Microstructure and Mechanical Properties of Mg-Zn-Y-Yb Alloys Produced by Consolidation of Rapidly Solidified Ribbons

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Abstract

Fabrication of $Mg_{95.75}Zn_1Y_3Yb_{0.25}$ bulk alloy has been performed through the consolidation of rapidly solidified ribbons. The $Mg_{95.75}Zn_1Y_3Yb_{0.25}$ bulk alloy exhibited excellent mechanical properties, high tensile yield strength of 530 MPa, and large elongation of 3 %. Microstructure of the alloy was characterized by equiaxed fine grains that consist of -Mg, long period ordered (LPO) structure phase, and Mg_5RE-type cubic compound. The strengthening of the alloys may be due to fine grains with LPO structure phase and Mg_5RE-type compound.

Keywords : Magnesium, Rapid Solidification, Consolidation, Mechanical Properties

1. Introduction

In the last decade, Mg alloys have been used in automotive and aerospace industries where weight reduction is an important requirement. Rapid solidification (RS) processing is suitable for the development of high strength Mg alloys, because the process realizes grain-refinement, increase in homogeneity, and so on. Recently, several nanocrystalline Mg-Zn-Y alloys with high specific tensile strength and large elongation have been developed by rapidly solidified powder metallurgy (RS P/M) processing [1]. The Mg-Zn-Y RS P/M alloys are characterized by long period ordered (LPO) structure and sub-micron fine grains. We have investigated the mechanical properties of ternary $Mg_{97}Zn_1RE_2$ (RE=Y, La, Ce, Pr, Nd, Sm, Eu and Yb) melt-spun ribbons annealed at 573 K, in order to develop new alloy compositions for Mg-Zn-RE RS P/M alloys. The $Mg_{97}Zn_1Y_2$ and $Mg_{97}Zn_1Yb_2$ RS ribbons exhibited combination of high hardness and good ductility, and composed of LPO phase and fine Mg-Yb compound precipitations, respectively [2]. In this study, we have tried to develop high-strength RS P/M alloys for consolidation of Mg-Zn-Y-Yb system RS ribbons.

2. Experimental Procedure

An alloy composition for the synthesis of consolidated bulk alloy was selected based on the preliminary investigations where both the hardness and ductility of many Mg-Zn-Y-Yb melt spun ribbons were measured. These RS ribbons were prepared by a single-roller melt spinning method and thereafter these ribbons were annealed in a vacuum at 573 and 673 K for 1.2 ks. The annealing temperatures correspond to consolidation temperatures of RS magnesium alloys [3]. The Mg-Zn-Y-Yb bulk alloy was produced by consolidation of RS ribbons. The RS ribbons were first cold pressed in a copper can with an inner diameter 20 mm and then degassed at 523 K for 900 s down to 10^{-2} Pa. In order to consolidate RS ribbons, hot extrusion was performed at an extrusion ratio 10 and at 623 K. Structure of RS ribbons, their annealed ribbons and their extruded bulk alloys were investigated by XRD and TEM. Mechanical properties of the extruded bulk alloys were measured with an Instron-type tensile testing machine.

3. Results and Discussion

Figure 1 shows the compositional dependence of Vickers hardness and bending ductility for the $Mg_{99-x}Zn_1(Y, Yb)_x$ RS ribbons annealed at 673 K. The hardness increased with increasing Y and Yb contents. Overaddition of Yb (>1.0 at. %) brought about a decrease in ductility. Combinations of high hardness and good ductility were obtained in $Mg_{95.75}Zn_1Y_3Yb_{0.25}$, $Mg_{95.5}Zn_1Y_3Yb_{0.5}$ and $Mg_{95.75}Zn_1Y_{2.5}Yb_{0.75}$ alloys. On the basis of this result, we selected a $Mg_{95.75}Zn_1Y_3Yb_{0.25}$ alloy for production of consolidated bulk alloys because this alloy exhibited the best-combined properties of hardness, ductility and lightweight. As a result of XRD, $Mg_{95.75}Zn_1Y_3Yb_{0.25}$ RS ribbons annealed at 673 K was consisted of α-Mg, $Mg_{12}ZnRE$ corresponding to LPO, and Mg_5RE phases.

Figure 2 shows testing-temperature dependence of the tensile yield strength in the $Mg_{95.75}Zn_1Y_3Yb_{0.25}$ bulk alloy consolidated from RS ribbons. The tensile yield strength was 530 MPa at room temperature and 385 MPa at 473 K. The elevated-temperature strength of the bulk alloy was two times as high as that of the commercial WE 54-T6 alloys (200

MPa) at temperatures below 473 K.

As a result of XRD, $Mg_{95.75}Zn_1Y_3Yb_{0.25}$ bulk alloy consolidated from RS ribbons was consisted of α-Mg, LPO and Mg_5RE phases.

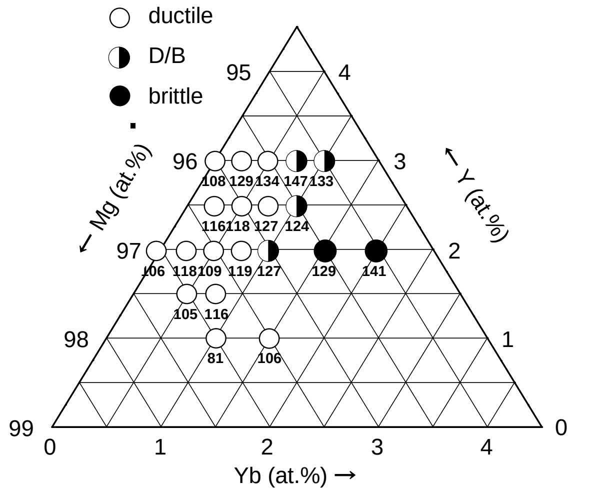

Fig. 1. Compositional dependence of Vickers hardness and bending ductility in $Mg_{99-x}Zn_1(Y, Yb)_x$ RS ribbons annealed at 673 K for 1.2 ks.

