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Synthesis of Zr-based bulk metallic glass–crystalline aluminum alloy composite by co-extrusion

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ABSTRACT

The effects of co-extrusion conditions like extrusion temperature and deformation rate on the fabrication of a Zr-based bulk metallic glass–Al clad material were investigated under the extrusion ratio of 5.06. The ranges of extrusion temperature and deformation rate were varied from 658 to 703 K and from 10^{-3} to 10^{-1} mm/s, respectively. Both macroscopic and microstructural characterizations reveal that sound materials compatibility could be obtained under the low deformation rate–low temperature within supercooled liquid region combination, showing homogeneous distribution of the rate of cross-sectional area between core and sleeve without crack or intermetallic compound in the vicinity of the interface.

1. Introduction

Bulk metallic glasses (BMGs) have excellent mechanical properties such as extremely high fracture strength and elastic limit, but their potential as structural engineering materials isn't burst out yet due to their disappointingly low level of the overall plasticity at room temperature [1,2]. To overcome this intrinsic drawback of BMGs, bulk metallic glassy composites containing nanocrystals, second-phase particles/fibers or in-situ formed micrometer-size dendrites have been developed. Fabrication of BMG matrix composites can be classified into two ways. The first method is to fabricate dissimilar metal composites during solidification, taking advantage of the high strength from the BMGs and of the large ductility from the crystalline alloys, respectively [3–5]. But this manufacturing process has its own drawback since the feasible microstructure exhibiting optimum properties is very susceptible to the process conditions such as overheating temperature, cooling rate and sample geometry. The second processing way is to fabricate BMG matrix composites by solid-to-solid forming process utilizing unique rheological properties of monolithic BMGs within supercooled liquid region (SLR).

This study is to perform co-extrusion of a Zr-based bulk metallic glass with a crystalline 7075 aluminum alloy for producing experimentally new bimetallic rods having high elastic limit and corrosion resistance. In order to determine proper co-extrusion parameters, both macroscopic and microscopic characterization of the protruded composite rods were investigated.

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2. Experimental procedures

Die-cast ingots of $Zr_{44}Ti_{11}Cu_{9.8}Ni_{10.2}Be_{25}$ (LM1B) BMG with 9 mm diameter and 150 mm length were supplied by Liquidmetal Technologies Inc. This alloy system was chosen as sleeve materials due to the absence of phase separation within its wide SLR extending over 120 K, which is helpful to avoid the formation of nanocrystals as long as possible [6]. Crystalline aluminum (type 7075) alloy was used as the core counterpart. After preparing cylindrical core samples with 4.5 mm outer diameter and 10 mm height together with sleeve samples with 9 mm outer diameter, 4.5 mm inner diameter and 10 mm height as shown in Fig. 1(a), the net-shape co-extrusion ability was tested with varying two major variables such as temperature and deformation rate under constant section area reduction of 80.25%. Schematic illustration of co-extrusion was shown in Fig. 1(b). Boron nitride spray was used as lubricant to reduce friction between BMG sleeve and die made of SKD61. Before performing actual co-extrusion process, 2 min of pre-heating was provided for each specimen in order to achieve a homogeneous temperature distribution.

To characterize the microstructure near the interface by means of optical microscope and field-emission scanning electron microscope (FE-SEM, model TESKAN MIRA II), co-extruded macrocomposite samples were sliced into several disks of around 1 mm thickness. The chemical compositions of the co-extruded materials were also qualitatively investigated by Oxford energy-dispersive X-ray spectroscopy (EDS). Nanoindentation measurements were also performed on the co-extruded samples embedded in resin and polished to a mirror finish by using an MTS Nanoindenter XP equipped with a triangular Berkovich diamond indenter. All of the nanoindentation tests were carried out under displacement-control mode with a depth limit of 1000 nm.

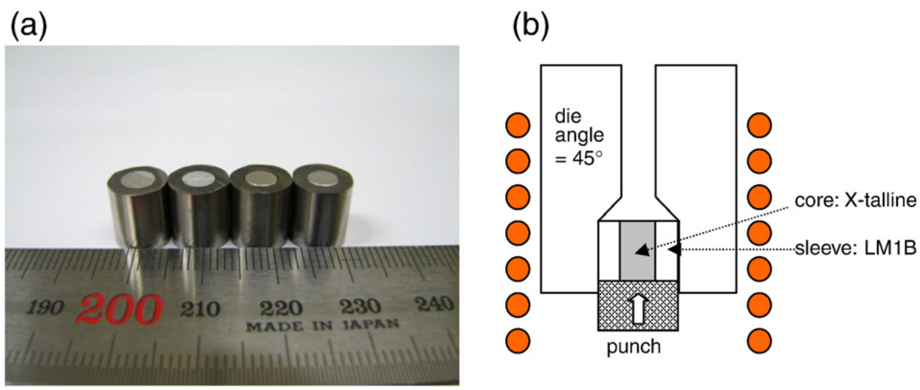

Fig. 1. (a) An image of initial LM1B BMG sleeve/7075 Al core samples to be extruded. (b) Cross-sectional schematics of laboratory-scale co-extrusion apparatus.

