A review of the different aspects, theories, and recent developments in the electropolishing of stainless steel

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ABSTRACT

Electropolishing is a surface finishing process, widely used in industry to provide clean, smooth, and corrosion-resistant surfaces on metal and alloys, especially steel. The general mechanism of electropolishing is discussed in this review paper followed by different theories proposed to explain the process starting from viscous theory to the most recently developed oxidation–dissolution theory. Since this process involves chemical and electricity reactions, it is quite complicated to understand using the existing theories. The effect of different factors like electrolyte types, processing time, operating voltages, etc. on the electropolishing of stainless steel is also discussed in detail. The most recent developments in electropolishing techniques like magneto electropolishing and electropolishing of additively manufactured steel components are also reviewed in this paper. All the techniques are compared with the classic electropolishing technique with respect to their processing conditions and output on the steel surface. Finally, the limitations and future perspectives of the currently available techniques are also discussed.

KEYWORDS Electropolishing, Surface Finish, Corrosion, Magneto Electropolishing
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1. Introduction

Electropolishing/electrochemical polishing/electrolytic polishing is a surface process that is widely used in industry to provide a dirt-free, smooth, bright, Beilby-free and corrosion-resistant surface on many metals and alloys (Yang et al., 2016). This process involves the anodic dissolution of metal or alloy surfaces and electrolytic removal of metals ion from the surface. This process not only smoothens the surface but also forms a thin corrosion-free layer on the surface (Diego et al., 2024). The process of electropolishing has been known for decades; initially, it was applied to brighten silver (Chaghazardi & Wüthrich, 2022). But, it has been rediscovered in the last few years because of the increasing demand for clean, smooth, and corrosion-resistant surfaces in the pharmaceutical, biomedical, semiconductor, and food and packaging industry (Rokicki & Rokosz, 2007). Electropolishing can be used for any kind of metal and alloy with only one condition that the material should be homogeneous and fine grained. This condition makes this polishing technique a great success for stainless steel (304, 304L, 316, 316L, etc.) (Mohan et al., 2001).

The electropolishing of stainless steel can be divided into three stages: anodic levelling, anodic brightening, and passivation. Anodic levelling focuses on reducing surface roughness through controlled metal dissolution of the surface's peaks and valleys under specific current and mass transport conditions (Łyczkowska-Widłak et al., 2020). Anodic brightening minimises the impact of the microstructure on the dissolution rate by forming a thin, precipitated salt layer over the electrode surface (Guo et al., 2023). Passivation, particularly effective for steel and copper, creates a chemically passivated layer on the steel surface during electropolishing. Unlike mechanical polishing processes, this layer significantly reduces the corrosion rate of steel, sometimes by a factor of 10^3 to 10^6 (Rotty et al., 2022). So, the overall process provides smoothening by eliminating large-scale surface irregularities (one micron to 4×10-5 inch) and brightening by removing small irregularities on a microscopic scale (10-2 micron to 10-7 inch) (Chatterjee, 2019). A smooth electropolished surface of a metal/alloy which seems bright to the naked eye is actually the final product of these two processes.

Usually, a solution of concentrated phosphoric and sulphuric acid is employed as an electrolyte for the electropolishing of stainless steel (Beamud-González et al., 2023). The use of a suitable electrolyte with optimised operating conditions in the electropolishing process can improve the whole process. The overall effect of electropolishing is much better than mechanical polishing for stainless steel, and the polished surface can attain a mirror-like finish. This process removes the top layer due to stress contamination along with oxygen, carbon, hydrogen, and other impurities to achieve ultrafine cleanliness of stainless steel. After electropolishing, hardly any contamination can grow on the stainless steel surface which makes it suitable to be used in the semiconductor, medical and food, and packaging industries (Lee & Lai, 2003). Many small and complex parts of the machines made of stainless steel are polished with the help of electropolishing as mechanical polishing is not suitable.

2. Electropolishing mechanism of stainless steel

Electropolishing (EP) of stainless steel is usually performed in three steps: (1) Sample preparation, (2) electropolishing, and (3) post-treatment. On an industrial scale, all these three steps require several large tanks to complete the whole process. All these three steps are schematically shown in Figure 1 and are discussed below:

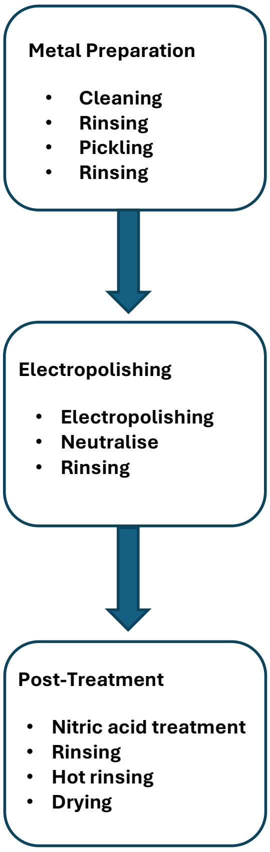

Figure 1. Schematic diagram showing the typical electropolishing process followed by the stainless-steel workpiece.

