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Influence of grain structure on quench sensitivity relative to localized corrosion of high strength aluminum alloy

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HIGHLIGHTS

- (Sub)Grain boundaries increase quench sensitivity relative to localized corrosion.
- Subgrain boundaries decrease corrosion resistance below quench rate of 630 °C/min.
- More (sub) grain boundaries leads to more GBPs and PFZ with decreasing quench rate.

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ABSTRACT

The influence of grain structure on quench sensitivity relative to localized corrosion of high strength aluminum alloy 7055 was investigated by electrochemical test, accelerated exfoliation corrosion test, optical microscopy (OM), scanning electron microscopy (SEM), transmission electron microscopy (TEM) and scanning transmission electron microscopy (STEM). The decrease of quench rate led to lower corrosion resistance of both the homogenized and solution heat treated (HS) alloy with equiaxed grains and the hot-rolled and solution heat treated (HRS) alloy with elongated grains, but there was a higher increment in corrosion depth and corrosion current density and a higher decrement in corrosion potential for the latter alloy, which therefore exhibited higher quench sensitivity. It is because in this alloy the larger amount of (sub) grain boundaries led to a higher increment in the amount of quench-induced η phase and precipitates free zone at (sub) grain boundaries with the decrease of quench rate, and there was a larger increment in the content of Zn, Mg and Cu in the η phase at grain boundaries due to slow quenching. The presence of subgrain boundaries in the HRS alloy tended to increase corrosion resistance at high quench rates higher than about 630 °C/min but decrease it at lower quench rates.

1. Introduction

7XXX series aluminum alloys have been widely used as structural materials in aircrafts due to their high specific strength. These alloys often exhibit quench sensitivity which was initially defined as a relative measure of the loss of hardening capability when slowly quenched from the solution heat treatment temperature [1]. The strength and hardness of these alloys after aging generally decrease with the decrease of quench rate [2–4]. For semi-products with large section, this problem is practically important because quench rate in the center layer is often lower due to the large size or requirement of controlling residual stress [5,6]. Therefore, a number of investigations have been focused on quench sensitivity relative to mechanical properties especially strength and hardness, which receives effect from many factors, such as chemical compositions, grain structure, homogenization, deformation and solution heat treatment [7–13]. As far as grain structure is concerned, it is known that the rise in the fraction of grain boundaries and subgrain boundaries tends to increase quench sensitivity relative to mechanical properties [7–9]. Grain structure has great effect on corrosion resistance [14–16], and it is essential to understand its effect on quench sensitivity relative to localized corrosion, because the decrease of quench rate tends to decrease the resistance to localized corrosion [17–19]. This can help to optimize microstructure of large section semi-products to achieve higher strength and

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higher corrosion resistance, which are always desirable for 7XXX series aluminum alloys.

Exfoliation corrosion (EXCO) is a typical localized corrosion form of 7XXX series aluminum alloys. The occurrence of EXCO can deteriorate mechanical properties seriously and leads to premature failure of these materials [20–22]. It is known that EXCO is actually a kind of intergranular corrosion (IGC) and closely associated with grain shape. Grains with a high aspect ratio tend to increase the susceptibility to EXCO [23–26]. Moreover, EXCO is also closely related to grain boundary precipitation state, which is primarily dependent on aging temperature and time. Coarse and more-spaced η phase particles at grain boundaries tend to decrease susceptibility to EXCO, and this was generally supposed to be responsible for higher resistance to EXCO of T7X-treated alloys than T6-treated ones [27–34]. However, it was suggested instead that the higher copper content in η phase particles at grain boundaries is the main reason for improved resistance to IGC, EXCO and stress corrosion cracking (SCC) of T7X-treated alloys [35–38]. Apart from aging, quenching has great effect on the precipitation state at grain boundaries, and therefore can affect resistance to EXCO. For instance, in some typical alloys such as 7075, 7449 and 7055, the resistance to EXCO decreases with the decrease of quench rate after solution heat treatment [17–19,39–41]; and the mechanism has been recently discussed in detail [19]. But when grain structure is changed in the alloy, how this quench rate effect changes is not clear and needs to be studied.

This work is focused on the influence of grain structure on quench sensitivity relative to localized corrosion of 7055 aluminum alloy, which exhibits high quench sensitivity relative to mechanical properties [42]. An end quenching technique was used to obtain different quench rates, and electrochemical test and accelerated EXCO test were used to evaluate resistance to localized corrosion. Based on microstructure examination by optical microscopy (OM), scanning electron microscopy (SEM), transmission electron microscopy (TEM) and grain boundary microchemistry examination by scanning transmission electron microscopy (STEM), the reason was discussed.

