



Correlations between stress corrosion cracking, grain boundary precipitates and Zn content of Al–Mg–Zn alloys



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ABSTRACT

The stress corrosion cracking susceptibility of traditional Al–Mg alloys modified by Zn was studied by using slow strain rate test both in the air and in 3.5 wt.% NaCl solution acidified with HCl to pH 3. Traditional Al–Mg alloys showed serious susceptibility to intergranular stress corrosion cracking, while Zn modified alloy showed relatively no susceptibility. It suggested that stress corrosion cracking resistance was significantly improved by Zn additions in acidified NaCl solution coupled with a transition from brittle failure to completely ductile failure. Both the distributions of grain boundary precipitations and grain boundary misorientation were modified by Zn addition to the Al–Mg alloys. Traditional Al–Mg alloys showed a continuous distribution of precipitations along the grain boundary, while Zn modified alloy showed a homogeneous precipitation in the matrix and discontinuous precipitation along the grain boundary. The low-angle grain boundaries had good resistance to intergranular stress corrosion cracking even though continuously precipitated along the grain boundary.

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1. Introduction

Al–Mg alloys have been considered in a wide variety applications as in marine and land transportation, due to their excellent properties such as high strength, good formability, corrosion resistance and weldability [1–4]. It is well known that Al–Mg alloys derive its strength from magnesium solid solution strengthening and strain hardening. The additions of Mg can largely increase the strength of the alloys [5]. However, when the magnesium content reaches to 3.5%, Al–Mg alloys are susceptible to intergranular corrosion and stress corrosion cracking (SCC) as exposed to increased temperature (above 65 °C) for a period of time [6–9].

SCC is a particularly insidious mode of corrosion that is the result of the combined effects of mechanical loading and a corrosive environment. The susceptibility to SCC as a result of thermal exposure, known as sensitization, is a consequence of continuously precipitated β -phase (Al_3Mg_2) along the grain boundary [10,11]. Thus, upon exposure to corrosive environments, the anodic dissolution of the grain boundary phase is more easily activated when the sample is stressed. In this case, fast intergranular stress corrosion cracking (IGSCC) is expected. The more continuous the

precipitation is, the more detrimental is the stress assisted intergranular dissolution damage. In case of anodic dissolution of the grain boundary phase, multiple mechanisms for crack propagation have been proposed. Jones et al. [12,13] reported hydrogen-induced crack growth is responsible for crack growth through β phase and the grain boundary between the particles. Dissolution of grain boundary β phase leads to severe crack tip acidification, hydrogen production, and embrittlement as sensitized in chloride solution [14]. The grain boundaries in 5083–H131 are embrittled by hydrogen precharging and the rates of IGSCC are fast by crack tip hydrogen diffusion [14]. The texture [15] or grain boundary orientation [16] could susceptibility to SCC, and also affect the growth of β phase. The importance of the nature of deformation slips in the materials on the SCC characteristics is well established and the crack propagation has largely dependent on the dislocation–particle interaction [17,18].

Some work [19,20] has indicated the additions of Mn, Zr, and Sc to Al–Mg alloys increases the mechanical properties as well as SCC resistance by hindering recrystallization. Carroll et al. [21] found that the Zn additions to 1–2 wt.% and minor Cu additions can improve the SCC resistance of Al–Mg alloys, due to the formation of stable ternary Al–Mg–Zn or Al–Mg–Zn–Cu phase at grain boundaries. G. Ben-Hamu [22] also found that Si addition to Mg–Zn–Mn alloys can significantly improve the SCC resistance as the Mg_2Si acts as a barrier for the stress corrosion crack

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propagation.

In this study, we systematically investigated the SCC behavior, and its relationship to the intergranular corrosion behavior of the Zn-modified Al–Mg alloy. The microstructure as well as the morphology of the fracture surface, distributions of the precipitates and grain boundary misorientations were examined. The objective was to identify comprehensively the correlation between alloying elements, microstructure, intergranular corrosion and SCC in Al–Mg–Zn alloys.

2. Experimental procedure

2.1. Material

The Al–Mg alloys used in this study were melted in the crucible furnace and then poured into a cast iron mold. The real chemical compositions of the experimental alloys were analyzed by Optical Emission Spectrometer during casting, and were shown in Table 1. The chemical contents of Zn increased from Alloy 1 to Alloy 3, while the chemical contents of Mg were almost the same. The ingots were homogenized, hot rolled, full recrystallized, cold rolled, stabilized at 250 °C for 1 h and finally stretched for 1%. All specimens were then subjected to a sensitizing treatment at 100 °C for 7 days.

2.2. Corrosion tests

According to ASTM-G129, slow strain rate test (SSRT) was used to evaluate the SCC susceptibility of the alloys. Samples for SSRT were machined from the sheets with their tensile axes parallel to the rolling direction. The gauge section size was 30 mm × 6 mm with a thickness of 2 mm. All specimens were lightly abraded along the tensile direction using 800 grit, 1500 grit and finally 2000 grit abrasive papers to ensure the same roughness during sample preparation. The polished samples were degreased in ethanol and then dried by cool air prior to testing. The samples for SSRT were divided into two groups. A group of samples was directly tested in air at a strain rate of $3.3 \times 10^{-6} \text{ s}^{-1}$. For the other group, the gauge sections were completely immersed in a 3.5 wt.% NaCl solution acidified with HCl (pH = 3) during testing, which was repeated at least twice in order to ensure reproducibility of the measurements. After SSRT, the broken specimens were etched in a boiling solution (a mixture of 46 mL H_3PO_4 , 20 g CrO and 1 L deionized water) to remove the corrosion products, cleaned with ethanol and dried in the cool air.

