Electropolishing offers sizeable — and microscopic — value to intensive contamination control requirements for metal surfaces.

Ultra-Clean Metal Begins With Electropolished Finish

BY R. KEITH RANEY

To be precisely clean, a surface must be clean microscopically.

While electropolishing presents a bright, smooth, uniform and clean-looking macro-surface finish, its real value lies in the ultra-clean quality of the microscopic surface. Properly electropolished surfaces are microscopically featureless — completely noncontaminating, nonparticulating and nonsticking. Much like glass, they offer contaminants no place to adhere and thus are easily and precisely cleanable.

The benefits of electropolishing are realized with reactor vessels, heat exchangers, blenders, storage tanks, piping and tubing, cleanrooms, food and beverage processing equipment, medical apparatus, machined parts and nuclear applications. The process is especially beneficial for the sterilization and maintenance of hygienically clean surfaces for food, drug, beverage and chemical processing.

Electropolishing streamlines the microscopic surface by removing the uppermost layer of a metal ion by ion, eliminating imperfections which trap and contain contaminants.

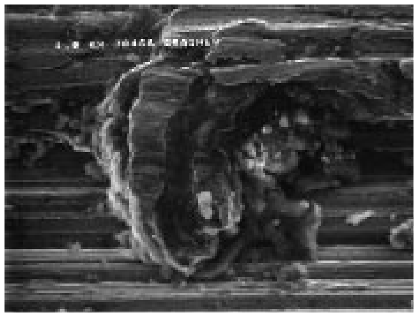
This controllable electrochemical process is similar to, but the reverse of, plating. In basic terms, the object to be electropolished is immersed in an electrolyte and subjected to direct D.C. current. The object itself is maintained anodic, with the cathodic connection being made to a nearby metal conductor.

Electropolished Vs. Mechanical

The differences between electropolishing and traditional mechanical finishing often are not readily obvious to the unaided human eye, particularly if both surfaces are polished to the same micro-inch surface finish. The merits of electropolished surfaces become apparent, however, when viewed under high magnification.

Even very fine mechanical polishing or buffing produces an abundance of scratches and strains in the metal surface, as well as a host of microscopic debris and embedded abrasives. Scanning electron microscope (SEM) photomicrographic analysis readily confirms this difference in surface characteristics. (See Tables 1, 1a.)

Unlike electropolishing, mechanical polishing and buffing distorts the surface, leaving smears, cavities and torn metal.



This 1000x SEM photomicrograph represents the surface of grained 304 stainless steel heavy gauge sheet as received from the mill. Note the extreme left-to-right surface striations, combined with the numerous cracks, crevices and torn and distorted metal. This surface offers major contamination potential.

This 1000x SEM photomicrograph represents the same grained 304 stainless steel surface after being mechanically polished to a Buffed No. 8 finish. Note the smeared metal and the depth of the distorted surface profile. While this surface appears very clean and bright to the unaided eye, it remains vulnerable to significant product contamination, as well as ongoing particulation of the imbedded abrasive used in the mechanical polishing and buffing process.

This 1000x SEM photomicrograph represents the grained 304 stainless steel surface after high-quality electropolishing. While the grained texture is still lightly visible to the unaided eye, the grain boundaries, torn metal, cracks, crevices and other contamination traps in the microscopic surface have been virtually eliminated. The small surface asperities still visible are non-metallic inclusions such as carbides and sulfides, both of which are relatively common in 304 stainless steel.

Photos courtesy of Delstar

These cracks and crevices are huge contamination traps which limit the overall cleanability of a metal surface, often beyond the reach of even the most diligent ultra-cleansing applications.

One significant consideration in a cost comparison of electropolishing vs. mechanical polishing is the geometry of the part to be polished. If after careful study you determine that either finish could meet your particular needs, the subsequent cost analysis would be largely dependent on the part's geometry.

Some intricate or complicated shapes are virtually impossible to mechanical polish, and therefore would be ideal for electropolishing. Likewise, there are other shapes which, by their relative simplicity or openness, can be mechanical finished or electropolished at about the same cost.

Material Matters

Most metals can be electropolished successfully, but best results are obtained with those having fine grain boundaries free of non-metallic inclusions and seams. The smoother the surface, the higher the brilliance and reflectivity will be after electropolishing is complete.

Stainless steels are the most frequently electropolished alloys for high-purity industries, primarily because the process produces a layer of chromium enrichment, passivating the surface to the point where only very low levels of iron remain in zero oxidation states. (See Figure 1.)

Other metals processed include molybdenum, tungsten, aluminum, copper, cupronickel, brass, bronze, beryllium copper, monel, inconel, hastelloy, titanium, columbium, beryllium, vanadium, tantalum, silver and gold. Multiphase alloys in which one phase is relatively resistant to anodic dissolution usually are not well suited to an electropolishing treatment.

Base metal conditions that can result in less than optimum electropolished finishes involve the presence of non-metallic inclusions, improper annealing, overpickling, heat scale, large grain size, directional roll marks, insufficient cold reduction or excessive cold working. These flaws, usually inherent in the metal as it

Figure 1
Microscopic Cross Section
of a Typical Passivation Surface
on Stainless Steel

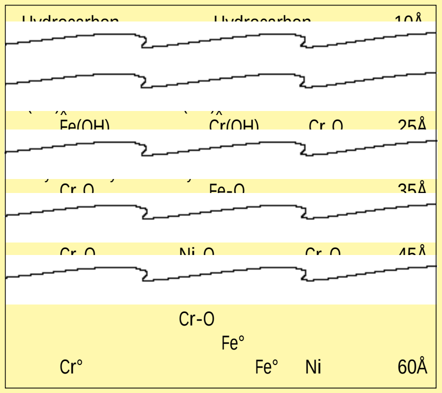


Table 1
Iron and Chromium Oxidation State Distribution
of "Model" Samples 1 and 2

ATOM & DESCRIPTION	Cr°	Cr-O	Fe°	Fe-O	TOTAL Cr / TOTAL Fe	Cr-O / Fe-O
Sample 1	0.14	2.18	0.47	1.42	1.24	1.54
Sample 2	0.45	4.36	1.18	1.14	2.07	3.82

All values are elemental percent: atomic percent abundance of Cr as Cr° and Cr-O, and atomic percent abundance of Fe as Fe° and Fe-O.