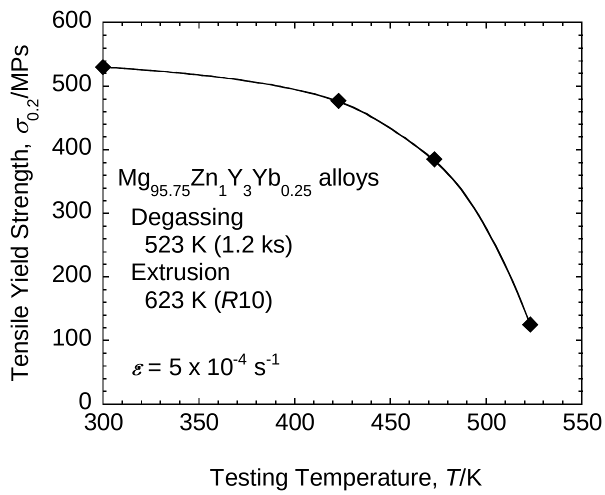

Fig. 2. Testing-temperature dependence of the tensile yield strength in $Mg_{95.75}Zn_1Y_3Yb_{0.25}$ bulk alloys.

Figure 3 shows a blight-field TEM image of the extruded bulk alloy. The alloy consists of equiaxed grains about 200 nm in average diameter as shown in Figure 3 (a). Fine lamellar phase and compounds were observed (Figure 3 (b) and 3 (c)). The electron diffraction pattern obtained from the fine-lamellar grain is shown in Figure 3 (d). The electron diffraction pattern shows that fine-lamellar phase is 14 H type LPO structure. Figure 3(e) shows electron diffraction pattern from the compound which was shown Figure 3(c). We don't finish characterization of this big cubic structured compound. However, we consider this compound corresponds to Mg_5RE phase. The high strength is due to the fine structure consisted of LPO and Mg_5RE phases.

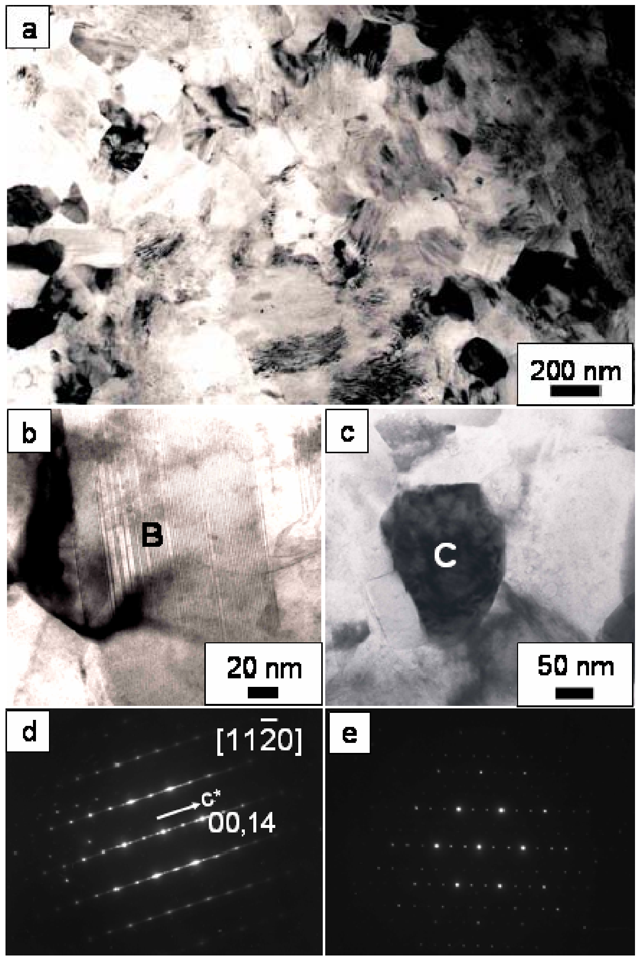

Fig. 3. (a) TEM micrograph of a $Mg_{95.75}Zn_1Y_3Yb_{0.25}$ bulk alloy consolidated from RS ribbons, (b) fine lamellar grain and (c) Mg_5RE-type compound. Electron diffraction patterns taken from (d) fine-lamellar grain and (e) Mg_5RE-type compound.

4. Summary

1) In the preliminary investigations, $Mg_{95.75}Zn_1Y_3Yb_{0.25}$ RS ribbon annealing at 673 K had the best combination of high hardness and good ductility.

2) $Mg_{95.75}Zn_1Y_3Yb_{0.25}$ alloy consolidated from RS ribbons exhibited high tensile yield strength (530 MPa) and good ductility (3 %). The alloy had fine grains about 200 nm that consisted of α-Mg, LPO and Mg_5RE phases.

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6. References

1. Y. Kawamura et al., :Mater. Trans., 42 (2002) 1172-1176.
2. Y. Kawamura et al., Mater. Sci. Forum, 419-422 (2003) 751-756.
3. F.H. Froes et al., ed., Processing of Structural Metals by Rapid Solidification, (Metals Park, Ohio, ASM International, 1987) 367-415.