International Journal of Scientific World, *10 (1) (2024) 5-9*

International Journal of Scientific World

Website: www.sciencepubco.com/index.php/IJSW

Research paper

Comparative study of surface roughness between electropolishing process and traditional sanding for low carbon steel

Tobias Eduardo Schmitzhaus [1] *, Matheus Do Nascimento Ângelo Cristaldo [1], Wagner Cristiano Schmitzhaus [1]

[1] *Department of Metallurgy, Federal Institute of Mato Grosso do Sul, Corumbá, Brazil*
**Corresponding author E-mail: tobias.schmitzhaus@ifms.edu.br*

Abstract

Steel is a versatile material utilized across various sectors, encompassing both industrial and decorative applications. AISI (American Iron and Steel Institute) 1005 steel, recognized for its low carbon content (approximately 0.05% carbon), is commonly referred to as mild steel and finds extensive use in society. This study aims to investigate the influence of electropolishing parameters, specifically current density, and time, on the surface roughness of steel. The methodology involved the preparation of samples for electropolishing tests, systematic variation of the parameters, and subsequent analysis of the resulting surface finish through roughness measurements. Samples subjected to higher current densities for shorter durations exhibited substantial reductions in roughness, while longer durations resulted in minimal or negligible changes in roughness regardless of the current density employed. This comparative analysis between electropolishing and traditional sanding techniques provides valuable insights into optimizing surface finishing processes for low carbon steel applications.

Keywords: *AISI 1005 Steel; Electropolishing; Roughness.*

1. Introduction

The pursuit of achieving optimal surface finish characteristics in metallurgical industries has been ongoing for many years. This quest is driven by the desire to enhance the visual appeal, functionality, and longevity of metal products across diverse applications. Key attributes sought in surface finishing include brightness, low roughness, and heightened corrosion resistance. However, traditional methods such as mechanical polishing have demonstrated limitations over time, notably in their ability to adequately address surface imperfections while also minimizing residual stresses.

Mechanical polishing, while effective in certain respects, often falls short in achieving the desired surface quality due to its tendency to ob-scure defects and induce compressive residual stresses. These residual stresses can weaken the material and make it more susceptible to corrosion and other environmental factors, thereby compromising the integrity and durability of metal components [1], [2].

In the early 20th century, significant advancements in surface finishing techniques were achieved through the discovery and development of electropolishing. Experimental evidence demonstrated that immersion of certain metals in an electrolytic solution subjected to controlled potential and electric current could lead to substantial improvements in surface finish. This breakthrough paved the way for the widespread adoption of electropolishing, a process characterized by the electrochemical dissolution of material from exposed metal surfaces. Unlike traditional mechanical polishing, which involves material deposition, electropolishing removes material from the surface, resulting in smoother, more uniform finishes [3].

The effectiveness of electropolishing is affected by factors such as polishing current, electrolyte temperature, polishing duration, surface preparation, and agitation or stirring of the electrolyte, which helps to remove products and bubbles from the anode. The cathode area should exceed the anode area for optimal polishing rates, with stirring or rotation of the specimen enhancing the reaction rate due to the diffusion-controlled nature of the electropolishing process. Stirring or utilizing a rotating disk electrode helps maintain a stable temperature and uni-form electrolyte composition, preventing the accumulation of corrosion products on the work piece surface. Hydrodynamics of the electro-lyte are crucial in the diffusion control process of electropolishing, as the transfer of reactants to the bulk solution dictates the process rate. These parameters play a crucial role in determining the extent of material removal and the resulting surface quality. Electropolishing has emerged as a preferred method for achieving superior surface finishes in metals, offering benefits such as enhanced shine, increased corro-sion resistance, and stress relief. Additionally, electropolishing ensures chemical cleanliness by removing surface impurities, further enhanc-ing the material's overall quality and performance [4].

The surface roughness observed during electropolishing is heavily influenced by the stability of the film created during the initial phase of the process. Crevices and indentations on the metal surface typically necessitate higher current densities to achieve uniform polishing. Throughout the electropolishing process, a layer of corrosion products develops on the metal surface, exhibiting greater viscosity compared to the surrounding bulk fluid. This layer's thickness varies across the anode surface, with deeper crevices exhibiting greater thickness due to higher current density. The process of leveling peaks and crevices on a rough surface follows a sequential pattern, with most peaks dissolv-ing in all directions while crevices preferentially dissolve in one direction. Diffusion during electropolishing occurs more rapidly at peaks than in crevices. To prevent unwanted selective etching once a uniform surface is attained, optimization of electropolishing conditions is essential [3].