2.1. Sample Preparation

Sample Preparation includes alkaline degreasing followed by acid pickling. During manufacturing, generally, stainless steel surfaces are contaminated due to oil, grease, fingerprints, or similar kinds of films. To remove all these, the stainless steel parts are dipped into alkaline solution and after that, the parts are handled very carefully to avoid any physical contact with human hands and the process equipment. It is necessary to remove these contaminations before EP because they do interact with electrolytes during EP and slow down the reaction. After alkaline degreasing, the alloy parts are dipped into an acidic solution. The acid rinse removes the alkaline layer from the surface and also any other contaminant which is not soluble in alkaline medium (Bauccio & ASM, 1993).

2.2. Electropolishing

Electropolishing is an anodic dissolution process utilising an electrochemical reaction (shown in Figure 2). The workpiece made of stainless steel which serves as the anode is immersed in an electrolyte (generally a combination of sulphuric and orthophosphoric acid) under controlled temperature conditions and is associated with the positive polarity of the power supply. The electrode instrument acts as a cathode and is attached to the negative polarity. The voltage is applied between the electrodes, and current starts flowing from anode to cathode through the electrolyte. The metal atoms on the workpiece start converting into metal ions and dissolve into the electrolyte solution due to the oxidation reaction. The cathode on the other side gains electrons and is reduced. The loss of ions into the electrolyte decreases the ion concentration of the electrolyte near the anode due to which the outermost layer of the anode surface appears to be more active than the inner layer.

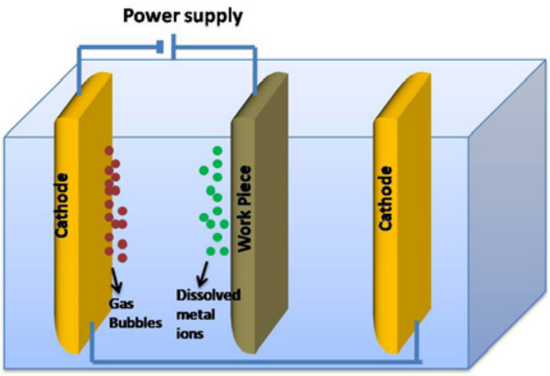

Figure 2. Schematic diagram of the electropolishing process.

Due to this situation, more metal ions can be removed away from the surface. During the oxidation reaction, oxygen is released from the surface of the anode which helps to move the electrolyte solution, and major spots on the workpiece are dissolved faster (Xue et al., 2022). The removal of metal ions from the surface of the workpiece depends upon the workpiece composition, electrolyte, electro-polishing time, temperature, etc. A standard electropolishing solution of stainless steel consists of a mixture of 96% sulphuric acid and 85% orthophosphoric acid. The whole process is carried out in the temperature range of 40 °C to 75 °C for a time duration of between 2 and 20 minutes (Grimm et al., 1992).

The dissolution of anodes in EP can be analysed via the current density-voltage curve, and Jacquet was the first to use this technique (Nurdillayeva et al., 2022). A classic current-voltage curve of the electropolishing process is shown in Figure 3. The curve can be subdivided into the etching, passivating, polishing, and gas evolution region. At low voltages, in the etching region, the workpiece dissolves and a few pits are formed on the metal surface. After etching, a passive oxide layer is established on the surface due to which a decrease in current density is observed with the increase in voltage. In the limiting current plateau region, an almost constant current is observed with the increase in voltage. This is the region in which electropolishing occurs at high anodic potentials (Ramasawmy & Blunt, 2007). During the electropolishing process, the current in the plateau region is used due to the generation of surface defects such as pits. Rong et al. (Yi et al., 2022) reported in their study that actual electropolishing is possible at a higher applied current than in the plateau region. So, according to them, the applied current density is a more important parameter than the plateau region.

