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Effect of multi-pass equal channel angular pressing on microstructure and mechanical properties of $Mg_{97.1}Zn_1Gd_{1.8}Zr_{0.1}$ alloy

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ABSTRACT

The microstructure and mechanical properties of as-cast $Mg_{97.1}Zn_1Gd_{1.8}Zr_{0.1}$ (at%) alloy processed by multi-pass equal channel angular pressing (ECAP) at 375 °C were investigated. The results show that besides the shattering process of β phases and dynamic recrystallization (DRX) phenomenon, the refining and re-distribution process of fine-lamellae LPSO phases is the other important feature of microstructure evolution with increasing ECAP passes. Both strength and ductility of the alloy are improved simultaneously with increasing ECAP passes. Notably, after 16 ECAP passes, the ultimate tensile strength, yield strength and elongation to failure of the alloy can reach 387 MPa, 324 MPa and 23.2%, respectively, which can be attributed to numerous units, mainly consisting of strip-distributed β phase particles, micro-sized and ultra-fined grains, high-density dislocations, and a large number of 14H LPSO microcells.

1. Introduction

Magnesium alloys based on the Mg–TM–RE (TM=Zn, Cu, or Ni; RE=rare earth metals) alloy system have attracted increasing attention due to their excellent mechanical properties [1,2]. The famous RS P/M $Mg_{97}Zn_1Y_2$ (at%) alloy exhibits extraordinary high yield strength over 600 MPa at room temperature because of the effects of grain refinement and the presence of a unique long period stacking ordered (LPSO) structure [3]. Thereafter, several conventional casting methods/processes have been applied to fabricate the LPSO-containing magnesium alloys [4–6]. Homma et al. have reported that the ultimate tensile strength (UTS) and elongation to failure of $Mg_{95.5}Gd_{1.8}Y_{1.8}Zn_{0.7}Zr_{0.2}$ (at%) alloy, which were prepared through an ingot metallurgy process with hot extrusion and subsequent aging, can reach 542 MPa and 8%, respectively [7]. Xu et al. have prepared a Mg–8.2Gd–3.8Y–1.0Zn–0.4Zr (wt%) alloy by large-strain hot rolling and aging, whose UTS and elongation to failure can reach 517 MPa and 4.5%, respectively [8].

However, although many LPSO-containing magnesium alloys can achieve high strength over 350 MPa through conventional hot-extrusion or rolling process, their processing time is relatively long, and more importantly, most of their elongation values are less than 10% at room temperature.

Equal-channel angular pressing (ECAP) has been proven to be an effective method to refine the microstructure and improve the corresponding mechanical properties of pure magnesium and magnesium alloys [9–11]. In this paper, the magnesium alloy with composition of $Mg_{97.1}Zn_1Gd_{1.8}Zr_{0.1}$ (at%) containing LPSO structures was first prepared, and then was subjected to multi-pass ECAP process. Finally, the relationships between mechanical properties and microstructures evolution were revealed by the tensile tests and microstructure observations.

2. Experimental procedures

Alloy ingot with an actual composition of $Mg_{97.1}Zn_1Gd_{1.8}Zr_{0.1}$ alloy (at%) was melted from commercial pure Mg and Zn (99.9 wt %) ingots, Mg–30Gd (wt%) and Mg–33Zr (wt%) master alloys under the protection of a mixed SF_6 (1 vol%) and CO_2 (99 vol%) atmosphere in an electric resistance furnace at 750–780 °C. The chemical composition was determined by inductively coupled plasma atomic emission spectrometry (ICP-AES). The billets for the ECAP process with the dimensions of $19.6 \times 19.6 \times 40\ mm^3$ were taken from the center of the ingot. ECAP process was carried out using the die with a die angle of 90° and an outer arc angle of 0°. The details of the ECAP process have been reported in Ref. [12]. The billets were subjected to 1, 4, 8, 12 and 16 ECAP passes,

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respectively at 375 °C with an average extrusion speed of 5 mm/min. The processing time period of 16 ECAP passes for the alloy billet is around 90 min.

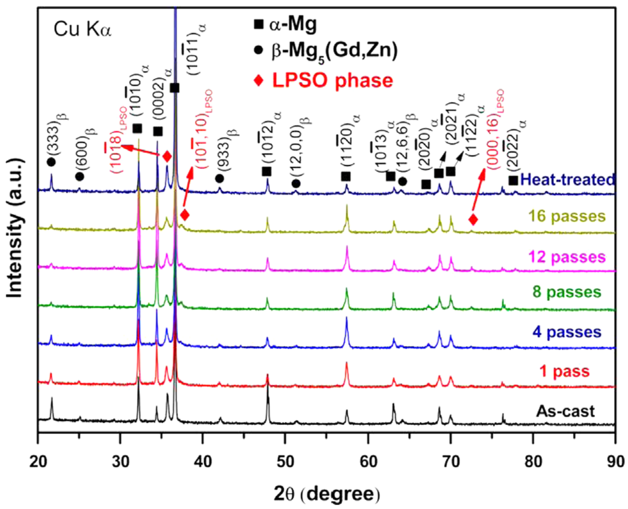

Fig. 1. XRD patterns of as-cast, heat-treated and ECAPed $Mg_{97.1}Zn_1Gd_{1.8}Zr_{0.1}$ (at%) alloys.

