DYNAMIC FRACTURE MODE ANALYSIS OF GLASS MATRIX COMPOSITES

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ABSTRACT

Acoustic Emission (AE) waveforms from the glass matrix composites during fracture toughness test were recorded by using the advanced AE measuring system with multi-channels. Locations of microfracture were estimated with good accuracy. Fracture mode and microfracture size were also evaluated by the source model of microcracking and the deconvolution method.

KEYWORDS

acoustic emission, microcrack, glass matrix composites.

INTRODUCTION

Many ceramic and glass matrix composites have been investigated for the high temperature use. In particle reinforced ceramics remarkable increase of toughness has been reported. The SiC particle reinforced glass composite was used as a model material where connection between matrix and fiber provides stress transfer. In this paper we try to apply the Acoustic Emission waveform inverse analysis method [1-3] to this material. Fracture process of this material is investigated in the terms of the location of microfracture by the arrival time differences, and the identification of fracture mode and the sizing of microfracture by the deconvolution method.

SOURCE LOCATION

Accurate source location is required in order to understand fracture processes. The location of each source event is determined by measuring the differences in the wave arrival time between two transducers [4]. Suppose that Δt_{ij} is the difference in the wave arrival time between i-th and j-th transducers. Let $\mathbf{r}_i$ denote the transducer positions ($1 \le i \le P$) and $\mathbf{r}$ denote the location of the source, where P is the total number of channels. We can represent the general equation for source location as

$$\alpha \Delta t_{ij} = |\mathbf{r} - \mathbf{r}_i| - |\mathbf{r} - \mathbf{r}_j|, \qquad (1)$$

where α is the longitudinal velocity of material. A nonlinear least-square method can be used to solve the equation (1) for the three dimensional source location $\mathbf{r}$ if $P \leq 4$, and the two dimensional source location if $P \leq 3$.

Theory of AE Source of Microcracking

It is well known that the faulting source in an elastic medium can be modeled. Let S denote a fault surface contains two adjacent opposite internal surface, labeled S^+ and S^-. Using the reciprocal theorem, the displacement field at position x' and time t, $\mathbf{u}(x', t)$, for point source can be represented as [1, 5]

$$u_i(x', t) = G_{ij}(x', x, t) * T_j(x, t) + G_{ij,k}(x', x, t) * D_{jk}(x, t), \qquad (2)$$

$$T_j(x, t) = \int_S [t_j(x, t)]\, dS, \qquad (3)$$

$$D_{jk}(x, t) = \int_S C_{pqjk}\, [u_p(x, t)]\, \nu_q\, dS, \qquad (4)$$

where * means a convolution integral with respect to time, $\int_S dS$ indicates a surface integral and $G_{ij}(x', x, t)$ is the displacement field in the direction x_i at position x' at time t due to an impulsive force in the direction x_j at position x at time 0, which is called as a Green's function. The displacement discontinuity is denoted by $[u(x, t)]$ for x on S, and the traction discontinuity is denoted by $[t(x, t)]$. The normal to S is $\mathbf{n}$ and C_{pqjk} is an elastic constant.

Suppose the microcracking on surface S. From equation (4), we can represent $D_{jk}(x, t)$ for an isotropic medium as

$$D_{jk} = \int_S \{\lambda\, [u_p]\, \nu_p\, \delta_{jk} + \mu([u_j]\, \nu_k + [u_k]\, \nu_j)\}\, dS, \qquad (5)$$

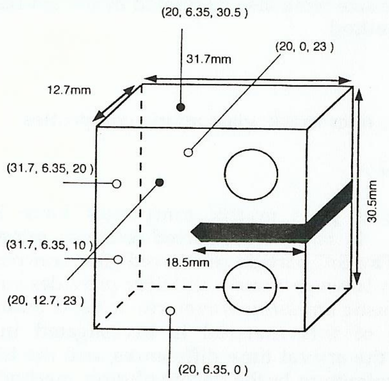


Figure 1. Dimension of specimen and position of AE sensors.

