Investigation of Electrochemical Corrosion Behaviour of 6082 Aluminum Alloy under Simulated Deicing Agent Conditions

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Abstract. In this study, the aluminum alloy of 6082 with different treatment processes (T1 and T6) was tested in simulated artificial deicing agent solution. The polarization curves show that the alloy suffered from pitting attack, the corrosion resistance of extruded sample (T1) is lower than that of forged sample (T6) in the same medium solution. With the increase of chloride ion concentration, the corrosion current density of T1 and T6 samples increased, the maximum corrosion depth increased, and the corrosion resistance of alloy samples decreased. The morphology on the polarized alloys show that the the surface of T1 sample revealed a higher number of pits. And the difference of corrosion resistance between T1 and T6 is closely related to the difference of microstructure.

1. Introduction
6082 aluminum alloy is widely used in automobile industry because of its low density, good formability and good corrosion resistance [1]. Although 6082 aluminum alloy has good corrosion resistance in most cases, it is easy to suffer pitting or intergranular corrosion when exposed to halogen ion environment for a long time, especially in Cl⁻ environment [2]. It is accept that pitting corrosion is one of the most common corrosion types of aluminum alloy, which is easily converted into intergranular corrosion in corrosive environment. Intergranular corrosion seriously reduces the binding ability between grains, which leads to the acute fracture of aluminum alloy members [3].

The use of deicing agent is one of the most common and effective methods to deal with road ice and snow problems in northern China. Deicing agents, chlorine containing compounds, are widely used in snow removal due to their low cost and high efficiency [4]. The main component of deicing agent is sodium chloride (NaCl), and its dosage varies with the amount of snowfall. The automobile is easy to be corroded when it runs in the snow water containing NaCl for a long time, especially the wheel hub, steering knuckle and chassis made of aluminum alloy.

A lot of study has been focused on the effect of Cl⁻ on the corrosion of aluminum alloys [5-7]. But minimal study was performed about corrosion behavior of 6082 aluminum alloy in the environment of deicing agent. In this study, the corrosion behavior of 6082 aluminum alloy was investigated in artificial deicing solution using potentiodynamic polarization technique.

2. Experimental Methods
Samples for the polarization curves were prepared by the following procedures : (i) the AA6082 samples with T1 (extrusion) and T6 (extruded and then forged) were cut into plates with a diameter of 14mm and thickness of 3mm (±0.5mm); (ii) they were sequentially grounded with 600#, 1000# and 2000# waterproof abrasive papers; (iii) the samples were polished with WJL-02B type silica suspension about10 minutes, until there was no obvious scratch on the surface of the samples; (iv) the
samples were dried with cold air and then put in the sealed bags. We also have prepared two kinds of sodium chloride solutions with different mass fractions (0.8% and 1.5%) to simulate the deicing agent solution.

The polarization curves were tested by ZAHMER electrochemical workstation using the triple-electrode system. The working electrode was AA6082 T1 and T6 sample. The chemical compositions of working electrodes were listed in Table 1. The auxiliary and reference electrodes are platinum sheet and saturated calomel electrode (SCE), respectively. The scanning range of the polarization curve was -3V to 3V of the open potential relative to the working electrode, and the scanning rate was 3mV/s. The electrochemical impedance spectroscopy was measured under open circuit potential (OCP), and the sinusoidal wave was used as the excitation signal with the frequency range of 10 mHz-100 kHz. The measured data were analyzed by ZMAN2.0 software. In addition, SEM (Model JEOL JSM-6510 LA) was applied to observe and analyse the corrosion morphologies after the test.

| Table 1. Chemical compositions of AA6082 aluminum alloy (wt.%) |
|-----------------|-------|------|-----|-----|-------|------|------|-----|-----|
| Si   | Fe   | Cu   | Mn  | Mg  | Cr    | Ti   | Zn   | Ni  | Al  |
| 1.04 | 0.27 | 0.064| 0.617| 0.72 | 0.13  | 0.02 | 0.03 | 0.007| Bal |

3. Results and Discussion

3.1. The Analysis of Polarization Curves

Figure 1 shows anodic polarization of 6082 alloys. In A-B interval, the active current of aluminum alloy increases when increasing the aluminum alloy electrode potential. In the B-C interval, the electrode potential gradually increases, while the current density basically remain unchanged or even slightly reduced. This interval is the passivation interval of the aluminum alloy. At this time, a water-soluble passivation film (Al₂O₃·H₂O) was formed on the surface of aluminum alloy. The equation of electrochemical reaction [8] is as follows:

\[
\begin{align*}
\text{Al} + \text{H}_2\text{O} & \rightarrow \text{AlOH} + \text{H}^+ + e^- \quad (1) \\
\text{AlOH} + \text{H}_2\text{O} & \rightarrow \text{Al(OH)}_2 + \text{H}^+ + e^- \quad (2) \\
\text{Al(OH)}_2 & \rightarrow \text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O} + \text{H}^+ + e^- \quad (3)
\end{align*}
\]

Figure 1. Anodic polarization curves of 6082 alloys

This layer of passivation film has great resistance, which has a huge baffle on the further corrosion of aluminum alloy. However, with the further increase of the electrode potential, the passivation film starts to pitting the parts in the vicinity of the C point, because of the strong permeability of the chloride ions. The electrochemical reaction equation [9] was as follows:

\[
\begin{align*}
\text{AlOH} + \text{Cl}^- & \rightarrow \text{AlOCl} + e^- \quad (4) \\
\text{AlOCl} + \text{Cl}^- & \rightarrow \text{AlOCl}_2 + e^- \quad (5)
\end{align*}
\]
The energy dispersive spectrometer (EDS) analysis of the electrochemical corrosion surface of the T6 sample showed that the contents of oxygen and aluminum elements were as high as 6.45% and 92.05%, which indicated the existence of the passivation film (Al₂O₃·H₂O) on the surface of working electrode.

