Corrosion Behavior of 7075 and 2A12 Aluminum Alloys in Different Water Environments

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Abstract. The corrosion of 7075 and 2A12 aluminium alloys are studied in three types of water, including freshwater lake water, salt lake water and saline lake brine in the Qinghai-Tibet Plateau region. The samples are immersed into the different water for different time, which are divided into four types of 30d, 60d, 90d and 120d. After undergoing dry and wet cycle immersion corrosion under natural conditions, it can be concluded that the two aluminum alloy samples have more serious corrosion in freshwater lakes, and 2A12 aluminum alloy is more corrosion resistant than the 7075 aluminum alloy. The corrosion is mainly pitting, accompanied by crevice corrosion and galvanic corrosion. \( Cl^- \) can pass through the passivation film on the surface of the samples to form pitting pits, while the dissolved \( Al^{3+} \) in the matrix and \( SO_4^{2-} \) in the water can form stable \( Al_2(SO_4)_3 \cdot xH_2O \), which plays a certain protective role for the sample.

Keywords. Aluminum alloy, Corrosion resistance, Saline lake brine, Fresh water, Salt water

1. Introduction

7075 aluminum alloy is Al-Cu-Mg-Zn alloy, which is a super-hard aluminum alloy with high strength, good wear resistance and toughness. It has specific application prospects in the aviation and navigation field [1]. 2A12 aluminum alloy belongs to the Al-Cu-Mg series hard aluminum alloy, which has suitable plastic forming performance and mechanical processing performance, and is an important structural material in the aerospace field [2]. As widely used material for aircraft, ship structure and lightweight weapon parts [3], 7075 and 2A12 aluminum alloy have good corrosion resistance in ordinary environment. However, the corrosion resistance is reduced in high humidity, high salt and acid rain environment [4]. Once the aluminum alloy is corroded during use, it will bring hidden dangers to safety [5]. To date, certain research on corrosion of hard-aluminum alloy has been carried out at home and abroad. J Huang et al. [6] found that as the corrosion time of 7075 aluminum alloy in NaCl solution prolonged, the degree of sample dissolution deepened, and the corrosion pits increased to form large-scale pitting corrosion. Z Li et al. [7] conducted accelerated corrosion tests on 2A12 aluminum alloy. In the early stage of corrosion, rough surfaces are more prone to pitting corrosion, and the corrosion rate gradually increases with time. However, there are few studies on the corrosion of freshwater lakes, salt lake and saline lake brine on the Qinghai-Tibet Plateau.
This paper compares and analyzes the corrosion experiment data of 7075 and 2A12 aluminum alloy in different typical water environments, reveals their corrosion behavior and corrosion mechanism, and provides a theoretical reference for the protection of hard-aluminum alloy.

2. Materials and Methods

The 7075 and 2A12 aluminum alloy plates are processed into rectangular sheet samples of different sizes according to the immersion time. The size of the samples immersed for 30d and 60d is 20mm×10mm×2mm, and the samples immersed for 90d and 120d is 20mm×10mm×3mm. Drill a small hole with a diameter of 2mm in the top-middle of the sample. Use sandpaper and a polishing machine to polish the pre-corroded surface of the sample to make it bright and free of scratches. Use acetone to remove oil, rinse with deionized water and air dry. Two kinds of aluminum alloy plates were suspended and immersed into the Koluk Lake freshwater lake sample, the Tosu Lake salt lake water sample, and the Chaka saline lake brine sample. The samples were divided into 4 groups according to the immersion time of 30d, 60d, 90d, and 120d. The samples were placed on the experimental terrace located at 101°75′E, 36°74′N, Xining City, Qinghai Province, with similar climatic conditions between the experimental site and the water sampling site, such as significant temperature difference between morning and evening. Due to the evaporation of water on sunny days and the replenishment of water in rainy weather, it undergoes a process of dry and wet cycle, and water samples are recharged every 10 days. The experimental instruments mainly include DMI3000M metallurgical microscope, JSM-5610LV scanning electron microscope, and INCA-X-ray energy spectrometer.

After the immersion corrosion experiment, first, observe the macroscopic morphology of the corrosion surface of the sample, then scrutinize the metallographic microstructure, and finally analyze the corrosion situation of the sample through the scanning electron microscope photos.

