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Full length article

Role of multi-microalloying by rare earth elements in ductilization of magnesium alloys

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Abstract

The present work investigates the influences of microalloying with rare earths on the mechanical properties of magnesium alloys. The amount of each rare earth element is controlled below 0.4 wt.% in order not to increase the cost of alloy largely. The synergic effects from the multi-microalloying with rare earths on the mechanical properties are explored. The obtained results show that the as-cast magnesium alloys multi-microalloying with rare earths possesses a quite high ductility with a tensile strain up to 25−30% at room temperature. Moreover, these alloys exhibit much better corrosion resistance than AZ31 alloy. The preliminary *in situ* neutron diffractions on the deformation of these alloys indicate that the multi-microalloying with rare earths seems to be beneficial for the activation of more slip systems. The deformation becomes more homogeneous and the resultant textures after deformation are weakened.

Keywords: Microalloying; Magnesium alloy; Ductility; Rare earth element

1. Introduction

Mg alloys with a low density and high specific strength is an ideal structure engineering materials for light-weighting applications. Compared with the traditional steel or aluminum materials, they have not been widely accepted by consumer. Their commercial products are mainly fabricated by die casting. In contrast to cast products, the wrought Mg alloys only have a small market with a proportion of less than 5% [1]. The main obstacles to prevent the wrought products from widespread applications are their low ductility/toughness and poor corrosion [2]. Therefore, to improve the formability and corrosion resistance becomes an urgent issue to extend the applications of Mg alloys.

The low ductility/toughness of magnesium is due to the intrinsically brittle nature of the hexagonal close-packed (h.c.p) crystal structure. The critical resolved shear stress of the basal <a> slip system of single-crystal Mg is approximately 1/100 of that of other slip systems at room temperature [3,4]. The basal <a> slip occurs readily in comparison with the other slip systems. Consequently, the formation of sharp basal <a> or near basal deformation textures leads to a high deformation anisotropy in Mg.

For magnesium alloys, three main reasons are responsible for their poor corrosion resistance. First, they are highly susceptible to galvanic corrosion, usually observed as heavily localized corrosion in the regions adjacent to the cathode. The cathodes can be external as other metals in contact with magnesium, or may be internal as second phases or impurity phases [5]. Second, the quasi-passive hydroxide film on the surface is

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not as stable as the passive films formed on aluminum [6]. Finally, as the components used in the automotive, the stress corrosion cracking is also one of dangerous reasons accounting for the limit of applications [7].

In order to overcome the above-mentioned problems encountered in Mg alloys, the multi-micro-alloying concept is introduced to develop new wrought Mg alloys [8,9]. The used alloying elements are mainly those rare earth elements with a large solubility in Mg. The designed alloys are close to a single phase solid solution. They were nominally expressed as Mg–REs–0.5Zr (wt.%). REs stands for rare earths elements; zirconium (Zr) was mainly used as the grain refiner [10]. Recent results demonstrated that the addition of REs is the most promising method to weaken the texture and improve the deformability of magnesium alloys [11–14]. Agnew et al. concluded that the addition of Y can promote the $c + a$ slip, which accommodates the c-axis deformation and then alleviate the deformation anisotropy [15]. Furthermore, the addition of REs in magnesium alloys increases the stability of anti-oxide film on the surface [16], which would be helpful for the improvement of corrosion resistance.

2. Experimental

2.1. Preparation

Mg–REs–0.5Zr alloys were prepared in a steel crucible under a cover gas mixture of CO_2 and SF_6. After stirring at 730 °C for 0.5 h, the alloy was cast to the mould preheated at 500 °C. The filled mould was held at 670 °C for 30 min under the protective gas to let the heavy impurities settle to the bottom and the light impurities float up to the top of the ingots. Then the permanent mold direct chill casting was used to prepare the alloys [17]. The whole steel crucible with the melt was immerged into the continuous cooling water at a speed of 20 mm/s. As soon as the liquid level of inside melt is aligned with the height of outside water, the solidification process was finished. The weight of each obtained ingot is about 2 Kg. The detailed chemical compositions of the alloys analyzed by X-ray fluorescence spectrometer are shown in Table 1. The content of Y is a little lower than the nominal composition of 0.4%. The compositions of other REs are close to the designed compositions of 0.4%.

