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MICROSTRUCTURE AND MECHANICAL PROPERTIES OF Mg-Zn-Y-M (M: MIXED RE) ALLOYS WITH LPSO PHASE

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Abstract

$Mg_{96}Zn_2Y_{1.9}M_{0.1}$ (M=Monazite base mixed Rare Earth (RE) ($Ce_{52.4}La_{26.0}Nd_{21.6}$) in at. %) alloys were prepared by high-frequency induction melting in an Ar atmosphere. The microstructure and mechanical properties of the extruded alloys were investigated. The microstructure contained very small sized RE intermetallic compound particles within the α-Mg matrix and between the LPSO intergranular phase in the $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys. The presence of the RE compound in the $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloy was responsible for its improved tensile and creep properties over those of the $Mg_{96}Zn_2Y_2$ alloy. Excellent tensile yield strength was obtained in the extruded $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys, with a yield strength of 379 MPa at room temperature and 312 MPa at 523K, respectively. Considerable improvement was observed in the creep behavior of the $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys at 473K. Extended creep life and reduced minimum creep rate were also observed.

Introduction

Several wrought magnesium alloys such as AM- and AZ- series are structural materials which are suitable for use in the computer, mobile phone and automobile industries mainly because of their low density [1,2]. However, the number of commercially available Mg alloys is still limited especially for application at room and elevated temperatures. For example, the above-mentioned alloys of AM- and AZ-series cannot be applied to power train parts operating at temperatures higher than 130℃ due to their poor elevated temperature mechanical properties [3].

Rare earth (RE) elements have been used in magnesium alloys and they can improve the casting characteristics, mechanical properties at room and elevated temperatures and corrosion resistance [4,5]. Some investigations have been done on the morphology, microstructure and strengthening mechanisms when Res are added to Mg-Zn and Mg-Al alloys [6,7]. Recently, Kawamura *et al.* developed rapidly solidified powder metallurgy (RS P/M) Mg-Zn-Y alloys with superior mechanical properties including a tensile yield strength of 610 MPa and an elongation of 5 % at room temperature [8]. The extruded $Mg_{97}Zn_1Y_2$ and $Mg_{96}Zn_2Y_2$ alloys also exhibited excellent mechanical properties. The tensile yield strength of $Mg_{96}Zn_2Y_2$ alloy was higher than that of $Mg_{97}Zn_1Y_2$ alloy at room temperature [9,10]. The $Mg_{97}Zn_1Y_2$ alloy consisted of fine α-Mg grains and the long period staking ordered (LPSO) phase and the improvement of mechanical properties in this alloy is consider to originate from the high dispersion of the bent LPSO phase and the refinement of those structures and the α-Mg grains. In contrast, the $Mg_{96}Zn_2Y_2$ alloy consisted of 3 phases with fine α-Mg, LPSO phase and the intermetallic RE containing compound. The volume fraction of intergranular phases (LPSO phase and the intermetallic RE compound) of $Mg_{96}Zn_2Y_2$ alloy was higher than that of the $Mg_{97}Zn_1Y_2$ alloy [10]. Therefore, to improve of mechanical properties of the Mg-Zn-Y alloys, the phases control is necessary to obtain an appropriate volume fraction of the α-Mg, LPSO phase and intermetallic RE compound.

In the present study, the investigation reported here focused on the influence of mixed RE, which was also effective in strengthening Mg-Zn-Y alloys at elevated temperature, on the microstructure and mechanical properties of the Mg-Zn-Y-M (M: Mixed RE) alloys.

Experimental procedure

The alloys, with nominal composition of $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ (M=Monazite base mixed RE ($Ce_{52.4}La_{26.0}Nd_{21.6}$) in at. %), were prepared by high-frequency induction melting in an Ar atmosphere and cast in a cylindrical steel mould (31 mm of diameter). Rods of 70 mm height and 29 mm length were cut from the initial ingots. The rods of as-cast alloy were extruded with an extrusion ratio of 10 at 623K and a ram speed of 2.5 mm/s. The phase structures of as-cast and extruded alloys were investigated by X-ray diffractometry (XRD), optical microscopy (OM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The mechanical properties of the investigated alloys were determined using tensile test specimens with a gage section of Ø 2.5 mm x 15 mm.

