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SiC Whisker-Reinforced SiAlON Composites: Effect of Sintering Aid Content

Terry N. Tiegs
Oak Ridge National Laboratory

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ABSTRACT

SiAlON matrix composites reinforced with SiC whiskers were hot-pressed with various levels of yttrium aluminum garnet (YAG) as a sintering aid. The YAG content affected the amounts of liquid phases present during fabrication. It was determined that some liquid phase is required to achieve high density composites. However, at high sintering aid levels, degradation of the matrix-whisker interface occurs and the composite fracture toughness is reduced.

INTRODUCTION

Composites reinforced with SiC whiskers have recently been of great interest because of their ability to increase the fracture toughness of ceramic materials as compared to their monolithic counterparts. The addition of SiC whiskers has been shown to increase the fracture toughness of alumina,[1,2] mullite,[3] silicon nitride,[4] and zirconia.[5] Improvements in the strength of the composites has also been observed. Extension of the property improvements to SiAlON-based materials is being investigated.[6] It was found that the sintering aids make a considerable difference in the mechanical behavior of the SiAlON-SiC whisker composites.

Research into the mechanisms responsible for the observed toughening behavior in the composite materials shows that crack-whisker interaction resulting in crack bridging and deflection are the major toughening processes.[7,8] For these mechanisms to operate, debonding along the crack-whisker interface must occur during crack propagation. This requires that the bonding between the matrix and the whiskers be relatively weak. The effect of sintering aid content on the character of that interface and the resulting effect on the composite mechanical properties was examined in the present study.

EXPERIMENTAL PROCEDURE

Composite specimens were fabricated by blending SiAlON,† yttria,†† and alumina††† powders with SiC whiskers* in hexane and dispersing the mixture with a high-shear homogenizer.** The mixtures were dried and hot-pressed in a graphite die at 1725-1775°C and 24 MPa (3.5 ksi) for 60 min. All of the composites fabricated contained 20 vol % SiC whiskers. The yttria and alumina sintering aids were added at a 3:5 ratio to form yttrium aluminum garnet ($3Y_2O_3$-$5Al_2O_3$) during densification.

Fracture toughness measurements were obtained using the multiple-indent flexure strength (MIFS) technique.[9] The technique employed flexure bars having nominal dimensions of 3 x 4 x >40 mm, with polished tensile surfaces that contained three Vicker's diamond indents (5 Kg load) to produce controlled flaws in the region of maximum tensile stress. The fracture strengths were determined by four-point flexure on bars having the same dimensions as the MIFS specimens, but with 220 grit diamond ground tensile surfaces. Both the MIFS and flexural test specimens were oriented so that the tensile surface was perpendicular to the original uniaxial pressing direction.

RESULTS

Composite densification as a function of the YAG content is shown in Fig. 1. As shown, with no sintering aid present, densification of the powder-whisker mixtures did not occur to any extent. However, with as little as 0.5 wt % YAG present, densities >95% T.D. were readily obtained. This indicates that a small amount of liquid phase is necessary to promote particle-whisker rearrangement during fabrication. Similar results have been observed with other sintering aid compositions.[10] The microstructure of composites is shown in Fig. 2 with the whiskers readily observed and no apparent degradation.

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†Vesuvius Crucible Co., Pittsburgh, Penn.; Grade AA Sialon powder; Composition 43 wt % Si, 14 wt % Al, 0.6 wt % Fe, 0.3 wt % Ti, 0.05 wt % Mg, all others <0.02 wt %.

††Molycorp Inc., Louviers, Col., Code 5600.

†††Ceralox Corp., Tucson, Ariz., Type HPA.

*American Matrix Inc. (AMI), Knoxville, Tenn.; Grade 1 SiC whiskers, received 9/88.

