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SHORT COMMUNICATION

Fracture Toughness of Chopped Glass Fibre Phenolic Composite

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ABSTRACT

The chopped glass fibre phenolic composite to be used for the construction of aircraft parts has been prepared and the fracture toughness of this composite was evaluated using J-integral method. The effects of humidity and 3 per cent *NaCl* on the fracture toughness values were also investigated. For this, a set of six specimens having crack lengths varying from 0-18 mm was tested. Five such sets of specimens were selected for the experimental studies to check the reproducibility of the results and to evaluate the effect of environment.

1. INTRODUCTION

For overcoming the difficulties encountered in accurately analysing the crack-tip region using linear elastic fracture mechanics (LEFM) concepts[1-5], a parameter called J-integral, was proposed by Rice[6] whose value depends on the crack-tip stress-strain field. Many researchers[7-8], who had used this method, came to the conclusion that the J-integral method may be chosen as a parameter to characterise the crack-tip environment because it can be evaluated experimentally and calculated with less difficulties than the plastic stress and strain intensity factor. Agarwal[9-10], *et al.* have demonstrated that the J-integral method can be used as a simpler method to obtain fracture toughness value for short fibre composites which are currently being considered for critical load-bearing applications. The chopped glass fibre phenolic composite is essentially used for the construction of aircraft parts, such as fin, door, internal structures, etc. This composite is also used for the manufacture of helmets for military personnel. These structures, fabricated with the help of this composite, are basically load-carrying members. Hence, it is worthwhile to evaluate the fracture toughness of this composite. In the present study, the J-integral method has been used for the determination of fracture toughness of this material.

2. EXPERIMENTAL SETUP

The short fibre-reinforced phenolic composite was prepared using a chopped strained mat of glass fibres having a mass of 0.6 kg/mm^2 and an average fibre length of 50 mm. The matrix material was phenolic resin PR-6521 supplied by Hylam Co. India. Prepegs (30 cm × 30 cm) were prepared using chopped strained mat (40 g) and a solution (100 ml) containing phenolic resin (40 g) dissolved in C_2H_5OH (100 ml). Prepegs were then heated in an oven at 80 °C for 1 hr. The composite plate (5 mm thick) was fabricated using eight such prepegs and finally cured at 160 °C for 1 hr with a pressure of 140.6 kg/cm^2. The cured plates exhibit a fibre weight fraction of 55 per cent. Single-edge notched

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specimens (150 mm × 25 mm) were selected for the test. The initial notches were machined using 1 mm thick slit cutter and crack length was varied from 0-18 mm. The fracture toughness tests were performed on a 10-tonne servohydraulic MTS machine. X-Y recorder of MTS machine was used for recording the loads and displacements. The data were analysed using the J-integral method.

To observe the effect of environment, some specimens were immersed in H_2O and some in 3 per cent $NaCl$ for 150 days. The fracture toughness of these specimens was also determined using the J-integral method.

3. RESULTS & DISCUSSIONS

Figure 1 shows typical load displacement curves for specimens with different initial crack lengths. All the tests were conducted under load-control condition. It was observed that specimens with smaller crack show a sudden fracture process, whereas specimens with larger crack show a more gradual fracture process beyond maximum load. The fracture process becomes unstable at a displacement beyond which the load decreases monotonically. This displacement is referred as a critical displacement. In Fig. 2, the

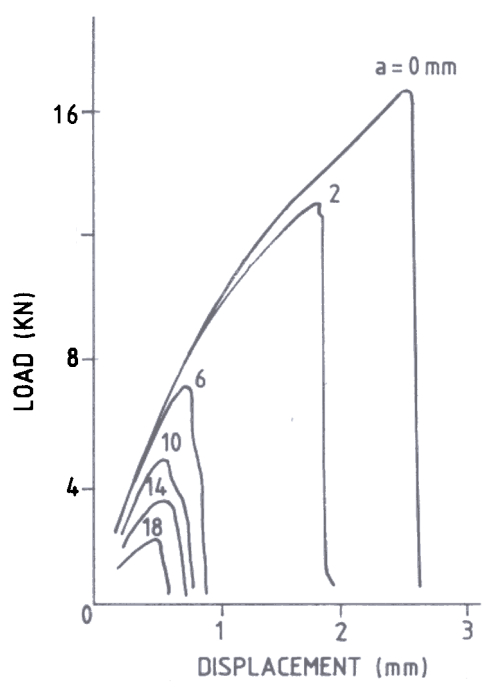

Figure 1. Load displacement curves for various initial crack lengths for unexposed specimens.

