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Title	The Effect of Fiber Direction on the Adhesion Strength and Energy Release Rate in Epoxy Composite Using Defragment Test
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Muhammad Kamran
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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 paper the adhesion strength and the energy release measured using defragment test for non woven three kinds of laminated composite specimens reinforced by carbon ,Kevlar and glass fibers with fiber volume fraction ratio (4.8%) , the direction of fiber in angles : 90^o ,45^0 ,0^0 with the loading direction, all samples post cured at temperature 25 ^{0}C . From results the high adhesion strength is at angle 0^0, for epoxy reinforcement Kevlar while the high energy release found in epoxy reinforcement Kevlar, the high adhesion strength and the energy release rate in 0^0 direction where the applied force in direction of fiber.

Key words: **Polymers composites, Fiber reinforced, Adhesion strength, Energy Release Rate, Defragment Test.**

1- 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 [1,2]. 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 work, 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 [3].

2- EXPERIMENTAL PROGRAM

The experimental part include the properties of fibers which used in reinforced and matrix material and also the results of fragmentation tests, the matrix material is epoxy (Sikadur-52) with mixing ratio 1/2, properties as in table (1) [5].

Table -1 : the properties of epoxy Sikadur-52.

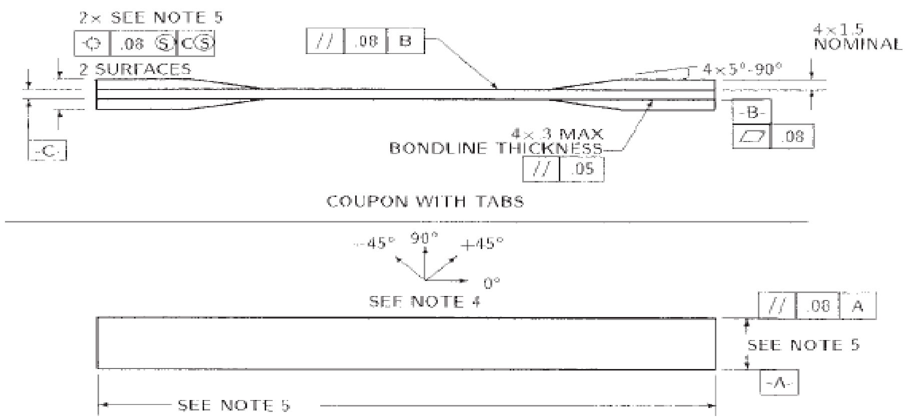
Density, g/cm^3	**1.0850**
E-modulus, Pa	**1100**
Thermal expansion coefficient	**$9.4x10^{-5}$ k^{-1}**
Max. tension N/mm^2	**37**
Max. compression N/mm^2	**52**

Table-2: The properties of reinforce fibers.

	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
Max. tension Mpa	1500	3200	4100

2.1- Specimen Preparation and Tensile Test.

Mold was made of steel material 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 0^0 ,45^0 ، 90^0 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 hours, the specimens dimensions done by D3039M39 ASTM D30 **[6] as shown in Fig(1).**



Fig(1): Tension Test Specimen Drawing (SI).

The specimen placed in the grips of the testing machine, taking care to align the long axis of the gripped 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 [7].

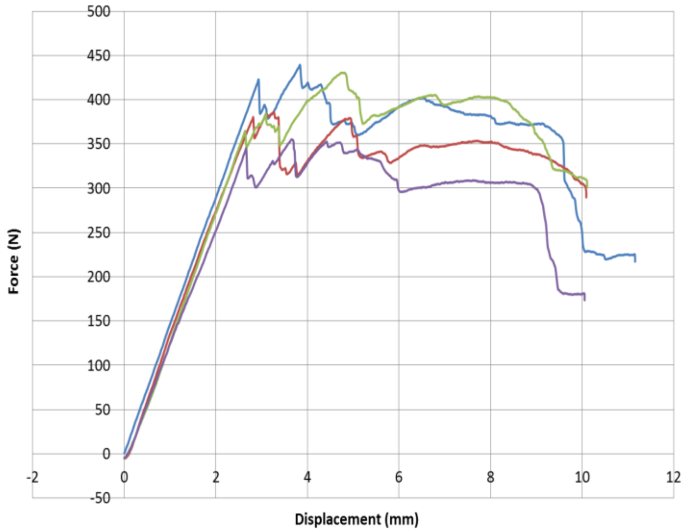


Fig 2 : Typical force-displacement defragment test.