Table 1a
Summary of ESCA, AES and SEM Results Before and After Electropolishing

QUANTITY MEASURED/ SAMPLE DESCRIPTION	TOTAL Cr/Fe (TOP 40Å)	Cr OXIDE Fe OXIDE	OXIDE THICKNESS	MAX. Cr/Fe RATIO IN OXIDE LAYER (AND AT MAX. OXYGEN LEVEL)	SEM CHARACTERIZATION OF SURFACE MORPHOLOGY	CONTAMINATION IN AND ON OXIDE LAYER
Sample 1 (Before Electropolish)	1.24	1.54	25Å	1.7, 1.6	Smooth, flat, major pits and machining marks. Grain structure evident.	Small amounts of sulphate and phosphate alumina, and trace levels of lead. Slight organic silicone traces.
Sample 2 (After Electropolish)	2.07	3.82	16Å	2.0, 2.0	Smooth, flat, minor pits and machining marks.	Small amounts of sulphate and phosphate. Slight organic silicone traces.

comes from the mill, are revealed with the removal of metal during electropolishing.

Electropolishing cannot smear over or otherwise conceal defects such as seams and non-metallic inclusions in metal. In addition, heavy orange peel, mold-surface texture and rough scratches are not removed by a practical amount of electropolishing and thus require initial cutdown with appropriate abrasives.

Quality Controlled

Electropolishing is both a science and an art. Quality work is determined by the precision and consistency of the process controls and how completely the electropolisher understands the physics and chemistry of the process.

High-quality electropolishing should exhibit brilliant luster and reflectivity. When viewed by the unaided eye, it should be free of "frosting," shadows, streaks or stains, pitted areas, orange peel, erosion, pebbly appearance and water spots. Under high magnification, electropolished surfaces should show no evidence of grain boundaries and should be essentially featureless.

The degree to which the electropolishing process is controlled determines the final quality and consistency of the finish. Many electropolishing shops employ, at best, minimal controls or none at all. Modern, computerized process controls are crucial for consistent and predictable quality.

For example, it is imperative that the proper electrolyte be used, that its temperature be maintained precisely and that its chemistry be monitored constantly for specific gravity, acid concentration and metals content. In addition, DC power must be applied to the component at the correct and optimum voltage and current density.

Some of these variables are functions of technology; others may be considered "the art of electropolishing" — the ability of an experienced technician to configure a cathode for optimum polishing in all places accessible, including corners and areas of low current density. Also important is the knowledge of where, when and how to agitate either the electrolyte or the part in order to prevent gassing streaks, flow marks and similar undesirable markings.

Standards and Specifications

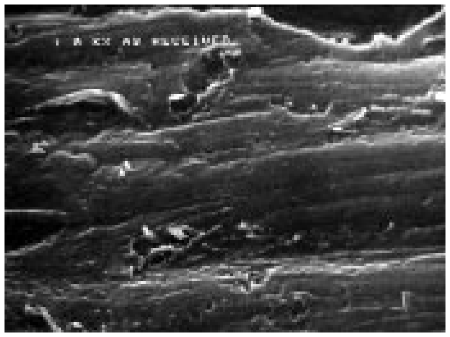
For many years the electropolishing industry operated by no generally accepted quality standards and process specifications. Controls were virtually nonexistent, and processes were governed largely by someone's "gut feel" without regard for the real physics and chemistry involved. As a result, quality often fluctuated widely, not only from company to company but from day to day within the same processing facility.

Today, top electropolishers adhere to specifications described in the Electropolish Standards and Specifications, better known as EFS-SPEC.

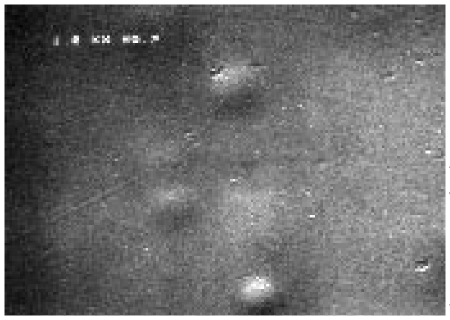
Companies in the high-purity and precision cleaning industries typically gravitate to the most demanding specification, which specifies the use of one or more accepted clinical certification of all electropolished surfaces in question. PC

About the Author

R. Keith Raney, vice president of process development for Delstar Electropolish (Houston, TX), has significant experience working with high-tech and high-purity companies.



This 1000x SEM photomicrograph represents the surface of an aluminum cylinder destined for hugh-purity gas transmission applications in the semiconductor industry. Before electropolishing, note the exposed grain boundaries, cracks, cavities and torn metal in the microscopic metal surface, all of which trap contaminants.



Photos courtesy of Delstar

This 1000x SEM photomicrograph represents the same cylinder wall surface after electropolishing. Note the complete absence of grain boundaries and torn metal. Extreme projections in the original surface profile have been rounded off and rendered completely smooth and noncontaminating.