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Effect of microstructure and texture on the mechanical properties of the as-extruded Mg–Zn–Y–Zr alloys

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Abstract

This work mainly studied the influence of the microstructure and crystallographic texture on the mechanical properties of the as-extruded Mg–Zn–Y–Zr alloys with different Y contents. The samples were machined from thick plates obtained by extrusion and the tensile tests were performed parallel to extrusion and transverse directions, respectively. Microstructure observation firmly indicated that the grain-refining effect of icosahedral quasicrystal phase (I-phase) was superior to that of the cubic W-phase. In addition, the tensile results indicated that I-phase could effectively improve the strength (yield strength and ultimate tensile strength) of alloys. However, strengthening effect of W-phase was lower. With the quantity of W-phase increasing, the strength of alloys was degraded. It also showed that the alloys were mechanically anisotropic, i.e. the longitudinal strength was higher than that of the transverse direction. However, the ductility of the transverse direction was superior. With the increase of Mg–Zn–Y phases, the anisotropy of the ultimate tensile strength (UTS) between the longitudinal and transverse directions increased remarkably. SEM fracture observations showed that the fractures of the TD samples were characterized by the typical “woody fracture”, with a large amount of cracked Mg–Zn–Y particles (I-phase and W-phase) distributed at the bottom of dimples. With Y content increasing, the average spacing of the zonal distributed Mg–Zn–Y particles on the fracture surface became narrow, which influenced the transverse mechanical properties greatly.

Keywords: Mg alloy; Crystallographic texture; Anisotropy; Woody fracture; Mechanical properties

1. Introduction

Recently, it has been reported that the mechanical properties of wrought Mg alloys are superior to those of cast Mg alloys, because the former has a finer grain structure [1]. Generally, wrought Mg alloys having a grain size less than 10 μm, can be easily obtained just through primary processing such as hot rolling or extrusion [2,3]. However, these procedures generally give rise to a strong basal texture. Since the critical resolved shear stress (CRSS) of a basal plane at room temperature is much lower than that of a non-basal plane [4], the mechanical properties of wrought Mg alloys are greatly influenced by the basal texture [5–9]. At present, wrought Mg–Zn–Y–Zr alloys have attracted wide attention because they have both high yield strength and tensile strength either at room or elevated temperatures [10]. It has been reported [11–15] that the content variation of rare earth elements (RE) and element Y in the alloys can influence the mechanical properties greatly, which is mainly ascribed to the Orowan mechanism [16]. However, due to the addition of element Y, a large amount of Mg–Zn–Y phases (W–$Mg_3Zn_3Y_2$ and I–Mg_3Zn_6Y) are formed at the grain boundaries of the as-cast alloys [10,17]. Therefore, when the as-cast ingots were forged into thick plates, Mg–Zn–Y phases were cracked and zonal distributed along the deformation direction [18]. With Y content increasing, the quantity of the zonal distributed Mg–Zn–Y phases will increase greatly and the influence of Mg–Zn–Y phases on the mechanical properties of the alloys should be taken into consideration. Therefore, the mechanical anisotropy of the as-extruded Mg–Zn–Y–Zr alloys should not be solely depended on the crystallographic texture, and the influence of Mg–Zn–Y phases should be considered.

Therefore, in the present studies, the longitudinal and transverse mechanical properties of the as-extruded Mg–Zn–Y–Zr alloys (with Y contents of 0, 1.08, 1.97and 3.08 wt.%) have

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Table 1
Chemical composition of the as-extruded Mg–Zn–Y–Zr alloys

Nominal alloy	Composition (wt %)				
	Mg	Zn	Y	Zr	Zn (wt %)/ Y (wt %)
Alloy I	Bulk	5.68	0	0.78	–
Alloy II	Bulk	5.53	1.08	0.83	5.12
Alloy III	Bulk	5.64	1.97	0.73	2.86
Alloy IV	Bulk	5.49	3.08	0.82	1.78

been investigated and compared to determine the influence of Mg–Zn–Y phases and the crystallographic texture on the mechanical anisotropy.

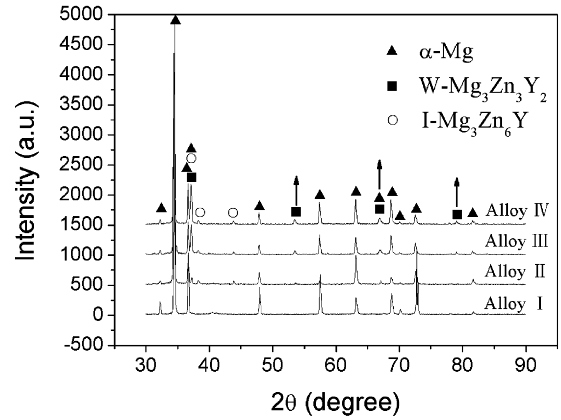

Fig. 1. X-ray diffraction patterns of the alloys I–IV. (The arrows in the figure indicate the intensifying tendency of the W-phase diffraction peak) (in JPEG format).

