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Effect of Zn addition on microstructure and mechanical properties of as-cast Mg−2Er alloy

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Abstract: The effect of Zn addition on microstructure and mechanical properties of the Mg−2Er alloy was investigated by X-ray diffraction (XRD) and scanning electron microscope (SEM). The results show that the alloys with 1% and 2% Zn (mass fraction) are composed of the *W*-phase and the *α*-Mg matrix. Meanwhile, the addition of 4%−10% Zn results in the formation of the *I*-phase, the *W*-phase and the *α*-Mg matrix. When the addition of Zn reaches 12%, the *W*-phase disappears and the phase constituents of the alloys mainly include the *I*-phase and the Mg_4Zn_7 phase besides the *α*-Mg solid solution. The alloy containing 6% Zn has better mechanical properties, of which the ultimate tensile strength (UTS) and the yield tensile strength (YTS) are about 224 MPa and 134 MPa, respectively, companying an elongation of 10.4%.
Key words: Mg−Zn−Er alloy; secondary phase; microstructure; mechanical properties

1 Introduction

As the lightest metallic structural material, magnesium alloys have received great attention in the last decade because of their potential for use in automotive and aerospace applications [1,2]. However, magnesium alloys generally exhibit moderate strength with limited ductility at room temperature due to their HCP structure [3]. To the best of our knowledge, the addition of the rare earth (RE) elements to magnesium alloys can improve the mechanical properties [4−6]. It can be seen from the Mg–Er phase diagram that the equilibrium solid solubility of Er in magnesium is relatively high, i.e., 32.7% (mass fraction) at 584 °C and decreases exponentially to about 16% as temperature decreases to 200 °C, forming an ideal system for precipitation hardening. ZHANG et al [7] have reported that the addition of Er significantly increased the mechanical properties of Mg alloys.

Zn is generally used as alloying element for magnesium alloy to enhance room temperature strength. A small amount of Zn can be dissolved into Mg matrix as solution strengthening element, while excess Zn will react with Mg to form (Mg, Zn)-containing phases [8,9]. LUO et al [10] have reported that the mechanical properties of the Mg−0.2Ce alloy containing Zn were superior to those of the Zn-free alloy. However, the effect of Zn addition on the microstructure and mechanical properties of the Mg−Er system alloy has not been studied in detail. Therefore, in the present work, the effect of Zn on the microstructure and phase formation of the Mg−2Er alloy was investigated.

2 Experimental

The as-cast Mg−2Er−*x*Zn (*x*=0, 1%, 2%, 4%, 6%, 8%, 10% and 12%, mass fraction) alloys were prepared from the pure Mg (99.99%), pure Zn (99.9%) and Mg−30%Er master alloys in a graphite crucible in an electric resistance furnace under an anti-oxidizing flux. The melt about 1200 g was poured into a steel mold. At last, an ingot with dimensions of 33 mm×120 mm× 200 mm was obtained.

The chemical compositions of alloys were analyzed by X-ray fluorescence (XRF) analyzer, as shown in Table 1. The phase analysis was performed by X-ray diffraction (XRD) with Cu K_α radiation. The

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Table 1 Chemical compositions of as-cast Mg−2Er−*x*Zn alloys

Nominal alloy	*w*(Zn)/%	*w*(Er)/%	*w*(Zn)/*w*(Er)
Alloy 1	0	1.9	0
Alloy 2	1.0	2.2	0.45
Alloy 3	2.1	2.0	1.05
Alloy 4	4.0	2.1	1.90
Alloy 5	6.1	2.0	3.05
Alloy 6	7.9	2.0	3.95
Alloy 7	10.0	1.9	5.26
Alloy 8	12.0	2.0	6.00

Note: Magnesium as balance

microstructure observations were carried out by scanning electron microscope (SEM, HITACHI S−450) and transmission electron microscope (TEM, JEM−2000FX, JEOL). The samples for SEM were mechanically polished and etched in a solution of 4 mL nitric acid and 96 mL ethanol. Specimens for TEM were prepared by electro-polishing and ion beam milling at an angle of incidence less than 10°.

Tensile test was carried out by using a DNS−20 universal testing machine under a constant speed of 1.0 mm/min at room temperature. Specimens for the tensile test were made into dog-bone shape with a size of 5 mm gauge diameter and 25 mm gauge length. Three specimens were tested for each sample.

