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Effect of the Extrusion Conditions on the Microstructure and Mechanical Properties of Indirect extruded Mg-Zn-Y Alloy with LPSO Phase

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Abstract

Mg alloys are the lightest commercial structural alloys and have excellent specific strength and stiffness characteristics. Due to its good castability, the die casting process has been established for the fabrication of various automobile components such as instrumental panels and seat frames. In particular, the application of Mg alloys to a conventional direct extrusion process is not considered to be cost-effective mainly due to their low extrudability.

The indirect extrusion process is free of friction between the billet and the container; hence, the extrusion pressure as well as surface cracking can be reduced considerably compared to the direct extrusion process, leading to its implementation at lower temperatures and higher speeds. In this study, Mg-Zn-Y alloy was subjected to the direct and indirect extrusion processes and the effects of the processing conditions on the microstructure and mechanical properties were investigated.

Introduction

Magnesium alloys, as one of the lightest structural metallic materials, have recently attained an increasing interest for use in computer, mobile phone and automobile industries because of their low density, high specific strength and stiffness, and good damping properties [1-3]. It is generally regarded that the main obstacle that must be overcome in Mg extrusions is their low extrusion speed, which leads to high production costs. Normally, high-strength Mg alloys are extrudable only at speeds of 0.5–2.5 m/min [4-5].

The direct extrusion process is the most widely used method of producing complex shapes in the non-ferrous metals industry. The major disadvantage of this process is that metal flow is inhomogenous, and consequently, the heat generated results in localised heating. This leads to undesirable mechanical and metallurgical features such as surface tearing and surface recrystallisation in extruded rods [6].

Conversely, in the indirect extrusion process, there is no friction between the billet and the container. This can result in significant reductions in extrusion pressure and also surface cracking, compared to the direct extrusion process, thus enabling its implementation at lower temperatures and higher speeds [7].

In this study, Mg-Zn-Y alloy with LPSO phase was underwent direct and indirect extrusion, and the effects of the processing conditions (metal flow rate) on the microstructure and mechanical properties were studied.

Experimental procedure

The investigated alloy, with a nominal composition of $Mg_{97}Zn_1Y_2$, was prepared by high-frequency induction melting in an Ar atmosphere, and then cast into a cylindrical steel mold (31 and 44 mm in diameter for direct and indirect extrusion, respectively).

Direct extrusion was performed using billets of 70 mm height and 29 mm length, whilst indirect extrusion utilized a billets of 120 mm height and 42 mm length. Extrusion was performed at 648K using an extrusion ratio of 10 and a ram speed of 1.0 - 9.9 mm/s.

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 extrusion texture and grain size of the as-extruded alloys were measured via electron backscatter diffraction (EBSD) using a field emission scanning electron microscope (FE-SEM). 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

Fig. 1 shows the dependence of tensile properties on metal flow rate of the $Mg_{97}Zn_1Y_2$ alloy after extrusion at (a) room temperature and (b) 523K. The constitutive equation for the extruded $Mg_{97}Zn_1Y_2$ alloy followed by metal flow rate was determined to be:

$$\dot{\boldsymbol{\varepsilon}} = \left\{ \frac{6V_e \ln R \times \tan\theta}{D(1-1/R\sqrt{R}} \right\}$$

where R is the extrusion ratio, V_e is the extrusion speed, θ is the half angle of the dies, and D is the diameter of billet.

At both room and elevated temperature (523 K), from 0.28 - 1.99 s^{-1}, the tensile yield strengths of the direct extruded alloys sharply decreased with increasing metal flow rate, while the elongation increased. The tensile yield strength of the indirect extruded alloys also decreased with increasing metal flow rate until 1.55 s^{-1}, after which the tensile yield strength were slightly decreased. At room temperature and 0.28 s^{-1}, the yield strength of direct and indirect extruded alloy were 342 MPa and 275 MPa, respectively.