Steel, as a fundamental product of the metallurgical industry, finds extensive use across numerous sectors, including architecture, automotive, masonry, and decorative arts. Its versatility and durability make it a preferred choice for a wide range of applications, where both aesthetic appeal and structural integrity are paramount. Electropolishing has proven to be particularly effective in enhancing the surface finish of steel, contributing to its widespread adoption in various industries [5], [6].

Despite the prevalence of electropolishing, studies focusing on conventional steels, particularly low-carbon variants such as AISI 1005, remain relatively limited. Therefore, there is a need for further research to explore the behavior of carbon steel when subjected to electropolishing. This study aims to address this gap by investigating the reduction of roughness in AISI 1005 steel through the electropolishing process, while varying current density and time parameters.

Specific objectives of this study include optimizing current density and time parameters of electropolishing to achieve the lowest roughness of the samples. Furthermore, the study aims to compare the electropolishing results of steel with typical roughness values obtained using various grit sizes of aluminum oxide water sandpapers. By accomplishing these objectives, this research seeks to contribute valuable insights into the effectiveness and efficiency of electropolishing as a surface finishing technique for carbon steel. Additionally, the study aims to explore the underlying mechanisms of electropolishing at a microstructural level, providing a deeper understanding of the interactions between the electrolytic solution, metal surface, and applied electrical parameters. Through these efforts, this research endeavors to advance surface finishing techniques for carbon steel, with potential implications for a wide range of industrial applications.

2. Materials and methods

The experimental procedure was performed in the Materials and Metallurgy Laboratory of the Federal Institute of Mato Grosso do Sul in Corumbá/Brazil. The methods were summarized in the flowsheet displayed in Figure 1.

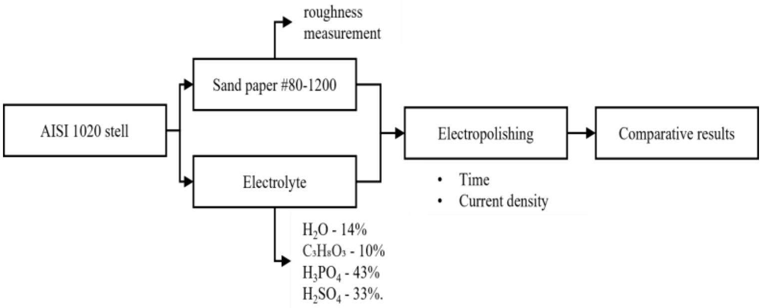

Fig. 1: Flowsheet of the Experimental Procedure.

2.1. Sample preparation

To prepare the samples for testing, the AISI 1005 steel sheet, located in the Metallurgy Laboratory (LAMET) at IFMS, underwent several steps. Chemical compositions were determined by optical emission spectrometry (Anacom moldel B2 advanced) and it is presented in Table 1. Initially, the sheet was marked and sized into 2.5cm x 2.5cm squares using a pencil and ruler for subsequent cutting. The cutting process was carried out using a manual saw. After cutting, the samples were filed to remove any remaining burrs, ensuring smooth edges for the subsequent sanding process. Following filing, the samples underwent sanding using grits ranging from P80 to P1200. A subset of the sam-ples was mechanically polished after sanding up to P1200 using velvet and alumina (1μ). Subsequently, the roughness of the samples was measured.

Table 1: Chemical Composition of Steel Obtained from Optical Emission Spectrometry

C (wt%)	Mn	Si	P	S	Fe
0.042	0.23	0.023	0.0088	0.0130	balance

2.2. Electrolyte preparation

Before conducting the Electropolishing tests, an electrolytic solution suitable for carbon steels was prepared according to the ASM Handbook Metallography (1985) [6]. The solution, with a total volume of 300 mL, consisted of the following reagents in the specified proportions: H2O (14%), glycerol (10%), phosphoric acid (H3PO4 (85%) – 43%), and sulfuric acid (H2SO4 – 33%). Sulfuric acid was added last during the solution preparation process to prevent glycerol oxidation, following the guidelines of the ASM Handbook Metallography (1985). To assist in solution preparation, four beakers (50 mL, two of 100 mL, and one of 250 mL), a funnel, and a volumetric flask with a capacity of 500 mL were used.

