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THE EFFECT OF THE INTERFACE ON THE FRACTURE CHARACTERISTICS OF INVESTMENT CAST GRAPHITE FIBER REINFORCED Sn-Pb ALLOY

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INTRODUCTION

The development of ceramic fiber reinforced metals is a rather new technology and the major advances in this field were made only in the last ten years. The main reason for the surge of interest in this area is the development of the technology to produce high performance ceramic fibers such as graphite, boron, Al_2O_3, SiO_2, SiC, B_4C, BeO, etc. at a reasonable price [1]. The most outstanding properties, retained even at elevated temperatures are reported for graphite fibers [2]. Thus, combination of graphite fibers and metallic matrices is the most promising. The main difficulty in producing such composites is still the manufacturing technique. There are basically two methods. One is the consolidation of fibers coated by metal using various deposition techniques such as electroplating [3 - 6], electroless plating [7] and chemical vapour deposition [10 - 13]. The other method employs various techniques to infiltrate fibers with the liquid metal. One of the major requirements for a good performance of a composite material is strength of the fiber/metal interface [14]. The application of investment casting technique for producing composite materials was first suggested by Glenny [15], being applicable mainly to the manufacturing processes of bulk composites. However, the handling problems of fibers and difficulties in controlling interfacial conditions have limited this process to production of large size metallic composites.

MATERIAL AND MANUFACTURING METHOD

Tensile test specimens were made from graphite fiber reinforced Sn-38% wt.% Pb alloy. In order to produce good wetting of fibers during a casting process, fibers were electroplated with copper. Specimens were cast by the lost wax process. Wax patterns with protruding fibers out of both ends of the pattern were made by sandwiching thin wax sheets and bundles of fibers. Then the sheets were built up to a desired thickness and then rolled into a standard tensile specimen in hot water. Upon making a mold and melting the wax out, the fibers remained in a reasonably good distribution for infiltration with the liquid metal. However during centrifugal casting, the pressure of the liquid metal filling the mold did not produce immediate infiltration between fibers, but instead it consolidated fibers again into separate bundles. This produced a non-uniform exposure of copper plated fibers to the flow of the liquid Sn-Pb alloy, and consequently different temperature gradients across the fiber-matrix interface. Thus mechanical properties of specimens and fracture characteristics were dependent on the type of interface developed.

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RESULTS

Figure 1 shows typical fiber distribution in the gauge section of the tensile specimen. Metal infiltration is not perfect. Some cavities indicate that presence of fibers in the mold produced uneven flow resulting in the porous metal.

Figure 2 shows the fracture surface around such a porosity. By the time the liquid metal reached this region, it was too cold to flow around the fibers and thus produced cavities; in places where it came in contact with fibers, the plated copper did not react with the matrix leaving pure copper around the fibers. Fractography shows an extensive plastic deformation of copper resulting in long pull-outs leaving extruded copper tubes. Such an interface may result in good energy absorption characteristics but not very efficient reinforcement.

Figure 3 shows one of the segregated bundles with good infiltration of the liquid metal between all fibers. However, it may be observed that fibers around the edge are much longer than in the centre. Upon closer examination of the outer fibres, it was found that they were completely denuded of copper by the flow of liquid metal. The stripping of plated copper resulted in a local agglomeration of fibers and almost complete debonding from the matrix. The fact that the fibers at the centre of the bundles fractured without an extensive pull-out indicates the existence of a strong interface. Figure 4 shows a higher magnification of an interface at the site of a broken fiber, near the centre of the segregated bundle. There is a narrow band of ductile deformation next to the fiber, then two regions of brittle failure, and again ductile fracture of the matrix. It is postulated that strong bonding occurs when copper reacts with the Sn-Pb alloy forming intermetallic phases which are stronger and more brittle than the matrix or plated copper. The identification of phases based on phase diagrams is shown in Figure 5. The light layer around the fiber is unreacted copper. The next dark band is Cu_3Sn, and the outer large layer is Cu_6Sn_5, bonded directly to the matrix.

Mechanical testing of the specimens confirmed the fractographic examinations. The best reinforcement was achieved in those specimens showing the largest volume of fibers surrounded with intermetallic phases. Specimens with unreacted copper showed good total elongation, thus good toughness, but poor strength. Specimens in which the liquid metal washed off the plated copper had the poorest reinforcement.

CONCLUSIONS

The lost wax process may be a feasible technique for manufacturing graphite fiber reinforced metals. The role of the interface becomes extremely important since graphite is not wetted by the liquid metal and therefore should be precoated with the same or different metallic coating. The compatibility of the coating and the matrix will determine the type of the interface formed and hence the efficiency of reinforcement. In order to avoid washing off the coating material. The matrix should preferably have a higher melting point than the plated metal. The lost wax process may thus be applied to produce graphite fiber reinforced metals but the casting conditions need to be very precisely controlled.