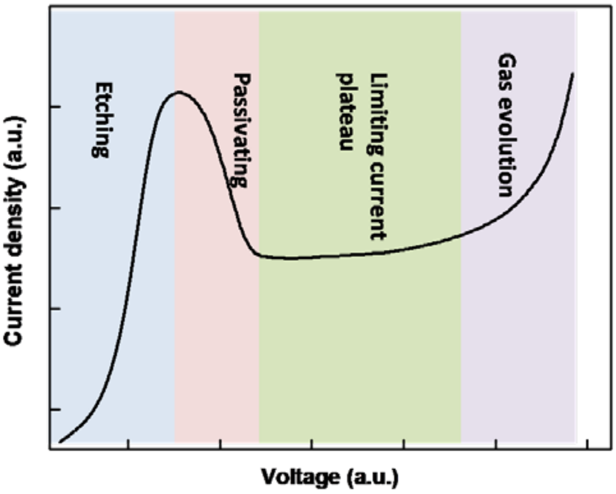

Figure 3. Typical voltage-current density curve during electropolishing.

2.3. Post-treatment

After electropolishing, a chemical layer of byproducts is formed on the surface which is removed by the washing of the workpiece. But the phosphates and sulphates of heavy metals are difficult to remove by rinsing with water, so, nitric acid is used for washing the workpiece after electropolishing. Residues of nitric acids are washed with cold water as they are soluble in water. At the end, the workpiece is passed through a hot water bath to flash dry it without cracking. Some parts do not dry completely after rinsing with hot water. For those parts, centrifugal dryers and heated air chambers are used to speed up the evaporation of moisture and prevent staining of the workpiece (Bauccio & ASM, 1993; Kang & Lee, 2007).

3. Theories of electropolishing

There are certain theories and hypotheses in the literature to explain the electropolishing process which is quite complex and influenced by many parameters and steps. The main theories which attempt to explain the complexity of the processes are discussed in this section:

Jaquet was the first to propose a mechanism known as “viscous film theory” to understand the mechanism of electropolishing (shown in Figure 4) (Jacquet, 1936). His theory was quite simple but provides the basis to develop new theories. According to his theory, the dissolution products form a viscous layer on the workpiece and hence decrease the current density due to high resistance which results in a decrease in the dissolution rate. It is assumed that the viscous layer is smooth near the electrolyte and therefore, the thickness of the layer is not uniform on the workpiece due to its rough surface. The viscous layer is relatively thick in the valleys as compared to the peaks. Due to the difference in thickness, an electrical resistance gradient will be created which will enhance the dissolution process at the peaks and decreases at the valleys. As a result of the different dissolution rates at different parts of the workpiece, a levelling effect will be achieved.

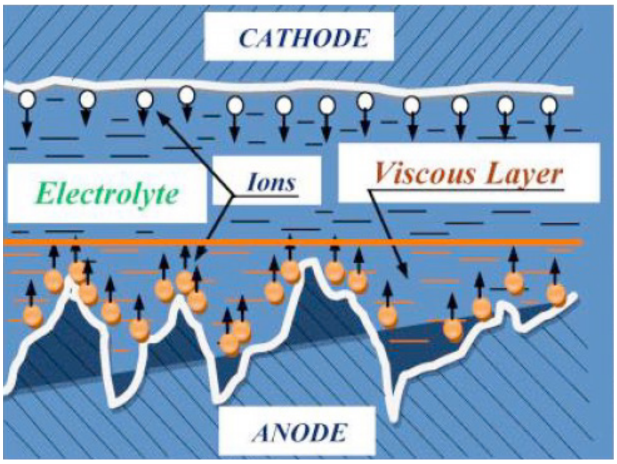

Figure 4. Schematic representation of viscous layer theory (Rokicki & Hryniewicz, 2012).

Hoar proposed a new theory for the electropolishing process, according to which a very thin inert layer is created on the workpiece (anode). But this layer is immediately dissolved by the electrolyte (Boucher et al., 2022; Han & Fang, 2020). The workpiece does not undergo dissolution directly into the electrolyte. Initially, it will be converted into metal oxide and then it will dissolve into the electrolyte solution. The oxide film is usually dissolved in the form of salt and/or oxysalt. In this theory, the viscous layer is formed similar to in Jacquet’s theory but here, the viscous layer is established amongst an oxide film and electrolyte, whereas according to Jacquet’s theory, it is formed between the anode and electrolyte.

The other theory for electropolishing was developed by Grimm et al. known as the duplex salt film model (Grimm et al., 1992). According to this theory, two films are formed on the surface of the workpiece: Figure 5(a) shows the compact and porous film regions. In the compact film region, the cations are transported through a dielectric barrier in the existence of a high electric field by a solid-state ionic conduction mechanism. The movement of the ions for the solid-state transport mechanism is quite low and the thickness of the film is considered to be in the range of nanometres. In the porous film region, the pores are filled with electrolyte solution, and the charge carriers transport the current by migrating through these pores. The high resistance of these salt films is explained by considering that the porous layers are less porous with a thickness in the range of microns. According to this theory, the thickness of the salt layer results in a potential drop increase along the restrictive plateau region.