Results and discussion

Figure 1 shows SEM micrographs of the as-cast $Mg_{96}Zn_2Y_2$ and $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys. As it is shown in the picture, the secondary phase with fine lamellar contrasts was observed in the grain boundary and dendrite arm boundaries for $Mg_{96}Zn_2Y_2$ and $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys. The secondary phase of the $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys had a sharp and smooth interface. According to the XRD results and EDS analysis, it can be confirmed that the secondary phases are LPSO and/or the Mg-RE compound in the $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys. In the $Mg_{96}Zn_2Y_2$ and $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys, continuous net-worked LPSO and intermetallic RE compound form a coarse interdendrite structure. The volume fractions of compound in $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys (3.1 %) were higher than that of the $Mg_{96}Zn_2Y_2$ alloys (0.9 %).

The room and elevated temperature tensile properties of the two kinds of alloy after extrusion are shown in Fig. 2. The yield strength, ultimate tensile strength and elongation of the $Mg_{96}Zn_2Y_2$ and $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ extruded alloys at room temperature were 376 MPa, 425 MPa and 5.1 %, and 379 MPa, 428 MPa and 5.0 %, respectively. The mechanical properties of the $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ are slightly higher than that of the ternary $Mg_{96}Zn_2Y_2$ alloys.

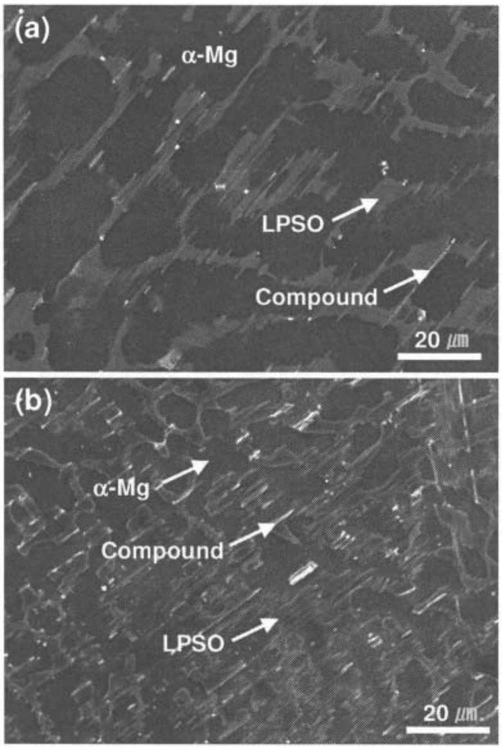


Figure 1. SEM microstructures of the (a) $Mg_{96}Zn_2Y_2$ and (b) $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys

The yield strength, ultimate tensile strength and elongation at elevated temperature (523 K) of the $Mg_{96}Zn_2Y_2$ alloy were 255 MPa, 265 MPa and 19 %, respectively. The tensile strength of the $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys at elevated temperature (523K) is higher than the tensile strength of $Mg_{96}Zn_2Y_2$ alloy.

The creep tests were carried out at 473 K and at applied stresses between 90 and 210 MPa. The 300 h creep curves for $Mg_{96}Zn_2Y_2$ and $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ tested at different stresses are shown in Fig. 3. The 300 h creep strain at 90 MPa was almost the same for both the $Mg_{96}Zn_2Y_2$ and $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys. The creep curves at 150 and 210 MPa exhibit a well-defined primary stage and a secondary stage for both the $Mg_{96}Zn_2Y_2$ and $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys. The creep resistance of both alloys investigated at a pressure of 210 MPa was poor.