**Brinkmann Instrument Co., Westbury, New York, N.Y., Model PT 45/80.

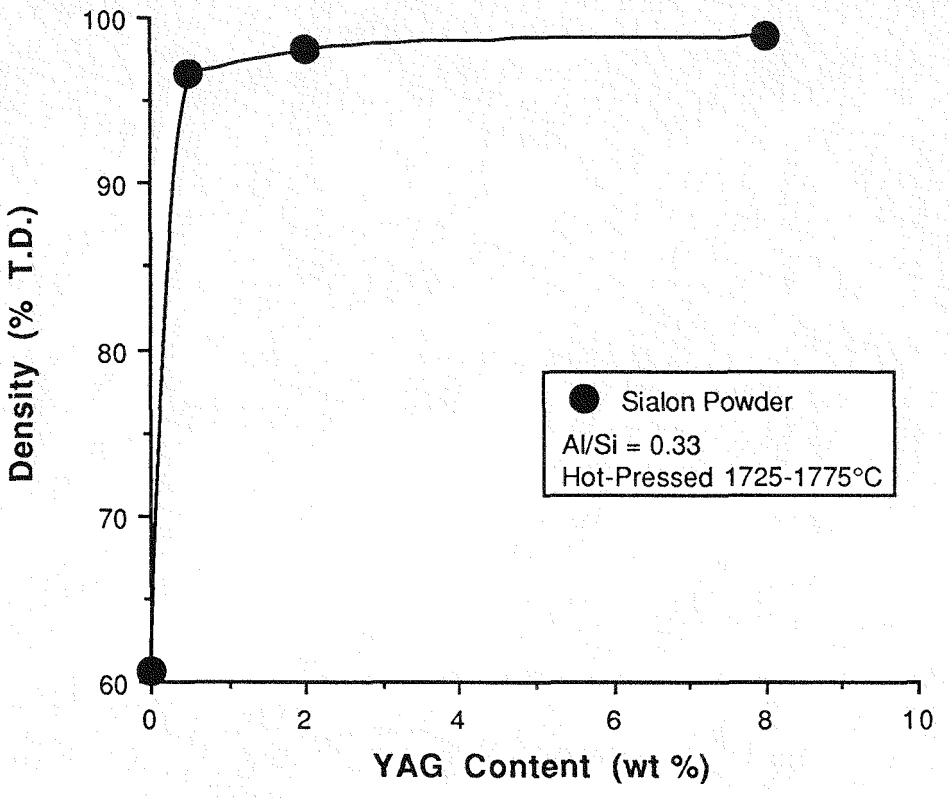

Fig. 1. Effect of YAG content on hot-pressing densification of SiAlON-20 vol % SiC whisker composites.

The effect of YAG content on the fracture toughness of SiAlON-20 vol % whisker composites is summarized in Fig. 3. The results show good fracture toughnesses in the range of 6-8 MPa$\sqrt{m}$ for the SiAlON composites containing 0.5 and 2 wt % YAG, but a decreased toughness at 8 wt % YAG. Examination of the fracture surfaces from these samples reveals two distinct levels of crack-whisker interaction. At the high YAG content (Fig. 4), the fracture surface is relatively smooth indicating minimal crack-whisker interactions and consequently poor toughening. In addition, few whiskers are readily discernable indicative of little debonding taking place at the crack-whisker interface. In contrast, the composites with the low levels of YAG (Fig. 5) showed rough surfaces and easily observed whiskers indicating extensive interactions and interfacial debonding. The flexural strength (Fig. 6) also showed a dependence on the YAG content analogous to the one observed for the fracture toughness.

