Corrosion Behaviour of Aluminum Alloy AA7075-T651

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Abstract. The present work investigates the corrosion behavior of a high strength aluminum alloy AA7075-T651 which is widely used in the aerospace industry. The alloy composed of Zn, Mg, and Cu as the main alloying elements. The T651 referred to a peak strength temper. X-ray diffraction (XRD) analysis detected MgZn$_2$ as the second phase next to the Al matrix. The corrosion behavior of AA7075 was studied by conducting an immersion test in 30 g/l NaCl and 10 ml/l HCl solution at 35°C based on ASTM B597 for 8, 16, 24 h. The specimen was then characterized by an optical microscope and scanning electron microscope (SEM). The results showed that the specimen experienced a severe corrosion attack as a result of immersion test, as indicated by the change in the surface appearance, the development of surface roughness, as well as significant weight loss. The surface became remarkably rough and grain embrittlement following the metal grain boundaries occurred down to 150 µm depth. The near surface layer became disintegrate and easily detached from the surface after immersion 16 and 24 h. The results indicated that the alloy was sensitive to intergranular corrosion.

1. Introduction
The high strength aluminum alloy AA7075 has been extensively used in aircraft industry owing to its excellent mechanical properties and high specific density [1-3]. The main alloying elements in AA075 are zinc (5.1-6.1 wt.%), magnesium (2.1-2.9 wt.%), and copper (1.2-2.0 wt.%). The microstructure of the alloy contained intermetallic precipitates such as Al$_7$Cu$_2$Fe, (Al, Cu)$_6$(Fe, Cu) phases which were the dominant precipitates, and Mg$_2$Si which present in small number [3]. The strengthening precipitate was MgZn$_2$ which existed as nanoparticles in the alloy. The high strength property was, however, counterbalance with the susceptibility of the alloy to local corrosion like pitting, intergranular, and exfoliation corrosion [4, 5].

The strengthening precipitates which segregated at the metallic grain boundaries of the alloy affected the resistance to intergranular corrosion. The intermetallic precipitates may change in morphology, composition, and type with thermo-mechanical treatment [6, 7]. The solution treatment and aging modified the distribution and size of intermetallic precipitates. The alteration in the microstructure can be characterized by measuring the electrical conductivity and mechanical hardness tests [3]. Meanwhile, the corrosion behavior was studied by performing an aqueous immersion test in chloride containing solution [8]. At peak strength condition of T6 and at overage T76 tempers, the precipitates Al$_7$Cu$_2$Fe, (Al, Cu)$_6$(Fe, Cu) phases induced pitting corrosion in the alloy [3]. The pit initiated due to the galvanic coupling of the intermetallic phases with the surrounding matrix. The potential difference between the intermetallic and matrix promote microgalvanic corrosion where the phase with lower potential corroded selectively. The Cu-rich phase was detrimental to most of Al alloys as the phase tended to
segregate along grain boundaries and induced corrosion of the surrounding matrix which deple-

ted in Cu [6, 7]. The Cu-rich intermetallic is unavoidably formed in aluminum alloy although present in low concentration [9, 10].

The current work investigates the corrosion behavior of AA7075 alloy in the T651 temper condition. The T651 indicated the basic temper T6 that the alloy has been solution treated, quenched, and artificially aged and in addition, the alloy has been stress relieved by stretching ½ to 2%. The main purpose was to clarify the dominant type of corrosion occurred in the alloy. The corrosion behavior was studied by performing an immersion test in chloride solution.

2. Experimental procedure

The material used was a rolled plate AA7075-T651 with a thickness of 2 mm. The plate was cut to give an area of 2.6 cm$^2$. The specimens were ground with #600 to #1500 grit paper followed by polishing with 1 µm diamond paste. Afterward, the specimens were degreased in acetone and ethanol for 3 min in an ultrasonic bath.

For microstructure investigation, the specimen was etched in 10 wt% NaOH solution for 2 min. The metallographic microstructure was studied by using an optical microscope Olympus CX31. For a higher magnification image, observation on the specimen morphology was performed by using FE-SEM (FEI INSPECT F-50). The elemental composition of the alloy was analyzed by EDX (EDAX EDS Analyzer).

The corrosion behavior of the specimen was examined by weight loss method in a mixture solution of 30 g/l NaCl and 10 ml/l HCl solution at 35°C for 8, 16, 24 h, based on ASTM B597 [11]. After immersion, the specimen was cleaned in running water followed by DI water and then dried in an air stream.

3. Results and Discussion

The microstructure of the as-polished specimen was studied by an optical microscope and the result is presented in figure 1. The microstructure consisted of numerous fine intermetallic particles as indicated by the dark spots with the size in the range 5-10 µm distributed randomly as shown in figure 1. Some of them were agglomerated to form bigger spots. The spots are voids where previously occupied by the intermetallic particles. The particles were possibly detached from the surface during etching and desmutting. The remaining intermetallic particles were observed as white particles, pointed by arrows in Fig. 1. The small spherical particles were in the size of few µm while the bigger particles might reach several 10$^{th}$ µm. The metallic grain boundaries were quite small between 10-20 µm. The grain boundaries which appeared dark were also occupied by continuous segregated intermetallic particles. The typical grain boundaries precipitate in the AA7075 alloy is the strengthening MgZn$_2$ phase [3].

