International Journal of Minerals, Metallurgy and Materials

International Journal of Minerals, Metallurgy and Materials

Volume 14 | Issue 7 Article 10

June 2007

Mg-Cu-Zn-Y-Zr bulk metallic glassy composite with high strength and plasticity

Wei Tian
Department of Materials Science and Engineering, Beihang University, Beijing 100083, China

Shujie Pang
Department of Materials Science and Engineering, Beihang University, Beijing 100083, China

Hua Men
Department of Materials Science and Engineering, Beihang University, Beijing 100083, China

Chaoli Ma
Department of Materials Science and Engineering, Beihang University, Beijing 100083, China

Tao Zhang
Department of Materials Science and Engineering, Beihang University, Beijing 100083, China

Recommended Citation

Tian Wei, Pang Shujie, Men Hua, Ma Chaoli, Zhang Tao. Mg-Cu-Zn-Y-Zr bulk metallic glassy composite with high strength and plasticity, *Int. J. Miner. Metall. Mater.,* 14 (2007), No. 7, Article 10, p. 43-45.

Journal of University of Science and Technology Beijing
Volume 14, Supplement 1, June 2007, Page 43

Mg-Cu-Zn-Y-Zr bulk metallic glassy composite with high strength and plasticity

Wei Tian, Shujie Pang, Hua Men, Chaoli Ma, and Tao Zhang

Department of Materials Science and Engineering, Beihang University, Beijing 100083, China
(Received 2006-06-22)

Abstract: $Mg_{65}Cu_{20}Zn_5Y_9Zr_1$ bulk metallic glass matrix composite with a diameter of 2 mm was produced by copper mold casting. Upon cooling the $Mg_{65}Cu_{20}Zn_5Y_9Zr_1$ melt, Mg_2Cu acicular crystalline phase precipitates uniformly with a size of about 20 μm long and 1 μm thick while the remaining melt undergoes glass transition. Room temperature compression tests revealed that the high fracture strength up to 830 MPa and the plastic strain of 2.4% before failure are obtained for the Mg-based bulk metallic glass matrix composite. The formation of the Mg_2Cu phase was proposed to contribute to high strength and plastic deformation of the material.

Key words: Mg-based alloy; metallic glass matrix composite; acicular crystalline phase; strength; plasticity

[*This work was financially supported by the National Natural Science Foundation of China (No. 50225103, 50471001 and 50631010).*]

1. Introduction

Mg-based metallic glasses are regarded as a new family of promising materials with low mass and high specific strength. Among them, ternary $Mg_{65}Cu_{25}Y_{10}$ alloy shows a high glass forming ability (GFA) so that metallic glass rods with diameters of 4 mm [1] and 7 mm [2] can be prepared by using the copper mold casting and high pressure die-casting methods respectively. Moreover, by substituting Zn [3], Ag [4-5] or Pd [6-7] for a portion of Cu in the $Mg_{65}Cu_{25}Y_{10}$ alloy, a significant improvement of the GFA was achieved. The Mg-based bulk metallic glasses (BMGs) possess high strength (630 MPa for $Mg_{65}Cu_{25}Y_{10}$ BMG) [1], which is 3-4 times higher than those of the crystalline ones. However, the Mg-based BMGs are brittle and hence their application as structural materials is limited. Therefore, development of Mg-based BMGs or bulk metallic glass matrix composites (BMGMCs) with good mechanical properties including plasticity is of great interests [8-11].

In the present work, a bulk metallic glass matrix composite with high strength and plasticity was synthesized in the Mg-Cu-Zn-Y-Zr alloy system with a small amount of Zr by copper mold casting. This paper intended to present the formation, microstructure and mechanical properties of the Mg-based BMGMCs. The origin of the improved mechanical properties was also discussed based on the microstructure.

