

Diffusion Bonding between Zr-Based Metallic Glass and Copper



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Abstract: The diffusion bonding capability between $Zr_{41.25}Ti_{13.75}Cu_{12.5}Ni_{10}Be_{22.5}$ bulk metallic glass and pure Cu with and without interlayer was studied on a Gleeble3500 thermomechanical simulator. Experimental results show that good diffusion bonding joints without cracks and voids can be obtained under both conditions. Atomic diffusion at the interface is obviously observed using EDS and EPMA methods, while the diffusion zones are very narrow. The crystalline phases transformed from amorphous state will accelerate the atomic diffusion at the interface.

Key words: diffusion bonding; metallic glass; interlayer; interface

Bulk metallic glasses (BMGs) exhibit excellent mechanical, physical and chemical properties compared to traditional crystalline alloys as a result of their unique short-range order and long-range disorder microstructures^[1-4]. Thus, they have a broad application prospects in the fields of electronics, machinery, chemicals and national defense. But the factors, such as room temperature brittleness and limited preparation dimension, have hindered their application as structural material^[5]. In order to overcome the negative factors, multi-materials containing BMGs and crystalline alloys have been investigated recently. Many processing methods were adopted to join BMGs and crystalline alloys, such as explosive welding^[6,7], electron beam welding^[8,9], pulse-current welding^[10,11], friction welding^[10,12] and friction stir welding method^[13,14]. However, the explosive welding is dangerous, electron beam welding and pulse-current welding will bring broad welding heat affected zone, and there exists larger residual stress at the interface during friction welding and friction stir welding. Compared with the previous welding means, the diffusion bonding method has the advantages of low bonding temperature, high bonding precision and small residual stress at the interface^[15]. In the present paper, the diffusion bonding capability between $Zr_{41.25}Ti_{13.75}Cu_{12.5}Ni_{10}Be_{22.5}$ (Vit1) BMG and

pure Cu was studied on a Gleeble3500 thermomechanical simulator based on the thermoplastic property of the Zr-based BMG in its supercooled liquid region. The joining interface was characterized in detail using SEM, EDS and EPMA methods. The impact of adding Ni interlayer on the diffusion bonding between Vit1 and Cu was also studied.

1 Experiment

The ingots of master alloy with nominal composition of $Zr_{41.25}Ti_{13.75}Cu_{12.5}Ni_{10}Be_{22.5}$ (at%) were prepared by arc melting elements of 99.99 wt% purity metals in a water-cooled copper crucible under a high purity argon atmosphere ($\geq 99.999\%$). The ingots were remelted several times to ensure the compositional homogeneity. Cylindrical specimens with 9 mm in diameter and 25 mm in length were prepared by injection casting into a water-cooled copper mould under a high purity argon atmosphere. The amorphous structure of the specimen alloy was confirmed by X-ray diffraction. Then the amorphous specimen was turned into short cylinders with a dimension of 8 mm in diameter and 5 mm in length. As-drawn copper was selected and the dimension was also the same with the Zr-based metallic glass. The interlayer material was Ni foil with a thickness of 30 μm .

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The Zr-based BMG and copper specimens were polished by SiC papers up to grit 2000#, and then further polished to a mirror state using diamond polishing paste. In order to remove the surface hardening layer after polishing, the copper was cleaned with a 10% hydrochloric acid ethanol solution for 3 min. All the specimens were ultrasonically cleaned in acetone for 5 min and then dried with cold wind before diffusion bonding test.

The glass transition temperature (T_g) and the first crystallization onset temperature (T_x) of $Zr_{41.25}Ti_{13.75}Cu_{12.5}Ni_{10}Be_{22.5}$ measured by the differential scanning calorimeter (DSC, TA Instruments DSC2910, Al₂O₃ crucible) at a heating rate of 40 K/min were 645 and 703 K, respectively. The diffusion bonding temperatures adopted in the present paper were 663, 673 and 683 K under a press of 10 MPa and the diffusion bonding time was 30 and 45 min. In order to keep consistency with the DSC data, the heating rate in diffusion bonding test was still 40 K/min. The thermocouple was welded at the side of Vit1 near the interface. Vacuum during diffusion bonding was kept at 10^{-3} Pa.

