Preparation of a novel uni-directionally aligned microwire-reinforced glass matrix composite

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It is well known that certain ceramic materials exhibit some very useful properties including high mechanical strength and elastic modulus, low density, high thermal stability and oxidation resistance, good erosion resistance and excellent electrical insulating properties. Unfortunately, ceramics also suffer from a number of major disadvantages, one of the most serious being a lack of toughness, or susceptibility to catastrophic failure, which severely limits their uses.

In an attempt to improve the fracture toughness of brittle ceramics, much work was carried out in 1960s and early 1970s, using metal or ceramic fibres as reinforcement [1]. Although the early work on fibre reinforcement led to some very impressive improvements in the work of fracture and fracture toughness of ceramic materials, it was soon appreciated that the factors which promote toughness in such systems did not necessarily lead to corresponding increases in strength. In particular, with a few notable exceptions, including carbon fibre, most fibres available at that time were of relatively large diameter, $\geqslant 50\,\mu m$, and acted as stress concentration sites which weakened the matrix; hence, although failure of the material was no longer catastrophic, the failure strain of the matrix was reduced. Interest in ceramic matrix composites, therefore, declined sharply in the 1970s due mainly to a lack of suitable commercially available small diameter fibres.

There has, however, been a great revival of interest in ceramic-matrix composites over the last few years due to the advent of a whole new range of commercially available fibres, at realistic prices. Such fibres include alumina-based materials with diameters down to

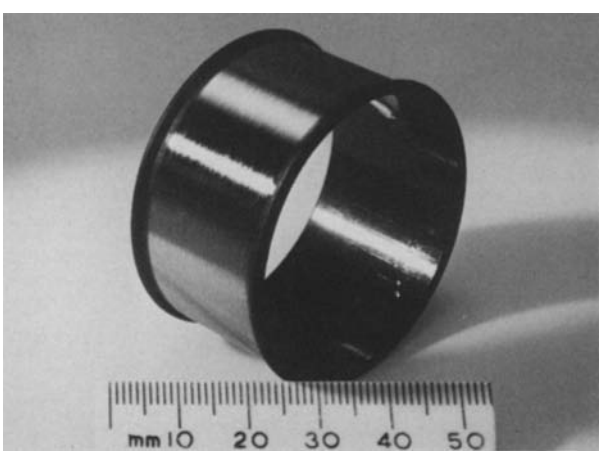

Figure 1 Spool containing ≈ 3 km of glass-coated copper microwire with a core diameter of ≈ 4 to 12 μm.

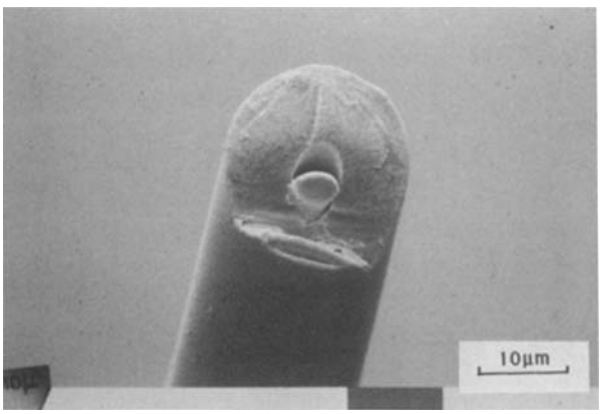

Figure 2 SEM of microwire showing surface detail and a fractured end.

< 10 μm (for example, ICI's RF-Saffil, Carborundum's Fibermax, and 3M's Nextel series), and silicon carbide of diameter 10 to 15 μm (Nippon Carbon Co.'s Nicalon). Employing some of these fibres, very substantial improvements in both toughness and strength have been noted for some ceramic systems [2, 3].

All of the recent work has concentrated on using ceramic fibre reinforcement [4–7]. Metal reinforcement does, however, offer a number of distinct advantages over ceramic fibres; these include the following: (a) metallic fibres generally exhibit useful ductility and are therefore less susceptible to damage and degradation of properties during composite fabrication, and (b) the ductility of the fibres can be utilized to yield composites of very high toughness, even with random, discontinuous reinforcement, which may be more appropriate for producing materials exhibiting isotropic properties.

At the present time, however, conventional die-drawn metal filaments are either not widely available in diameters < 50 μm, or are prohibitively expensive. Nevertheless, an intrinsically inexpensive route by

Figure 3 Copper microwire–Pyrex glass composite bar after removal from the hot-pressing die.

