INFLUENCE OF MATRIX CRACKS ON STRESS TRANSFER BETWEEN GLASS FIBRES AND EPOXY RESIN USING PHOTOELASTICITY

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1 Introduction

In a continuous fibre composite, the tensile strength depends on the ability of the matrix to transfer stress to the fibres through shear at the fibre/matrix interface, at a fibre fracture. In this way the reinforcing efficiency of the fibres is maintained. In order to study fibre/matrix interfacial adhesion and stress transfer in the fibre composite materials, the fibre fragmentation test is now commonly used. The test involves a single fibre embedded completely in a matrix that is subjected to an axial tension. Load is transferred from the matrix to the fibre by the interfacial shear stress. As the applied stress increases, the fibre breaks into smaller fragments. A noteworthy phenomenon in the fibre fragmentation test, which has been mentioned by many researchers [1-2], is that a transverse matrix crack often appears around a fibre-break for strong interfacial adhesion. So far experimental micro-mechanical studies cannot quantify the influence of a transverse matrix crack on stress transfer at the interface.

In this study, phase-stepping photoelasticity has been used to quantify the shear stress profile at the fibre/matrix interface at the ends of fibre-breaks with the transverse matrix cracks.

2 Phase-stepping photoelasticity

An automatic polariscope with four CCD cameras was mounted on a microscope in order to simultaneously collect four photo-elastic images at micro-scale. The pairs of quarter-wave plates and analysers in front of the cameras within the polariscope are orientated so as to generate four phase steps in the photo-elastic data. A filter which transmits light of wave-length of 542 ± 5 nm was used to produce an essentially monochromatic green light source. In the phase-stepping photoelasticity, the isoclinic angle, q, and the relative retardation, d, are given by solving the light intensity equations of the four phase-stepped images [3]

$$q = \frac{1}{2}\tan^{-1}\left[\frac{i_2 - i_3}{i_2 + i_3 - 2i_1}\right] \quad (1)$$

$$d = \frac{1}{2}\tan^{-1}\left[\frac{i_2 - i_3}{\sin 2q\,(i_2 + i_3 - 2i_4)}\right] \quad (2)$$

where i_1 to i_4 are the light intensities observed by each CCD camera. The relative retardation, d, in the specimen is related to the fringe order [4], N, by

$$d = 2pN \quad (3)$$

The relationship between the isochromatic fringe order, N, and the principal stresses σ_1 and σ_2, or maximum shear stress, σ_{max} in a two dimensional model can be written as [4]

$$t_{max} = (s_1 - s_2)/2 = f_s N/2t \quad (4)$$

where t is the thickness of the sample and f_s is the stress fringe constant of a material. The interfacial shear stress along fibre direction, $ô_{xy}$ can be calculated using the maximum shear stress, $ô_{max}$, and the isoclinic angle, è, according to Mohr's circle for a two-dimensional model by [5]

$$t_{xy} = t_{max} \sin 2q \quad (5)$$

3 Experimental

A cold-cured epoxy resin system Araldite LY5052 and Aradur HY 5052 (Ciba-Geigy) were used in the present study. The mixture was cured at room temperature for at least seven days. The resin had a Young's modulus of 3.2 GPa and tensile strength of 73 MPa. Single short glass fibre of diameter 125 microns was embedded in the epoxy. Young's modulus of the glass fibre was found to be 115 MPa [6]. The specimens of the single fibre composites were subjected to uniaxial tension along the fibre direction to achieve fibre fragmentation. The load was interrupted temporarily at intervals of applied matrix stress to capture photoelastic images in the matrix near the fibre-breaks using the phase-stepping automated polariscope. The images then were processed to obtain isoclinic angle and isochromatic fringe order using Eqs. (1) ~ (3).

4 Results and discussion

It was observed that matrix cracks were initiated at each fibre fracture. The transverse matrix cracks formed in the fragmentation test had different sizes, depending on the elastic energy stored in the fibre. Figure 1 shows the normalised interfacial shear stress profiles for different transverse crack lengths at two levels of applied stress. The interfacial shear stresses were normalized by the applied matrix stress. When the transverse crack has propagated by a short length into the matrix the maximum shear stress is close to the fibre-end. However for large transverse crack, the maximum occurred at 0.4 mm from the fibre-break. As the crack length increases the stress transfer is delayed. This shows that a matrix crack can reduce the efficiency of stress transfer from the matrix to the fibre, which is similar to those predicted by Liu *et al.* [7] and Johnson *et al.* [8].

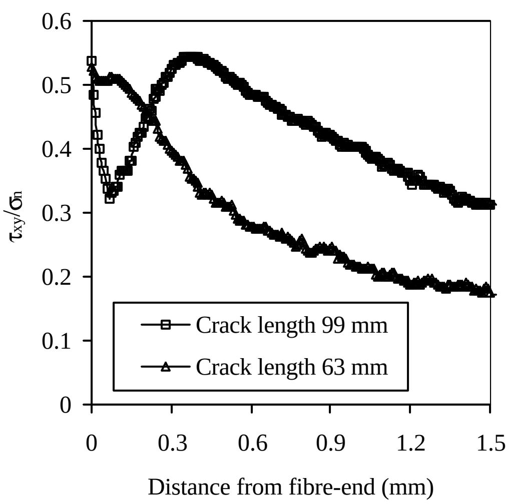

Fig. 1. Interfacial shear stress profile at two levels of load for different crack length

Liu *et al.* and Johnson *et al.* have shown theoretically that the presence of a transverse matrix crack significantly influenced the stress transfer mechanism. It was shown that the stress transfer length increases with the length of the transverse matrix crack, therefore reducing the reinforcing efficiency of the fibre.

5 Conclusions

Phase-stepping automated photoelasticity was used to quantify the stress field surrounding the broken fibre in the presence of a transverse matrix crack which had propagated into the epoxy resin matrix. The effect of matrix cracking perpendicular to the fibre axis has been studied. The size of transverse matrix crack increases the critical fibre length and delays stress transfer. The maxima in the shear stress plot observed in the FEA calculations were also observed in the photoelasticity results.

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