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STRENGTH and FRACTURE IN GLASS MATRIX COMPOSITES

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### **Publication Date**

1975-05-01

Submitted to Journal of the American  
Ceramic Society

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STRENGTH AND FRACTURE IN GLASS MATRIX COMPOSITES

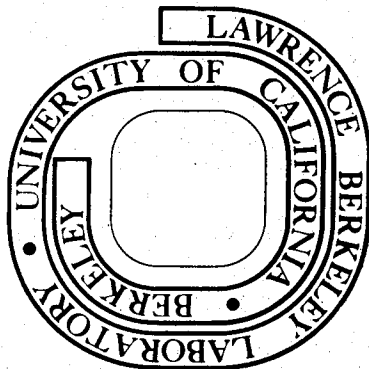
Dipak R. Biswas and Richard M. Fulrath

May 1975

Prepared for the U. S. Energy Research and  
Development Administration under Contract W-7405-ENG-48

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## STRENGTH AND FRACTURE IN GLASS MATRIX COMPOSITES

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The uniaxial bend strength and fracture initiation energy of glass matrix composites were measured by 4-point bending and the double cantilever beam method respectively. For glass matrix composites, Hasselman and Fulrath<sup>1</sup> proposed that a second phase dispersed particle would limit the size of the Griffith flaws in the glass matrix, and strengthen the composite. When the strength of the composite was plotted against  $(E/d)^{1/2}$  where  $E$ =Young's modulus and  $d$ =av. mean free path between the particles, it showed two distinctly different regions (Fig.1). In region I, the average distance between particles was greater than the induced flaw size in diamond sawed surfaces and the strength was independent of the second phase. In region II, the flaw size was governed by the mean free path between the particles and the strength was a function of volume fraction and particles size of the second phase. The straight line in region II should give a slope of fracture energy of the composite.

In the present work, soda borosilicate glass was used as a matrix and non-spherical alumina and spherical tungsten particles were used as the dispersed phase. Glass matrix composites were fabricated by vacuum hot pressing at 725°C using 1000 to 2000 PSI pressure for 10 to 40

minutes. Hot pressed compacts were cut into specimens 0.05 inch thick by 0.25 inch wide and over 1 inch long with a precision diamond saw. Uniaxial bend strength was measured by using a 4-point bending machine with a 0.75 inch overall span. The diamond sawed surface was stressed to failure. Fracture initiation energy was measured by the double cantilever beam method using the following equation:<sup>2</sup>

$$Y_I = \frac{6P^2 L^2}{EW^2 t^3} [1 + 1.32 (t/L) + 0.542 (t/L)^2]$$

where P is the load at the point of catastrophic failure, E is Young's modulus and L, W, t are geometric constants. The experimental results were shown in Table I. A plot of uniaxial bend strength and fracture initiation energy against the volume fraction of nonspherical alumina is shown in Fig. 2. The above equation was derived by Gilman<sup>3</sup> and modified by Widerhorn, et al.<sup>2</sup> The equation was used to study isotropic homogeneous material with a slow moving crack. When a second phase was introduced into a glass matrix, the system became nonhomogeneous, particularly for glass-nonspherical alumina composites as observed from the microstructural studies, and the specimen failed catastrophically. The applicability of above equation to calculate the fracture energy of glass matrix composites is questionable.

Specimens like glass or glass matrix composites, with a machined notch have numerous microflaws left along the root of the notch. Fracture can initiate at these microcracks that are formed during diamond sawing. For the double cantilever beam test, the microflaws

around the notch act as stress concentrators and the load necessary to fracture the specimen depends on these microflaws. In the 4-point bending test, the load was recorded at the time of fracture. At the surface of the specimen there are a number of microflaws produced by diamond sawing and when the load reaches a certain critical value at the tip of the microflaws, failure occurs. This leads to the possibility that both tests are governed by identical parameters for glass matrix composites.