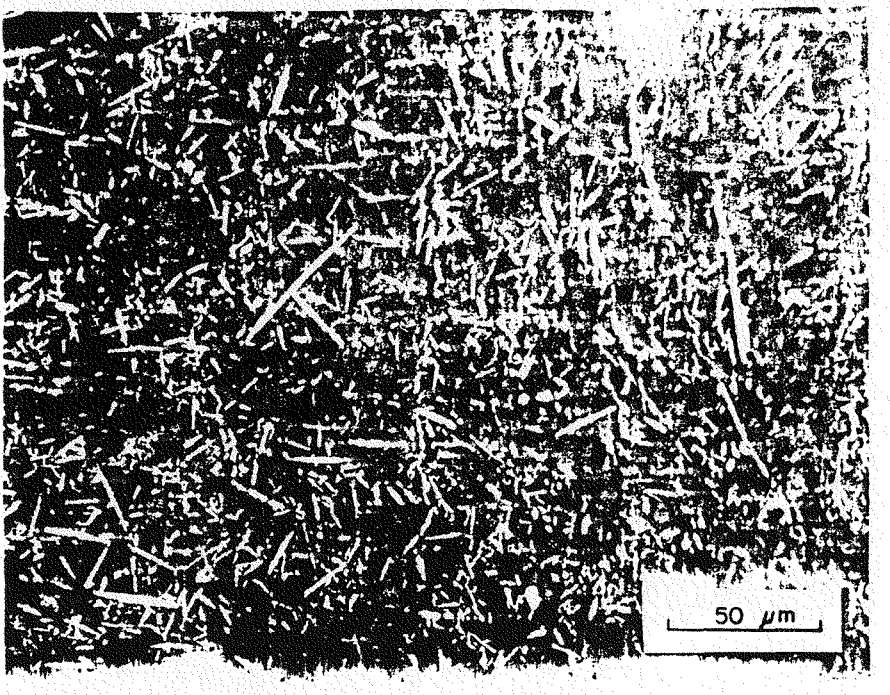

Fig. 2. Microstructure of SiAlON-20 vol % SiC whisker composites. Homogeneous disperson of the whiskers is observed with no apparent whisker degradation.

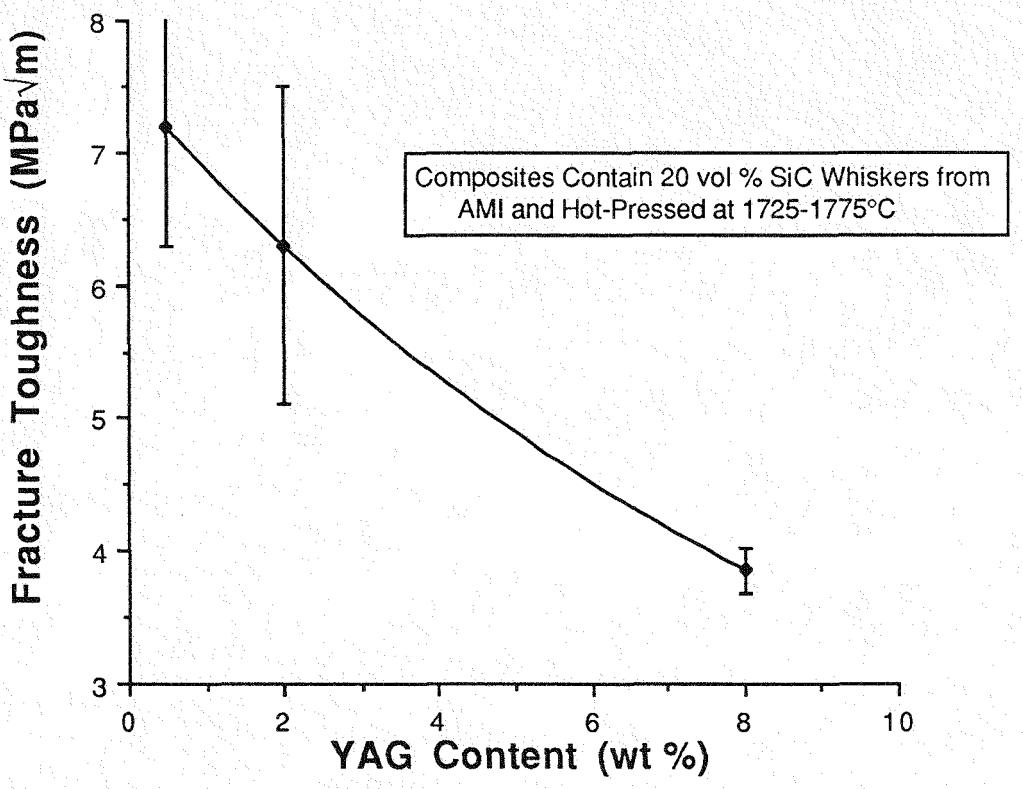

Fig. 3. Effect of YAG content on fracture toughness of SiAlON-20 vol % SiC whisker composites.

CONCLUSIONS

During fabrication the different levels of YAG content result in a range of amount of liquid phase present, and indeed some liquid phase is necessary for densification. As the amount of liquid phase increases, particle/whisker rearrangement is enhanced and densification is readily accomplished. However, with higher amounts of liquid phase, increased bonding at the matrix-whisker interface develops. The result of this "stronger" bonding is an inhibition to debonding at the interface during crack propagation which leads to decreased crack-whisker interaction. The final effect is a decrease in the fracture toughness from that achieved with more modest amounts of sintering additives.

