FRACTURE BEHAVIOR OF FUSED QUARTZ PARTICULATE COMPOSITES

Wang Runze (王润泽) Liu Yanling (刘延伶)
Luoyang Institute of Refractories Research, China

I. INTRODUCTION

Extensive works have been done to enhance the fracture toughness of brittle ceramics. In most cases, the dispersion of a second phase particle in the brittle matrix has been proved to yield considerable increases in fracture toughness. Various toughening mechanisms have been proposed[1–2].

The fracture behavior of the fused-quartz particulate composites in which both particle and matrix are fused-quartz has not been investigated up to date. In this paper fracture surface energy behavior and other mechanical behavior of the fused quartz particulate composites have been investigated. The effect of the particle volume fraction on the thermal shock damage resistance parameter (R'''') of the fused-quartz particulate composites has also been studied.

II. EXPERIMENTAL PROCEDURE

(1) Preparation of materials

The fused quartz glass with 99.5% SiO_2 was used as the raw material for this work. The slip was prepared by ball milling. About 46% of the particles had the size of less than 5 μm. The density of the slip was about $1.82 g/cm^3$. The particles of the fused-quartz glass with average size of 144 and 464 μm were admixed in the slip at 0.08, 0.16, 0.24, 0.32 and 0.40 particle volume fractions. The greens of particulate composites were formed by the slip casting method. After drying they were fired at 1000°C for 2 hrs.

(2) On elastic modulus

The elastic moduli of the fused quartz particulate composites at room temperature were determined by the tapping method[3]. The specimens with size as 25×25×150mm were selected. The Young's elastic modulus was calculated according to the following formula:

$$E = mM/bR^2$$

where M is the form factor of the specimen, b and m are the width and the mass of specimen respectively, and R is the base frequency of the specimen which was recorded by the test apparatus.

(3) On fracture surface energy

The fracture surface energies were determined by work-of-fracture method and the notched-beam test. The work-of-fracture technique, described by Nakayama[4], is used to determine the fracture surface energy (γ_{WOF}) required to propagate a crack completely through a specimen. The notched-beam test[5] gives the energy (γ_{NBT}) required to initiate the propagation of a crack. The specimen geometries required for these tests were shown in Fig. 1. The 3-point bending tests used to determine γ_{WOF} and γ_{NBT} were conducted at room temperature with crosshead speeds of 0.05 mm/min and 1 mm/min, respectively.

The value of γ_{WOF} was then calculated from the total work (W) done for propagating the crack, which can be determined by measuring the area under the load-deflection curve with a planimeter. Hence γ_{WOF} can be calculated from the expression:

$$\gamma_{WOF} = W/2A$$

where A is the projected area of the fracture surface. And γ_{NBT} can be calculated by

$$\gamma_{NBT} = K_{IC}{}^2(1 - \nu^2)/2E$$

where K_{IC} is the fracture toughness, E and ν are the Young's elastic modulus and the Poisson's ratio, respectively.

(4) On strength

The three point bending strengths were determined at room temperature on the specimen of 75×15×25 mm. The span of the specimen was 60mm. The cross head rate was 1 mm/min.

III. RESULTS

The effect of the particle volume fraction (V_f) on the elastic modulus (E), the bending strength (S), and the fracture surface energy (γ_{NBT} and γ_{WOF}) for the fused-quartz particulate composites were shown in Fig. 2 and 3, respectively.

A typical fracture path for the notched-beam best specimen of the fused-quartz particulate composites was shown in Fig. 4, and the representative fracture surface SEM photograph of the notched-beam test specimen was shown in Fig. 5.

IV. DISCUSSION

(1) Apparent elastic modulus

In the present work, the effect of the particle volume fraction on the elastic modulus of the fused-quartz particulate composites was investigated. As shown in Fig. 2(a) the apparent elastic moduli of the fused-quartz particulate composites for both particle size series with 144 and 464 μm were found increasing linearly with the particle volume fraction. The slope of the E vs. V_f curve, (i.e. dE/dv_f) for both particle size series are 10.4 and 24.4, respectively. This indicates that the increase rate of the apparent elastic modulus for large particle size series is faster than that for small particle size series.

(2) Fracture surface energy

The fracture surface energy γ_{NBT} is regarded as the energy for crack initiation which is a strength-controlling factors. Fig. 3.(a) shows that γ_{NBT} increases linearly with the increase of the particle volume fraction and that the fracture surface energies γ_{NBT} for the composites with particle size of 144 μm are greater than that for composite with particle size of 464 μm.