Figure 2 shows microstructures of direct ((a) and (c)) and indirect ((b) and (d)) alloys extruded with a metal flow rate of 0.28 ((a) and (b)) and 1.99 s^{-1} ((c) and (d)). The direction of extrusion is parallel to the horizontal direction in these as well as all subsequent microstructural figures presented in this paper. In In each micrograph in Figure 2, three areas can be seen: the dynamically recrystallized (DRXed) α-Mg fine-grain region, the hot-worked α-Mg coarse-grain region, and the LPSO phase region.

To quantitatively describe the change in the dispersion of the LPSO phase, the dispersion level, D_L (μm^{-1}), is defined in this study by the following expression: [8]

$$D_L = \frac{\sum N_v}{\sum L_v}$$

where L_v (μm) is the length of a vertical line segment L drawn perpendicular to the extrusion direction within the micrographs in Fig. 2, and N_v is the number of LPSO phase regions intersected by segment L. The total length of segments, $\sum L_v$, is greater than 5 mm.

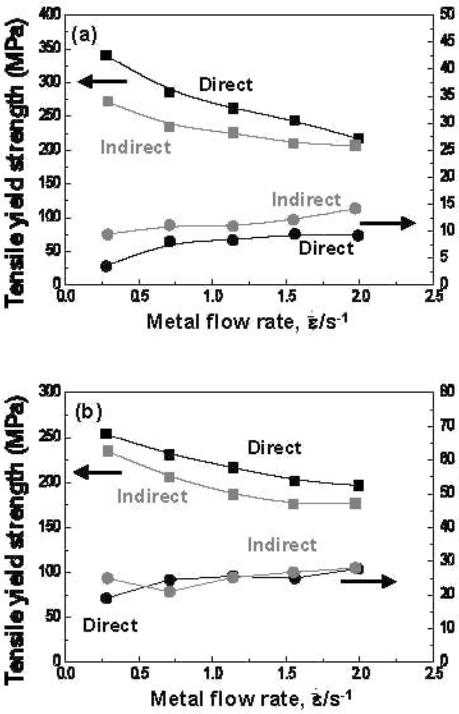

Figure. 1 Dependence of mechanical properties of direct and indirect extruded $Mg_{97}Zn_1Y_2$ alloys on the metal flow rate, at(a) room and (b) elevated temperature (523 K).

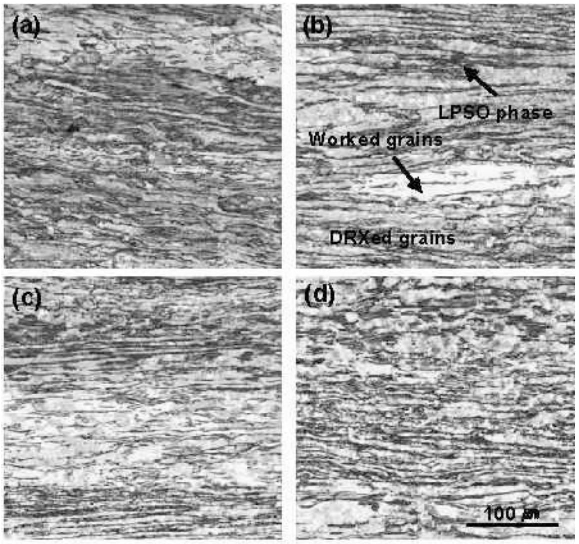

Figure. 2. Optical micrographs of direct and indirect extruded $Mg_{97}Zn_1Y_2$ alloys at low and high metal flow rates: (a) direct and $0.28s^{-1}$, (b) indirect and $0.28s^{-1}$, (c) direct and $1.99s^{-1}$, and (d) indirect and $1.99s^{-1}$

Fig. 3 shows the relationship between the dispersion of LPSO phase in the direct and indirect extruded $Mg_{97}Zn_1Y_2$ alloys and the metal flow rate. The dispersion and refinement of the fiber-shaped LPSO phase for indirect extruded $Mg_{97}Zn_1Y_2$ alloys are higher than those of the direct extruded Mg alloys.