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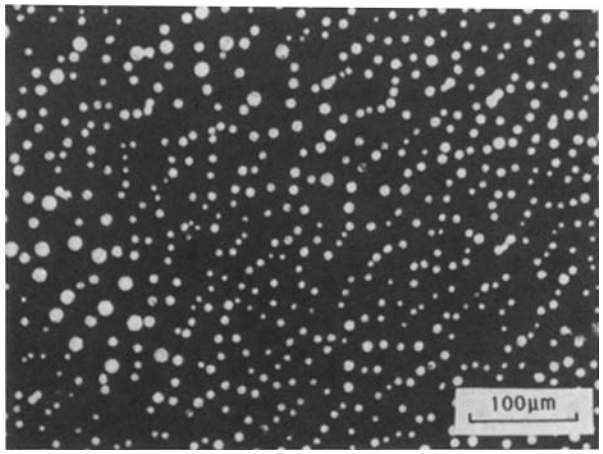

Figure 4 Optical micrograph of sectioned and polished composite.

which very fine microwire materials can be produced directly from the melt is available, namely the versatile Taylor-wire method [8, 9]. In its simplest form, this technique consists of producing a fine metal filament by the drawing down of a glass tube containing the molten metal or alloy. In principle, many different types of material can be produced in the form of fine filaments encapsulated in a suitable compatible glass [10]. By suitable control of the process parameters, it is feasible to produce metal filaments of diameter in the range ≈ 1 to 100 μm, with glass coating thicknesses in the range ≈ 2 to 30 μm. Microwire materials have been successfully prepared by the Taylor-wire route with very high mechanical strengths, in excess of 3000 MPa, coupled with moderate ductility [10]. Although the availability of fibres produced by this technique is limited at the present time, increasing demand and a greater awareness of their unique properties may ensure a more adequate future supply.

It was originally proposed by Nixdorf [11] in 1970 that microwires could be used as a reinforcement in polymer, metal or ceramic matrix composites, after stripping of the glass coating. Recently, Goto and Nishio [12] have reported the preparation of a polymer matrix composite utilizing an iron-based microwire, both with and without its glass coating removed. It is, however, also possible, in principle, to produce glass matrix composites directly by hot-pressing Taylor-wire tows. It is also feasible to produce glass–ceramic matrix composites by using a suitable glass which can subsequently be subjected to a controlled crystallization heat-treatment, as proposed recently by the present authors [13].

The present letter reports the preliminary results of a feasibility study aimed at assessing the viability of producing microwire-reinforced glass–matrix composites using copper microwire prepared by the Taylor-wire route.

The particular microwire employed in the present work consisted of a copper core ≈ 4 to 12 μm in diameter with a Corning Code 7740 Pyrex borosilicate glass coating of thickness ≈ 4 to 10 μm. A typical spool of material is shown in Fig. 1, and a scanning electron micrograph (SEM) of the microwire is shown in Fig. 2. Tows of this material, prepared simply by cutting the filament and removing it from the spool, were laid up in a graphite mould. The material was subsequently hot-pressed at 930° C and 12 MPa pressure in an inert atmosphere to produce composite bars ≈ 50 mm $\times$ 15 mm $\times$ 1 mm in size. A typical bar is shown in Fig. 3.

An optical micrograph of a bar that has been sectioned and polished is shown in Fig. 4 and SEMs of a fracture surface are shown in Fig. 5. It can be seen that a relatively uniform and random distribution of fibres is achieved, and the matrix is free from microcracking or gross porosity. As illustrated in the fracture SEMs, fracture of the composite leads to a combination of plastic failure and pull-out of the filaments. The density of the samples, as determined by water immersion, is $\approx 3.02\,\mathrm{g\,cm^{-3}}$. This result, together with the micrographic evidence, indicates a filament content of ≈ 12 vol. % for these particular materials. As noted earlier, however, it is possible, in principle, to vary the fibre content by varying the glass-coating thickness.

We have shown the viability of producing metal microwire-reinforced glass using Taylor-wire materials. Currently we are preparing a variety of materials with different volume fractions of filament in order to enable comprehensive mechanical and other property data to be accumulated. The details of these evaluations will be reported at a later date.

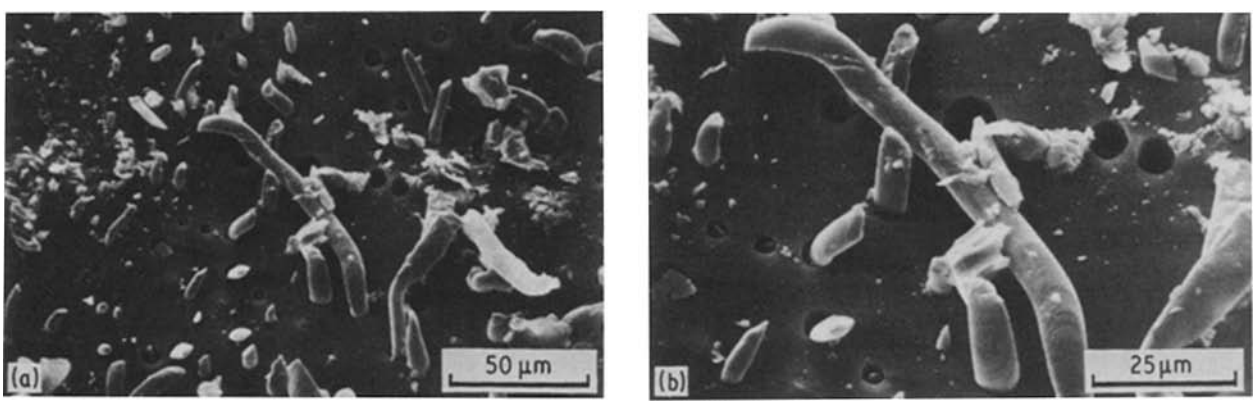

Figure 5 Fracture surfaces of composite showing plastic failure and pull-out of fibres.

Acknowledgements

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