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Fabrication of Zr-based bulk metallic glass/aluminum alloy multi-materials by stacking extrusion

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ABSTRACT

Zr-based bulk metallic glass(BMG)/7075 aluminum alloy multi-materials have been successfully fabricated by extrusion in the vertical stacking form. Extrusion tests were carried out at 713 K within the supercooled liquid region(SLR) and the ram speed of 2 mm/min. An interface of which Al alloy is inserted into BMG and wrapped tightly by BMG in the periphery is obtained. The interface between BMG and Al alloy has been characterized by a variety of techniques including Optical Microscope (OM), Scanning Electron Microscope(SEM), X-ray diffraction(XRD) and Transmission Electron Microscope(TEM). The interface is estimated to be defect-free. BMG matrix maintains well amorphous with only a small quantity of nanocrystals at the interface, and elements diffusion is also detected. Both the macrostructure and microstructure analyses indicate a good bonding between dissimilar materials at the interface.

1. Introduction

Bulk metallic glasses(BMG) have attracted attention due to their extraordinary mechanical properties such as superior strength, hardness and excellent corrosion resistance. However, size limitation, difficulty in applications in combination with other materials and difficulty in processing caused by room temperature brittleness have hindered their potential for structural applications [1,2]. Therefore, substantial studies have recently focused on producing BMG-based multi-materials.

When heated to supercooled liquid region(SLR), bulk amorphous alloy exhibits a sharp softening rheological behavior [3–6]. Taking advantage of softening behavior and thermal stability of bulk amorphous alloy in SLR, thermoplastic forming of BMG has been extensively studied [7–9]. Based on the thermoplastic forming theory, Ragani et al. [10] and Gravier et al. [11] proposed a solid-to-solid joining method to produce crystal/amorphous composite materials, making full use of the excellent superplastic forming performance of BMG in SLR. Ragani et al. [10] prepared lamellar composites of lightweight alloy (Al or Mg alloy) and BMG by co-compression, showing that simultaneously thermal deformation of dissimilar alloys contributing to the bonding between them. However, the compression process tends to cause oxides at the interface, reducing the bonding strength. Gravier et al. [11] and Lee et al. [12] fabricated rod-type composites with Zr/Mg-based BMG as cores in association with Al/Mg alloys as sleeves through extrusion process in SLR, showing that good interfacial bonding can be achieved by extrusion and oxides can be avoided. Since then, a lot of studies have been performed focused on fabricating composites of BMG and crystal materials by extrusion [13–16].

Inspired by the compression and extrusion process mentioned above, we propose a new method of welding BMG and crystal materials by means of extrusion, of which two samples are stacked along the axial direction. Therefore, the objective of the study described here is to perform a novel processing method to fabricate amorphous/crystal composites, and properties of the composites are also presented.

2. Materials and methods

The amorphous rods of $Zr_{44}Ti_{11}Cu_{9.8}Ni_{10.2}Be_{25}$(at. %), labeled as LM1B, were supplied by MATERION INC, with 10 mm diameter and 100 mm height. The original rods have been confirmed to have an absolute amorphous nature by X-ray diffraction (XRD). The temperature of glass transition (Tg), crystallization temperature (Tx), and supercooled liquid region(ΔT) were estimated to be 629 K, 735 K and 106 K by differential scanning calorimetry(DSC), respectively [17]. Correspondingly, the temperature of co-extrusion

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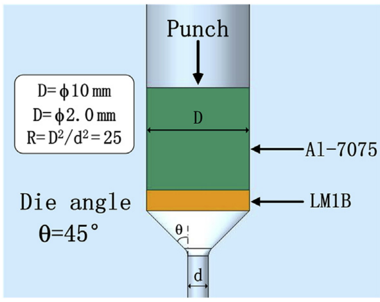

Fig. 1. Schematic illustration of the laboratory scale extrusion die and work-pieces positions.

was set at 713 K whereas the ram speed was 2 mm/min. Rod-type crystalline aluminum (7075 type) alloy was chosen as the crystalline material with 10 mm diameter. The BMG and Al-7075 alloy rods were sliced into 2 mm and 10 mm height using a wire cutting machine, respectively, and then polished and ultrasonically cleaned. A universal testing machine and a vertical split-type extrusion die were used. Fig. 1 shows the schematic illustration of laboratory scale extrusion die as well as work-pieces positions during extrusion process. It should be mentioned that the two billets were stacked along the axial direction, which distinguished from other compounding methods [10–16]. After the die being heated to setting temperature, extrusion specimens were placed into die cavity according to the order shown in Fig. 1, and then maintained for 3 min to homogenize temperature before processing.