The change in toughening behavior with increasing YAG content maybe due to several factors. The most probable would be that the reactivity of the liquid phase increases at the higher YAG levels. There may also be an effect due to changing thermal expansion and modulus differences between the various phases with changing YAG content and the magnitude of the resulting residual stress levels. It would also be expected that the observed behavior is dependent on the specific

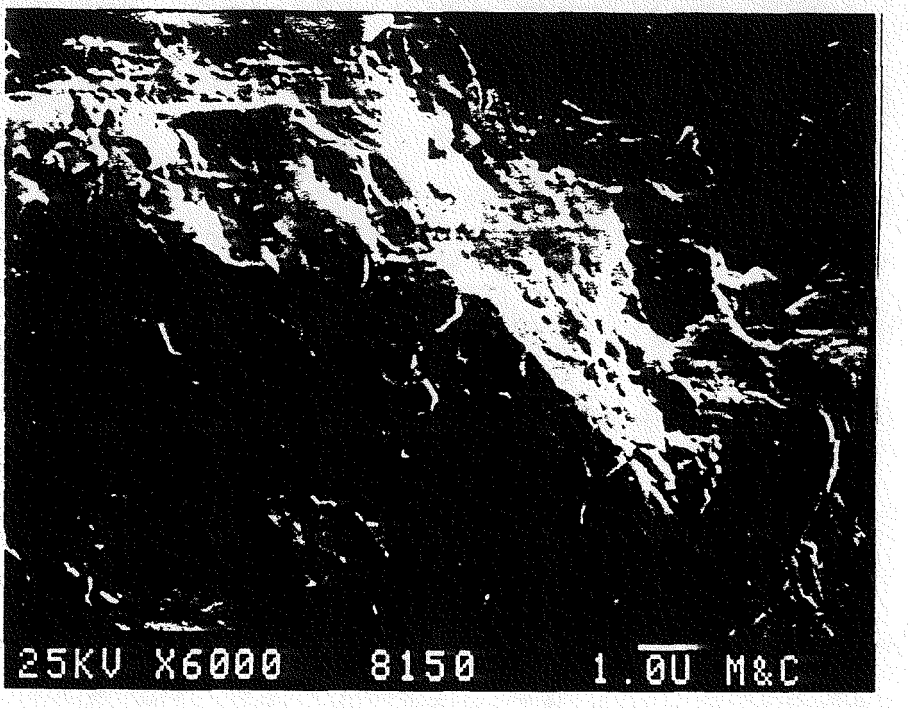

Fig. 4. Fracture surface of SialON-20 vol % SiC whisker composite containing 8 wt % YAG as a sintering aid. No whiskers are readily discernible indicating limited debonding at whisker-matrix interface.

