Mg-Y-Cu Bulk Metallic Glass Obtained by Mechanical Alloying and Powder Consolidation

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Abstract

$Mg_{55}Y_{15}Cu_{30}$ metallic glass powders were prepared by the mechanical alloying of pure Mg, Y, and Cu after 10 h of milling. The thermal stability of these $Mg_{55}Y_{15}Cu_{30}$ amorphous powders was investigated using the differential scanning calorimeter (DSC). T_g, T_x, and ΔT_x are 442 K, 478 K, and 36 K, respectively. The as-milled $Mg_{55}Y_{15}Cu_{30}$ powders were then consolidated by vacuum hot pressing into disk compacts with a diameter and thickness of 10 mm and 1 mm, respectively. This yielded bulk $Mg_{55}Y_{15}Cu_{30}$ metallic glass with nanocrystalline precipitates homogeneously embedded in a highly dense glassy matrix. The pressure applied during consolidation can enhance thermal stability and prolong the existence of amorphous phase within $Mg_{55}Y_{15}Cu_{30}$ powders.

Keywords : Mechanical alloying, Bulk metallic glass, Supercooled liquid region, Vacuum hot pressing

1. Introduction

Recently, a novel bulk metallic glass (BMG) with a wide supercooled liquid region exceeding 20 K has been prepared by the high-pressure die-casting or mold-casting method [1]. Since solid Mg does not react as readily with oxygen as its liquid counterpart. In this regard, an alternative method to prepare an amorphous alloy is *via* mechanical alloying (MA) [2]. In this paper, we report the glass formability and thermal stability of mechanically alloyed $Mg_{55}Y_{15}Cu_{30}$ powders prepared by high-energy ball milling. The consolidation of $Mg_{55}Y_{15}Cu_{30}$ metallic glass powders into a bulk form by a vacuum hot-pressing method was also investigated in details.

2. Experimental Procedure

Elemental powders of Mg, Y, and Cu were weighed to yield the desired compositions: $Mg_{55}Y_{15}Cu_{30}$, and a SPEX 8000D shaker ball mill was employed for MA. The bulk samples were prepared by consolidating the as-milled powders in a vacuum hot pressing machine. The structure and thermal stability of the as-milled and bulk samples was analyzed by X-ray diffractometer, scanning electron microscopy, transmission electron microscopy, and differential scanning calorimeter (DSC).

3. Results and Discussion

Figure 1 shows the X-ray diffraction patterns of the starting and as-milled $Mg_{55}Y_{15}Cu_{30}$ powders as a function of milling time. With ball milling up to 7.5~10 h, a broad diffraction peak at $2\Theta = 35-40^\circ$ is the main feature of these patterns, indicating that the as-milled powders are predominantly amorphous.

The thermal stability of $Mg_{55}Y_{15}Cu_{30}$ amorphous powders were investigated by differential scanning calorimetry and the corresponding DSC scans were presented in Figure 2. The glass transition temperature (T_g) and the crystallization temperature (T_x) are 442 K and 478 K, respectively. The supercooled liquid region ΔT_x. is 36K. For melt-spun $Mg_{50}Y_{15}Cu_{35}$ amorphous alloys, Kim *et al* [3] have reported that T_g, T_x and ΔT_x are 451K, 505K and 54K, respectively. MA is a high-energy ball milling process involving the collision of fine powders with milling balls and vial. The oxygen and iron contents in mechanically alloyed powders are always more than 1 at. % due to the large surface area of the fine particles and iron contamination from the milling tools. Seidel *et al* [4] have investigated the effect of oxygen and iron on the thermal properties of mechanically alloyed and rapidly quenched Zr-Al-Cu-Ni and Zr-Ti-Cu-Ni alloys. Their results indicated that the influence of oxygen impurities is more significant than that of iron contaminations. Though the effects of contamination were not investigated in the current study, the impurity contents were presumably responsible for the different thermal stability of mechanically alloyed powders and melt-spun specimens.

