EVALUATION OF INTERLAMINAR FRACTURE TOUGHNESS OF E-GLASS EPOXY COMPOSITE MATERIAL UNDER MODE 1 LOADING

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ABSTRACT

Delamination is one of the major failure modes seen in the laminated polymeric matrix composite (PMC). Accurate prediction of delamination , initiation and propagation is important for the design and analysis of robust composite structures. This paper examines critical load and corresponding displacement of double cantilever beam (DCB) composite specimens made of glass/epoxy of two different layups. Experiments were conducted on these laminates, and the fracture energy, G_{IC} *, was evaluated at the crack tip. The applied load-displacement history and crack extension to estimate fracture energy is a requirement. Reduction scheme as Modified Beam Theory is used to calculate the Energy Release Rate. based on cubic and power law are also proposed to determine Young's modulus and energy release rate and found good agreement with the published and test results.*

Keywords: *Delamination, Double Cantilever Beam, Fracture Energy Modified Beam Theory, Reduction Scheme .*

1 . INTRODUCTION

Delamination is a failure mechanism in which the laminae separate due to poor inter-laminar fracture toughness and inter-laminar stresses and results in loss in stiffness, loss of strength, and the expected life of material. The critical strain energy release rate is the generally accepted measure of total energy required to initiate a delamination in the material, and is denoted by the symbol G. This value has been found to depend on the mode of delamination which happens in 3 modes-mode1(opening mode),mode 2 (shear),mode3 (tear). Thus there are three G, values: G , G_a, and G_{mc} for mode 1, mode II and mode III respectively. Many aspects of delamination have been studied, including various test methods for different modes, experimental data reduction methods, material effects, environmental effects, and effects of various testing parameters, fiber orientation, stacking sequence, and so on.

The critical strain energy release rate, Gc , can be affected by many factors, including composite structural parameters such as fiber volume fraction and ply orientation, and materials properties of the constituent materials such as tensile strength and elastic modulus of the resin and the fiber

The mode 1 Delamination test has traditionally been treated as the most important form of delamination characterization. The double cantilever beam (DCB) test is the most commonly used mode I delamination test and is the only test of Delamination characterization of composite laminates that has been standardized by the ASTM 5528-94a[1].This test method describes the determination of the opening Mode I interlaminar fracture toughness, G_{IC}, of continuous fiber-reinforced composite materials using the double cantilever beam (DCB) specimen.

D 3039/D 3039M[2] Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials test method is limited to use with composites consisting of unidirectional carbon fiber and glass fiber .This test method determines the in-plane tensile properties of polymer matrix composite materials reinforced by high-modulus fiber .The composite material forms are limited to continuous fiber or discontinuous fiber-reinforced composites in which the laminate is balanced and symmetric with respect to the test direction.

M. Kenane[3] , carried out experiments on unidirectional glass/epoxy laminates regarding the Delamination Growth ,both static growth of cracking and delamination fatigue-crack growth experiments have been carried out on unidirectional glass/epoxy laminates. Three specimen types were tested: double cantilever beam (DCB), mixed-mode bending (MMB) and end loaded split (ELS), for mode I, mixed-mode (I+II), and mode II loading, respectively. They have been expressed in terms of the total fracture resistance, G_{TR} , in static loading, and the measured delamination growth rates, da/dN, versus the total strain energy release rate ΔGI, in fatigue loading. A large number of G_H/G_I mode ratios have been studied. For each modal ratio, several specimens were tested. Experimental results were correlated through the plotting of the total fracture resistance, G_{TR} , versus the G_H/G_I modal ratio, and of the parameters d and B versus the G_H/G_I modal ratio. Good agreement was obtained between theses experimental results and calculations from a semi-empirical relationship.

Mr.ChavanV.B[4]et al, worked on the characterization of Glass Fiber/Epoxy composite material. Different manufacturing processes are used for making Glass Fiber/Epoxy composite . Ultimate tensile strength and flexural strength of the fiber glass polyester composite increased with increase in the fiber glass Volume fraction. The Young’s modulus of elasticity of the composite increased with the fiber glass Volume fraction.

Srikanth Rao et al [5] evaluated the fracture toughness of glass fiber/ Epoxy Composites under Mode 1 loading as per ASTM D5528 Standards. Specimen with different volume fractions of fiber and epoxy were tested and found that the sample with higher fiber composition has higher fracture toughness and stated that the fracture toughness increases with fibre composition. It also indicates that the material is behaving more like a ductile material as the fiber content is increasing, thus crack propagation decreases with the increase of fracture toughness.