The fracture surface SEM observations indicated that the relaxation phenomenon occurred in the interface between the particle and the matrix. Moreover the crack had propagated along the interface between them as shown in Fig. 4. It is suggested that the bonding of interfaces between the particle and the matrix is weak. Although no thermal expansion mismatch exists between particle and matrix, and no microcracks were observed under optical microscope, it could be expected that the particle itself is a mismatch of elastic modulus for the matrix. Thus, localised stress concentration appears at the interface between the particle and the matrix. Consequently the interfaces are weakened. When a primary crack propagates, a decohesed zone ahead of the crack is formed. It was expected that the decohesion between the particle and the matrix could significantly contribute to the increase of fracture toughness because of the energy consumption by decohesion. For the above reasons, we believe that the toughening mechanism for the fused-quartz particulate composites is the decohesion of weak interface.

The work-of-fracture is regarded as the energy for crack-propagation. The work-of-fracture (γ_{WOF}) like the fracture surface energy (γ_{NBT}), increases with the increasing of the particle volume fraction as shown in Fig. 3(b). However, γ_{WOF} exhibits an exponential relation with the particle volume fraction V_f, whereas γ_{NBT} shows a linear relation with V_f, i.e. the increase of γ_{WOF} with increasing the particle volume fraction is much faster than that for γ_{NBT}. Besides, the work-of-fracture γ_{WOF} is greater than the fracture surface energy γ_{NBT} by an order of magnitude.

The published works on the secondary phase inclusion dependency of the work-of-fracture are rare. The fracture behavior of hot pressed magnisia containing metal particle was investigated by Hing and Groves[6], they found the energy for crack propagation increases with the volume fraction of metal particle. They had attributed the increase of the work-of-fracture to plastic deformation of metal particles. In this work, because the fused-quartz particle is brittle, considerable plastic deformation is unable to develop during fracture.

As indicated earlier, the interface of the particle and the matrix is weak, and the decohesion of weak interface contributes to the increase of the energy for crack iniation. However, if the crack continuously propagates after its initiation, decohesion yet occurs ahead of the crack front. The process will continue up until the fracture process comes to an end. It shows that the decohesion of weak interface not only contributes to the increase of the energy for crack initiation, but to the increase of the energy for crack propagation also.

(3) Bending strength

The bending strength is invesely proportional to the particle volume fraction as shown in Fig. 2(b). The strength decreases with increasing the particle volume fraction. The fracture surface energy γ_{NBT}, the Young's elastic modulus E, and the crack size are the strength-controlling factors. Although no microcrack was found in the fused-quartz particulate composites, the weak interfaces might be assumed as the latent cracks. The bending strength of the fused-quartz particulate composites with particle size of 144 μm is found to be greater than that with particle size of 464 μm, Hence the latent crack of the former is smaller than that of the latter.

(4)The thermal shock damage resistance parameter

On the basis of Hasselman's theory of thermal shock fracture[7,8], the thermal shock damage resistance R'''' can be expressed as follows:

$$R'''' = E\gamma_{WOF}/S^2(1-\nu)$$

In present work, the variation of R'''' with the particle volume fraction was shown in Fig. 6. It was an exponential relation. This relation explains why the fused-quartz particulate composite can withstand nicely the severe thermal shock environment.

REFERENCES

[1] F.F. Lange, Phil. Mag., 22 (179) 983 (1970).
[2] A.K. Khaund & P.S. Hicholson, J. Mater. Sci, 15, 1(1980), 177.
[3] F.Z. Lou, Y.N. Niu & F.J. Zou, The Refractory Materials (China), 6(1980), 33.
[4] J. Nakayama, J.Amer. Ceram. Soc., 48,11 (1965), 583.
[5] R.W. Davidge & G. Tappin, J. Mater. Sci., 3,2 (1968), 165.
[6] P.Hing and G.W.Groves, ibid, 7 (1972), 422.
[7] D.P.H. Hasselman, J. Amer. Ceram. Soc., 46,11 (1963), 535.
[8] D.P.H. Hasselman, Ibid, 52,11 (1969), 600.

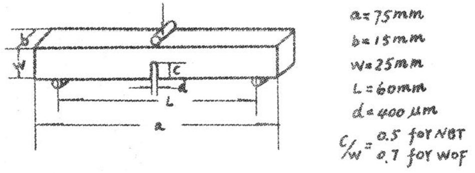

Fig. 1 3-point bending specimen for fracture surface energy tests