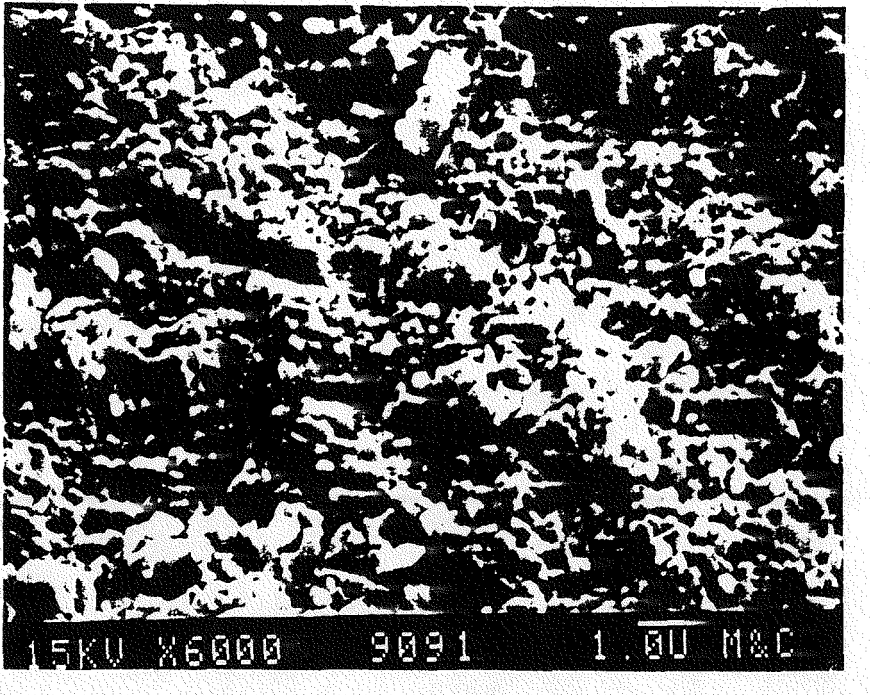

Fig. 5. Fracture surface of SiAlON-20 vol % SiC whisker composite containing 2 wt % YAG as a sintering aid. Whiskers are readily discernible indicating extensive debonding at whisker-matrix interface.

sintering aid used. In other words, using sintering aids other than YAG should affect the liquid phase reactivity, thermal expansion and modulus so that the toughening effects will be different.

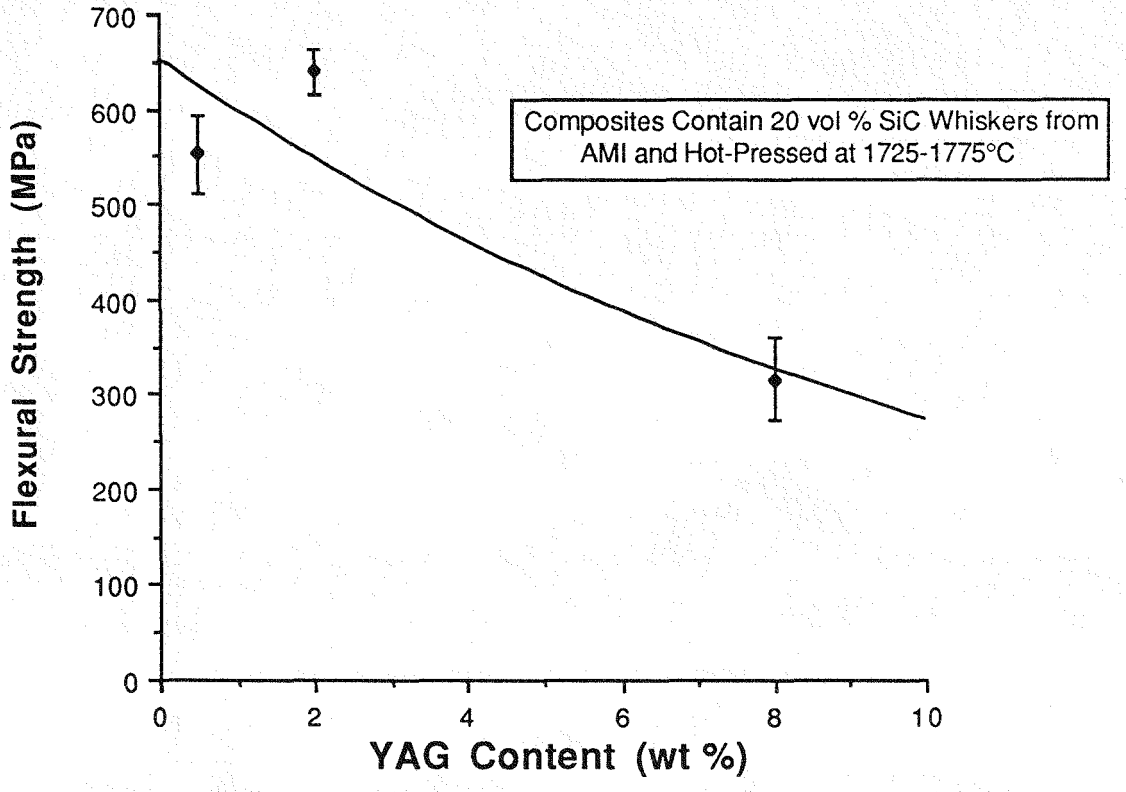

Fig. 6. Effect of YAG content on flexural strength of SiAlON-20 vol % SiC whisker composites.

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