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Full Length Article

Mechanical properties of Mg-8Gd-3Y-0.5Zr alloy with bimodal grain size distributions

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Abstract

The Mg-Gd-Y-Zn-Zr alloys are representational and potential age-hardening systems as reported in the past ten years, but their mechanical properties are still dependent on the grain size and its distribution. The effect of bimodal structure on mechanical properties of Mg-8Gd-3Y-0.5Zr alloy with bimodal grain size distributions was investigated. The results suggested that the volume fraction of fine grain (FG) and coarse grain (CG) could be controlled by combined processes of hot forging, extrusion and annealing. And for the present alloys with bimodal grain size distribution, the improvement of strength is still attributed to the grain refinement. The morphology of bimodal grain size distribution has a marked impact on the ductility of the alloy, i.e. with the increase of coarse grain volume fraction, the elongation to failure increases at the beginning and then decreases. The mechanism of the toughening effect of bimodal grain size distribution on the Mg-Gd-Y-Zn-Zr alloys with bimodal grain size structure has been discussed.

Keywords: Mg-Gd-Y-Zr alloy; Forging; Extrusion; Bimodal grain size distribution; Mechanical properties

1. Introduction

Wrought Mg alloys have attracted great interest in recent years owing to their mechanical properties superior to those of cast alloys, which makes them ideal for many practical applications in industry field. However, poor ductility and lower mechanical properties especially at elevated temperatures limit further use of Mg alloy. This limitation is being overcome with the development of rare-earth (RE) Mg alloys [1]. The relatively high strength of RE Mg alloys is due to precipitation hardening caused by strengthening precipitate phases formed by rare earth addition [2–5].

The processes such as extrusion, rolling and forging are generally introduced as methods to obtain wrought Mg-RE alloys. Mg-Y-Nd-Zr alloys with the yield strength (YS) of about 200 MPa, ultimate tensile strength (UTS) of little less than 300 MPa and superior elongation (EL) to failure of about 15% were produced by hot extrusion [6,7]. Chen, Z. [8] and Xia, X. [9] obtained Mg-Gd-Y-(Zn)-Zr alloy with almost ultrafine dynamically recrystallized (DRXed) grains via rolling and extrusion, respectively. The YS, UTS and EL of the alloy were about 350 MPa, 250 MPa and 12%, respectively. Mg-7Gd-5Y-1Nd-0.5Zr exhibiting an excellent balance between strength and ductility was fabricated by multidirectional forging [10].

In 2012, Xu, C. et al. [11] prepared Mg-8.2Gd-3.8Y-1.0Zn-0.4Zr alloy sheets with bimodal grain size distribution of fine DRXed grains and large deformed grains. The sheets exhibit excellent tensile properties at room temperature, i.e. their YS, UTS and EL were 426 MPa, 517 MPa and 4.5%, respectively. Bimodal grain size distribution was first introduced to nanostructure materials to produce higher ductility, in addition to high strength. Many theoretical studies have analyzed the mechanical performance of the bimodal alloys, relevant to the grain size and volume fraction of coarse grains [12–14]. Besides, much attention has been paid to the experimental and modeling research of mechanical properties of bimodal materials [15–21]. For example, Wang et al. [12] achieved high ductility in a nanostructured copper and proposed an idea of improving strain hardening to derive good ductility from other nanostructured materials, where abnormal grain growth is often observed. Bimodal structure was also applied to Ni alloys, e.g.

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both high ductility and strength are achieved in bulk multimodal and bimodal nanostructured nickels fabricated by forging [17]. Recently, Wu et al. [19,22] have reported a Ti metal with heterogeneous lamella structure, owning ultrafine-grain strength and coarse-grain ductility and they have presented a perspective on heterogeneous materials.

As for Mg alloys, little study on bimodal structure has been carried out. Last year, Xiao et al. [23] have applied interrupted hot deformation to a cast Mg-Gd-Y-Zr alloy and found an improvement of tensile ductility with little drop in strength by increasing the volume fraction of ultrafine grains (UFGs), i.e. with the volume fraction of UFGs raised from 30% to 70%, EL increased from 15% to 23%. However, in their study, alloys with volume fraction of UFGs higher than 70% have not been prepared and the impacts of the grain size distribution and volume fraction of coarse grains on the strength have not been mentioned. Thus, it is meaningful to provide a supplement of the impact of volume fraction of coarse grains on the ductility and to figure out the impact of bimodal structure on strength, which is the very purpose of the present study. The present work was aimed to investigate the mechanical behaviors of a Mg-8Gd-3Y-0.5Zr alloy with bimodal grain size distribution prepared by hot forging and hot extrusion. The effect of bimodal structure on mechanical properties of Mg-8Gd-3Y-0.5Zr alloy would be discussed.

