Mg-rich Mg-Cu-Zn-Gd Bulk Metallic Glass Composites with Enhanced Plasticity

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1. Introduction

The extensive research worldwide on bulk metallic glasses (BMGs) in various alloy system is motivated by their potential engineering application as new high-strength structural materials over past decades. Recently, there has been a strong demand of developing a high strength and damage-tolerant materials with low specific weight for saving of energy and other natural resources. Thus, a considerable amount of research activities devoted to the Mg-based BMGs, which could result in a great progress of glass-forming ability (GFA) up to 1 inch diameter. However, like other BMGs, the Mg-based BMGs do not exhibit appreciable plastic deformation in a uniaxial mode at room temperature, preventing their engineering applications. Thus, improvement on plasticity has been strongly requested from the progress in engineering potential of Mg-based BMGs. However, there is a lack of systematic approach for modulation of secondary phases of in-situ Mg-based BMG composites, although the brittleness of Mg-based BMGs can be overcome by using in-situ methods to generate BMG matrix composites with glassy matrix and secondary crystalline phase [1-3]. In the present study, we further explore this concept and show a series of in-situ composites with different scales and fractions of long-period order structure (LOS) phase in Mg-Cu-Zn-Gd BMG-forming alloys. The effect of both scales and fractions of LOS phases by controlling alloy composition and cooling condition will be systematically reported. In our experiment, with an increase of Mg content, the amount and size of the flake-shaped LOS precipitates are uniformly distributed in the glassy matrix. Thus, these in-situ composites remarkably exhibit enhanced plasticity, which can be attributed to the generation of multiple shear bands and the deformation of the LOS phase.

2. Experimental

The nominal composition of the alloys studied in this work were $Mg_{65+x}(Cu_{0.67}Gd_{0.33})_{30-x}Zn_5$ (x=0, 6, 12, 14, 16, 18). The pre-alloyed Mg-80 wt% Gd was alloyed with high purity Mg (99.9 %), Cu (99.9 %) and Zn (99.95 %) in the boron nitride (BN) coated graphite crucible under a dynamic argon atmosphere using an induction furnace. The injection-cast specimens were prepared by re-melting the alloys in quartz tubes and ejecting with an over-pressure of 50 kPa through a nozzle into the Cu mold having cylindrical cavities of 1-3 mm in diameter.

The structure of the as-cast specimens was examined by XRD using monochromatic Cu K_α radiation for a 2θ range of 10–80°. Thermal analysis of the as-cast specimens was carried out using DSC at a constant heating rate of 0.667 K/s. Room-temperature compressive test was performed at a strain rate of 1×10^{-4} s^{-1}. Samples for compression test with dimensions of 2 mm diameter and 4 mm height were prepared from the as-cast specimens. The strain was determined from the platen displacement after correction for the machine compliance. The surface of the fractured specimen was observed using SEM.

3. Results

The composition of the alloys studied in this work was designed in accordance with the following two rules: (i) LOS phase should be easily precipitated from the Mg-Zn-RE alloys; and (ii) the alloys should exhibit high GFA so that an amorphous structure may be easily prepared using the conventional copper mold casting method. Because, it is well known that Zn is the key for the formation of a long-period chemical-ordered as well as stacking ordered structure for LOS phase and