V. Alfred Franklin et al[7] examined critical load and corresponding displacement of double cantilever beam (DCB) composite specimens made of glass/epoxy of three different layups. Experiments were conducted on these laminates, and the fracture energy G_{IC}, was evaluated considering the root rotation at the crack tip and found that the value of unidirectional specimen is higher than other two layups because of extensive fiber bridging during crack propagation and concluded that the effect of rotational stiffness on critical load is negligible if too large.

2. Fabrication And Calculation Of Volume Fraction Of E-Glass Epoxy Composite

2.1 Fabrication Of The Composite

Composite Specimen was fabricated according to ASTM D 5528,the Standard Test Method for Mode I Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites.Hand layup process was employed in the preparation of the composite. For Delamination Test, laminates must contain an even number of plies, and shall be unidirectional, with delamination growth occurring in the 0° direction. A non-adhesive insert at the mid plane of the laminate was inserted during layup to form an initiation site for the delamination .

Fig 1 E-Glass epoxy composite

After the preparation of the laminate , it is then cut into the required dimension of 125×25 mm using the mechanical cutting machine. The Double Cantilever beam test is then carried on the universal testing machine for the delamination process.

3 MODE-I (DCB TEST)

DCB Test is done as per the Standard Test Method for Mode I Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites(ASTM D5528).The width and thickness of each specimen to the nearest 0.05 mm (0.002 in.) at the midpoint and at 25mm(1 in.) from either end are measured. The variation in thickness along the length of the specimen shall not exceed 0.1 mm (0.004 in.).The average values of the width and thickness measurements were recorded. Mark both edges of the specimen just ahead of the insert to aid in visual detection of delamination onset.

Mark the first 5 mm (0.2 in.) from the insert on either edge with thin vertical lines every 1 mm (0.04in.). Mark the remaining 20 mm (0.8 in.) with thin vertical lines every 5 mm (0.2 in.).The delamination length is the sum of the distance from the loading line to the end of the insert (measured in the un-deformed state) plus the increment of growth determined from the tick marks. The hinges are properly adhered to the specimen so that the hinges should be strong enough for the experiment to be carried out till the end of the delamination length.


Fig 2 Specimen mounted on UTM

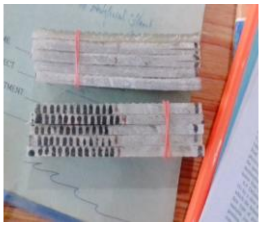


Fig 3 Specimen with markings

The specimen is loaded at a constant cross head displacement of 1mm/min and is marked for every 5mm on the sides for noting down the load values for a continuous constant Delamination length.

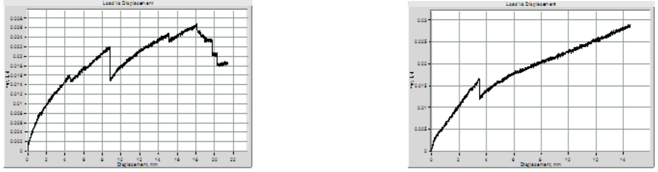
The load and displacement values are noted continuously for every 5mm of Delamination length and also the load v/s displacement graph is also obtained from the UTM. The experiment is carried out till the end of the Delamination length and the other specimen is mounted.

4 RESULTS AND DISCUSSION

For Sample 1 of volume fraction 22:78 with an orientation of 90°and sample 2 of volume fraction 30:70 with an orientation of 0°, the Load v/s displacement values are noted and the inter-laminar fracture toughness is calculated by using the Modified Beam theory (MBT), Compliance Calibration method (CC).

4.1 LOAD VS DISPLACEMENT DATA OF TWO SAMPLES

4.1.1 Sample 1 of fiber: resin volume fraction 22:78 with fiber direction 90^{0}orientation


Specimen 1

Specimen 2

Fig 3 Load v/s displacement Graph of Specimen 1& 2with fiber: resin volume fraction of 22:78

The Figure 3 shows the load v/s displacement data of Specimen 1 with fiber: resinvolume fraction of 22:78. The specimen is mounted on the UTM and the crosshead displacement of 1 mm/min is given and the load v/s displacement history is obtained.