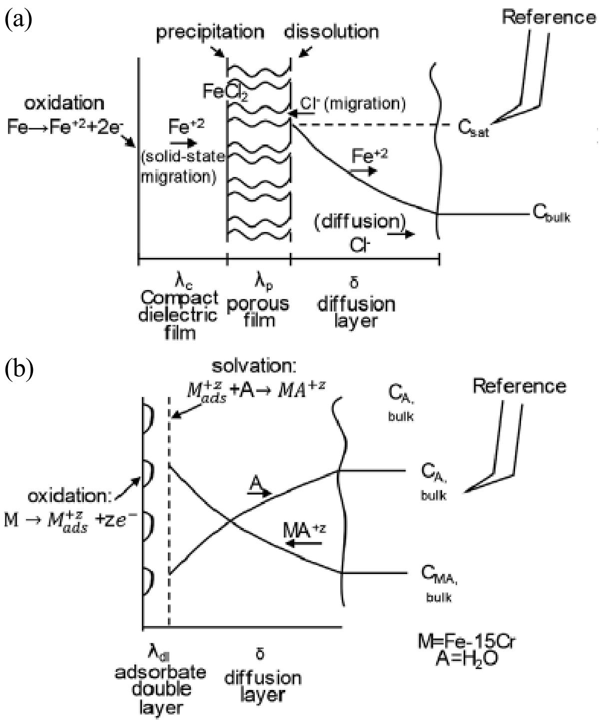

Figure 5. Representative model of (a) salt film and (b) adsorbate acceptor (Grimm et al., 1992; Matlosz et al., 1994).

The adsorbate acceptor mechanism to explain the electropolishing was proposed by Matlosz et al. as shown in Figure 5(b) (Matlosz et al., 1994). According to this theory, the dissolution mainly comprises two steps: (1) oxidation of the metal to adsorbed cations and (2) salvation of these cations by acceptor species. The whole process is limited by the diffusion of the receiving species by the electrolyte diffusion layer. The buildup of adsorbed ions on the electrode will lead to blocking of the surface and results in an increase in the potential drop for workpiece dissolution. According to this theory, when the concentration of acceptor species at the electrolyte/electrode interface drops to zero, the system attains the state of limiting current or plateau region.

Rockiki et al. (2012) proposed a new theory named enhanced oxidation-dissolution theory. According to them, the Haor theory should be amended for the electropolishing process at very high rotational speeds under the oxygen evolution regime. They studied the electropolishing of stainless steel AISI 316L under high rotational speeds. They observed that at such high speeds, the viscous layer is not present on the surface of the anode which eliminates the possibility of any mass transport by the diffusion process and results in a decrease in current density. The dissolution is carried out by the tunnelling of ions through vacancy and dislocation sites of the oxide, and current is only controlled by the thickness of the oxide film. The oxide film is thick over the valley and shallow over the peaks. The resistivity of the peaks is less than that of valleys and as a result, they dissolve faster as compared to valleys, and a levelling is achieved.

4. Factors affecting electropolishing

4.1. Temperature

In the electropolishing process, the mass transport is highly dependent upon the electrolyte temperature as a lower temperature reduces the solubility of metal ions and also slows down the diffusion process which further reduces the current density. Chen et al. (Chen et al., 2005) recorded the current-voltage curve for austenitic stainless steel at temperatures of 60, 70, and 80 °*C* and found that as the temperature increases, the current density also increases which helps to generate a better smooth surface after electropolishing. Similar kinds of results have been reported by the I-V study of 316 stainless steel by Mengyan et al. (shown in Figure 6) (Li et al., 2006). According to them, as the temperature increases, the viscosity decreases which results in this kind of change in current density with respect to temperature.

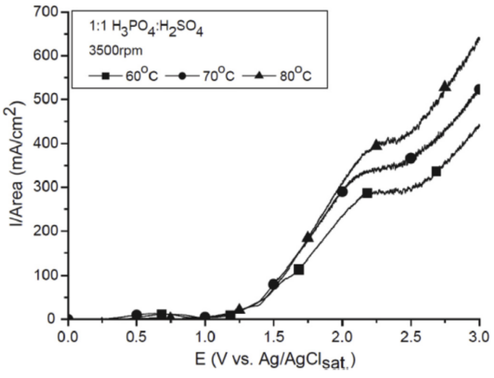

Figure 6. Current density-voltage curve for stainless steel (Li et al., 2006).

