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EFFECT OF ZINC CONTENT ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF EXTRUDED Mg-Zn-Y-La ALLOYS WITH LPSO PHASE

Jonghyun Kim[1] and Yoshihito Kawamura[2]
[1]Kumamoto Technology and Industrial Foundation; 2080-10 Tabaru, Mashiki-machi, Kamimashiki-gun, Kumamoto, 861-2202, JAPAN
[2]Department of Materials Science, Kumamoto University; 2-39-1, Kurokami, Kumamoto, 860-8555, JAPAN

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Abstract

$Mg_{98.4}Zn_xY_{1.5}La_{0.1}$ (X=0.25 to 2.0 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. Specifically, for extruded $Mg_{98.15}Zn_{0.25}Y_{1.5}La_{0.1}$ alloy, the presence of this RE compound after heat treatment was responsible for the observed improvement in tensile and creep properties, which were similar to those of the $Mg_{96}Zn_2Y_2$ alloy. Excellent tensile yield strength was obtained in the extruded $Mg_{98.15}Zn_{0.25}Y_{1.5}La_{0.1}$ alloys, with a yield strength of 275 MPa at 523K.

Introduction

Magnesium alloys, as one of the lightest structural metallic materials, have recently attained an increasing interest for use in the weight reduction for the computers, mobile phone and automobile industries because of their low density, high specific strength and stiffness, and good damping property [1, 2]. However, the number of commercially available Mg alloys is still limited, especially for application at room and elevated temperatures. For example, AM- and AZ-series could not be applied to power train parts operating at temperatures higher than 130°C due to their poor elevated temperature mechanical properties [3]. The recent developments of heat resistance Mg alloys are mainly concentrated on the improvement of conventional Mg-Zn and Mg-Al based alloys by alloying with third element, such as Si, rare earth (RE), alkaline earth metals, etc. [4].

Recently, Kawamura *et al.* developed rapidly solidified powder metallurgy (RS P/M) Mg-Zn-Y alloys with superior mechanical properties; a tensile yield strength of 610 MPa and an elongation of 5 % at room temperature was achieved [5]. 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 [6,7]. 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 considered to originate from the high dispersion of the bent LPSO phase, and the refinement of those LPSO structures and the α-Mg grains. In contrast, the $Mg_{96}Zn_2Y_2$ alloy consisted of 3 phases: 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 [7]. Therefore, to improve the mechanical properties of Mg-Zn-Y alloys, phase control is necessary to obtain an appropriate volume fraction of the α-Mg, LPSO, and intermetallic RE compound.

The investigation focused on the influence of Zn contents, which were also effective in strengthening Mg-Zn-Y alloys with ductility at room and elevated temperature and improving creep properties for economical efficiency, on the microstructure and mechanical properties of $Mg_{98.4}Zn_xY_{1.5}La_{0.1}$ alloys.

Experimental procedure

The alloys, with nominal composition of $Mg_{98.4}Zn_xY_{1.5}La_{0.1}$ (X=0.25 to 2.0 at.%), were prepared by high-frequency induction melting in an Ar atmosphere and then cast into a cylindrical steel mould (31 mm of diameter). Rods of 70 mm height and 29 mm length were cut from the cast ingots and then extruded at 623K with an extrusion ratio of 10 and a ram speed of 2.5 mm/s. Heat treatment was then performed at 473K for 1.5h. The phase structures of as-cast and extruded alloys were investigated through 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 ϕ 2.5 mm × 15 mm.

Results and discussion

Figure 1 shows SEM micrographs of the as-cast $Mg_{98.4}Zn_xY_{1.5}La_{0.1}$ (X=0.25 to 1.5 at.%) alloys. As shown in the picture, the secondary phase with fine lamellar contrasts was observed in the grain and also dendrite arm boundaries, and 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.

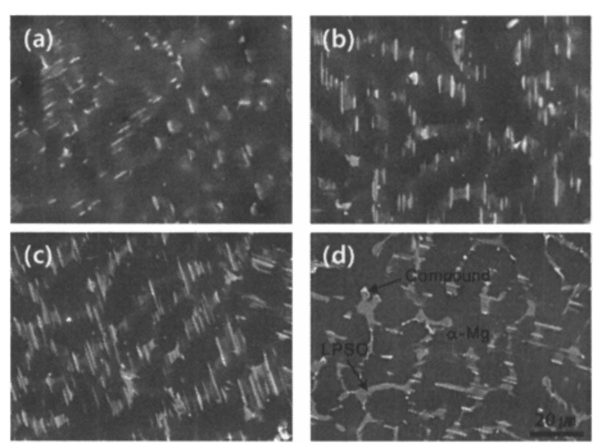


Figure 1. SEM microstructures of the as-cast $Mg_{98.4}Zn_xY_{1.5}La_{0.1}$ alloys: (a) x=0.25 (b) x=0.5 (c) x=1.0 and (d) x=1.5

In the $Mg_{96.9}Zn_{1.5}Y_{1.5}La_{0.1}$ alloys, continuous net-work of LPSO and intermetallic RE compounds form a coarse interdendrite structure. The volume fractions of both secondary phase (LPSO and compound) in $Mg_{98.4}Zn_xY_{1.5}La_{0.1}$ alloys increased with increasing Zn contents.

