant

SUPER ALLOYS, CAST

100NT-2

Creep Strength* (M psi)

Temp	Stress for 1% creep in 1000 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	21.8	17.4	13.8
1600	16.0	11.7	8.5

Chemical Composition – Typical

	%		%		%
C	1	Ni	30	Co	20
Mn	1.5	Mo	3	N	–
Si	.5	W	2.2	Se	–
P	–	Ti	–	Al	–
Cr	20	Ta	2	Fe	Rest

Stress-Rupture Strength* [1] (M psi)

Temp	10 hr	100 hr	1000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	40.5	30.5	22.8
1600	35	26.1	19.3
1700	25.8	18.2	13.1
1800	18.8	13.6	9.9

[1] 2260F, ½ hr, WQ

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
70-1200	21-648	8.5	15.3
-1350	-732	8.8	15.8
-1500	-815	9.0	16.2
-1600	-870	9.0	16.2
-1800	-981	9.3	16.7

Mechanical Properties

Form or Condition	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Red. Area %
2260F, WQ	100	–	1.5	1

*Grant

SUPER ALLOYS, CAST

X-50

Chemical Composition – Typical

	%		%		%
C	.8	Ni	20	Co	40
Mn	.6	Mo	–	N	–
Si	.5	W	12	Se	–
P	–	Ti	–	Al	–
Cr	23	Ta	–	Fe	Rest

Creep Strength* (M psi)

Temp	Stress for 1% creep in 1000 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	18.2	13.5	10.1
1600	13.2	10.5	8.5

Physical Properties
Density at 70F or 21C
0.320 lb/cu in (8.855 S.G.)

Stress-Rupture Strength* (M psi)

Temp	10 hr	100 hr	1000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	38.4[1]	29.2[1]	22.5[1]
1600	25.4[2]	20.1[2]	16.2[2]
1700	19.7[3]	16.3[3]	13.8[3]
1800	12.2[3]	9.7[3]	7.8[3]

[1]1500F, 50 hr
[2]1600F, 50 hr
[3]As cast

Mechanical Properties*

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi	Elong 2" %	Red. Area %
1500F, 50 hr	1500F	60	53	1.0	0
	1600	50	36	1.4	1.1

*Grant

SUPER ALLOYS, CAST

STELLITE 23
61

Chemical Composition – Typical

	%		%		%
C	.40	Ni	2	Co	Rest
Mn	.60	Mo	–	N	–
Si	.60	W	5	Se	–
P	–	Ti	–	Al	–
Cr	23	Ta	–	Fe	1

Creep Strength* (M psi)

Temp	Stress for 1% creep in 1000 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	17	13	10
1600	–	–	–

Physical Properties
Density at 70F or 21C
0.309 lb/cu in (8.54 S.G.)

Thermal Conductivity §

Watts per cm/°C at	
200C	0.154
300	0.176
400	0.180
500	0.189
600	0.212

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
70-600	21-315	7.64	13.75
-800	-426	7.96	14.33
-1000	-537	8.18	14.72
-1200	-648	8.48	15.26
-1500	-815	9.24	16.63
-1600	-870	–	–
-1800	-981	–	–

Stress-Rupture Strength (M psi)

Temp	10 hr	100 hr	500 hr	1000 hr
1000F	–	–	–	–
1100	–	–	–	–
1200	71	58	50	47
1300	50	39	32.3	30
1350	46[1]	35.2[1]	–	27[1]
1400	–	36	28	25
1500	–	27.2	22.5	21.8
1600	–	16	13	12
1700	17	14	12.2	11.5
1800	12.5	8.6	6.2	5.4

[1]1500F, 50 hr.

Mechanical Properties*

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi[3]	Elong 2" %	Red. Area %	E 10^6 psi	End Lt M psi[1]
As cast	Room	103.4	58.4	7.0	11.2	29.0	–
	1000F	77.1	41.4	14.8	24.1	27.9	–
1350F, 50 hr	1000	92.5	72.5	1.7	4.1	27.6	–
As cast	1200	82.9	40.7	15.6	21.5	33.5	44[2]
1350F, 50 hr	1200	97.5	74.7	1.8	6.6	25.0	–
	1350	79.6	63.1	2.0	6.5	27.0	–
	1500	58.5	40.6	7.8	12.7	23.5	38[2]
	1600	45.8	33.1	9.8	16.8	21.9	–
As cast	1700	37.5	–	7	35.7	–	–
1700F, 16 hr	1700	43.6	–	18	35.7	–	–
As cast	1800	33.1	–	32	40.6	–	–
1700F, 16 hr	1800	33.0	–	27	39.5	–	–

[1]At 10^8 cycles; alternate bending at 120 cycles/sec.
[2]Condition not given
[3].2%
*Collected, mostly from Grant

Technological Properties
Machinability Difficult
Weldability Apt to crack

* Grant
§Metals Handbook

SUPER ALLOYS, CAST

STELLITE 27
6059

Creep Strength* (M psi)

Temp	Stress for 1% creep in 1000 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	15	11.7	9
1600	11	9	7.3

Chemical Composition – Typical

	%		%		%
C	.40	Ni	32	Co	Rest
Mn	.60	Mo	6	N	–
Si	.60	W	–	Se	–
P	–	Ti	–	Al	–
Cr	23	Ta	–	Fe	–

Stress-Rupture Strength (M psi)

Temp	10 hr	100 hr	500 hr	1000 hr
1000F	–	–	–	–
1100	–	–	–	–
1200	58	55	49	46
1300	45	37	31.5	29
1350	44.2*	36.4*	–	30*
1400	35	28	–	–
1500	29.2	23.4	19.7	18.4
1600	21.4*	16	12.9	12
1700	16	12	9.7	8.6
1800	12.5	9.3	7.5	6.8

Physical Properties

Density at 70F or 21C
0.296 lb/cu in (8.21 S.G.)

