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Short communication

Effects of Er on the microstructure and mechanical properties of an as-extruded Al–Mg alloy

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ABSTRACT

The effects of rare-earth element Er on the microstructure and mechanical properties of an as-extruded Al–Mg alloy have been studied. It has been shown that without solution treatment after thermomechanical process, the addition of Er obviously decreases the yield strength, tensile strength and elongation of the as-extruded Al–Mg alloy. Microstructural analysis indicates that coarse constituents with Er and Mg have been formed in the alloys containing Er, and thus reduce the solubility of Mg in the matrix. The reducement of solubility of Mg decreases the interaction between Mg solute atoms and dislocations, and thus degrades the yield strength of the alloy. During deformation, the constituents with Er and Mg fracture first and act as the microcrack sources due to the stress concentration. The results indicate that solution treatment after thermomechanical process is a fundamental procedure to improve the mechanical properties of the Al–Mg alloys by the addition of Er element.

1. Introduction

Al–Mg series alloys have been widely used in aerospace and vehicle industries due to good combined properties such as medium strength, high ductility, excellent corrosion resistance and weldability [1]. In general, mechanical properties are required to be further improved to broaden the application of Al–Mg alloys. Currently, two methods have been used to improve the mechanical properties of Al–Mg alloys: pre-strain and micro-alloying. Previous studies [2–6] have reported the influence of pre-deformation on subsequent typical mechanical behavior of Al–Mg alloys, such as hardness, yield strength, flow stress and elongation. In most cases, the strength increases sharply with pre-strain, and more gradually for larger pre-strain. In some cases, such as 5083 Al [4,6], larger pre-deformations result in a mild lowering of the subsequent flow stress. Dalla Torre et al. [7] attributed this to the increasing misorientation between the subgrains and a decreasing width of the cell wall, leading to a greater effectiveness of boundaries to act as sinks for defects. Previous studies [8–15] indicated that the strength of Al–Mg alloys can be substantially improved by the addition of small amount of scandium due to the presence of elastically hard, coherent and nano-sized Al_3Sc (LI_2) particles, which strongly inhibit the dynamic recrystallization and dislocation movement. Kendig and Miracle [16] and Ocenasek and Slamova [17] have shown that the effect of Sc is largely amplified by the simultaneous addition of Zr since the newly formed $Al_3(Sc,Zr)$ particles decrease the lattice parameter mismatch between the matrix and the precipitates. However, the key problem of the wide application of the Sc-containing Al–Mg alloys is the high cost of scandium. Xu et al. [18] showed that Er can largely improve the mechanical properties of Al–Mg alloys due to the presence of fine and dispersed secondary Al_3Er particles after hot-rolling and solution treatment. The Al_3Er particles are coherent or semi-coherent with the matrix and act as heterogeneous nuclei during the process of recrystallization nucleation and thus remarkably refine the grains. Based on the work of Xu et al. [18], this paper further studies the effects of Er on the microstructures and mechanical properties of a hot-extruded Al–Mg alloy without solution treatment.

2. Experimental

Table 1 shows the nominal composition of the studied alloys. The alloys were prepared by a casting metallurgy method in a graphite mould, with pure Al (99.9%), pure Mg (99.9%) and Al–10 wt.% Er master alloy. The ingots were homogeneously annealed at 470 °C for 10 h, followed by air cooling to room temperature. Then the ingots were converted into rods by hot extrusion at 450 °C, with an extrusion ratio of 9:1.

The mechanical properties was tested at room temperature using a smooth dog-bone-shaped tensile specimen that had a gauge size of 6 mm in diameter and 40 mm in length at a constant strain rate of $2 \times 10^{-5}\ s^{-1}$ by an Instron-8802 testing machine. All the specimens have an axis along the extrusion direction. The microstructures were studied by scanning electron microscopy

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Table 1
The nominal composition of the studied alloys (mass fraction, %).

Samples	Mg	Er	Cr	Ti	Zr	Mn	Al
1	5.0	0	0.15	0.18	0.15	0.35	Balance
2	5.0	0.4	0.15	0.18	0.15	0.35	Balance
3	5.0	1.0	0.15	0.18	0.15	0.35	Balance

(SEM) and transmission electron microscopy (TEM). For SEM observation, a HITACHI S450 SEM with EDS was used. The TEM specimens were prepared by double-spray electro-polishing method (the electro-polishing solution was mixture of HNO_3 and CH_3OH with a ratio of 1:3) and analyzed by a Tecnai G^2 20 TEM.

3. Results

3.1. As-extruded microstructure

Fig. 1 shows the as-extruded microstructures of the alloys. It can be seen that the microstructures are similar for all three alloys after extrusion. The microstructures include high-density dislocations, which are generated due to working hardening during hot extrusion. The dislocations are distributed "quasi-uniformly" as Taylor lattice, a typical dislocation structure in Al–Mg alloys.

