Investigation of the Failure Behavior of $(Zr_{55}Cu_{30}Al_{10}Ni_5)_{100-x}Nb_x$ Composite Tungsten Wire Reinforced During Compressive Test

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1- Introduction

Monolithic BMGs generally fail in a catastrophic manner during deformation at room temperature due to the formation of highly localized shear bands. To overcome this problem and in order to achieve an extended ductility, a fabrication of BMG composites has been practiced. During a melt infiltration process, in Zr-based BMG matrix reinforcement by tungsten wire composites, tungsten diffuses into the matrix and zirconium diffuses into the tungsten fiber leading to formation of a diffusion bond in the interface of the composite. When a liquid alloy spreads on a tungsten fiber, further interdiffusion may cause higher dissolution of the tungsten fiber resulting in the formation of some crystalline phases presenting as a layer (known as reaction layer) or particles (called as convection of particles) in the microstructure of the matrix. It is reported that some refractory elements such as Nb and Ta can reduce the interface interaction of W/Zr-based BMG matrix composite. The BMG materials deform heterogeneous at low temperature and high strain rate. During the compressive test the vein like pattern forms that is being typical fracture feature for metallic glass. This vein-like pattern often extends along a uniform direction which was explained by the local melting within the primary shear bands. In this study the failure behavior of W/ $(Zr_{55}Cu_{30}Al_{10}Ni_5)_{100-x}Nb_x$ composite during compressive test has been investigated.

2- Experimental

Ingots of $(Zr_{55}Cu_{30}Al_{10}Ni_5)_{100-x}Nb_{(x=0,2)}$ were prepared by arc melting high purity elements in Ti-gettered and Ar atmosphere on a water-cooled copper crucible. The prepared molten alloy was cast into a water-cooled copper mold (i.e. using suction casting method) to make BMG rods with a 4mm diameter. A tungsten wire of 1mm diameter was strengthened and cut into 50mm lengths and cleaned in an ultrasonic bath of acetone and ethanol. The tungsten wires were placed at the bottom of sealed 4mm ID stainless steel tubes (304). The volume fraction of W wires was 70%. The assembly of the tubes was washed by repeated evacuation (up to 10^{-5} mbar) and by purging high purity Ar gas several times followed by heating at temperature of 950◦C in an electrical furnace and holding for 15 min under a 3.5 bar Ar pressure then they were quenched in water. Composite specimens were cut by a low speed saw for preparing quasi-static compression test samples. Mechanical properties were measured with a SANTAM (STM250) testing machine. The gauge dimension of specimens was 4mm in diameter and 8mm in height for compressive test and the strain rate was 10^{-4} s^{-1}. The microstructural observations were carried out by scanning electron microscopy (SEM) VEGA TESCAN model.

3- Results and Discussion

The backscattered micrographs of W/ $(Zr_{55}Cu_{30}Al_{10}Ni_5)_{100-x}$ $Nb_{(x=0,2)}$ composites infiltrated at 950◦C for 15 min are shown in Fig. 1.

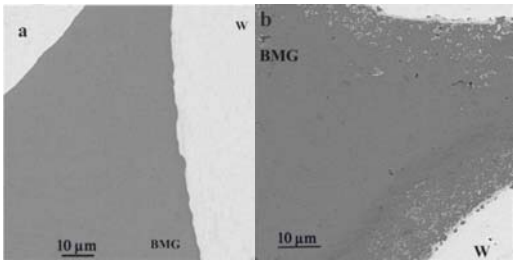

Fig. 1 SEM backscattered micrographs of $W/(Zr_{55}Cu_{30}Al_{10}Ni_5)_{100-x}Nb_{(x=0,2)}$ composites that infiltrated at 950°C for 15 min a) X=2 b) X=0

According to Fig. 1 the formation of crystalline phase is seen in Nb free composite sample in Fig. (1-a). The SEM backscattered micrographs of The Nb free composite is shown in Fig. 2. According to Fig. 2 the crystalline phase is formed near the matrix. The energy dispersive spectroscopy (EDS) analysis from this phase is shown in Table 1. The W_2Zr intermetallic crystalline phase forms in the composite interface or matrix because of high affinity between Zr and W.

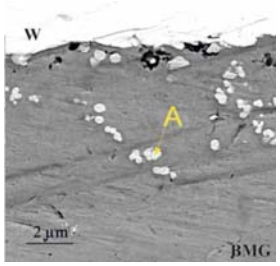

Fig. 2 SEM backscattered micrographs of $W/(Zr_{55}Cu_{30}Al_{10}Ni_5)_{100-x}Nb_{(x=0)}$ composites that infiltrated at 950°C for 15 min.

Table 1 Energy dispersive spectroscopy (EDS) analysis from the W_2Zr

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Spectra: 5-ZONE A

Element	Series	unn. C [wt.-%]	norm. C [wt.-%]	Atom. C [at.-%]
Aluminium	K series	4.08	4.89	16.41
Nickel	K series	1.72	2.06	3.17
Copper	K series	9.13	10.93	15.57
Tungesten	L series	40.80	48.85	48.47
Zirconiom	L series	27.78	33.27	16.38
	Total:	83.5 %		

Fig. 3 shows the quasi-static stress–strain curves of $W/(Zr_{55}Cu_{30}Al_{10}Ni_5)_{100-x}Nb_{(x=0,\,2)}$ composites samples infiltrated at 950°C for 15 min.