2. Experimental procedure

2.1. Materials and end-quenching test

In order to have very different grain structure, a fully homogenized ingot and a hot-rolled thick plate of 7055 aluminum alloy were used. The chemical compositions were (wt.%): Al-8.10Zn-2.08Mg-2.25Cu-0.11Zr, Fe < 0.07, Si < 0.07. Specimens with a size of 125 mm in length × 25 mm in width × 25 mm in thickness were cut for end-quenching test. After solution heat treatment by heating to 470 °C and holding for 1 h in an air furnace, the specimen was taken out rapidly, placed in a fixture and cooled to room temperature by exposing at one end to a vertical stream of room temperature water, and then aged at 120 °C for 24 h in an oil bath immediately. Fig. 1 shows the schematic of end-quenching test. In order to obtain quench rates at varying distances from the water-cooled end in the specimen during end-quenching, small holes were drilled on a reference specimen to insert thermocouples; the time-temperature data were recorded and the average quench rate through 420–230 °C was estimated to be about 1250 °C/min, 630 °C/min, 164 °C/min, 138 °C/min and 135 °C/min at the locations of 3 mm, 23 mm, 53 mm,78 mm, 98 mm from the water-cooled end, respectively. It is obvious that quench rate decreases with the increase of distance from the water-cooled end, which is similar to the change of quench rate from the surface layer to the center layer in the semi-products with large section during quenching [2]. With the decrease of quench rate, the hardness after aging decreases for both the homogenized and solution heat treated (HS) alloy and the hot-rolled and solution heat treated (HRS) alloy, see Table 1 [12].

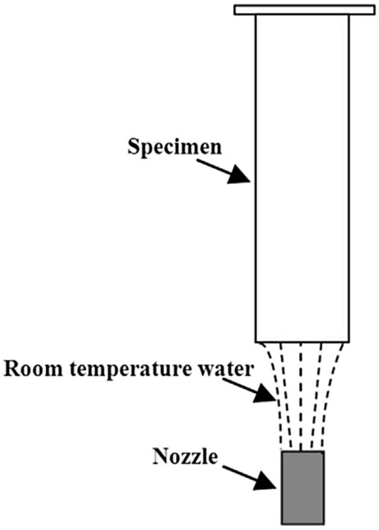

Fig. 1. Schematic of end-quenching of the samples after solution heat treatment.

2.2. Polarization curves test

Samples were cut from the end-quenched and aged specimens for polarization curves measurement using instrument IM6ex. A three-electrode cell with a platinum counter electrode and a saturated calomel reference electrode were used. All tests were perfomed at room temperature in aqueous solution of 4 mol/L NaCl+0.5 mol/L KNO_3+0.1 mol/L HNO_3, and the exposed surface area was 1 cm^2.

2.3. Accelerated EXCO test

Accelerated EXCO test was performed according to GB/T 22639-2008 specification [43]. A slice with thickness of 2 mm was cut from the center layer in the end-quenched and aged specimen, degreased using 10% NaOH solution, pickled with 30% HNO_3 solution, rinsed using acetone and distilled water, and then dried. The slice was immersed in the solution of 4 mol/L NaCl+0.5 mol/L KNO_3+0.1 mol/L HNO_3 (pH 0.4), and the ratio of solution volume to exposed surface area was 25 mL/cm^2. The temperature during immersion was maintained at 25 ± 2 °C in a thermostat water bath. After immersion for different time, the exfoliation rating was determined by visual examination according to GB/T 22639-2008 specification [43]. The corroded surface was recorded by a digital camera. The rating, N, means no appreciable attack, PA-PC represents a range from slight to severe pitting corrosion and EA-ED indicates a range from slight to severe exfoliation. The corrosion morphology on the surface was also examined by a Quanta-200 SEM. After immersion for 48 h, metallographic cross-section samples were prepared to observe corrosion morphology and to

Table 1
Effect of quench rate on the Vickers hardness of the HS and HRS alloy after aging, standard deviation is also given.

Quench rate (°C/min)	1250	630	164	138
The HS alloy	198.7 ± 2.6	196.0 ± 3.4	189.8 ± 4.5	188.8 ± 1.3
The HRS alloy	197.1 ± 1.3	188.9 ± 2.2	173.6 ± 1.2	170.1 ± 1.0