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THE SOURCE FOR LEAD-FREE ASSEMBLY INFORMATION

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LEAD-FREE CLEANING

CONTRACT ASSEMBLERS AND LEAD-FREE

LEAD-FREE HAND SOLDERING

BACKWARD AND FORWARD LEAD-FREE COMPATIBILITY

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You have Choices For Lead-free Wave *Selective and Tinning Operations*

As engineers begin the switch to lead-free soldering, the cost of the lead-free solder becomes more evident. Since lead is replaced with metals much higher in cost, the conversion to lead-free will increase the overall cost of assembly. Lead is being replaced with tin, silver, copper and other additives which are many times more expensive than lead.

In the reflow process, lead-free solder pastes are primarily made with Tin-Silver-Copper (SAC) solder powder. The IPC SVPC has endorsed the SAC305 (Sn96.5 Ag3.0 Cu0.5) alloy as the best option for SMT. In wave soldering operations, the switch to lead-free can mean an initial investment in bulk solder purchase to re-fill the solder pot. Many assemblers are qualifying SAC solder for wave soldering – a recent study showed that 49% had selected SAC for wave soldering and 20% had chosen tin-copper based solders. The others are still considering the options.

So how do you choose your alloy for the wave operation? What are some of the main points to consider?

SAC alloys will wet more rapidly than tin-copper based solders but this is not necessarily a problem unless the boards are thicker, difficult to solder or a weaker no-clean low solids flux is used. More reliability data is available for SAC solders and if you are a contract assembler your customer may ask you for such data. Less reliability data exists for tin-copper based alloys.

With tin-copper based alloys, the flux selected will be most important and choosing a liquid flux designed for the slower wetting behavior of tin-copper based solders will mean good hole-fill and less defects to rework.

Tin-copper based solders are sometimes doped with nickel or other elements to give a finer grain structure, brighter solder joints and less dross formation. The initial cost of the alloys is much less than SAC and therefore adding to its attraction.

Kester's new K100 and K100*LD* solders are typical examples of these tin-copper based solders available on the market today. Both materials are low-cost, low-dross and can easily be implemented into wave soldering applications. While both materials present an advantage of lowered Copper dissolution when compared to Sn63, the K100*LD* has been proven to be the lowest-dissolution of any alloy available on the market, even traditional Sn63. Both alloys can be used in wave, selective and dip tinning operations.

Choosing the alloy, the fluxes, insuring proper storage and handling of parts and optimizing the operation to suit the slightly reduced wetting of tin-copper based solders can make the process reliable with the added benefit of reduced alloy costs.

Lead-free Hand Soldering - *Ending the Nightmares*

Most issues during the transition seem to be with Hand Soldering

As companies transition over to lead-free assembly, hand soldering will continue to be a common application. An article from Tech Search International in 2004 stated that Asian companies have found that lead-free hand soldering was more of a problem than lead-free SMT or wave soldering.

Kester has been getting numerous calls in reference to lead-free hand soldering in recent months. Most of the requests for training through Kester University are related to lead-free hand soldering and rework. In many cases, the assemblers are using materials from various solder suppliers with similar issues occurring in all cases. Often the problems are more than material issues.

Switching to lead-free on Monday morning when operators had been soldering with leaded solder on the previous Friday is not recommended. Although this may seem obvious, some assemblers have attempted this, with line stoppages occurring only a few hours into the transition to lead-free hand soldering. Operator complaints, loss of reliability and poor joint quality were experienced. This could be a production engineer's nightmare but it need not be this way if the basic concepts of hand soldering are revisited, some experience gained prior to the transition and adequate training of operators is performed before and after the switchover.

Here are some questions often asked by assemblers in reference to hand-soldering with lead-free solders. These are also some of the issues addressed during the lead-free hand-soldering on-site audit done through Kester University.

Which alloys and fluxes are compatible with lead-free hand-soldering?

The limiting factor with lead-free solders is probably its availability in wire form; some alloys are not easily drawn into wire, as is the case with tin-bismuth solders.

At this time, the most popular alloys used to make wire are tin-silver-copper SAC and tin-copper (SnCu) based solders. This compliments the industry well at this time where 68% of the SMT assemblers and 50% of the wave assemblers have chosen SAC alloys for hand soldering. In wave soldering 20% have chosen SnCu based solders due to the cost of silver-bearing bar solder. Wire solders for hand assembly are therefore readily available in these two alloys.

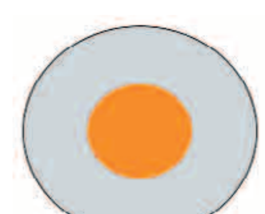
The main differences between SAC and SnCu solders are the melting point; the melting temperatures are approximately 217°C and 227°C respectively. From a soldering performance perspective, SAC wets more readily than SnCu based solders, so flow with SAC solders will be better, everything else being equal.

Both SAC and SnCu solders are available in no-clean, water washable and rosin-based flux formulas. No-clean accounts for over 85% of the total wire usage while water washable is less than 15% and rosin-based less than 5%.

What are the key variables in choosing a good lead-free solder wire?

The flux content in the wire will be the most critical factor in determining wetting behavior. Lead-free solders such as SAC, SnCu and the higher temperature option tin-antimony SnSb wet a little slower than Sn63Pb37 when compared using similar conditions in wetting balance tests.

Lead-free solder wires should contain at least 2% flux by weight. Leaded solders are available with lower flux percentages as low as 1% by weight; this low flux percentage will not work well with lead-free.



Solder wire showing flux core.