In their study, two inflection points were observed within the range of 1.5-1.8 volts which is basically due to the presence of different phases on the surface.

Lee in his study directly correlated the surface roughness after electropolishing with the temperature of the electrolyte (Lee, 2000). During the electropolishing of STS316L stainless steel with a phosphoric-sulphuric acid-distilled water electrolyte, it was found that the surface roughness decreases with the increase in electrolyte temperature (Figure 7) because the electropolishing effect is more active with high current efficiencies and a continuous supply of fresh electrolyte due to low viscosities.

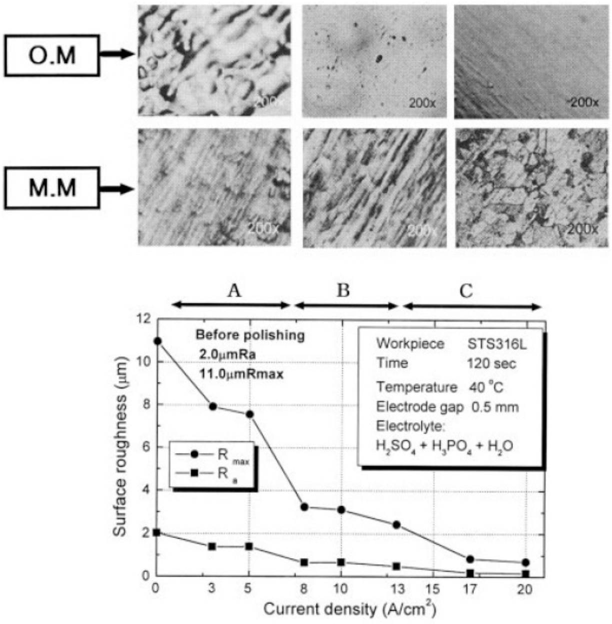

Figure 7. Graph depicting the relationship between surface roughness and current density. O.M.: optical micrographs; M.M.: metallic micrographs (Lee, 2000).

4.2. Electrolyte composition

In the electropolishing process, the electrolyte works as a transporter of current, heat, and reaction products. Organic, inorganic, or organic/inorganic solutions are generally used as electrolytes for the electropolishing process (Chatterjee, 2019; Lochyński et al., 2019). Most of the electrolytes used for the electropolishing technique consist of 50-75% acids, 5-15% deionised water by weight, and the remaining by weight one or more inhibitors. The volume ratio of acids is generally about 1:1 or 1:2 and is a critical parameter in electropolishing (Xue et al., 2022; Hwang & Kim, 2023). H. Chen et al. (2022) studied the effect of water concentration in the electrolyte solution on the anodic polarisation curves and impedance diagrams during the electropolishing of stainless steel. The electropolishing process was conducted in a phosphoric acid–sulphuric acid–water solution at 70 *°C* and 1600 *rpm*. It was observed that the limiting current plateau becomes less pronounced with the increase in water concentration because water in the electrolyte acts as an acceptor for dissolved metal ions. At the optimum concentration of water of around 15%, a smooth surface free of crystallographic defects and mechanical polishing is obtained.

Organic additives like glycerol, mono-di, and triethanolamine, etc. are also added to the electrolytes to improve the smoothening of stainless steel surfaces by the electropolishing process (European Commission, 2006). The main bath additives used with the electrolyte for electropolishing of stainless steel are listed in Table 1. Lochynski et al. (Lochyński et al., 2016) reported a study on electropolishing of AISI 304 stainless steel in 51 *wt* % phosphoric acid, 35% sulphuric acid, 3% organic additives, and water. They studied the effect of different additives such as ethanolamine, diethanolamine, triethanolamine, triethylamine, glycerol, and butyl glycol considering any three at a time. It was concluded from the study that lowering the plateau level in the current potential curve can verify the selection of additives for the electropolishing process. High gloss, low surface roughness, and mass loss were observed with the addition of additives during electropolishing. Among all the studied additives, triethanolamine exhibited the best results per surface area unit of electropolished surface in comparison to glycerol as shown in Figure 8.

Table 1. Bath additives used in the electropolishing of stainless steel.

