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TITLE: PERFORMANCE OF COMMERCIAL AND RESEARCH GRADE SiC WHISKERS
IN A BOROSILICATE GLASS MATRIX

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PERFORMANCE OF COMMERCIAL AND RESEARCH GRADE
SiC WHISKERS IN A BOROSILICATE GLASS MATRIX

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EXTENDED ABSTRACT

I. Objective

Commercial silicon carbide (SiC) whiskers produced in the United States and in Japan, and research grade SiC whiskers grown at Los Alamos by the VLS** method were added to a borosilicate glass matrix⁺ at a 20 vol% level. The objective of the study was to evaluate the influence of these whiskers on the fabricability, microstructure, and mechanical properties of the composites.

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*Member, The American Ceramic Society.

**Vapor-Liquid-Solid method of crystal growth.

+Code 7740 (Pyrex), product of Corning Glass Works, Corning, NY.

II. Materials and Procedure

Table I presents the types and size characteristics of the whiskers used in this study. The length and diameter values shown for the commercial whiskers were provided by the manufacturer. The composite fabrication procedure is summarized in Figure 1. Note that blending of the whiskers and glass powder was performed dry and the composites were consolidated by hot pressing. Consolidation of the composites was markedly influenced by the size characteristics of the whiskers in that the larger the diameter and length of the whiskers, the more difficult it was to achieve a high density. However, in all cases >97% theoretically dense composites were produced by employing minor modifications in the hot pressing time-temperature-pressure schedule. Test specimens were prepared as indicated in Figure 2. Note that the flexure test specimens were rotated 90° from the orientation used for the fracture toughness specimens. Consequently a portion of the whiskers in the flexure specimens were aligned roughly parallel to the loading directions, since the hot pressing operation forced some whisker alignment parallel to the plane of the disk. All testing was performed at a cross-head speed of 0.05 mm/min.

III. Results and Discussion

In all cases, addition of the whiskers to the glass produced an improvement in the mechanical properties, compared to the values measured for the glass without whiskers. Representative stress strain curves are shown in Figure 3. While the glass matrix without reinforcement exhibited a linear stress-strain curve up to the point of fracture, the whisker-reinforced composites all displayed a non-linear stress-strain behavior. The extent of inelastic deformation was greatest for the Los Alamos 4-5A whiskers. The observation of inelastic deformation prior to catastrophic fracture of the SiC whisker-glass composites suggests the formation of microcracks which do not propagate catastrophically under rising load conditions. This means that the composites are essentially exhibiting R-curve type behavior.² It is likely that some microcracks form at the ends of discontinuous whiskers, since there is a tensile stress

concentration in the matrix at these locations.³ Such microcracks are then being arrested from further growth, presumably through interactions with adjacent whiskers.

A summary of all the mechanical property results is given in Table I. The average strength for the matrix alone was 77 MPa. This is in agreement with that reported for glass in general.^{4,5} Cross-reference of Table I with Table II reveals that the strength of the composites increased with decreasing whisker diameter, with the highest strength occurring for the 0.05-0.2 μm diameter Tateho SiC whiskers. It is the opinion of the authors that this conclusion should be handled with caution, but this general trend has been previously reported by Rice.⁶ No marked increase in elastic modulus was observed for any of the composites. All the composites showed significantly higher fracture toughness, in the range of 4-5 times that of the matrix. However, no definitive trends in toughness vs. whisker characteristics could be discerned.

Fractographic results of the five composites are presented in Figure 4. Two views are shown for the composite containing the Tokamax SiC whiskers because extensive glass-rich and whisker-rich areas were observed. The composites containing the Tateho SCW #1 and Exxon F-9 SiC whiskers also displayed inhomogenieties, but not to the degree exhibited by the Tokamax composite. The microstructure of the composites containing the Los Alamos whiskers appeared reasonably homogeneous, and these were the only systems that displayed any significant degree of whisker pullout.