Thermal Conductivity

Watts per cm/°C at	
200C	0.141
300	0.155
400	0.166
500	0.181
600	0.198

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient × 10^{-6} per Deg F	per Deg C
70-600	21-315	7.53	13.55
-800	-426	7.79	14.02
-1000	-537	8.04	14.47
-1200	-648	8.29	14.92
-1500	-815	8.67	15.61
-1600	-870	8.84	15.91
-1800	–	–	–

Mechanical Properties*

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi[3]	Elong 2" %	Red. Area %	E 10^6 psi	End Lt M psi[1]
As cast	Room	82.5	46.9	7	10.3	28.0	36[2]
	1000F	50.5	36.6	4.3	10.3	26.2	–
	1200	48.9	35.0	3.8	8.0	27.0	41[2]
1350F, 50 hr	1350	66.2	50.8	3.2	4.6	20.2	–
	1500	51.2	38.2	10.1	14.4	18.7	31[2]
	1600	41.4	30.8	11.5	20.1	18.2	–
As cast	1700	43.0	–	23	26.5	–	–
1700F, 16 hr	1700	45.4	–	16	34.0	–	–
As cast	1800	33.4	–	24	50.3	–	–
1700F, 16 hr	1800	33.7	–	26	41.7	–	–

[1] At 10^8 cycles; alternate bending at 120 cycles/sec.
[2] Condition not given
[3] .2%

*Grant

SUPER ALLOYS, CAST

CM-469

Chemical Composition – Typical[1]

	%		%		%
C	.03	Ni	–	Co	–
Mn	–	Mo	25	N	–
Si	–	W	–	Se	–
P	–	Ti	–	Al	–
Cr	60	Ta	–	Fe	14

[1] Vacuum cast

Stress-Rupture Strength*[1] (M psi)

Temp	10 hr	100 hr	1000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	–	–	–
1600	–	37.8	21.4
1700	–	–	–
1800	–	–	–

[1] As cast

Technological Properties

Machinability: Can be machined with carbide tools

Physical Properties

Density at 70F or 21C
0.284 lb/cu in (7.87 S.G.)

Mechanical Properties

Tensile Strength, Brittle, 1350F 100 M psi
Hardness, Vickers 498, as cast

*Grant

SUPER ALLOYS, CAST

STELLITE 30

422-19

Chemical Composition – Typical

	%		%		%
C	.40	Ni	16	Co	Rest
Mn	.60	Mo	6	N	–
Si	.60	W	–	Se	–
P	–	Ti	–	Al	–
Cr	23	Ta	–	Fe	1

Creep Strength* (M psi)

Temp	Stress for 1% creep in 1000 hr	10,000 hr	100,000 hr
1000F	–	–	–
1100	–	–	–
1200	–	–	–
1300	–	–	–
1350	–	–	–
1400	–	–	–
1500	18.4	13.2	9.5
1600	14.5	11.6	9.5

Physical Properties

Density at 70F or 21C
0.300 lb/cu in (8.31 S.G.)

Coef. of Thermal Expansion

Temp Range Deg F	Deg C	Coefficient $\times 10^{-6}$ per Deg F	per Deg C
70-600	21-315	7.70	13.86
-800	-426	7.86	14.15
-1000	-537	7.91	14.24
-1200	-648	8.07	14.53
-1500	-815	8.42	15.16
-1600	-870	8.54	15.37
-1800	–	–	–

Stress-Rupture Strength (M psi)

Temp	10 hr	100 hr	500 hr	1000 hr
1000F	–	–	–	–
1100	–	–	–	–
1200	–	–	–	–
1300	–	–	–	–
1350	60.8	47	–	36.3
1400	–	–	–	–
1500	33	28.6	24.1	21.7
1600	24.2	18.8	15.5	14.8
1700	19	16	12.3	11.5
1800	14	10	7.9	7.1
2000	5.5	3	–	–

Mechanical Properties*

Form or Condition	Test Temp	Tensile Strength M psi	Yield Strength M psi[3]	Elong 2" %	Red. Area %	E 10^6 psi	End Lt M psi[1]
As cast	Room	98.1	55.1	5.0	11.9	33.0	–
	1000F	62.9	42.5	6.2	9.2	25.6	–
	1200	59.9	37.6	6.3	10.7	27.5	52[2]
1350F, 50 hr	1350	77.8	61.4	1.8	2.7	24.8	–
	1500	64.0	47.6	3.0	3.4	25.6	–
	1600	48.9	35.9	9.6	17.8	17.3	–
As cast	1700	45.2	–	17.0	26.6	–	–
1700F, 16 hr	1700	47.1	–	18.0	33.3	–	–
As cast	1800	36.3	–	24.0	33.7	–	–
1700F, 16 hr	1800	37.8	–	21.0	38.7	–	–

[1] At 10^8 cycles; alternate bending at 120 cycles/sec.
[2] Condition not given
[3] .2%

*Grant

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The column "Code" refers to numbers given in *"Steel's* Specifications Handbook Cross Index of Chemically Equivalent Specifications and Identification Code for Ferrous and Nonferrous Alloys."

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