

The Effect of Post Cure on the Mechanical Properties of Chopped Fiber Reinforced Epoxy Laminate Matrix

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Abstract: This study presents the effect of cure and post-cure on mechanical properties of random chopped e-Glass, carbon fiber reinforced epoxy composites. At first, 2 mm fibers reinforced epoxy matrix of dog-bond specimens cure for 12 h at room temperature 25°C and post cure for 12 h at 50 and 100°C temperatures for all specimens a fragmentation tensile test where used, the strain energy release rate was calculated at cure and post cure temperatures, the strain energy release rate increase as post cure temperature increase.

Key words: Chopped fiber, e-Glass fiber, carbon fiber, epoxy matrix, fragmentation test, strain energy release rate

INTRODUCTION

Composites are generally used because they have desirable properties which could not be achieved by either of the constituent materials acting alone. The most common composite is the fibrous composite consisting of reinforcing fiber embedded in polymer matrix, short fiber reinforced thermoset polymer have several attractive characteristics that make them worthy of consideration such as in components having complex geometric contours and resin/short fibers can be easily injection or compression molded to produce parts having complex shapes (Gibson, 1994). Curing is an irreversible reaction where chemical covalent cross-links are formed which are thermally and mechanically stable. The curing process plays a major role in achieving the final mechanical properties and chemical resistance of the material (Kumar *et al.*, 2015). State of epoxy polymer resin is liquid (soft) before the fabrication of composite which then changes to solid matrix (hard) after curing. Current investigation intends to study the effect of the post cure on the strength of composite fiber length on mechanical and thermos-mechanical properties of short e-Glass, carbon fibers composites, using 2 mm fibers length to reinforce an epoxy resin matrix. Mechanical properties were obtained by defragment tensile tests with dog-bond specimens, the produced plates were then subject to a cure and post cure processes. The cure was at room temperature, 50 and 100°C. From defragment test the force (kN) versus deformation (mm) for each specimen and the strain energy can be derived for elastic and plastic

deformation (Atkins and Mai, 2000; Tada *et al.*, 2000) toughness energy values can be readily calculated from the load-deformation plot using numerical integration, integration was done by summing the area under the curve between successive load/deformation data points consecutively, a polygon quadrilateral with two parallel sides is a trapezoid (Petersen *et al.*, 2006; Greenspan *et al.*, 1986).

Where:

$$\text{Area} = \sum \frac{1}{2}(\text{basic} + \text{top})(\text{height}) \quad (1)$$

The toughness energy represented by the area under the curve would be including the stress failure, friction force effect and residual thermal stresses.

MATERIALS AND METHODS

Experimentation: A fiber length and diameter averaging of 3 cm and 10 μm, respectively were used as the reinforcement for short-fiber/epoxy and carbon/epoxy composite system. Dog-bond specimens of 40% fiber volume fraction with epoxy resin produced using steel moulds Fig. 1 and the specimens dimension as in Fig. 2. Dog bone tensile test samples are primarily used in tensile tests. Universal testing machine (maximum capacity 190 kN, crosshead speed 1 mm/min). The sample has a shoulder at each end and a gauge section in between. The shoulders are wider than the gauge section which causes a stress concentration to occur in the middle when the sample is loaded with a tensile force. This stress



Fig. 1: Dog bond steel mold

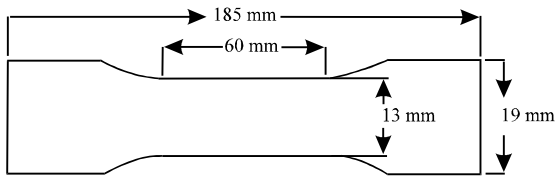


Fig. 2: Dimensions of dog-bond specimen (Anonymous, 2014)

concentration ensures a higher probability that the sample will rupture away from the ends. When the rupture of a sample occurs in the midsection it is attributed to the material reaching its maximum tensile strength whereas if the sample ruptures at one of the ends or in the grip itself the failure may be attributed to improper loading or a pre-existing defect in the material. The produced plates were then subject to a cure and post cure processes. The cure was at room temperature for 12 h in the mold and the post cure was carried out as follows: 50°C for 12 h, 100°C for 12 h.