Figure 2 shows that both the strength and the fracture initiation energy of the glass-nonspherical alumina composites increased with increase in volume fraction of alumina. Similar information was reported by Lange.<sup>4</sup> From the Hasselman postulate, the fracture energy should be a constant, as evident from the slope of region II in Fig. 1. Therefore, soda borosilicate glass-spherical tungsten composites were tested exactly as that described for glass alumina composites. The results are plotted in Fig. 3 and shows that the strength increased by a factor of 2 with 47.4 v/o W but the fracture initiation energy was nearly the same as that for the glass. The fracture surfaces were examined by scanning electron microscopy and it was observed that the fracture surface always remained in the glass matrix. Thus the strengthening in glass matrix composites with spherical dispersions can be explained by the proposed fracture theory.<sup>1</sup> The effects of nonspherical particles on the strength and fracture energy in glass matrix composites is more complex and cannot be presently explained by a simple theory.

Table I. Uniaxial Bend Strength and Fracture Initiation Energy of Glass Matrix Composites

Composites	Average Dispersed Particle Size ( $\mu$ )	Volume Fraction Of Dispersed Phase	Elastic Modulus ( $\times 10^{-6}$ PSI)	Uniaxial Bend Strength ( $\times 10^{-3}$ PSI)	Fracture Initiation Energy ( $\times 10^{-3}$ ergs/cm <sup>2</sup> )
Glass-Non Spherical Alumina	Glass*	-	11.7	14.4 $\pm$ 10.8%	6.4 $\pm$ 15.0%
		0.244	16.5	18.5 $\pm$ 9.6%	13.8 $\pm$ 16.5%
	15	0.300	17.8	20.8 $\pm$ 7.6%	17.1 $\pm$ 12.0%
		0.326	18.8	20.7 $\pm$ 6.1%	17.0 $\pm$ 7.4%
		0.350	19.3	21.5 $\pm$ 7.1%	16.2 $\pm$ 11.5%
	25	0.4000	21.0	23.4 $\pm$ 9.8%	19.0 $\pm$ 6.4%
		0.446	22.8	24.3 $\pm$ 5.4%	20.2 $\pm$ 7.2%
		0.420	21.6	23.3 $\pm$ 6.3%	21.0 $\pm$ 18.0%
	33	0.470	23.3	23.0 $\pm$ 8.7%	18.6 $\pm$ 13.9%
		Glass**	-	11.7	7.2 $\pm$ 7.7%
Glass-Spherical Tungsten	70	0.105	13.4	7.15 $\pm$ 4.7%	6.2 $\pm$ 13.0%
	15	0.475	21.7	14.2 $\pm$ 9.0%	8.4 $\pm$ 17.0%

\* 70% SiO<sub>2</sub>, 16% Na<sub>2</sub>O, 14% B<sub>2</sub>O<sub>3</sub>

\*\* 65% SiO<sub>2</sub>, 8% Na<sub>2</sub>O, 27% B<sub>2</sub>O<sub>3</sub>

## REFERENCES

1. D.P.H. Hasselman and R.M. Fulrath, "Proposed Fracture Theory of a Dispersion-Strengthened Glass Matrix," J. Am. Ceram. Soc., 49 [2] 68-72 (1966).
2. S.M. Wiederhorn, A.M. Shorb, and R.L. Moses, "Critical Analysis of the Theory of the Double Cantilever Method of Measuring Fracture-Surface Energies," J. Appl. Phys., 39 [3] 1569-72 (1968).
3. J.J. Gilman, "Direct Measurement of the Surface Energies of Crystals," - ibid - 31 [12] 2208-18 (1960).
4. F.F. Lange, "Fracture Energy and Strength Behavior of a Sodium Borosilicate Glass- $\text{Al}_2\text{O}_3$  Composite System," J. Am. Ceram. Soc., 54 [12] 614-20 (1971).
5. D.P.H. Hasselman and R.M. Fulrath, P.343-78 in "Ceramic Microstructure" Edited by R.M. Fulrath and J.A. Pask (1966).