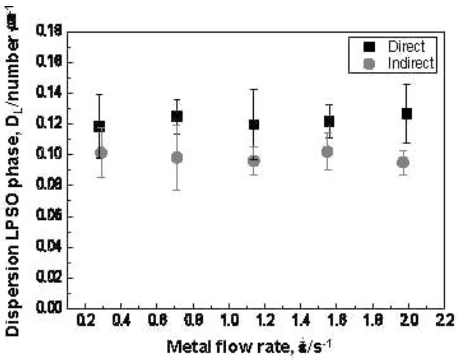

Figure 3. Relationship between dispersion LPSO phase of the direct and indirect extruded $Mg_{97}Zn_1Y_2$ alloys and metal flow rate

Figs. 5 and 6 show inverse pole figure (IPF) maps of longitudinal cross-sections of direct and indirect extruded $Mg_{97}Zn_1Y_2$ alloys, at metal flow rates of 0.28 and $1.99s^{-1}$, respectively.. The $Mg_{97}Zn_1Y_2$ alloy shows a bimodal α-Mg grain structure composed of fine recrystallized grains of approximately 1-3 μm in size, and coarse unrecrystallized parent grains with grain sizes greater than 10 μm. It is noteworthy that dynamic recrystallization occurs in the α-Mg matrix in the vicinity of LPSO phase.. Comparing both metal flow rates, the volume fraction of the DRXed region is larger for the slower rate ($0.28s^{-1}$), while that of the worked grains region is larger for the faster rate ($1.99s^{-1}$)..

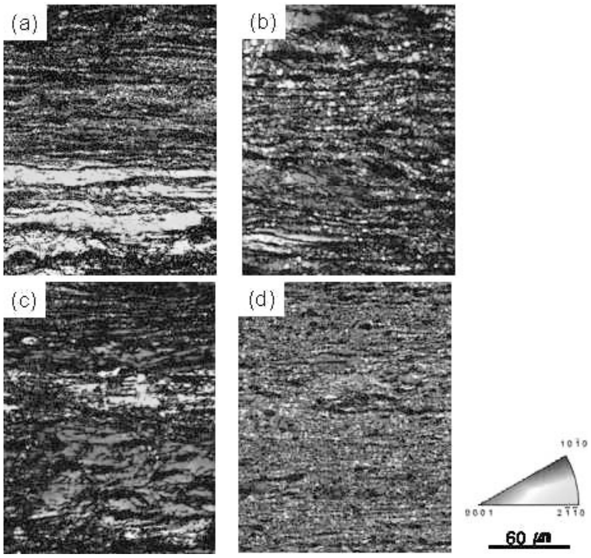

Figure. 4. IPF maps obtained from a longitudinal cross-section of direct and indirect extruded $Mg_{97}Zn_1Y_2$ alloy at a metal flow rate

of 0.28 s^{-1}: (a) direct, center region (b) indirect, center region (c) direct, edge region and (d) indirect, edge region

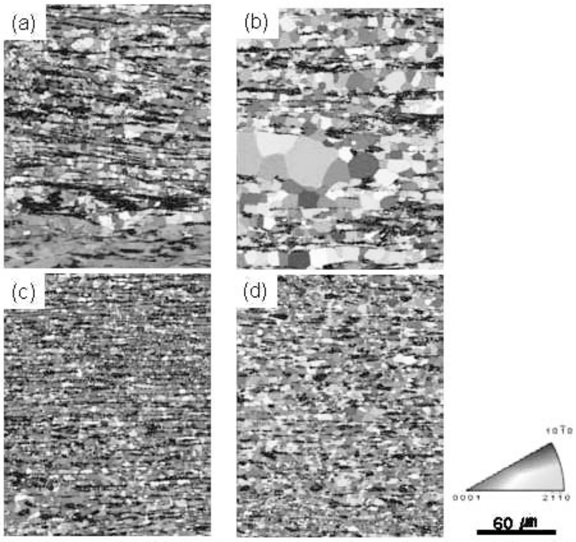

Figure. 5. IPF maps obtained from a longitudinal cross-section of direct and indirect extruded Mg$_{97}$Zn$_1$Y$_2$ alloy at a metal flow rate of 1.99 s^{-1}: (a) direct, center region (b) indirect, center region (c) direct, edge region and (d) indirect, edge region

