Shop Talk

Electropolishing*

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Practical applications, equipment, electrolytes and troubleshooting are examined for the electropolishing process.

Since the early investigations by Jacquet and Elmore nearly 50 years ago, electropolishing has become a useful tool for a variety of metal finishing applications and has achieved a reasonable degree of commercial development and utility.

Essentially, electropolishing is the improvement in the surface finish of a metal by making it anodic in a suitable solution. With the proper selection of

current density, temperature and other conditions, the surface is smoothed and brightened while metal is removed. Figure 1 depicts a fundamental setup for the electropolishing operation.

Figures 2 and 3 are photomicrographs illustrating the effects of electropolishing on two types of substrates. Figure 2a shows a machined and tapered carbon-steel pin before electropolishing. Figure 2b shows the same pin after electropolishing for 7 min in an electrolyte based on chromic, sulfuric and phosphoric acids. Almost complete removal of all machining lines has been achieved and an obvious smoothing of the surface has also been realized. Figure 3a is the "as is" photomicrograph of a beryllium-copper electrical connector pin. Figure 3b is the same connector after electropolishing in a chromic-phos-

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Fig. 2-Carbon steel pin (a) before and (b) after electropolishing.

phoric-acid-based electrolyte for 5 min. The leveling and brightening of the beryllium-copper surface is dramatic, and close inspection of the photomicrograph reveals that substantial deburring of the part has also taken place.

The photographs point out some of the outstanding features of electropolishing. Where the metal or alloy is suitable, electropolishing will produce a chemically clean, lustrous to mirror-bright surface. In contrast to mechanical polishing, electropolishing does not incorporate foreign inclusions into the surface layer. In fact, because it removes surface metal, electropolishing tends to displace surface inclusions arising from stamping, machining and the like. The electropolished surface also is more passive and decidedly more corrosion resistant than a mechanically polished surface.

In electropolishing, both micro- and macro-asperities are preferentially removed. The removal or reduction of the surface micro-asperities increases surface reflectivity and reduces surface friction. Burrs may be regarded, to some degree, as asperities, and during electropolishing they are dissolved at a more rapid rate than the rest of the surface. Deburring is one of the common applications for electropolishing.

Electropolishing is exceptionally useful for polishing complex and convoluted parts. Because electropolishing will occur wherever the process solution contacts the workpiece, difficult parts can be finished by electropolishing at the appropriate current density much more readily than they could be treated by mechanical polishing.

Electropolishing is an economical finishing process. Depending on the electrolyte being used, the running chemical costs, plus power charges, range from 0.15 to 0.45 per dm² (1.40 to 4.20 per ft²) per minute of electropolishing time. Labor costs for racking and unracking are additional. Costs for pre-cleaning and water usage should also be added to the basic running costs.

Most of the common metals and alloys can be electropolished with varying degrees of success. In general, the more homogeneous and fine-grained the structure of an alloy or metal is, the better the results of electropolishing will be. Because of their basic metallurgical makeup, nickel-containing stainless steels (300 series) have a structure that is particularly well suited for electropolishing and thus constitute a large portion of the commercial applications for electropolishing.

High-quality aluminum alloys, as well as homogeneous brasses and copper alloys, also electropolish well. Nickel-silver alloys and Fig. 3–Beryllium-copper connector (a) before and (b) after electropolishing. other nickel alloys are usually fine-grained

and respond to electropolishing. Carbon steels ordinarily do not produce a very bright surface when electropolished. Commercial applications for electropolishing carbon steels are usually limited to surface conditioning and cleaning prior to plating, deburring or otherwise modifying the surface to conform with engineering specifications. These engineering applications include the reduction of surface stress, the improvement of surface friction, the reduction of gear wear and the use of electropolishing to produce desired dimensional requirements.

Alloys containing silicon, phosphorus and tin do not electropolish satisfactorily, producing a surface which, although clean, is frosty and lacking in brightness. Cadmium, lead, tin and zinc alloys are not ordinarily electropolished commercially. Gold and silver alloys are electropolished to a limited degree commercially - primarily for surface improvement prior to mechanical polishing. Some limited electropolishing is done commercially on titanium and tungsten alloys.

Table 1 summarizes some of the published formulations for electropolishing electrolytes and their operating conditions. Proprietary electropolishing solutions are available from a number of suppliers. These compositions may be modified to some extent but would usually operate under the outlined conditions.