S.No.	Organic Additives	Bath Type
1	>1 wt% 2-amino-2-methyl-1-1-propanol	> 1 wt% nanooxidising acid (H_3PO_4), citric acid, tartaric acid, oxalic acid, acetic acid, gluconic acid, glycolic acid, succinic acid, H_2SO_4. (Baylan et al., 2020)
2	>0.1 wt% triethanolamine, diethanolamine, monoethanolamine	>0.1 wt% of H_3PO_4, citric acid, tartaric acid, oxalic acid, gluconic acid, glycolic acid, succinic acid, and their salts with Na, K, and ammonium (Taguchi, 2007)
3	3 wt % triethanolamine	H_3PO_4: 51 wt% H_2SO_4: 40.91 wt% (Lochyński et al., 2014)
4	2.27 vol% ethanolamine or diethanolamine or triethanolamine	H_3PO_4: 56.82 vol% H_2SO_4:41.90 vol% (Mohan et al., 2000)
5	25 or 35 vol% glycerol	H_3PO_4 and H_2SO_4 (volume ratio 3:2 or 2:1) (Lin & Hu, 2008)
6	10 vol% glycerol	H_3PO_4 and H_2SO_4 (volume ratios: 5:5/6;4/7:3) Water content: 0/10/20/30 (vol %) (Hocheng et al., 2001)
7	10 vol% glycerol	H_3PO_4: H_2SO_4: Dionised water (60:20:10 vol%) (Habibzadeh et al., 2014)

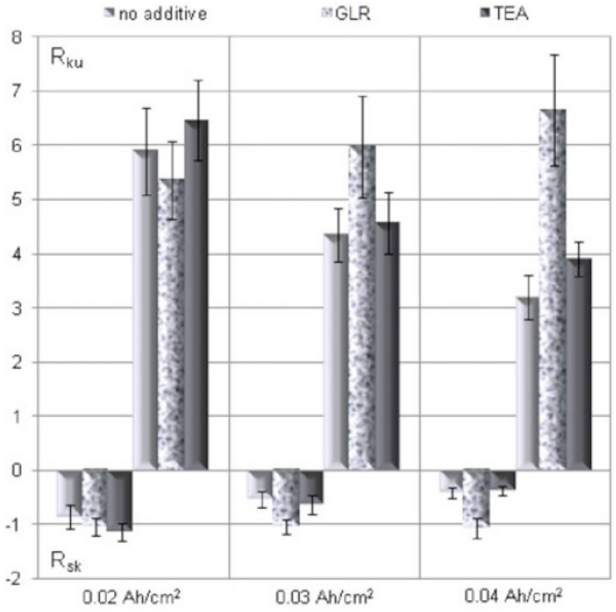

Figure 8. The average values and standard deviation bars of the roughness parameters for the AISI 304 stainless steel samples electropolished in baths with glycerin (GLR) or triethanolamine (TEA) and without any additive (Lochyński et al., 2016).

4.3. Electrolyte ageing

In the industry, the electrolyte solution is reused many times to decrease the cost of the process and also to minimise the removal of acidic waste into the environment (Eozenou et al., 2006). But, the re-usage of electrolyte affects the current density because of the absorption of cations over time and results in uneven polishing and deterioration in the gloss of the final surface obtained after electropolishing (Urlea & Brailovski, 2017). The decrease in performance of the electropolishing process due to the reuse of electrolytes is known as electrolyte ageing or bath ageing. Jayashree et al. (2002) studied the effect of ageing on the electropolishing of stainless steel in monoethanolamine for a longer duration of one hour as compared to the normal processing time of 3-15 minutes. They reported that an electropolishing bath offers a maximum reflected surface with minimal electrical power consumption (Jeyashree et al., 2000).

Research is ongoing to find new ways to improve or clean the contaminated electrolyte bath. Generally, industrial baths use a combination of phosphoric acid and sulphuric acid as electrolytes. With the passage of time, copper, nickel, iron, and chromium ions migrate into the bath during anodic dissolution and affect the final surface of the workpiece (Huang et al., 2014). Nurdillayeva et al. (2020) have proposed a method to remove copper ions from such contaminated baths with the use of an electrochemical reactor. Another method based on galvanisation was proposed by Hunsom et al. (2005) for the complete reduction of copper. In this process, a cell consisting of steel as the cathode and coated titanium grate as the anode separated by a membrane was used for the reduction of copper. In a report by Khan, the 50-hour process was conducted to remove the zinc and nickel ions from the electrolyte solution by using stainless steel as the anode and aluminium as the cathode (Khan, 2005).

4.4. Electropolishing time

The roughness and shine of the surface are considered to improve with the increase in electropolishing time. Haidopoulos et al. (2006) studied the electropolishing process on 316 stainless steel used for stent application. A combination of phosphoric acid, sulphuric acid, distilled water, and glycerol were used as the electrolyte. They evaluated the relationship between the composition and duration of electropolishing. The atomic force micrographs recorded at intervals of 1.5 minutes to 5 minutes during the process are shown in Figure 9. It can be observed from the figure that as the duration of electropolishing increases, the surface becomes smoother, defect-free, and homogeneous. Grain boundaries become visible even after 3 minutes of the process. At the beginning of the process, the polishing effect is faster because of the high potential difference between the valleys and peaks. But as the process continues, the peaks undergo dissolution which decreases the potential difference, and the polishing process slows down with time.