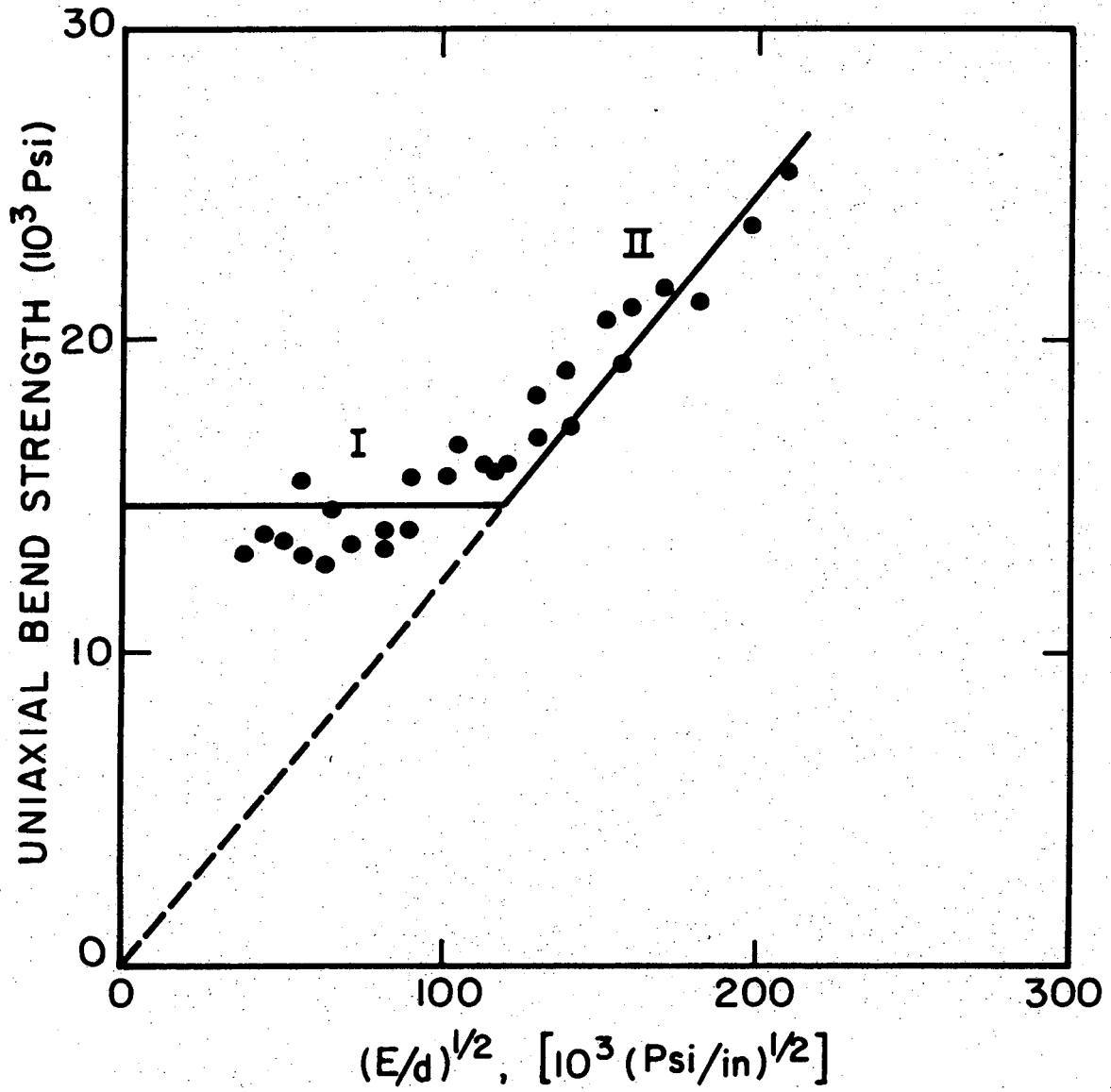


ACKNOWLEDGMENT

This work was done under the auspices of the United States Energy Research and Development Administration.

