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Research on the Plasma Electrolytic Polishing Formulas for Stainless Steel

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Abstract

Plasma Electrolytic Polishing (PEP) technology offers advantages such as stress-free processing, high polishing quality, and improved surface corrosion resistance. The electrolyte composition for PEP is particularly important as it affects the quality of PEP, including glossiness and surface roughness. Different materials require different electrolyte formulations. Stainless steel is widely used in Taiwan; therefore, this research discusses the PEP technology for stainless steel. Ammonium sulfate is a common electrolyte formulation for stainless steel. However, to improve the quality of PEP, additional components can be added to ammonium sulfate. This study investigates the effects of different additives. Seven additives were individually added to ammonium sulfate to prepare the PEP electrolyte, and then 316L stainless steel specimens were polished. During the PEP process, information such as current, specimen size, and surface roughness (Ra) was recorded. The results indicated that the electrolyte with the addition of Salt-A, Organic Acid, or Inorganic Acid exhibited the best polishing effect.

1 Introduction

Plasma electrolytic polishing (PEP) is an innovative processing technique that combines plasma technology with electrochemical surface processing. Compared to traditional mechanical polishing methods, PEP offers several

advantages, including being stress-free, providing high quality, having fewer restrictions on the shape of workpieces, and improving surface corrosion resistance [1]. During the PEP process, the workpiece is immersed in a polishing solution at a specific temperature and concentration. During the polishing process, the electrolysis reaction occurs first, causing an instantaneous short circuit due to the direct contact between the workpiece and the polishing solution. During the short-circuit process, a large amount of heat is released, causing the polishing solution on the surface of the workpiece to vaporize instantly and form a vapor layer primarily composed of steam. This vapor layer completely separates the workpiece from the polishing solution. The presence of the vapor layer greatly increases the resistance between the anodic (workpiece) and the polishing solution, creating localized high voltage. Breakdown occurs within the vapor layer, leading to ionization and discharge, which locally forms discharge channels and generates plasma. This results in intense and complex physical and chemical reaction between the metal surface and the vapor layer, leading to the simultaneous formation of reaction products and their removal. A microscopic perspective on workpiece surface, the projections have more chances to form discharge channels, resulting in a reduction in surface roughness [2-5].

In the domestic market, the development of PEP technology is still in its infancy, and there is still room for technical advancement in materials like stainless steel, titanium alloys, and nickel-based alloys. Among these, stainless steel is widely used in various industries in the country, therefore, this study prioritizes the exploration of PEP technology for stainless steel. The composition of the electrolyte plays a crucial role in the success of the PEP process. The composition of the electrolyte can significantly impact factors such as glossiness and surface smoothness. Currently, ammonium sulfate is the most common composition for stainless steel. However, to further improve the quality of PEP, additional components can be added to the ammonium sulfate solution. Therefore, this study aims to investigate the effects of different additives on the electrolyte's polishing performance.

2 Experiment

The research process is illustrated in Figure 1. The polishing was conducted using 316L stainless steel specimens with dimensions of 30 mm × 50 mm, which were chosen to facilitate measurements of gloss and surface roughness.

To demonstrate the effects of different electrolyte components on PEP, the specimens were roughened with sandpaper to achieve a surface roughness of Ra 1.5 ± 0.1 μm. The appearance of the specimens after roughening is shown in Figure 2.

An aqueous solution of ammonium sulfate was prepared, and seven different additives were added to the solution respectively. The electrolyte was then heated to 90°C and placed in a beaker. A cathode plate was inserted, and the 316L stainless steel specimens were fixed to the anode clamp. The power supply was turned on, and the voltage was set to 330 V. The 316L stainless steel specimens were immersed in the electrolyte in the beaker, and the reaction was allowed to proceed for 10 minutes. Upon completion of the PEP reaction, the 316L stainless steel specimens are removed from the beaker, rinsed with tap water, and dried using an air gun before further measurements.

The length of the specimens was measured before and after polishing, and the size reduction rate was calculated using Equation 1. A gloss meter (3nh, YG268, China) was used to measure the gloss, and the gloss data measured using a 20° light source was recorded. Surface roughness (Ra) values were measured using a surface roughness tester (ACCRETECH, Handysurf E-35A, Japan), with 8 points measured on each specimen. The surface roughness reduction rate was calculated using Equation 2.

$$\text{size reduction rate } (\%) = 100 - \left(\frac{length_{(after\ polishing)}}{length_{(before\ polishing)}} \times 100\right) \quad (1)$$

$$\text{surface roughness (Ra) reduction rate } (\%) = \left(\frac{Ra_{(before\ polishing)} - Ra_{(after\ polishing)}}{Ra_{(before\ polishing)}} \times 100\right) \quad (2)$$