Typical flux distribution in a solder wire, the density of the flux is close to 1 g/cc; therefore the volume is more obvious in the cross-section. Different percentages of flux are used at times but the percent is usually 2 or 3% for lead-free. A lower amount of flux may result in more difficulties during soldering.

If wetting is too sluggish with 2% flux, 3% flux in the wire may be tried but this will give higher residues, not always cosmetically appealing in no-clean applications.

Another important point is to insure the flux is designed for lead-free applications and therefore it should be able to withstand higher soldering tip temperatures without charring, spattering and decomposition. Some fluxes may smoke more when using hotter tip temperatures.

When choosing a solder wire, make sure to observe the flux IPC classification. Many no-cleans meet the ROL0 classification meaning they are rosin based, low corrosivity and halide free. These are the most reliable and meet the SIR and corrosion tests in the IPC J-STD-004 specification. With lead-free there is a tendency to use higher activity to compensate the reduced wetting; this is not necessarily a good idea.

Water washable fluxes will be more active, often classified as ORH1 and do better with lead-free soldering. However, you should insure the residues are still completely removable in hot water; doing ionic contamination testing is recommended. If ionic contaminants still remain after water washing, a clean process change may be warranted such as increasing the cycle time, water temperature or a change of cleaning agent.

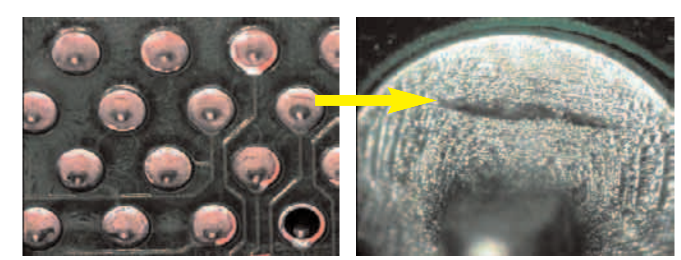
In comparative studies done with SAC and SnCu alloys, wetting balance tests indicate that using the same flux types that SAC outperforms SnCu solders in the time required to reach maximum wetting. This applies also to SnCu solders with dopants of nickel or other additives.

In choosing an alloy it is important to determine the overall solderability of the parts to be assembled. If the parts are older, more oxidized, or manually handled, SAC alloys may be a better choice.

What are the main changes associated with lead-free hand assembly cosmetics?

Lead-free solders flow a little slower than Sn63Pb37 using the same activation levels for the fluxes. The contact angles are slightly larger and feathering out of the solder is therefore less pronounced. The solder joints tend to be less reflective than the Sn63Pb37 alloy. Some retraining is required prior to a full transition to lead-free is done.

In some cases certain shrinkage effects (described in Section 5 of the IPC-STD-610D) may occur. The IPC-610 classifies these as soldering anomalies and not necessarily defects. As mentioned on page 5-22 of the above document, it is not a defect for Class 1, 2 and 3 provided that the bottom of the tear is visible and the shrink hole does not contact the lead, land or barrel wall. See the photos below for examples taken from the Kester laboratory.

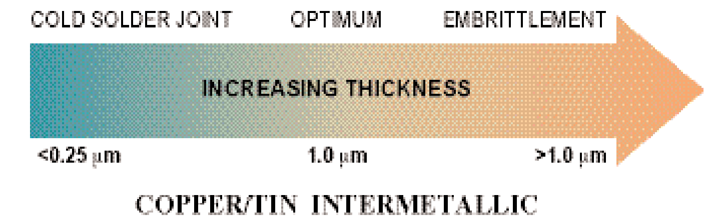


Solder shrinkage effects on solder joints.

What is the best soldering tip temperature for lead-free SAC and SnCu?

The temperature of the tip or contact temperature is very important to ease the lead-free hand-soldering operation. When using Sn63Pb37 solders temperatures as low as 650°F have been used but with lead-free 700-800°F is best. The higher temperature does compensate for the slower wetting exhibited with these lead-free alloys.

Above 800°F issues of board and component damage may arise. At temperatures below 700°F, cold solder joints and flagging are the normal complaints.



Higher temperatures and longer contact with the parts to be soldered may also increase the intermetallic bond layer. So avoiding prolonged contact and repeated rework is not recommended. The above diagram shows what happens as the bond layer increases in thickness a higher risk of embrittlement occurs.

How about the soldering tips with lead-free solders?

Lead-free tips are required however the tip design is just as important. Lead-free is less forgiving and the right tip for the job will go a long way in preventing defects.

Choose a tip with enough heat-delivering capacity. Fine point tips cannot be used in all applications and in some cases a tip such as a chisel type is best suited to deliver sufficient heat to the parts to be soldered.

See the diagram below for correct tip selection criteria.

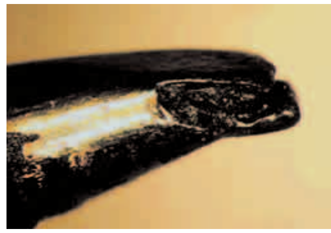
Proper tip selection.

How about tip life with lead-free solders?

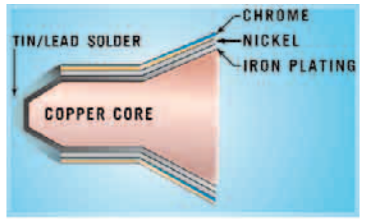
Tip life will be reduced with lead-free solders and it is important to choose tips really designed for lead-free soldering. Many tips are only tinned with lead-free solder and the iron plating is no different than traditional soldering tips. High tin solders will dissolve iron more quickly and reduces tip life. Some assemblers have reported substantial reductions in tip life of up to 75% when converting from leaded to lead-free soldering.