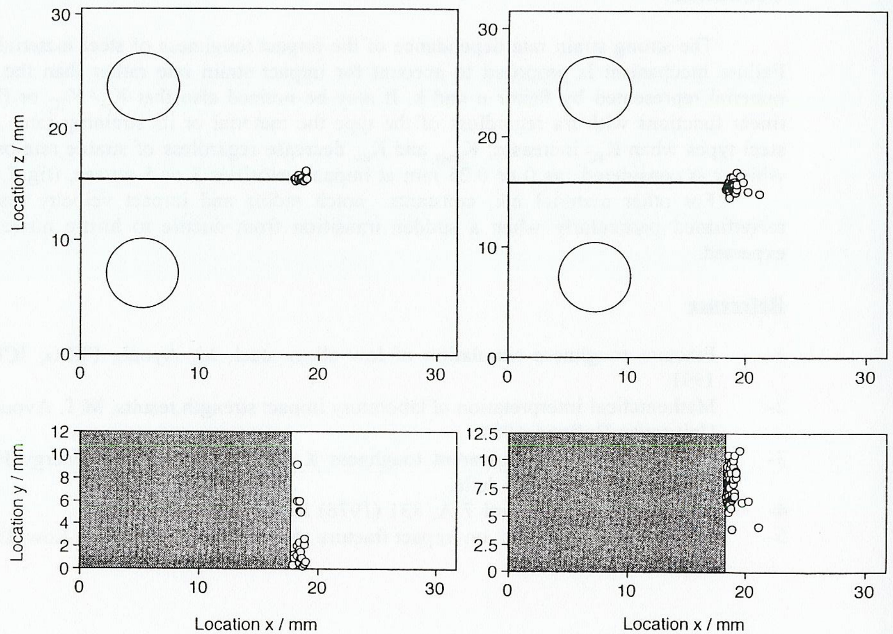
where λ and μ are Lamé's constants, and δjk is Kronecker's delta. In the case of microcracking, $[t(x, t)] = 0$ on S. Finally the displacement field due to debonding can be represented as, from equations,

$$u_i(x', t) = G_{ij,k}(x', x, t) * D_{jk}(x, t). \qquad (6)$$

Consequently, AE source of microcracking is equivalent to a dipole force.

MATERIALS

In this study PbO-SiO_2-B_2O_3-Al_2O_3 glass was chosen as matrix glass and SiC was chosen as dispersed ceramics particle. Because thermal expansion constants of PbO-SiO_2-B_2O_3-Al_2O_3 glass and SiC are almost same and the difference of elastic modulus is large. The average size of SiC particle is about 8μm and 50μm, and the volume fraction of SiC particle was 5% and 30%. The glass powder and SiC particle were mixed by ball-milling in methanol and were dried in air. The powder was sintered by hot pressing under the following conditions.



(a) d=8μm, V_f=5% (b) d=50μm, V_f=5%

Figure 2. Results of location during fracture toughness test.

The hot pressing temperature was 630°C that was 30°C higher than softening point and the pressure was 25.5MPa, the sintering time was 30 minutes in argon gas atmosphere. The sintered samples was performed X-ray diffraction (XRD) analysis and density was measured by Archimedes method and elastic modulus by ultrasonic method.

FRACTURE TOUGHNESS TEST

Fracture toughness test was carried out by an Instron type testing machine at constant cross head speed of 0.5 mm/min, at room temperature in air. Figure 1 shows the dimension of specimen and the position of AE sensors. AE signals during fracture toughness test was recorded with data of load and crack opening displacement (COD) by measuring system mentioned above, at the same time side views of specimen were photographed.

AE MEASUREMENT AND ANALYSIS SYSTEM

AE measuring system with multi-channels has been used in experiments. AE waveforms were recorded by the wave memory with sampling rate of 50 ns and 2 kwords each channel. Also conventional AE parameters such as event and amplitude with the load to specimen were analyzed. Microcomputer was used to record the AE parameters and waveforms via interface.