In The Table 1, the load and displacement values with the delamination length are initially noted and the compliance is calculated. By using the data obtained from the experiment the inter-laminar fracture toughness (G_{ic}) is calculated using Modified beam theory method and Compliance calibration method. Energy release rate (G) is also calculated.

Table 1: Interlaminar Fracture toughness of Specimen 1 with fiber: resin volume fraction of 22:78

Delamination length a (mm)	Load Point displacement δ (mm)	Load P (KN)	Compliance C (mm/KN)	Inter laminar Fracture toughness, G_{ic} (KJ/m^2)		Young's modulus E_{if} (N/m^2)	Energy release rate ERR (J/m^2)
				MBT	CC		
45	4	0.0150	266.1344	0.04595	0.076719	64.30916	1.535683
63	10	0.0186	537.6344	0.132593	0.208292	39.23318	5.005923
68	15	0.0176	852.2727	0.180117	0.273329	28.23191	7.28713
72	18	0.0249	722.8916	0.284418	0.409900	41.36568	12.75794
76	20	0.0268	744.3245	0.324808	0.453672	46.49645	15.51179
80	25	0.0205	1214.772	0.291559	0.392112	34.56605	15.01847
86	30	0.0201	1490.313	0.324843	0.424842	32.94309	17.69425
92	35	0.0181	1933.702	0.319157	0.404208	30.90338	18.53821
98	40	0.0176	2272.727	0.343775	0.429222	28.87458	20.54539

In The Table .2, the load and displacement values with the delamination length are initially noted and the compliance is calculated. By using the data obtained from the experiment the inter-laminar fracture toughness (G_{ic}) is calculated using Modified beam theory method and Compliance calibration method. Energy release rate (G) is also calculated

Table 2: Interlaminar Fracture toughness of Specimen 2 with fiber: resin volume fraction of 22:78

Delamination Length a (mm)	Load point Displacement δ (mm)	Load P (KN)	Compliance C (mm/KN)	Inter laminar fracture toughness, G_{ic} (KJ/m^2)		Young's modulus E_{if} (N/m^2)	Energy release rate ERR (J/m^2)
				MBT	CC		
45	4	0.0139	287.7698	0.042495	0.0677984	53.90749	1.716031
65	10	0.0191	523.5602	0.136158	0.1977494	39.37306	6.153738
69	15	0.0227	660.793	0.232309	0.3114036	39.20146	11.18849
72	18	0.0296	608.1081	0.338103	0.4299451	54.22741	17.66453
76	20	0.0241	829.8755	0.291324	0.3725173	43.29339	15.99002
80	25	0.02277	1097.936	0.322585	0.4221133	35.56787	18.87345
86	30	0.0252	1190.476	0.406659	0.5251126	37.50581	24.98483
92	35	0.0255	1372.549	0.449641	0.5694656	38.87021	29.25365
98	40	0.0176	2272.727	0.343775	0.4292278	28.87458	20.54539

4.1.2 Sample 2 of Fiber: resin volume fraction 22:78 with fiber direction 0^0 orientation

Specimen 1 **Specimen 2**

Fig 4 Load v/s displacement Graph of Specimen 1& 2with fiber: resin volume fraction of 30:70

Figure 4 shows the load v/s displacement data of Specimen of sample 2 with fiber: resin volume fraction of 30:70 for the specimen mounted on the UTM for the crosshead displacement of 1 mm/min

Table 3: Interlaminar Fracture toughness of Specimen 2 with fiber: resin volume fraction of 30:70

Delamination length, a (mm)	Load point Displacement δ(mm)	Load P (KN)	Compliance C(mm/KN)	Inter laminar fracture toughness, G_{ic} (KJ/m^2) MBT	CC	Young's Modulus E_{if} (N/m^2)	Energy release rate ERR (J/m^2)
45	4	0.02	200	0.05432	0.09906	122.019	1.56955
60	10	0.03	333.3333	0.17557	0.31409	114.351	6.69920
68	15	0.036	416.6667	0.29435	0.51820	113.223	12.5142
72	18	0.035	508.4746	0.33582	0.56528	102.660	14.9619
76	20	0.034	588.2353	0.34687	0.55713	97.8663	16.1313
80	25	0.03	833.3333	0.37068	0.54056	75.9511	17.9311
86	30	0.032	937.5	0.4533	0.73680	77.4095	23.1324
92	35	0.034	1029.412	0.53794	1.00631	80.3521	28.7909

