Mastering **metallic** colors

My anodized-titanium card case is deep blue when I hold it normal to my line of vision. But rotating the case changes its color, eventually reaching a nice shade of violet. Why does the object change color? Anodized-aluminum parts, for example, look the same at any angle.

The answer lies in the behavior of light and its interaction with the microscopic structure of anodized-aluminum or titanium surfaces. Metal-oxide layers are a natural consequence of the reaction between surface metal atoms and oxygen in the ambient air or water. In reactive metals such as aluminum, magnesium, titanium, and niobium, the oxide layer that forms is compact and tenacious, providing a natural layer of protection from corrosion.

First, consider aluminum. The oxide that forms naturally on aluminum-alloy surfaces is less than 20-nm thick. This is below the wavelength of visible light and, therefore, invisible. Aluminum oxide, or alumina, is hard — equal in hardness to heat-treated tool steels — and provides a protective layer for the soft aluminum base. However, the thin oxide layer is easily scratched or abraded. Making the oxide thicker through anodizing gives greater protection.

Anodizing gets its name from the use of the aluminum piece as the anode in an electrolytic circuit. Sulfuric acid typically serves as the electrolyte bath and a metal plate serves as the cathode. Applying a dc current accelerates the oxidation reaction on the aluminum surfaces. The result is the growth of aluminum-oxide crystals that form a layer 20 to 50-μm thick — more than 1,000 times its natural thickness. Increasing the voltage across the anode and cathode thickens the oxide layer.

Unlike the natural oxide, the anodized layer contains many tiny pores about 20-nm in diameter. Immersing the anodized-aluminum part in a bath of dye fills these pores with dye particles. The aluminum part is then submersed in boiling water, which hydrates the aluminum-oxide crystals, sealing in the dye. A wide array of metallic-color finishes can be developed on aluminum parts, limited only by the dye colors available.

If no dye is used, the sealed surface results in a clear-anodized layer. A hard-anodized layer comes from using sulfuric acid at low temperatures, producing an oxide layer that's harder with even smaller pores. Hard anodizing is used for bearing surfaces and applications that need high abrasion resistance.

Now for titanium: When titanium is the anode in an anodizing circuit, a uniform layer of oxide forms over the surface, rather than the porous layer of aluminum. Again, boosting the voltage makes the oxide layer thicker. However, the titanium-oxide-layer thickness of 350 to 700 nm is in the range of visible light, but is clear. Light thus reflects from the oxide surface and the titanium surface beneath the oxide — just as light reflects from a mirror glass surface and the mirrored surface beneath the glass.

When the thickness of the clear-oxide surface is equal to, say, the wavelength of blue light, waves reflected from both surfaces reinforce each other. The wavelengths of other colors interfere to some degree, leaving a blue appearance. So, without dyes, the color of anodized titanium normal to an individual's view comes solely from the thickness of the clear-oxide layer. As the part rotates, the color change comes about because the light waves pass through the oxide layer at an angle, which has the effect of increasing the layer thickness. And light wavelengths that reinforce each other are from adjoining parts of the visible spectrum. — *Howard A. Kuhn*

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