3.2. Mechanical properties

Table 2 shows the mechanical properties of the studied alloys. It can be seen that Er severely degrades both the strength and ductility of the tested Al–Mg alloys. When the content of Er reaches 0.4 wt.% and 1 wt.%, the tensile strength of the Al–Mg alloy has been decreased by 21.1% and 9.9%, respectively; the yield strength has been decreased by 6.5% and 4.7%, respectively; and the elongation has been decreased by 64.2% and 27.3%, respectively, compared to the alloy without Er.

3.3. Microstructure after tensile testing

Fig. 2 shows the microstructures of the studied alloys after tensile deformation. It is clear that the dislocations in alloy 1 are still distributed quasi-uniformly as Taylor lattice, which has uniform arrays of dislocations without clear spaces or pile-ups. However, the dislocations in alloys 2 and 3 are distributed non-uniformly and form cell structures rather than Taylor lattice. The dislocation density of the cell walls is very high due to the mutual trapping of dislocations into low energy configuration.

3.4. Fracture surfaces

Fig. 3 shows the fracture surfaces of the studied alloys after tensile deformation to fracture. It can be seen that alloy 1 has very fine and uniformly distributed dimples of several microns, which exhibit typical characteristics of the ductile fracture. However, the fracture surfaces of alloy 2 and alloy 3 contain variously sized dimples and intergranular cracks, and the size of dimples is larger than that of alloy 1. In addition, the coarse dimples contain secondary

Table 2
Mechanical properties of the tested three alloys[a].

Samples	σ_b (MPa)	$\sigma_{0.2}$ (MPa)	δ (%)
1	374	211	18.3
2	295	197	6.55
3	337	201	13.30

[a] Each data is the average value of seven experiments, and the maximum error is less than 10%.

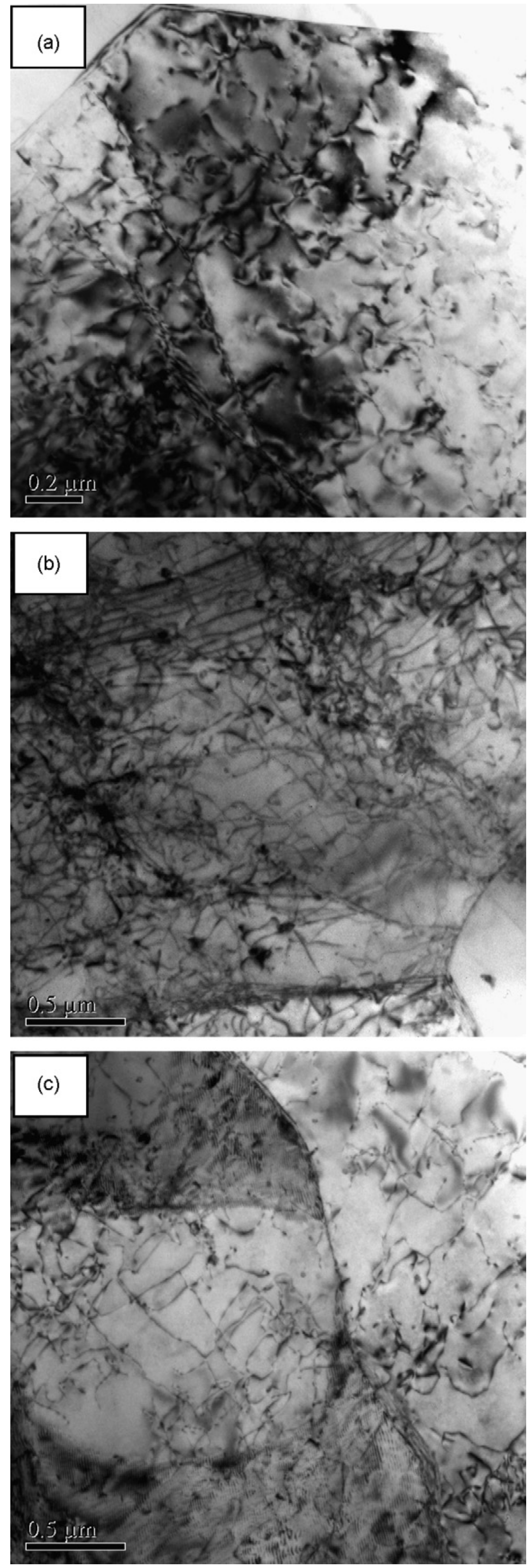

Fig. 1. TEM microstructures of the as-extruded alloys, (a) without Er, (b) with 0.4 wt.% Er and (c) with 1.0 wt.% Er.