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Evaluation of Mode-I Fracture Toughness of Epoxy-Glass Fiber Composite Laminate

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ABSTRACT: The conventional materials fail to meet the requirements of high technology applications like space applications. In order to meet the requirements like high temperature and wear resistances new materials are being searched. The composite materials are the best alternative for those applications.

The applications of composite materials have recently increased because of high strength/stiffness for lower weight, superior fatigue characteristics, facility to change fiber orientations, etc. At the same time, these materials pose new problems such as inter ply cracking, inter laminar de-lamination and fiber cracking. Composite materials failure can be reduced by increasing fracture toughness.

Our aim is to evaluate the fracture toughness of glass fiber/epoxy composites. Composites were prepared with glass fiber reinforced with epoxy based polymer. The fracture toughness of the specimen was employed to conduct mode-I fracture test using special loading fixtures as per ASTM standards of DCB5528 specimen.

KEYWORDS: Glass fiber, epoxy resin, hardener, DCB testing, fracture toughness

I. INTRODUCTION

The role of engineering materials in the development of modern technology need not be emphasized. It is materials through which a designer puts forward his ideas into practice. We use a variety of materials for our needs and comfort and have been developing new materials for meeting our technological requirements. As the levels of technology have become more and more sophisticated, the materials used also have to be correspondingly made more efficient and effective. Several performance characteristics are expected from these materials. They are:

- The materials to be used for sophisticated applications like aircraft and space applications should have higher performance, efficiency and reliability.
- Materials have to be of light-weight for many applications so that the resulting products can be efficient and cost effective.
- Materials must have combinations of properties for specific uses since present day product of modern technological origins operate in environment that are special or
- Extreme like very high temperature (of order of 2500 °K), cryogenic condition, vacuum (as in space), high hydrostatic pressure (as in deep sea) .

The conventional material may not always be capable of meeting the demand of such environments. Hence new materials being created for meeting these performance requirements and composite materials from one class of such materials are developed.

Knowledge of a laminated composite materials resistance to inter laminar fracture is useful for product development and material selection. A recent survey on emerging technologies has given the composite materials one

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of the top ten fields in engineering. The increasing use of composite materials in structural and space applications generated considerable interest for the development of techniques to predict the response under various loading conditions.

The technology has progressed to a stage where never composite materials are being considered, on an experimental basis for numerous applications in various fields. Such as aircraft, satellite launching vehicles, rocket missiles, railways, automobile, energy, construction, infrastructure, medical, biomedical, Marine, sports etc...

The composite Laminates are constructed by stacking several unidirectional layers in specified sequence of orientation. Hence, the failure of a single layer does not give the total failure of the laminate. However, it leads to progressive failure of the laminate. The common modes of failure in the composite materials are crack growth, fiber breakage and delaminating. Hence the study of crack growth behaviors in composite laminate is of special significance.

II. LITERATURE REVIEW

As stated above, researchers are working with the problems of inter ply cracking, de- lamination and fiber cracking. This work is aimed at predicting the extent of crack propagation in a FRP composite laminate subjected to loads. Chamois presented the difference between fiber composites and traditional materials. Any predictive approach for simulating structural fracture in fiber composites needs To formally quantify: all possible fracture modes the types of flaws they initiate, and the coalescing and propagation of these flaws to critical dimensions for imminent fracture. Guo has developed experimental method to find dynamic mode-I de-lamination fracture toughness at high crack-propagation speeds. This method uses load, deflection and crack extension. He also proposed the strain-energy release rate calculation for correlating the crack-propagation. Valaria La Saponaran found de-lamination growth in DCB both experimentally and by numerical analysis. J.R.Reeder found the effect of elevated temperature and loading rate on delamination fracture toughness. Rani F.El-Hajjar did experiments on fracture toughness and crack growth in FRP Pultruded composites. Dan Mihai Constantinescu found fracture toughness and laminar damage of textile composites. Jin Zhang studied the effects on the mode-I fracture toughness and nano creep properties of CFRP.

III. EXPERIMENTAL PROCEDURE TO DETERMINE FRACTURE TOUGHNESS

A. MATERIALS:

i. E-Glass Fiber

Fiber glass has a white color and is available as a dry fiber fabric as shown in Fig.1. It has good strength & electrical resistivity. It is used in circuit boards of computers to provide stiffness and electrical resistance. Because of electrical resistance it is suited for applications where radio-signal transparency is desired in aircraft redoes and antenna. It has a specific gravity 2.54g/cc and a melting point 1555°F(846°C). Refract. Index is 1.547



Fig. 1 Glass fiber

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ii. Epoxy resin: Epoxy polymers are made by reacting epichlorohydrin with bisphenol-A in an alkaline solution which absorbs the HCl released during the condensation polymerisation reaction. Each chain has a molecular weight between 900 and 3000 with an within the polymer chain. The epoxy is cured by adding a hardener in equal amounts and being heated to about 120°C. The hardeners are usually short chain diamines such as ethylene diamine.