IV. Summary

Dry blending of the whiskers and glass powder yielded composites of satisfactory, but not optimum, homogeneity. The whiskers inhibited composite densification, but this could be remedied by modifying the hot-pressing conditions. All types of whiskers produced improvements in the flexural strength of the composites, with the highest value achieved with the smallest diameter whiskers. The composites displayed a 4 to

5-fold increase in fracture toughness compared to that displayed by the unreinforced glass, but definitive trends could not be related to the whisker size characteristics.

A much more extensive article on this work is in preparation for publication in the American Ceramic Society Bulletin or Advanced Ceramic Materials. It is hoped this will be published in late 1986 or early 1987.

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Table I. SiC Whisker Dimensional Characteristics

	Tateho SCW #1 ^a	Tokamax ^b	Exxon F-9 ^c	Los Alamos 3-4B ^d	Los Alamos 4-5A ^d
Diameter (μm)	0.05 - 0.2	0.1 - 0.5	0.6	1 - 3	3 - 10
Length (μm)	10 - 40	50 - 200	10 - 80	50 - 150	300 - 1000
Average Aspect Ratio ^e	200	415	75	50	100

^aProduct of Tateho Chemical Industries Co., Ltd., Hyogo-Ken, Japan; distributed in the U.S. by the Mitsubishi International Corp., New York, NY.

^bProduct of Tokai Carbon Co., Ltd., Tokyo, Japan; distributed in the U.S. by Mitsubishi International Corp., New York, NY.

^cFormerly Exxon Enterprises Inc., SILAG Div.; now ARCO Chemical Co., Advanced Materials Unit, Greer, SC. The Exxon F-9 grade is the predecessor of the SC-9 grade now produced by ARCO.

^dProduced at the Los Alamos National Laboratory, Los Alamos, NM, by the VLS crystal growth technique. The designations 3-4B and 4-5A simply refer to growth (and thus size) designations. For more information see reference 1.

^eEstimated from the length and diameter values presented in this table.

Table II. Summary of Mechanical Properties for
Borosilicate Glass - 20 vol% SiC Whiskers

	<u>Glass</u>	<u>Tateho</u>		<u>Exxon</u>	<u>Los Alamos</u>	
		<u>SCW #1</u>	<u>Tokamax</u>	<u>F-9</u>	<u>3-4B</u>	<u>4-5A</u>
Density (% of theoretical)	99.6	97.4	>97.1	99.1	99.7	98.3, 99.5 ^a
Flexure Strength (MPa)	77.0	187.9	176.8	156.1	135.8	125.9
Elastic Modulus (GPa)	68.2	66.6	74.8	64.2	75.4	65.4
Inelastic Strain ($\times 10^{-6}$)	0	523	470	378	275	575
Fracture Toughness ($\text{MPa}\cdot\text{m}^{1/2}$)	0.97	4.52	3.83	4.43	5.49	4.51

^aThe reported mechanical properties are the combined average for two different samples displaying two different densities.

FIGURE CAPTIONS

Figure 1. Summary of procedure used to fabricate SiC whisker - borosilicate glass matrix composites.

Figure 2. Sampling, fabrication, and testing specifications used to evaluate the flexure strength and fracture toughness of the composites.

Figure 3. Representative stress-strain curves.

Figure 4. Scanning electron photomicrographs of flexure test specimen fracture faces.

COMPOSITE FABRICATION PROCEDURE

TEST SPECIMEN DESIGN-GLASS MATRIX COMPOSITES

BOROSILICATE GLASS-20 VOL% SiC WHISKER COMPOSITES

MST-6

Los Alamos

BOROSILICATE GLASS-20 VOL% SiC WHISKER COMPOSITES

FRACTOGRAPHIC RESULTS

TOKAMAX

TOKAMAX

TATEHO SCW NO.1

EXXON F-9

LOS ALAMOS 3-4B

LOS ALAMOS 4-5A