Troubleshooting of Electrolytic Color Anodizing of Aluminum

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Electrolytic color anodized aluminum offers a highly durable finish for architectural and residential applications. The use of two-step electrolytic color anodizing of extruded aluminum is widely prevalent in the industry. This article describes the basic process in brief, and then goes on to discuss the interdependency of the anodizing and the electrolytic coloring processes critical for color uniformity and quality of finish. It offers some practical tips to avoid common problems and how to troubleshoot.

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Background

In commercial and residential architecture, anodized aluminum (both clear and colored) has been widely used for doors, windows, and curtain walls. In such applications, aluminum as extrusion and sheet metal are commonly used. Starting in the mid 1980's, two-step electrolytic coloring processes have been widely used throughout the industry to produce color-anodized aluminum. They produce a variety of colors, commonly referred to as "earth tone colors", ranging from champagne to medium bronze to dark bronze, and black. The resultant finish from such processes offer high corrosion and wear resistance, and the color does not fade away when exposed to the UV light of the sun.

Basic principles of the two-step electrolytic color anodizing process

As the name suggests, there are two steps to this coloring process, and they are both electrolytic. The first step is the anodizing of the aluminum, and the second step is the coloring of the aluminum. Because the anodizing and coloring are done separately, the process can produce all the ranges of colors over anodic coatings of thickness from Class I and II.

The anodizing is done using the sulfuric acid process (generally with the addition of some kind of hard coat additive) and DC rectifiers. During the coloring process, an AC power supply is used, and it provides the traditional sinusoidal waveform, its modified waveform, or combinations of both. Many proprietary processes are commercially available for electrolytic coloring. The electrolytes used in these processes are acidic and typically contain dissolved tin, hence the name, "The Tin Process". To a lesser extent, cobalt and nickel are also used in coloring processes. Although cobalt is considerably more expensive than tin, it can (unlike tin) produce a deep black color over thin anodic coatings. Over the years, the tin process has become very popular, due to decreasing costs and more effective implementations.

As mentioned above, the first and most important step in the two-step electrolytic coloring process is the sulfuric acid anodizing of the aluminum. It is necessary to tightly control the concentrations of sulfuric acid, dissolved aluminum, and hard coat additive, as well as the bath temperature, air agitation, voltage, voltage ramp rate, and current density. Proper control of these variables yields anodic coatings that are both uniform in thickness and consistent in film characteristics, such as porosity and thickness of the barrier layer.

After the aluminum parts are anodized and thoroughly rinsed with water, they are immediately transferred into the electrolytic coloring solution. They remain in the coloring solution for a minute or two, to let it penetrate and saturate the pores of the anodic coating before applying the AC current. During the electrolytic coloring step, current passes through the pores and the barrier layer at the base of the anodic coating. The current causes the tin metal to be deposited into the anodic pores, starting at the base and building upwards. Because the porosity and the barrier layer of the anodic coating provide the path for the current to flow through during electrolytic coloring, they greatly affect current efficiencies that cause metal deposition, thereby controlling the apparent color and uniformity of the final product.

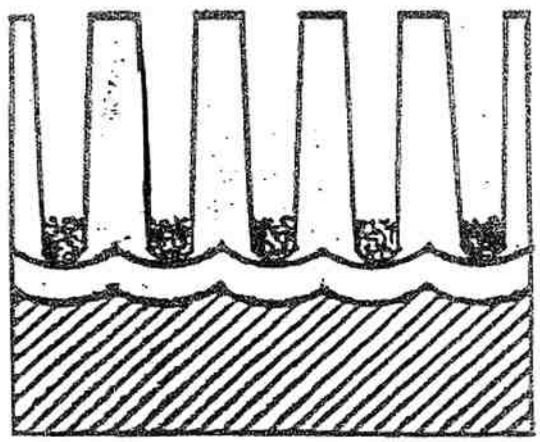

Figure 1. Sketch of an anodic coating on aluminum - shows the barrier layer, anodic pores and the metal deposits at the base of the pores.

The amount of the tin and its oxides deposited at the base of the anodic pores (Figure 1) is directly proportional to the refraction of light from the anodic film, which affects the apparent color. If the deposited amount is low, the lighter colors of champagne and light bronze are formed. If the deposited amount is high, the darker and most popular colors of medium and dark bronze are formed. These two colors are widely used on extrusions that go into the fabrication of doors and windows installed on office buildings, shopping malls, and high-rise apartments.

The Tin Process

As mentioned earlier, the electrolyte used in the tin process for the electrolytic coloring consists of an acid (usually sulfuric), dissolved tin salts, stabilizers, and color enhancers. The so-called "counter electrodes" used in the coloring bath could be soluble electrodes made of tin, or insoluble electrodes made of stainless steel or graphite. The AC power supplies could be simply manual, or they could come with programmable computer units. The coloring bath is operated at about 20 °C (75 °F) and with continuous circulation of the solution to cause a gentle rolling action at the top.