Epoxy resins are much more expensive than polyester resins because of the high cost of the precurs or chemicals most noticably epi chloro hydrin. However, the increased complexity of the 'epoxy' polymer chain and the potential for a greater degree of control of the cross linking process gives a much improved matrix in terms of strength and ductility. Most epoxies require the resin and hardener to be mixed in equal proportions and for full strength require heating to complete the curing process. This can be advantageous as the resin can be applied directly to the fibers and curing need only take place only at a time of manufacture. And known as pre-preg or pre impregnated fibre.

iii. Hardener

A substance added to control the degree of hardness of the cured film. It is also a substance or mixture added to plastic composition to promote or control the curing action by taking part in it.



Fig. 2 Epoxy resin and hardener

3.2 Preparation of Specimen: The required mixture of resin & hardener (as shown in Fig.2) were made by mixing them in (10:1) parts in a beaker. When the epoxy resins modified with different contents of particles were prepared through vacuum assisted hand lay-up procedures, they were diffused into unidirectional fibers to form the glass fiber/epoxy composites. The process is that the final mixture epoxy resin with the H-100 curing agent was poured on one dry glass fiber layer and then impregnated into the dry fibers with the assistance of a hand roller until the fiber bundles were permeated completely by the resin. Then, another ply of dry fiber was stacked on it. The repeating process continued until the 12 layers of glass fibers were fabricated (as shown in Fig. 3). Since the interlaminar fracture toughness of composites was measured from the double cantilever beam (DCB) specimens, during the process, a porous film was inserted in the mid-plane of the laminates for the creation of pre-crack. The entire stacking was then sandwiched between two steel plates with porous Teflon fabric on the surfaces and then sealed within a vacuum bag. The whole laminates were cured in a hot press with a suggested temperature profile under vacuum conditions.



Fig. 3a – Tray (on left), 3b - Prepared Glass fiber laminates (on right) Fig. 4 Prepared specimens of Glass Epoxy Laminate after cutting

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The specimens were cut into the required dimensions as per ASTM D5528 standards for fracture toughness test shown in the Fig. 4.

3.4 Test Procedure: Fracture toughness was evaluated from the specimens that were made of ply laminates with a porous film inserted in the mid-plane during the layup process for creating the initial crack. Symmetric loadings applied in opposite directions were transferred into the cracked end of the specimens through a pair of hinges bonded on the specimen surfaces resulting in the mode I crack extension. Prior to the fracture tests, specimens were pulled out such that the precrack can extend around 4 mm penetrating the resin enriched area and reach the “true” crack tip where the fracture toughness begin to be measured. All specimen preparations and experimental procedures were performed based on ASTM standard D5528 (as shown in Fig. 5).

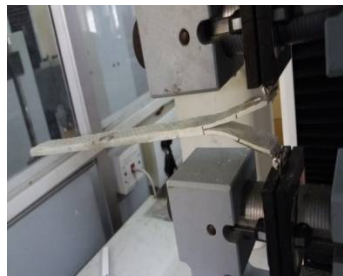


Fig. 5 DCB Testing

IV. RESULTS

Mode I Fracture Toughness test as per ASTM D 5528 standard have been carried out on Fracture toughness testing machine Fig. 5. The Results from the test have been evaluated as per ASTM D 5528 and computed and recorded. The following are the results of the experiment

