ELECTROPOLISHING
APPLICATIONS AND TECHNIQUES

Abstract

This presentation discusses several current practical applications of electropolishing and/or passivation. The emphasis is not on these processes alone, but rather in combination with conventional mechanical finishing, i.e., abrasive belting, polishing/buffing, and blasting. More specifically, this paper examines ways mechanical finishing combined with electropolishing provides levels of smoothness, cleanliness, and corrosion resistance beyond that of mechanical finishing alone. This discussion is limited to stainless steel base materials. Areas of interest include recent trends in electropolishing, quality considerations, costs, packaging, off-site or field applications, and environmental considerations.

Introduction

History of electropolishing

Electropolishing has been practiced commercially since the 1930's. The first widespread use of electropolishing was primarily to add cosmetic appeal to consumer goods such as cookware and fountain pens. In recent years, the emphasis has shifted to engineering applications, especially in the food, medical, pharmaceutical and semiconductor industries.

Description of electropolishing

Electropolishing is the electrochemical dissolution of a metal surface to improve the smoothness, reflectivity, cleanliness, passivity, or some combination of these surface characteristics.

Micro-Metal Removal

Electropolishing is a "micro" metal removal process as opposed to conventional mechanical finishing processes, which are "macro" metal removal/distortion processes. As such, it can easily complement mechanical surface finishing processes such as rolling, grinding, blasting, and polishing and buffing.

While the reflectivity, sparkle, and shine produced by electropolishing are obvious to the eye, some of the more subtile effects are apparent only through more sophisticated examination, such as surface chemical analysis, profilometry and in-service performance trials.

Nearly all metals and alloys can be electropolished, but in actual practice, stainless steel accounts for the greatest majority of commercial electropolishing. The inherent strength and corrosion resistance of stainless steel makes it the material of choice for process equipment and many consumer products.

Electropolishing Practice

The process

The part to be electropolished is connected to the anodic (+) side of a direct current power supply, and the cathodic (-) side is connected to an inert metal, typically lead or stainless steel. Both the part and the cathode are immersed in an acidic solution, and as the current flows through this circuit, metal is dissolved from the (anodic) part. Almost immediately large quantities of oxygen are liberated at the surface of the part, forming a dense gaseous layer. Because of the tendency of electrical current to flow from points and projections, these areas are dissolved preferentially, resulting in a smoothing of the surface. The viscous boundary layer that forms as a result of the gassing contributes to the preferential dissolution of peaks and projections. The process is optimized by control of the solution chemistry, temperature, current density, and time.

Some parts can be introduced directly into the electropolishing system, while others may require pretreatment to remove grease, soils, or scale. After processing the parts must be thoroughly rinsed to remove the highly corrosive electropolishing solution.

Simply shaped parts may be electropolished by using general-purpose cathodes, located several inches or more away from the part. Complex shapes may require the use of elaborate and complex fixtures and special purpose-built conforming cathodes to obtain uniform electropolishing over the entire part or to electropolish selected areas. Other considerations are the evolved gas and proper solution movement to prevent gas entrapment or collection.

Figure 1
Electropolished Bowl-shaped Fixture with Sanitary Fittings

Electropolishing solutions are highly acidic and corrosive, requiring the use of corrosion resistant equipment and close attention to worker safety.

Electropolishing of large parts can require dc currents of several thousand amperes, necessitating the use of large rectifiers, heavy cables and/or buss. In addition, it is necessary to provide cooling for the solution and electrical connectors.

The process of electropolishing is a relatively quick process. Typical times range from one to twenty minutes, although longer times are sometimes necessary. Metal removal on a plane surface is generally less than one thousandth of an inch. It is not uncommon to remove up to ten times this amount on sharp edges. For this reason, electropolishing is often used for deburring. In general, curved forms and complex shapes electropolish better than flat surfaces.

