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The Effect of Fiber Direction on the Adhesion Strength and Energy Release Rate in Epoxy Composite using Defragment Test

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Abstract: In this study, the adhesion strength and the energy release rate measured using defragment test for non-woven three kinds of unidirectional laminate composite specimens reinforced by carbon, Kevlar and glass fibers with fiber volume fraction ratio 4.8%, the direction of fiber in angles: 0°, 45°, 90° with the loading direction, all samples post cured at temperature 25°C. From results, the high value of strength and the energy release rate of laminate composite specimen is at 0° direction for each kind of specimens while the high value of strength and the energy release rate of laminate composite for all kinds of specimens found in epoxy reinforcement Kevlar.

Key words: Polymers composites, fiber reinforced, adhesion strength, energy release rate, defragment test

INTRODUCTION

Many of modern industries require materials with mechanical properties that cannot found in traditional materials such as metal, alloys, ceramics and polymers. Fibers reinforced epoxy composites have been shown to have the combination of strength, low weight material and low fabrication coasts, composites are one of the most widely used materials because of their adaptability to different situations and the relative ease of combination with other materials (Callister, 2000; Meyers and Chawla, 1999). Fibers bridging a crack can absorb more or less energy depending on their bond characteristics. The pull-out process involves first, a debonding action which provides an alternative path for the crack to follow and is preceded by the formation of a new surface at the fiber matrix interface. Moreover, the fiber deformation and compliance during pullout contributes directly to the total deformation of the composite. To study, the mechanical behavior of fibers reinforced epoxy matrix composite it is necessary to study the stress versus crack opening displacement of the composite, crack width, crack opening and crack propagation in a specific location. In this research, it was used dog-bone specimens of polymeric composites with three fibers kinds and three fiber orientations, the tensile strength of specimens with the reinforcement oriented at 0° is governed by the tensile strength of the fibers while for the 90° ones the specimens fail by crack propagation through the matrix and/or the fiber/matrix interface (Leung and Li, 1991).

MATERIALS AND METHODS

The experimental part include the properties the epoxy (Sikadur-52) matrix as in Table 1 with mixing ratio 1/2 and the properties of fibers used in reinforced as in Table 2.

Specimen preparation and tensile test: Mold was made of steel consisted of three pieces to get dog bone specimens. First small quantity of the resin is placed on the surface of the mold and spread with a brush to ensure that it is distributed by digestion, the fibers of 8 mm diameter arrange in unidirectional 0°, 45°, 90° angles for each of the three kind of specimens and then epoxy resin (1:2) poured with fiber volume fraction 4.8%, this done for carbon, Kevlar and glass fiber, the specimens cured at room temperature for 72 h, the specimens dimensions done by D3039M39 ASTM D30 as shown in Fig. 1.

The specimen placed in the grips of the testing machine, taking care to align the long axis of the gripped

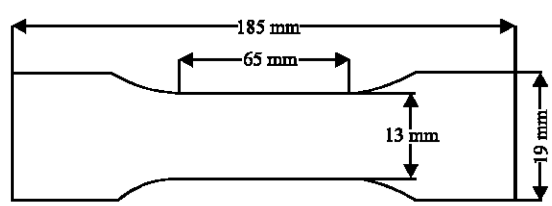

Fig. 1: Tensile specimen dimensions

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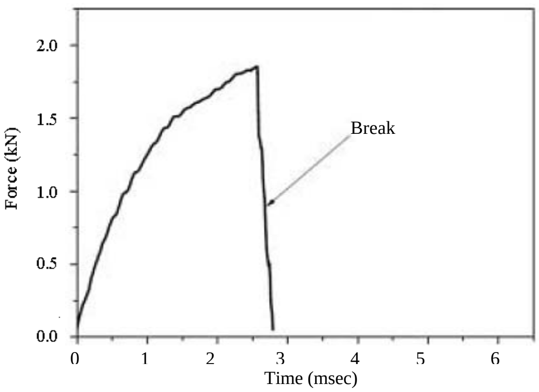

Fig. 2: Typical force-displacement defragment test (Minak *et al*., 2011)

Table 1: Properties of epoxy Sikadur-52

Factors	Values
Density (g/cm^3)	1.0850
E-modulus (Pa)	1100
Thermal expansion coefficient (k^{-1})	9.4×10^{-5}
Maximum tension (N/mm^2)	37
Maximum compression (N/mm^2)	52