Not all soldering tips are equal when comparing dissolution rates so choosing tips carefully and asking for compatibility information is a good practice.

May 2006



Lead-free tip failure after 3 weeks



Cross-section of typical solder tip, with lead-free the solder is lead-free

How can a good lead-free hand soldering process be designed to ease the operation?

In a recent study published by Tech Search International in December 2004, hand soldering was found to be more problematic to implement when compared to lead-free wave soldering and SMT.

The reason could be that hand soldering is more operator-dependent than SMT and wave soldering but also the surface tension in lead-free solders is slightly higher. Wetting or spread is also a little slower when compared to traditional leaded solders.

To improve operator issues and wetting behavior, proper optimization of the soldering process is key. To avoid issues, use a flux content of 2-3% by weight in the solder wire, use a solder tip temperature of 700-800° F. Also Tin-Silver-Copper (SAC) solder will flow more readily than Tin-Copper (SnCu) solder.

The main issues encountered with lead-free hand soldering are cold solder joints, poor wetting, flagging and de-wetting. These can be avoided.

A step-by step process transition would be as follows:

- ✦ Ensure the tips are designed for lead-free
- ✦ Ensure the temperature is set to 700-800°F
- ✦ Ensure the flux content in the wire is a least 2% by weight
- ✦ Use the correct tip for the job
- ✦ Ensure the parts are easily solderable with the chosen flux
- ✦ Avoid prolonged contact times
- ✦ Avoid needless reworking of the joint

Which defects can appear and how can they be avoided?

The common issues reported with lead-free are:

- ✦ Grainy joints
- ✦ Cold solder joints
- ✦ De-wetting
- ✦ Flagging
- ✦ Poor wetting and wicking
- ✦ Flux charring and darkened residues
- ✦ Difficulty with the cleaning of residues

Grainy joints may be caused by an elevated tip temperature and the dissolution of the metals being joined.

Cold solder joints can be caused by several things such as reduced tip temperature, too weak of a flux or insufficient flux in the wire.

De-wetting can be caused by prolonged tip contact and the dissolution of the plated metals, exposing a less solderable surface.

Flagging can be caused by elevated soldering tip temperatures or the use of solder wires with low volumes of flux. Flux activity may be low also and prolonged contact with the iron is de-activating it.

When using a water washable cored wire, flux charring and cleaning difficulties can be caused by elevated soldering temperatures or a flux that is not properly designed for the higher temperatures required for lead-free. Avoiding prolonged contact and using lower soldering temperatures can help with this situation.

My soldering iron tips are charring, turning black and de-wetting when I use lead-free solder wire, what can I do?

Not all fluxes are created equal and some are thermally incapable of sustaining the higher soldering temperatures used with lead-free solder. A recent video clip from OK International demonstrates this well when two solder wires are compared side by side. This is referred to as "black tip syndrome".

Once "black tip syndrome" occurs, the reduction in heat transfer makes lead-free hand soldering difficult, tip life is reduced, tip costs and operator frustration goes up and reliability goes down.

Proper flux selection, using lead-free tips and lead-free hand soldering process training for operators will offset these costs. The important points to avoid these phenomena are listed below.

- ✦ Use lead-free solder wires with lead-free designed fluxes
- ✦ Avoid using elevated temperatures
- ✦ If tip-tinner is used, wipe excess tinning material on a clean sponge
- ✦ Do not use pressure to compensate for lack of wetting
- ✦ Use the right tip geometry
- ✦ Use the correct wire diameters
- ✦ Segregate work areas for lead-free and leaded
- ✦ Identify lead-free irons and work stations

These are some of the questions asked by customers moving forward with lead-free assembly. A little training goes a long way in avoiding costly issues with the hand-soldering process.

Although the process is more operator dependant, using the tech tips mentioned above can make hand-soldering less frustrating for the operators and engineers. Maintaining the same levels of reliability they are accustomed to with leaded soldering is therefore very achievable with no nightmares of poor joints or reduced production output.

Peter Biocca is the lead-free Senior Market Development Engineer at Kester. Comments or questions pertaining to this article can be sent to pbiocca@kester.com.

Understanding Flux Behavior of *Non-Clean Lead-Free Solder Paste After Reflow Processes*

Solder paste consists on powder metal in thickened flux with addition of special agents that help to maintain its consistency, slump, viscosity, etc. The majority of solder paste contains between 80 to 90% mass of solder metal, which equivalents to 30 – 40% volume while the rest is accounted by flux and special agents. After the reflow process, flux residues are left behind on the assembly. The amount of residues depends on the reflow profile and the solder paste's brand name. One of the inconveniences of flux residues beside its bad appearance as shown in Figure 1 is its serious effects on in-circuit testing. During testing the test pins might fail to penetrate the hard residue that can be located on the test points resulting in misclassification of non-defective boards. Therefore, minimum flux residues should be left on the assembly after soldering.

Thermal analysis of the new lead free solder pastes allows us to understand the impact of higher reflow temperatures and flux behavior. It is possible to identify where in the process the flux is being evaporated indicating that the solder paste is still active and how much is left behind. Critical areas on the reflow profile are at the end of the soak and on the peak areas where reflow temperatures are at its highest resulting in higher oxidation of the solder paste and surface finishes. To ensure good solder joint formation it is critical that the solder paste remains active on theses areas. In addition, this analysis allows us to design flux management systems that will improve the performance of the reflow ovens. Where to exhaust air or nitrogen in the oven and how to filter the vapors are critical issues that needs to be taken into consideration during oven design.

