Materials Science and Engineering A 458 (2007) 290–294

MATERIALS SCIENCE & ENGINEERING A

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Tribological behaviour of $Cu_{60}Zr_{30}Ti_{10}$ bulk metallic glass

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Received 9 October 2006; received in revised form 12 December 2006; accepted 13 December 2006

Abstract

Dry sliding wear of as cast and different annealed states of $Cu_{60}Zr_{30}Ti_{10}$ bulk metallic glass was studied using pin-on-disc measurement technique. The relaxed metallic glass showed high hardness and excellent wear resistance. An inverse relation between the hardness and wear rate was observed for the as cast and annealed metallic glass. Coefficient of friction measured for all the above samples was found in a narrow range of 0.3–0.4 being less for as cast sample.

Keywords: Bulk metallic glass; Crystallization; Relaxation; Dry sliding wear; Pin-on-disc

1. Introduction

Metallic glass was first synthesized by Klement et al. [1] in 1960 in the form of splats and an attempt to produce it in bulk form was first made by Chen [2] in 1974. Since then bulk metallic glasses (BMGs) have been developed in a number of systems. It is interesting to note that glassy alloys are used for making magnetic tapes [3,4] as they exhibit better wear resistance coupled with soft magnetic property. The excellent mechanical properties combined with high glass forming ability makes BMG a suitable class of material for the production of precision mechanical parts such as high precision gears [5]. Due to the combination of high hardness and toughness, BMGs are expected to exhibit superior wear resistance. Some of the studies have shown that metallic glasses have higher wear resistance than their crystallized state [6,7]. There are also reports indicating that the wear performance of metallic glasses is inferior to the annealed state [8] and traditional crystalline alloys [9]. In view of these discrepancies, the dry sliding wear properties of $Cu_{60}Zr_{30}Ti_{10}$ bulk metallic glass in the as cast and different annealing states was studied in detail in the present investigation.

2. Experimental details

The Cu-based alloy with the nominal composition of $Cu_{60}Zr_{30}Ti_{10}$ was prepared by arc melting the mixtures of pure Cu, Zr and Ti metals in a Ti-gettered argon atmosphere. Bulk metallic glass rods with 3 mm diameters were then prepared by suction casting into a copper mold. The amorphous structure was confirmed using a diffractometer with Cu $K\alpha$ radiation. Differential scanning calorimetric (DSC) measurements were performed under a purified argon atmosphere in a Netzsch STA409PC at a heating rate of 20 K/min. The alloy was annealed at different temperatures for 1 h (Table 1). The sample annealed in the supercooled liquid region is termed as relaxed sample. The Vicker's microhardness was measured at loads of 50, 100, 200 and 500 g.

Dry sliding wear tests were conducted using pin-on-disc (ASTM G99) wear testing machine. The applied normal loads used were 20 and 40 N resulting in an applied pressure of 3 and 5.6 MPa. The tests were conducted under constant sliding distance 1.32 km and sliding velocity 1 m/s. The weight loss of the pins was measured in an electronic balance of ±0.1 mg precision. Average surface roughness, R_a, of the specimen before wear testing, measured by Perthometer, lie in the range of 0.36–0.54 μm. The co-efficient of friction was continuously monitored during wear testing. Wear rate is the ratio of weight loss per unit sliding distance where the weight loss is difference between the pin weight before and after the wear test. The

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0921-5093/$ – see front matter © 2007 Published by Elsevier B.V.
doi:10.1016/j.msea.2006.12.060

Table 1
Heat treatment conditions used for the $Cu_{60}Zr_{30}Ti_{10}$ alloy in the present study

Sample name	Condition
As cast	As cast
Relaxed	Annealed in supercooled liquid region (723 K for 1 h)
Tx_1	Annealed at the offset of first crystallization peak (795 K for 1 h)
Tx_2	Annealed at the offset of second crystallization peak (845 K for 1 h)

worn surfaces of the pin after the wear test were characterized by scanning electron microscopy (SEM) using JEOL JSM-820.