Table 2: The properties of reinforce fibers

Factors	E-Glass fiber	Carbon fiber	Kevlar fiber
Diameter of fiber (mm)	10	10	10
Elongation (%)	4.88	1	3
Density (kg/m^3)	2.54	1.75	1.44
E-modulus (Pa)	75	250	130
Maximum tension (MPa)	1500	3200	4100

specimen with the test direction. Tighten the grips, recording the pressure used on pressure controllable (hydraulic or pneumatic) grips. Apply the load to the specimen at the specified rate until failure while recording data, record load versus strain (or transducer displacement) continuously or at frequent regular intervals. If a transition region or initial ply failures are noted, record the load, strain and mode of damage at such points. If the specimen is to be failed, the maximum load was record, the failure load and the strain (or transducer displacement) at or as near as possible to, the moment of rupture. The typical tensile test represented by load-displacement curves are shown in Fig. 2, the initial linear part of the load-displacement curves correspond to the strain potential energy stored in the composite specimen when a load was applied. When the applied load was high enough to create a new surface area, the introduced crack started to propagate until the test specimen failed catastrophically (Hull and Clyne, 1996). The experimental results using universal testing machine (200 WaW, 190-0 KN), tension speed 1 mm/min) shown in Fig. 2-5.

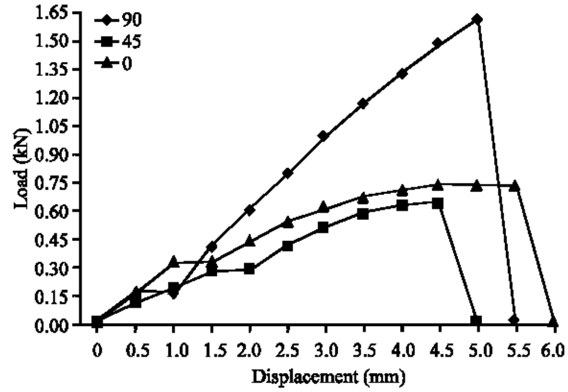

Fig. 3: The load (kN) vs. displacement (mm) for epoxy-glass fiber in 0°, 45°, 90° directions

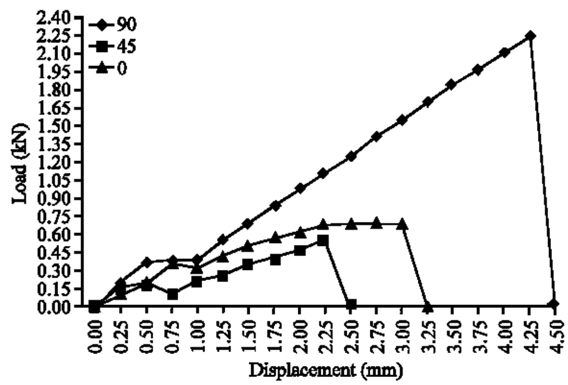

Fig. 4: The load (kN) vs. displacement (mm) for epoxy-carbon fiber in 0°, 45°, 90° directions

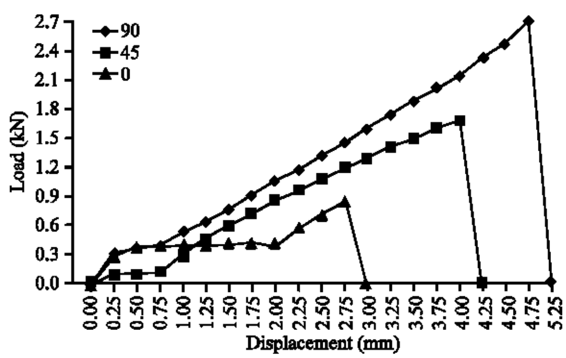

Fig. 5: The load (kN) vs. displacement (mm) for epoxy-Kevlar fiber in 0°, 45°, 90° directions

RESULTS AND DISCUSSION

Non-woven glass mat was reinforced thermoset epoxy matrix by hand layup process. The mechanical properties such as adhesion strength, energy release rate were calculated. The highest strength of adhesion was measured from the force graph versus the distance

Table 3: The values of forces vs. fiber directions for glass fiber reinforce epoxy matrix

Fiber direction	Force at elastic strain region for fiber and matrix (kN)	Force at plastic strain for matrix and elastic for fiber (kN)	Force at deformation region for fiber and matrix (kN)	Force at fracture region for composite (kN)
90°	0.15	0.38	0.6	0.75
45°	0.30	0.50	1.0	1.40
0°	0.40	0.70	1.2	1.70

Table 4: The values of forces vs. fiber directions for carbon fiber reinforce epoxy matrix

Fiber direction	Force at elastic strain region for fiber and matrix (kN)	Force at plastic strain for matrix and elastic for fiber (kN)	Force at deformation region for fiber and matrix (kN)	Force at fracture region for composite (kN)
90°	0.3	0.43	0.64	1.00
45°	0.4	0.60	0.90	1.40
0°	0.7	1.20	1.65	2.36

