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Microstructure and tensile properties of as-cast and as-aged Mg–6Al–4Zn alloys with Sn addition

Xuguang Dong, Junwei Fu, Jing Wang, Yuansheng Yang *

Institute of Metal Research, Chinese Academy of Science, Shen yang 110016, China

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ABSTRACT

The effect of 0–1.8 wt.% Sn addition on the microstructure and tensile properties of Mg–6Al–4Zn alloys was investigated. The results indicate that α-Mg dendrite is gradually refined with increasing Sn content and interdendritic $Mg_{21}(Al,Zn)_{17}$ and $Mg_{17}Al_{12}$ intermetallics can also be refined with 0.6 wt.% Sn addition. However, higher Sn addition leads to the coarsening and continuous distribution of the interdendritic intermetallics due to the stronger interdendritic segregation of Al and Zn. With the modified casting structure, the as-cast Mg–6Al–4Zn–0.6Sn alloy shows optimal ultimate tensile strength and elongation. After ageing treatment, the density of nano-scaled continuous precipitates into α-Mg matrix in all the Sn-containing alloys is enhanced markedly, which results in higher tensile strength due to enhanced ageing strengthening. Meanwhile, based on the microstructural analyses, alloy with 1.2 wt.% Sn can restrict forming discontinuous precipitates at grain boundary effectively. The as-aged Mg–6Al–4Zn–1.2Sn alloy possesses the excellent combination of strength and ductility.

1. Introduction

As conventional cast magnesium alloys, Mg–Al–Zn based alloys have been extensively used in automobile and electronic industries due to their low cost, high specific strength, moderate corrosion resistance [1]. Considering the castability, the Zn content in Mg–Al–Zn based alloys is generally less than 1 wt.%, which results in the development of commercial AZ system alloys, such as AZ91, AZ80, AM60 and AZ31 magnesium alloys. However, recent results indicate that adjusting Zn content of AZ system alloys is an effective method to improve the combination of strength and ductility [2–6]. Therefore, based on the previous works concerning the castability of Mg–Al–Zn alloys [7], AZ system alloys with higher Zn-content are considered as the potential candidates for the development of magnesium alloys with high strength and ductility.

Additionally, alloying techniques are widely used to improve the mechanical properties of commercial AZ system alloys. Li et al. [8] found that Sn addition can suppress the formation of discontinuous precipitation at grain boundary in aged AZ91D alloy. And there is no discontinuous precipitation when the Sn addition is up to 2.0 wt.%. Sevik et al. [9] investigated the microstructure and mechanical properties of AM60 alloys with 0.5–4.0 wt.% Sn addition. It was shown that 0.5 wt.% Sn addition remarkably increased the impact strength and 4.0 wt.% Sn led to the optimal ultimate tensile property of 212 MPa. Based on the in situ fracture observation, Kima et al. [10] found that addition of 3.0–5.0 wt.% Sn into AZ51 alloy can improve the tensile and fracture properties by introducing twins in α-Mg grain and suppressing crack initiation and propagation. Recently, Turen [11] investigated the effect of Sn addition on microstructure, mechanical and casting properties of AZ91 alloy, which indicated that 0.5% Sn addition not only increased the strength and ductility but also improved the casting properties. In addition, our previous investigation [12] found that the Mg–4Al–2Sn alloy shows great potential for the development of high ductility magnesium alloys. Therefore, Sn element is considered as an effective alloying addition to improve the casting and mechanical properties of Mg–Al based alloys. However, up to now, the mechanism of the influence of Sn element on the microstructure and mechanical properties of cast AZ system alloys containing higher Zn content (>1.0 wt.%) is still not clear.

In the present study, the higher Zn-content Mg–6Al–4Zn alloy was chosen as the based alloy due to its moderate castability and excellent mechanical properties [5,7]. The microstructure, phase composition and mechanical properties of Mg–6Al–4Zn alloy with 0–1.8 wt.% Sn additions were investigated, to seek the favorable effects of Sn addition on the solidification microstructure, precipitation strengthening and tensile properties. The results will be helpful for the future development of new-style Mg–Al–Zn-Sn system alloys with high strength and ductility.

2. Experimental procedures

The Mg–6Al–4Zn–xSn (wt.%) (x = 0, 0.6, 1.2 and 1.8) alloys were prepared from commercial pure (>99.9%) Mg, Al, Zn and Sn, by

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* Corresponding author. Tel.: +86 24 23971728; fax: +86 24 23844528.
E-mail address: ysyang@imr.ac.cn (Y. Yang).

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Table 1
Chemical compositions of the experimental alloys.

