Development of High Strength Mg-Zn-Gd Alloys by Rapid Solidification Processing

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Abstract

Rapidly solidified ribbon-consolidation processing was applied for preparation of high strength bulk Mg-Zn-Gd alloys. Mg alloys have been used in automotive and aerospace industries. Rapid solidification (RS) process 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) process. Mg-Zn-Y RS P/M alloys are characterized by long period ordered (LPO) structure and sub-micron fine grains. The both additions of rare earth elements and zinc remarkably improved the mechanical properties of RS Mg alloys. Mg-Zn-Gd alloy also forms LPO structure in -Mg matrix coherently, therefore, it is expected that the RS Mg-Zn-Gd alloys have excellent mechanical properties. In this study, we have developed high strength RS Mg-Zn-Gd alloys with LPO structure and nanometer-scale precipitates by RS ribbon-consolidation processing. $Mg_{97}Zn_1Gd_2$ *and* $Mg_{95.5}Zn_{1.5}Gd_3$ *and* $Mg_{94}Zn_2Gd_4$ *bulk alloys exhibited high tensile yield strength (470 MPa and 525 MPa and 566 MPa) and large elongation (5.5% and 2.8% and 2.4%).*

Keywords: Magnesium, Rapid solidification, Mg-Zn-Gd alloy, Long period ordered (LPO) structure

1. Introduction

Recently, we have reported that some rapidly solidified powder metallurgy (RS P/M) Mg-Zn-Y alloys show high strength and good ductility [1]. The RS P/M Mg-Zn-Y alloys are characterized by long period ordered (LPO) structure that is in α-Mg matrix coherently.

LPO structure has been observed in Mg-Zn-(Gd, Tb, Dy, Ho, Er, Tm) alloys as well as Mg-Zn-Y alloy. In the Mg-Zn-(Tb, Dy, Ho, Er) alloys, LPO structure forms mainly from Zn and rare earth-enriched grain boundary as secondary phase. In the Mg-Zn-(Gd, Tb, Tm) alloys, on the other hand, the LPO structure precipitates uniformly from super-saturated solid solution -Mg matrix coherently [2]. Therefore, the RS Mg-Zn-Gd alloys with highly dispersed LPO structure are candidates for novel high strength lightweight materials.

In this study, RS P/M processing was applied for preparation of high strength Mg-Zn-Gd alloys. The RS P/M Mg-Zn-Gd were fabricated for the optimum alloy compositions, and their mechanical properties and microstructures were investigated.

2. Experimental methods

Master alloys were prepared by high-frequency induction heating in an argon atmosphere. The melt-spun Mg-Zn-Gd alloy ribbons were produced in argon gas atmosphere using single-roller melt spinning method. The ribbons were annealed in a vacuum at 623 K for 1.2 ks. The annealing temperature corresponds to a typical temperature of RS Mg alloys. The hardness and ductility of the RS ribbons was measured using a micro Vickers hardness tester and 180-degrees bending testing.

The large-scaled Mg-Zn-Gd RS P/M alloys were prepared by the consolidation of RS ribbons. The consolidation was carried out by hot-extrusion at extrusion ratio of 10, at 623 K and at a ram speed of 2.5 mm/s. Tensile tests were carried out using an Instron-type tensile testing machine at room temperature with an initial strain rate of $5 \times 10^{-4}\ s^{-1}$. The microstructure of the alloys was investigated by X-ray diffractometer (XRD) and Transmission Electron Microscopy (TEM).

3. Results and Discussion

Figure 1 shows the phase diagrams obtained from the results of XRD of the Mg-Zn-Gd RS ribbons after annealing at 623 K. Gd-rich Mg-Zn-Gd alloys consisted of α-Mg, Mg_3Gd and Mg_2Gd compounds. On the other hand, Zn-rich Mg-Zn-Gd alloys consisted of α-Mg and $Mg_3Zn_3Gd_2$ compound. When the Gd/Zn ratio in the Mg-Zn-Gd alloys was 1.3-2, long period ordered (LPO) structure formed. In the cast alloy of Mg-Zn-Y system, it has been reported that LPO phase formed in Y/Zn ratio ranging from 1 to 2. The compositions forming LPO phase in the Mg-Zn-Gd alloys are similar to those in the Mg-Zn-Y alloys.

Figure 2 shows the Vickers hardness and bending ductility of the Mg-Zn-Gd RS ribbons annealed at 623 K for 1.2 ks.

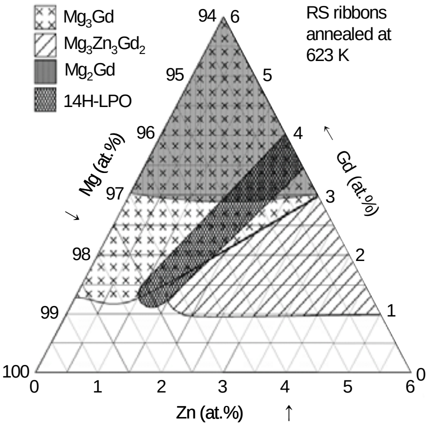

Fig. 1. Phase diagram obtained from the results of XRD in Mg-Zn-Gd RS ribbons after annealing at 623 K.