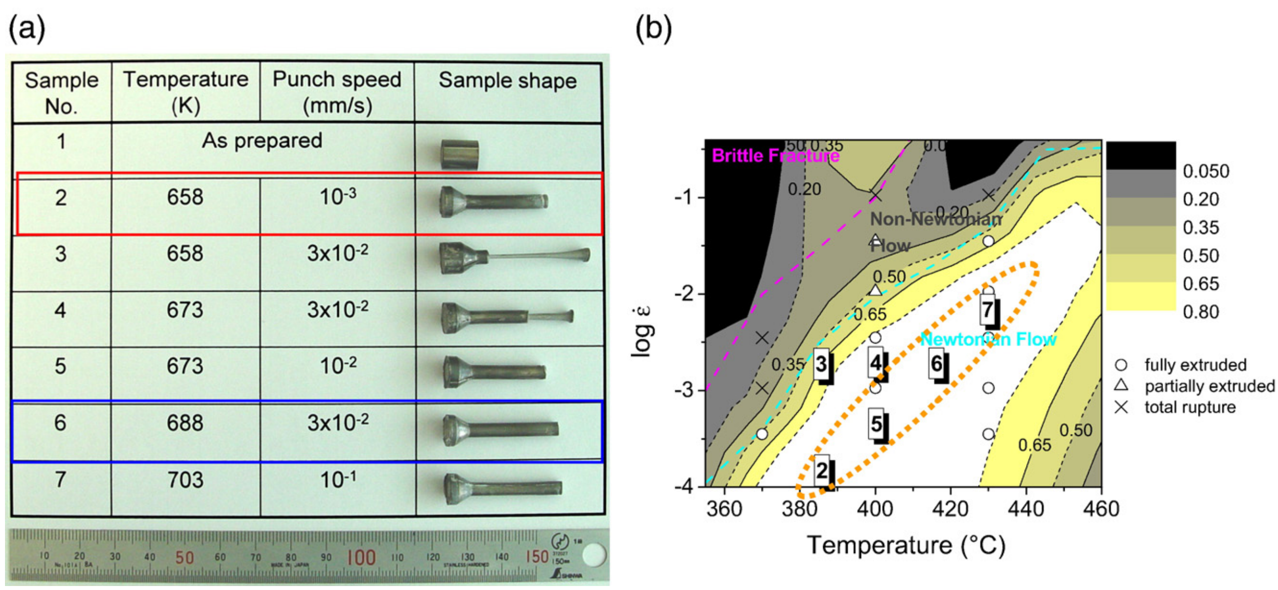

Fig. 2. (a) Macroscopic co-extrusion features with test conditions and (b) Processing map for LM1B BMG.

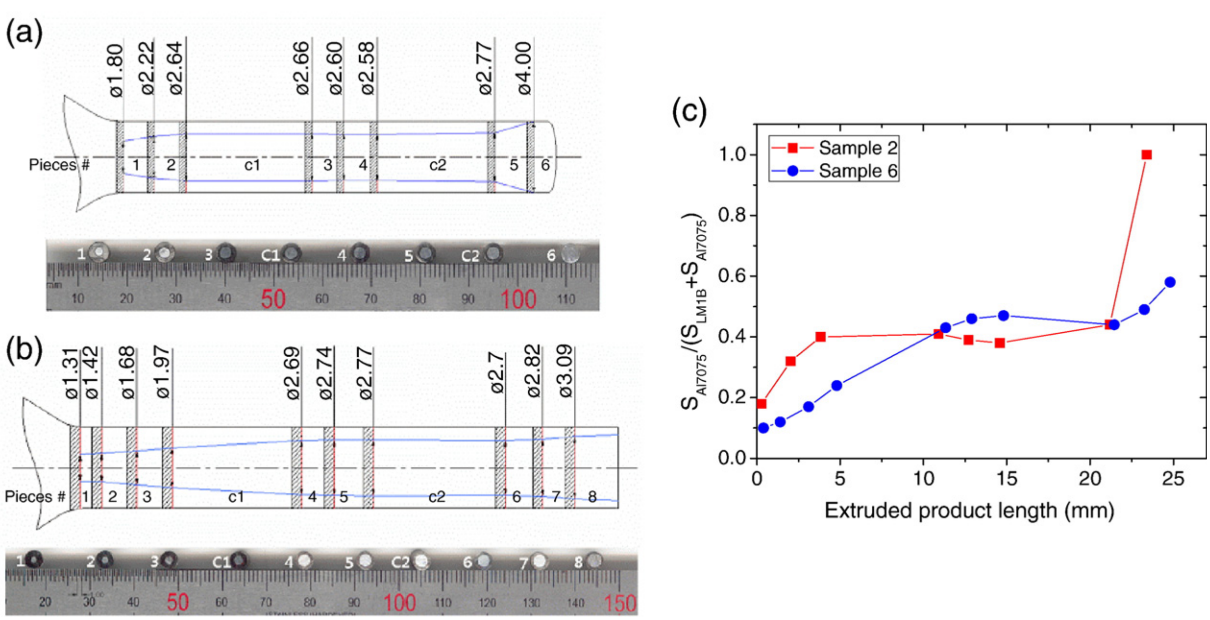

Fig. 3. Cross-sectional and plotted images of the co-extruded rods for (a) sample 2 and (b) sample 6. Fig. 3(c) shows the rate of cross-sectional area for samples 2 and 6 as a function of product length.