3 Results and discussion

3.1 Microstructure of as-cast Mg−2Er−*x*Zn alloys

Figure 1 displays the XRD patterns of the as-cast alloys with different Zn contents. It reveals that the alloy 1 mainly consists of *α*-Mg matrix. For alloys 2 and 3, the *w*(Zn)/*w*(Y) ratio is less than 2, and the main secondary phase is *W*-phase ($Mg_3Zn_3Er_2$). However, the main secondary phases in alloys 4, 5, 6 and 7 include the *W*-phase ($Mg_3Y_2Zn_3$) and *I*-phase ($Mg_3Zn_6Er_1$). When the *w*(Zn)/*w*(Er) ratio increases with the increasing addition of Zn, the strength of the diffraction peak of the *W*-phase gets gradually weak and the strength of the diffraction peak of the *I*-phase becomes intensive. When the content of Zn reaches 12% (*w*(Zn)/*w*(Er) ratio is 6), the *W*-phase disappears and the main secondary phases are the *I*-phase and Mg_4Zn_7. Therefore, the formation of the *I*-phase and *W*-phase depends on the *w*(Zn)/*w*(Er) ratio.

The SEM images of the as-cast alloys 1−8 are shown in Fig. 2. It can be seen that the microstructure of the alloy 1 is much coarser than those of alloys 2−8. In the Mg−2Er alloy, some bright phases which are the $Mg_{24}Er_5$ phases are observed. Adding 1% Zn, the fine granular and strip secondary phase is formed. According to the XDR result, the secondary phase is the *W*-phase. With the increase of Zn content, the volume fraction of the secondary phase as well as its size increases. When the content of Zn reaches up to 12% (*w*(Zn)/*w*(Er) ratio is 6), the dendritic spacing is about 40 μm, while the width of the strip secondary phase is 2−5 μm.

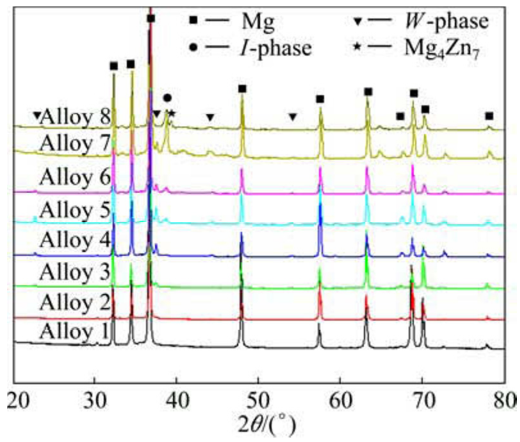

Fig. 1 X-ray diffraction patterns of as-cast Mg−2Er−*x*Zn alloys

To further confirm the existence of the *I*-phase, TEM observation was conducted for the as-cast Mg−2Er−12Zn alloy. Figure 3(a) shows the TEM image and the corresponding selected area diffraction pattern (SADP) of the *I*-phase. The SADP shows a distinct characteristic of the *I*-phase [3]. Figure 3(b) shows the TEM image of Mg−Zn phase. It indicates that the Mg_4Zn_7 phase appears in the as-cast Mg−2Er−12Zn alloy with a composition of $Mg_{41}Zn_{59}$ determined by EDS.

3.2 Mechanical properties of as-cast Mg−2Er−*x*Zn alloys

A comparison of the typical mechanical properties of all the alloys is shown in Fig. 4. The strength and elongation of the as-cast alloys tend to be improved with increasing Zn addition. The results show that the alloy 5 exhibits a higher strength, and the ultimate tensile strength (UTS) and tensile yield strength (TYS) are about 224 MPa and 134 MPa, respectively, with an elongation of 10.4%. Compared with the alloy 1, the TYS and UTS increase from 56 and 111 MPa to 134 and 224 MPa, respectively, when the content of Zn increases from 0 to 6%. Moreover, the elongation is nearly doubled. The improvement of mechanical properties of the alloys is mainly due to the strengthening effect of the secondary phase [11]. When the Zn content is in the range of 8%−12%, the content of the secondary phases (*W*-phase and *I*-phase) is high, and the size also becomes large. In the research of the cast Mg−Zn−Y−Zr alloys [12,13], it is suggested that the *α*-Mg/*I*-phase eutectic pockets could retard the basal slip and no cracks can be observed at the *α*-Mg/*I*-phase interface. However, the