However, the creep resistance and tensile strength at elevated temperature for the $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloy were both higher than that of the $Mg_{96}Zn_2Y_2$ alloy at a pressure of 210 MPa. Therefore, intermetallic RE compound's effect on the mechanical properties at elevated temperature needs to be investigated. To do this, a heat treatment experiment was designed.

Figure 4 shows the microstructures of heat treated $Mg_{96}Zn_2Y_2$ and $Mg_{96}Zn_2Y_{1.9}RE_{0.1}$ alloys at 573 to 673K for 1h. The average α-Mg grain size of $Mg_{96}Zn_2Y_2$ and $Mg_{96}Zn_2Y_{1.9}RE_{0.1}$ alloys was increased with increasing heat treatment temperature. While the heat treatment conditions were 573K for 1h, no remarkable changes were observed in the microstructure of heat treated $Mg_{96}Zn_2Y_2$ and $Mg_{96}Zn_2Y_{1.9}RE_{0.1}$ alloys. However, the average α-Mg grain size of $Mg_{96}Zn_2Y_2$ alloy was 3.4 μm at 623K and the average α-Mg grain size of $Mg_{96}Zn_2Y_{1.9}RE_{0.1}$ alloys was 1.8 μm at 623K.

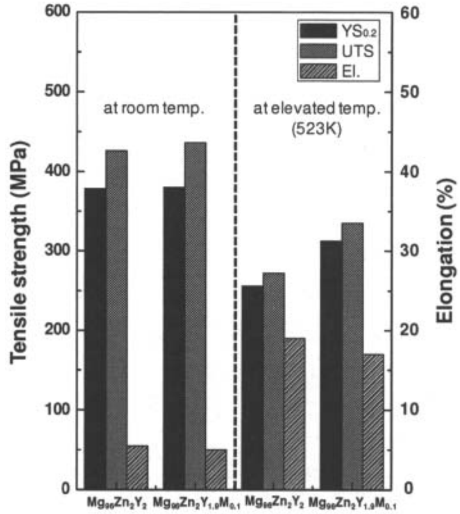


Figure 2. Mechanical properties of $Mg_{96}Zn_2Y_2$ and $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys at room and elevated temperature

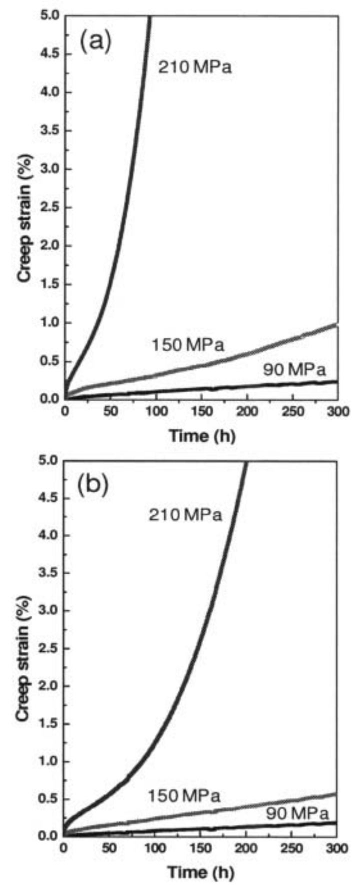


Figure 3. Creep curves of (a) $Mg_{96}Zn_2Y_2$ and (b) $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys at 473 K. the applied stress were 90, 150 and 210 MPa

Figure 5 shows the optical microstructures of extruded $Mg_{96}Zn_2Y_2$ and $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys. The $Mg_{96}Zn_2Y_2$ and $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys consist of α-Mg grains, the internetallic RE compound and the LPSO phase. This Mg-RE compound exists within the α-Mg matrix and between the LPSO phases in the $Mg_{96}Zn_2Y_2$ and $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys. The volume fraction of intermetallic RE compound in $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys (3.1 %) was higher than that of the $Mg_{96}Zn_2Y_2$ alloys (0.9 %). These results indicate that the strengthening of the quaternary $Mg_{96}Zn_2Y_{1.9}RE_{0.1}$ alloy system at elevated temperature is depended on the LPSO phase, fine-grained α-Mg matrix grains and especially, the highly dispersed compounds and the amount of the compounds.

