Study of Fracture Toughness of Fly-ash Filled Cross-ply Glass Fibre Reinforced Epoxy Resin

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ABSTRACT

The present research program is related to study the fracture toughness property of fly-ash filled cross-ply glass fibre reinforced epoxy resin with different orientation of fibre along the applied tensile load. The results show that fracture toughness of fly-ash filled cross-ply composites is independent of initial crack length but dependent on orientation of fibre. An emperical formula relating the fracture toughness of the composite for different orientation of fibre is found. Also, debonding phenomena is improved by adding fly-ash filler in glass fibre reinforced epoxy resin materials.

KEYWORDS

Glass fibre, Epoxy resin, Fly-ash, fracture toughness, orientation of fibre, fractograph

INTRODUCTION

The need to reduce weight in structures such as air-crafts, automobiles, satellites and in recreational equipment has led to the rapid development of fibre reinforced plastics. Some of the recently developed fibre reinforced plastics that have great potential usage in the automotive industry are sheet molding compounds. These materials are composed of randomly distributed fibres in a matrix of polyester resin and various fillers. Watanbe and Yasuda, (1982) studied the fracture behaviour of sheet moulding compound which consists of unsaturated polyster resins with glass fibre reinforcement and particle filler. They showed that the tensile strength of sheet moulding compound was reduced by abnormal flow during moulding. Donaldson (1985) used notched off-axis tensile test to characterise the mixed mode I and mode II behaviour of unidirectional graphite-reinforced epoxy and thermoplastic composite material. He found that the more brittle epoxy and tougher thermoplastic showed very bisimilar fracture surfaces for equimixed mode ratios. Owen and Bishop (1972) showed that fracture toughness (K_C) could be considered to be a genuine material parameter for design purposes. Lange (1970) developed a model which suggested that the increased crack front length could significantly contribute to the fracture energy of a brittle, particulate composite material. The fracture energy behaviour of several polymer particulate composites has been reported by Broutman and Sahu (1971). Owen and Rose (1973) determined the fracture toughness of polyester/glass laminates and studied the effect of adding a flexibilising agent to the matrix resin. In determining 'K_c' they took into account the development of yielded zone ahead of the crack tip and made corrections to their measured values to allow for this damaged zone. They give values of K_c of about 10 $MNm^{-3/2}$ for composites containing chopped strand mat and about 15 $MNm^{-3/2}$ for composites containing glass fabric and they found that these were largely unaffected by additions of up to 50% of the plasticiser. Parhizgar et al (1982) have reported experimental results on fracture toughness of unidirectional glass/epoxy (Scotchply 1002) composites. Garg (1986) and Konish Jr. et al., (1972,1973) have presented similar data on graphite/epoxy composites. Both the crack orientations, crack perpendicular and parallel to the fibres are considered by these investigators. Thorat and Lakkad (1983) have measured fracture toughness of unidirectional glass fibre/epoxy and carbon fibre/epoxy composites. They have, however, considered only crack oriented perpendicular to the fibres. Results of all these investigators indicate that fracture is triggered by a critical stress intensity factor, which is a characteristic of the crack orientation and is independent of the initial crack length and specimen geometry (Roodpishi, 1988). In this paper, the effect of orientation of fibre along the tensile load and initial crack length on fracture toughness of fly-ash filled cross-ply E-glass fibre reinforced epoxy resin composites is investigated.

EXPERIMENTS

For the preparation of fly-ash filled cross-ply glass fibre reinforced epoxy resin; the Areldite (CY-230) and Hardner (HY-951) were weighed in the ratio of 10:1 and then 6% of fly-ash by weight were mixed with areldite and hardner. They were mixed thoroughly by hand stirring for 15-20 minutes and it was ensured that no air bubbles were present due to addition of fly-ash in the areldite and hardner. Using the mixture and E-glass fibre woven mats; the composite sheet (with fibre volume fraction 0.47) were moulded by hand lay-up technique. The sheets were taken out after the curing time in room temperature. The single notched specimens with different angles of orientation of fibre (45°/45°, 60°/30°, 75°/15° and 90°/0°) were marked over the (90°/0°) sheets and cut accordingly by hand saw. Also, transverse type (90°) fly-ash filled glass fibre reinforced epoxy resin was moulded. The geometry of single notched specimens were prepared with overall dimensions of 100 mm length, 25 mm width, 4 mm thickness and initial crack length 7 mm, 9 mm, 11 mm and 13 mm. Aluminium tabs were glued to the single edge notched specimens to facilitate friction gripping.

Tests were conducted on commercially available Hounsfield Tensometer. The specimen was fixed in a suitable grip attached to the tensometer. The loading of the specimen was then started by rotating the handle slowly at a constant speed. The load was applied continuously till the fracture occured. A quasi-controlled fracture was observed, which will be discussed in the next section. Finally, Scanning Electron Microscopy (SEM) was employed to understand the fracture mechanism of the fly-ash filled composite materials.