2.1. Materials

A total of three water samples were chosen for the experiment, namely freshwater lake water, salt lake water and saline lake brine (table 1).

| Table 1. | Ion content in all water samples used in the experiment (unit: mg/L). |
|----------|--------------------------|
|          | Na⁺ | K⁺ | Ca²⁺ | Mg²⁺ | Cl⁻ | SO₄²⁻ |
| Freshwater lake water | 14.7 | 0.8 | 5.2 | 5.9 | 24.5 | 19.1 |
| Salt lake water | 742 | 26.2 | 3.5 | 204.2 | 1176.8 | 630.5 |
| Saline lake brine | 5241.1 | 736.1 | 16.0 | 4690 | 18566.4 | 5275.8 |

The metal materials used in the experiment are 7075 aluminum alloy and 2A12 aluminum alloy. The composition of the material is as follows (table 2 and table 3):

| Table 2. | Chemical composition of 7075 aluminum alloy. |
|----------|----------------------------------------------|
| Composition | Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Al |
| wt.% | ≤0.4 | ≤0.5 | 1.2-2.0 | ≤0.3 | 2.1-2.9 | 0.18-0.28 | 5.1-6.1 | ≤0.2 | Rest |

| Table 3. | Chemical composition of 2A12 aluminum alloy. |
|----------|----------------------------------------------|
| Composition | Si | Fe | Cu | Mn | Mg | Cr | Ni | Zn | Ti | Al |
| wt.% | 0.5 | 0.5 | 3.8-4.9 | 0-0.9 | 1.2-1.8 | 0.1 | 0.5 | 0.25 | 0.15 | Rest |
2.2. Experimental Environmental Conditions

Experimental environmental conditions such as atmospheric temperature, atmospheric humidity, rainfall, etc. will affect the results of the immersion corrosion test. Data on environmental conditions were recorded for 30d (March), 60d (March-April), 90d (March-May), and 120d (January-April) (table 4).

| Immersing time (d) | Average ambient temperature (°C) | Average atmospheric humidity (%) | Average rainfall (mm) |
|--------------------|---------------------------------|---------------------------------|----------------------|
| 30                 | 3                               | 47.0                            | 9.9                  |
| 60                 | 6                               | 47.5                            | 19.5                 |
| 90                 | 8                               | 49.3                            | 42.0                 |
| 120                | 0.5                             | 46.0                            | 10.3                 |

3. Analysis and Characterization

3.1. Macroscopic Morphology Observation

The samples in figure 1-figure 4 are placed in the order of the immersion water samples. The samples immersed for 30d, 60d, 90d, 120d are freshwater lake water, salt lake water, and saline lake brine from left to right.

Figure 1 shows the sample soaked for 30 days. With the increase of $Cl^-$ concentration, the oxidation film of the aluminum alloy sample surface is destroyed. The film cannot effectively protect the substrate, and gradually dissolve the bare metal substrate. Both 7075 and 2A12 aluminum alloy immersed in freshwater lake water, the surface of the sample loses its metallic luster by naked eyes, and the corrosion is more serious than the corrosion in salt lake water and saline lake brine. The reason is that as the $SO_4^{2-}$ concentration increases, The oxide film on the surface of the aluminum alloy is destroyed, and the $Al^{3+}$ produced by the dissolution of the matrix and the adsorbed $SO_4^{2-}$ on the surface form stable and insoluble $Al_2(SO_4)_3 \cdot xH_2O$ [8], which in turn has a good anti-corrosion effect on the aluminum alloy.

![Figure 1](image1.png)

Figure 1. Samples immersed for 30 days, where (a) is 7075 aluminum alloy, and (b) is 2A12 aluminum alloy.

The sample picture after 60 days of immersing is shown in figure 2. After the immersion corrosion test, the samples were observed morphology of the corrosion surface, and it can be seen that the 2A12 aluminum alloy samples were subjected to lighter corrosion. Relatively speaking, 2A12 aluminum alloy has stronger corrosion resistance than 7075 aluminum alloy. Furthermore, aluminum chloride is soluble [9], so there is not a large amount of aluminum chloride layer on the surface of the aluminum alloy.
Figure 2. Samples immersed for 60 days, where (a) is 7075 aluminum alloy, and (b) is 2A12 aluminum alloy.

The immersion time is 90d as shown in figure 3. It is observed that the 7075 and 2A12 aluminum alloy samples immersed in salt lake water and saline lake brine still maintain a certain degree of brightness locally and no corrosion products appear. This is because the highest average temperature at 90 d, which corresponded to a longer daylight time, and the wettability of the sample surface was reduced, so the corrosion rate of both samples was reduced. In addition, due to the high precipitation, rainwater washed away corrosive ions such as \( \text{Cl}^- \) [8] from the surface of the samples, the degree of corrosion was reduced. However, corrosion products appeared locally on the samples immersed in freshwater lake water, and the black matrix completely lost its metallic luster.

Figure 3. Samples immersed for 90 days, where (a) is 7075 aluminum alloy, and (b) is 2A12 aluminum alloy.