RESULTS AND DISCUSSION

The curves of the tensile load versus deformation were obtained, showing a nearly linear until final failure and clearly show that the specimens fail immediately at maximum load. The tensile strength was assumed as the value of peak load divided by cross section area. The correct energy (U) for calculating the strain energy release rate for mode I is:

$$U = \frac{1}{2} P_Q (U_Q - U_i) \quad (2)$$

Where:

- P_Q = The peak load
- U_Q and U_i = The displacements in the fragmentation tests

Toughness values (G_{Ic}) were calculated from the corrected energy, the strain energy release rate G_{Ic} (J/m²) given by:

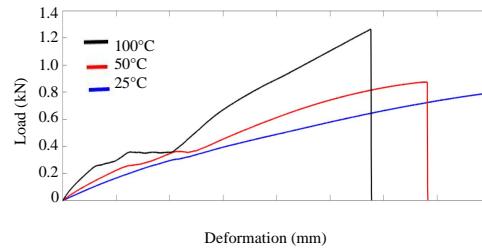


Fig. 3: Load-deformation curves for random e-Glass fiber reinforced epoxy matrix at post cure temperatures 25, 50 and 100°C

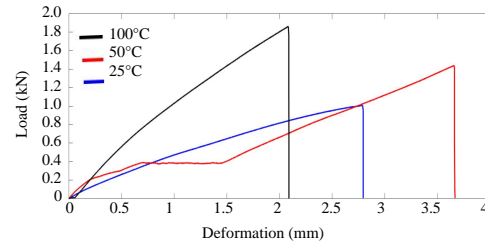


Fig. 4: Random-deformation curves for random carbon fiber reinforced epoxy matrix at post cure temperatures 25, 50 and 100°C

$$G_{Ic} = \frac{U}{BW\Phi} \quad (3)$$

Where:

- B = The specimen thickness
- W = The specimen width
- Φ = An energy calculation factor calculated from the ratio of crack length to coupon width

The correct energy represented by the area under curve have been calculated by numerical integration of the values which are tabulated from each force displacement curves (Fig. 3 and 4). In continuous fibers (the specimen were assumed to be perfectly embedded in an aligned arrangement) the orientation of fiber with respect of load direction plays an important role in determining the fracture toughness tensile load as the crack propagate through matrix and fiber when the direction of fiber is perpendicular with applied force or the crack propagate through the matrix only when the applied load is in direction of align fibers. In random orientation of chopped fiber reinforced epoxy matrix the applied force in parallel fiber direction will be less probable than other applied force-fiber directions. The strain energy release rate for each post cure temperature calculated by Eq. 3 and the tabulated values in Table 1, shown in Fig. 5. The temperature applied during the cure process would effected the chemical reactions in the resin which cause the desired changes in the molecular structure by

Table 1: Strain energy release rate for e-Glass fiber reinforced epoxy and carbon fiber reinforced epoxy at post cure temperatures 25, 50, 100 °C

Post cure temperature °C	Post cure time (h)	G _{IC} for e-Glass fiber reinforced epoxy (kN/mm)	G _{IC} for carbon fiber reinforced epoxy (kN/mm)
25	12	0.013435	0.014560
50	12	0.014133	0.016346
100	12	0.015410	0.019134

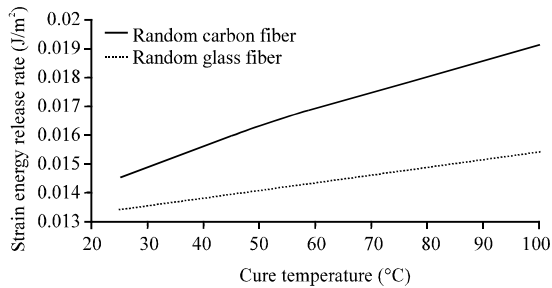


Fig. 5: The strain energy release rate-cure temperature for random e-Glass fiber, random carbon fiber reinforced epoxy matrix

increasing the cross linking and also effected the thermal stresses were the matrix resin and its reinforcement usually do not have the same thermal expansion coefficients.

CONCLUSION

The mechanical properties of chopped random orientation fiber reinforced epoxy matrix was affected by cure temperature by increasing the strain energy release rate as the post cure temperature increase for chopped e-Glass fiber and carbon fiber reinforced epoxy matrix the epoxy matrix do not fully cure at room temperature and as heat increase the cross-linking increase in the epoxy reaction (Hasan and Ismaeel, 2017). From the present

investigation it was observed that post curing at 100°C for 12 h gave better thermal and mechanical properties as compared to post curing at different temperatures.

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