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Microstructure and mechanical properties of extruded Mg–8Gd–2Y–1Nd–0.3Zn–0.6Zr alloy

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ABSTRACT

The microstructure and mechanical properties of extruded Mg–8Gd–2Y–1Nd–0.3Zn–0.6Zr alloy rods were investigated. The as-extruded alloy exhibits a weak basal texture that the {0 0 0 1} basal planes in most grains are distributed parallel to the extrusion direction. The strength of the peak-aged alloy is greatly improved due to the fine β′ precipitates. Tension–compression asymmetry is observed in both the as-extruded and peak-aged alloys. The asymmetry at room temperature is connected with the texture which induces large difference in twinning generation between tension and compression. While increasing the test temperatures, the activation of twinning is suppressed, but the mechanical asymmetry still exists. For the as-extruded alloy it is related to the presence of dynamic strain ageing or dynamic precipitation during deformation; and for the peak-aged alloy it is associated with the β′ precipitates.

1. Introduction

Mg alloys, used as the lightest metal structural materials, are attracting great attention in lightweight design. Commercial Mg alloys including AZ and AM series have been widely used in the automobile and electronic industries due to their good room temperature mechanical properties, corrosion resistance and high castability [1]. However, their poor heat resistance restricts their service temperature. The addition of rare earth elements (RE) to Mg alloys has been recognized as an effective way to improve the mechanical properties of these alloys at both room and elevated temperatures. The enhancement of mechanical properties is attributed to the excellent age hardening response of Mg–RE alloys. Recently, the Mg–Gd based alloys such as Mg–10Gd–3Y–0.45Zr [2], Mg–9Gd–4Y–0.4Zr [3], and Mg–8Gd–3Y–0.5Zr [4] were developed and extensively investigated. Particularly Homma et al. [5] reported an extraordinary high strength Mg–10Gd–5.7Y–1.5Zn–0.65Zr alloy that exhibits an ultimate tensile strength of 542 MPa and tensile yield strength of 473 MPa. These superior strengths originate from the dispersive precipitates due to ageing and the fine grains obtained through hot extrusion.

On the other hand, owing to the hexagonal close-packed (hcp) crystal structure of Mg alloys, the introduction of wrought processes, such as extrusion or rolling, generally gives rise to a crystallographic texture [6,7]. Where a significant fraction of grains with their basal planes preferentially oriented parallel to the extrusion or rolling direction. Mechanical twinning especially the tension twinning is easily activated during compression along the extrusion or rolling direction, whereas it is not favored during tension along the same direction. That leads to the tension–compression asymmetry of textured Mg alloys. Since the critical resolved shear stress (CRSS) for non-basal slip systems at room temperature is much higher than those for basal slip system and twinning modes, the texture plays an important role on the plastic deformation behavior of wrought Mg alloys [8]. It is of great interest to investigate the mechanical properties of wrought Mg–Gd based alloys, which are influenced by the crystallographic texture in addition to the precipitates. Previous study indicated that the as-cast Mg–8Gd–2Y–1Nd–0.6Zr alloy exhibits a good balance of strength and ductility [9]. In the present work, 0.3 wt.% Zn was further added to this alloy in order to increase its age hardening response [10], and the microstructure and mechanical properties of the extruded Mg–8Gd–2Y–1Nd–0.3Zn–0.6Zr alloy rods were investigated.

2. Experimental

Alloy ingot with a nominal composition of Mg–8Gd–2Y–1Nd–0.3Zn–0.6Zr (wt.%) was prepared from high

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Table 1
Chemical composition of the experimental alloy (wt.%).

Gd	Y	Nd	Zn	Zr	Fe	Si	Mg
7.48	1.20	0.83	0.16	0.43	0.002	0.005	Bal.

purity Mg and Zn (99.9 wt.%), the Mg–20RE (RE = Gd, Y and Nd, wt.%) and Mg–30Zr (wt.%) master alloys in an electric-resistant furnace under an anti-oxidizing flux protection. The chemical composition of the ingot was analyzed using inductively coupled plasma atomic emission spectrometry, and the results are listed in Table 1. The ingot in diameter 80 mm was homogenized at 520 °C for 10 h followed by quenching into water at about 60 °C, and then was hot extruded at 380 °C with an extrusion ratio of 28 into rods 15 mm in diameter. Some extruded rods were directly aged at 200 °C for 64 h (T5 treatment) to obtain the peak hardness, i.e. 114 Hv.

The microstructures were characterized using an Olympus GX71 optical microscope and a JEM-2100F transmission electron microscope (TEM). The texture of the extruded rods was measured by X'pert PRO X-ray diffractometer (XRD). The reflecting surface was parallel to the extrusion direction (ED). The hardness of the aged alloy was measured by a Vickers microhardness (Hv) Tester (FM-70) with a loading force of 25*g* and a holding time of 15 s. Tensile specimens with a gauge length of 25 mm and a diameter of 5 mm and compressive specimens with a length of 12 mm and a diameter of 8 mm were prepared from the obtained samples. The tensile and compressive tests were performed using a WSM-50KB universal testing machine at room and elevated temperatures under a strain rate of $1.11 \times 10^{-3}\,s^{-1}$. The load direction was parallel to the ED. The heating-plus-holding time was 10 min to equilibrate the temperature of the specimens in tensile and compressive tests at elevated temperatures.