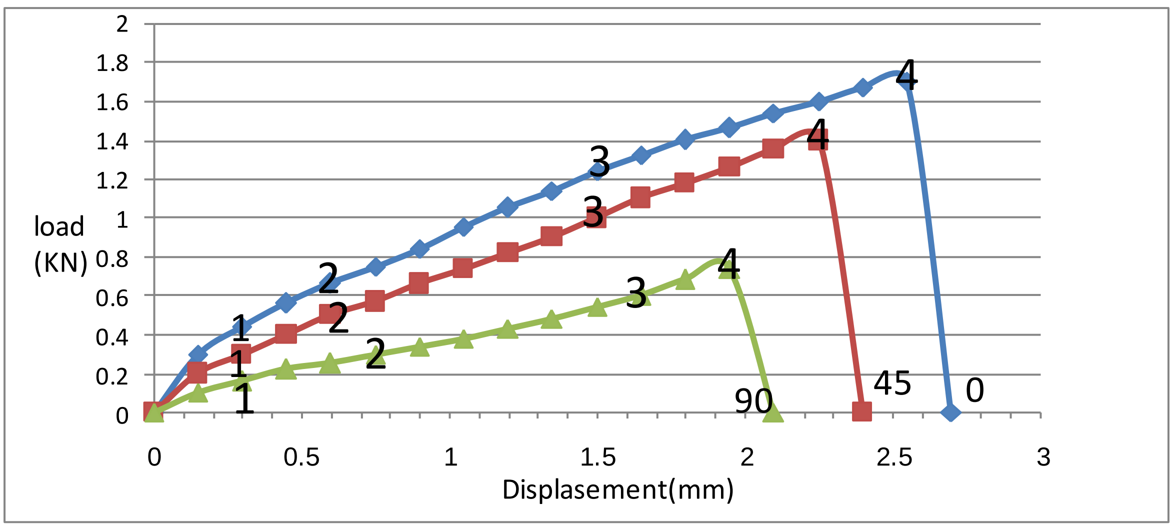


Fig 3: The load (KN) Vs. displacement (mm) for epoxy-glass fiber in 0^0,45^0,90^0 directions.

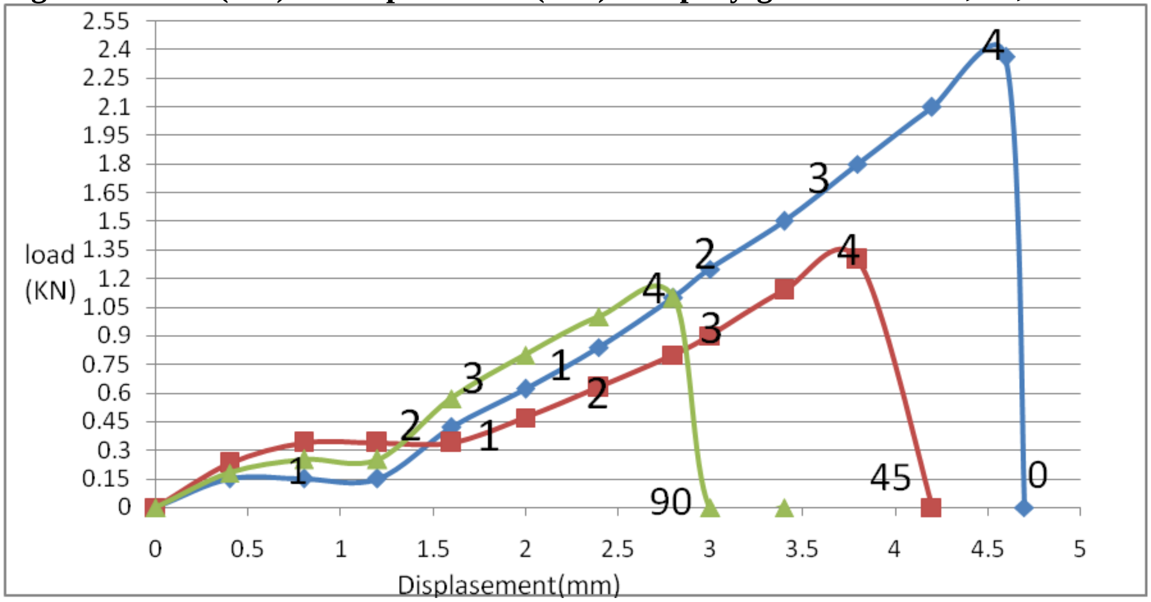


Fig 4: The load (KN) Vs. displacement (mm) for epoxy-carbon fiber in 0^0,45^0,90^0 directions.

