How Can Electropolishing Help You?

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Electropolishing is an excellent alternative to mechanical finishing. Where cleanliness or surface smoothness is a concern, electropolishing is a viable option. It provides a superior contamination free surface, removing the mechanically fractured grain structure and embedded hydrocarbons. Other benefits include improved corrosion resistance and friction reduction. This paper reviews the basics of the electropolishing process, including what happens on the surface, and how individual components such as the electrolyte, work piece, and power can affect the process.

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What is Electropolishing?

Electropolishing is an electrochemical process where thin layers of metal(s) are removed from the surface of a metal/alloy sample. The sample serves as the anode, which is submerged in an ionized solution under an imposed direct current. Electropolishing is the opposite of electroplating. Electroplating deposits material, while electropolishing removes material.

The ionized solutions used for electropolishing are also called electrolytes and typically composed of inorganic acids. Commonly used inorganic acids include sulfuric acid, phosphoric acid, chromic acid and perchloric acid. In the presence of water, these acids exist mainly in ionic form as positive and negative ions. To electropolish, each material may require the use of a different electrolyte (composition and acids ratio).

Common electropolished materials are stainless steel and copper. Electropolishing of stainless steel is routinely performed. The most common electrolyte used for stainless steel electropolishing is a mixture of sulfuric and phosphoric acid in water. The acids ratio varies according to the stainless steel grade and the desired finish. Most electrolyte compositions are commercially available.

Figure 1 shows a schematic of an electropolishing cell. The tank or the tank liner (if required) is made of a material compatible with the electrolyte and the process temperature.

The sample to be electropolished, or work piece, is submerged in the electrolyte and connected to the anode (+) of a DC power supply (rectifier). On the other side of the tank, a rod or a plate is connected to the cathode (-) of the power supply. The cathode can be made of copper, lead, tungsten, stainless steel, etc. Based on its applications, the electropolishing system may require heating/cooling equipment with temperature control device, some type of mechanical or air agitation, pumping with flow meter control, and possibly filtration. An exhaust system is highly recommended, due to fume generation during the process.



Figure 1 – Schematic of an Electropolishing System

The total amperage required is calculated by multiplying the total surface area of the sample by the desired current density. In a matter of seconds after the rectifier with preset amperage is turned on, a viscous film is formed on the work piece. The film is composed of salts resulting from electropolishing, and the surface brightening is attributed to this film. The film thickness controls the metal removal rate. Figure 2 illustrates the variation in film thickness as a result of surface asperities. The film is thinner on the peaks than on the valleys. This viscous film resists current flow, so most of the current is concentrated on the areas with less resistance, in this particular case on the peak.

This will remove more material than on the valley, where less current flows. Metals from the surface layer lose electrons and dissolve in the acid solution in ionic form $(Fe^{3+}, Ni^{2+}, Cr^{6+})^{1}$.

 $Fe^{0} \rightarrow Fe^{3+} + 3e^{-}$ $Ni^{0} \rightarrow Ni^{2+} + 2e^{-}$ $Cr^{0} \rightarrow Cr^{6+} + 6e^{-}$

Then at a proper cathode current density, Fe^{3+} is reduced to Fe^{2+} and Cr^{6+} is reduced to Cr^{3+} .

$$Fe^{3+} + e^{-} \rightarrow Fe^{2+}$$
$$Cr^{6+} + 3e^{-} \rightarrow Cr^{3+}$$

Most of the nickel and some of iron will precipitate as sludge in the form of nickel sulfate monohydrate (NiSO₄ H₂O) and ferrous sulfate monohydrate (FeSO₄ H₂O)¹. Some of the iron that remains in the trivalent form (Fe³⁺) along with the trivalent (Cr³⁺) and hexavalent (Cr⁶⁺) chromium remains dissolved in the solution, continuing to concentrate the solution.