Fig. 2 shows the tensile properties of the five studied alloy compositions, at (a) room temperature and (b) 523K, after extrusion..,At room temperature, from 0.25 - 1.0 at.% Zn, the yield and ultimate tensile strengths of the alloys at room temperature sharply increased with increasing Zn addition, while the elongation decreased. Above 1.0 at.% Zn, tensile properties of Mg alloys only slightly increased.

The yield strength, ultimate tensile strength and elongation of $Mg_{96.9}Zn_{1.5}Y_{1.5}La_{0.1}$ at room temperature were 345 MPa, 391 MPa and 5.3 %, respectively. However, at 523K, they were 255 MPa, 223 MPa and 28 %, respectively. Therefore, the yield and ultimate tensile strengths are both slightly higher at room temperature than at elevated temperature.

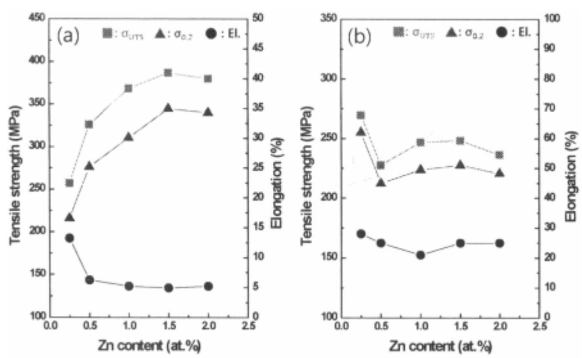


Figure 2. Mechanical properties of $Mg_{96}Zn_2Y_2$ and $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys at room and elevated temperature

As a result the effect of the intermetallic RE compounds on the mechanical properties at elevated temperature needs to be investigated. To do this, the extruded alloys were heat-treated at 473 K for times ranging from 0.5 to 6 h, and then reanalyzed. From micro-hardness test result of $Mg_{98.15}Zn_{0.25}Y_{1.5}La_{0.1}$ alloy after heat treatment, the hardness increased with increasing heat treatment time up to 1.5 h, but changed little afterwards.

Figures 3(a) shows the tensile properties at room temperature of the studied extruded alloys after heat treatment at 473 K for 1.5 h, which shows the same trends observed without heat treatment properties. For $Mg_{96.9}Zn_{1.5}Y_{1.5}La_{0.1}$, the yield strength, ultimate tensile strength and elongation of the $Mg_{96.9}Zn_{1.5}Y_{1.5}La_{0.1}$ extruded alloys after heat treatment at 523 K were 275 MPa, 298 MPa and 23 %, respectively.

The creep tests were carried out at 473 K and at applied stresses between 90 and 210 MPa. The 300 h creep curves for $Mg_{98.15}Zn_{0.25}Y_{1.5}La_{0.1}$ after heat treatment tested at different stresses are shown in Fig. 3. The creep curves at 150 and 210 MPa exhibit well-defined primary and secondary stages for Mg alloys. The creep resistance at 210 MPa was poor. Overall, the creep resistance of this alloy was almost that of $Mg_{96}Zn_2Y_2$ alloy [8].

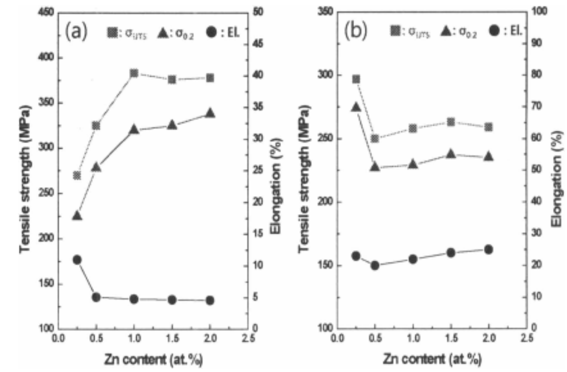


Figure 3. Mechanical properties of $Mg_{96}Zn_2Y_2$ and $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys at room and elevated temperature

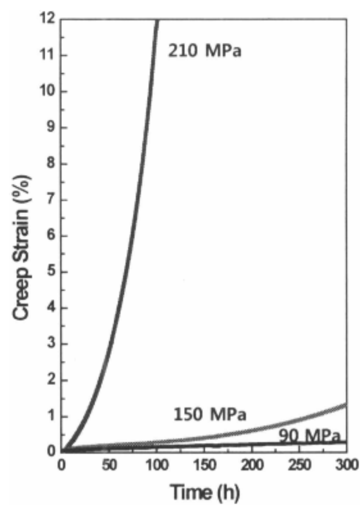
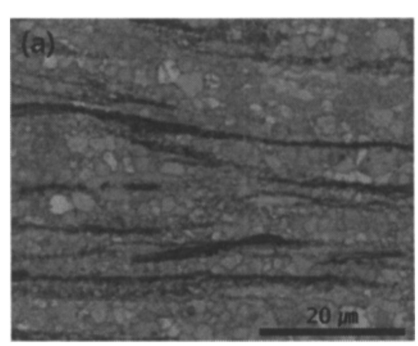