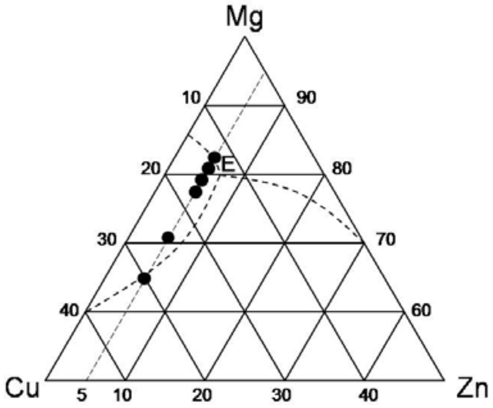

Fig. 1 Mg-Cu-Zn ternary diagram

Mg-Cu-Gd system exhibit best GFA in ternary Mg-based BMGs, we combined the two ternary Mg-Zn-Gd and Mg-Cu-Gd system into a pseudo-ternary Mg-(Cu-Gd)-Zn system to realize the two above-mentioned objects. The nominal compositions are as expressed as $Mg_{65+x}(Cu_{0.67}Gd_{0.33})_{30-x}Zn_5$ (x = 0, 6, 12, 14, 16, 18). As shown in Fig. 1, our designed compositions are expected to be of high GFA since all the designed pseudo-Mg-(Cu-Gd)-Zn ternary alloys are close to the binary (Mg_2Cu+(Mg_2Cu+ Mg_2Zn)) eutectic line of the Mg-Cu-Zn ternary system. Although the addition of Gd in Mg-Cu-Zn may change the position of the eutectic lines and points, it is still believed that the eutectic reactions of Mg-Cu-Zn system may provide some reference for judging GFA of the designed alloys.

To evaluate the GFA of the (a)-(f) alloys $Mg_{65+x}(Cu_{0.67}Gd_{0.33})_{30-x}Zn_5$ (x = 0, 6, 12, 14, 16, 18), XRD analysis were performed with rod samples with 2 mm diameter. As shown in Fig. 2, the XRD patterns (a) and (b) show broad diffraction peak, which is characteristic of amorphous structure. Pattern (c) shows sharp peaks from the crystalline phase superimposed on a broad halo peak (marked by arrows), indicating the coexistence of crystalline and amorphous phase, which represents composite microstructure. Finally, patterns (d)-(f) show many diffraction peaks, which could be analyzed into a mixture of α-Mg, Mg_2Cu, and MgCuZn phases.

Based on the further intensive structural analysis, we can realize that (C) $Mg_{77}Cu_{12}Gd_6Zn_5$ alloy can be fabricated into in-situ BMG matrix composite with flake-type α-Mg with LOS as a secondary phase (not shown). In particular, the Mg-Cu-Gd-Zn BMG composites with LOS precipitates exhibit enhanced comprehensive plasticity. The pronounced plasticity

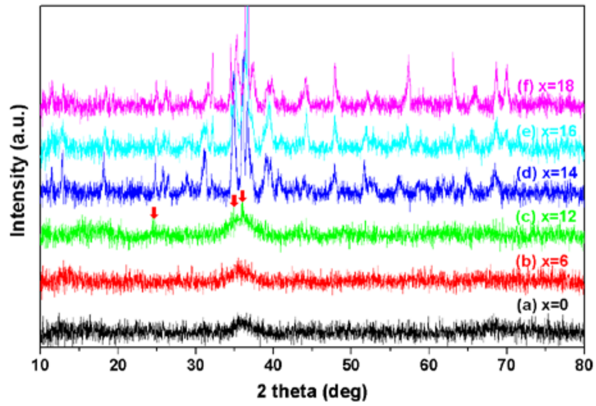

Fig. 2 XRD patterns of injetion-cast $Mg_{65+x}(Cu_{0.67}Gd_{0.33})_{30-x}Zn_5$ (x = 0, 6, 12, 14, 16, 18) rods with 2 mm diameter

of the composites was obtained due to mainly attributed to the generation of multiple shear bands. However, it is also suggested that the deformation of the LOS phase itself makes some contribution to the plasticity of the composite in Mg-rich Mg-Cu-Gd-Zn BMG composites.

4. Conclusion

In the present study, we have successfully prepared LOS phase dispersed in-situ Mg-based BMG composites in newly developed Mg-Cu-Gd-Zn alloy system by the appropriate composition design and well controlled solidification. The volume fraction, length and width of the flake-type LOS phase vary depending on the Mg contents and cooling condition, which is closely related to enhanced plasticity of BMG composites. It is believed that the finding of a novel BMG matrix composites reinforced by in situ LOS precipitates provides a possibility of using Mg-based BMGs as an engineering materials.

5. References

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