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The Effect Of Fracture Toughness On The Plastic Deformation Of Tinb/Cu-Based And Tinb/Zr-Based Bulk Metallic Glassy Composites (Bmgcs).

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ABSTRACT: The fracture toughness is a critical material property that determines engineering performance. Because of the unique and distinctive mechanical properties of bulk Metallic glasses (BMGs), they have received substantial attention over a few decades. However, many of them exhibit poor plasticity because the deformation of these materials are highly confined to few shear bands. In this study, two kinds of bulk metallic glasses namely Cu-based and Zr-based Bulk Metallic Glass with no plastic strain are adopted as matrixes. Both of them were reinforced by crystalline TiNb with the same volume fraction and particle size. The data obtained by the loading tests showed that the plastic strain of Zr-based BMGCs was much higher than the Cr-based BMGCs. In this research we are relating changes in the plastic strain to the fracture toughness of the material. In the composite having high fracture toughness, the strength of the main crack is reduced due to the formation of micro-cracks on the surface of the specimen which simultaneously resulted in a large plastic strain in the Zr-based BMGCs. On the contrary, for the Cr based BMGCs, crack propagated rapidly throughout the volume, so no such micro-cracks were generated and thus the plastic strain generated in the latter was much less than the Zr-based BMGCs.

Keywords: Composites; Bulk metallic glasses; fracture toughness; plasticity.

1 Introduction

Bulk Metallic Glasses (BMG or Bulk Amorphous Alloys) are a new class of metallic alloys with a unique amorphous atomic structure [1]. The amorphous atomic structure provides very high yield strength and very high elastic limit under impact conditions. The lack of ductility significantly limits the engineering applications of BMGs [2] and [3]. In order to overcome the problem of low plasticity, the development of bulk metallic glass composites (BMGCs) have been proven to be an effective way. Cu-based bulk metallic glasses have excellent properties and advantages, due to their high strength, relatively low cost and reasonable plasticity caused by inhomogeneous microstructure [4-6]. Cu-based bulk metallic glasses usually show poor plasticity due to the deformation of BMGs is highly localized in a few shear bands [7]. Indeed, this shortcoming also emerges in most of bulk metallic glasses whatever the main component is [8-9]. Many researchers are working on the fabrication bulk metallic glassy composites (BMGCs) to improve the plasticity of BMGs by introducing nanoscale crystalline phases into the metallic glassy matrix in order to form multiple shear bands which would enhance the plasticity of such BMGCs [10-12]. According to many papers it has been reported about the effect of the reinforcement properties, such as size of the particles and mechanical properties of reinforced phases on the plasticity of BMGCs [13-15]. But any report of gaining large plasticity due to any reinforcement with the BMGs have been very less. Certain Zr based bulk metallic glasses have shown that after reinforcement the plastic strain increased. $(Zr_{48}Cu_{36}Al_8Ag_8)_{99.25}Si_{0.75}$ [16] and $Zr_{57}Nb_5Al_{10}Cu_{15.4}Ni_{12.6}$ [11] BMGs reinforced by Ta gained 22% and 4% plastic strain, respectively. Certain $Zr_{55}Cu_{30}Al_{10}Ni_5$ reinforced by Al_2O_3, 1.2% plastic strain was obtained [10]. Any plastic deformation in crystalline alloys are considered as the accumulating effect of innumerable dislocations slips and/or twining. But in bulk metallic glasses, no such crystalline structure is present so no dislocations takes place and only rearrangement of atoms takes place when any stress is applied and shear strain is developed. In previous works, the introduction of the reinforcement inducing the initiation and propagation of shear bands in the glassy matrix to improve its plastic deformation has been discussed widely. In this work, we focused on the effect of fracture toughness on the plastic deformation of glassy matrix of BMGCs. By studying fracture toughness, the development of crack in the glassy matrix and the formation and propagation of shear bands were discussed. The compression results indicated that higher plastic strain was obtained in the TiNb/Zr based composite than that of TiNb/Cu based glassy composite.

2 EXPERIMENTAL PROCEDURE

Master ingots of the metallic glasses were prepared by arc melting a mixture of the constituent elements in an inert atmosphere. Our purpose is to produce glassy powders of the Bulk metallic glasses so that they could be sintered to form the composite. For this, the samples were remelted in a quartz tube using a heating coil followed by injection through a nozzle with a diameter of 0.6mm. The powders prepared are then sieved according to their particle sizes with the help of normal sieving methods. The powders under with particle size of 50 µm were used along with TiNb with particle size of 20–50 µm were used in this study. The BMG powder and the TiNb powder were then compacted in a cylindrical shape of radius 30mm. Then the compact was sintered at a heating rate of 50K/min initially and then lowered it to 10K/min as it approached the sintering temperature (Ts). It was held for 10 minutes at the sintering temperature. The sintered specimen was pressurized at 500MPa from both ends to finish the preparation. The surface morphology of the sintered specimen prepared, broken surface of bending test specimens and compressive test samples were observed under scanning electron microscope (SEM). The mechanical properties under uniaxial compression were measured using Universal testing machine. Fracture toughness test was conducted to determine the resistance of the material to further crack extension with ASTM E399 which is predominantly used for precracked specimens. Compression test was performed using the specimen which were prepared by cutting the sintered sample into specimen of length 2.5mm, width 2.5mm and height 5mm. The dimensions of the specimen for single edge notch 3 point bending test (3 PB) or Flexural test were 50 mm × 3mm × 3 mm.

