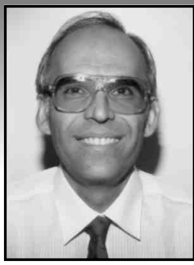

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Electropolishing: Relatively New . . . Interestingly Diverse

About 70 years ago, some practical research and development introduced our industry to a rather unique electrolytic process. It improves corrosion resistance, deburrs, enhances surface finish, and prepares the base metal for additional finishing work. Very appropriately, this practical conditioning operation is referred to as *electropolishing*. It's been a specialized workhorse in our industry since the early 1950s. Many of us would be surprised at how many commercial and engineering applications specify electropolishing. We probably touch objects on a routine basis that have been electropolished. Items that are electropolished include medical equipment and products (prosthetics, stents, special screws, surgical instruments), tanks and assorted vessels, pipes and tubes, automotive trim and wheels, aircraft and aerospace parts, electrical components and parts, equipment for food service, farming, and harvesting, drilling equipment, and various machining and fabricating. There are many other applications.

What it Is

It's not complicated at all. Use the model of reverse current electrocleaning as a guide. Metal parts (ferrous or nonferrous) are immersed in predominantly acidic electrolytes. The parts are anodic. Switch on the DC rectifier and current flows from the part to the cathode. Oxidation of the part indicates that surface metal ions are being removed. Balanced equations identify what oxidation/reduction chemical reactions do occur (see above table).

- At the Part (+ anodic)
  - Metal - (electrons) = Metal Ions (M^{++})
  - $4(OH) - 4(\text{electrons}) = 2H_2O + O_2$
- At the Cathode (- cathodic)
  - $2H^+ (+)\ 2(\text{electrons}) = H_2$
  - Metal Ions (M^{++}) (+) (electrons) = Metal

How It Works

The complimenting reactions and degree of metal removal are factors of time, solution temperature, bath chemistry, current density, and the metal alloy being treated. Metal dissolution—its removal from the substrate surface—is the focus of electropolishing. Visual inspection or microscopic observation of a metal surface clearly shows the disparity in the leveling or grade. This is commonly referred to as *highs and lows* or *peaks and valleys*. In many electroplating applications the objective is to level out or make the surface more equivalent (*e.g.*, acid copper plate, buff, followed by additional acid copper and bright nickel, etc.).

While electroplating is a "building process," electropolishing is just the opposite—an "unbuilding process." In electropolishing, the anodic current density (ACD) is highest at the "peaks" and lowest in the "valleys." With increasing ACD, metal dissolves faster at the peaks, developing a smooth, leveled, and relatively "valley-free" surface. Metal removal, based on controlled operating parameters, may range from 0.0001 to 0.0025 inches. Micro and macro asperities are removed. Polishing of the metal surface occurs only when the ACD is in the correct range for the particular application. ACD out of preferred range results in etching instead of polishing. Once the operating parameters have been generally set, voltage is modified until the desired polishing action is obtained. Higher ACD generates significant gassing, resulting in streaks emanating from holes, slots, and edges. As a rule of thumb, 5–15 volts is a range for most of the commonly electropolished metals and alloys. This voltage range represents ACD of 50–500 ASF.

The surface characteristics of a properly electropolished part may include:

- Low RMS (surface roughness) as a quantitative measurement confirming high leveling, reflectance, brightness, and smoothness.
- Improved corrosion resistance of many ferrous alloys due to a fresh oxide formed with oxygen gassing off the surface.
- Absence of surface imperfections: burrs, scales, cracks, pits, fissures, and machining marks (within tolerable limits of removal by electropolishing).

Applications

Deburring

Burrs can be thin or thick, heavy metal protrusions. A more pronounced burr will permit higher ACD for a higher rate of removal. The actual dimensions of the burr and tolerance of the part being worked determine if electropolishing will remove the burr. By electropolishing to deburr, ACD of 500–2000 ASF is required. The secondary benefit is polishing simultaneously while deburring.

Passivation

Stainless steel comprises over 90 percent of electropolished parts. There is no better, complete passivation method for stainless steel. The oxide formed is a uniform, thick layer. Electropolishing also removes organic and metallic surface contaminants. This permits formation of the corrosion resistant surface layer. Formation of the electropolishing-induced oxide layer even benefits low and high carbon steels. Brass and copper alloys are also sufficiently passivated.

Friction

Removal of small asperities on the surface, along with the high degree of smoothness and polishing, offers another benefit. The coefficient of friction of metals is reduced. In fact, compared to mechanically polished surfaces, the electropolished equivalent has about a 70–80 percent lower coefficient of friction.

Surface Preparation & Finishing

Cleaning, polishing, deburring, and surface refinement have been discussed. Other surface conditioning benefits include: eliminating hydrogen embrittlement, improves service life of stamped parts and springs, resists bacteria impregnation, and highlights cracks and fissures in fabricated and machined parts. In fact, electropolishing is one of the best detection methods for cracks and fissures.

