Mechanism Study and Parameter Optimization of A356 Aluminum Alloy 
Electrochemical Polishing

Ehsan SaebNoori¹, Ali Navidinejad¹, Amin Rabiei Baboukani¹
1 Advanced Materials Research Centre, Department of Materials Engineering, Najafabad Branch, Islamic Azad University, P.O.Box 517, Isfahan, Iran

Abstract: The aim of the present study was to find a good method for electropolishing A356 Aluminum alloy. Consideration of the fundamental current density-voltage relation and limiting current density has made it possible to identify an optimum applied voltage for good electropolishing through variation of different parameters (electrolyte, bath temperature, electrode distance, surface roughness before polishing, cathode material, etc.). A mixture of water, perchloric acid and ethanol with different ratio were used as the electropolishing solutions. The electropolished surfaces have been investigated by various electrochemical and morphological techniques, including scanning electron microscope (SEM), atomic force microscope (AFM), roughness measurement and potentiostatic polarization test. The significant findings of the present study are that electropolishing can also improve the corrosion resistance as well as the smoothness.

Keywords: “electropolishing”, “Smoothness”, “corrosion resistance”.

Introduction
Mechanical polishing is a traditional methods to improve the surface quality in metals and alloys. Mechanical polishing is a time-consuming and multi-stage technique to reduce roughness and brightness. The accuracy of this method is low [1]. Parts that have complex geometric shapes, always faced with the problem of non-uniformity surfaces. Electropolishing is a good way to reduce the surface roughness and brightness due to uniformity of surface in the nanometer size for complex geometric shapes [2]. Electropolishing is a electrochemical process in which a surface with good passivation capability, reducing roughness and increase the brightness can be achieved. Electropolishing with corrosion-resistant surface, prevent the component from hydrogen cracking [3].

Electropolishing process was first developed by Madsen in 1925 [4]. The purpose of electropolishing process was enhancing the quality of the plated surface. Development electropolishing process was carried out widely by Jacquet in 1935 on copper and other metals [5]. The aim of that research was the brightness of electropolishing surface on different concentration of the electrolyte. Jin and colleagues, conducted a study on electropolishing of Niobium and examined various parameters of electropolishing on surface roughness and electropolishing speed. The results of the study showed that electropolishing created a very good surface properties and could be the perfect solution to eliminate the surface defects on the Nb sheets [6]. In research research, the electropolishing process of multiphase alloys and compounds is not well considered.

A356 Aluminium alloy is part of the casting alloys. This alloy, used widely in the space, medical, pharmaceutical, food, automotive and nuclear industry. The important reasons for using this alloy in various industries is high-molding capability, good weldability, high tensile strength and good corrosion resistance [7-11]. In some industries due to high sensitivity, in addition to the features mentioned, surface characteristics of the alloy is among the most important factors for the application. Therefore, in this study, we tried to study the behavior of the A356 aluminum alloy in the electrolyte and achieved the optimum conditions for electropolishing process.

Experimental Procedure
A356 aluminum alloy from Dubal company, 99%ethanol and methanol, 37% perchloric acid and 98% glycerol from Merck company are the materials used in this research. For Electropolishing process of aluminum alloys, samples dimensions of 1.5×9 Cm² and 2.25mm thickness was cut. Then, specimens were polished with 100 and 400 sandpapers and washed with acetone. At least, samples were transferred into the electropolishing cell. To determine the optimal concentration of perchloric acid solution containing perchloric acid/ethanol, the reaction solution was prepared at four different concentrations of perchloric acid. Preparing electrolytes is shown in Table 1. In electropolishing cell, 316L stainless steel is used as a cathode.

* Corresponding author: Tel: +98 9307257455.
E-mail address: saebnoori@pmt.iaun.ac.ir.
Table 1: Preparations of electrolyte at various percentages of perchloric acid and ethanol

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>Perchloric (%V)</th>
<th>Ethanol (%V)</th>
<th>T (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>15</td>
<td>85</td>
<td>25</td>
</tr>
<tr>
<td>S2</td>
<td>20</td>
<td>80</td>
<td>25</td>
</tr>
<tr>
<td>S3</td>
<td>25</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>S4</td>
<td>30</td>
<td>70</td>
<td>25</td>
</tr>
</tbody>
</table>

To investigate the I-V curves and corrosion tests, PARSTAT-2273 was used. To examine, electropolishing surface of samples, scanning electron microscope (SEM) LEO-VP435 model was used. To study surfaces of samples before and after electropolishing process, atomic force microscopy (AFM), DS-95-200E model were used.

