Modern Applications for Electropolishing

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The AESF has not published expanded technical information about electropolishing for more than 30 years. The most recent AESF Illustrated Lecture on the subject, titled "Electropolishing," was written by G.R. Schaer in 1971. In the last 30 years, electropolishing of stainless steels has grown remarkably. Industries employing electropolishing now include medical devices, surgical implants, food and beverage equipment, automotive, aeronautical and aerospace applications, pharmaceutical and biopharmaceutical industries, microelectronics, vacuum applications, and many others. A sub-committee of AESF's Emerging Technologies Committee (Electrochemical Metal Removal) has recognized the need for updated information to advance the practice of electropolishing among its members. This paper is intended to review the state of the art as last reported and to recommend a direction for continued study of the process. The paper will focus on modern issues related to electropolishing of stainless steels and will suggest topics for future discussion through AESF's technical subcommittee process.

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Introduction

The newly formed AESF sub-committee on Electrochemical Metal Removal was created to provide a forum to promote the use of electrochemical metal removal operations for surface finishing and machining, and for disseminating related knowledge about research, development, and technology implementation. The sub-committee will consider topics related to processes such as electropolishing, electrochemical deburring, electrochemical machining, laser cutting, electro-discharge machining, etc. This presentation is offered as a basis for discussion of electropolishing under this new sub-committee.

AESF has published a modular series of "Illustrated Lectures" on various aspects of metal finishing for many years. The series formerly included a document entitled, "Electropolishing", authored by G. R. Schaer, published by the American Electroplaters' Society (the forerunner of AESF), and copyrighted 1971. Publication of this document was discontinued in the early 1990's and AESF no longer offers a training publication on this topic.

This paper will refer to and will discuss selected portions of the Schaer publication. However, AESF has withdrawn that publication, and this presentation is not intended as a critique of that original work. The present paper is intended primarily as an initial offering for the electropolishing interests of the sub-committee. Hopefully, the present article will encourage future sub-committee papers that lead to preparation of a new edition of the Illustrated Lecture or to other dedicated training documents.

Electropolishing, the Illustrated Lecture

The publication by Schaer[1] addressed four principal questions:

What is electropolishing?

Why is electropolishing used?

How is electropolishing done?

What equipment is needed?

In some respects, the answers to the four questions above have changed little over the last thirty years. The Schaer publication is still an acceptable discussion of the chemistry, the mechanism of smoothing and the phenomenon of burr removal. The fundamentals of the electropolishing bath itself are essentially the same as they have always been, although there is increasing emphasis on expanding the overall process to include the cleaning and descaling steps familiar to most platers and anodizers. In many shops, electropolishing was initially considered as a "stand-alone" finishing system for stainless steels, accomplishing simultaneous cleaning, descaling, and polishing without the need for separate tanks for those operations. Today, the more sophisticated applications recognize that the process works better if organic residues and oxides are removed before electropolishing is attempted.

In other respects, the proliferation of high technology applications has greatly increased the use of electropolishing to enhance corrosion resistance in a variety of gaseous and liquid environments. These new high technology applications have given rise to new specifications and control techniques that are not commonly used in assessing the quality of electroplated work. Conforming to these new technical requirements presents one of the greatest challenges for even the experienced plater to market an electropolishing process for the high technology applications.

Technical descriptions of electropolishing equipment, chemicals, and procedures[2, 3] are issued periodically in the metal finishing trade publications. These articles provide excellent guidance on the fundamentals of the process, but cannot address the special issues related to development of a viable operation designed to meet the needs of the high technology industries.

Why is electropolishing used?

Schaer's publication contained the following list of the applications[1] for electropolishing:

1. Decorative finishing
2. Burr removal
3. Better corrosion resistance
4. Better adhesion of deposits
5. Reducing friction

In the majority of stainless steel applications, the emphasis has historically been on bright, shiny, deburred parts. In recent years, expectations for bright finishes have become more sophisticated. Some applications now demand a surface that appears essentially flat and featureless, free of occlusions, even under microscopic examination. Burr removal may be verified by high magnification inspection. The decorative and burr removal segment of the market is expected to continue to grow at a rapid pace.