Tank & In-Situ Techniques

While electropolishing is generally considered a "tank" process, the size and shape of some parts can require other methods. Some parts, such as pipes or vessels, can themselves become the "tank" for internal electropolihsing. Other parts may be so large or complex as to require the use of a "wand" or "in-situ" technique wherein the part is made anodic and the electropolishing solution and cathode are brought to the part using a device that may be referred to as an "electrified paint brush".

Part size may vary from small hollow needles to vessels of 15,000 gallon capacity and more. In most cases, the size and configuration of the parts to be electropolished is only limited by the imagination of the electropolishing technician.

Surface Improvements

Electropolishing can produce mirror-bright reflective surfaces that enhance consumer appeal and maintain their appearance indefinitely.

Smoothness is improved by electropolishing. In terms of microinch (µ") R_A (roughness arithmetic average) numbers, surfaces are improved by about one-half; that is , a 100 µ” R_A surface will improve to about 50 µ” R_A, or a 10 µ” R_A will improve to about 5 µ” R_A. The exception to this occurs at very low R_A numbers where there may be no measurable improvement. In fact, very low R_A numbers can actually increase as electropolishing exposes voids or inclusions that may have been smeared over by mechanical methods.

SURFACE MEASUREMENTS COMPARISON

RMS (Micro-inch)	**RMS** (Micron)	**R_A** (Micro-inch)	**R_A** (Micron)	**Grit Size**
80	2.03	71	1.80	80
58	1.47	52	1.32	120
47	1.20	42	1.06	150
34	.86	30	.76	180
17	.43	15	.38	240
14	.36	12	.30	320

These values are average data from many tests; therefore, slight deviations from the norm do exist. However, because of the number of tests performed, reasonable accuracy is assumed. Because of the many variables which create this data, deviations of ±5% would be considered well within good measurement parameters.

The relationship between abrasive grit numbers and surface roughness in terms of micro-inches is sometimes a basis for specification. The values are approximately as follows:

Abrasive Grit Number	Surface Roughness R_A, Micro-inches	Abrasive Grit Number	Surface Roughness R_A, Micro-inches
500	4 to 10	180	25 to 40
320	6 to 15	120	45 to 60
240	8 to 20	60	140 to 180

Microcleanliness is vastly improved over mechanical finishes. Even the best mirrorbright buffed finish can be seen to include smears and tears and included abrasive, oxides, and debris when examined microscopically by Scanning Electron Micrograph (SEM). The same surface after electropolishing may not appear different to the unaided eye, but SEM examination at 1000X shows a “featureless” surface free from foreign material and abrasive damage. This microcleaning process partially explains the improved corrosion resistance of electropolished surfaces.