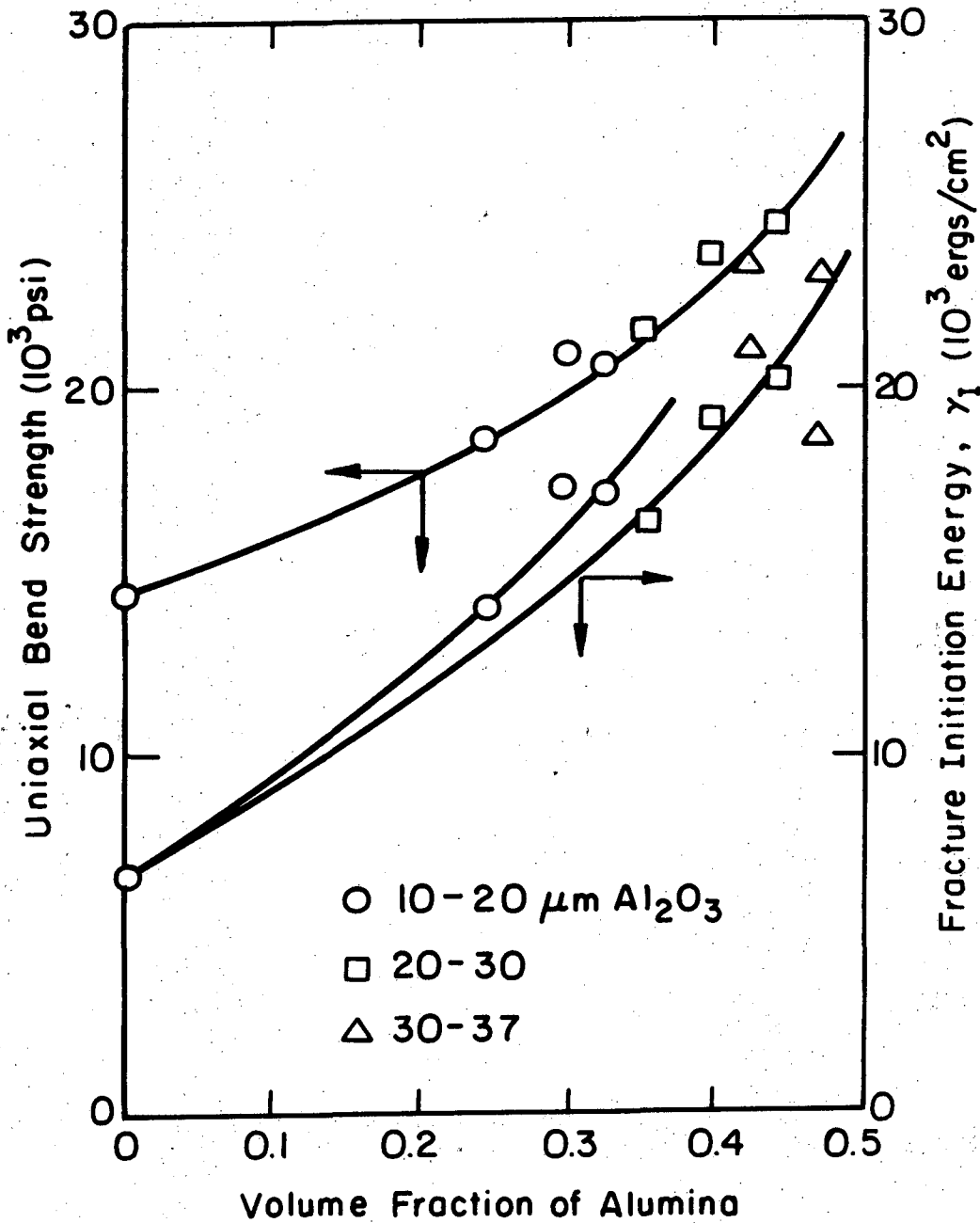
Figure Captions

- Fig. 1. Uniaxial bend strength vs.  $(E/d)^{1/2}$  for glass matrix composites containing spherical  $Al_2O_3$  particles as the dispersed phase.
- Fig. 2. Uniaxial bend strength and fracture initiation energy for glass matrix composites as a function of the volume fraction of dispersed phase non-spherical  $Al_2O_3$  particles.
- Fig. 3. Uniaxial bend strength and fracture initiation energy for glass matrix composites as a function of the volume fraction of dispersed phase spherical W particles.