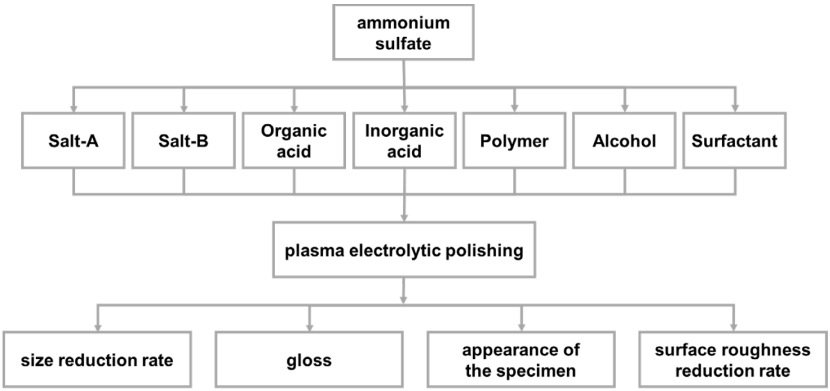

Figure 1: *Research architecture diagram*



Figure 2: *The 316L stainless steel specimen before polishing*

3 Results and Discussion

Seven different additives, including Salt-A, Salt-B, Organic Acid, Inorganic Acid, Polymer, Alcohol, and Surfactant, were individually added to the ammonium sulfate electrolyte, and the 316L stainless steel specimens underwent PEP. The results showed that all conditions were able to make the surface smoother and to improve gloss, with polishing current density ranging from 0.07 to 0.30 A/cm².

The size reduction rate calculated from the difference in length of the stainless steel specimens before and after polishing is shown in Figure 3. The results indicate that PEP with the addition of Salt-B, Organic Acid, and Inorganic Acid to the electrolyte resulted in higher size reduction rates of 0.09%, 0.09%, and

0.10%, respectively. This suggests that the inclusion of these three additives in the electrolyte results in a greater quantity of material removal. This could be due to the PEP process that the surface of the stainless-steel specimen (anode) oxidizes, and it leads to the formation of an oxide film. The anions of Salt-B have a stronger corrosive effect on the oxide layer, thereby enhancing the material removal quantity. Additionally, the inclusion of Organic Acid or Inorganic Acid in the electrolyte, which lowers the pH, can facilitate the formation of oxides. Consequently, the addition of Salt-B, Organic Acid, and Inorganic Acid to the electrolyte facilitates the oxide formation and removal processes during PEP, leading to a higher quantity of material removal.

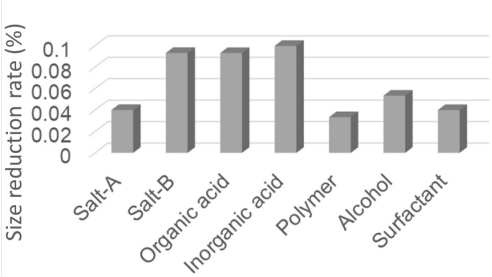

Figure 3: *Size reduction rates of 316L stainless steel specimens after PEP using ammonium sulfate electrolytes with the addition of seven different additives respectively.*

Figure 4 shows the gloss measurements of 316L stainless steel specimens after PEP using ammonium sulfate electrolytes with the addition of seven different additives. The gloss was measured using a 20° light source, as metallic polished specimens are high-gloss materials, using the 20° light source suitable for this measurement. The results reveal that after PEP with the addition of Salt-A, Organic Acid, and Inorganic Acid to the ammonium sulfate electrolyte, the specimens exhibited higher gloss values of 523 GU, 535 GU, and 493 GU, respectively. In contrast, when Surfactant was added to the ammonium sulfate electrolyte and used for PEP of 316L stainless steel specimens, the gloss was significantly lower, with a gloss value of only 143 GU.

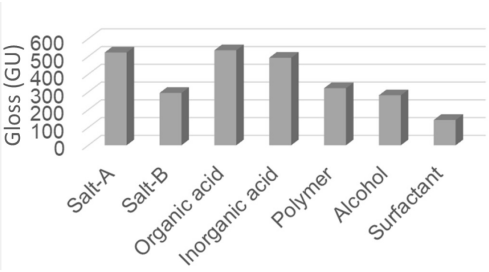

Figure 4: *Gloss of 316L stainless steel specimens after PEP using ammonium sulfate electrolytes with the addition of seven different additives respectively.*

Figure 5 shows the photos of 316L stainless steel specimens after PEP using ammonium sulfate electrolytes with the addition of seven different additives. It can be observed that all 316L stainless steel specimens became significantly brighter and smoother after polishing with the various electrolytes. Among them, the electrolyte containing Salt-A exhibited the best polishing effect, followed by those containing Organic Acid and Inorganic Acid.