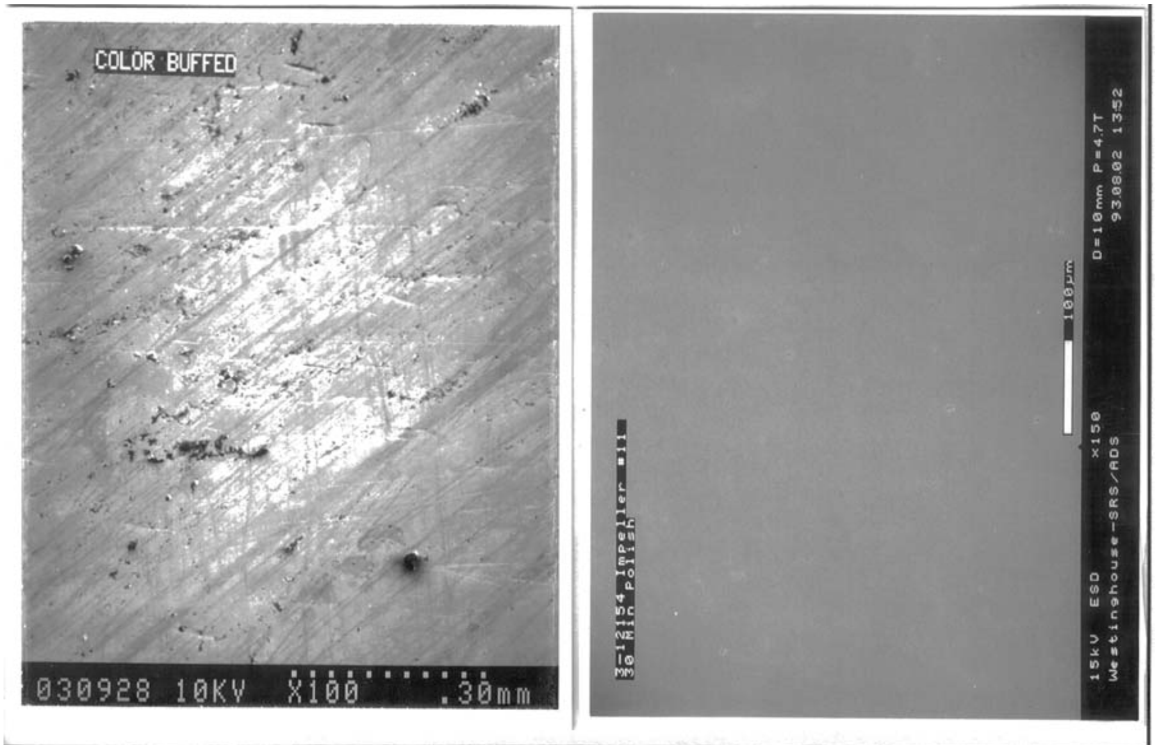

Figure 2

SEM Photomicrographs
Photo on left shows a mechanically "color buffed" surface
Photo on right showa a mechanically polished surface after electropolishing

Electropolishing is known to improve the passivity or corrosion resistance of stainless steel. As evidence of this, the latest version of ASTM A 967 recognizes electropolishing as an accepted method of passivation. While the phenomenon of passivity may not be fully understood, there is evidence that free iron is removed from the outer few angstroms of the surface, resulting in a surface richer in nickel and chromium than the parent material. In addition the chromium and nickel at the surface are more completely oxidized than occurs naturally.

Electropolishing also removes all or part of the mechanically deformed and stressed layer, thereby providing a third mechanism for improved corrosion resistance. This removal of a highly stressed surface layer can also improve fatigue resistance.

Electropolished surfaces are more resistant to staining and contamination and are more easily cleaned. This again is due to the microsmoothed surface, which is an obvious advantage in food, pharmaceutical, and medical equipment.

MECHANICAL PREFINISHING

Some parts can be electropolished with no mechanical prefinishing, but in many cases electropolishing is best used to complement mechanical finishing. Electropolishing operates in the micro range, smoothing and leveling defects of a few thousandths inch size. Larger defects may never be removed by electropolishing, hence the need for mechanical prefinishing.

Phase changes, alloy segregation, and carbide precipitation may become more noticeable after electropolishing, particularly when these changes are caused by welding and are in limited areas. This problem can sometimes be minimized by passivation prior to electropolishing.

Sand, grit, or glass bead blasting generally produces surfaces too coarse to be completely smoothed by electropolishing. SEM examination of blasted surfaces after electropolishing shows the surface to be decontaminated and smoothed, but the major disturbances are still present.

Similarly, coarse abrasive polished finishes may never have all of the scratches removed. In general, electropolishing can completely smooth abrasive scratches from 220 grit or finer. Coarser abrasive scratches will remain visible. Mechanical prefinishing finer than about

320 grit does not always result in a better finish after electropolishing.

Some mill finishes produce excellent electropolish results without mechanical prefinishing. The general-purpose cold rolled 2B finish will electropolish bright, smooth, and clean, although any nicks or scratches from handling and fabrication will need mechanical prefinishing to produce a uniform electropolished finish. The 2B finish is actually preferable to mill finishes No. 3 or No. 4, which are produced by relative coarse abrasives of 50 –150 grit and on which the polishing lines will remain visible.

Hot rolled acid pickled finish No. 1 will electropolish shiny and white, but will show many of the depressions and undulations resulting from the hot rolling and descaling process. To produce a mirror finish on this material requires multiple passes with succeedingly finer abrasives prior to electropolishing.