2. Experimental procedure

The composition of the Mg-Gd-Y-Zr alloy investigated was 8% Gd, 3% Y, 0.5% Zr, respectively, and balanced Mg (wt. %), hereafter denoted as GW83 K. The as-cast ingot prepared by semi-continuous casting method was machined into cylinders with the size of Φ190mm × 130 mm, subsequently homogenized at 773 K for 9 h and then cooled in air. Forging experiments were carried out with a 250 kg pneumatic hammer using a stretching mode that the billets were lengthened with the reduction of cross-section. The cylinders were free-forged along two equivalent directions (perpendicular to each other and rotated for 90 °C repeatedly) into cuboids with a square cross-section of 120 mm × 240 mm and were then water quenched to avoid grain growth after deformation.

Afterwards, samples with a dimension of Φ60 mm × 70 mm were cut along the lengthening direction of the cuboids. The cylinders were extruded to 30 mm diameter rods at 623 K, 648 K, 673 K, respectively, with an extrusion ratio of 4:1 and an extrusion rate of 2 mm/s. Prior to extrusion, these cylinders were preheated at corresponding extrusion temperature for 0.5 h in a resistance furnace. After extrusion, the rods were quenched into water immediately to maintain the microstructure. In order to get more samples with different bimodal grain size distribution, two methods were introduced to the experiment, i.e. annealing at 623 K and changing sampling location. The parameters of the samples were listed in Table 1. Nos. A1–A5 are for samples with various grain sizes after annealing. No. B (L1–L9) is for samples obtained from different locations along the extrusion direction. The schematic of sample B (L1–L9) is shown in Fig. 1. Due to the difference in cooling speed during the extrusion process, the recrystallization and the extent of grain growth are different and as a consequence, samples with different grain sizes can be obtained along the extrusion direction.

Table 1
Parameters of the samples.

Extruding temperature	Sampling method	Name
A (648 K)	–	A-A1
	Annealing at 623 K for 10 min	A-A2
	Annealing at 623 K for 20 min	A-A3
	Annealing at 623 K for 30 min	A-A4
	Annealing at 623 K for 40 min	A-A5
B (623 K)	Location 1	B-L1
	Location 2	B-L2
	Location 3	B-L3
	Location 4	B-L4
	Location 5	B-L5
	Location 6	B-L6
	Location 7	B-L7
	Location 8	B-L8
	Location 9	B-L9
C (673 K)	–	C

The tensile specimens along extrusion direction (ED) with a gauge length of 10 mm, cross-sectional area of 3×1.2 mm^2, were cut from the samples and tested at ambient temperatures using a Zwick/Roell testing machine with a cross-head speed of 0.5 mm/min. The tensile test for each sample was repeated three times to ensure repeatability and accuracy, and the results were averaged (with error bar) to evaluate the tensile value. To obtain precise microstructure corresponding to the mechanical properties, the specimens used to analyze microstructure were cut from the nearest area to the gauge length (with plane parallel to ED). The microstructures were examined by using optical microscopy (OM) and electron backscattering diffraction (EBSD) technology. The samples used for OM were mounted, polished and etched by a picric acid solution while those used

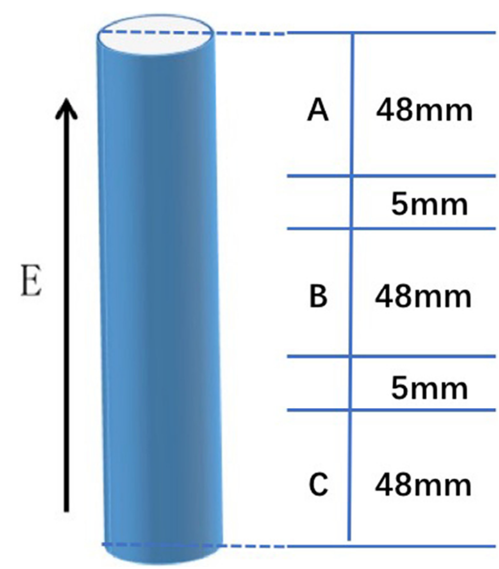

Fig. 1. The selection criteria of locations 1–9 of sample B (L4, L8, L9 from region A, respectively; L3, L5, L7 from region B, respectively and; L1, L2, L6 from region C, respectively).

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