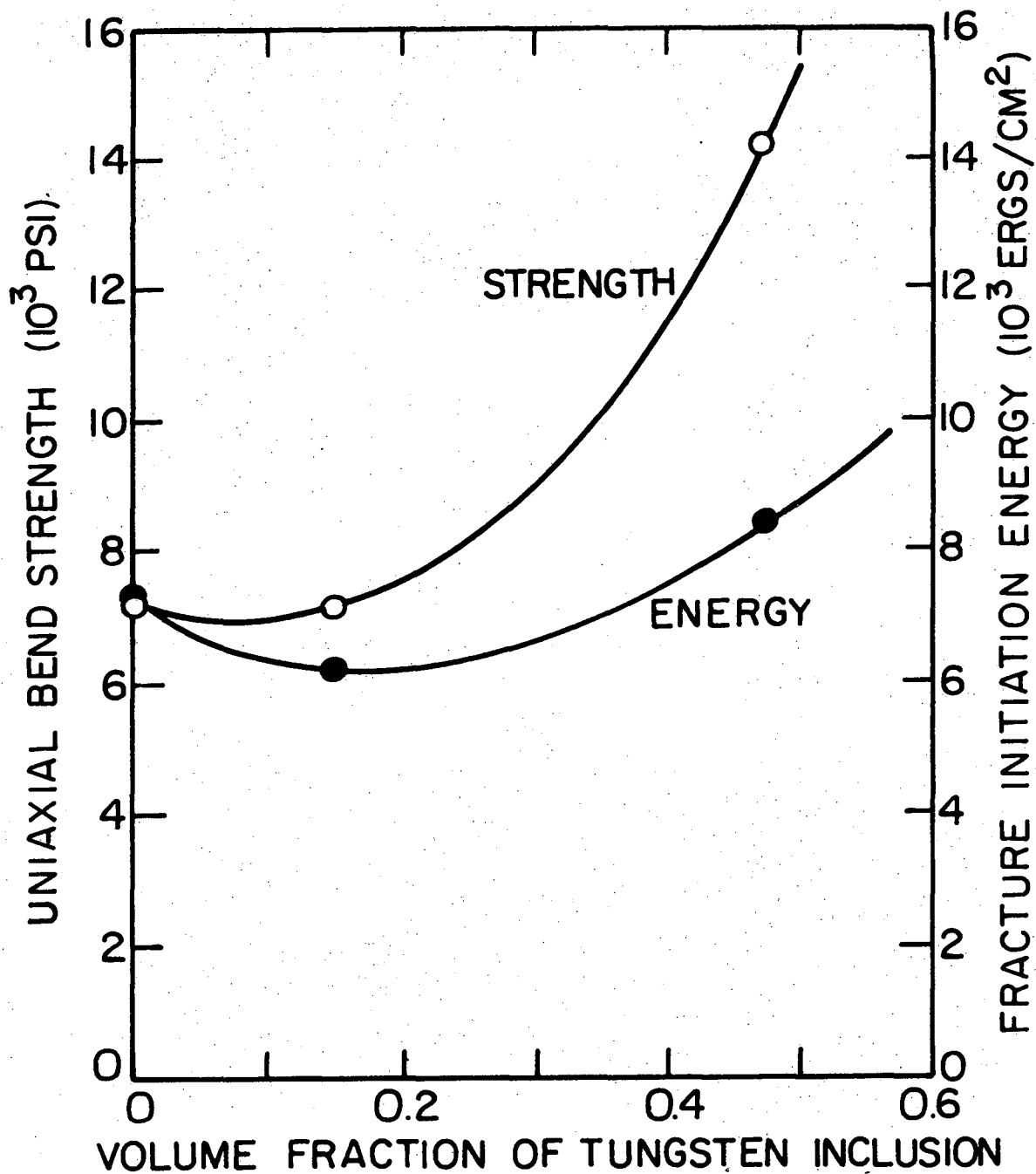
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Fig. 1.



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Fig. 2.



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Fig. 3.

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