WELD PREFINISHING

Weld prefinishing prior to electropolishing can be a particular problem. Depending on the weld techniques and the skill of the welder, there can be voids and inclusions that can never be removed without exposing more of the same defects. Top-quality welds, on the other hand, can often be satisfactorily electropolished with no prefinishing.

Figure 3

Properly prepared welds. after Electropolishing

Passivation before electropolishing may be necessary to produce the best results.

Electropolishing can be an excellent tool for burr removal. In fact, there are some cases in which it is difficult to imagine any other method that would produce equivalent results. Burrs inside very small drilled, pierced, or tapped holes are an example. Electropolishing can remove these burrs, and because of the preferential removal of projections, can remove them without altering dimensions.

Burr removal can require mechanical prefinishing. A pierced hole, for example, may have a burr perpendicular to the surface. Such a burr may be too large to be removed by electropolishing. A mechanical operation such as belt lapping can be used to remove the majority of the burr, leaving a small, sharp burr in the hole. The remaining burr can then be removed by electropolishing. Burrs most amenable to removal by electropolishing are those which are small, sharp, and difficult or impossible to remove mechanically.

Electropolishing is also a valuable tool for producing fine radii, for example where two ground surfaces meet. Electropolishing can remove any fine burr and leave a small but definite radius. Electropolishing can be used as a precision machining method where it is necessary to remove a very thin layer of metal to achieve a precise dimension with a fine surface finish.

ELECTROPOLISHING vs. MECHANICAL POLISHING

Electropolishing and mechanical polishing are more complementary processes than they are competitive processes.

Removal of significant stock or larger imperfections requires mechanical finishing. Mechanical polishing of large volumes of identical items can be more highly automated than electropolishing and can have lower unit costs. Mechanical polishing may not require the use of hazardous chemicals. Electropolishing accomplishes more than improved smoothness and appearance. It also produces microclean and micro-smooth surfaces which are corrosion and contamination resistant.

RECENT TRENDS AND APPLICATIONS

There has been a great deal of interest in the past several years for producing extremely clean and corrosion resistance components for use with Ultra-pure gas/liquids. Electropolishing has proven to be a very effective method in this field. Piping, valves, vessels, pumps, and

Figure 4
Electropolished manifold for high purity process

other components used in handling ultra-pure gasses and liquids are often mechanically finished and then electropolished to surface roughness values that are extremely low. The final evaluation of the electropolishing consists of two parts – evaluating the surface appearance microscopically and evaluating the surface chemistry. The first is intended to determine the efficiency of the polishing action itself. The second is to ensure that the resulting surface is properly passivated and protected as is possible.

Methods for evaluating electropolishing[1] include the following:

1. Scanning Electron Microscopy (SEM) – An instrument method for examining the surface for smoothness and to detect other surface features that may be a potential site for the accumulation of particles. This is similar to examining the surface of an orange with multiple cameras and producing a single image of a portion of the orange's surface.
2. Auger Electron Spectroscopy (AES) – A technique to analyze the atomic composition of a surface. This analytical method can only determine the identities of the elements present on the surface and cannot differentiate between chromium as metal and trivalent or hexavalent chromium. In combination with other techniques, it is possible to examine at various depths or layers. This is similar to determining the elements only in a particular layer of an onion. This method provides data that can be presented in the form of charts, graphs or trend lines.
3. Electron Spectroscopy for Chemical Analysis (ESCA) - A technique for determining the composition of the oxide. It can differentiate between various forms of the elements present, such as chromium as metal, trivalent chromium, and hexavalent chromium. Measurements can also be made at various depths from the surface. This is similar to determining the various constituents in a particular layer of an onion. The data collected can also be used to express chromium/iron ratios, the thickness of the oxide layer, and degree of oxide formation in the layer. This method provides data that can be presented in the form of charts or graphs.