Equipment Requirements

From Table 1, it is clear that electropolishing solutions are usually mineral acid mixtures and may be operated at elevated temperatures. Tanks, cathodes, coils, rinse tanks, exhaust casings, etc., therefore must be constructed of materials resistant to the electrolyte being used.

Chemical lead-lined steel tanks give excellent service life where electrolytes based on sulfuric, phosphoric or chromic acids are utilized. When using lead-lined tanks, it is important to remember that they are conductive and stray currents may develop. These stray currents do not adversely affect the lead to any great degree, but may produce poor current distribution during electropolishing.

Polyethylene, polypropylene, fiberglass, polyvinyl chloride and steel tanks lined with these materials can also be used for the electropolishing tank. When using these materials for construction, however, it is imperative to ensure both their compatibility with the electrolyte and their long-term temperature stability. Otherwise, the electrolyte may degrade the resin, particularly at welded areas, causing resin cracking and failure. Stainless-steel tanks (316 series) may provide good service with some electrolytes. Even so, an anodic stray current could actually electropolish the stainlesssteel tank and cause it to dissolve before very long.

Cathodes constructed of chemical lead give long-term service with most electrolytes. Copper or stainless-steel cathodes can also be used with some systems. Copper cathodes should not be used with electrolytes containing chromic acid, nor should stainless-



steel cathodes be used with electrolytes that contain sulfuric acid and that are operated at elevated temperatures. The cathode-toanode area for electropolishing should be 2:1 or 3:1.

Heating and/or cooling coils should also be fabricated from materials compatible with the electropolishing solution. Teflon coils, although costly, give excellent service with complete stability and electrical neutrality. Chemical lead coils also afford good service. For maximum service, chemical lead coils should be reinforced at the solution/air interface with an additional thickness of lead. Quartz electric immersion heaters can also be used to heat the electropolishing solution. Immersion heaters should be sized for a 6 to 8-hr heat-up time with a thermostat and time control. This setup reduces the total kilowatt requirement for heat-up and lowers the initial expense of the immersion heater. Sensing elements for thermostat controls should be Teflon coated.

To remove the acid mist and gases produced during electropolishing, the tank should be exhausted. Fiberglass, PVC or other plastic exhaust casings and ducts give excellent service. Exhausts should be designed to provide an air flow of 85 m³/min (3000 ft³/min) at the tank. Exhaust fans should be constructed of an acid-resistant material for maximum service.

Following electropolishing, rinse tanks, fabricated from polyethylene, polypropylene or fiberglass are resistant to most electrolytes, give good service and are economical. A three-stage countercurrent running rinse effectively removes most electropolishing solutions from the workpiece.

Racking

Plastisol-coated copper-splined racks with titanium contact tips give the best long-term service for electropolishing. When designing the rack, provision should be made for sufficient cross-sectional area in the rack spline and contact point to carry the relatively high current density used in electropolishing. This insures good current distribution on the rack, prevents overheating the rack and thwarts arc burning at contact points. Parts should be spaced and mounted on the rack to avoid shielding, allow good drainage and prevent the formation of air or gas pockets. Contact to the work should be firm and positive and in an area where any resultant rack mark would not be objectionable to the finished quality. The part should be positioned on the rack so that the surface requiring the best finish faces the cathode.

Some electrolytes are so-called sludging types. During operation, these baths accumulate a sludge that must be removed from the bottom of the electropolishing tank. Racks designed for use in this type of system should be made so that they will not contact the sludge when it is at its maximum buildup. Parts with deep recesses, internal diameters or blind areas require auxiliary or conforming cathodes for complete and uniform electropolishing. Racks should be designed to permit easy entry into (and exit from) the electropolishing tank with a minimum distance of 8.75 cm (3.5 in.) from the cathode. In general, racking practices for electropolishing are very similar to those for high-current-density chromium plating.

Pretreatment

As is the case in most metal finishing operations, good surface preparation is necessary for effective electropolishing. The work should be free of oils, grease and grit. Conventional methods of cleaning such as vapor degreasing, alkaline soak cleaning or alkaline electrocleaning are also suitable for electropolishing. The preferred method naturally will depend on the nature of the soil on the part.

When using alkaline precleaning, a mild acid dip (1 to 2 wt%) compatible with the electrolyte should be used to neutralize the alkali prior to introduction of the work to the electropolishing tank. Parts should be allowed to drain to avoid excessive drag-in of water in the electrolyte. Too much water in the electropolishing solution is usually detrimental to the chemical balance of the solution and can cause pitting, etching and/or loss of the polishing effect.