Figure 4. Creep curves of (a) $Mg_{96}Zn_2Y_2$ and (b) $Mg_{96}Zn_2Y_{1.9}M_{0.1}$ alloys at 473 K. the applied stress were 90, 150 and 210 MPa

Figure 5 shows the microstructures of extruded $Mg_{98.15}Zn_{0.25}Y_{1.5}La_{0.1}$ alloy (b) without heat treatment and (a) with heat treatment at 473 K for 1.5 h. The average α-Mg grain size without heat treatment was 1.5 ㎛ and after heat treatment was 5.2 ㎛. The compounds precipitates by annealing at high temperature in the α-Mg matrix.



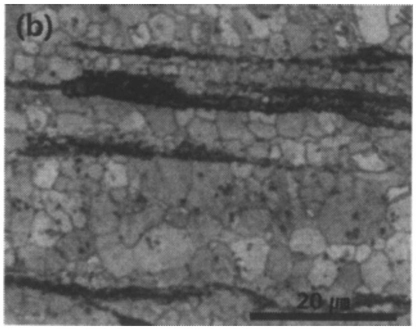


Figure 5. Microstructures of extruded $Mg_{98.15}Zn_{0.25}Y_{1.5}La_{0.1}$ alloy (a) without heat treatment and (b) with heat treatment at 473 K for 1.5 h

Figure 6 (b) shows the microstructures of extruded $Mg_{98.15}Zn_{0.25}Y_{1.5}La_{0.1}$ alloy with subsequent heat treatment at 473 K for 1.5 h. The $Mg_{98.15}Zn_{0.25}Y_{1.5}La_{0.1}$ alloys without heat treatment consist of α-Mg grains, the internetallic RE compounds and the LPSO phase (fig. (a)). The Mg-RE compounds exists between the LPSO phase in the Mg alloys. After heat treatment, the Mg-RE compounds exist within the α-Mg matrix and between the LPSO phases in the $Mg_{98.15}Zn_{0.25}Y_{1.5}La_{0.1}$ alloys. These results indicate that the strengthening of the quaternary $Mg_{98.15}Zn_{0.25}Y_{1.5}La_{0.1}$ alloy system at elevated temperature is dependent on the LPSO phase, fine-grained α-Mg matrix grains and especially, the highly dispersed Mg-RE compounds. Specifically, the amounts of these compounds are very important in this case.

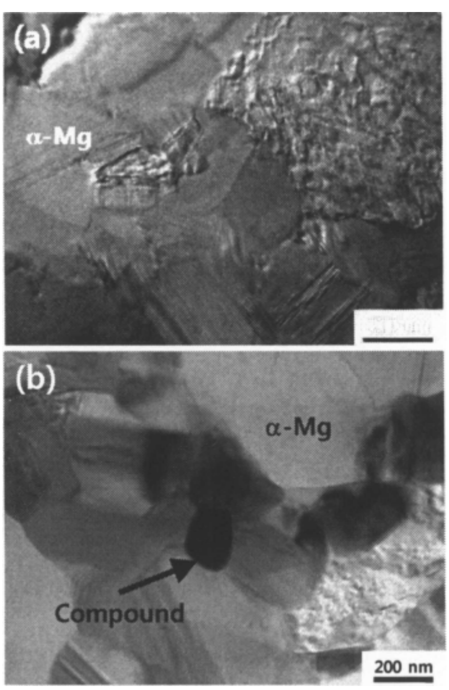


Figure 6. TEM images of extruded $Mg_{98.15}Zn_{0.25}Y_{1.5}La_{0.1}$ alloy (a) without heat treatment and (b) with heat treatment at 473 K for 1.5 h

Conclusions

(1) Very small sized intermetallic RE compounds precipitates existed in α-Mg matrix in the $Mg_{98.4-x}Zn_xY_{1.5}La_{0.1}$ (X=0.25 to 2.0) alloys.

(2) The precipitation of these compounds phase in extruded $Mg_{98.15}Zn_{0.25}Y_{1.5}La_{0.1}$ alloy during subsequent heat-treatment was responsible for its improved tensile and creep properties.

(3) The tensile strength of extruded $Mg_{98.15}Zn_{0.25}Y_{1.5}La_{0.1}$ alloy at elevated temperature with heat-treatment was higher than that for extruded $Mg_{96}Zn_2Y_2$ alloy

Acknowledgements

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