Anodizing & Electrolytic Coloring

The electrolytic coloring can be imparted into anodic coatings of various film thicknesses. However, the resulting color and its uniformity are mostly a reflection of the underlying anodic film characteristics such as porosity, barrier layer, etc. These film characteristics are greatly influenced by parameters such as anodizing voltage, solution conductivity, uniformity of temperature, and air agitation within the solution. Thus, without finding significant variances in the thickness of the anodic coating, one could find color uniformity problems (within the same areas of an extrusion) due to variations of temperature and agitation within different areas of the anodizing bath. These variations drastically alter the mentioned film characteristics, although they only have a minor effect on the anodic coating thickness. To state it paradoxically, “what you don’t see is what you get”. Putting the electrolytic coloring over the anodic coating is like taking an X-ray image of the anodic film underneath. It starts to reveal the defects that are invisible to the naked eye. For example, in areas of the anodizing bath where there is little or no agitation (the “hot zones”), the entrapment of heat would greatly increase the solution conductivity in that local area and lead to the widening of the anodic pores and thinning of the barrier layer. These two, in combination, would cause the color to shift towards a darker shade. The point here is that, while it is a common practice in an anodizing shop to regularly and religiously check the anodic coating thickness, very little attention is paid to assure uniform air agitation and temperature of the bath. Often, they are neglected because there is no physical access for the operators and maintenance staff to investigate. Hence, it is advisable to have catwalks along all sides of the anodizing tank, to provide ample access for the required service and maintenance.

Good common practices for anodizing & coloring

Although this paper deals with troubleshooting, it is important to first mention the practices that help to prevent problems. However, other factors do adversely affect the appearance of the colored finish. These include variations in the etching or bright dipping of the aluminum surface, variations in the sealing after the anodizing and coloring, and variations in the alloy and tempering. These, and other factors, are beyond the scope of this paper. Hence, I have only listed the parameters of anodizing and coloring that are critical to ensuring the standard color uniformity.

Racking

- Do not use titanium racks.
- Use only aluminum racks, preferably made of the 6063 T5 or T6 alloy.
- Ensure the aluminum racks are sized to carry the electrical current load.
- Make sure the aluminum racks are stripped before use, every time.
- Use plastic “C” clamps to secure heavy extrusions on to the rack.

- Use aluminum hooks for lighter profiles of the extrusions.
- Allow for ample space between extrusions racked in a row.
- The widest and critical dimensions of the extrusion should be facing out.

Anodizing Process

- Maintain sulfuric acid concentration level within + or – 5 g/L.
- Maintain dissolved aluminum concentration level within + or – 1 g/L.
- Maintain the bath operating temperature within + or – 0.5 °C (1 °F).
- Maintain an anode to cathode ratio of 3:1.
- Maintain a constant workload area on every rack for anodizing.
- Use constant current control; anodize all loads at the same current density.
- Keep the same slope or ramp control for the current on all loads.
- Keep anodic coating thickness variations within 3 μm (0.12 mil).
- Maintain a vigorous but uniform air agitation of the anodizing solution.
- Check for the uniformity of the bath temperature and air agitation.

Coloring Process

- Maintain equal spacing between the rows of counter electrodes.
- If using tin electrode strips, check them regularly and replace as necessary.
- Maintain solution level at least 5 cm (2 in.) below that of anodizing.
- Maintain a mild and uniform solution circulation. No Air Agitation.
- Maintain bath temperature within + or – 0.5 °C (1°F).
- Allow for a 1 to 2 min dwell time before applying power.
- Maintain the bath chemistry as recommended by your supplier.

Troubleshooting most common problems related to the anodizing process

Problem	Possible causes	Remedies
Non-uniform color within a part	Coating thickness variations in excess of 3 µm (0.12 mil)	Check electrical contacts; maintain tight controls on bath chemistry & temperature.
Color varies- load to load	Poor manual ramp control. Ramping too fast. Power applied suddenly.	Use automatic ramping. Ramp at 10% of total time. Always use ramp control.
Darker colors	Low anodizing voltage. High bath temperature. High sulfuric acid. High dissolved aluminum	Increase the voltage. Lower the bath temperature. Lower the sulfuric acid level. Lower the aluminum level
Lighter colors	High anodizing voltage. Low bath temperature. Low sulfuric acid. Low dissolved aluminum	Lower the voltage. Increase the bath temperature. Increase the sulfuric acid. Raise the aluminum level.
Patchy colors	Non-uniform air agitation Poor temperature control	Provide air agitation from underneath and along the entire length of the workload. Ensure the heating coils are located uniformly within the tank. Check thermostat.
Fish tailed dark spots	Air entrapment on parts	Rack parts on an incline

Troubleshooting most common problems related to the coloring process

Problem	Possible causes	Remedies
Picture framing – color darker on the outside of the workload and lighter on the inside.	Bath acid level, too high Bath conductivity, too high Voltage, too low	Decrease acid level. Lower bath conductivity. Increase the voltage.
Reverse picture framing – color lighter on the outside of the workload and darker on the inside.	Bath acid level, too low. Bath conductivity, too low. Voltage, too high.	Increase acid level. Raise bath conductivity. Lower the voltage.
Darker colors with red undertones.	Bath temperature over 20 °C (68 °F).	Lower the bath temperature.
Lighter colors with green undertones.	Bath temperature below 15 °C (60 °F)	Raise the bath temperature.
Vertical zebra stripes on parts.	Broken tin counter electrodes. No electrical contact.	Check & replace broken tin electrodes. Check and tighten electrical contacts

Summary

For the two-step electrolytic coloring process, the importance of maintaining tight controls on the anodizing bath chemistry and its operating parameters cannot be over emphasized. They are paramount for achieving color uniformity and consistent quality of finish, load after load. The quality of finish produced by the electrolytic coloring during the second step of the process is very much a reflection of the quality of the anodized film underneath. In other words, quality problems caused by poor anodizing practices cannot be solved later by some miracle in the coloring process. By clearly understanding and appreciating the interdependency between anodizing and electrolytic coloring, and by taking the necessary steps to control the critical parameters discussed above, one can lower the rejects, maintain consistent quality, and eliminate most operational problems.