3. Results and discussion

Fig. 2 shows the morphology and microstructures of the interface between BMG and Al alloy after extruded at 713 K and 2 mm/min. As shown in Fig. 2(a), due to the use of vertical split-type extrusion die, flash is formed on the sides of the sample. Microstructure of the cross section of the interface is presented in Fig. 2(b), where the sample exhibits an interface of which Al alloy is inserted into BMG, and wrapped tightly by BMG in the periphery. The interface morphology shown in Fig. 2(b) indicates that significant nonuniformity in the flow of the work-piece during extrusion process, and the material flow rate around axis is much faster than that near the die wall. Several main reasons can interpret the formation of the special interface. First of all, the interfacial friction between billets and steel mold should be attributed to, making the flow rate of the billet around the axis being much faster than that near the die wall and bringing about a rudiment of interface form [18]. Secondly, because of the flow dead zone existed around the die angle, a portion of peripheral material are stuck around the die angle [19]. Last but not the least, the difference of flow stress under the test condition between LM1B and 7075 plays a great role [12], leading to Al alloy squeezed out previous around the axis, and the lagging LM1B near the cylinder wall are left to wrap the advanced Al alloy at last. Along the axial direction of extruded rod, from BMG to aluminum side, the wrapped amorphous gradually decreases and is finally replaced by the aluminum completely.

The smooth and continuous interface demonstrates that welding has accured in a satisfactory manner. In addition, from high resolution photographs at higher magnification presented in Fig. 2(c)-(e), no obvious joining defects such as micro-cracks, micro-voids and brittle intermetallics are identified. Some small burr-like bulges are found at top of Al alloy at the interface shown in Fig. 2(c), forming a small range of mechanical locking. Furthermore, the special interface with cladding increases the contact area of dissimilar materials, which is undoubtedly benefit for improving bonding strengh.

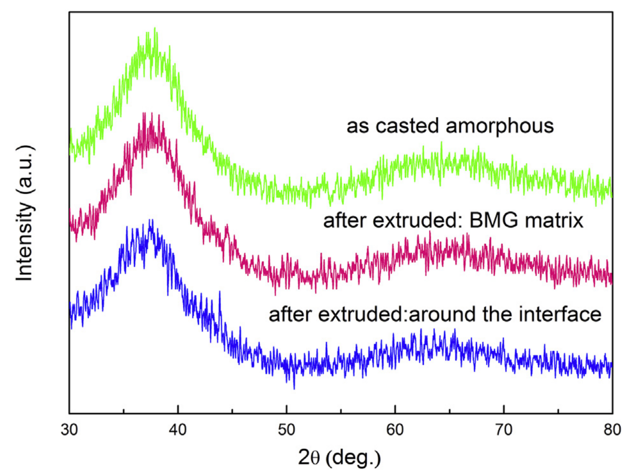

Fig. 3. XRD diffraction patterns of LM1B before and after extrusion at 713 K and 2 mm/min.

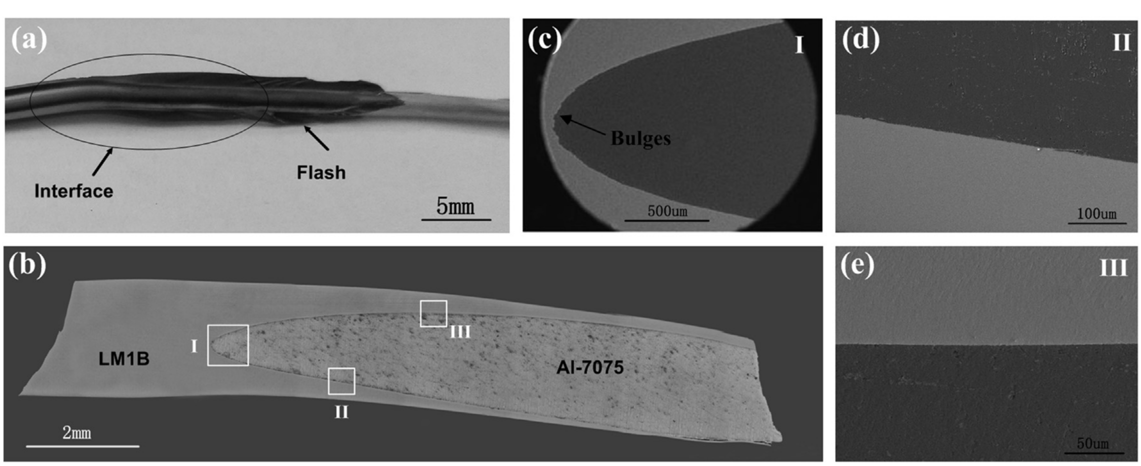

Fig. 2. Morphology and microstructures of the interface. (a)image of the interface appearance taken by camera, (b)optical micrograph of the overall appearance of the cross section of the interface taken by Leica DCM8, (c), (d) and (e)SEM observations of different regions at the interface shown in (b) at higher magnifications.