Table 4 : Interlaminar Fracture toughness of Specimen 2 with fiber: resin volume fraction of 30:70

Delamination length 'a' (mm)	Load Point Displacement δ (mm)	Load P (KN)	Compliance C (mm/KN)	Inter laminar fracture toughness, G_{ic} (KJ/m^2) MBT	CC	Young's Modulus E_{if} (N/m^2)	Energy release rate ERR (J/m^2)
45	3	0.0236	127.1186	0.048077	0.109053	189.8923	1.389057
58	6	0.0322	186.3354	0.115194	0.245083	191.6216	4.262661
63	10.85	0.0393	276.0814	0.24285	0.456593	148.4603	9.673866
68	18	0.0369	487.8049	0.362059	0.576478	95.86835	15.39254
76	20	0.037	534.7594	0.38156	0.56287	106.7741	17.7445
80	25	0.025	992.0635	0.31131	0.31414	63.29431	15.0621
86	30	0.022	1310.044	0.32440	0.34097	54.97745	16.5541

The table 3 and 4 shows the load and displacement values with the delamination length are initially noted and the compliance is calculated. By using the data obtained from the experiment, the inter-laminar fracture toughness (G_{ic}) is calculated using Modified beam theory method and Compliance calibration method. Energy release rate (G) is also calculated.

4.2 DELAMINATION RESISTANCE CURVE

The propagation of the crack along the Delamination length with the interlaminar fracture toughness is shown in the figures below.

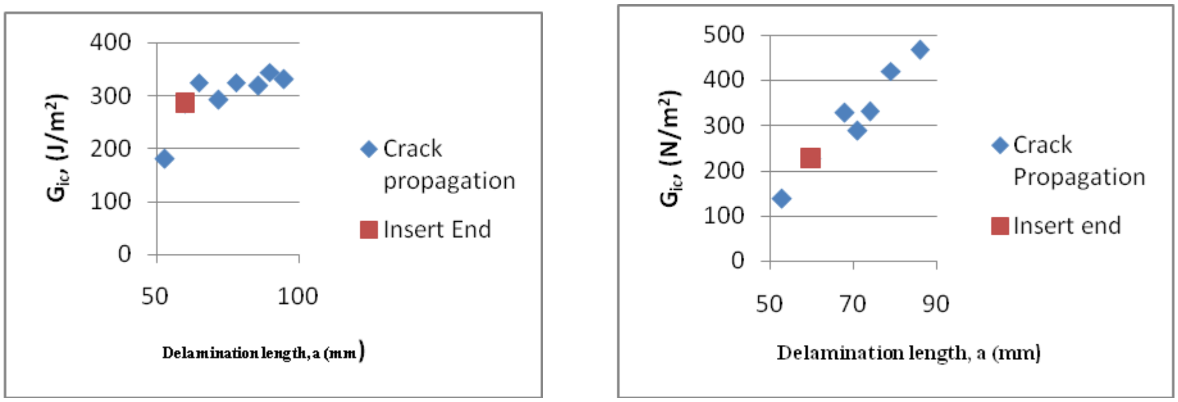


Fig5 Delamination Resistance curve of Specimen 1 with fiber:resin volume fraction of 22:78

Fig 5 show the propagation of the crack along the delamination length after the insert end in the Specimen 1 and 2 with fiber: resin volume fraction of 22:78.

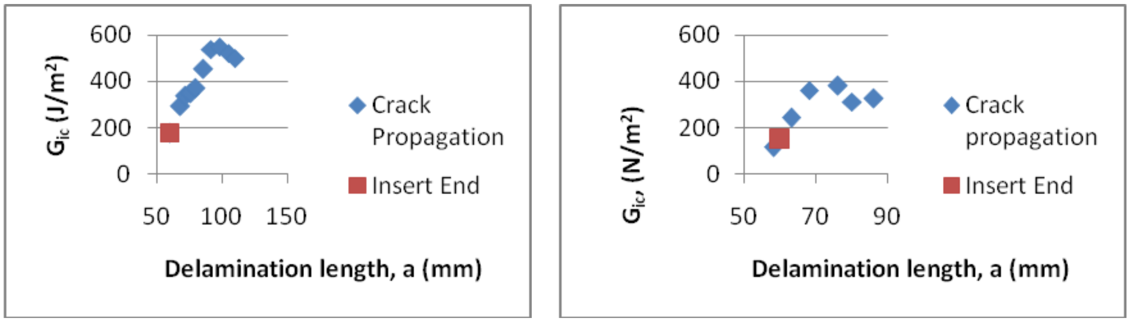


Fig 6 Delamination Resistance curve of Specimen 1 with fiber:resin volume fraction of 30:70

Fig 6 shows the propagation of the crack along the delamination length after the insert end in the Specimen 1 with fiber: resin volume fraction of 30:70.

