Epoxy resin–metallic glass composites

This note describes the results of a preliminary investigation into the mechanical properties of composites consisting of an epoxy resin matrix reinforced by metallic glass ribbons. The only previous study of this type of composite was performed by Goldwasser and Kear [1]. They concluded that the metallic glass ribbons produced good composite mechanical properties in both longitudinal and transverse directions, although there was some difficulty in achieving satisfactory bonding at the resin–ribbon interface. In the present work, the objective was to provide a more quantitative assessment of the mechanical properties of epoxy resin–metallic glass composites.

A large number of continuous ribbon–reinforced composites were prepared by curing a mixture of Araldite* AY103 epoxy resin and HY951 hardener, in which had been placed lengths of Metglas† 2826 ribbon. The resulting specimens were typically 100mm long, 18mm wide and 9mm thick, and contained between one and forty ribbons parallel to the longitudinal axis of the specimen. The individual ribbons were typically 100mm long, 2mm wide and 50μm thick. Specimens were cured at a variety of temperatures in the range 295 to 373 K, and were subsequently polished and then tensile tested to failure in the longitudinal direction, with a strain rate of $\sim 10^{-4}$ sec^{-1}. Similar tensile tests were also performed on the unreinforced epoxy resin matrix and on individual metallic glass ribbons, in the latter case using a capstan grip system which has been described previously [2]. The first series of experiments with specimens reinforced by a single ribbon showed the following:

(1) The stress–strain curve and fracture morphology was independent of whether the ribbon width was parallel to the specimen width or specimen thickness. Accordingly, in subsequent multiple ribbon-reinforced specimens no attempt was made to control the orientation of the ribbons except that their long axis was always parallel to the long axis of the specimen.

(2) In unnotched specimens, failure was initiated by fracture of the ribbon. This indicated an effective stress transfer from the resin onto the ribbon, and therefore a good bond between resin and ribbon. In notched specimens, the stress concentration produced initial fracture in the resin matrix. Only limited debonding was seen as the crack propagated through the ribbon, again showing a good resin–ribbon bond.

(3) As the curing temperature was raised, tensile behaviour was more reproducible. However, with a curing temperature of 373K the metallic glass became brittle [3] and the composites showed premature failure at a low fracture stress.

(4) Photoelastic observation with polarized light showed that specimens cured above room temperature contained some residual stress around the ribbon, presumably caused partly by resin shrinkage when curing, and partly by differential contraction on subsequent cooling. The stress patterns disappeared rapidly on applying a tensile stress, indicating that the magnitude of the residual stress

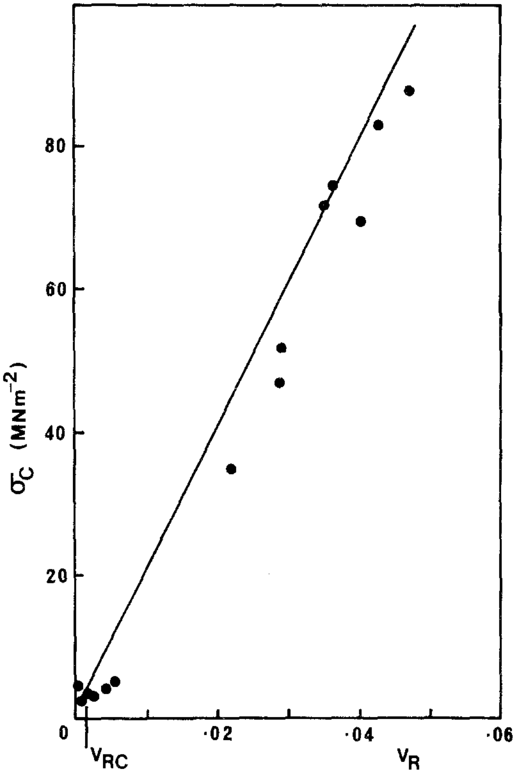

Figure 1 Composite tensile fracture strength, σ_C, as a function of volume fraction, V_R, for unnotched multiple ribbon-reinforced epoxy resin–metallic glass composites. The data points are experimental measurements, and the solid line is predicted from the law of mixtures.

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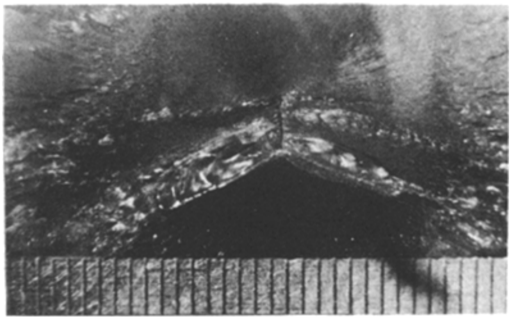

Figure 2 Optical micrograph of the fracture surface of a composite containing 1 metallic glass ribbon. Fracture can be seen to have initiated at the ribbon and then radiated out to the edges of the specimen.

was small compared to the composite fracture stress.

For a well-bonded composite, the tensile fracture strength is expected to follow the law of mixtures [4], $\sigma_C = \sigma_R V_R + \sigma'_M(1 - V_R)$ where σ_C is the composite fracture strength, σ_R is the fracture strength of the reinforcement, σ'_M is the strength of the matrix at a strain equal to the fracture strain of the reinforcement, and V_R is the volume fraction of the reinforcement. From the law of mixtures, a critical volume fraction, V_{RC} is required to achieve a composite fracture strength greater than that of the matrix alone, σ_M, and is given by $V_{RC} = (\sigma_M - \sigma'_M)/(\sigma_R - \sigma'_M)$. To test these equations, σ_C was measured as a function of V_R on a series of unnotched multiple ribbon-reinforced specimens, all cured for 6.5×10^4 sec at 323 K. (This curing treatment was convenient experimentally although it did not maximize the fracture strength of the epoxy resin). The results are shown in Fig. 1, together with values of σ_C and V_{RC} predicted from the law of mixtures using measured values of ~ 2000, 5.0 and 2.0 MNm^{-2} for σ_R, σ_M and σ'_M, respectively. As can be seen, the results are in reasonable agreement with the law of mixtures, again showing that the resin–ribbon interface is sufficiently strong for tensile stress to be transferred onto the ribbon to produce efficient reinforcement. In all the multiple ribbon-reinforced specimens, failure was initiated by fracture of the ribbons, and a typical fracture surface is shown in Fig. 2.

The results of this study show that it is possible to produce good reinforced composites by embedding metallic glass ribbons in an epoxy resin matrix.

Acknowledgements

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