Electropolishing will remove light, uniform scale and heattreating discoloration without the need for pre-pickling. However, when scale is heavy, dense or non-uniform, pre-pickling is necessary to avoid an etched or pitted electropolished surface.

Post-Treatment

Following electropolishing, parts should be thoroughly rinsed to completely remove the acid electrolyte. Some electropolishing baths are extremely viscous and difficult to rinse, especially when these solutions are old. In the case of these viscous baths, a warm water rinse may be required in the first stage of the rinse cycle. Certain parts that can entrap the electrolyte may require additional treatment in a mild alkaline dip (15 to 30 g/L; 2 to 4 oz/gal sodium bicarbonate or 1 to 2 wt% ammonia) to neutralize any residual acidity and prevent subsequent corrosion or staining. Aged electrolytes, high in dissolved metal content, tend to leave films of metal salt on the work, even with thorough rinsing. These residues usually dissolve in a dilute acid dip. The strength and type of acid used for this dip depend on the metal being electropolished. It should be strong enough to cut the residual film without attacking the basis metal.

Solution Control

The metal anode dissolves in the electropolishing solution. In most systems, this metal is not plated out on the cathode but builds up in the electropolishing solution. As the bath is operated, there is an increase in the metal concentration, the specific gravity and the electrical resistance of the electrolyte. At the same time, the acidity of the electrolyte decreases and oxidizers or additives are consumed. Water is lost by evaporation and electrolysis.

Depending on the type of electrolyte, and after reaching a certain dissolved metal concentration, the quality of the final finish will suffer or the bath will begin to sludge.

Chemical analysis of the solution on a routine basis results in consistent, good-quality electropolishing. A daily reading of specific gravity provides an estimate of the concentration of both dissolved metal and water and indicates any gross changes in solution composition. Analysis for solution acidity, acid ratios, dissolved metal and other constituents should be run as frequently as necessary to maintain the bath within its prescribed limits. A loss of solution level due to dragout and water evaporation should be made up with additions of fresh electropolishing solution and water.

In contrast to plating, where metal ions are continually depleted from the bath, electropolishing is continually introducing metal ions into the system. To maintain the electropolishing bath at a point at which it will produce good results, the metal concentration must be kept below a certain level. This is usually accomplished in one of three ways:

- 1. The solution is permitted to reach a predetermined metal concentration and then maintained at that level by decanting a portion of the solution and replacing it with fresh electrolyte on a daily ampere-hour basis.
- 2. The bath is operated until the metal content reaches a level that produces poor-quality results and then is cut by a substantial amount (20 to 50%) or remade completely.
- If possible, the bath is permitted to reach a level at which the metal precipitates as an insoluble sludge of metal salts that is periodically removed.

Method 1, although slightly more costly chemically, produces more consistent results and may require less labor and handling than the other two methods.

Process Limitations

As with most systems, electropolishing has certain limitations. Some of these shortcomings are as follows:

- 1. The throwing power of electropolishing solutions is generally poor, *i.e.*, relatively high current densities are required.
- 2. Electropolishing removes metal, so parts with close dimensions must be made oversized or metal loss must be tolerable.
- 3. Electropolishing does not "flow" the metal surface. Deep scratches or surface imperfections are not smeared over and hidden as they are by mechanical polishing.
- 4. Not all materials can be successfully electropolished.

Table 2, a troubleshooting chart, outlines some of the more common electropolishing problems, their possible causes and remedies.

Waste Treatment

Depending on the electrolyte being utilized and the metal being treated, different electropolishing solutions require slightly altered treatment for disposal. The majority of electropolishing solutions are based with mineral acid and can be readily neutralized with alkali to an acceptable pH level. However, the electropolishing solution also contains the metal ions of the material that was processed. If, for example, 300-series stainless steel is being treated, the electrolyte will contain, in addition to the acid, dissolved iron, nickel and chromium. These metals will precipitate at the alkaline pH level and can be filtered out as the metal hydroxide.

