Synchrotron X-ray Diffraction Measurement of Reinforcement Strains in Uniaxially Stressed Bulk Metallic Glass Composites

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Introduction

Bulk metallic glasses (BMGs) are amorphous alloys with very high strength (close to 2 GPa), high fracture toughness (up to 55 MPa•m$^{1/2}$), excellent wear and corrosion resistance, and a very high elastic limit (~2%).[1] Composites of BMGs exhibit increased strength and ductility as compared to the BMG matrix, by a combination of load transfer to stiffer second phases and arresting of shear bands by the second phases. As demonstrated in Reference 2 for Cu-Mo composites, synchrotron radiation can be used to measure in-situ elastic strain and stresses in composites subjected to an external stress. The goals of this research are: (1) to perform such measurements on BMG composites, for which the matrix is elastic and the reinforcement can become plastic, and (2) to assess load transfer and interface delamination during deformation.

Methods and Materials

A composite, consisting of a Vitreloy 106 BMG matrix ($Zr_{57}Nb_5Al10Cu_{15.4}Ni_{12.6}$) and 10 vol% tungsten particles of ~15 micron diameter, was subjected to *in situ* uniaxial tensile tests performed at the 5-BM-D beamline at DND-CAT. Using a small screw-driven tensile loading system, the composite was loaded to 1050 MPa, unloaded to 0 MPa, and reloaded to 1650 MPa in steps of 150 MPa; stress was held constant during each of the 600-s x-ray exposures. The experimental design and analysis procedure for these experiments has been described in detail in Reference 5. The sample was irradiated with monochromatic 65-keV x-rays in the Laue geometry, and the complete Debye-Scherrer {110} diffraction cone from the reinforcing particles was recorded using a CCD camera. Also recorded for calibration purposes was the {110} Debye-Scherrer cone from an iron powder standard attached to the sample.

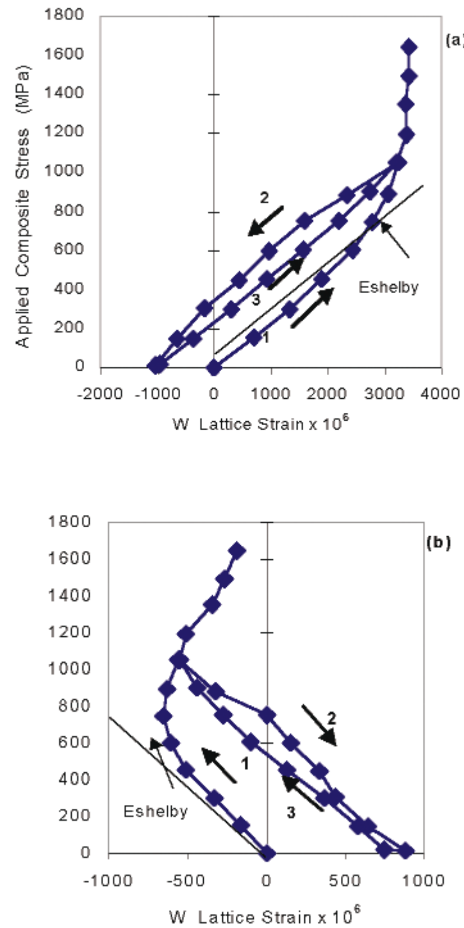

FIG. 1. Applied composite stress vs. lattice strain: (a) 10% W axial; (b) 10% W transverse for loading (1), unloading (2) and reloading (3). Eshelby elastic predictions are given as lines.

Results

The strain evolution in the axial and transverse directions for the tungsten particles is shown in Figs. 1a and b, where the applied stress on the composite is plotted against the lattice strain in the particles. Initial residual stresses due to thermal expansion mismatch during cooling from fabrication are calculated, using the Eshelby equivalent inclusion method and a stress-free temperature of 420ºC (the glass-transition temperature of the V106 matrix). These stresses are small (i.e., -265 MPa for W) and are assumed negligible in Fig. 1.

Discussion

As shown in Fig. 1(a) in the axial direction the initial loading is elastic until yielding begins around 500 MPa applied stress. The stress-strain curves bend upwards during continued loading beyond the yielding of the particles. This indicates a decrease of load transfer as mismatch is reduced by plastic deformation of the particles within the matrix, which remains elastic at all stresses in this study.[1] During unloading from 1050 MPa to 0 MPa the particles exhibit elastic behavior, with the W axial strains becoming compressive, but remaining elastic, below ~350 MPa of applied composite stress. Subsequent W reloading is elastic up to ~1000 MPa due to strain hardening, and plastic upon further loading to 1650 MPa. The slopes in the three elastic regions are the same, indicative of good interfacial strength with no debonding.

Figure 1(b) shows the W lattice strain response in the transverse direction. Initially the transverse strains are negative due to Poisson contraction. Beyond the yield point of the particles, the effective Poisson's ratio ν of tungsten increases from 0.28 to 0.5, above the V106 matrix ν of 0.38. The trajectory of transverse strains therefore reverses direction as the Poisson's mismatch causes lattice expansion perpendicular to the loading axis. During unloading and reloading to ~1000 MPa the transverse strains behave elastically as expected, and during continued loading above 1000 MPa the transverse expansion continues.

As tungsten has a higher stiffness than the BMG matrix (by a factor of 5), load transfer is expected during composite deformation: the particles carry stresses higher than the applied stress on the composite, thereby lowering the mean stress carried by the matrix. This mechanism can be modeled by the Eshelby equivalent inclusion method in the elastic regime. Figure 1 shows Eshelby elastic predictions, which are in good agreement with data in the elastic range.

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