Table 5: The values of forces vs. fiber directions for Kevlar fiber reinforce epoxy matrix

Fiber direction	Force at elastic strain region for fiber and matrix (kN)	Force at plastic strain for matrix and elastic for fiber (kN)	Force at deformation region for fiber and matrix (kN)	Force at fracture region for composite (kN)
90°	0.22	0.6	1.00	1.44
45°	0.43	0.8	1.43	1.80
0°	1.00	1.6	2.40	2.80

in Fig. 3-5 and the values of forces in the regions of load-displacement for all specimens tabulated in Table 3-5. The strain energy release rate is the amount of energy dissipating during the fracture per unit of newly broken surface area, this quantity is important to fracture mechanics because the energy that must be provided at the tip of the crack to evolve to be parallel of the amount of energy that is dissipated due to the formation of new surfaces calculated by:

$$G_{ic} = \frac{U}{BW\Phi} \tag{1}$$

Where:

B = The coupon thickness
W = The coupon Width
Φ = An energy calculation factor calculated from of crack length to coupon width
U = The corrected energy calculated from Fig. 6

Where, P_Q is the Peak load and U_Q and U_i are the displacements in the fracture and fragmentation tests, respectively in any region and the correct energy U calculated by Eq. 2:

$$U = \frac{1}{2} p_Q (U_Q - U_i) \tag{2}$$

Where:

U = The corrected energy
P_Q = The Peak load
U_Q and U_i = The displacements in the fracture and any region in fragmentation tests

Table 6: The values of strain energy release vs. fiber directions for glass fiber reinforce epoxy matrix

Fiber direction	Strain energy release rate (kJ)
0°	56.80
45°	38.58
90°	17.40

Table 7: The values of strain energy release vs. fiber directions for carbon fiber reinforce epoxy matrix

Fiber direction	Strain energy release rate (kJ)
0°	136.2
45°	64.8
90°	37.5

Table 8: The values of strain energy release vs. fiber directions for Kevlar fiber reinforce epoxy matrix

Fiber direction	Strain energy release rate (kJ)
0°	156.10
45°	82.67
90°	53.40

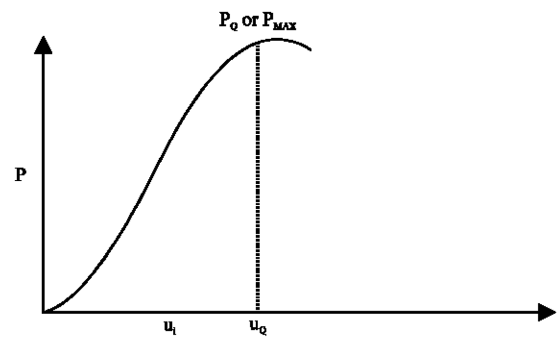

Fig. 6: Typical load-displacement curve in fracture test

In this research, the energy release rate (G_{ic}) calculated from Eq. 1 and 2 where the crack length is equal the width of coupon in fracture region of composite in Table 6-8.

From the Table 4-6, it can be observed that force at the four regions increase depending on the direction of fiber related to load direction, this means that the transverse contraction is higher than the applied longitudinal extension (Poisson's ratio), i.e. as the matrix pulling, the fibers tend to stretch and squeeze. The Poisson's ratio of the epoxy is close to the one of the absolutely incompressible isotropic material. Therefore, the matrix is pushed out the composite in the thickness direction leading to expansion of the composite in the out-of-plane direction the material of fiber, i.e., in 0° direction the crack tip perpendicular to fiber direction the crack cut the fiber in order to propagate until the fracture where the specimen separated into two parts in 90° direction the crack tip will propagate at interface between fibers which have weak bonds corresponding to the bonds in fibers (Fig. 7). It can be also observed that adhesion strength and the energy release rate depended on the material of fiber which was the less in glass fiber reinforced epoxy matrix and the higher value in

Fig. 7: The fracture direction vs. fiber direction

Kevlar fiber reinforced epoxy matrix, depend on the adhesion forces at interface (Hasan and Albdere, 2017).

CONCLUSION

In this study, an experimental method for evaluating the tensile fracture toughness and the energy release rate, the high strength and the energy release rate for all specimens are in 0° direction where the applied force in direction of fiber and the fracture is perpendicular to fibers, the fracture resisted by the matrix, interface and fibers while in 90° the fracture resisted by matrix only. The highest toughness and the energy release rate value are for Kevlar fiber reinforced epoxy matrix in 0° directions for mechanical properties of Kevlar fiber and high adhesion at interface.

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