3. Results and discussion

3.1. Microstructure and texture

The microstructure of the as-extruded alloy is shown in Fig. 1. It consists of fully recrystallized grains with an average size (linear intercept) of 28 μm. Fig. 2 shows a typical TEM image and corresponding selected area electron diffraction pattern of the peak-aged alloy, where a lot of fine plate-like precipitates exist in the α-Mg matrix. The extra spots observed in the selected area electron diffraction pattern at $1/4\{0\bar{1}10\}_\alpha$, $1/2\{0\bar{1}10\}_\alpha$, and $3/4\{0\bar{1}10\}_\alpha$ are in accordance with the β′-phase that has been reported in many Mg–RE alloys [2,5,11]. The plate-like β′-phase with a bco structure ($a \sim 2a_{Mg}$ = 0.64 nm, $b \sim$ 2.2 nm, $c \sim c_{Mg}$ = 0.52 nm) forms on the prismatic planes of α-Mg matrix, and these prismatic plates play a dominate role in the strengthening of Mg–RE alloys [2,5].

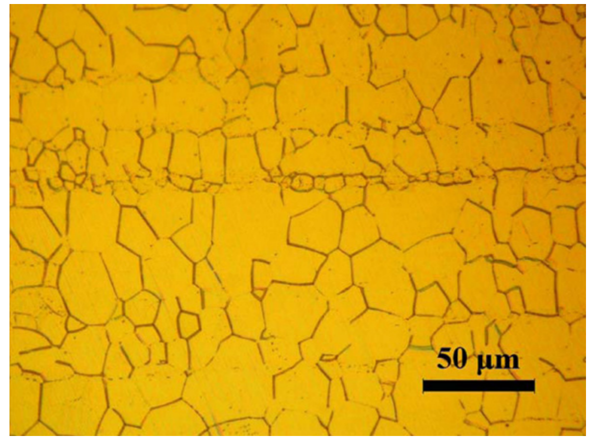

Fig. 1. Optical micrograph of the as-extruded alloy.

The {0 0 0 2} pole figure of the as-extruded alloy is presented in Fig. 3. It is found that the pole figure exhibits a roughly basal texture, in which the main component of {0 0 0 1} basal planes is distributed parallel to the ED, meanwhile, there is a moderate component of the basal planes tends to be inclined at about 50° to the ED-radial direction (RD) plane. This result is similar to previous investigations showing that Mg alloys containing RE alloying elements usually develop weaker and more random textures during rolling or extrusion [6,12]. In addition, the texture of the extruded alloy could be preserved effectively in the peak-aged alloy due to the negligible grain growth during isothermal ageing [5].

3.2. Mechanical properties

3.2.1. Tensile deformation

The tensile true stress–strain (s–s) curves obtained in the as-extruded and peak-aged alloys are shown in Fig. 4. It indicates that

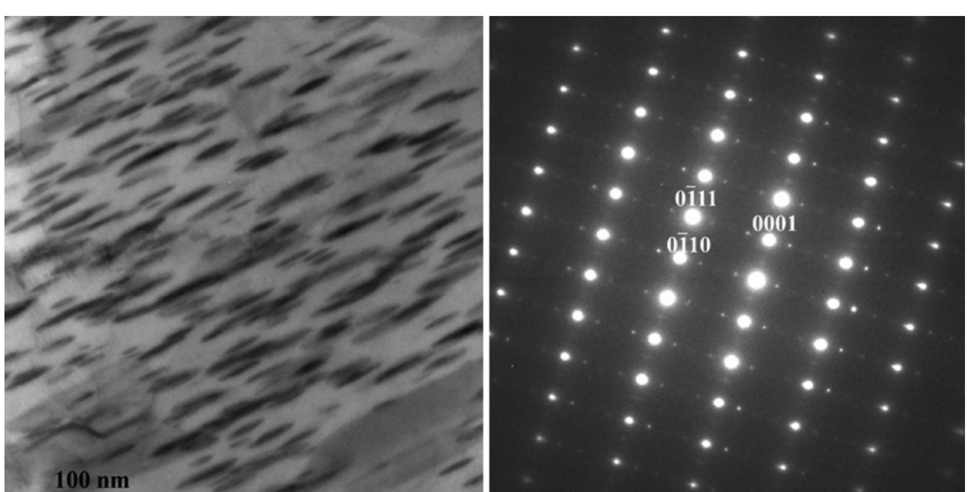

Fig. 2. TEM image showing fine precipitates in the peak-aged alloy, and associated $[2\bar{1}\bar{1}0]$ Mg diffraction pattern.