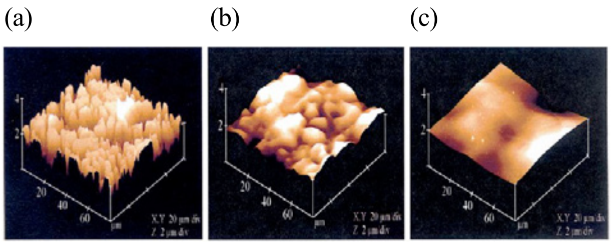

Figure 9. AFM micrographs of 316-stainless steel surfaces: (a) as received; (b) electropolished for 1.5 minutes at room temperature; and (c) electropolished for 5 minutes at room temperature (Haïdopoulos et al., 2006).

5. Recent developments in the electropolishing technique for stainless steel

5.1. Magneto electropolishing

In the magneto electropolishing process, a magnetic field is applied to the standard electropolishing system. This magnetic field helps to increase or decrease the rate of dissolution process under oxygen evolution to achieve an electropolished surface (Dong et al., 2023). This combination offers better smoothness, an increase in surface energy, and high corrosion resistance in a shorter span of time. The effect of a magnetic field on the overall process can be sub-divided into three processes: electron transfer, mass transfer, and morphology of the treated material surface (Rotty et al., 2022; Guo et al., 2023).

Hinds et al. (2001) were the first to examine the effect of a magnetic field on the electrode deposition of copper in an aqueous solution. Hryniewicz et al. (2007) compared the process of electropolishing on 316L stainless steel with and without a magnetic field. Under the oxygen dissolution process, the current densities were observed to decrease followed by a decrease in the dissolution of material in the presence of a magnetic field. The decrease in dissolution is directly dependent upon the applied magnetic field. On the contrary, when this process was carried out below the oxygen evolution region, an increase in dissolution rate was observed. Even in their research, they found that when the magneto electropolishing process is carried out under an oxygen evolution region, a contradiction is observed for all the three established theories to some extent. The magnetic field applied during the process generates the Lorentz force, and this force mechanically rotates the electrolyte around the axis parallel to the direction of the magnetic field. The rotational motion of the electrolyte reduces the thickness of the viscous layer and increases the rate of mass transport and dissolution. Hryniewicz et al. (2008; 2006) in their report compared the X-ray photoelectron spectroscopy results of AISI 316L stainless steel after EP and MEP. They observed a higher Cr:Fe ratio (3:3) in a workpiece after MEP as compared to EP. The higher ratio of Cr:Fe will enhance the corrosion resistance of the steel. Even during MEP, both metallic Cr and Fe are converted into their oxides. MEP was performed at 350 mT with the current density of 50 A/dm^2. The 316L stainless samples exhibited a decreased corrosion rate in the Ringer's body fluid. The MEP technique is considered to be an advantageous process to improve the performance of stainless steel in the biomedical field (Kityk et al., 2020).

5.2. Electropolishing of additively manufactured stainless steel

Additive manufacturing (AM) methods have become the centre of attention worldwide as these methods are enabling the design and production of complex engineering materials which were not possible with traditional manufacturing methods (Egan, 2023). However, the surface finish of engineered parts is highly rough which makes them unsuitable for their practical usage in the field of biomedical engineering, aerospace, and automobile (Melchers & Jeffrey, 2004; Gibson et al., 2010; M.A.J. & Herbert, 2003). The surface finish or roughness of these parts plays a very crucial role in deciding their sensitivity towards crack propagation, corrosion, premature failure during fatigue loading, and their ability to integrate with other components (Persson & Gorb, 2003; Ranjbar-Far et al., 2010). Generally, the roughness of the exterior part of the additively manufactured part is in the range of 5 μm which can be improved up to the 0.5 μm level, whereas the internal roughness is around 15 μm as loose metal powder remains adhered to the surface (Tyagi et al., 2019). Milling, blasting, or thermal deburring are commonly used techniques for the surface polishing of metal parts or alloys, but these cannot be employed for AM components due to their complex internal design as it is difficult to reach the small and narrow internal surfaces (Nazneen et al., 2012). Of all these surface finishing techniques, electropolishing has a unique advantage as its electrolyte solution can easily reach intrusions or hidden surfaces which are mainly inaccessible by other techniques. Electropolishing can easily remove scales, oxides, chemicals, and surface irregularities along with the surface burns from delicate and complex AM components. Electropolishing also helps to improve the corrosion properties of steel as it removes all the surface imperfections which act as the corrosion initiation sites. This technique also helps to remove small cracks and defects from the parts and improves the fatigue life of AM components (Nazneen et al., 2012; Zhao et al., 2002).