![Figure 1. The optical microscope image of the as-polished AA7075 surface.](image-url)
The elemental composition of the alloy is listed in Table 1 which is obtained from the EDX analysis. The main alloying elements detected in the alloy are Mg, Cu, and Zn and some impurities of Fe and Mn. The signal from Zn was rather low probably existed in solid solution matrix or as small precipitates. The result indicated that the intermetallic precipitates shown in Fig. 1 was mainly composed of Cu-rich and Mg-rich phases. The phases existed in the AA7075 alloy are MgZn$_2$, Al$_2$CuMg, and Al$_2$Cu$_2$Fe [12].

**Table 1.** The composition of AA7075 analyzed by EDX.

| Element | Wt% | At% |
|---------|-----|-----|
| Mg      | 2.64| 2.82|
| Si      | 0   | 0   |
| Mn      | 0.52| 0.24|
| Fe      | 0.25| 0.12|
| Cu      | 2.42| 0.99|
| Zn      | 0.29| 0.12|
| Al      | Bal.| Bal.|

The corrosion mechanism of the AA7075 alloy was studied by performing an immersion test in NaCl-HCl solution at a temperature of 35°C for 8, 16, and 24 h. The result of weight loss measurements is plotted as a function of time as shown in Fig. 2 while the corresponding FE-SEM cross-sectional corrosion morphologies are displayed in Fig. 3. The weight loss increased linearly with exposure time with the slope of 27 mg.cm$^{-2}$.h$^{-1}$. The alloy showed weight losses of 0.01, 0.04, and 0.07 g.cm$^{-2}$ after an immersion time of 8, 16, and 24 h, respectively.

The images of cross-section corrosion morphology as displayed in Fig. 3 confirmed the weight loss results in Fig. 2. A significant corrosion attack along grain boundaries was already observed after 8 h immersion. The depth of attack was about 150 µm from the specimen surface. The grain boundaries were corroded as indicated by thicker and darker boundaries relative to the uncorroded parts. Prior to the corrosion test, the grain boundaries of the as-polished alloy were occupied by either cathodic or anodic phases. The type of intermetallic precipitates will be investigated in our future work. The used of electrochemical microcell system was proved to be the useful method to investigate local corrosion phenomena induced by small precipitates [13].

![Figure 2](image.png)  
**Figure 2.** The weight loss of AA7075 after immersion in 3.5% NaCl solution for 8, 16, and 24 h.
The precipitates existed in aluminum alloys typically have different potential, higher or lower than the solid solution matrix. The potential gradient causes galvanic coupling which promotes galvanic corrosion. The matrix next to the cathodic precipitates was susceptible to corrosion while the anodic precipitates tend to corrode than the matrix. The corrosion morphology of AA7075 alloy shown in Fig. 3 indicated that the precipitates at grain boundaries were anodic type corresponded to the MgZn$_2$ phase since the grain boundaries were selectively attacked by corrosion leaving corrosion products. At an extended immersion time of 16 and 24 h, the depth of attack was relatively the same as that of 8 h but the degree of corrosion attack increased. The outer layer which was severely corroded was detached from the specimen surface resulting in a rough surface layer covered by the corrosion product. The corrosion product appeared as darker areas relative to the surrounding in Fig. 3. The corrosion product was presumably composed of aluminum oxide and chloride complexes similar to the reported work in ref [7]. The metallic grains near the surface were disintegrated as the areas along grain boundaries suffered from severe corrosion. The grain boundaries embrittlement occurred down to ~100 µm depth from the surface after 16 h immersion while deeper ~200 µm after 24 h exposure time. The corrosion test results indicated that the AA7075-T651 alloy was susceptible to intergranular corrosion.

Figure 3. The cross-section FE-SEM images of AA7075 specimen after immersion in 3.5% NaCl for a) 8 h, b) 16 h, and c) 24 h.
4. Conclusion

The corrosion study on AA7075-T651 alloy revealed that the metallic grain boundaries were sensitized by the segregation of intermetallic phases along the grain boundaries. The microstructure study indicated that the phase existed along the grain boundaries was mainly the strengthening phase MgZn$_2$ which is more anodic than the surrounding Al matrix while other intermetallic precipitates such as Cu-rich and Fe-rich phases distributed randomly in the alloy as spherical particles in the order of 10 µm size. The grain boundaries were susceptible to intergranular corrosion. The MgZn$_2$ phase which segregated along the grain boundaries was selectively corroded during exposure in aqueous corrosive solution. At a short exposure time of 8 h, corrosion led to intergranular attack down to 150 µm depth from the surface. The grain boundaries were disintegrated and further detached from the surface after prolong exposure time of 16 and 24 h. A corrosion prevention method is necessary to be developed for the AA7075 alloy to protect the alloy from intergranular corrosion.

References

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