COEXTRUSION OF A CRYSTALLINE ALUMINUM ALLOY WITH A ZR-BASED BULK METALLIC GLASS

K.S. Lee, S.H. Kang, Y.S. Lee

Materials Processing Division, Materials Deformation Group, Korea Institute of Materials Science, 531 Changwondaero, Changwon, Gyeongnam 641-831, South Korea

Introduction

To improve mechanical properties of monolithic bulk metallic glasses (BMGs), various bulk metallic glass matrix composites have been fabricated, such as glassy composites containing nanocrystals, second-phase particles, fibers or in-situ formed dendrites with micrometer-size. Although these composites developed so far could be characterized as different types of materials, the primary idea for enhancing room temperature mechanical properties in terms of elongation or toughness is that these nano-crystals, second-phase particles, fibers and dendrites play an important role of hindering the catastrophic brittle fracture caused by the localization of few shear bands [1~2].

For controlling diffusion and reaction at the interface more effective, a low cost, flexible fabrication of the composites by solid-to-solid forming process was recently reported by applying warm co-extrusion [3]. On the other hand, BMGs are prone to be crystallized, which lead to changes in the properties of glassy phase when thermo-mechanically processed within supercooled liquid region [4]. This suggests that process window for fabricating BMG/crystalline macro-composite has to be carefully controlled for escaping crystallization-induced embrittlement of the glassy phase. Accordingly, the aim of this study is to carry out co-extrusion of a Zr-based bulk metallic glass with AA7075 crystalline alloy at temperatures within supercooled liquid region for producing experimentally new bimetallic rods in millimeter length scale. The mechanical, thermal and microstructural properties of the protruded macrocomposites are also investigated.

Experimental

In this study, die cast $Zr_{44}Ti_{11}Cu_{10}Ni_{10}Be_{25}$ (at. %) bulk metallic glass (BMG), referred to as LM1B, was selected as the sleeve materials. Also typical crystalline AA7075 alloy was used as the core counterpart. Cylindrical rod-type ingots of LM1B with 9 mm diameter and about 150 mm length were supplied by Liquidmetal Technologies Inc.
After preparing cylindrical sleeve billet with 9 mm outer diameter, 4.5 mm inner diameter and 10 mm length by electric discharged machine (EDM), as shown in Fig. 1(a), laboratory-scale hot extrusion for this LM1B/AA7075 macro-composite was performed with varying two major process variables, i.e. temperature and deformation rate, while considering the experimentally constructed processing map of LM1B indicating near net-shape processability [5]. Punch jig and die were made of SKD61 with an initial diameter of 9 mm and the protrusion diameter of 4 mm indicating reduction ratio of 5.06. Boron nitride spray was used for lubrication and easy detachment after extrusion.
After extrusion, LM1B/AA7075 macrocomposite samples were sliced into several disks of 1 mm thickness, with one side prepared to observe the microstructure near the interface by optical microscope and TESKAN MIRA II field-emission scanning electron microscope (FE-SEM). The chemical composition of the extruded materials, especially near the interface of this bimetallic rods, were qualitatively analyzed by energy dispersive X-ray spectroscopy (EDS) attached with JEOL JSM-5610 SEM.

Results and Discussion

Fig. 1 shows the impact of the test conditions on the macroscopic feature of co-extruded samples. For Samples 3 and 4, only soft core materials were observed to squeeze out while the simultaneous bimetall rods started to be extruded later, as presented in Fig. 1. Such a macrostructural incompatibility at the initial stage of extrusion is presumably explained by the following reason. Simultaneous plastic deformation of two

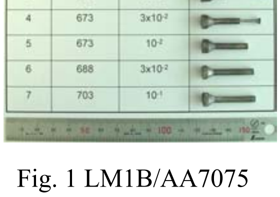

Fig. 1 LM1B/AA7075 bimetallic rods

materials is very hard when the difference of the flow stress between both materials is too high. For the case of Sample 4, flow stress of LM1B is around 600 MPa, more than three times higher than AA7075 (< 200 MPa) at the same temperature (673 K) and punch speed ($3x10^{-2}$ mm/s), which causes such an incompatibility. On the other hand, macroscopic compatibility of the bimetallic rod is much more improved for Sample 5, since the slight decrease of the punch speed (10^{-2} mm/s) drastically reduces the flow stress of the LM1B down to ~200 MPa. These results are in good accordance with another co-extrusion case where a flow stress relation less than 2.5 was suggested as a prerequisite for compatible co-extrusion [6].

Table 1 Identification of the extrusion conditions in reference to temperature and constant punch speed.

