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ARTICLE

# Effect of Rare Earth Metals on Mechanical and Corrosion Properties of Al-Zn-Mg-Cu-Zr Alloy

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**Abstract:** The effect of rare earth metals on mechanical and corrosion properties of 7085 aluminum alloy (Al-7.5Zn-1.5Mg-1.4Cu-0.15Zr) was investigated by means of optical microscopy (OM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Intergranular, exfoliation corrosion, hardness, tensile test and electrical conductivity test were performed Al alloys on both with and without rare earth additives. Results show the Al alloys with rare earth metals present better mechanical properties such as higher strength and hardness as a result of finer microstructure in comparison with those without the additives. The corrosion resistance is greatly improved by adding rare earth metals. Intergranular corrosion resistance is enhanced from Level IV to Level II, the denudation level for 48 h is improved from $E_B$ to $P_A$ and $I_{SSRT}$ reflecting stress corrosion resistance was enhanced from 65% to 96%.

**Key words:** 7085 aluminum alloy; rare earth metals; inter granular corrosion; exfoliation corrosion; stress corrosion cracking

7085 alloy (Al-7.5Zn-1.5Mg- 1.4Cu-0.15Zr) is developed as the new generation aluminum alloy, and applied to the areas of large aircraft[1]. However, one of the main drawbacks for its wider application is the corrosion resistance.

One of the most important properties for Al alloys in aircraft is corrosion resistance, since they often suffer various conditions such as temperature, loading stress, creep, and fatigue[2]. Although corrosion resistance can be enhanced by solid-solution treatment, the strength is thus reduced as a result of it.

In order to improve comprehensive property of alloys, some researchers studied 7085 aluminum alloy from different respects. Xiao et al.[3] reported that partial resolution heat treatment improved corrosion resistance but decreased the strength. Luo et al.[4] demonstrated that enhanced-solid-solution raised the denudation level from $E_B$ to $P_B$. Rare earth metals can refine recrystallized grains, leading to the length of boundaries per unit volume increase and precipitates more sparsely distributed along grain boundaries to present coarse catenary formation, which benefits the corrosion resistance[5]. The purpose of this work is to investigate the effect of rare earth metals on mechanical and corrosion properties of 7085 aluminum alloys, so as to improve corrosion resistance without sacrificing the strength.

## 1 Experiment

### 1.1 Materials preparation

Experiments were carried out on 7085 aluminum alloy with main chemical composition (wt%) of 7.5 Zn, 1.5 Mg, 1.4 Cu, 0.15 Zr and Al balance. Cuboid samples were cast in the water-cooled copper mold. The ingots were subjected to homogenization in the air resistance furnace, then through rolling deformation, the final thickness was 1 mm. Specimens were solution treated at 470 °C for 2 h and artificially aged at 120 °C for 24 h.

### 1.2 Experimental methods

The micro-hardness testing was performed on a MH-3L hardmeter with a load of 100 g for 15 s. The microstructures were examined using optical microscopy and transmission electron microscopy. Samples for OM observation were chemically etched in Keller's reagent. Thin foils for TEM were prepared by mechanical polishing to 100 μm and

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final twin-jet electro polishing in the solution of 25% $HNO_3$ +75% $CH_3OH$ at –25°C.

Inter granular corrosion test was carried out as GB7998-2005. Samples were suspended in the corrosion fluid (made up of 57 g NaCl and 10 mL HCl, and 1 L distilled water) for 6 h. The temperature was controlled at (35±2) °C, and surface to volume ratio $A/V$ was 20 $mm^2$/mL.

Exfoliation corrosion test was carried out according to ASTM G34-2001. The concentrations of NaCl, $KNO_3$ and $HNO_3$ were 4.0, 0.5 and 0.1 mol/L, respectively. The temperature was controlled at (25±2) °C, and $V/A$ was 20 mL/$cm^2$. The EXCO surface morphology was record for a certain time by a digital camera.

The SCC susceptibility was evaluated by the slow strain rate test (SSRT) at a strain rate of $10^{-6}$ $s^{-1}$ in air and in 3wt% NaCl +0.5vol% $H_2O_2$ solution. Rectangular tensile specimens with a gauge length of 30 mm and a width of 10 mm were used. The susceptibility to SCC was calculated by the ratio of elongation. It was defined as follows: $I_{SSRT} = I_{Corr}/I_{Air}$, where $I_{Air}$ is the elongation in air, and $I_{Corr}$ is the elongation in corrosion solution. The higher $I_{SSRT}$ is, the better the corrosion resistance is.