2.2. Microstructural observations

Microstructures were examined using optical microscope and scanning electron microscopy (SEM). The polished samples for optical observations were taken from the same locations. They were chemically etched in a solution of 8 g picric acid, 5 ml acetic acid, 10 ml distilled water and 100 ml ethanol. The optical microstructure was characterized using a light microscope (Reichert-Jung MeF3, Germany) with a polarization system. The specimens for SEM observations were electropolished after mechanical polishing. During electropolishing, no any water-containing agents were used. After polishing, the specimens were observed using SEM immediately.

Table 1
Chemical compositions of typical alloys (wt.%).

Sample	Y %	Dy %	Gd %	Sm %	Zr %
Mg04YZr	0.20				0.029
Mg04GdZr			0.38		0.203
Mg04DyZr		0.38			0.209
Mg04SmZr				0.44	0.180
Mg04Y04GdZr	0.28		0.38		0.154
Mg04Y04DyZr	0.27	0.36			0.193
Mg04Y04SmZr	0.21			0.46	0.210
Mg04Gd04DyZr		0.45	0.38		0.188
Mg04Gd04SmZr			0.38	0.46	0.209
Mg04Dy04SmZr		0.36		0.45	0.216
Mg-04Gd04Dy04SmZr		0.34	0.38	0.45	0.217
Mg–04Y04Gd04Dy04SmZr		0.35	0.38	0.44	0.209

2.3. Mechanical properties

The tensile and compressive tests were performed in accordance to DIN EN 1002 at room temperature using a Zwick 050 testing machine. For the tension tests, specimens with a gauge length of 25 mm and a diameter of 5 mm with threaded heads were used. The compressive samples had a length of 16 mm and a diameter of 11 mm.

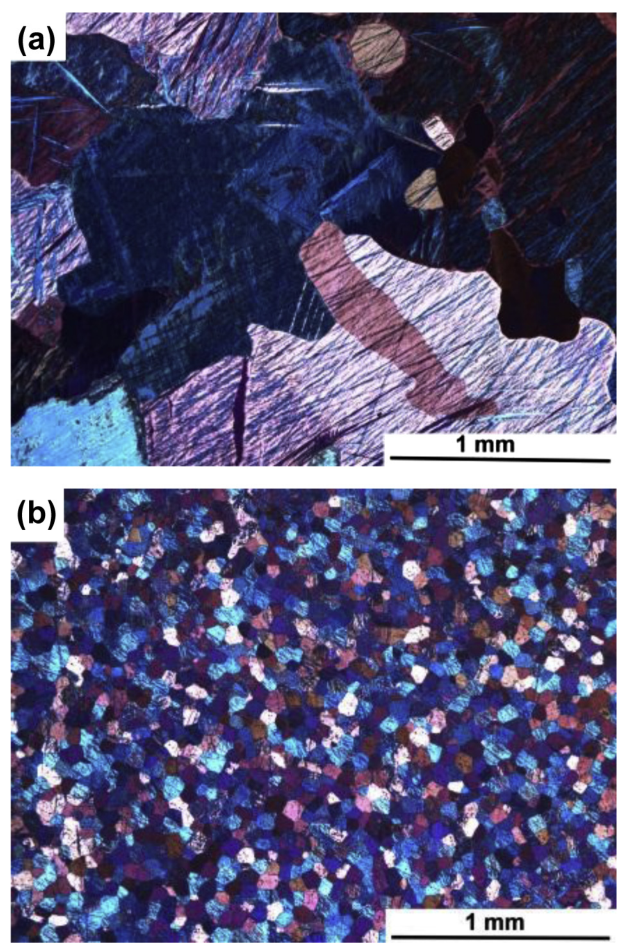

Fig. 1. Optical microstructures of Mg–0.4Y–0.4Gd–0.4Dy alloy, (a) without Zr and (b) with Zr.