As can be seen from Figure 1, the polarization curves of T6 and T1 samples show the same change rule with the increase of sodium chloride concentration in the solution. Table 2 shows the fitting results of polarization curve. For the same sample, the natural corrosion potential (E_{corr}) fluctuates with the increase of NaCl solubility. However, when the sample is in the same corrosive medium, the E_{corr} of T6 sample is more positive than that of T1. When the concentration of corrosion medium is constant, the E_{corr} of T6 sample is far less than that of T1. The E_{corr} of the same sample increases with the increase of sodium chloride solubility. The E_{corr} represents the thermodynamic process of electrode reaction, while the I_{corr} represents the kinetic process. This is, the I_{corr} is an important parameter in evaluating the corrosion resistance of the materials. The smaller I_{corr} implies the better the corrosion resistance of the materials [10]. According to the data in Table 2, It is concluded that the corrosion resistance of T6 sample is obviously better than that of T1, when the mass fraction of sodium chloride is certain. While the I_{corr} increases with the raise of the mass fraction sodium chloride at the same process conditions, the corrosion resistance of AA6082 is weakened.

| Samples         | E_{corr}(V) | I_{corr}(µA/cm²) |
|-----------------|-------------|-----------------|
| T6(0.8wt% NaCl) | -1.26       | 56.45           |
| T1(0.8wt% NaCl) | -1.33       | 76.33           |
| T6(1.5wt% NaCl) | -1.27       | 84.58           |
| T1(1.5wt% NaCl) | -1.32       | 101.25          |

3.2. SEM Image Analysis of 6082 Aluminum Alloy

Figure 2 shows the corrosion morphology of T6 and T1 samples in different concentrations of sodium chloride solution. When the concentration of corrosive medium is constant, the number and size of pitting pits on the surface of T1 sample are larger, indicating that the pitting sensitivity of T1 sample is stronger, which is consistent with the test results of polarization curve. With the increase of NaCl concentration, the pitting corrosion of T6 and T1 samples is more serious, indicating that chloride ion concentration plays an important role in the corrosion of aluminum alloy, which is consistent with previous studies [6-10].

Figure 3 shows the cross-section corrosion morphology of T6 and T1 samples in different concentrations of sodium chloride solution. It can be seen from the figures that the corrosion crack trend of T6 and T1 samples is obviously different. This is related to the treatment process of the sample. The flow lines of T6 sample after forging surround all the initial crystalline α-Al matrix in the form of curve, but the extrusion streamline of T1 sample is arranged in a straight line along the vertical direction. The difference of microstructure results in the difference of corrosion morphology. Further observation on the cross-section morphology of T1 sample shows that the corrosion is basically along the extrusion streamline, that is to say, the initial crystallization of α-Al in T1 sample is always in active corrosion state, resulting in high current density on the surface of sample. As shown in Figure 3, the main channel of intergranular corrosion develops along the direction of forging or extrusion streamline. Therefore, more α-Al is exposed to the corrosive medium for T1 sample, which leads to continuous electrochemical corrosion of the alloy. Macroscopically, the corrosion current density increases and the corrosion resistance decreases.
Figure 2. Surface corrosion morphology of samples in different concentrations of sodium chloride solution, (a) 0.8wt% NaCl-T6, (b) 0.8wt% NaCl-T1, (c) 1.5wt% NaCl-T6, (d) 1.5wt% NaCl-T1

Figure 3. Cross section morphology of T6 and T1 samples in different concentrations of sodium chloride solution, (a) 0.8wt% NaCl-T6, (b) 0.8wt% NaCl-T1, (c) 1.5wt% NaCl-T6, (d) 1.5wt% NaCl-T1

Table 3. Maximum corrosion depth of 6082 aluminum alloy in different mass fractions of NaCl solution

| Samples            | The maximum depth (μ m) |
|--------------------|-------------------------|
| T6(0.8wt% NaCl)    | 83.34                   |
| T1(0.8wt% NaCl)    | 91.37                   |
| T6(1.5wt% NaCl)    | 108.68                  |
| T1(1.5wt% NaCl)    | 151.33                  |

The maximum depth of the corrosion pits is listed in Table 3. When the mass fraction of sodium chloride solution is constant, the corrosion depth of T6 is more shallow than that of T1. When the processing condition is constant, the corrosion depth of AA6082 increases with the raise of mass fraction of sodium chloride. When the mass fraction of sodium chloride is increased from 0.8% to 1.5%, the corrosion of aluminum alloy is aggravated due to chlorine ions have a very strong
permeability, the higher the concentration of chloride ions, the stronger the permeability. Therefore, the corrosion current density of the alloy surface increases and the corrosion resistance decreases. This result is consistent with that of electrochemical test.

4. Conclusions
(1) The corrosion resistance of forged specimens (T6) is better than that of extruded specimens (T1), at constant mass fractions of sodium chloride solution.
(2) The corrosion resistance of AA6082 decreases when increasing the mass fraction of sodium chloride solution, at the same conditions of processing.

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6. References
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