5 FINITE ELEMENT ANALYSIS

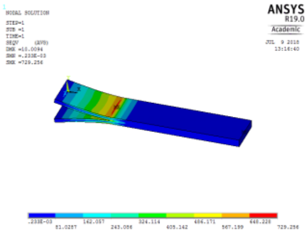


Fig 7 VCCT Simulation for specimen 1 of Fiber orientation 0^0

Fig 7 shows the Finite element analysis of the Sample 1 with fiber: resin volume fraction of 30:70 and the fiber orientation of 0^0 is done in the ANSYS by using the Virtual crack closure technique and the Energy release rate is 4.5386 $(\frac{J}{m^2})$.

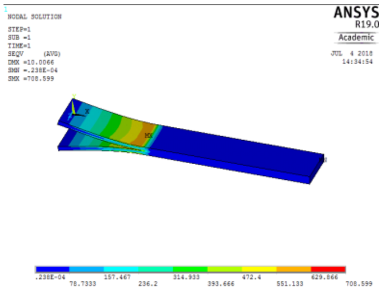


Fig. 8 VCCT Simulation for Specimen 2 of Fiber orientation 90^0

Figure 8 shows the Finite element analysis of the Sample 2 with the fiber: resin volume fraction of 22:78 and the fiber orientation of 90^0 is done in the ANSYS by using the Virtual crack closure technique and the Energy release rate is 1.5950 $(\frac{J}{m^2})$.

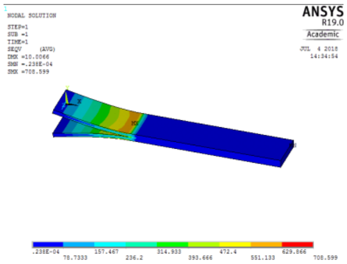


Fig 9 VCCT Simulation for Specimen 2 of Fiber orientation 90^0

From the Figure 9, Finite element analysis of the Sample 2 with the fiber: resin volume fraction of 22:78 and the fiber orientation of 90^0 is done in the ANSYS by using the Virtual crack closure technique and the Energy release rate is 1.5950 $(\frac{J}{m^2})$.

6 COMPARISION OF EXPERIMENTAL AND SIMULATION ENERGY RELEASE RATE

The Energy Release rate calculated from the experiment and the finite element analysis are compared in the table 5, and also it is observed that the energy release rate is more for the volume fraction in which the fiber content is more.

Table 5 Comparison of Experimental and simulation energy release rate

Fibre orientation	Energy release rate $(\frac{J}{m^2})$		% Variation
	Experiment	ANSYS	
0^0	6.5973	4.5386	30
90^0	3.8590	1.5950	40

7 CONCLUSIONS

The following conclusions are drawn from the present work

- The Interlaminar fracture toughness calculated by using the Modified beam theory Method,
  - For fiber: resin volume fraction of 22:78 is 0.2523 $(\frac{KJ}{m^2})$,
  - For fiber: resin volume fraction of 30:70 is 0.273 $(\frac{KJ}{m^2})$.
- The Interlaminar fracture toughness by Compliance calibration method ,

  - For fiber: resin volume fraction of 22:78 is 0.33 $(\frac{KJ}{m^2})$,
  - For fiber: resin volume fraction of 30:70 is 0.37 $(\frac{KJ}{m^2})$.

It was found that the Inter laminar fracture toughness is more for the Sample with more fiber volume content.

- The Energy release rate calculated from the experimental technique,
  - For fiber: resin volume fraction of 22:78 is 3.8590 $(\frac{J}{m^2})$,
  - For fiber: resin volume fraction of 30:70 is 6.5973 $(\frac{J}{m^2})$.
- The Energy release rate calculated by using the Virtual crack closure technique (VCCT) from the finite element analysis,
  - For fiber: resin volume fraction of 22:78 is 1.5950 $(\frac{J}{m^2})$,
  - For fiber: resin volume fraction of 30:70 is 4.5386 $(\frac{J}{m^2})$.

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