The diffusion bonding test was carried out on a Gleeble3500 thermomechanical simulator. The structures of the alloy as-cast and after joining were investigated by X-ray diffractometry (PHILIPS X' Pert MPD, Cu $K\alpha$). The joint quality was detected by scanning electron microscopy (SEM, TESCAN VEGAII LMH). The composition distribution along the interface was investigated by energy dispersive spectrometer (EDS, TESCAN VEGAII LMH) and electron probe micro-analyzer (EPMA, EPMA-1720).

2 Results and Discussion

Table 1 shows the parameters and results of diffusion bonding between Vit1 and Cu. Under the condition without interlayer, the joint cannot be formed at a short time when the diffusion bonding temperature is 663 K. When the bonding time reaches 45 min, the joint can be formed. However, no joint is formed at low temperatures until the bonding temperature reaches 683 K under a pressure of 10 MPa and holding for 45 min when a thickness of 30 μ m Ni interlayer is added.

2.1 X-ray diffraction analysis

Fig.1 shows the XRD patterns of $Zr_{41.25}Ti_{13.75}Cu_{12.5}Ni_{10}Be_{22.5}$ bulk metallic glass of the as-cast and after diffusion bonding. The alloy still remains at amorphous state after heating for 45 min at the joining temperatures of 663 and 673 K. While many crystalline diffraction peaks appear when the bonding temperature reaches 683 K, indicating that crystalline phases have been generated from the substrate of amorphous alloy.

2.2 Interface characteristics of Vit1/Cu joint

Fig.2 shows the backscattered electrons micrographs of the macrostructure and the microstructure of the joint in the diffusion bonding process with parameters of 663 K, 10 MPa and 45 min. The macroscopic plastic deformation occurs only at the side of Zr-based metallic glass. As the bonding temperature

Table 1 Parameters and results of diffusion bonding between Vit1 and Cu

Interlayer	Temperature/ K	Pressure/ MPa	Time/ min	Deformation/ %	Joints forming
No	663	10	30	14	No
	663	10	45	20	Yes
30 μ m Ni foil	663	10	45	20	No
	673	10	45	23	No
	683	10	45	27	Yes

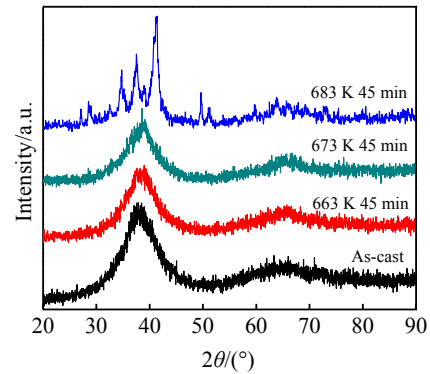


Fig.1 XRD patterns of $Zr_{41.25}Ti_{13.75}Cu_{12.5}Ni_{10}Be_{22.5}$ bulk metallic glass of the as-cast and after diffusion bonding

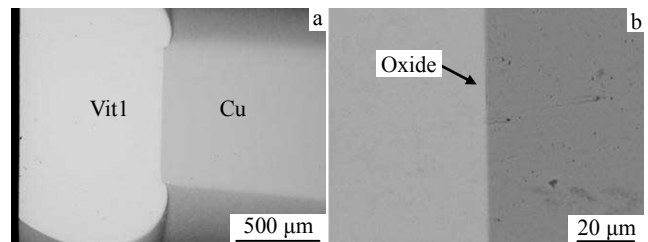


Fig.2 Backscattered electrons micrographs of the macrostructure (a) and microstructure (b) of the joint at the diffusion bonding process with parameters of 663 K, 10 MPa and 45 min

is within the super-cooled liquid region of amorphous alloy, the equilibrium viscosity of the alloy decreases sharply and the metallic glass exhibits superplasticity. The bonding pressure of 10 MPa exceeds the flow stress at this temperature and therefore the alloy can be deformed easily. While for copper, the bonding pressure is lower than the flow stress so that macroscopic plastic deformation cannot occur. The interface between Vit1 and Cu is flat and no cracks and voids can be found as shown in Fig.2b. Chen has studied the contributions of atomic diffusion and plastic deformation to the diffusion bonding of Zr-based metallic glass to crystalline aluminum alloy based on a mathematical model^[15]. The study has found that plastic deformation plays a dominated role in the void shrinkage stage in the amorphous alloy side, while in the aluminum alloy side, atomic diffusion plays a major role. In the present paper, no obvious void can be found at the interface

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