3. Results and discussion

Fig. 1 shows the DSC trace of the as cast $Cu_{60}Zr_{30}Ti_{10}$ glassy alloy with two crystallization peaks. The crystallization studies on this alloy by earlier investigators [10] have also revealed the similar crystallization peaks in the temperature range used in present study. The temperatures of heat treatments carried out on the as cast alloy are shown in Fig. 1 and Table 1, which are (i) in the supercooled liquid regime (termed as relaxed state), (ii) at the offset of the first crystallization peak (Tx_1) and (iii) at the offset of the second crystallization peak (Tx_2). Fig. 2 shows the XRD patterns of the glassy alloy in different annealing conditions. The annealing in supercooled liquid region still exhibited an amorphous structure while some crystalline phases have appeared in the Tx_1 and Tx_2 samples. The crystalline phase after the second stage crystallization has been identified as equilibrium $Cu_{10}Zr_7$, Cu_8Zr_3 and Cu_3Ti_2 phase. At the first crystallization stage, less intense XRD peaks of equilibrium phases were also observed. Crystallization studies done by Kasai et al. [10] shows the formation of equilibrium phases at the third crystallization stage, but in present study the heat treatment was done for 1 h due to which the equilibrium phase were obtained during 1st and 2nd stage of crystallization. The average size of the crystalline phases in the annealed samples was estimated from XRD results with the Scherrer formula [11] as 45 nm and 65 nm in Tx_1 and Tx_2 samples, respectively. Fig. 3 shows the microhardness of the sample with various loads. The results indicate that the hardness of metallic glass is more in the relaxed state in comparison to both as cast BMG and crystallized samples. The figure also shows that the hardness decreases with increase in the load for both glassy and crystallized alloy.

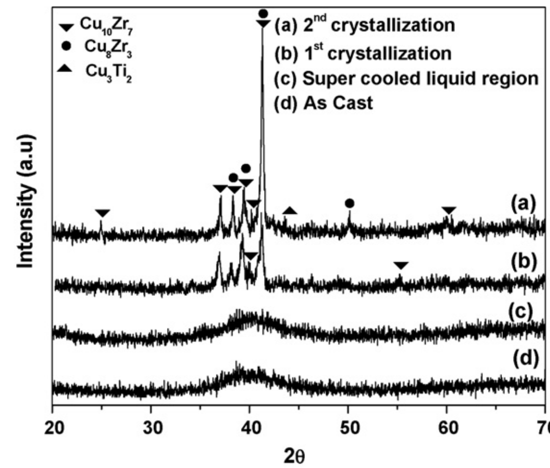

Fig. 2. XRD patterns of metallic glass in different annealing states.

Concustell et al. [12] have also shown that structural relaxation results in an increase in hardness in comparison to as cast BMG and crystallized samples in case of $Cu_{60}Zr_{22}Ti_{18}$ alloy. During structural relaxation, a more dense randomly packed structure is obtained due to annihilation of free volume. This leads to restriction on the shear band movement in the relaxed amorphous alloy, which results in an increase in hardness [12]. The annealing conditions used in the present study have led to crystals, which are larger than the usual shear band sizes in bulk amorphous alloys and hence they are not able to disrupt shear-band propagation, which has possibly resulted in a lower hardness on crystallization.

Fig. 4(a) shows that the as cast BMG has lower coefficient of friction (μ) than that annealed at Tx_1 and Tx_2. In addition, the relaxed BMG has lower μ values than both as cast BMG

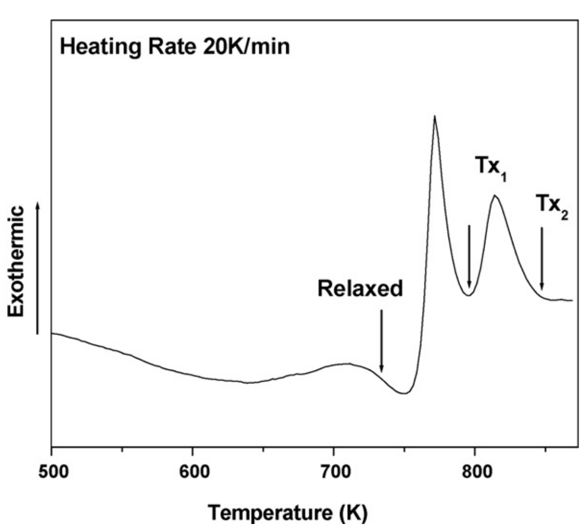

Fig. 1. DSC trace of as cast $Cu_{60}Zr_{30}Ti_{10}$ BMG.

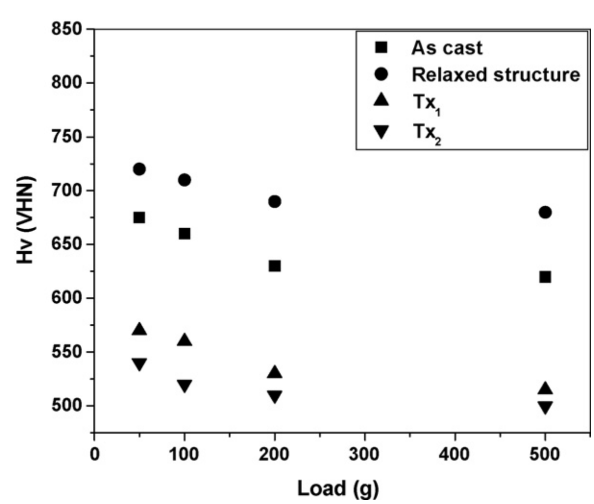

Fig. 3. Hardness (H) vs. load (P) for as cast, relaxed, Tx_1 and Tx_2 samples.