Operating Parameters

A wide variety of common metals and alloys are successfully electropolished, especially the nickel-rich 300 series stainless steels. The electrolyte is typically a mixture of mineral acids. Parts are predominantly racked.

Metal / Alloy	**Temperature** °F	**Temperature** °C	Anodic CD ASF	Voltage
Aluminum	150-200	66-93	10-60	10-30
Copper	65-160	18-71	20-300	6-18
Nickel	85-125	29-52	100-200	10-18
Stainless Steels	110-190	43-88	50-500	6-18
Carbon Steels	110-140	43-60	100-300	10-18
Titanium	60-105	16-40	80-500	3-10

The above ranges in the operating parameters reflect the use of more than one type of electrolyte.

The solutions are acidic, typically composed of these inorganic acids: chromic, fluoboric, hydrochloric, phosphoric and sulfuric, in varying combinations and strengths. Organic additives, such as glycols help to condition the surface during electropolishing. Process baths do not have the complexity of analysis control compared to many electroplating solutions. Electropolishing baths are also more tolerant to contaminants.

Equipment

Rack tips should be compatible with the chemistry of the electropolishing solution (*e.g.*, stainless steel, copper, phosphor-bronze). Racks should have enough splines to carry needed amperage across the surface of parts. The higher operating current densities will tend to heat the electropolishing process solution. Therefore, cooling (coil, chiller, etc.) may be required. Heating is readily accomplished by electric immersion or forced steam, using 316 stainless steel or titanium coils. Rubber or Koroseal®-lined tanks may be used. Stainless steel tanks are not recommended, due to possibility of stray currents, that would etch the tank. The density of electropolishing solutions may range from 12-15 lb/gal. Therefore, sufficient thickness and size distribution of the tank should include capacity to hold the weight of electrolyte. Agitation is important to provide solution movement. Mild air agitation, filter pump, or mixer are sources of agitation.

Analysis Control

The usage ampere hours will track the bath service life. Metal removal off parts concentrates these contaminants in the bath. Specific gravity of the solution increases, along with formation of insoluble sludges. As part of the analysis control, portions of the bath may need to be decanted, with appropriate reconstitution of water and electrolyte, to maintain operating bath specific gravity range. The solution's specific gravity is also affected by loss of water via drag-out and evaporation. Analysis of the acid content and multi-acid ratios can be determined by titration. Dissolved metals can be determined by specific gravity difference versus a make-up control bath, or quantitatively by atomic absorption. Appropriate solution decanting helps maintain dissolved metals in range of the electrolyte's operating limits.

Typical Process Cycle

1. Soak clean to remove organic soils (oils & grease)
2. Acid dip to neutralize alkaline films
3. Electropolish
4. Rinse & dry

Besides the popular stainless steel, other metals electropolished include: copper alloys, brass, beryllium copper, many aluminum alloys, phosphor bronze, low and high carbon steels, titanium, silver, gold, and several of the inner transitional metals. Aluminum alloys and castings having high silicon content (*e.g.*, series 380, 413) are sensitive to electrolyzing. Metals high in sulfur and lead are also a problem. Electropolishing provides an alternative to high-temperature immersion polishing of aluminum. By electropolishing aluminum, the hazards associated with hot immersion acid solutions are eliminated: no toxic nitric oxide fumes, reduces overall plant corrosion, and lower operating temperatures.

Limitations

Electropolishing is not a metal finishing "cure all." It has some limitations and shortcomings. It will not level deep cracks, fissures or pits (defects that are present significantly into the surface structure). These problems require mechanical polishing, if the surface is at all salvageable. Alloys having one phase not conducive to the anodic treatment will not respond well. Parts engineered or designed with very close tolerances (tapped holes, etc.) may be damaged because electropolishing removes metal. For electropolishing to be appropriate, critical areas of parts should be designed to compensate for metal removal.

Electropolishing, applied correctly, offers many outstanding benefits to metal finishing. In an age of precision and accuracy, electropolishing provides all the benefits described, rapidly and within given tolerances. Chemical and power costs are typically low. Related labor savings include: possible elimination of mechanical finishing (buffing, polishing, and grinding), simultaneous cleaning, and descaling.

Electropolishing—relatively new, diverse, and worth looking into.

Finishing Facts

- The pyridine based "hot" nickel brighteners provide markedly improved deposit leveling, possibly reducing the nickel thickness requirement. When first introduced, these pyridine-based organic compounds contributed to deposit brittleness and low current darkening. Refinements in production of these compounds resulted in very pure, high-grade materials, that virtually eliminated these problems.
- When selecting a cleaner, you can have your cake and eat it, too. There are many specialty blended cleaners that remove a wide variety of oils. On cooling or in the absence of agitation, some of these oils are released and removed from the cleaner solution.
- A key link between artillery ordnance and metal finishing is hard chrome plating. P&SF

Questions?
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