A theoretical material removal can be determined by using Faraday's law². The law states that the amount of material removed at the anode or deposited at the cathode is proportional to the applied current, time and chemical equivalent weight.

$$g = Iet/96500$$
 where:

g = grams of metal(s) I = current in amperes t = time in seconds e = chemical equivalent weight (Faraday's law states that for any element, One Gram Equivalent equals 96,483 Coulombs or 1 Faraday.)

The actual material removal is less than the theoretical (calculated) material removal. During electropolishing, oxygen generated at the anode and hydrogen at the cathode consume some of the current. These reactions along with other factors contribute to the loss of electropolishing efficiency.

Because each metal has a different electrochemical potential, removal rates vary for different metals. For stainless steel, this variation in removal rates assists in increasing the corrosion resistance. Using 316-grade stainless steel where the iron content is about 65% by mass and the chromium content is 16 to 18%, the mass ratio of Cr/Fe is about 0.26. During electropolishing, iron is removed at a higher rate than nickel or chromium. Therefore, the electropolished surface becomes enriched with chromium. The new ratio of Cr/Fe in the electropolished surface can become greater than 1.0. A chromium enriched surface and the stable chromium oxide formed by electropolishing contribute to a more corrosion resistant surface.







Figure 2: Surface Appearance Before and After Electropolishing

Factors Affecting Electropolishing Quality

Once an electropolishing system has been constructed and an electropolishing solution chosen, acceptable operational parameters must be determined, usually by experimentation. Operating parameters include composition, temperature, levels of metal contamination, and specific gravity of the solution, method of agitation, and anode current density. These parameters will affect the quality of the electropolished surface. Equally important are alloy composition and surface preparation of the component that is to be polished.

Electropolishing solution

A properly maintained electropolishing solution is very important. Whether the solution is a premix purchased from a supplier or developed in-house, the bath needs to be tested and maintained regularly.

The composition and the specific gravity of the solution may be the most important parameters for achieving the desired surface quality. To maintain the solution within the proper limits, a quality control and maintenance program must be established.

Dissolved Metals

During electropolishing, metal(s) are removed from the surface and dissolved in the solution. These metals will exist in the solution in the form of metal ion salts. Some salts will reach a limit of saturation and precipitate; others with a higher solubility limit will continue to concentrate in the solution. As the level of concentration increases the quality of the electropolished surface decreases, especially its luster. Therefore, metal levels in the solution should be monitored and fresh solution added as appropriate.

Temperature

Because electropolishing generates heat, this process must be performed in a highly controlled manner to assure operator safety and achieve good surface quality. If the temperature is too low, electrical conductivity of the solution decreases. Too low a conductivity may not achieve the desired current density. If the solution temperature is too high, the polished surface may become discolored. One should maintain an appropriate temperature range by using a heating or cooling system and a properly sized electropolishing tank. Knowing the maximum amperage per tank and using as a general rule 0.8A/Liter of solution, the total volume of electropolishing solution required can be calculated.

Agitation

Agitation is required to disperse the localized heat generated by the electropolishing process, and to remove oxygen from the anode and hydrogen from the cathode. The presence of oxygen bubbles on the anode may result in a spotty electropolish finish or dead zones with no electropolishing at all. There are various agitation methods, such as air bubbling, use of a mixer, anode agitation, solution pumping, etc.

Current density

In order to achieve the desired surface finish, the proper anode current density must be maintained. If the current density is too low, the surface may etch. A high current density results in a pitted surface. The proper current density for any material can be determined experimentally. The experimentation can be performed in a simple electropolishing system as shown in Figure 1, using a solution with the appropriate composition. Using a sample of known surface area, the rectifier's voltage is set to maximum. Starting from zero, the amperage is increased at small increments. Amperage and voltage are recorded for each setting, resulting in a plot of current density vs. applied voltage. Figure 3 shows the typical current density – voltage relationship for electropolishing. Numerical values are different for each material, but the shape of the curve is consistent. Three specific zones denote this polarized curve³. The first region (ab) is the etching zone where gassing begins, resulting is an etched surface. The process in zone (bc) is very unstable, leading to either an etched or lustrous surface. Polishing occurs in region (cd), resulting in a bright lustrous appearance. The pitting zone (de) occurs at higher amperage, resulting in either etching, brightening or pitting. The most effective current density to achieve the desired results must be determined experimentally.



