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Dyeing Anodized Aluminum

More than a thousand companies in North America color anodize aluminum. These companies vary from job-shops with 45-gallon tanks to architectural plants with vessels that hold 7,000 gallons or more. The majority of these firms use organic dyes to color an equally wide range of products. Items range from sporting equipment and cosmetic packages, to automotive and space station parts.

Regardless of the company size or the product that is color anodized, the same technical questions come up time and time again. Questions relating to dye choice, bath preparation and quality control are common, as well as the effects of alloys, anodizing conditions, and rinsing, which all too often lead to costly defects and downtime. Then there is that black smut or white spotting problem that comes and goes, leaving many anodizers scratching their heads. This article will attempt to answer some of these questions.

All About Dyes

When it comes to choosing a dye, an anodizer should think about buying an economical product that he/she confidently feels will produce the target color in a consistent manner. Other factors may include light- or heat-fastness requirements, ease of use, and spent dye disposal. It is very easy to judge the economy of a dye solely on its price, but this is not a wholly accurate measure. What is the lost value of a defect, or a faded part that has been returned by an angry customer? How about the cost of dye disposal? Another important factor should be productivity. For instance, high-performance black dyes can easily color a 0.4 mil thick anodic film. That's half the anodize time and power typically used throughout the industry!

The preparation of a dye bath is relatively simple. The dye bath should be filled about 2/3 full with hot demineralized water and the dye added to it. If the dye is purchased in powder or granulated form, a slurry should be prepared first by taking a half-filled bucket of the pre-heated water and adding the dye with stirring. The slurry is then added to the tank with agitation to ensure complete dissolution. A liquid dye can be added directly to the tank. If required, a buffering salt and a little acid is also added to adjust and maintain the pH. Most dye baths are run at a pH of 5.5–6.0, and are kept there with sodium acetate and a little acetic acid. Since there are exceptions, one should always consult the technical bulletin supplied by the dye vendor before making up a bath.

Dyeing is a straightforward process where the anodized load is simply immersed in the dye bath for a period of time sufficient to achieve the desired shade. The desired shade should be achieved in no less than two minutes; otherwise, uniformity of color within the load and between loads can become an issue. For special cases where optimal light or heat fastness is important, full saturation dyeing is necessary. For these cases, the dye must be in good working order, and the load must be left to soak for 20 minutes or longer.

Quality control of a dye bath usually takes the form of monitoring pH and concentration. In general, the solubility of a dye is proportional to pH. The lower the pH, the lower the solubility. One should keep in mind that many dyes are multi-component mixes. If one or more of these components is sensitive to pH fluctuations, color shifts can occur. The optimum pH can be achieved by either adding sodium hydroxide, to increase the pH, or acetic acid, to reduce it.

Concentration is best monitored with a spectrophotometer at the wavelength where maximum absorption takes place. For the majority of anodizers who do not have this equipment, a visual method can be used with good results. In the lab, make up known standards of varying concentration. Dilute each by the same amount to a point where you can tell differences by looking through the solutions—for black dyes the dilution should be about 200/1. Finally, dilute your unknown bath by the same amount and make a visual comparison with the standards. This method can be surprisingly accurate once you've had a little practice.

All too often, the concentration of a dye bath is where it should be, yet it does not dye as it did when it was first made up. The color can be off, or just too light. A dye is a complex organic molecule that can be sensitive to drag-in of contaminants, growth of molds, and even, in some cases, heat. When the effective strength of dilute dye bath falls off, the prudent course of action in many instances is to simply dump the bath and then recharge. Struggling to keep the bath in reasonable working condition is usually not justified, considering the potential costs in production time, rework, and unhappy customers.

Because of their concentration and size, black dye baths may be the exception. The cost of dye to recharge and the expense of disposing the spent bath can outweigh production slow downs and lower-quality finished products. Anodizers often find it in their best interest to continue to run these tanks as long as possible.

Measuring effective dye strength is

not easy. It involves dyeing panels in standardized baths as well as the test bath, extracting the dye adsorbed by the panels and finally measuring the quantity of dye extracted. The practiced anodizer will often have a good "feel" for the effectiveness of their black dye bath by simply noting how well and how fast the dye is picked up by their parts compared to when the bath was first charged.

There are differences of opinion as to how to use effective strength values as a QA tool, or whether it is necessary at all. Studies have shown that some dyes can be used for long-term outdoor exposure applications. For such product applications, both the choice of dye and the effective strength are important. Therefore, if a product's light-fastness is guaranteed, effective strength of the dye should be monitored.

Other Process Effects

Proper cleaning and rinsing are important in achieving color uniformity. If the soil is not completely removed during the pretreatment, the possibility exists for areas where the color won't take. Improper rinsing will more typically result in mottled or streaked films. In the cases where microporosity, blind holes, or otherwise difficult-to-rinse areas exist, white spots may result. A good idea is the use of a nitric acid immersion treatment between the anodizing and coloring steps. This procedure serves to condition the film for improved dye up-take, and minimize the risk of a variety of potential coloring problems.

The morphology and inherent color of the "as-anodized" oxide film directly impacts how well a part accepts dye and its final appearance. Both alloy and the anodizing process determine these coating characteristics. Usually, an anodizer can do little with regard to alloy selection; however, some control over the final appearance can be established by adjusting the current density, time and temperature in the anodizing tank.

As a general rule, increased current densities and lower anodizing temperatures create less porous coatings of reduced clarity. An extreme example would be hard coat where current densities of 25 A/ft^2 (or higher), at 300°F (or lower), produce coatings which can be nearly opaque. Dyeing becomes a challenge, and the palette of available colors is limited. Common methods of dealing with this challenge include immersion for 2-5 minutes in a 10-percent nitric acid solution, or re-anodizing for 5 minutes under more aggressive conditions. Both of these methods will deteriorate wear resistance to some extent.

On the other extreme are coatings that are highly porous. These are anodized at elevated temperatures (75°F or higher) and low current density (12 A/ft^2 or lower). These "soft" coatings are relatively easy to dye, and allow for the production of a wider palette, including bright colors. Soft coatings are also more difficult to seal and tend to develop more smut. The preferred conditions for decorative anodizing is to run the temperature at or near 70°F, and the current density between 12-15 A/ft^2.

Sealing is a necessary step toward achieving a quality color-anodized part. Often a nickel seal is best used, either alone or in combination with a hot water or mid-temperature magnesium seal. The nickel is a functional component of the seal. It serves to lock in the dyestuff, minimize bleed-out, and improve the color fastness of the product. A common problem that is usually blamed on the seal is the presence of smut, which is a powdery surface residue that is often found on deep colors and black.

It is important to understand that the source of this defect may, in fact be the soft anodize conditions, or even inadequate de-oxidizing following the pretreatment. If the defect can be traced to the seal tank, then pH should be examined, filtration should be used, and the dispersant level in the seal, checked. By using proper anodizing and sealing conditions this defect can be eliminated in an effective manner.

In Summary

Despite the relative simplicity of the color-anodizing process, things can go astray. If not kept in check, individual production parameters and their varied interactions can lead to costly production down time, defects, or even customer claims. By following the basics for good cleaning, rinsing, anodizing, dyeing, and sealing, very few problems will be encountered. It's the responsibility of all anodizers to produce a product which will continue to give color-anodized aluminum the perception of quality we have come to enjoy. *P&SF*