2. Experimental procedures

The materials used in this study were the as-extruded Mg–Zn–Y–Zr magnesium alloys with different Y contents, which were prepared by special technology in magnesium alloy research department of IMR, China. Through inductively coupled plasma atomic emission spectrum (ICP-AES) apparatus, the chemical compositions of the alloys I–II were determined (listed in Table 1). The alloys were made by melting high-pure magnesium in an electric resistance furnace, and then 6.3 wt.% Zn, 2.0 wt.% Zr and different wt.% Y were added under the protection of SF_6 and CO_2 mixed gas. After stirring the molten alloy and keeping for 30–40 min at 710 °C to homogenize it, molten alloys were cast into cylindrical ingots with 110 mm in diameter, and 500 mm in height. It has been reported [14] that the tensile properties of the as-cast Mg–Zn–Y–Zr magnesium alloys without homogenization were superior. Therefore, in this experiment no homogenized treatment was carried out to the as-cast Mg–Zn–Y–Zr alloys. Then the as-cast ingots were extruded into thick plates with cross section of 14 mm × 60 mm at 390 °C. The extrusion ratio was 10:1.

Microstructures of the alloys I–II on the L (longitudinal)–T (transverse) plane were examined by the means of optical microscope (Axiophoto 2 image). The samples were etched with an etchant of 4 ml nitric acid and 96 ml water. Phase analysis and the (0 0 0 2) pole figures representing the basal plane were determined by D/Max 2400 X-ray diffractometer (XRD). The tensile bars with a gauge length of 25 mm and 5 mm in diameter were machined from the alloys. The axial directions of the tensile specimens were parallel to the extruded direction (ED samples) and parallel to the transverse direction (TD samples), respectively. Tensile experiments were conducted on the MTS (858.01 M) testing machine with the constant strain rate of $1 \times 10^{-3}\ s^{-1}$ at room temperature. SEM (XL30-FEG-ESEM) observations using either secondary electron imaging (SEI) or Backscatter electron imaging (BEI) has been done to determine the fracture characteristics and the distribution and quantity of the cracked Mg–Zn–Y phases (I-phase and W-phase) on the fracture surfaces.

3. Experimental results

3.1. The microstructures of the as-extruded Mg–Zn–Y–Zr alloys

XRD analysis reveals that the main phases vary with Y content, as shown in Fig. 1. It shows that with the addition of element Y, the main phases of alloy II are I-phase and α-Mg, whereas the main phases of alloys III and IV are I-phase, W-phase and α-Mg. With the increase of Y content, the diffraction peak of W-phase will be gradually intensified. It has been reported [17,19,20] that I-phase could form interdendritic eutectic pockets with α-Mg. Therefore, based on the optical microstructure of the as-cast alloys I–IV [21], it was very easy to distinguish W-phase from I-phase by their different morphologies. It also indicated [22] that for alloy II, I-phase was the main ternary phase, whereas for alloys III and IV, with the increasing of Y content, the quantity of W-phase gradually increased and I-phase mainly existed at the triple junctions of grain boundaries. In the previous work [11], it indicated that Zn/Y (in wt.%) ratios of I-phase (Mg_3Zn_6Y) and W-phase ($Mg_3Zn_3Y_2$) are 4.38 and 1.10, respectively. By a comparison of Zn/Y ratios of the alloys, when Zn/Y ratio exceeds 4.38, it will meet the requirement to completely form I-phase. However, when Zn/Y ratio was between 1.10 and 4.38, then the quantity of Zn could not meet the requirement to completely form I-phase and some W-phase would be formed to make element Y being fully existed in the form of Mg–Zn–Y phases [11]. With the decreasing of Zn/Y ratio, more W-phases will be formed in the Mg matrix. Therefore, through checking the different Zn/Y ratios (listed in Table 1) of the alloys, the change process of the main phases can be easily understood.

The microstructure observations of the as-extruded Mg–Zn–Y–Zr alloys with different Y contents are shown in Fig. 2. It shows that the grain size decreases with the addition of element Y. For alloy I (ZK60), the grain size is about 15 μm, whereas the grain size of alloys II and III (with Y contents of 1.08 and 1.97 wt.%, respectively) is about 8 μm. When Y content reaches to 3.08 wt.%, the grain size of alloy IV is further refined, with the size about 2–4 μm. Although the grain