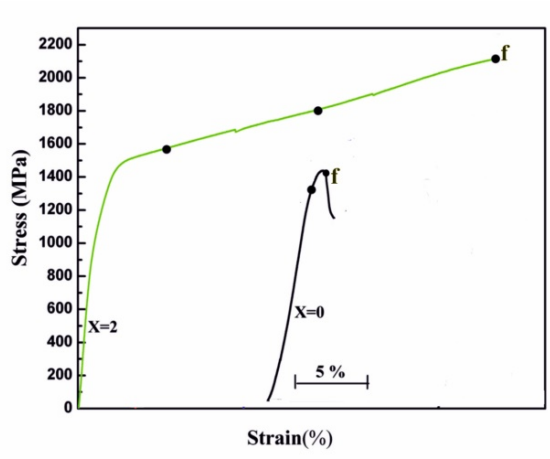

Fig. 3 Stress–strain curves of $W/(Zr_{55}Cu_{30}Al_{10}Ni_5)_{100-x}Nb_{(x=0,1,2,3)}$ composite samples infiltrated at 950°C for 15 min

As shown in Fig. 3, the composite sample with X=2 has the best mechanical properties (plastic strain and compressive strength) and the lowest plastic strain and compressive strength belongs to the composite sample with X=0. As shown in Fig. 3, the amount of plastic strain before failure in the composite sample with X=2 is 28%.

Fig. 4 and Fig. 5 show the backscattered SEM micrographs of BMG matrix and $W/(Zr_{55}Cu_{30}Al_{10}Ni_5)_{100-x}Nb_{(x=0)}$ composite sample (at failure point according to the detected points in Fig. 3) infiltrated at 950°C for 15min.

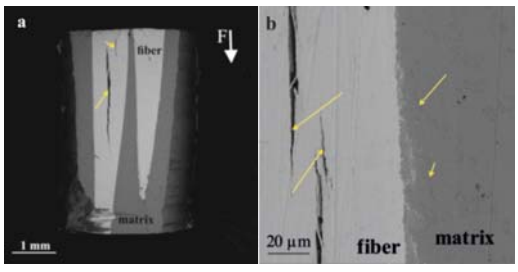

Fig. 4 SEM backscattered micrographs at matrix and fiber in different stages of compressive test in $W/(Zr_{55}Cu_{30}Al_{10}Ni_5)_{100-x}Nb_{(x=0)}$ infiltrated at 950°C for 15min at failure point

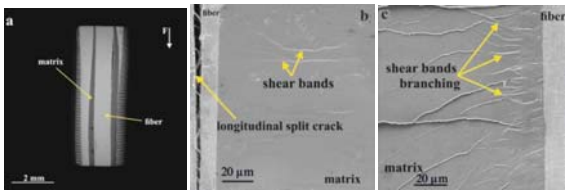

Fig. 5 SEM backscattered micrographs at matrix and fiber in different stages of compressive test in $W/(Zr_{55}Cu_{30}Al_{10}Ni_5)_{100-x}Nb_{(x=2)}$ infiltrated at 950°C for 15min at failure point

With comparison of the presented figures, it can be concluded that the fracture happens within the tungsten fiber near the W/BMG interface region with the increase of the external loading at the fracture point. The shear bands are formed in the composite sample with X=0 but they do not have enough time to propagate in the BMG matrix due to rapid conversion of shear bands to shear cracks and for this reason the shear bands are not visible in the matrix and W/BMG interface distinctly in Fig. 4.
The SEM micrographs of the fracture surface from the $W/(Zr_{55}Cu_{30}Al_{10}Ni_5)_{100-x}Nb_{(x=0,2)}$ composite samples are shown in Fig. 6.

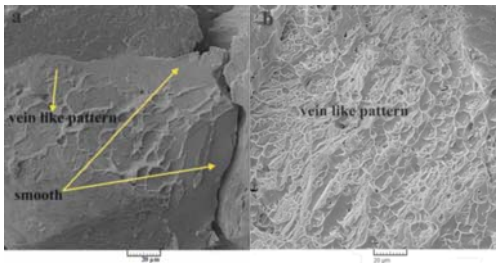

Fig. 6 SEM micrographs of fracture surface from the $W/(Zr_{55}Cu_{30}Al_{10}Ni_5)_{100-x}Nb_{(x=0,\,2)}$ composite samples infiltrated at 950 °C for 15 min a) X=0 b) X=2

As can be recognized in Fig. 6, there are two regions; first one is a vein like pattern, being typical fracture feature for metallic glass and second one is smooth. According to Fig. (6-b), the density of the veins has increased with the addition of Nb in the matrix and increase of the shear bands propagation.

4- Conclusions

The addition of two atomic percent Nb in $W/(Zr_{55}Cu_{30}Al_{10}Ni_5)_{100-x}Nb_{(x=2)}$ composite sample cause the lack of the W_2Zr crystalline phase formation in the composite interface and this reason can delay the shear bands conversion to cracks. The propagation of shear bands in this composite also cause the increase of shear bands numbers and local melting within them. Therefore, the composite fracture surface converts to vein-like pattern mode during the compressive test.