Material/Work piece

Another very important factor contributing to the electropolishing quality is the material composition and its surface cleanliness. The presence of inclusions, such as manganese sulfides, above certain percentages and sizes may be detrimental to quality when pitting and etching occur.

Surface cleanliness must not be overlooked either. Silicates, water residues, grease, oils, polishing compounds, and other processing contaminants may result in etched or spotty surfaces. Therefore, all surfaces must be degreased and cleaned with adequate solvents, followed by rinses in mineral free water (deionized or reverse osmosis water).

Level of Electropolishing

The thickness of material removed by electropolishing distinguishes the level of electropolishing as:

- a. *Micro-electropolishing*, where brightness is achieved without any visible surface leveling and no distinguishable changes in surface roughness are measured by surface profilometry. The thickness of removed material is less than one micrometer.
- b. *Macro-electropolishing* removes asperities and depressions larger than one micrometer, thus creating a smoother and brighter surface. Macro-electropolishing shows measurable reduction in the surface roughness. If the process of electropolishing removes 25.4 μ m (0.001inches) from a surface with an initial surface roughness of R_a = 0.5 μ m (20 μ in), then the surface roughness will be reduced approximately by half, to about 0.25 μ m (10 μ in).

Electropolishing Limitations

- Not all metals and alloys are suitable for electropolishing.
- Some stainless steel grades may not be suitable for electropolishing. This may be due to: mass porosity, globular inclusions, impurities imbedded during machining or cold work, etc.
- Electropolishing is not economical to remove large burrs, deep scratches, rough surface, etc.
- When large amounts of material are removed, large amounts of hazardous waste are created.



Figure 4: Beilby Layer

Benefits of Electropolishing

- Electropolishing removes and levels small mechanical defects (burrs, scratches, sharp edges, flow lines, asperities, etc.).
- Electropolishing removes smut, oxides and scales resulting from previous works.
- Electropolishing polishes shapes and small orifices where mechanical polishing is difficult or impossible.
- Electropolishing removes the Beilby Layer ⁴ (Figure 4), the surface layer that contains defects introduced during a machining operation such as cutting or milling. The Beilby Layer is the fractured crystal surface structure resulting from any mechanical operation. It has a depth of approx. 2.5µm (0.0001in). Cutting, drilling, grinding, honing, buffing and other mechanical finishing processes will fracture the surface grain structure of the metal/alloy into smaller grains and the most outer layer becomes amorphous. This fractured surface contains embedded grease, lubricant oils, cooling fluids, or polishing media. Therefore, electropolishing is the preferred process when cleanliness is a must.
- Electropolishing reduces friction (torque where applicable).
- An electropolished surface is a hygienically cleaner surface, and can be maintained better than a mechanically polished surface. Also, the electropolished surface remains bright and lustrous much longer than a mechanically polished surface.
- Electropolishing can be performed at lower cost than mechanical polishing/buffing.
- For stainless steel, electropolishing increases the Cr/Fe ratio and forms a very stable chromium oxide, enhancing corrosion resist

Electropolishing Applications

Electropolishing has a wide application range. Figure 5 shows samples of a disk and elbow made from stainless steel, before and after electropolishing. The predominant areas of application for stainless steel are:

- Semiconductor industry
- Pharmaceutical industry
- Medical and implant devices
- Chemical and Petrochemical industry
- Food processing and Beverage industry
- Dairy products industry

Summary

Electropolishing should be considered as a method for achieving superior surface quality. An alternative to mechanical finishing, electropolishing produces a superior, contamination-free surface, a benefit that mechanical surface processes are unable to match. Other benefits are improved corrosion resistance and reduced surface friction. Utilization of electropolishing over mechanical finishing can result in great cost savings. By evaluating the identified process

quality surfaces.



Figure 5: Samples of 316L Stainless Steel Before and After Electropolishing

References

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