Sample ID	Initial core/sleeve outer diameters (mm)	Diameter of the protruded part (mm)	Temperature (K)	Constant punch speed (mm/s)
1	9 / 4.5	- (Before extrusion)	-	-
2	**9 / 4.5**	**4**	**658**	**10^{-3}**
3	9 / 4.5	4	658	$3x10^{-2}$
4	9 / 4.5	4	673	$3x10^{-2}$
5	9 / 4.5	4	673	10^{-2}
6	**9 / 4.5**	**4**	**688**	**$3x10^{-2}$**
7	9 / 4.5	4	703	10^{-1}

As is reported by other researcher, the cross-sectional distribution of the protrusion is the main parameters to determine dimensional stability [7]. For the sound co-extruded Samples 2 and 6 macroscopically, the images of the protrusion product could be plotted as shown in Figs. 2(a) and 2(b). Also the ratio of cross-sectional area as a function of extruded product length was presented as Fig. 2(c). Excluding very initial and final stages of co-extrusion, Sample 2 exhibits homogeneously distributed cross-sectional area ratio along the direction of extrusion when compared with Sample 6. Although the ratio of cross-sectional area is not completely the same throughout the extruded product length between 4 and 21 mm, the unevenness of the ratio of cross-sectional area is less than 10 % for sample 2. This indicates that the fairly good homogeneity of a core area ratio seems to be indebted to bypass crystallization-induced increasing of flow stress for the glassy phase during co-extrusion process, which breaks feasible flow compatibility of both alloys.

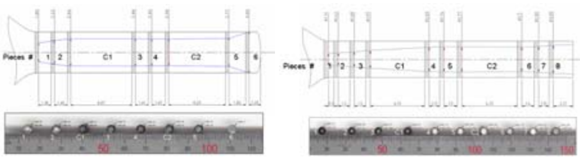

Fig. 2 Plotted images of the co-extruded bimetallic rods: (a) sample 2 and (b) sample 6.

Fig. 3(a) and (d) shows the micrograph of the region close to the interface developed during co-extrusion observed by FE-SEM for Samples 2 and 6, respectively. Between the sleeve LM1B BMG and core AA7075, a smooth, continuous band of ~5 μm width is clearly noticed for sample 2. However, some holes are observed for sample 6 indicating inadequate extrusion in terms of macroscopic surface morphology, though there are not so much difference in the compositional change for the Al and Zr elements (Figs 3(c)(d)). Compositional analysis performed by EDS in Figs. 3(c) and 3(f) reveals that this band consists of considerable amount of oxygen together with other metallic elements from sleeve and core.

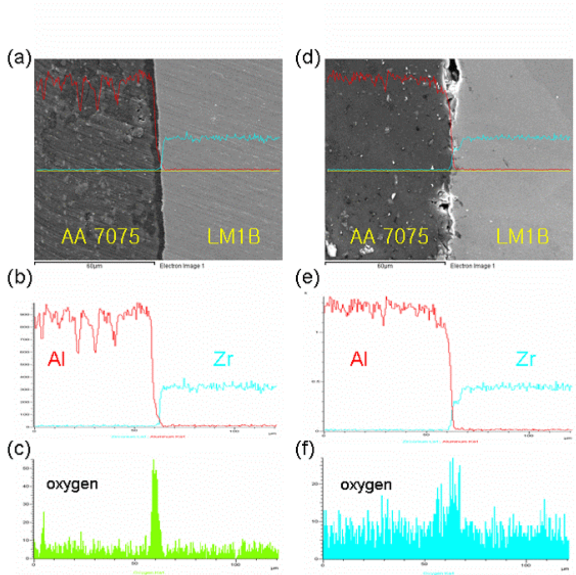

Fig. 3 Microstructure and EDS results of the co-extruded macrocomposites at region close to the interface of Samples 2 (a~c) and 6 (d-f), respectively.

Conclusion

Zr-based LM1B BMG/AA7075 bimetallic rods are successfully synthesized using co-extrusion. Sound materials compatibility was determined as sample 2 which conformed to low temperature – deformation rate combination.

References

1. H. Kato, T. Hirano, A. Matsuo, Y. Kawamura and A. Inoue: *Scripta Mater.*, 2000, **43**, 503.
2. Z.F. Zhang, F. Wu, G. He and J. Eckert: *J. Mater. Sci. Technol.*, 2007, **23(6)**, 747.
3. S. Gravier, S. Puech, J.J. Blandin and M. Suery: *Adv. Eng. Mater.*, 2006, **8(10)**, 948.
4. H.W. Zhang and T.J. Zhou: *Phys. Lett. A*, 2006, **350**, 297.
5. K.S. Lee, H.-J. Jun, C.P. Kim, J. Eckert and Y.W. Chang: *Key Eng. Mater.*, 2007, **345-346**, 105.
6. J.L. Alcarez, Ph.D. thesis, ESII, Universidad de Navarra, San Sebastian, 1993.
7. P. Kazanowski, M.E. Epler and W.Z. Misiolek: *Mater. Sci. Eng. A*, 2004, **369**, 170.