ACKNOWLEDGEMENTS

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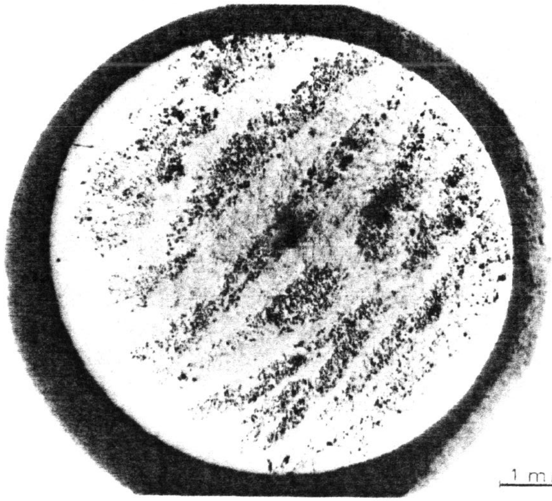

Figure 1 Typical Fiber Distribution in the Cross-Section of a Tensile Test Specimen

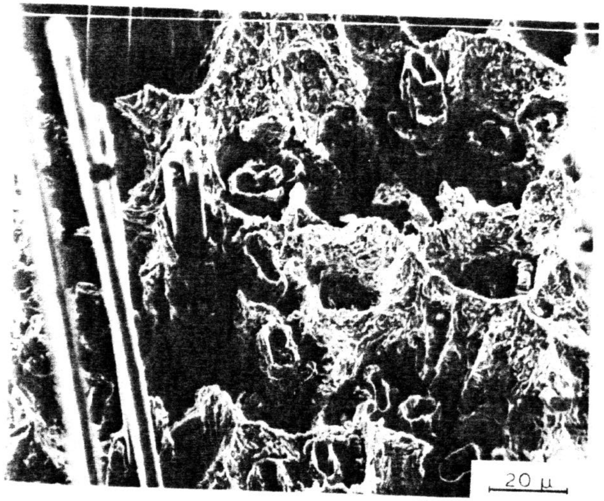

Figure 2 Fractured Surface of a Specimen Showing Porosity Where Copper did not React with Matrix and Liquid Metal did not Infiltrate Between all Fibers

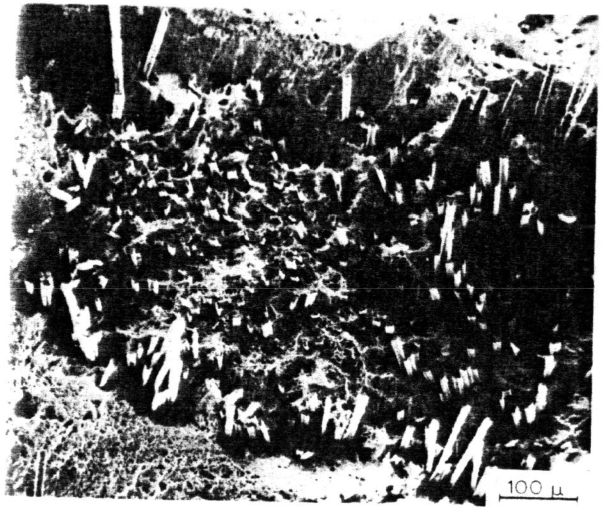

Figure 3 Fractured Surface of a Segregated Bundle of Fibers. Poor Bonding on Outer Edges Results in Long Pull-Outs

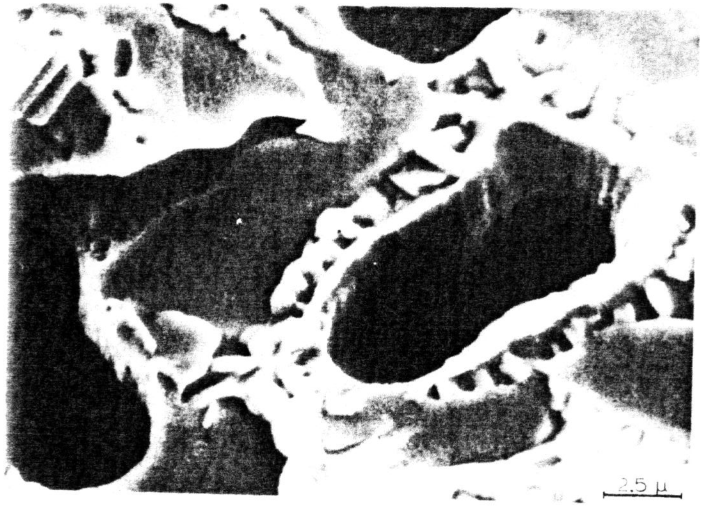

Figure 4 Close-Up of Fractured Interface Where Copper Reacted with Sn-Pb Alloy Forming Intermetallic Phases

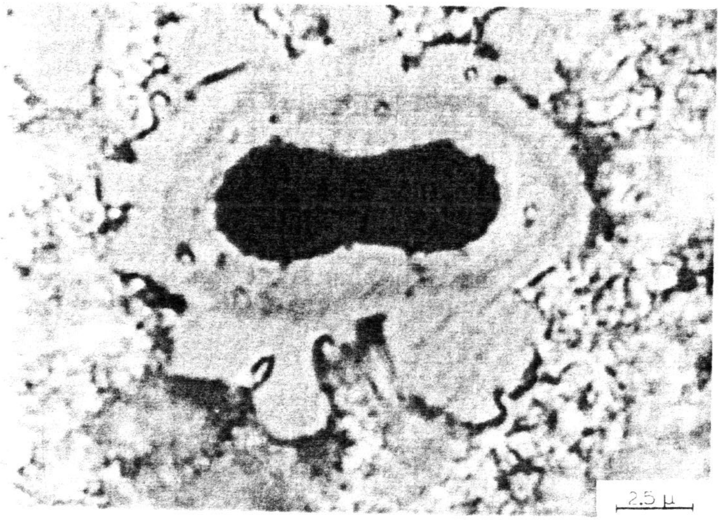

Figure 5 Detail of Graphite/Matrix Interface. Phases Enclosing Fiber are, In Order, Cu, Cu_3, and Cu_6Sn_5