The capability of the process to improve corrosion resistance has increased in importance. Specifications that once called for salt spray resistance testing may now include spectroscopic measurements of the surface oxide to attest to the quality of the electropolished finish. Properties such as the oxide thickness, the ratio of chromium to iron, and the depth of chromium enrichment may be required for qualification of the process. Figure 1 shows a typical spectroscopic analysis[4] of the near-surface composition of electropolished stainless steel and indicates the key parameters used to evaluate the surface oxide.

The use of spectroscopic analytical techniques is believed to be unique in most metal finishing applications. In many cases, outside laboratories are used for even routine analyses, as the equipment is expensive to own and operate. A description of the equipment and the methods employed is beyond the scope of this paper.

Electropolishing offers some interesting features that enhance the mechanical properties of metallic surfaces. Schaer draws attention to the broad capability of the process to improve the surface properties of a machined steel product by reducing surface roughness, removing the disturbed metallic layer, increasing adhesion of plated finishes, reducing friction, and allowing higher loading on steel shafts and gears. However, the applications for mild or tool steels are not the driving force for the growth of electropolishing. The effect may be caused, in part, by the need for chromic acid in many of the formulations for polishing mild or low alloy steels [1-3].

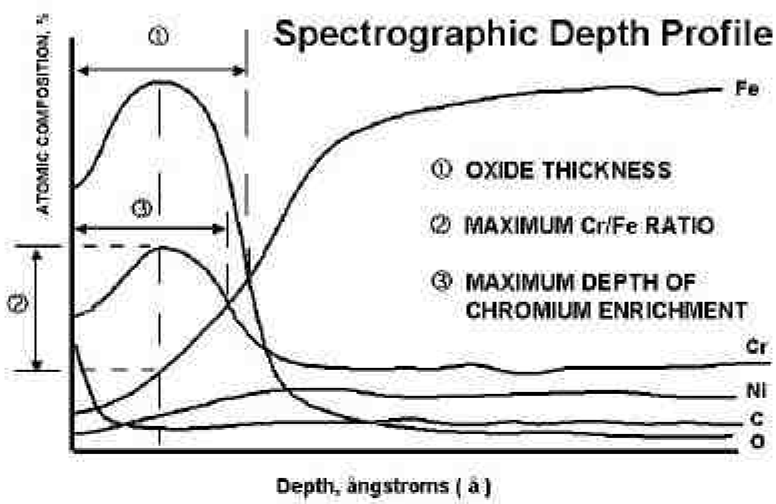

Figure 1. Typical Spectroscopic Analysis of Electropolished 316L SS.

Applications for electropolished finishes have expanded dramatically over the last fifteen to twenty years. One of the leading forces in the expansion has been the microelectronics industry with its demands for mirror-quality, corrosion-resistant finishes that can be employed in ultraclean gas systems used to manufacture semiconductors. This development has focused on the 300-series stainless steels, certain nickel alloys, and specialty metals such as the Hastelloys.

Other modern trends

Although electropolishing offers surface improvements on mild steels and other low alloy steels, these applications have not been responsible for the growth of the process. A general view of the modern electropolishing industry shows that the growth has been primarily in the stainless steel alloys.

Early in the microelectronics era, it was discovered that the "garden variety" stainless steels developed surface defects during electropolishing due to the presence of non-metallic inclusions in the raw material. Consequently, special clean alloys[5] were developed by domestic and international steel manufacturers to meet the requirements of that industry. The new alloys are now finding their way into many other applications, such as pharmaceutical equipment, medical implants, vacuum applications, and others where ultraclean, mirror finishes are required.

Figure 2 shows a comparison of a standard grade of Type 304 stainless steel plate used in a high technology application both before and after electropolishing. In the mid-1980's, the equipment buyer offered these photos as an illustration of an acceptable finish. The particles, occlusions, or other surface defects visible on the polished surface represented the state-of-the-art at that time.