The polarization curve test was conducted at CHI660D, and saturated calomel electrode and platinum electrode were used as reference electrode and auxiliary electrode, respectively. The solution system was 4.0 mol/L NaCl+0.5 mol/L $KNO_3$+0.1 mol/L $HNO_3$. The experimental temperature was controlled at (25±2) °C.

## 2 Results and Discussion

### 2.1 Microstructure

Fig.1 shows the cast microstructure of 7085 aluminum alloys with and without rare earth additives. Grains of alloy without rare earth are coarse and heterogeneous. The average grain size is about 80 μm (Fig.1a). The grains of 7085-Y aluminum alloy are refined, and grains are homogeneous. The average grain size is about 41 μm (Fig.1b). 7085-Er alloy is equivalent to that of 7085-Y alloy with a decreased grain size of 34 μm (Fig.1c). However, with rare earth Sc addition, the grains of alloy are significantly refined, and the average grain size is only 25 μm (Fig.1d).

In order to further explore the grain refinement mechanisms of rare earth metals on the alloys, this work studied 7085 and 7085-0.15Sc alloys. It's found from Fig.2, there were a large amount of small primary phase, and they diffusely distributed in the matrix. In order to further probe into the composition of these primary phases, two trial districts were randomly selected to be applied to EDS analysis (Figs.2a, 2c and 2b, 2d). We found that the primary phase of 7085 alloy included Zn, Mg, Cu, Zr elements, while 7085-Sc alloy precipitated a lot of particles with Sc. Therefore, we can conclude the grain refinement mechanisms of rare earth metals on 7085 aluminum alloy as follows: rare earth promptes alloys to generate small $MgZn_2$, $Al_2Cu$ and $Al_3Sc$ precipitates. They are diffusely distributed in the matrix and play an important role as a kind of alterant. When the alloy is solidifying, precipitates become heterogeneous nucleation cores and decrease the strain energy of nucleation, which obviously refine the grains[6,7].

### 2.2 Mechanical properties

Table 1 shows the mechanical properties of four samples. Both tensile strength and elongation of samples with rare earth additives are higher than those without rare earth, indicating the rare earth improves the mechanical property. Specifically, after adding Sc, the tensile strength is as high as 608.3 MPa, the elongation is 12.48%, the hardness HV is 1889 MPa. Compared with the alloys without rare earth, they are increased by 14.4%, 23.7% and 10.9%, respectively.

The fracture morphologies of four samples are shown in Fig.3. The fracture morphologies of samples after aging treatment are obviously different. The fracture surfaces of 7085 alloy are characterized by river pattern, and the fracture mode is transgranular and cleavage fracture (Fig.3a). The fracture mode of 7085-Y alloy is also transgranular and cleavage fracture, and cleavage crack extending along low index surfaces leads to cleavage fracture (Fig.3b). The fracture surfaces of 7085-Er and 7085-Sc alloy are characterized by heterogeneous dimples, and the fracture mode is transgranular and quasi-cleavage fracture, as a result of cleavage crack extending along high index surfaces (Figs.3c and 3d). The dimples of 7085-Er alloy are larger and denser, so its plasticity is better and the elongation is higher.

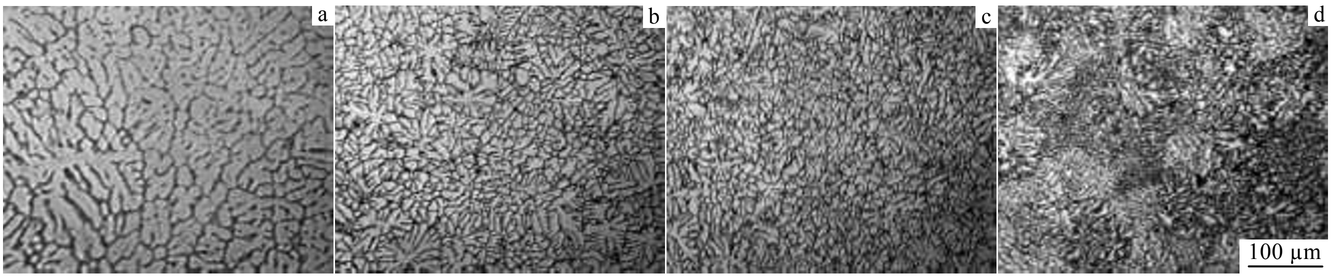


Fig.1 Microstructures of 7085 (a), 7085-Y (b), 7085-Er (c), and 7085-Sc (d) alloys