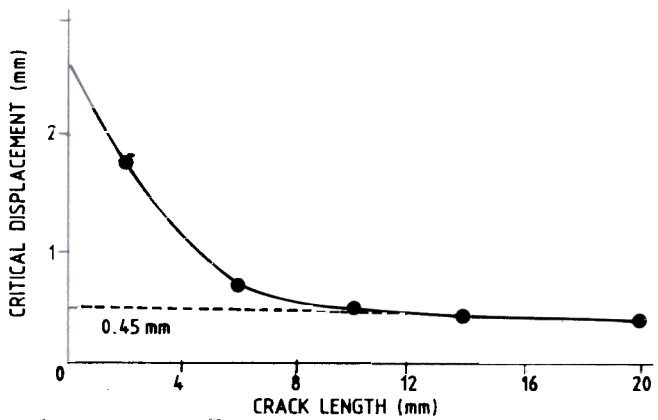

Figure 2. Variation of critical displacements with initial crack lengths.

critical displacements have been plotted against the crack lengths. It can be seen from the behaviour of this curve that initially the critical displacement decreases with the increase in crack length, and after that, it remains constant for crack longer than 10 mm. The initial variation in critical displacement occurs due to the significant deformations away from the crack-tip because of large loads. The critical value of J-integral is obtained corresponding to the critical displacement of 0.45 mm.

To obtain the value of J-integral experimentally through energy interpretation[11], the load displacement curve can be used as follows:

$$J = -\frac{dU}{da} \tag{1}$$

where U is the potential energy per unit thickness and a is the crack length.

It may be mentioned that when the displacement is kept constant for evaluating J, the potential energy U reduces to the area under the load displacement curve per unit thickness and is equal to the strain energy. So, area under load displacement curves is first obtained and plotted against crack length for several displacements (Fig. 3). It can be observed from this plot that for a given displacement, energy absorbed by a specimen decreases as the crack length increases because of smaller loads. The variation in energy absorbed is less for cracks shorter than 10 mm compared to longer cracks because in specimens with longer cracks, the energy absorbed is essentially in the

vicinity of the crack-tip and is thus strongly influenced by the crack length. The J-integral value is obtained from Eqn (1) through slopes of the energy curves in Fig. 3. The J-integral value is independent of crack length for crack longer than 10 mm since the energy curves are straight lines in this range. The variation of J with displacements has been shown in Fig. 4. The critical value of J corresponding to the critical displacement is 28.5 KJ/m^2. For smaller cracks, the value of