Another innovative application that has potential is electropolishing as preparation for PVD coatings. There is some evidence that PVD coatings may be applied over electropolished stainless steel surfaces with greater success than over nickel-chromium plated surfaces. One of the reasons for this successful application is that electropolished surfaces are virtually featureless and provide an extremely clean surface for the

PVD coating. Most of these applications will also include mechanical polishing/buffing on at least selected areas followed by electropolishing prior to PVD coating.

Other considerations

Packaging

Packaging can create problems during the subsequent processing. In addition, insufficient packaging can permit damage during transit that may not be overcome during processing.

Bubble wrap is sometime used. When in direct contact with the parts, chemicals within the wrap may cause etch patterns which become evident during processing. Pre-applied protective coatings must be completely removed prior to fabrication, especially from areas subject to heating such as during welding. The adhesive film must be completely removed, usually by wiping with a solvent such as acetone, prior to mechanical finishing or electropolishing.

It is common practice among metal finishers to return parts in the packaging received with the parts. This should be considered when preparing parts for shipment to the metal finisher.

Costs

When considering Electropolishing with or without Mechanical Finishing, one must consider the benefits available which may not be available with other lower cost options. These processes may not be appropriate for inexpensive, mass produced consumer products. However, in many applications, these processes will compare vary favorably when compared with alternatives such as nickel chrome plating, which often also requires fixturing and conforming anodes.

Costs include the direct labor involved in racking the parts. In some cases, there may be considerable hand work in fabrication of conform-

[1] Electropolishing Surface Analytical Techniques, Ed Bayha, MCP, Charlotte, NC, (704) 563-0070

ing electrodes. This is best done by a skilled operator with considerable experience. During the actual electropolishing operation, costs include the labor of the operator, the chemicals (and their subsequent disposal), utilities to maintain the proper temperature in the solution (both heating and cooling may be required), power for the rectifier and the investment in tanks, material handling equipment and facilities.

After processing handling

As noted above, it is common practice to return parts in the packaging received. Best practice following Electropolishing includes wrapping the parts in non-acid, sulphur-free paper. If necessary, the parts can then be over-wrapped with bubble wrap.

During subsequent handling or installation, care should be taken to avoid contact with carbon steel or non-passivated stainless steel. Such contact can result in the transfer of free iron which will degrade the passavity of the part.

Job shop or off-site processing

Repetitive or new parts are probably best handled in a properly equipped Job Shop. However Electropolishing is one of the few processes which do lend themselves to off site or “wand” applications.

There are special considerations which must be taken into account during off site operations. The chemicals used are highly corrosive and hazardous. Further, the rinse water generated after (and possibly before) processing is considered a hazardous waste. It is best if the site has waste treatment capabilities to handle this rinse water, which will contain trivalent chromium, nickel ions and dilute acid.

If such facilities are not available at the site, the rinse water must be collected. A one-time EPA generator permit must be obtained and arrangements made for transporting this hazardous waste to an approved and licensed facility.

Environmental

Electropolishing is classified by the EPA as a metal finishing operation in the same category as Electroplating. The facility must have proper permits for the generation of waste, maintain proper records of operations, and meet all requirements of Federal, State and local regulating authorities.

Summary

Electropolishing is a special Metal Finishing operation which can provide unique and valuable properties and characteristics to a part or to equipment not obtainable in any other way. When used with Mechanical Finishing operations, the result is a finish which is actually better than the sum of the two separate processes.

For applications such as equipment used in pharmaceutical, food, chemical and semiconductor industries, Electropolished surfaces are often key to successful and economical operation of the process or equipment.

Biography

Johnson H. Cutchin, Sr. – President of Palmetto Plating Co., Inc. and Omnitek, Incorporated. Attended the University of Georgia and Clemson University. Founded Palmetto Plating Co., Inc. in 1964 and Omnitek, Incorporated in 1986.

Ralph R. Hammond-Green – has worked in metal finishing for thirty-five years, primarily in electroplating and anodizing. He attended Hiram College, Hiram, Ohio, majoring in Chemistry, and is a member of AESF.