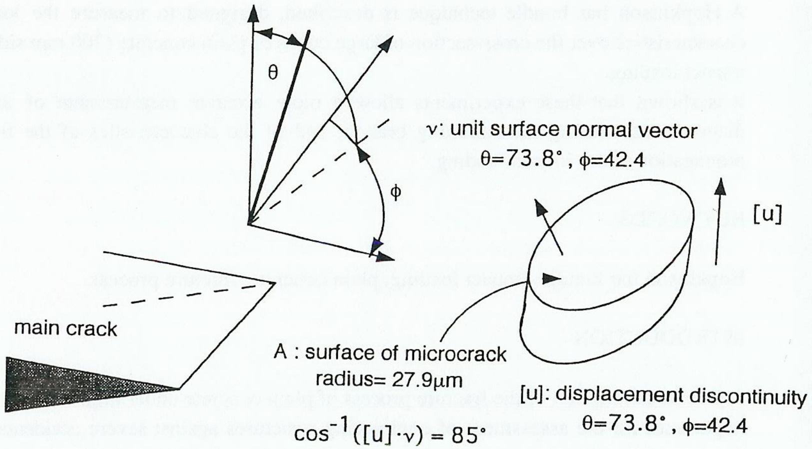


Figure 3. Example of microcracking size and fracture mode by AE source characterization.

RESULTS

Figure 2 shows the location results by AE. The errors of source location are given by a sampling rate, positions of transducers and dimensions of transducers. A sampling rate of 20 MHz and a longitudinal velocity give the maximum error of about 0.6 mm in source location. Although the size of the piezoelectric element is about 1 mm, the error of positions in attachment of transducers is smaller than this. Then the experimental error on each coordinate is estimated to be approximately 1 mm.

The deformation moment tensor has to be determined to obtain the mode and orientation of microcracking. We have presented the multiple deconvolution method to determine the moment tensor. Moment tensor D_{jk} is determined by the frequency deconvolution method using some time points from longitudinal wave arrival. Applying the nonlinear least-square method, the displacement discontinuity [u] and the normal v are obtained from the determined moment tensor D_{jk}. Figure 3 indicates the inclination of the microcrack plane to the main crack surface and the inclination of the microcrack plane to the direction of the displacement discontinuity. This result has demonstrated that a microcracking occurs in mixed mode of tensile and shear, but the shear component is stronger. Figure 4 shows the distribution of crack radius. Figure 5 shows the distribution of the mode angle. A cracking of particle and a debonding at interface were observed from the fracture surface. The estimated value of radius agrees well with the size of particle which is observed at the location of source event in front of the precrack tip. It can be concluded that the recorded AE events due to microcracking are identified as a cracking of particle and a debonding at interface in front of the precrack.

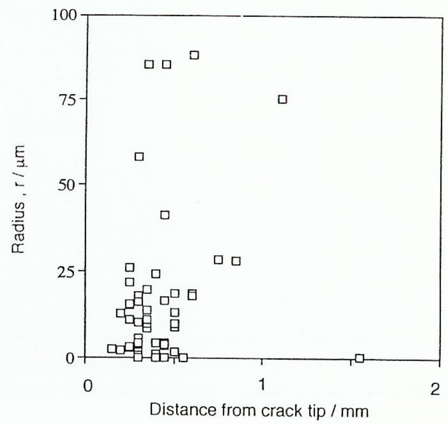


Figure 4. Distribution of microcracking size.

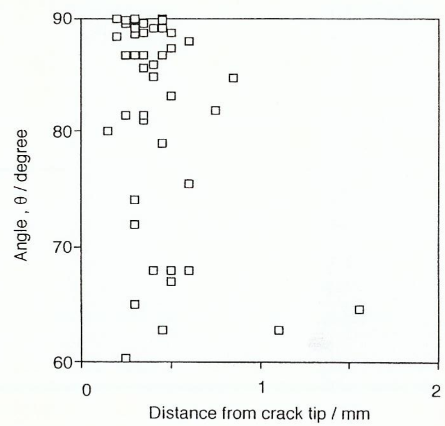


Figure 5. Distribution of fracture mode.

CONCLUSIONS

Acoustic emission waveform analysis was employed to evaluate the microfracture process in the SiC particle reinforced glass matrix composite. Locations of microfracture of this composite during the fracture toughness test were estimated. A model of AE source of microcracking was proposed. Microcracking size and fracture mode were also evaluated by this source model of microcracking and the deconvolution method.

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