Goulet et al. (2019) studied the electropolishing of AM 316 stainless steel components synthesised with a laser sintering technique in a glass beaker using an acidic electrolyte solution composed of a mixture of phosphoric acid and sulphuric acid. The solution was kept under agitation and a current of around 60 A/dm^2 was maintained throughout the experiment. They demonstrated that electropolishing is better in reducing the surface roughness until a counter electrode is placed in close proximity to the target surface. In this study, they even demonstrated that electropolishing is better than polishing in terms of surface smoothness.

In another study, the electropolishing of AM components was reported in deep eutectic solvents: ChCl-EG at different potentials between 0.5 and 4.5 volts for 20 minutes. It was finally concluded through these experiments that surface roughness can be achieved under 800 nm at the potential corresponding to the end of the current limiting plateau (Rotty et al., 2017). The results of this study are also shown in Figure 10.

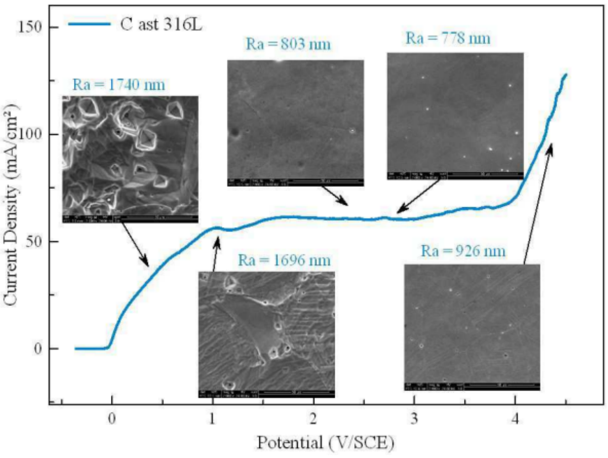

Figure 10. SEM morphologies and surface roughness of electropolished AM components of stainless steel at different potentials (Rotty et al., 2017).

The effectiveness of this technique for AM components can be more effectively understood through the fact that it can remove around a 200 μm thick layer from the surface, and the surface roughness can be decreased to below 0.1 μm under optimised experimental conditions (Rotty et al., 2017).

Despite all the above stated promising results, electropolishing is still limited by the inevitable need to maintain proximity between the anode and cathode. In the case of AM components, different optimum electropolishing conditions should be maintained for inner and outer parts which makes this technique a little impractical. Moreover, it is difficult to remove byproducts from hidden parts through stirring (Goulet et al., 2019). So, still, research is ongoing to develop new optimised experiments to achieve better results, especially for the inner parts of AM components. However, the customised electropolishing for the inner surfaces of AM components, can be achieved by up to 77% surface roughness improvement with minimal thickness loss, enhancing both the internal and external quality (Fayazfar et al., 2021; Zaki et al., 2022), and also some research is exploring alternating chemopolishing and electropolishing for improved surface finishing of the inner parts of AM components, aiming for optimal results in challenging environments (Sanchez et al., 2022; Dillard et al., 2022).

6. Conclusion and future perspectives

The fundamental mechanism and theories of electropolishing are reviewed in detail. After discussing the currently available theories, it can be concluded that the understanding of the electropolishing process is still limited due to the different reactions associated with the process. The factors which influence the electropolishing of stainless steel were discussed and reviewed in detail. The traditional electropolishing technique generally uses acids as electrolytes which corrode the electrolytic bath in the long run and are also considered harmful for the environment. To solve these issues, new techniques have been developed like electropolishing by using eutectic solvents and plasma electrolytic polishing techniques.

Despite the wide usage of electropolishing techniques in the industry, still, this technique should be improved to obtain better results. This technique should be modified to remove material from the internal parts of additively manufactured components. Even improvements are also needed for materials at the nanoscale because this technique is still limited to the thickness of a few microns. Electropolishing is also used for biomedical implants. But only a few reports are available in the literature that discuss the effect of electropolishing on the bioactivity of these implants after polishing. This field should be properly explored so that this technique can be widely used to polish the stainless steel surfaces used in biomedical applications. As discussed, the microstructure of the workpiece also influences the end product of electropolishing but only a few reports are available in the literature, so, this aspect can be explored in the future.

Note of contributors

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