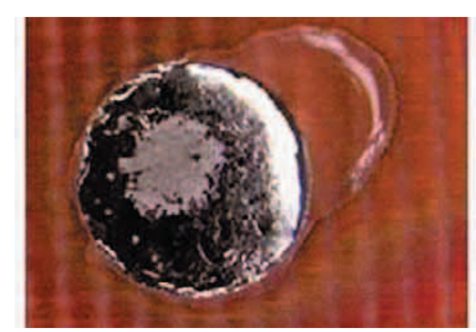


Figure 1. Lead Free Solder Joint with Flux Residue

The use of a Thermogravimetric analyzer(TGA)provides useful information that helps us to understand and compare the behavior of different lead free solder pastes. TGA measures the weight change as a function of time and temperature. On this experiment a clean copper coupon is manually printed with solder paste using a 5 mil thick mini-stencil. As a result the amount of solder paste being deposited is in the range from 5 to 10 mg. The coupon is placed in a ceramic holder on the TGA and it is subjected to 4 minute ramp soak spike and linear profiles under a nitrogen environment as show in Figure 2 and 3 respectively.

The amount of flux evaporation was calculated by oven zones. In this case, a 10 heating and 3 cooling zones oven was simulated. From 10 solder pastes that were tested normally flux starts evaporating at 120°C at which only 1% of the flux evaporates in the preheat areas. In the soak area, the evaporation of the flux depends on the chemistry and usually is between 20% and 30% of the flux. In this evaluation extremes values of 45% were calculated, which result in poor performance of solder paste in the peak areas. On the peak area flux looses typically 45% to 60% of its weight. 10 to 20% of the flux still evaporates on the cooling zones resulting in potential condensation of the vapors and contamination of the internal parts of the reflow ovens. Figue 2 and 3 shows an example of a solder paste's performance under two different reflow profiles. The highest weigh lost measured at 230C was found on this paste (35.9% and 32.2% for ramp soak spike and linear and linear profiles respectively), which indicates poor heat resistance.

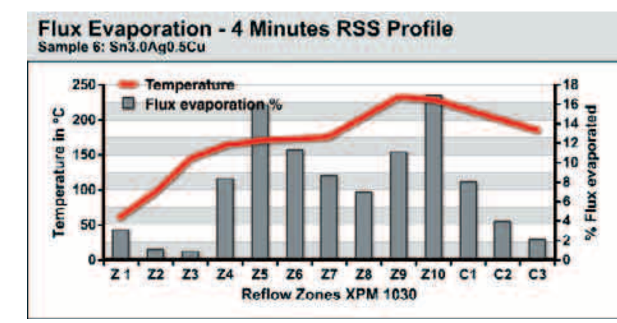


Figure 2. Ramp Soak Spike Profile

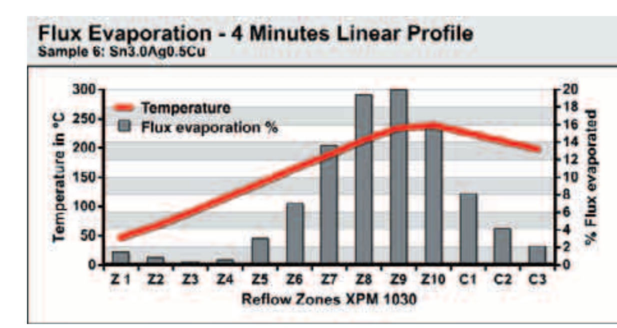


Figure 3. Linear Profile

In addition to the previous test, a 3 minute and 5 minute profiles were performed on 7 solder pastes of different alloys and paste suppliers and the amount of residues was recorded. The parameters of the profiles that were used are shown in Table 1 and the results of the test on Table 2. The amount of residues was calculated by % weight. For example if after reflow the sample had a weight of 92.6% of the initial amount and the metal content is specified as 88.5% then the amount of flux residue left is (92.6-88.5)/(100-88.5) = 35.4%

Table 1. Reflow Profile

Parameter	3 minute - Profile	5 minute - Profile
30 – 120°C	55 seconds	70 seconds
120 – 217°C	80 seconds	131 seconds
Peak	233.3°C	233.8°C
Time Above 217°C	68 seconds	102 seconds

Table 2. Flux Residues Left After Reflow Soldering

Sample	Alloy	Residue Left (%) 3 min Profile	Residue Left (%) 5 min Profile	Difference (%)
1	SAC 305	35.4	36.9	1.5
2	Sn0.7Cu0.05Ni	39.2	29.2	30.0
3	Sn3.75Ag0.25Cu	50.6	54.0	-3.4
4	SAC 305	44.6	39.5	5.1
5	SAC 305	48.0	37.5	10.5
6	SAC 305	52.0	31.0	21.0
7	Sn3.8Ag0.7Cu	46.9	28.8	18.1

For all 3 minute profiles all solder pastes lefts between 35% and 52% of residues whereas between 30% and 54% for 5 minute profiles. Solder pastes from sample 1, 3, and 4 show small differences between the two profiles indicating that these pastes are compatible to reflow profile with higher conveyor speeds. Also, some solder pastes need longer reflow profiles to ensure less residues on the assembly.

Conclusion

The amount and where in the profile the evaporation of flux occurs depend on the reflow profiles as well as the solder paste brand name. Solder paste with poor activity in the peak areas will perform poorly and poor slump resistance can be observed resulting in bridging or solder beading.

High speed profiles (3 minutes vs 5 minutes profiles) can be used without affecting the performance of some solder pastes while others need longer heating profiles to reduce the amount of residue left in the assembly.

The importance of these studies helps us to understand the behavior of new flux chemistries used in lead free solder paste and provide useful knowledge for the designing of new lead free reflow soldering equipment.