Figure 3 compares before and after photos of the surface of a special grade of 316L stainless steel designed for semiconductor and vacuum specifications. The photomicrographs in Figure 3, taken about 1994, illustrate that the special grade can be polished to a nearly flat and featureless surface with a minimum of surface defects. The electropolished finish shown in Figure 2 would no longer be acceptable for these high technology applications.

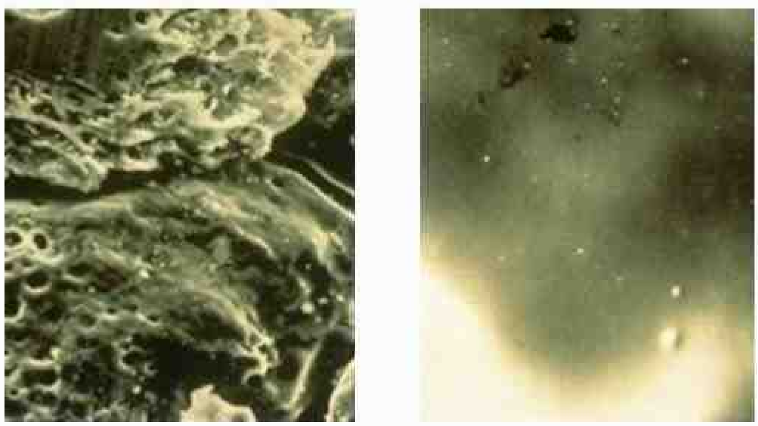

Figure 2. Typical Surface Specification, standard grade Type 304 (1986), Before electropolishing (left) and after electropolishing, (right).

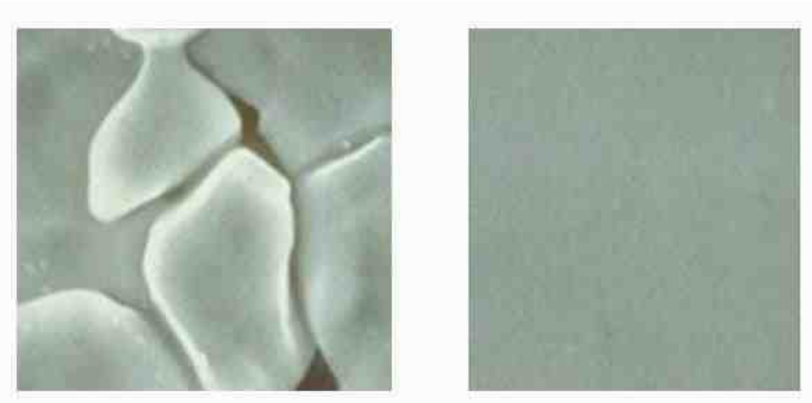

Figure 3. Typical Surface Specification, special grade 316L (1994),
Before electropolishing (left) and after electropolishing, (right).

Electropolishing of aluminum and aluminum alloys has also grown sharply in recent years. Part of the growth is undoubtedly related to the fact that an electropolishing bath can be used in place of the traditional "bright dip" bath, eliminating the generation of oxides of nitrogen. Another factor may be that the chromic acid baths traditionally recommended for aluminum have been replaced by non-chrome formulations. Electropolished aluminum parts generally have to be anodized to produce the optimum in corrosion resistance for most markets.

Among the medical implant applications, new methods of electropolishing are constantly being sought to handle special purpose alloys such as titanium, nickel-titanium (nitinol), cobalt-chromium alloys, MP35N, 22Cr13Ni5Mn, and others. Each new alloy poses a different set of problems for the electropolisher.

New part-forming techniques such as laser cutting, EDM, and ECM are rapidly replacing traditional methods of metal cutting. Stainless steels and some of the new alloys used in the medical industry form tenacious oxides in the heat-affected zones as a result of these cutting methods. These oxides can be difficult to remove and can affect the quality of subsequent electropolishing. There is a need to characterize these oxides and to develop suitable descaling methods for laser-cut stainless steels, nitinol, cobalt chromium, and other specialty alloys. Possibly, the tenacious character of the oxide is a result of the cutting conditions, and some modifications to the method might produce oxides that are more easily removed.