Figure 4 shows the sample immersed for 120 days, three samples of 7075 aluminum alloy after immersion corrosion test, more serious corrosion occurred than 2A12 aluminum alloy. The surface of the 7075 aluminum alloy sample, immersed in freshwater lake water, was dark as a whole. The others immersed in salt lake water and saline lake brine, some gray unevenly distributed corrosion products appeared on its corrosion surface, and the surface of the sample became rough. The 2A12 aluminum alloy had pitting corrosion in the saline lake brine, and the corrosion of both two aluminum alloy samples in saline lake brine is stronger than the salt lake water.

Figure 4. Samples immersed for 120 days, where (a) is 7075 aluminum alloy, and (b) is 2A12 aluminum alloy.
3.2. Metallographic Microscopic Observation

The 7075 and 2A12 aluminum alloy samples with an immersion time of 60d were selected for metallographic microscopic observation. Figures 5 and 6 are in the same order as the macroscopic morphology of the corrosion surface of the samples. After the oxide film rupture, corrosion pits appear on the surface of aluminum alloy, and the initial size of the corrosion pits is small and difficult to detect [10].

![Figure 5](image1.png)

**Figure 5.** Metallographic photomicrograph of 7075 aluminum alloy sample in different (a) freshwater lake water, (b) salt lake water, and (c) saline lake brine water environment.

It can be seen from figure 5 that the 7075 aluminum alloy sample exhibited pitting corrosion and crevice corrosion after being immersed in the three water samples. The pitting corrosion originated from the pitting nucleus on the surface of the aluminum alloy. Once formed, it will accelerate to the inside with hidden danger and destructive; Crevice corrosion originates from the tiny crevices on the surface of aluminum alloy, which is more prone to form corrosion pits. The size of the corrosion pits is different, and some of the corrosion pits are large, showing small hole-like, which are unevenly distributed over the corrosion surface, and the local distribution is relatively dense.

As shown from figure 6, the surface of 2A12 aluminum alloy samples immersed in freshwater lake water is more severely corroded than those immersed in other water samples, and the black pit-like corrosion pits appearing are obviously larger. The samples immersed in salt lake water and saline lake brine are distributed with pore-like corrosion pits, but there are no dense local corrosion pits and large corrosion pits.

![Figure 6](image2.png)

**Figure 6.** Metallographic photomicrograph of 2A12 aluminum alloy sample in different (a) freshwater lake water, (b) salt lake water, and (c) saline lake brine water environment.

3.3. Surface Morphology and Corrosion Product Analysis

Figure 7 shows the scanning electron micrographs of the 7075 aluminum alloy samples immersed for 120d. The energy spectrum analysis results of different positions on the surface of the sample can be obtained.

The corrosion products of the samples immersed in freshwater lake water are mostly continuous and irregular dots or lumps; Samples immersed in salt lake water and saline lake brine have a scale-like distribution of corrosion products layer on the surface. The sample matrix adheres to the corrosion products with cracks on it.
Figure 7. EDS spectra of corrosion products of 7075 aluminum alloy samples in different (a) freshwater lake water, (b) salt lake water, and (c) saline lake brine water environment.

It can be seen from the above figure that the main element of 7075 aluminum alloy is Al, which also contains elements such as Mg, Cu, Zn, and Si, and the corrosion layer contains more elements such as Cl and O. As the sample is affected by the wet and dry cycle process, oxidation by air before corrosion, the main components of corrosion precipitates are $Al_2(OH)_3$ and $Al_2(SO_4)_3 \cdot xH_2O$ [11]. $Cl^-$ passes through the passivation film on the sample surface and is adsorbed to form pitting corrosion, which is the leading cause of pitting pits. The wet and dry cycle process is continuously repeated, making the corrosion penetrate deeper into the sample matrix. Since the second phase of aluminum alloy $\eta(MgZn_2)$ [12] causes galvanic corrosion with the aluminum alloy matrix, the sample surface shows discontinuous corrosion distribution characteristics.

4. Conclusions
The immersion of 7075 and 2A12 aluminum alloy samples is affected by the concentration of $Cl^-$ and $SO_4^{2-}$. The samples in the freshwater lake water are subjected to the most serious corrosion, followed by the saline lake brine, the salt lake water relatively better.

The wettability of the surface of the two samples is decreased with long sunshine time and high temperature, and the corrosion rate is reduced. When the precipitation is considerable, the corrosive ions on the surface of the sample are washed by rainwater, and the degree of corrosion is decreased.
The 7075 aluminum alloy samples showed pitting corrosion in all three water samples after immersion and developed to the depth, with uneven distribution of corrosion products. The 2A12 aluminum alloy samples immersed in salt lake water and saline lake brine did not show dense local corrosion pits and had better corrosion resistance than 7075 aluminum alloy samples.

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