Table: 1 For specimen ‘C’ with orientation 0° -45° 45° 0°

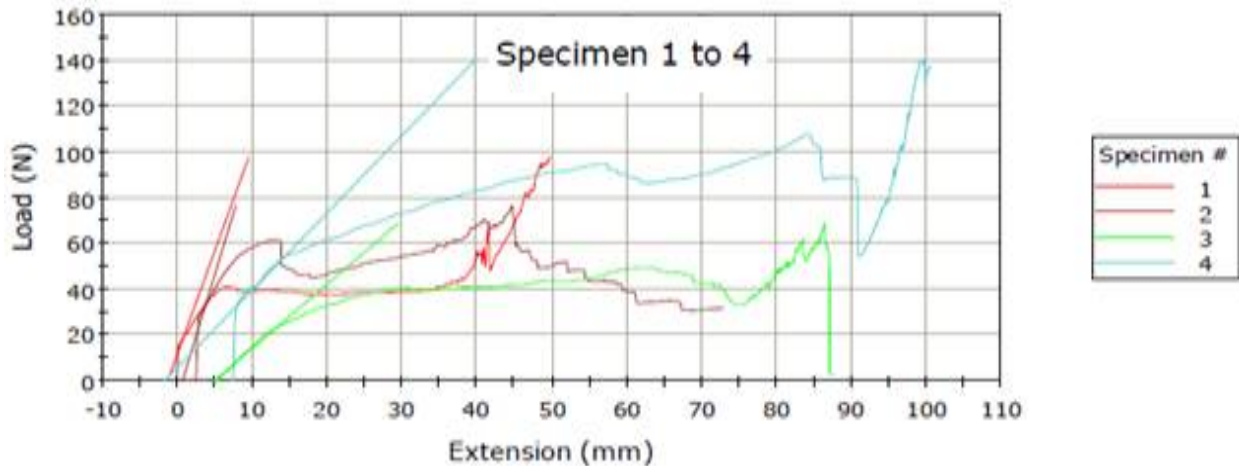
S.N o.	Maximum Load,P (N)	Crack length,a (mm)	Young’s Modulus,E (Mpa)	Tensile stress at Maximum Load,σ (Mpa)	Tensile strain at Maximum load,e (mm/mm)	Fracture toughness, K _{IC} (J/m ²)
1	97.89925	49.724	597.61580	65.26617	0.49724	18.24026
2	76.43932	42.166	718.44433	50.95955	0.42166	13.11495
3	68.94221	81.331	185.57687	45.96148	0.81331	16.42789
4	140.75590	91.733	224.78349	93.83727	0.91733	35.62034
Av g	96.00917	66.239	431.60512	64.00611	0.66239	20.85086

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Graph: 1- Load(N) Vs Extension(mm)

Model Calculations for Table 1:

The formulae used for fracture toughness, $K_{IC} = (EG_{IC})^{1/2}$

Griffith's criterion, $G_{IC} = \sigma^2 \pi a / 2E$

Evaluation of Fracture Toughness for sample using the above values:

$$G_{IC} = \sigma^2 \pi a / 2E = (65.26617^2 * \pi * 49.724) / (2 * 597.61580) = 0.55672$$

$$K_{IC} = (EG_{IC})^{1/2} = (597.61580 * 0.55672)^{1/2} = 18.2402 \text{ J/m}^2$$

Table: 2 For specimen 'D' with orientation 45° -45° 45° -45°

S.N o.	Maximum Load,P (N)	Crack length,a (mm)	Young's Modulus,E (Mpa)	Tensile stress at Maximum Load,σ (Mpa)	Tensile strain at Maximum load,e (mm/mm)	Fracture toughness, K _{IC} (J/m ²)
1	146.77113	44.100	381.98206	97.84742	0.44100	25.75304
2	57.09154	88.233	329.20892	38.06103	0.88233	14.16954
3	82.90364	68.733	219.67567	52.26910	0.68733	18.16038
4	58.48447	29.411	296.07033	38.98965	0.29411	8.38038
Av g	86.31270	57.619	306.73424	57.54180	0.57619	16.61583

Table: 3 For specimen 'E' with orientation 45° 90° 45° 90°

S.N o.	Maximum Load,P (N)	Crack length,a (mm)	Young's Modulus,E (Mpa)	Tensile stress at Maximum Load,σ (Mpa)	Tensile strain at Maximum load,e (mm/mm)	Fracture toughness,K _{IC} (J/m ²)
1	54.94004	20.486	532.61716	36.62669	0.20486	6.57031
2	67.60565	18.428	594.41461	45.07043	0.18428	7.66815
3	68.07683	17.966	650.52032	45.38455	0.17966	7.62418
4	35.71883	43.366	122.67509	23.81256	0.43366	6.21499
Av g	56.58534	25.061	475.05680	37.72356	0.25061	7.01940

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Table: 4 For specimen ‘F’ with orientation 0° 90° 0° 90°

S.No.	Maximum Load,P (N)	Crack length,a (mm)	Young's Modulus,E (Mpa)	Tensile stress at Maximum Load, σ (Mpa)	Tensile strain at Maximum load,e (mm/mm)	Fracture toughness, K_{IC} (J/m ²)
1	63.78637	223.342	448.27454	42.52425	2.23342	25.18731
2	91.34468	24.867	356.70901	60.89645	0.24867	12.03548
3	206.53829	26.933	521.26168	137.69220	0.26933	28.32119
4	155.64854	61.967	1200.64183	103.76569	0.61967	32.37382
Avg	129.32947	84.277	631.72176	86.21965	0.84277	24.47945

V. CONCLUSION

Fracture toughness is more for specimen ‘F’, which indicates that the crack growth is less for this sample (i.e.,) for orientation 0° 90° 0° 90°. That indicates that the above oriented specimen is preferable among all the other oriented specimens. The crack propagation decreases with the increase of fracture toughness. In the fracture test the sample bears maximum stress up to some limit and then it starts decreasing before it gets failed.

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