Ursula Marquez is a Process and Research Engineer, Denis Barbini is Advanced Technologies Manager for Vitronics Soltec and Gerjan Diepstraten is a Senior Process Engineer for Vitronics Soltec. Comments or questions pertaining to this article can be sent to umarquez@vsww.com.

What I Don't Know That I Don't Know:
Things to Worry About with the Pb-Free Transition

The issues and concerns with transitioning to lead-free can be summed up in one question:

Will my Pb-free product keep my customer just as happy as SnPb?

The answer is somewhat simple. For your customer to be happy, your product has to work. And for your Pb-free product to work, it has to have no defects (quality) and last just as long (reliability). Designing, controlling, and ensuring sufficient quality and reliability is fundamentally based on understanding what has changed with Pb-free and how these changes influence quality and reliability.

First Pass

So, what in Pb-free is there to worry about it? At first pass, quite a bit. It can include:

✦ **Component Plating**
- Tin Whiskers
- Creeping Corrosion (Palladium Plating)
- Melting (SMT Connectors)
- Loss of Functionality

✦ **Connector Plating**
- Fretting Corrosion
- Stress Relaxation

✦ **Board Plating**
- Long-Term Storage
- Champagne Voiding
- Black Pad

✦ **Solder**
- Tin Pest
- Kirkendall Voiding
- Electromigration
- Mixed Solder
- Long Term Reliability
- Board Flexing
- Mechanical Shock
- Insufficient Hole Fill
- Fillet Cracking
- Pad Liftoff

✦ **Reflow Profile**
- Popcorning

✦ **Capacitors**
- Ceramic (Flex Cracking and Thermal Shock)
- Tantalum/Polymer (Popcorning)
- Aluminum (Electrolyte Boiling)

✦ **Printed Circuit Boards**
- Cracking/Delamination
- Degradation of Plated Through Holes (PTHs)
- Dendritic Growth
- Conductive Anodic Filaments (CAF)

Don't panic! A closer look at this list reveals that not all problems are created equal.

Tin Whiskers

Tin whiskers are needle-like growths that emanate from tin-based platings on components and connectors. If these conductive whiskers grow long enough, they can bridge adjacent connections and cause electrical shorts.

This failure mechanism seems to be causing the greatest degree of discomfort in the Pb-free transition. NASA and the US Air Force have banned tin plating because of whiskering concerns. Industrial consortiums like iNEMI and ELFNET have spent years attempting to predict tin whisker's behavior.

What is a Director of Reliability to do?

The first step is to focus. Excluding life-threatening or mission-critical applications, components of concern should be limited to those that have one of the following characteristics:

✦ Lead-to-lead pitch less than 1 mm
✦ Metal can housing (e.g., through-hole crystals/oscillators)
✦ Compressive contact points (e.g., see Figure 1)
✦ Welds

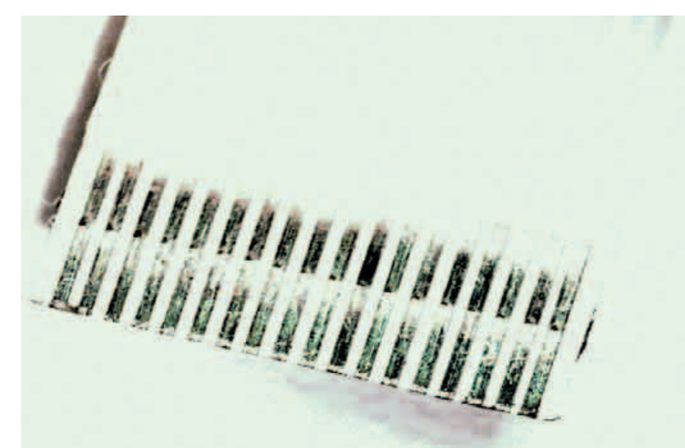


Figure 1: Do not use tin plating on flex circuitry

Once the critical components are identified, ask the supplier if you can get the plating changed to palladium (or gold, in the case of flex circuitry). After initially being resistant, the component industry has responded to increasing concerns by offering OEMs a choice, even if your production volumes are relatively low. Some component manufacturers have even changed their entire fine-pitch line to palladium plating. And asking for palladium tends to be cheaper, quicker, and more definitive than any other mitigation technique available.

If there are no alternatives to tin plating, the next step is based on your level of risk. If your reliability requirements are low or your design life is short, require test results based on JEDEC standard JESD22A121. Come up with your own failure definition as an industry standard is currently absent. Some specifications state absolute requirements, such as a maximum whisker length, while others provide relative requirements (1/3 or 1/2 the minimum spacing).

If your reliability level is medium or your design life is closer to 10 years, require the manufacturers of your at-risk components to perform mitigation. The most widely accepted techniques are a nickel underplate (minimum thickness of 1.2 microns) between the copper lead frame and the tin plating, or annealing the component at 150°C for 1 hour within 24 hours of plating. Some component manufacturers will claim to have proprietary whisker-free tin plating process, but be skeptical and ask for data. Their process may work, but if they don't know why, it will be difficult to maintain consistent tin whisker behavior for every batch.

If you need high reliability for a long time (20 years or more), you may have to consider elimination. This currently includes solder dipping or conformal coating. Both come with their own risks.

Long-Term Storage of Lead-Free Solderability Plating

Pb-free board platings, which includes electroless nickel/immersion gold (ENIG), immersion tin (ImSn), immersion silver (ImAg), and organic solderability preservative (OSP), have been on the market for years, so most failure mechanisms or quality issues are pretty well known at this point. Examples include Black Pad with ENIG and Champagne Voiding with ImAg. If you have always used HASL plated boards, the biggest change will be storage times. Except for ENIG, which many companies tend to avoid because of cost, all alternative Pb-free platings should be limited to 12 months of storage. This is because over time ImSn will form intermetallics (temperature), OSP-coated copper will oxidize (humidity), and ImAg will tarnish (gaseous sulfides).