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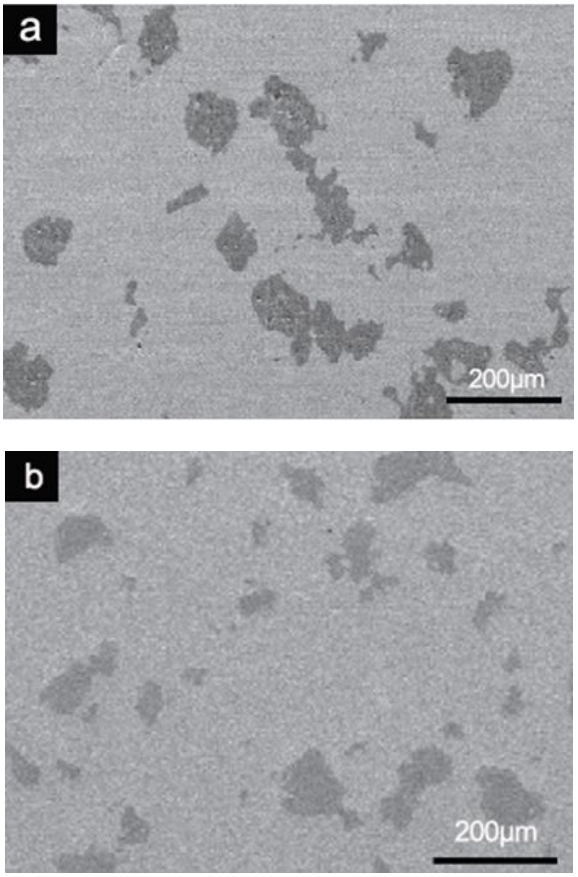

Fig. 1. *SEM micrographs of composites of (a) TiNb/ $Cu_{46}Zr_{42}Al_7Y_5$; (b) TiNb/ $Zr_{55}Cu_{30}Al_{10}Ni_5$*

3 RESULTS

SEM micrographs of the cross section of the two BMGCs specimens containing TiNb particles with particle sizes below 50μm are shown in Fig. 1(a, b).The figure shows good bonding between the glassy matrix and the secondary phase particles. Figure shows the extent of homogenous dispersion of TiNb particles in the two BMG samples namely $Zr_{55}Cu_{30}Al_{10}Ni_5$ (Fig. 1(a)) and $Cu_{46}Zr_{42}Al_7Y_5$ (Fig. 1(b)) glassy matrix. The mechanical properties of the sintered BMGs and BMGCs containing TiNb were investigated by compression test. The compressive stress–strain curves are shown in Fig. 2. The results show that the plasticity is improved for both $Zr_{55}Cu_{30}Al_{10}Ni_5$ and $Cu_{46}Zr_{42}Al_7Y_5$ due to the addition of TiNb particles. It is clearly seen that the larger plastic strain is obtained in $Zr_{55}Cu_{30}Al_{10}Ni_5$ glassy matrix composite than $Cu_{46}Zr_{42}Al_7Y_5$. It indicates that the effect of TiNb on improving the plasticity of $Zr_{55}Cu_{30}Al_{10}Ni_5$ glassy matrix is more effective than that of $Cu_{46}Zr_{42}Al_7Y_5$glassy matrix. During loading process for any material, when the load strength is exceeded, the crack is formed. On continued loading, crack propagates through the section until complete rupture occurs. Therefore the failure of material is closely related to the formation and propagation of the crack. Generally, fracture toughness of material is regarded as its resistance to crack propagation. Therefore, the fracture toughness of the two kinds of $Zr_{55}Cu_{30}Al_{10}Ni_5$ and $Cu_{46}Zr_{42}Al_7Y_5$ bulk metallic glassy samples is studied. Fig. 3 shows typical load-displacement of notched 3 PB samples. Then the plot of load versus displacement was prepared that determined that the Zr based BMGCs had great elongation than Cu based BMGCs. And the fracture toughness was calculated. The results show that fracture toughness value of $Zr_{55}Cu_{30}Al_{10}Ni_5$ is higher than that of $Cu_{46}Zr_{42}Al_7Y_5$, which are 125 MPam1/2 and 94 MPam1/2, respectively. The broken surfaces of $Cu_{46}Zr_{42}Al_7Y_5$ and $Zr_{55}Cu_{30}Al_{10}Ni_5$ samples after 3 PB test were observed. The defects are regarded as soft spots to yield firstly and then the soft spots can rapidly spread out when the stress exceeds the certain critical regions. Generally, larger specimen possesses lower fracture toughness.