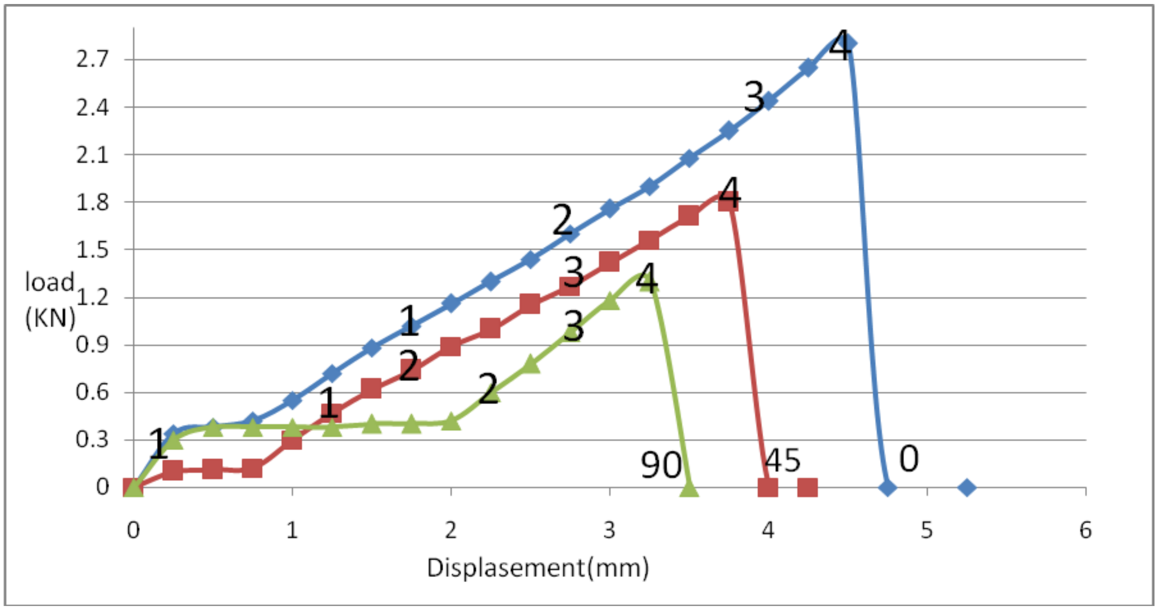


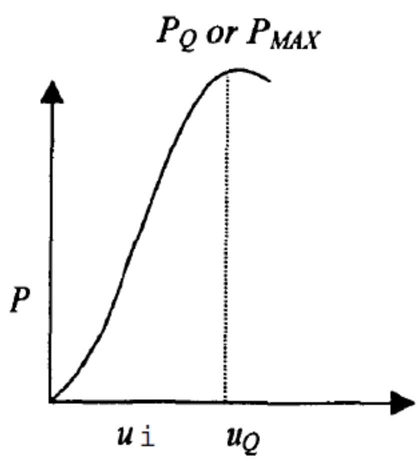
Fig 5: The load (KN) Vs. displacement (mm) for epoxy-Kevlar fiber in 0^0,45^0,90^0 directions.

3- Results and Discussion

Non-woven glass mat was reinforced in 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 in above figures 3,4,5 and the values of forces in the regions of load-displacement for all specimens tabulated in 3,4,5. 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:.

$$G_{ic} = \frac{U}{BW\Phi} \qquad \text{.........................1}$$

Where B is the coupon thickness, W is the coupon width, Φ is an energy calculation factor calculated from of crack length to coupon width, U is the corrected energy calculated from (Figure 6) .



Fig(6):Load-displacement curve in fracture test .

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 equation (2):

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

U is the corrected energy, P_Q is the peak load and U_Q and U_i are the displacements in the fracture and any region in fragmentation tests. In this work the energy release rate (G_{ic}) calculated from equation (1) and equation (2) , where the crack length is equal the width of coupon in fracture region of composite tables 6,7,8.

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	0.15	0.38	0.6	0.75
45^0	0.3	0.5	1	1.4
0^0	0.4	0.7	1.2	1.7

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	0.3	0.43	0.64	1
45^0	0.4	0.6	0.9	1.4
0^0	0.7	1.2	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	0.22	0.6	1	1.44
45^0	0.43	0.8	1.43	1.8
0^0	1	1.6	2.4	2.8

Table-6: The values of strain energy release Vs. fiber directions for glass fiber reinforce Epoxy matrix.

Fiber direction	Strain energy release rate($kJ/m^{2)}$
0^0	56.8
45^0	38.58
90^0	17.4

Table-7: The values of strain energy release Vs. fiber directions for carbon fiber reinforce Epoxy matrix.

Fiber direction	Strain energy release rate (KJ/m^2)
0^0	136.2
45^0	64.8
90^0	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/m^2)
0^0	156.1
45^0	82.67
90^0	53.4

From the tables 3,4,5 , 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 0^0 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 90^0 direction the crack tip will propagate at interface between fibers which have weak bonds corresponding to the bonds in fibers Figure (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 Kevlar fiber reinforced epoxy matrix, depend on the adhesion forces at interface [8].

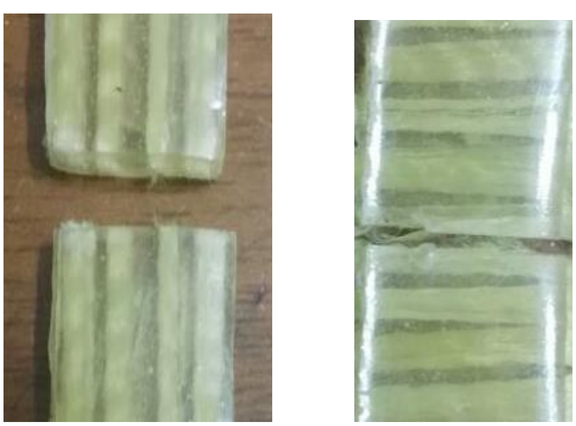


Figure 7 : The fracture direction Vs. fiber direction.

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