The as-milled $Mg_{55}Y_{15}Cu_{30}$ powders were hot pressed at 453 K under a pressure of 1.2GPa for 30 minutes. Its polished cross-sectional view as examined by SEM was shown in Figure 3. Figure 4 displays XRD traces and DSC scans of the as-milled and bulk $Mg_{55}Y_{15}Cu_{30}$ specimens. Though the pressing temperature is 25K below the crystallization temperature, nanocrystallization of Mg_2Cu and $Mg_{24}Y_5$ phases from the amorphous phases was noticed. The residual amorphous phase in the bulk sample is about 62% of that of as-milled specimen as estimated from the ratio of first exothermic peak area between two specimens. The nanocrystalline phase existed in the as-milled powders was suggested to be the preferred nucleation site for the acceleration of crystallization rate during hot pressing.

For comparison, as-milled powders were isothermally annealed at 453K for 30 min. and the XRD is shown in Figure 4. Although the annealing condition is the same as those of the hot-pressed sample, the XRD pattern exhibits the crystalline peaks of Mg, Mg_2Cu and $Mg_{24}Y_5$ phase and an ambiguous amorphous background. In the present study, the major difference between annealed and hot-pressed specimens is the employment of high pressure. The high pressure involved during consolidation can thus prolong the existence of amorphous phase inside $Mg_{55}Y_{15}Cu_{30}$ powders.

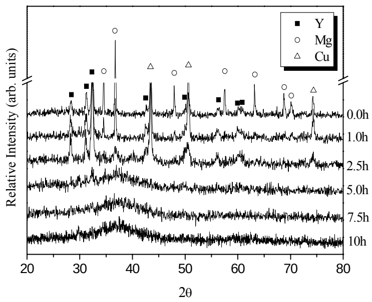

Fig. 1. X-ray diffraction patterns of mechanically alloyed $Mg_{55}Y_{15}Cu_{30}$ powders as a function of milling time.

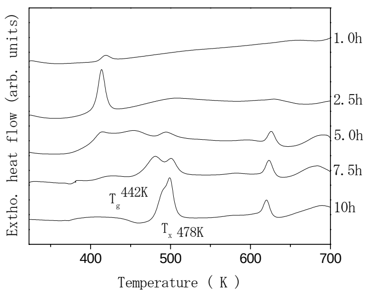

Fig. 2. DSC traces of mechanically alloyed $Mg_{55}Y_{15}Cu_{30}$ powders as a function of milling time.

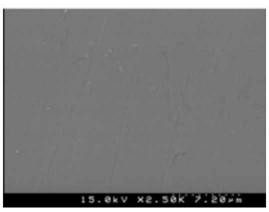

Fig. 3. Polished cross-sectional view of vacuum hot-pressed $Mg_{55}Y_{15}Cu_{30}$ disk specimen.

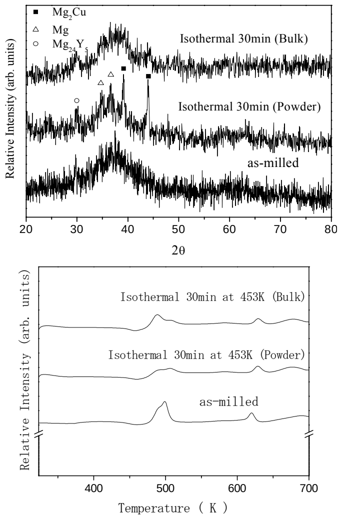

Fig. 4. XRD and DSC data of as-milled, heat-treated, and bulk $Mg_{55}Y_{15}Cu_{30}$ specimens.(a)XRD patterns and (b) DSC scans.

4. Conclusion

In the present study, amorphous $Mg_{55}Y_{15}Cu_{30}$ alloy powders can be prepared by mechanical alloying technique after 10 hours of milling. The thermal stability examined by DSC shows that the $Mg_{55}Y_{15}Cu_{30}$ amorphous powders exhibited a supercooled region of 36K. After vacuum hot pressing, bulk $Mg_{55}Y_{15}Cu_{30}$ metallic glass with nanocrystalline precipitates homogeneously embedded in a highly dense glassy matrix was obtained. The applied pressure during consolidation can enhance the thermal stability and prolong the existence of amorphous phase inside $Mg_{55}Y_{15}Cu_{30}$ powders.

5. References

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