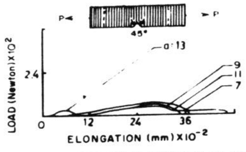

FIG. 1. LOAD V/S ELONGATION OF TRANSVERSE (90°) HYBRID GLASS FIBRE SPECIMEN

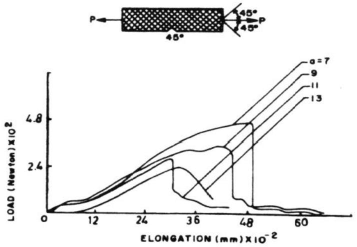

FIG. 2. LOAD V/S ELONGATION OF CROSS-PLIED(45°/45°) HYBRID GLASS FIBRE SPECIMEN

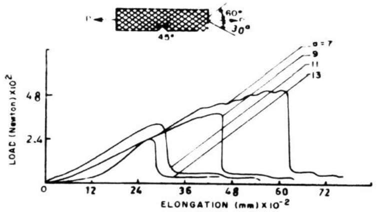

FIG. 3. LOAD V/S ELONGATION OF CROSS-PLIED(60°/30°)HYBRID GLASS FIBRE SPECIMEN

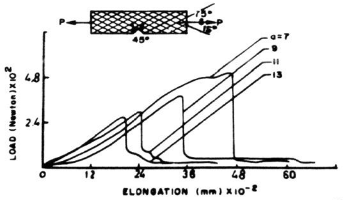

FIG. 4. LOAD V/S ELONGATION OF CROSS-PLIED (75°/15°) HYBRID GLASS FIBRE SPECIMEN

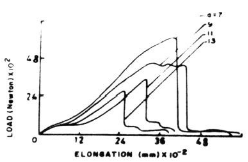

FIG. 5. LOAD V/S ELONGATION OF CROSS-PLIED (90°/0°) HYBRID GLASS FIBRE SPECIMEN

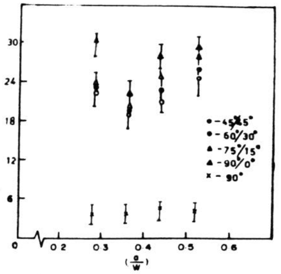

FIG 6 FRACTURE TOUGHNESS V/S RATIO OF INITIAL CRACK LENGTH AND WIDTH OF CROSS-PLIED AND TRANSVERSE(90°)TYPE COMPOSITES.

RESULTS AND DISCUSSION

The load-elongation curves obtained from uniaxial tension test on the fly-ash filled transverse glass fibre/epoxy resin, cross plied glass fibre/epoxy resin with different orientation of fibre (45°/45°, 60°/30°, 75°/15° and 90°/0°) along the applied tensile load as shown in figures 1 to 5. It is being observed that all the specimen show a quasi-controlled fracture, because all the fibres present in the specimens were not having the same direction. It is also observed that in the case of transverse fibre direction (Fig.1), the crack propagation is of mode I. It is further been observed that while applying the axial load, the specimens, in the case of transverse fibre direction undergoes an uniform elongation and an uniform fracture completes the failure phenomena, whereas for cross-plied (45°/45°, 60°/30°, 75°/15° and 90°/0°) fibre direction, the specimen deforms elastically and then it prevents the increment in the applied load by deforming plastically. This behaviour is observed for several number of times till the fracture occur suddenly and there is a sharp drop in the applied load, but the failure is yet not complete and the specimen is still capable of bearing some load (Fig.2 to 5).

Figure 6 shows the fracture toughness versus ratio of initial crack length and width for various types of transverse direction as well as cross-plied fibre directions. In all the cases, it has been seen that the fracture toughness is independent on the ratio of initial crack length and specimen width, specimen's width being constant for all specimen. Therefore, the results show that the fracture toughness is independent in initial crack length. The maximum difference between these values is 7%. Thus, for the case of cracks along the fibre orientation, the fact that the fracture toughness is a constant material property independent of initial crack length was verified. In the case of cross-plied, the values of fracture toughness is also independent of initial crack length. It is also a fact that the cracks do not grow along their original direction and the crack tip displacements cannot be separated into different modes (Thorat et al., 1983, Parhizgar et al., 1981).

Figure 7 shows that fracture toughness versus orientation of fibre along the applied tensile load for different initial crack length. The fracture toughness increases with an increase in the orientation of fibre. These observations are acceptable, since maximum strain energy release rate and fracture toughness occur in-plane crack propagation i.e. for crack propagation along the direction of initial crack length, whereas the minimum strain energy release rate and fracture toughness occur in a 90° out of plane crack propagation (Perhizgar, 1981). It is also a fact that the fracture energy of fly-ash filled cross-plied glass fibre reinforced epoxy resin may be higher than the un-filled glass fibre reinforced epoxy resin (Roodpishi, 1988). Because, the fly-ash particles arrest the path of crack and debonding of fibres, as can be seen from figure 8.

CONCLUSIONS

The results of this investigation clearly show that the fracture toughness of fly-ash filled cross-plied glass fibre reinforced epoxy resin is independent on the initial crack length but dependent on the orientation of fibre along the applied tensile load. An empirical relation is found.

$$K_1\alpha = (1.95\alpha^2 + 0.25\alpha + 1) K_{1T}$$

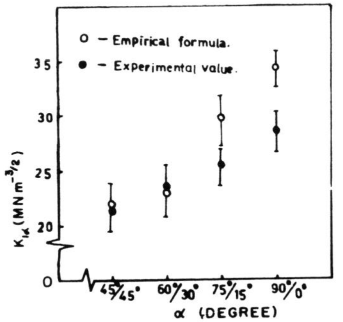

FIG. 7. FRACTURE TOUGHNESS V/S ORIENTATION OF FIBRE ALONG THE APPLIED LOAD FOR (a = 11 mm).

Fig. 8. FRACTOGRAPH OF CROSS-PLIED HYBRID GLASS FIBRE COMPOSITES (X384)

This empirical formula relates $K_{1\alpha}$, the fracture toughness when the fibre and applied load are at an angle α (radian), K_{1T}, the fracture toughness when the fibre is transverse along the applied load. Finally, fly-ash filled epoxy resin is not deformed during matrix deformation under tensile load due to their strong cohesive strength which increases the fracture energy of composites.

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