Alloy code	Nominal composition	Practical chemical composition (wt.%)			
		Al	Zn	Sn	Mg
AZ64	Mg–6Al–4Zn	5.98	4.01	–	Balance
AZT640	Mg–6Al–4Zn–0.6Sn	5.94	3.98	0.58	Balance
AZT641	Mg–6Al–4Zn–1.2Sn	5.97	3.94	1.22	Balance
AZT642	Mg–6Al–4Zn–1.8Sn	5.95	3.95	1.77	Balance

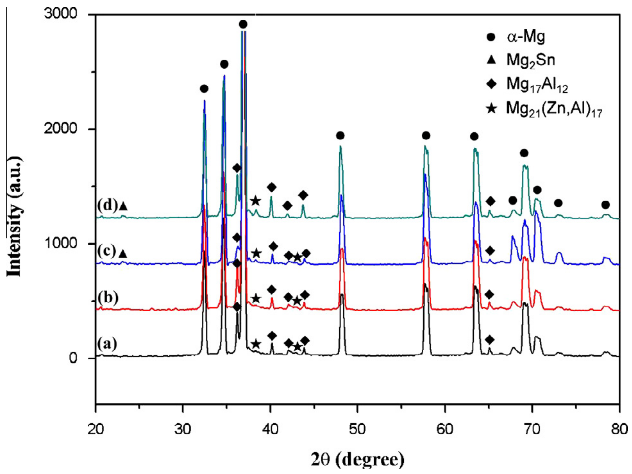

Fig. 1. XRD patterns of as-cast (a) AZ64, (b) AZT640, (c) AZT641 and (d) AZT642 alloys.

melting in an electronic resistance furnace under the protection of 99.5% CO_2 and 0.5% SF_6 mixture. The alloying melt was held at 720 °C for 30 min to homogenize, then cast into the permanent mold preheated to about 200 °C to produce the ingots with the dimensions of 20 mm × 40 mm × 160 mm. Through inductively coupled plasma atomic emission spectrum (ICP-AES) apparatus, the chemical compositions of alloys were measured and listed in Table 1. In order to ensure the $Mg_{21}(Al, Zn)_{17}$ and $Mg_{17}Al_{12}$ phases sequentially dissolved into α-Mg matrix without any grain boundary melting, the two-step solution treatment was conducted for all the alloys at 350 °C for 12 h and 380 °C for 12 h, followed by water quenching. After isothermal ageing treatment at 175 °C for 16 h, the aged specimens were cooled by dry quenching. The microscopy samples were polished and etched in 1% oxalic acid solution. Microstructure was observed by optical microscopy (OM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The volume fractions of interdendritic intermetallics were measured by metallographic analysis software. The solute concentration of the interdendritic and interdendritic areas was the average value of five measurements by electron probe micro-analyzer (EPMA). Phase compositions were determined by X-ray diffraction (XRD) and energy dispersive spectrometer (EDS). Besides, Thermo-Calc software package was used to predict the equilibrium phase composition of Mg–Al–Zn ternary alloy at 175 °C. Tensile samples were obtained from the center of all the ingots by using an electric spark machine and the specimen gauge length was $\varphi 5 \times 25$ mm under the test standard ISO 6892-1:2009 [13]. Tensile tests were conducted on an Instron-type testing machine at a constant crosshead speed of 1 mm/min at room temperature.

3. Results and discussion

3.1. As-cast microstructure

The XRD results of the as-cast alloys are shown in Fig. 1. It can be seen that all the as-cast alloys contain the $Mg_{21}(Al,Zn)_{17}$ and

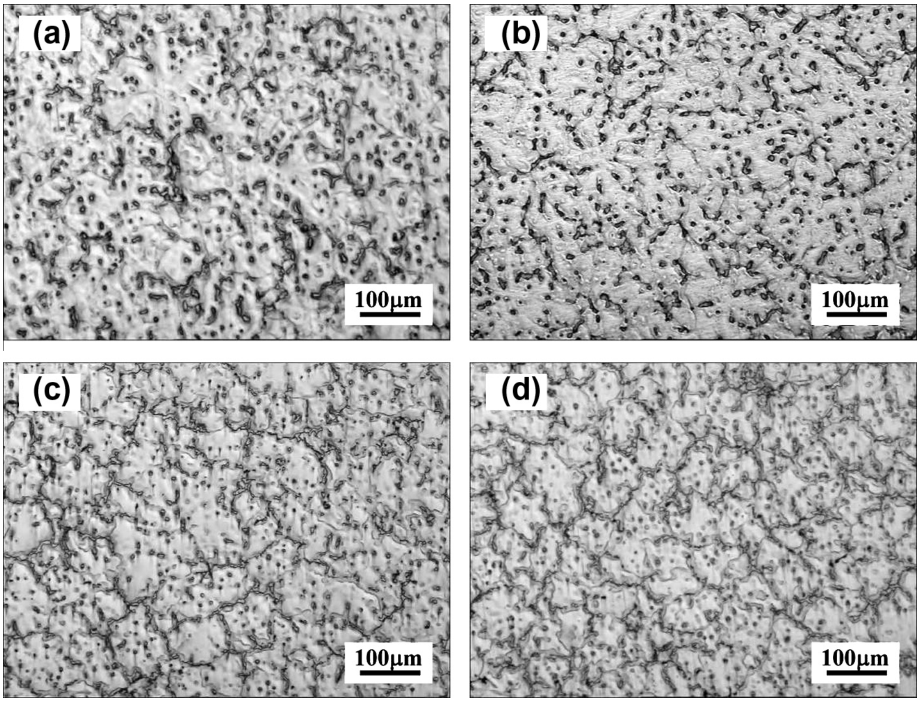

Fig. 2. Optical microstructure of as-cast (a) AZ64, (b) AZT640, (c) AZT641 and (d) AZT642 alloys.