Mixed Solder

Mixed solder refers to when you are not ready to make the transition to Pb-free, but your ball grid array (BGA) components already have. How to reflow SnAgCu (SAC) solder balls using SnPb solder paste? The answer is very carefully and slightly hotter. The SAC solder ball must collapse, which means a minimum peak temperature of 217°C. Most component manufacturers and OEMs recommended at least 225 - 230°C, which is not substantially hotter than existing SnPb profiles (215 - 220°C). A slight twist is that the finer the pitch, the harder this is to accomplish. If your BGAs are 1 mm pitch, mixed solder

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should be fine. If your components are 0.5 mm pitch, you may wish to switch to Pb-free sooner than later.

Long Term Reliability of Lead-Free Solder

The figurative pot of gold at the end of the rainbow has been predicting the long-term reliability of Pb-free solder. That is, what happens to Pb-free solder after thousands of hours of temperature cycling, power cycling, or vibration?

For temperature cycling, the complete answer is too complex for this short article. But the general trend can be seen in Figure 2. For high risk components (large, ceramic, leadless) subjected to accelerated testing (-40 to 125°C, -40 to 85°C, 0 to 100°C), there is the potential for SnPb to outperform SAC. Extended dwell times at hot temperature increases this risk. However, under more realistic field conditions, such as room temperature to 85C, it can be seen that SAC is far superior to SnPb, even with extended dwell times.

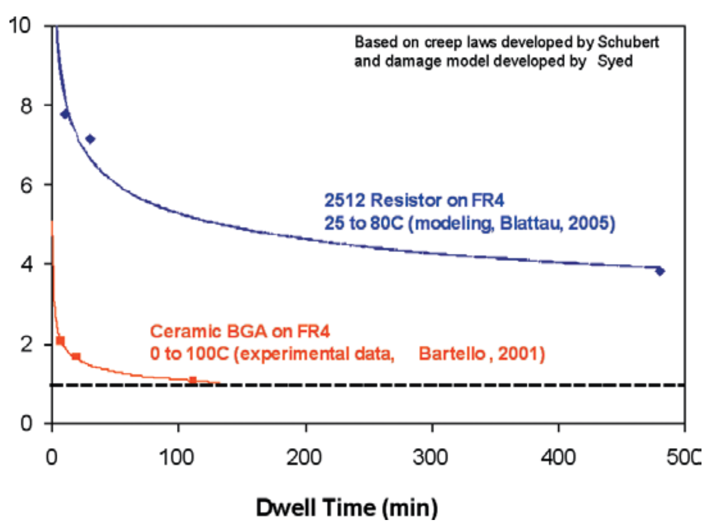

Figure 2: Influence of dwell time on reliability of SAC solder

For vibration environments, SnPb outperforms SAC at higher plastic strain ranges where low-cycle fatigue occurs. Under the lower plastic strain ranges expected in the field, the time to failure becomes roughly equivalent.

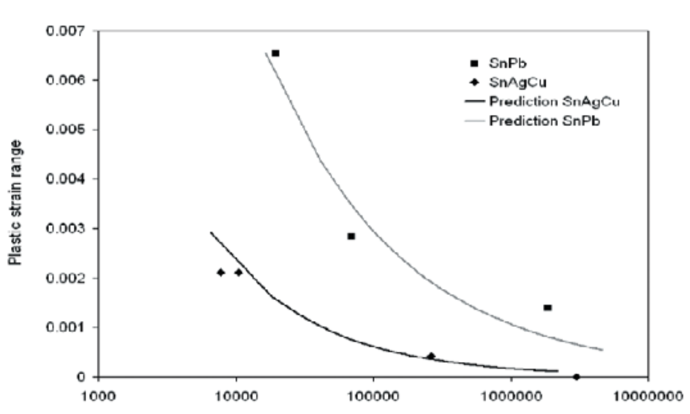

Figure 3: Vibration behavior of SAC solder

Board Flexing / Mechanical Shock

The bigger concern with SAC solder is its ability to resist board flexure during manufacturing and mechanical shock during shipping and operation. A number of studies have shown that SAC alloys can fail at loads up to 50% lower than SnPb when subjected to shock, drop, or static board bending. This loss in performance seems to come from a combination of brittle intermetallics and a greater transfer of stress because SAC is a stiffer material than SnPb.

In response, companies are focusing on maintaining better control over the manufacturing environment, specifically by reducing the maximum allowable strain values from 1000 to 750 or 500 microstrains. In addition, since SnNi is not as shock resistant as SnCu, companies that expect shock and drop in their operating environments are moving away from ENIG as part of their Pb-free transition.

Wave Soldering

Issues related to wave soldering have only recently started to be addressed. The biggest concerns are insufficient hole fill and fillet cracking shown in Figure 4.

Insufficient hole-fill can turn a double-sided solder joint into a single-sided solder joint. Fillet cracking can turn a single-sided solder joint into an early failure. Luckily, both flaws are preventable (higher solder pot temperatures can prevent insufficient hole fill and slower cooling and some design changes can mitigate fillet cracking) and detectable. Just be sure to be look for them.