The SCC susceptibility index (I_{SCC}) is defined as the loss of reduction of area after SSRT and shown in Eq. (1),

$$I_{\text{SCC}} = \left(\frac{\psi_{\text{air}} - \psi_{\text{sol}}}{\psi_{\text{air}}} \right) \times 100\% \quad (1)$$

where ψ_{air} and ψ_{sol} are the value of reduction of area in the air and in the corrosive solution, respectively.

The susceptibility to intergranular corrosion of each alloy was assessed using nitric acid mass loss test (NAMLT, according to ASTM-G67). The specimens with a dimension of 50 mm by 6 mm by product thickness were polished with 320# grade SiC papers, washed with ethanol to remove any grease, and rinsed with

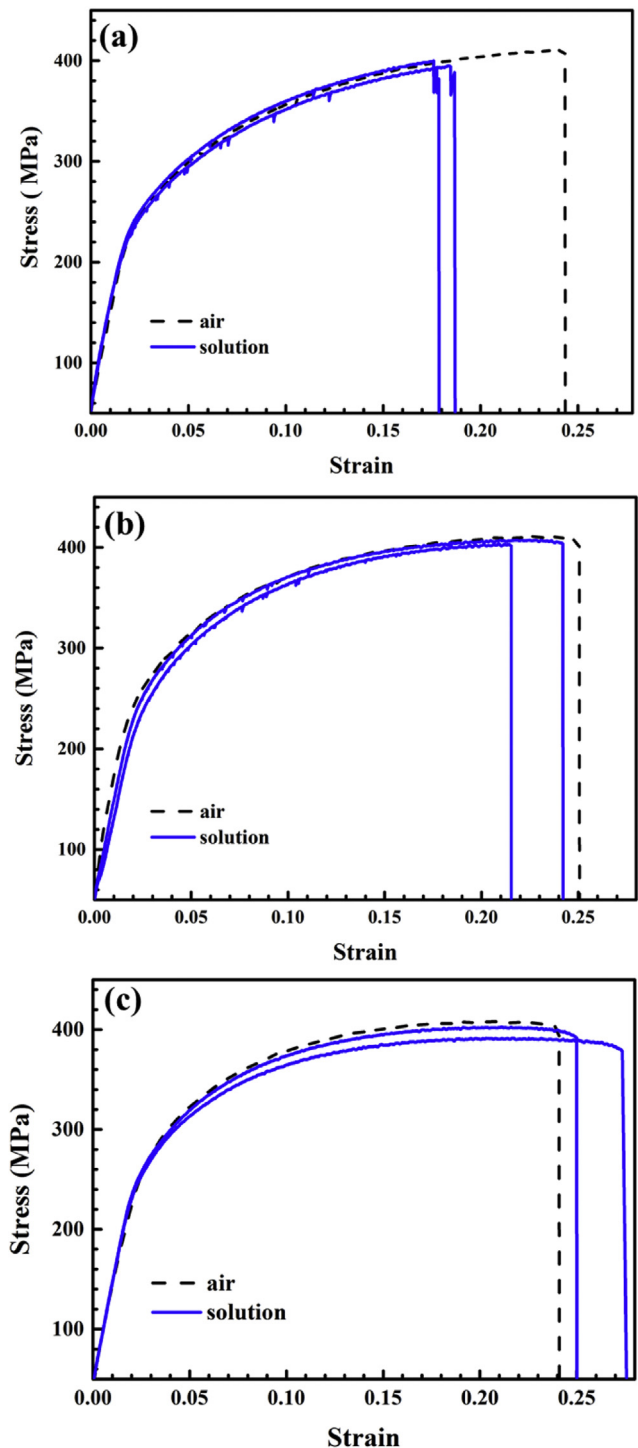


Fig. 1. Typical SSRT curves of three alloys tested in air and in acidified 3.5 wt.% NaCl solution: (a) Alloy 1, (b) Alloy 2 and (c) Alloy 3.

deionized water. The 50-mm dimension was parallel to the longitudinal direction of the alloy sheet. Weigh the samples, measure all three dimensions and calculate the total surface before NAMLT. Then, samples for NAMLT were immersed into 70 wt.% HNO_3 for 24 h. Weigh the samples after NAMLT and calculate the mass losses per unit area to evaluate the susceptibility to intergranular corrosion. The IGC test for each alloy was repeated twice to ensure the reproducibility.

Table 1

Chemical compositions of the experimental alloys in the present study (wt.%).

Alloy	Zn	Mg	Mn	Ti	Si	Zr	Cu	Fe	Cr	Al
1#	0.00	5.70	0.80	0.07	0.15	0.15	0.15	0.2	0.03	Balance
2#	0.60	5.83	0.83	0.07	0.14	0.15	0.15	0.19	0.03	Balance
3#	0.95	5.78	0.83	0.07	0.14	0.15	0.15	0.19	0.03	Balance

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