Results and Discussions

Figure 1 shows the effect of different concentrations of perchloric acid in the perchloric acid - ethanol electrolyte on I-V curve. According to Figure 1, with increasing concentrations of perchloric acid, the amount of current density at the maximum point of curve in S1, S3 and S4 dropped. The highest voltage range is between 5-7.5V and it is related to S3 at a concentration of 25% perchloric acid. With increasing perchloric acid concentration up to 30%, stable current density range decreases which is similar to Nirdosh study [12]. Furthermore, as a result of increased concentrations from 25% to 30%, current density increased from 1.17 to 1.4. Table 2 summarizes the test conditions and the optimum range of current density and voltage for 25% perchloric acid. In table 2, D is distance between the electrodes and C is cathode.

<table>
<thead>
<tr>
<th>Constants</th>
<th>Electropolishing Variables</th>
<th>Voltage Range EP (V)</th>
<th>EP Current (mA/Cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T= 25°C</td>
<td>Perchloric X%</td>
<td>5-7.5</td>
<td>1.17</td>
</tr>
<tr>
<td>D=15mm</td>
<td>Ethanol X%</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>C=316L stainless steel</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2 shows I-V curve for electropolishing of aluminum alloy in 25% perchloric acid and 75% ethanol, 20mV scan rate at 25°C. Figure 3 shows SEM images of the surface of A356 aluminum alloy before and after electropolishing process in 25% perchloric acid and 75% ethanol. According to the figure, smoothness of surface after electropolishing process increased significantly. Figure 4 shows SEM micrographs of A356 aluminum alloy after electropolishing process. By applying 12V (zone 4) cavities is created on the surface. Figure 5 shows the effect of electropolishing process on the surface roughness of A356 aluminum alloys in 25% perchloric acid and 75% ethanol for four potential. According to the figure, at 6.5V, minimum surface roughness achieved. By increasing the voltage, the thickness of the adhesive layer gradually increase and the surface roughness increase again [15]. Figure 6 shows AFM image of the surface of the aluminum alloy before and after electropolishing process in perchloric acid/ethanol electrolytes for 2 min at 6.5V.
Proceedings of Iran International Aluminum Conference (IIAC2016)  
May 11-12, 2016, Tehran, I.R. Iran

Figure 3: SEM image of the surface in 25% perchloric acid and 75% ethanol for two minutes at 6.5V, a) before and b) after electropolishing process

Figure 4: SEM image of the sample after electropolishing process by applying high voltage

Figure 5: Electropolishing effect on the surface roughness of A356 aluminum alloys in 25% perchloric acid and 75% ethanol in different potential

Given previous research on electropolishing of aluminum alloy, types of sticking layer on the surface of the alloy is oxide or hydroxide [16,17]. This layer is formed during the electropolishing process and covers the entire surface of the alloy. In A356 aluminum alloy, oxide layer may be made from Al₂O₃ or Al(OH)₃ in the form of a sticky layer. Sticky layer will control the flow of metal ions during electropolishing. By reducing the thickness of the oxide layer, current density increases and mass transfer occur faster. In other words, a sticky layer is electropolishing speed controller [18].

Polarization curves for A356 aluminum alloy before and after electropolishing process in 3.5% NaCl solution is shown in figure 7. Electropolishing electrolyte is 25% perchloric acid and 75% ethanol. The electrochemical parameters of polarization curves is shown in Table 1. By comparing the polarization curves before and after electropolishing process, it can be seen that the corrosion current density of electropolishing sample after...
electropolishing decreased. This represents an increase corrosion resistance of the sample after electropolishing process.

![Figure 7: Polarization curves for A356 aluminum alloy before and after electropolishing process in 3.5% NaCl solution](image)

Table 3: Electrochemical parameters of polarization curves for A356 aluminum alloy before and after electropolishing process in 3.5% NaCl solution

<table>
<thead>
<tr>
<th>Sample</th>
<th>( E_{corr} ) (mv)</th>
<th>( I_{corr} ) (A/Cm(^2))</th>
<th>( R_{p} ) (ohm)</th>
<th>( \beta_{p} ) (mv)</th>
<th>Corrosion Rate (mpy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Electropolishing Process</td>
<td>-720</td>
<td>4.13\times10^{-7}</td>
<td>74</td>
<td>7.59</td>
<td>0.175</td>
</tr>
<tr>
<td>After Electropolishing Process</td>
<td>-700</td>
<td>3.12\times10^{-7}</td>
<td>76.22</td>
<td>17.68</td>
<td>0.132</td>
</tr>
</tbody>
</table>

**Conclusion**

1. According to I-V curves, optimum concentration of electrolyte solution for electropolishing process of A356 aluminum alloy is 25% perchloric acid and 75% ethanol.
2. Stable range of voltage and current density for the electrolyte was measured 4.5-7V and 1.08mA/Cm\(^2\), respectively.
3. AFM results showed that the electropolishing process improve the smoothness of surface and surface roughness decreased from 500nm to 140nm.
4. SEM images showed that electropolishing process of A356 aluminum alloy in 25% perchloric acid and 75% ethanol improves the surface quality.
5. Polarization curves of the A356 aluminum alloy before and after electropolishing process in 3.5% NaCl solution showed that electropolishing process improve the corrosion resistance.

**References**