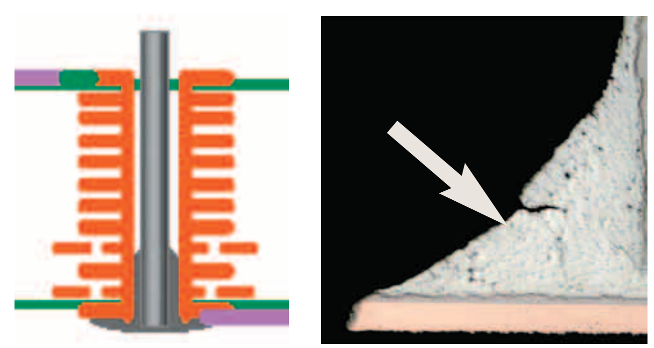

Figure 4: Examples of insufficient hole fill and fillet cracking

Ceramic Capacitors (Thermal Shock)

Initial concerns with ceramic capacitors and SAC solder focused on the potential for increased flex cracking. Recent research by Kemet and DfR has proved this not to be case. The issue that remains is thermal shock. Because of higher temperatures for SAC solder, the maximum wave solderable chip capacitor should be reduced from 1210 to 1206 or 0805.

Printed Circuit Boards

Maintaining the quality and reliability of printed circuit boards (PCBs) as they are subjected to higher reflow and wave temperatures is probably the number one quality concern of OEMs. As a general guideline, the larger the PCB and the higher its density, the greater the potential for quality issues during Pb-free reflow.

OEMs with small boards with no BGAs may have to do little other than perform some construction analysis on their PCBs. OEMs with larger boards, e.g. 12 x 18, and with BGAs and CSPs, may have to consider changes in board material and qualification testing.

For those OEMs with PCB designs at higher risk, the first step is to re-categorize your laminates to include both glass transition temperature (Tg) and time to delamination (t260 or t288). Tg should be at least 150°C and t260 should be at least 15 minutes. Once your materials are chosen, qualification testing should be performed using test coupons. These coupons should assess the reliability of the PTH and the robustness of the design to conductive anodic filament (CAF) formation after multiple Pb-free reflows.

Once the laminate is qualified, construction analysis of the initial build is still necessary. Areas of potential cracking includes under BGA pads and between plated through holes with a pitch 1 mm or less.

In conclusion, there are potential quality and reliability issues during the transition to Pb-free, but they can be overcome with the appropriate knowledge and preparation.

Dr. Craig Hillman is the CEO of DfR Solutions. Dr. Nathan Blattau is the Vice President of DfR Solutions. Questions and comments pertaining to this article can be sent to askdfr@dfrsolutions.com

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Process & Equipment Change Considerations *for Lead-Free Wave Soldering*

Wave soldering with leaded solder alloys has been around for a long time. A lot of research, testing, and sharing of information has taken place to the point where most soldering applications using leaded solder can be optimized within a certain range of parameters.

Let's look at some of the considerations that go into the process of soldering a board:

Component	*Parameters*
FLUX	♦ Choose a flux that interacts well with your production process ♦ Determine the best method of administering the flux (i.e. spray fluxer of foam fluxer?)
PREHEATER	♦ Determine the temperature setting to heat the PCB based on the flux used ♦ Determine the best settings to achieve an optimal thermal curve so the PCB doesn't heat too rapidly or cool off between the preheater and the wave ♦ Controllable so that the required topside temperature can be achieved without the burning the flux on the bottom of the board
WAVE	♦ Choose a solder alloy and solder pot ♦ Determine the solder temperature necessary for both waves ♦ Determine the dwell time ♦ Choose an atmosphere for soldering (nitrogen?)

At first glance, it would seem by changing the solder alloy from a traditional eutectic alloy to a lead free alloy only a few parameters of the wave component would need to be adjusted. However, by changing the solder alloy, all of the parameters above are affected and will need to be adjusted. Let's look at each component in detail and see how the move to lead free soldering will change the parameters.

FLUX

Choosing a flux

Flux serves the purpose of preparing the metallic parts of the PCB for soldering. There are three types of flux: rosin, water soluble, and no-clean. Each type has its pros and cons. Rosin fluxes (RMA, RA) are mildly active, but require aggressive cleaning (usually with chemistry) after soldering. Water-soluble flux offers good overall soldering performance, but must be completely removed by cleaning after soldering. No clean flux is the most difficult to work with for good soldering results, but does not require cleaning.

Process engineers have had to take these flux characteristics into consideration when designing a process. Now with the lead free solders, flux choices will need to be re-evaluated for the higher temperatures generally required for no-lead soldering.

Flux residues may also be more of a concern, especially during the inspection process. No lead solder joints may appear dull and grainy, yet may be perfectly fine. As inspectors adjust to new criteria for solder joints, flux residue will complicate the process.

As for exactly which flux you choose, you can ask your solder supplier for their recommendations for a compatible flux. You could also conduct some testing with solder and flux combinations at a soldering test lab.

Applying flux

While many companies find the foam fluxer on their wave soldering machines sufficient for their processes, it seems the industry standard for flux application is the spray fluxer. Spray fluxers are configured in a variety of ways: ultrasonic, reciprocating, dual head, dual tanks, manual controls, and programmable controls. Programmable spray fluxers offer the best control of flux applications. This is also the most expensive option.

Another consideration in choosing a spray fluxer is the maintenance required to keep the spray fluxer operating at its best. This is especially true if you select a rosin or high solid flux. Nozzles will need to be cleaned on a regular basis to prevent clogging. Conveyor fingers will also need to be cleaned regularly to reduce the spreading of flux throughout the wave soldering machine.

If you are using multiple solder alloys in your production line, you may need to use more than one flux. You may opt to have a dual tank spray fluxer with an easy change over. You may decide to apply one of the fluxes with a spray fluxer and the other with a foam fluxer.