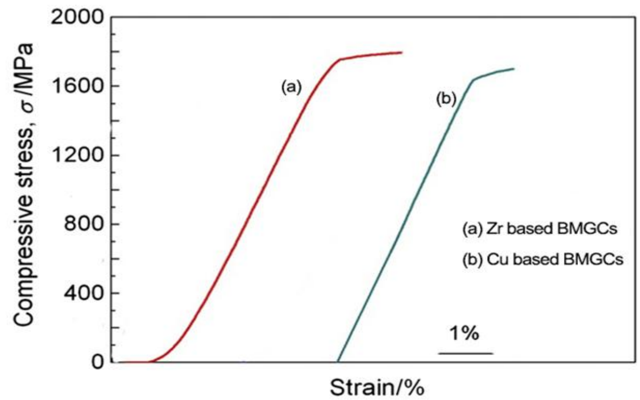

Fig. 2. *Stress-strain curves of (a) TiNb/ $Zr_{55}Cu_{30}Al_{10}Ni_5$ and (b) TiNb/ $Cu_{46}Zr_{42}Al_7Y_5$ composites*

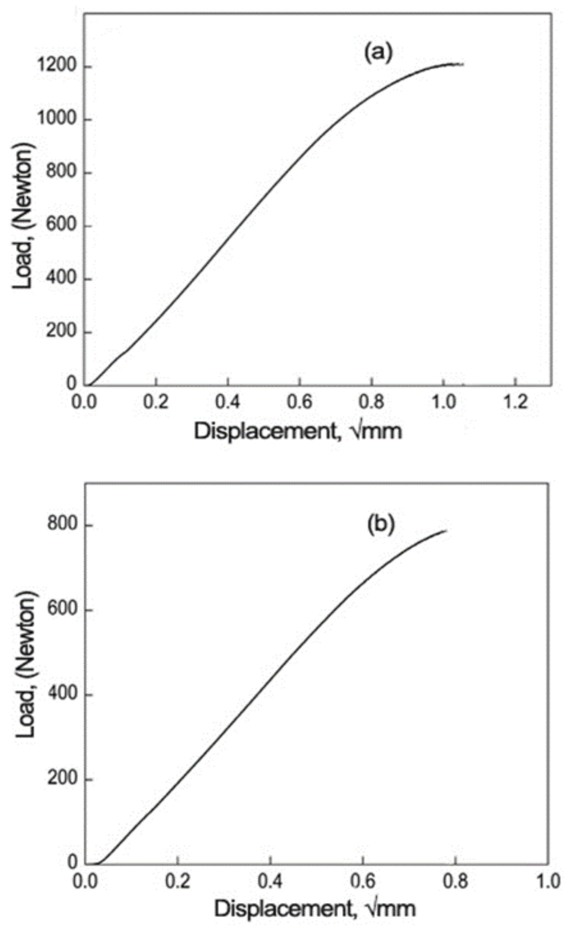

Fig. 3. *Load–displacement curves for (a) $Zr_{55}Cu_{30}Al_{10}Ni_5$ and (b) $Cu_{46}Zr_{42}Al_7Y_5$.*

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4 DISCUSSION

The deformation of the metallic composite is taking place in multiple stages as follows:

1) The generation and movement of shear bands. Due to the discrepancy of Young's modulus and yield strengths between alloyed material and the BMGCs, stress concentration is introduced to the interface between TiNb and the composite. Apart from the ductile nature, more shear bands are generated and due to these shear zones, the plasticity of the BMGCs is highly improved.
2) The generation of micro-crack. When more number of shear zones are generated under higher loading, the amount of defects rises rapidly, and then micro-crack is formed.
3) The propagation and growth of micro-crack. In this stage, the two types of BMGCs show varying overall properties. As we all know, the most important and basic requirement of a crack to propagate and grow is stress concentration. These stresses when overcome the inter particulate bonding strength of the material.

Griffith theory also states that, when a crack propagates, the elastic strain energy is released throughout the volume of the specimen. As a result of this two new crack surfaces are generated which indicate the surface energy. Now the existing crack will develop if the elastic strain energy released by performing so is greater than the surface energy created the two new crack surfaces. Therefore, the crack propagation and growth is rapid.

5 CONCLUSIONS

TiNb/Cu-based and TiNb/Zr-based BMGCs were fabricated successfully and then compression test and bending test were performed and the results were drawn. Larger plastic strain was obtained in the TiNb/Zr-based composite than that of TiNb/Cu-based composite. The study of fracture toughness indicated the glassy matrix with high toughness is benefited to the formation of micro-crack, which retards the failure of sample.

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