Figure 6. shows the DRXed α-Mg grain size at center and edge regions of direct and indirect extruded Mg$_{97}$Zn$_1$Y$_2$ alloys. The grain size in both direct and indirect extruded Mg$_{97Z}$n$_1$Y$_2$ alloys increase with increasing metal flow rate. The grain sizes of the indirect extruded Mg$_{97}$Zn$_1$Y$_2$ alloys in center and edge regions of extruded samples are both larger than those in the respective regions in the direct extruded Mg alloys.

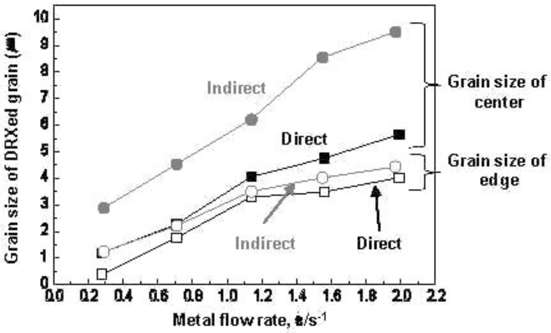

Figure. 6. Grain size of center and edge regions in direct and indirect extruded Mg$_{97}$Zn$_1$Y$_2$ alloys as a function of metal flow rate.

Conclusions

(1) The tensile yield strength of both direct and indirect extruded alloys decrease with increasing metal flow rate. At a given metal flow rate, the tensile yield strength of direct extruded Mg$_{97}$Zn$_1$Y$_2$ alloys is higher than that of the indirect extruded alloys.

(2) The dispersion and refinement of the fiber-shaped LPSO phase regions in indirect extruded Mg$_{97}$Zn$_1$Y$_2$ alloys are both higher than those of the direct extruded Mg alloys.

(3) The grain sizes of the indirect extruded alloy in the edge and center regions are both larger than that those in the respective regions in the direct extruded alloys.

References

1. A. A. Luo, "Recent magnesium alloy development for automotive powertrain applications," *Materials Science Forum* , 419-422 (2003) 57-66.
2. Magnesium & Magnesium alloys, ed. M. M. Avedesian & H. Baker: ASM International, Materials Park, OH (1999), 3-6.
3. A. Luo, M.O. Pekguleryuz, "Cast magnesium alloys for elevated temperature applications," *Journal of Materials Science*, 29 (1994) 5259-5271.
4. Y. Kawamura and M. Yamasaki, "Formation and Mechanical Properties of Mg$_{97}$Zn$_1$RE$_2$ Alloys with Long Period Stacking Ordered Structure," *Materials Transactions*. 48 (2007) 2986-2992.
5. S. Yoshimoto, M. Yamasaki and Y. Kawamura, "Microstructure and Mechanical Properties of Extruded Mg-Zn-Y Alloys with 14H Long Period Ordered Structure," *Materials Transactions*. 47 (2006) 959-965.
6. Atwell, D.L., Barnett, M.R., "Extrudability of magnesium alloys," *Magnesium Technology*, (2007) 145-150.
7. T. Sheppard and S.J. Paterson, "Some observations on metal flow and the development of structure during the direct and indirect extrusion of commercial purity aluminum," *Journal of Mechanical Working Technology*, 7 (1982) 39-56.
8. Hirano M, Yamasaki M, Hagihara K, Higashida K, Kawamura Y, "Effect of Extrusion Parameters on Mechanical Properties of Mg97Zn1Y2 Alloys at Room and Elevated Temperatures," *Materials Transactions*. 51 (2010) 1640-1647.