2.3. Electropolishing

All tests were conducted with samples sanded up to #220 grit, in triplicate. Electrical circuit/apparatus for electropolishing was assembled Figure 2(a), where the power source provided the electrical current, and the multimeter functioned to set and visualize the electric current supplied to the system. The anode and cathode were submerged in the electrolytic solution inside the beaker, which was subjected to magnetic stirring at scale 2 (as indicated by the stirrer marking) and heated to 38°C, as instructed ASM Handbook Metallography (1985) [6]. Figure 2(b) illustrates the real assembled apparatus.

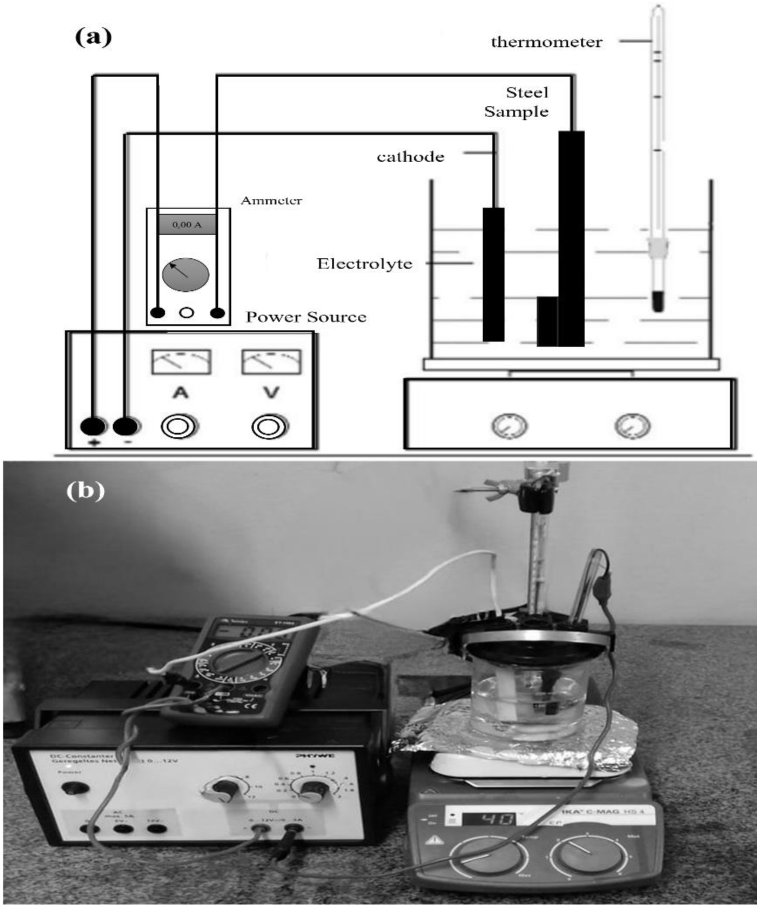

Fig. 2: (A) Schematic Apparatus Used to Perform Electropolishing. (B) Real Apparatus Used in Electropolishing Tests.

Two parameters were systematically varied in the process: electric current density and time. When considering the variation of electric current density, particular attention was given to the gas evolution mechanism. The aim was to select current densities that would result in min-imal gas evolution while ensuring an efficient material removal rate. Consequently, two current densities were chosen along with two corre-sponding time durations: 0.25 and 0.5 A/cm², 10 and 20 minutes, respectively. This resulted in a total of four electropolishing parameters.

Prior to and following the tests in the ultrasonic washer, the samples were thoroughly washed with 96% alcohol and subsequently dried using a domestic dryer.

2.4. Roughness measurements

Surface roughness measurements were conducted both before and after the electropolishing process using an Rugosimeter 400 TR.200 DIGIMESS, as figure 3 shows.

Fig. 3: Rugosimeter 400 Tr.200 Digimess.

To perform the measurements, the samples were placed on a clean and level marble bench. The roughness tester was positioned so that the probe was within the usable area of the sample.

The roughness tester operated with measurements in the micrometer (µm) magnitude and according to the following parameters:
LTH (Cut-off): 0.80mm;
STD (Regulatory standard): ISO;
FIL (Filter): RC;
RAN (Measurement range configuration mode): ±40µm.