2. Experimental

A master alloy with the nominal composition of $Mg_{65}Cu_{20}Zn_5Y_9Zr_1$ was produced by induction melting the mixture of pure Mg, Zn and an arc-melted intermediate Cu-Y-Zr alloy under a purified argon atmosphere. From the master alloy, ribbons and rod samples with a diameter of 2 mm were prepared by melt-spinning and by injection casting using a copper mold respectively, under a purified argon atmosphere. The microstructure of ribbons and cast-rods were examined by X-ray diffraction (XRD) using a Rigaku D/max 2200 diffractometer with CuK_α radiation. The as-cast rods were also studied by optical microscope. The thermal properties associated to glass transition, supercooled liquid region and crystallization of the ribbon and rod samples were analyzed by a Perkin-Elmer differential scanning calorimeter (DSC-6) under flowing purified argon at a heating rate of 0.33 K/s. The mechanical properties of the Mg-based BMGMC were measured with a SANS CNMT5504 testing machine using a strain rate of 1.67×10^{-2} mm/s and the size of the rod samples used was ϕ2 mm×4 mm. The fractured samples subjected to the compressive tests were observed by JS-5800 scanning electron microscope (SEM).

3. Results and discussion

Fig. 1 shows the XRD patterns of the

Corresponding author: Tao Zhang, **E-mail:** zhangtao@buaa.edu.cn

$Mg_{65}Cu_{20}Zn_5Y_9Zr_1$ alloy ribbon and cast rod with a diameter of 2 mm. The XRD pattern of the melt-spun ribbon exhibits a broad diffraction peak and no crystalline peak, indicating its glassy structure. For the as-cast rod, the XRD pattern shows sharp peaks, which correspond to a crystalline phase Mg_2Cu, superimposed on a broad halo peak. This indicates in-situ formation of the $Mg_{65}Cu_{20}Zn_5Y_9Zr_1$ bulk composite consisting of glassy matrix and crystalline phase Mg_2Cu. The optical micrograph of the as-cast $Mg_{65}Cu_{20}Zn_5Y_9Zr_1$ alloy is shown in Fig. 2. A composite structure consisting of uniformly dispersed acicular crystalline phase of Mg_2Cu (dark phase) in the metallic glass matrix (white area) can be observed. The average size of the Mg_2Cu precipitates was estimated to be about 20 μm long and about 1 μm thick.

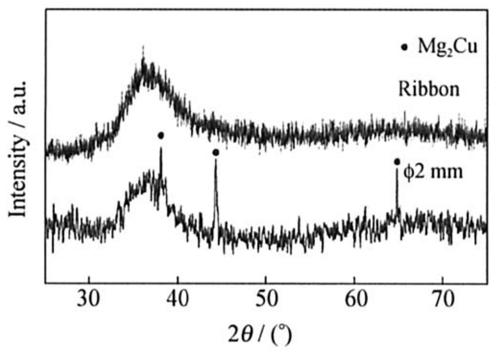

Fig. 1. XRD patterns of the $Mg_{65}Cu_{20}Zn_5Y_9Zr_1$ alloy ribbon and cast rod with a diameter of 2 mm.

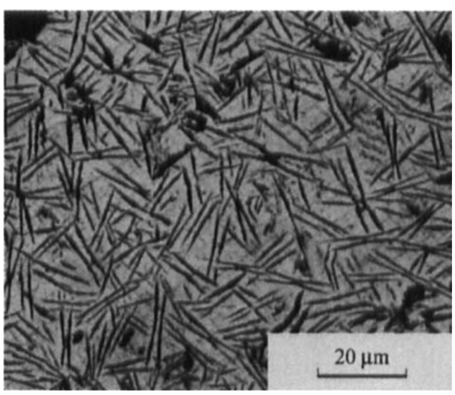

Fig. 2. Optical micrograph of the as-cast $Mg_{65}Cu_{20}Zn_5Y_9Zr_1$ composite.

Fig. 3 shows the DSC trace of the as-cast $Mg_{65}Cu_{20}Zn_5Y_9Zr_1$ rod of 2 mm in diameter. For comparison, the DSC trace of the melt-spun ribbon is also included. Both the DSC traces exhibit distinct glass transition followed by a supercooled liquid region prior to the occurrence of multi-stage crystallization. The alloy ribbon and rod show almost identical glass transition temperature (T_g=400 K), crystallization temperature (T_x=430 K) and supercooled liquid region (T_x–T_g =30 K). However, the heat releases of the main crystallization peaks for the as-cast rod with a diameter of 2 mm and the melt-spun ribbon are about 2.7 and 3.4 J/g respectively. Accordingly, it is estimated that the $Mg_{65}Cu_{20}Zn_5Y_9Zr_1$ rod of 2 mm in diameter is composed of 20% crystalline phase.