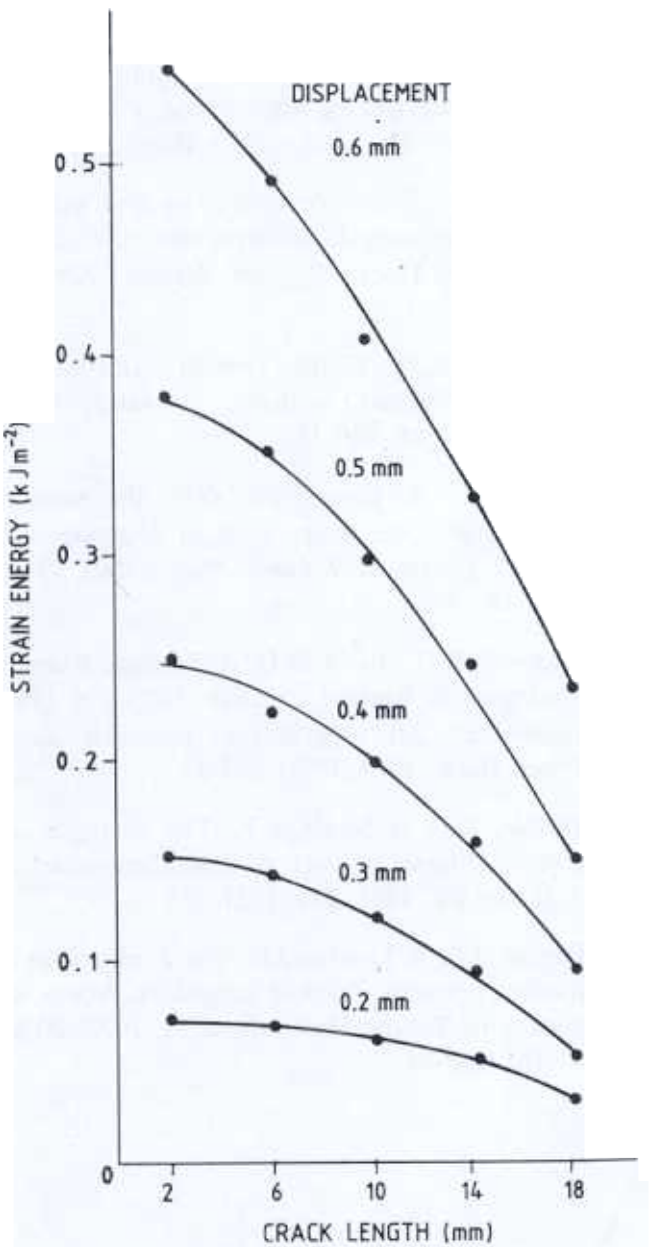

Figure 3. Strain energy per unit thickness of specimens for different displacements.

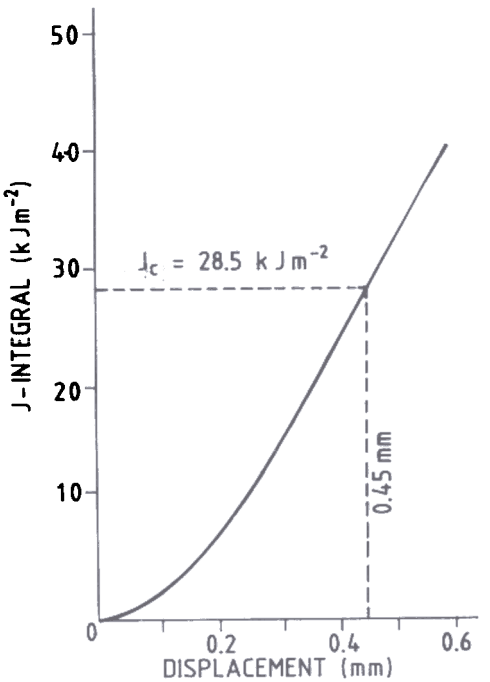

Figure 4. J-integral as a function of displacement

J-integral depends upon the displacement as well as the crack length because the slope of the energy curve changes with crack length (Fig. 3). It appears that when the crack is longer than 10 mm or when the ratio of crack length to specimen width $a/w >$ 0.40, the fracture behaviour is governed essentially by the crack-tip environment, resulting in the constant critical displacement and a unique value of J-integral. For these crack lengths, the fracture load is small which does not cause any material damage away from the crack-tip region.

From Fig. 4, the critical value of J(J_c) can be obtained. It has been shown that J_c is related to the parameters of LEFM. For plane stress case, it is related to critical stress intensity factors in mode-I, K_c, by the following relation:

$$J_c = K_c^2 / E \qquad (2)$$

where E is the modulus of elasticity.

The present composite has an average value of E = 9.005 Gpa. Therefore, Eqn (2) gives K_c value for the composite specimens equal to 16 MPa$\sqrt{m}$.

The same procedure was adopted in determining the fracture toughness values of the

composite in H_2O and 3 per cent *NaCl*. The obtained values in H_2O and 3 per cent *NaCl* are 4.8 MPa$\sqrt{m}$ and 3.0 MPa$\sqrt{m}$, respectively. From these results, it can be seen clearly that the fracture toughness value is significantly influenced by different environment, such as humidity (H_2O) and 3 per cent *NaCl*. The phenomenon can be explained based on the fact that moisture absorption by the matrix results in swelling of the composite. Since swelling of the composite lamina is restrained by the short fibres, significant residual stresses are introduced in the composite. In the case of *NaCl* environment, the situation is further deteriorated by the absorption of both chloride and H_2O molecules, and as a result of this the fracture toughness value of the composite is further reduced.

4. CONCLUSIONS

The following conclusions have been drawn:

- The fracture toughness was evaluated as 16 MPa$\sqrt{m}$ and the value is independent of crack length when $a/w > 0.40$.
- H_2O and 3 per cent *NaCl* environment influence the fracture toughness of this composite. The evaluated values of the composite in H_2O and 3 per cent *NaCl* are 4.80 MPa$\sqrt{m}$ and 3.0 MPa$\sqrt{m}$, respectively.

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