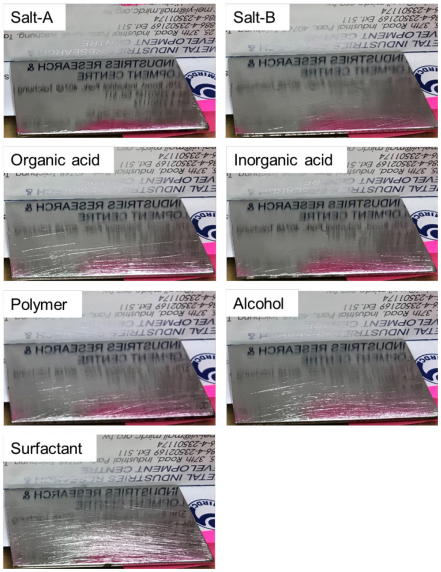

Figure 5: *Photos of 316L stainless steel specimens after PEP using ammonium sulfate electrolytes with the addition of seven different additives respectively.*

Figure 6 shows the surface roughness (Ra) reduction rates of 316L stainless steel specimens after PEP using ammonium sulfate electrolytes with the addition of seven different additives. The results indicate that the surface roughness (Ra) reduction rates for all conditions were greater than 50%. Among them, the addition of Salt-A resulted in the most significant reduction in surface roughness, achieving a surface roughness reduction rate of 74.9%, with a surface roughness of Ra 0.24 μm.

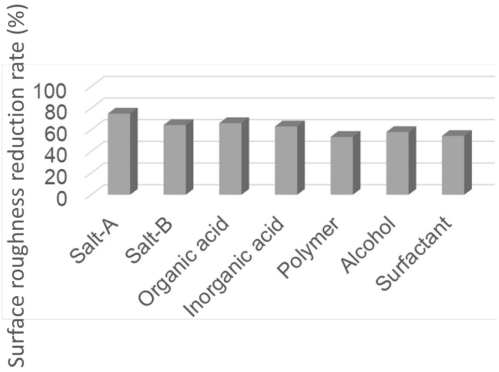

Figure 6: *Surface roughness (Ra) reduction rate of 316L stainless steel specimens after PEP using ammonium sulfate electrolytes with the addition of seven different additives respectively.*

4 Conclusion

Using Salt-A as an additive in the ammonium sulfate electrolyte for PEP of 316L stainless steel, the polished specimens exhibited good glossiness; however, the material removal quantity was relatively low. This electrolyte is suitable for PEP polishing of workpieces that require high precision and high gloss. On the other hand, when Organic Acid or Inorganic Acid is used as additives in the ammonium sulfate electrolyte for PEP of 316L stainless steel, the polished stainless steel specimens exhibited both good glossiness and a higher material removal quantity. Therefore, these two electrolytes can be used on workpieces with poor initial surface roughness and are applicable to the polishing of workpieces that are difficult to sand in advance of the surface treatment stage.

This study focused on adjusting the composition of the PEP electrolyte for 300 series stainless steels, and it can be used to satisfy the requirements for surface smoothness and gloss enhancement of different 316L stainless steel workpieces, and to achieve the industry's improving demands for the polishing quality of 316L stainless steel workpieces.

Literature

[1] Belkin PN, Kusmanov SA, Parfenov EV. Mechanism and technological opportunity of plasma electrolytic polishing of metals and alloys surfaces. Applied Surface Science Advances 1:100016, 2020.

[2] Sergey V. Zakharov, Mikhail T. Korotkikh, Electrolyte-Plasma Polishing Ionization Model. Advances in Mechanical Engineering Lecture Notes in Mechanical Engineering LNME:193-208, 2020.

[3] Cornelsen M, Deutsch C, Seitz H. Electrolytic plasma polishing of pipe inner surfaces. Metals 8(1):1–12, 2017.

[4] Wang J, Suo LC, Guan LL, Fu YL. Analytical study on mechanism of electrolysis and plasma polishing. Advanced Materials Research 472-475:350–353, 2012.

[5] Zeidler H, Böttger T, Schröder S, Schneider M, Lämmel C, Sahr F, Tardelli J, Exbrayat L. Analysis of Plasma-Electrolytic Polishing Process Initiation. Procedia CIRP 108:782–786, 2022.