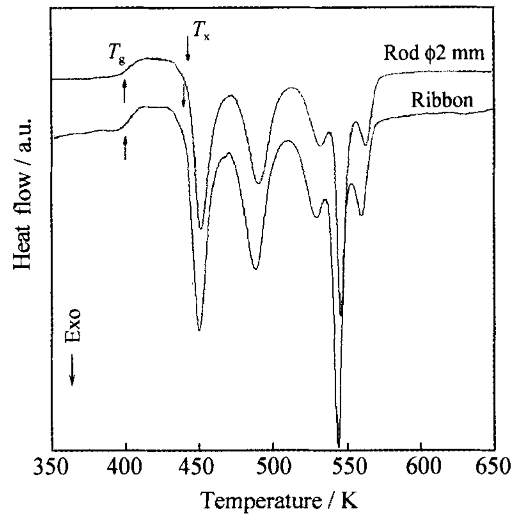

Fig. 3. DSC curves of the $Mg_{65}Cu_{20}Zn_5Y_9Zr_1$ alloy ribbon and cast rod with a diameter of 2 mm.

A compressive stress-strain curve of the $Mg_{65}Cu_{20}Zn_5Y_9Zr_1$ BMGMC is shown in Fig. 4. It is revealed that the Mg-based composite undergoes obvious elastic and plastic deformation prior to final failure. The fracture strength is up to 830 MPa and the plastic strain is about 2.4%.

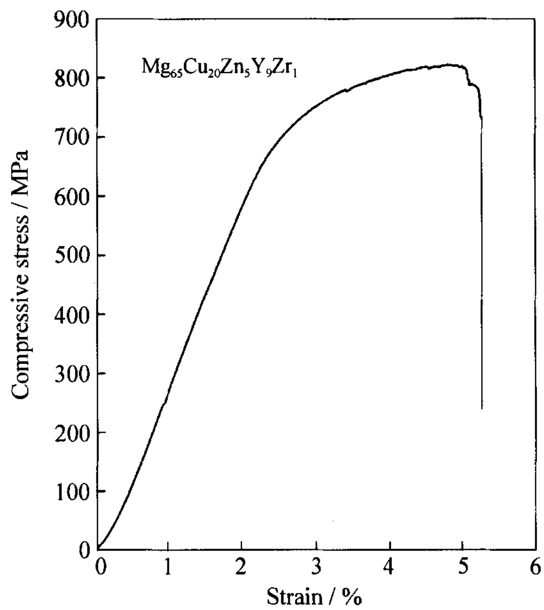

Fig. 4. Compressive stress-strain curve of the bulk $Mg_{65}Cu_{20}Zn_5Y_9Zr_1$ composite with a diameter of 2 mm.

Fig. 5 shows the SEM images of the surface morphology of the fractured $Mg_{65}Cu_{20}Zn_5Y_9Zr_1$ composite, in which (a) and (b) were taken from the fracture surface and the lateral surface respectively. It is seen that on the fracture surface well-developed vein-like pattern is dominant, which is typical for a ductile material. A number of crystalline particles can also be seen on the fracture surface. It is suggested that these particles were formed by the compressive deformation of acicular crystalline phase Mg_2Cu. Moreover, on the lateral surface, primary and branched shear bands can be observed on multiple and intersecting planes.

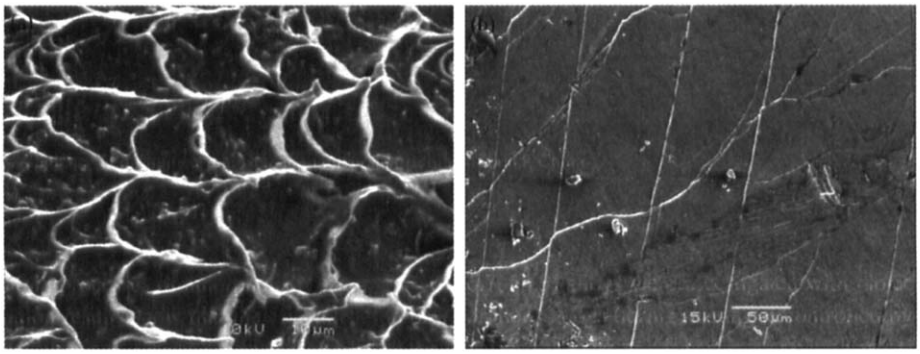

Fig. 5. SEM images of the surface morphology of the fractured $Mg_{65}Cu_{20}Zn_5Y_9Zr_1$ composite: (a) the fracture surface; (b) the lateral surface.