Electrolytes that contain chromic acid as part of their composition require conventional reduction of the hexavalent chromium prior to neutralization. Proprietary and non-proprietary electrolytes should be evaluated to determine whether they contain components that might function as complexants and prevent precipitation of the dissolved metal ions. They should also be investigated to determine if they contain any materials that might require special treatment prior to disposal. *P&sF*

Technical Editor's Note: The preceding article is based on material contributed by Walter Schwartz for the AES Update series that ran in this journal. Since this article was written, much has changed. Indeed, the outlook for hexavalent chromate has drastically changed. Nevertheless, these processes remain relevant to a large portion of the finishing community. The reader may benefit both from that information and the historical perspective of the technology. The Update series was begun and coordinated by the late Dr. Donald Swalheim, and brought practical information to the metal finisher. In some cases here, words were altered for context.

Electrolyte Composition		Operating Conditions	
1. Aluminum & Aluminum Alloys			
Sodium carbonate Trisodium phosphate Water	15% 5% 80%	74-88°C (165-190°F) 5.0-6.0 A/dm ² (46-56 A/ft ²)	
Fluoboric acid	2.5%	30°C (86°F) 15-30V 1.0-2.0 A/dm ² (9-18 A/ft ²)	
Phosphoric acid Sulfuric Acid Chromic Acid Water	50-75% 0-10% 5-20% Balance	65-95%C (149-203°C) 10-18V 5.0-20.0 A/dm ² (46-186 A/ft ²)	
2. Copper & Copper Alloys			
Modified phosphoric acid and alcohol or glycol mixtures (proprietary)		20-40°C (68-104°F) 6-15V 2.0-10.0 A/dm² (18-93 A/ft²)	
Phosphoric acid Chromic acid Water	75-84% 0-15% Balance	40-70%C (104-158°F) 12-18V 10.0-30.0 A/dm² (93-279 A/ft²)	
3. Nickel & Nickel Alloys			
Phosphoric acid Sulfuric acid Hydrochloric acid Water	15-70% 15-60% 0-2.5% Balance	30-50°C (86-122°F) 10-18V	
4. Stainless Steels			
Phosphoric acid Sulfuric acid Water	40-65% 15-45% Balance	45-80°C (113-176°F) 10-18V 5.0-50.0 A/dm ² (46-465 A/ft ²)	
Phosphoric acid Sulfuric acid Organic additives Water	30-65% 15-55% 2.5-15% Balance	45-80°C (113-176°F) 6-18V 5.0-50.0 A/dm ² (46-465 A/ft ²)	
Phosphoric acid Sulfuric acid Glycolic acid Water	0-40% 15-55% 10-30% Balance	45-85°C (113-185°F) 6-18V 5.0-50.0 A/dm² (46-465 A/ft²)	
5. Carbon Steels			
Phosphoric acid Sulfuric acid Chromic acid Water	45-75% 5-40% 0-12% Balance	45-60°C (113-140°F) 10-18V 10.0-30.0 A/dm ² (93-279 A/ft ²)	
6. Titanium & Titanium Alloys			
Hydrofluoric acid Ethylene Glycol Water	6% 88% 6%	25-40°C (77-104°F) 8.0-10.0 A/dm ² (74-93 A/ft ²)	
Hydrofluoric acid Chromic acid Water	10% 40% Balance	15-20°C (59-68°F) 3-7V 20.0-50.0 A/dm² (186-465 A/ft²)	

Table 1—Electrolytes & Operating Conditions for Electropolishing

Problem	Causes	Remedy
Pitting	Poor surface preparation.	Check pre-cleaning and pre-pickling. Reduce water drag-in or addition.
	Excessive water in bath.	Check for leaks in heating or cooling coils. Increase solution and/or work agitation.
	Gas (oxygen) not being removed from work surface.	Modify position of part on fack.
Poor-quality electropolishing	Incorrect electrolyte balance. High metal content. Low electropolishing current density. Poor rack contact.	Analyze and adjust bath. Decant portion of solution. Raise voltage and average current density. Check for make-or-break contact on bus bar. Check for positive rack contact and rack conductance.
Staining after electropolishing	Poor rinsing. Excessive delay in transfer to rinse cycle. Metal contamination producing immersion deposit.	Improve rinse cycle. Neutralize electropolishing solution. Decrease dwell in air. Remove source of contamination or introduce post-dip to remove immersion
	High dissolved metal content.	deposit. Post-dip to dissolve metal salt film.
Gas patterns or streaking	Poor escapement of gas away from work; gas pocketing.	Change positioning of part on rack. Increase agitation of work bar or solution. Reduce operating voltage if possible.

Table 2—Troubleshooting Chart for Electropolishing