3. Results and discussion

The division of the electropolishing parameters was carried out and named as follows: A2520 (250 mA/cm2 - 20min); A2510 (250 mA/cm2 - 10min); A5020 (500 mA/cm2 - 20min); A5010 (50 mA/cm2 - 10min). All tests were plotted on a graph of sandpaper grit versus roughness, which can be seen in Figure 4. The assessment of the electropolishing efficiency was conducted by comparing the typical roughness of samples sanded with various grit sizes against the final roughness of the polished samples.

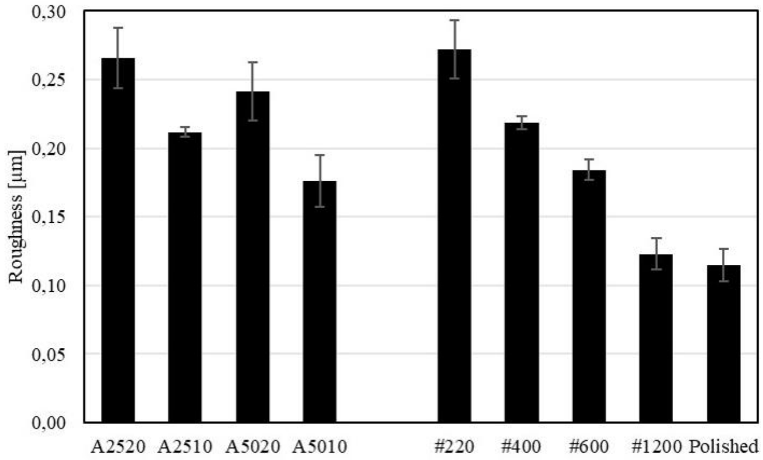

Fig. 4: Roughness and Standard Deviation of All Tested Parameters.

The electropolishing procedure encompasses two distinct processes: anodic leveling and anodic brightening. The reduction in surface roughness of the samples is attributed to the anodic leveling process, which occurs during the initial stage of electropolishing. The anodic leveling process results in varying rates of material dissolution between the peaks and valleys. According to the theory of viscous layers (Jasquet's Theory) [7], dissolution rates and mass transport rates are higher at the peaks compared to the valleys. These differences are attributed to the disparity in current density between the peaks and valleys, with higher current density observed at the peaks [3], as depicted in Figure 5.

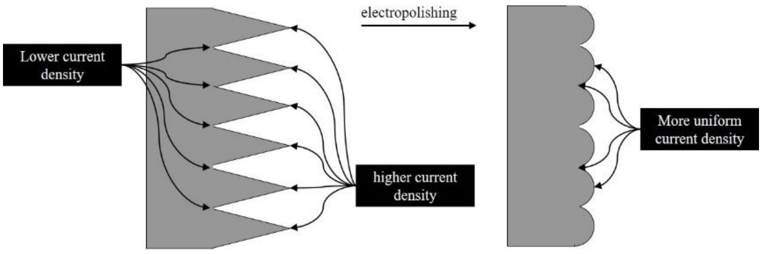

Fig 5: The Illustration of Anodic Leveling Process.

The anodic leveling process is initiated by the presence of surface irregularities on the workpiece, evident at the macroscopic level through the presence of valleys and peaks [8]. Figure 4 shows that two out of the four parameters utilized exhibited a significant reduction in roughness (A2510 and A5010), reaching a roughness comparable to that obtained with a P600 sandpaper (A5010). These parameters share the same electropolishing time, indicating an advantage in electropolishing for 10 minutes instead of 20.

The visual aspect (brightness) was qualitatively evaluated through photographic records, where the electropolished samples generally exhib-ited the same characteristic, with the electropolished region appearing dull, showing no significant differences with changes in operational parameters. Figure 6 below illustrates the characteristics before and after electropolishing.

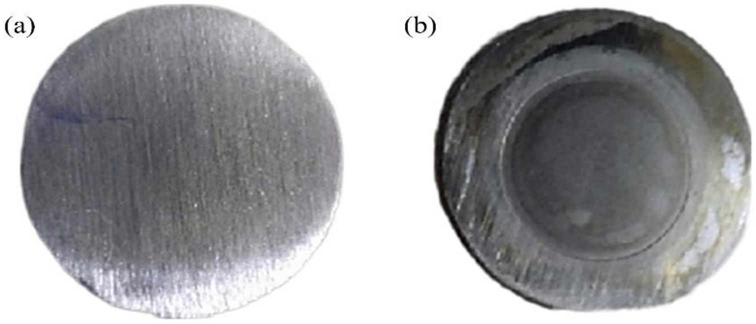

Fig 6: (A) Sample Sanded with P220. (B) Electropolished Sample A5010.