It has been reported that the $Mg_{65}Cu_{20}Zn_5Y_{10}$ alloy can be formed into glassy rods with a diameter up to 5 mm [3]. In this study, the addition of 1wt% Zr to the $Mg_{65}Cu_{20}Zn_5Y_{10}$ alloy for replacing Y leaded to the precipitation of Mg_2Cu acicular crystalline phase and formed the metallic glass matrix composite. The micrometer-sized Mg_2Cu phase might act as an obstacle to the local shear deformation of the glassy matrix, resulting in the propagation of shear bands or branching into secondary shear bands. The branching can distribute the plastic strains associated with the shear band, and the shear strain in any one branch may be much smaller than that of a single, un-branched shear band. These make a crack cutting through the whole cross section more difficult, and retard the shear fracture of the alloy, therefore the plastic stain prior to failure is increased. As a result, the Mg-based composite material possesses combined high strength and large plastic strain.

4. Conclusions

$Mg_{65}Cu_{20}Zn_5Y_9Zr_1$ bulk metallic glass matrix composite with high strength and plasticity were developed. The in situ composite with a diameter of 2 mm was produced by copper mold casting. In the composite, the Mg_2Cu acicular crystalline phase of about 20 μm long and about 1 μm thick are uniformly dispersed in the glassy matrix. The Mg-based composite exhibites high strength up to 830 MPa and plastic strain of about 2.4%. It is suggested that the improved mechanical properties could be due to the precipitation of Mg_2Cu phase in the glassy matrix during solidification.

References

[1] A. Inoue, A. Kato, T. Zhang, *et al.*, Mg-Cu-Y amorphous alloys with high mechanical strengths produced by a metallic mold casting method, *Mater. Trans. JIM*, 32(1991), No.7, p.609.

[2] A. Inoue, T. Nakamura, N. Nishiyama, *et al.*, Mg-Cu-Y amorphous alloys with high tensile strength produced by a high-pressure die casting method, *Mater. Trans. JIM*, 33(1992), No.10, p.937.

[3] H. Men, Z.Q. Hu, and J. Xu, Bulk metallic glass formation in the Mg-Cu-Zn-Y system, *Scripta Mater.*, 46(2002), p.699.

[4] S.V. Madge and A.L. Greer, Effect of Ag addition on the glass-forming ability and thermal stability of Mg-Cu-Y alloys, *Mater. Sci. Eng. A*, 375-377(2004), p.759.

[5] E.S. Park, H.G. Kang, W.T. Kim, *et al.*, The effect of Ag addition on the glass-forming ability of Mg-Cu-Y metallic glass alloys, *J. Non Cryst. Solids*, 279(2001), p.154.

[6] K. Amiya and A. Inoue, Preparation of bulk glassy $Mg_{65}Y_{10}Cu_{15}Ag_5Pd_5$ alloy of 12 mm in diameter by water quenching, *Mater. Trans.*, 42(2001), p.543.

[7] H. Ma, E. Ma, and J. Xu, A new $Mg_{65}Cu_{7.5}Ni_{7.5}Zn_5Ag_5Y_{10}$ bulk metallic glass with strong glass-forming ability, *J. Mater. Res.*, 18(2003), p.2288.

[8] H. Ma, J. Xu, and E. Ma, Mg-based bulk metallic glass composites with plasticity and high strength, *Appl. Phys. Lett.*, 83 (2003), No.14, p.2793.

[9] Y.K. Xu, H. Ma, J. Xu, *et al.*, Mg-based bulk metallic glass composites wit plasticity and gigapascal strength, *Acta Mater.*, 53(2005), p.1857.

[10] G.Y. Yuan, C.L. Qin, and A. Inoue, Mg-based bulk glassy alloys with high strength above 900 MPa and plastic strain, *J. Mater. Res.*, 20(2005), No.2, p.394.

[11] G.Y. Yuan and A. Inoue, The effect of Ni substitution on the glass-forming ability and mechanical properties of Mg-Cu-Gd metallic glass alloys, *J. Alloys Compd.*, 387(2005), p.134.