The tensile specimens with the gauge sections of $2 \times 2 \times 8$ mm^3 were cut from the billet along with the longitudinal direction. Tensile tests were performed on a TF50S electronic universal material test machine with an extension rate of 0.5 mm/min at the room temperature. The microstructure morphologies on the longitudinal section were observed by an optical microscope (OM, Olympus BX51), a scanning electron microscope (SEM, JEOL 6500) and a transmission electron microscope (TEM, JEOL-2000 EX). The etching solutions for OM and SEM were a mixed solution of 6 g picric acid + 10 ml acetic acid + 10 ml water + 80 ml ethanol and a 4% nital solution, respectively. The phase compositions of alloy with different ECAP passes were analyzed by X-ray diffraction (XRD, BRUKER D8). The transversal fracture morphologies after tensile tests were also observed by SEM equipped with an energy dispersive spectroscope (EDS).

3. Results and discussion

Fig. 1 shows the XRD patterns of as-cast and ECAPed $Mg_{97.1}Zn_1Gd_{1.8}Zr_{0.1}$ (at%) alloys. In order to figure out the heat effect on the alloy phase, the XRD pattern of the as-cast sample after heat treatment at 375 °C for 90 min is also shown in Fig. 1, which indicates that there is no phase change for the as-cast sample after heat treatment. The as-cast alloy is mainly composed

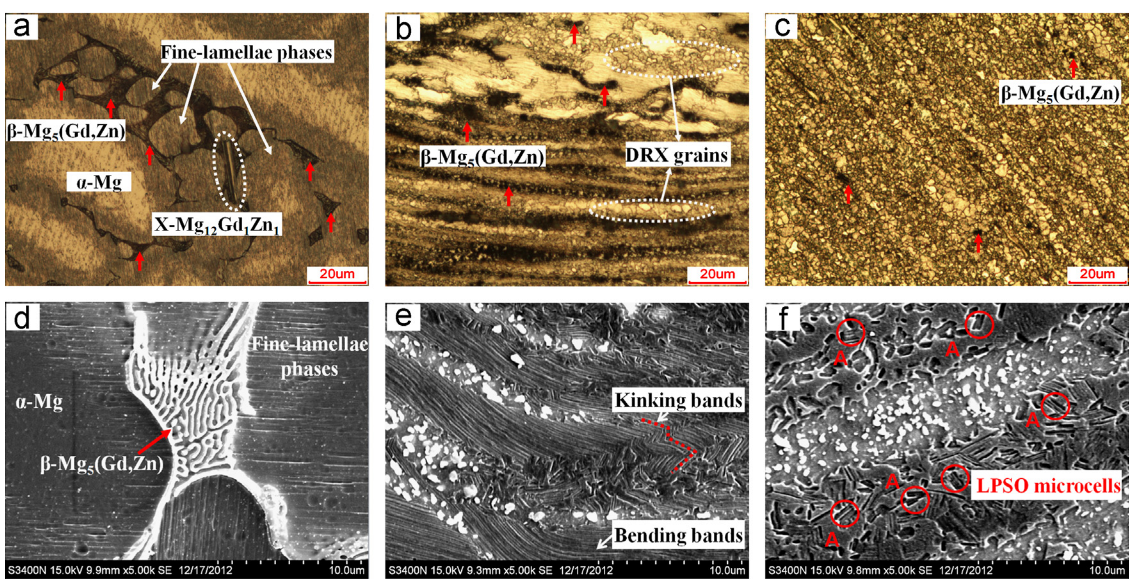

Fig. 2. OM and SEM images of $Mg_{97.1}Zn_1Gd_{1.8}Zr_{0.1}$ (at%) alloy, (a and d) as-cast, (b and e) 4-pass and (c and f) 16-pass. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

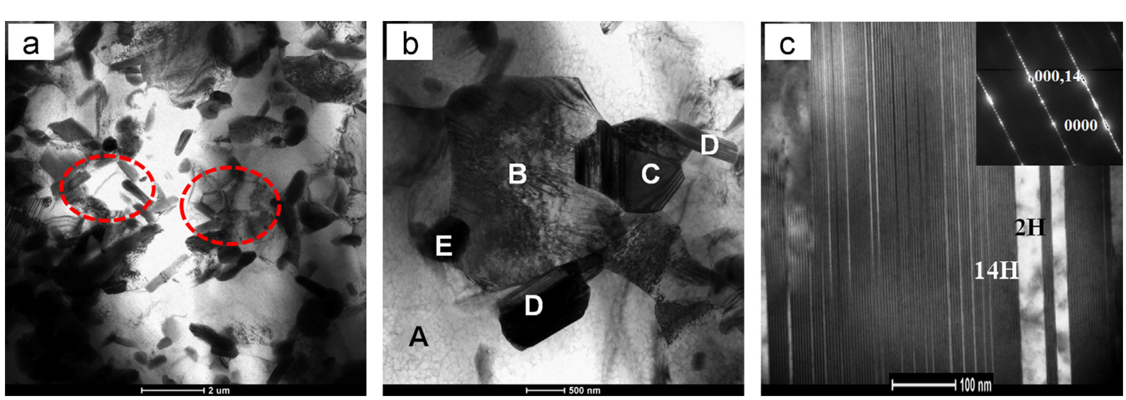

Fig. 3. TEM images: (a) 16-pass at lower and (b) 16-pass at higher magnification, and (c) fine-lamellae LPSO phases.