Any of the electropolished samples has a bright surface (Figure 15), the electropolishing process just undergone in anodic leveling step and it is not turn into anodic brightening. The anodic brightening process takes place when microscopic irregularities are present in the valleys and peaks of the surface and the process can mitigate it [9].

Regarding about samples A2520 and A5020, showed little to no reduction in roughness compared to their initial state (sanded with P220). This result suggests that times exceeding 10 minutes do not promote significant improvement in surface finish (reduction in roughness) and may compromise brightness. Additionally, there is a considerable standard deviation in all tests except for parameter two, indicating limited repeatability of the process across all energy source conditions, temperature control, agitation, and solution composition.

This behavior may be caused by a challenge associated with continuous DC electropolishing, that is the uneven removal of anodic metal from the surface, resulting in a rougher surface texture. This occurs due to the formation of a passive oxide film on the anode surface during the electropolishing process, described by the equation (1):

$$M + xH2O \rightarrow M(Ox) + 2xH+ + 2xe- \quad (1)$$

The continuous supply of DC current creates areas of high current density and low current density on the anodic surface. Over time, the oxidative film generated in high current density areas may block some sections of the anodic surface, while striping continues in unblocked areas, leading to the formation of irregular anode surfaces [3]. So, the prolonged electropolishing time (20 min) may have favored this phenomenon to occur more intensely, compromising both the roughness and the brightness of the samples. Additionally, difficulties in maintaining all operational parameters stable may have contributed to surface heterogeneities caused by O2 evolution, which can lead to pitting corrosion [5].

4. Conclusion

In conclusion, the research demonstrates that significant reductions in surface roughness were consistently achieved across varying current densities, particularly within shorter processing times, notably at 10 minutes. These reductions were noteworthy enough to match the roughness levels obtained using a #600 grit sandpaper, marking a considerable improvement over the conventional sanding process, which typically requires around 30 minutes. Specifically, electropolishing yielded equivalent roughness outcomes in just 10 minutes under A5010 parameter.

However, it was observed that at higher processing times, the reduction in surface roughness was negligible. Similarly, at higher processing times and higher current densities, the reduction in roughness was minimal, with the surface roughness levels largely remaining unchanged. Furthermore, irrespective of the processing parameters utilized, there was no discernible enhancement in the brightness of the electropolished samples.

Acknowledgement

This work was supported by the Federal Institute of Science and Technology of Mato Grosso do Sul.

References

[1] W. Han, F. Fang. Fundamental Aspects and Recent Developments in Electropolishing. International Journal of Machine Tools and Manufacture 139 (2019) 1–23. https://doi.org/10.1016/j.ijmachtools.2019.01.001.
[2] Z. Chaghazardi, R. Wüthrich. Review—Electropolishing of Additive Manufactured Metal Parts. Journal of The Electrochemical Society 169 (2022), 043510. https://doi.org/10.1149/1945-7111/ac6450.
[3] G. Yang, B. Wang, K. Tawfiq, H Wei, S. Zhou, G. Chen. Electropolishing of Surfaces: Theory and Applications. Surface Engineering 33 (2017), 149–166. https://doi.org/10.1080/02670844.2016.1198452.
[4] D. Landolt. Fundamental Aspects of Electropolishing. Electrochimica Acta 32 (1987) 1–11. https://doi.org/10.1016/0013-4686(87)87001-9.
[5] S.D. Cramer, B.S. Covino. Metals Handbook: Corrosion- Fundamentals, Testing and Prevention; ASM International, California, 2003. https://doi.org/10.31399/asm.hb.v13a.9781627081825.
[6] J. Newby. Metals Handbook: Metallography and Microstructures; ASM International, United States of America, 1985.
[7] P.A. Jacquet. On the Anodic Behavior of Copper in Aqueous Solutions of Orthophosphoric Acid. Transactions of The Electrochemical Society 69 (1936) 629. https://doi.org/10.1149/1.3498234.
[8] E. Pujiyulianto, S. Suyitno. The Effect of Electropolishing Time Variation at Room Temperature and Low Voltage on the Surface Quality of Cardiovascular Stent. Advanced Materials Research 1154 (2019) 91–101. https://doi.org/10.4028/www.scientific.net/AMR.1154.91.
[9] B. Chatterjee. Science and Industry of Electropolishing. Jahrbuch Oberflachen technik 71 (2015) 71–93.