The hardness of the alloys increased with increasing Zn and/or Gd contents. Particularly, Gd addition was effective for increase in hardness. The ductility, however, decreased by excess formation of Mg_2Gd phase. It was noted that the alloys with LPO structure exhibited high hardness and good ductility as shown in Figs. 1 and 2.

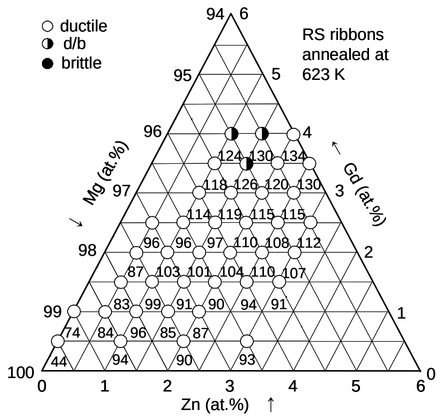

Fig. 2. The Vickers hardness and ductility of Mg-Zn-Gd RS ribbons annealed at 623 K for 1.2 ks.

The $Mg_{97}Zn_1Gd_2$, $Mg_{95.5}Zn_{1.5}Gd_3$ and $Mg_{94}Zn_2Gd_4$ RS P/M alloys were fabricated by consolidation of RS ribbons, because they have LPO structure and showed high hardness and good ductility form the results of preliminary examination.

The mechanical properties of the Mg-Zn-Gd RS P/M alloys are shown in Fig. 3. The tensile yield strength of the $Mg_{97}Zn_1Gd_2$, $Mg_{95.5}Zn_{1.5}Gd_3$ and $Mg_{94}Zn_2Gd_4$ bulk alloys were 470, 525 and 566 MPa, respectively. The elongations of the $Mg_{97}Zn_1Gd_2$, $Mg_{95.5}Zn_{1.5}Gd_3$ and $Mg_{94}Zn_2Gd_4$ alloys were 5.5, 2.8 and 2.4 %, respectively.

The XRD patterns of the Mg-Zn-Gd bulk alloys are shown in Fig. 4. The Mg-Zn-Gd bulk alloys consist of α-Mg, Mg_3Gd and $Mg_{12}ZnGd$ corresponding to LPO phase. The improvement in the mechanical properties of the Mg-Zn-Gd RS P/M alloys is considered to the originated from the increase in volume fraction of LPO phase and the its refinement.

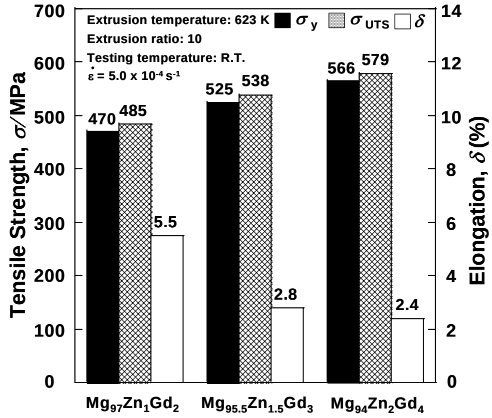

Fig. 3. The mechanical properties of Mg-Zn-Gd RS P/M alloys

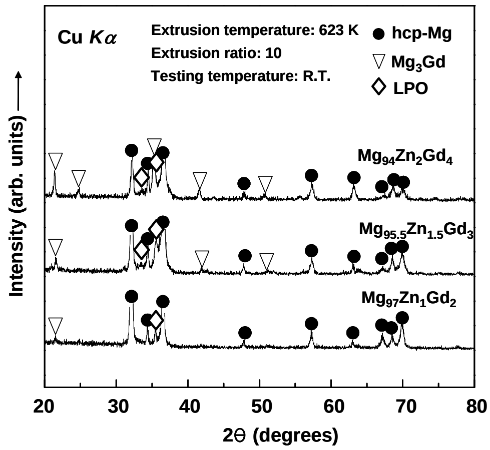

Fig. 4. X ray diffraction patterns of the Mg-Zn-Gd RS P/M alloys.

4. Summary

Large-scaled Mg-Zn-Gd RS P/M alloys with LPO structure have been produced by consolidation of RS ribbons. The $Mg_{97}Zn_1Gd_2$、$Mg_{95.5}Zn_{1.5}Gd_3$、$Mg_{94}Zn_2Gd_4$ RS P/M alloys exhibited high tensile yield strength (470 MPa, 525 MPa, 566 MPa) and large elongation (5.5%, 2.8%, 2.4%).

5. References

1. Y. Kawamura, K. Hayashi, A. Inoue, T. Masumoto: Mater. Trans., JIM 42 (2002) 1172-1176.
2. M. Yamasaki, T. Anan, S. Yoshimoto, Y. Kawamura: Scr. Mater., 53 (2005) 799-803.