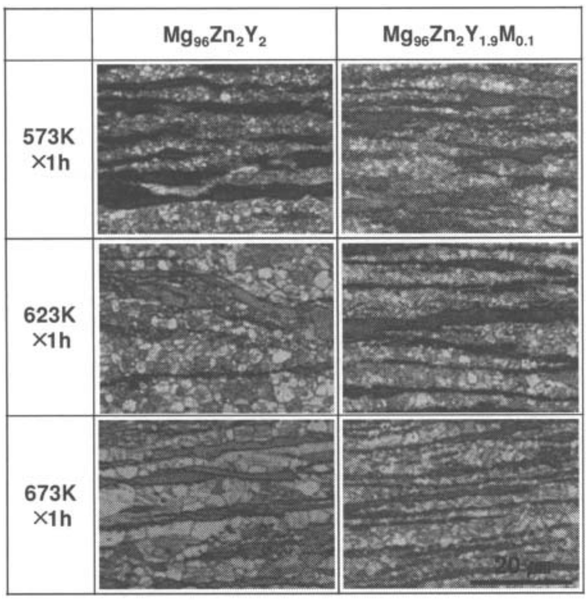
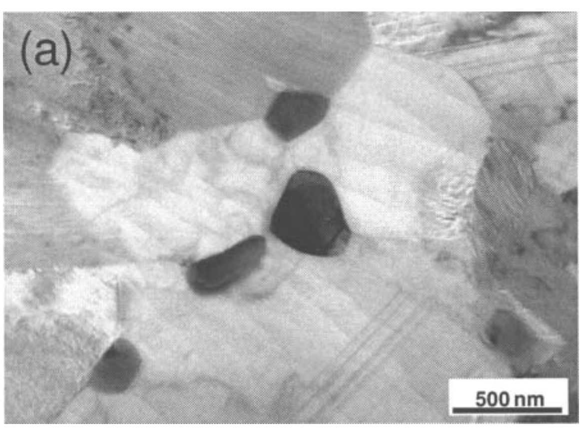


Figure 4. Optical microstructures of $Mg_{96}Zn_2Y_2$ and $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys after heat treatment



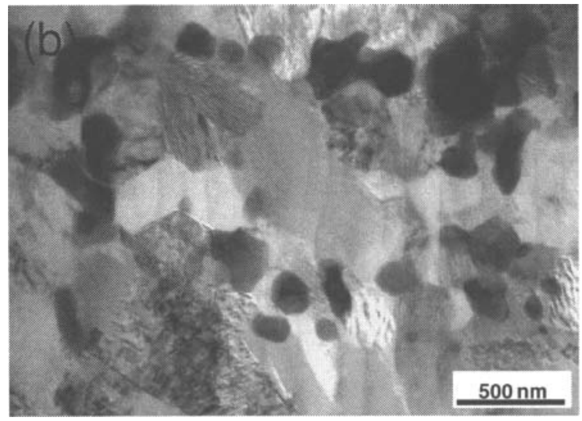


Figure 5. TEM microstructures of the extruded (a) $Mg_{96}Zn_2Y_2$ and (b) $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys

Conclusions

(1) Excellent tensile yield strength was obtained in the extruded $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys, with a yield strength of 379 MPa at room temperature and 312 MPa at 523K.

(2) The very small sized intermetallic RE compound exists in the α-Mg matrix and between the LPSO phases in the $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys. The presence of intermetallic RE compound in $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloy was responsible for its improved tensile and creep properties over those of $Mg_{96}Zn_2Y_2$ alloy.

(3) Considerable improvement in the creep behavior of the $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys at 473K was observed. Extended creep life and a reduction in the minimum creep rate were also observed.

Acknowledgements

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