As an aside, if you are using multiple solder alloys and/or fluxes, make sure you're labeling and record keeping is meticulous. Contamination of the lead free process by the leaded solder can easily happen. You should also have some sort of control key procedure for changing the alloys and fluxes.

PREHEATER

Heating the PCB

The melting temperature of lead-free solders is higher than leaded solders. Therefore, the PCB should enter a lead free solder wave hotter than it would a leaded solder bath. This presents some challenges. You must heat the PCB to a higher temperature without overheating the flux. Heating the topside of the PCB is more important with no lead solders.

In order to heat the PCB to a higher temperature without burning the flux or the board surface, the most efficient heat source should be used. In other words, the difference in temperature between the heat source and the board should be as small as possible. This is accomplished by using low watt density, black bodied infrared emitters (I.R. heater) on the bottom-side of the preheater.

The I.R. preheater is physically configured as a continuous radiating surface, comprised of 1" wide strip heaters side-by-side. This provides a uniform heated surface with a lower surface temperature, and allows for 98% of the radiated energy to reach the circuit card. This is accomplished because the lower heater surface temperatures allow the circuit board to be positioned closer to the radiating surface.

In general, long wavelength infrared is less color sensitive and better absorbed than short wavelength infrared. Its temperature determines the wavelength produced by a radiant source. Lower temperatures produce longer wavelengths. The result is more uniformly heated circuit boards. More energy is absorbed by the circuit with less energy reflected away from the board.

Line sources of heat, such as metal tubulars, quartz tubes and lamps, rely on reflectors that redirect 50% of the radiated energy towards the product. These reflectors become oxidized with time and coated with vaporized flux products. This dramatically reduces the efficiency of the preheater. In contrast, full surface radiant emitters are coated with high emissivity black paint. They function as black body radiators, do not use reflectors, and do not loose efficiency with time and use.

The I.R. preheater is best when used in conjunction with a forced air convected preheater. The force air convected preheater acts as heater for the topside of the PCB. Lead-free solders do not seem to flow up thru-holes as easily as leaded solders. Topside preheat will allow better process control, giving the operator the ability to more accurately control the temperature of the topside of the board.

Thermal Curve

Not only is the temperature of the PCB crucial, but how it gets to that temperature, and maintains it, is also important. . The best approach is a gradual, steady increase in board temperature. It is also important that once the board reaches its ideal temperature in the preheating zone, the temperature does not drop before entering the wave. The best way to avoid this pitfall is to choose a wave soldering machine with the preheater as close as possible to the wave zone. There should not be a gap between these two areas. If the board cools too much before entering the wave, thermal shock will negatively affect the wave soldering results.

WAVE

Choosing an alloy and solder pot

As the electronics industry is making a change from Tin / Lead solders, many substitutes have been formulated to make a Lead Free solder. Most of the lead free alloys are comprised of Tin, Silver, and small amounts of copper or nickel or some other proprietary chemical mix. Again, the best way to determine exactly which alloy would be best for you is to consult with your solder supplier or visit an independent test lab.

However, once you have selected your solder alloy, you must carefully select a solder pot. One common element in the lead free solders is a high tin content. The tin is a corrosive agent to steel. Stainless steel will resist the corrosion only slightly longer than steel. Some companies have developed composite coatings. These coating are vulnerable to normal wear and tear. Composite coatings are not effective in resisting tin corrosion over a long period of time. None of these solder pot solutions is a viable option for long term use.

The best choice for a solder pot is either a pure Titanium pot or a pot that has been ion nitrided with a Titanium barrier plate. The nitride process actually changes the molecular composition of the metal, rather than just coating it. This molecular process in conjunction with a Titanium barrier plate over the most active surface of the solder pot is an excellent choice for lead free solder pots. A pure Titanium pot is the best solution if it is available. In tests done by companies that have been using lead free solders for more than a few years already, these two types of pots have resisted the corrosive effects of the tin.

Individual Wave Temperatures

A good wave soldering machine gives the operator control over as many parameters as possible, including individually controlling the temperature of both solder waves. Being able to have the waves at different temperatures allows for a continuation of thermal ramping. This is the most efficient use of heat throughout the entire soldering process.

Dwell Time

Lead free solders do not seem to have the same wicking qualities as leaded solders. Solder does not flow as easily through holes on the PCB. Two ways to overcome this challenge is to increase the dwell time in the solder bath and to minimize the distance between the surface mount and laminar waves. Increasing the dwell time in the laminar wave to 3.0 - 5.0 seconds will give the solder time to flow up through holes. If the distance between the two waves is minimal, there is less thermal loss and an effective continuation of the overall dwell time.

Nitrogen…or not

Wave soldering in an inert atmosphere has been around for a long time. One of the reasons for using Nitrogen as part of the soldering process was to reduce the amount of dross formed by the wave.

Lead free solder alloys are more expensive than their leaded counterparts. Therefore the value of the dross formed is also higher, and represents a bigger loss to an operating budget. The argument for Nitrogen here is to reduce the dross and reduce the operating cost. However, in some testing done with lead free solders, the amount of dross formation is actually less that with the leaded solders. Also consider that when using a soldering machine with a propeller rather than an impeller you will reduce dross production. Using Nitrogen only as a money saver in respect to dross formation may depend on the cost of your lead free alloy and the amount of dross produced by the solder pump system.

Another reason for using Nitrogen with leaded solder alloys has been to improve the appearance solder joints. Nitrogen made the solder joints shinier. This may present a new set of problems for inspection with the lead free solders, which tend to yield duller solder joints.

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