It has long been known that electropolishing is capable of improving a given surface finish by approximately 50% while simultaneously removing approximately 25.4ìM (0.001") on the diameter of the part. Finishes produced by a combination of mechanical sanding and electropolishing normally produce the best performance. For the highest-level specifications, abrasive polishing is often limited to water-lubricated or dry sanding, and organic lubricants, buffing compounds, and rouges are specifically excluded.

New specifications

In the early 1980's, the highest quality electropolishing was produced by and for the pharmaceutical industries. By the mid-1980's, the microelectronics industries had begun to drive electropolishing to a new level of achievement, using spectroscopic analysis of the surface oxide to characterize the finish.

The electronics industries have also codified the specifications for defining a well-electropolished finish. These specifications[6] require sophisticated analyses of the thickness and composition of the surface oxide. Similar specifications are gradually being adopted by the medical and pharmaceutical industries for the most demanding applications.

The new electronics applications also brought along new test methods for defining an electropolished surface. Testing procedures such as ESCA (electron spectroscopy for chemical analysis), XPS, (X-ray photoelectron spectroscopy), AES (Auger electron spectroscopy) and SEM (scanning electron microscopy) were unique in the metal finishing industry. The cost of these tests, as well as the equipment to perform them, tends to limit participation in these markets to those companies prepared to take on high tech methods of quality assurance.

ASTM has issued two new specifications[7, 8] that, for the first time, allowed the use of electropolishing as a means of passivation for stainless steels. Other specification-setting societies, such as SAE/AMS[9], have issued or will soon issue new specifications covering electropolishing as a means of passivation. The advent of these specs has helped to expand applications for electropolishing into many new market areas. In addition, there are numerous "in-house" specifications imposed by the large buyers of electropolished hardware. In the medical implant industries, the term "biocompatibility" infers a special concept of corrosion resistance required for a metal product in contact with bodily fluids.

Use of the spectroscopic methods of analysis has focused the attention of the semiconductor industry on various defects in the surface oxide, such as the occurrence of carbonaceous or other non-metallic residues. Consequently, electrolyte formulations containing organic additives are generally considered unsuitable for all semiconductor polishing. It appears likely that the same issues may soon concern the medical implant industry.

Electropolishing operations increasing come under the requirements for FDA, ISO, and other quality assurance programs. Manufacturers of critical parts have become increasingly concerned about the origin, history, and maintenance of chemicals and chemical processes, requiring careful records to ensure reliability of a process and to permit total traceability through the manufacturing steps. The requirements have favored the use of proprietary electrolytes over self-formulated baths.

Much information has been published on the advantages of pulse in plating and anodizing studies; however, very little information is available on the use of pulse power in electropolishing. Some recent studies suggest that pulse rectification may actually increase pitting defects[10].

Conclusions

1. New applications for electropolishing have expanded the technology required to successfully operate the process.
2. New specifications have been developed to define the corrosion resistant properties of electropolished metals.
3. New metals have been developed that require continual changes in the electropolishing technology.
4. New test methods have emerged to describe the quality of the electropolished finish.
5. New AESF training programs are needed to assist member companies to develop marketable electropolishing services.

Recommendations for future committee work

1. Approximately thirty years have passed since AESF has offered a training manual or a course of study related to electropolishing. The Electrochemical Metal Removal sub-committee should consider issuing an updated edition of the "Illustrated Lecture: Electropolishing".
2. Laser cutting processes and EDM processes appear to complicate the problem of scale removal for the electropolisher. Basic input from the sub-committee members involved with these processes should be sought.
3. Some unofficial studies show that EDM recast can be removed by electropolishing, but definitive data should be developed.
4. Electropolishing increases the ratio of chromium to iron in the surface oxide. Published studies are needed to define the polishing parameters required to control this phenomenon.

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