Fracture Behavior of Reinforced Composite with Epoxy Laminates using DCB Method

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***Abstract* - Fiber reinforced composites are less weight but withstand good strength which can be used in Aerospace, Aircraft, Marine & Defense application. Delamination of the laminates composites are one of the vital form of failure in laminated composites due to the lack of reinforcement in the thickness direction. Thus delamination behavior of studies is much importance before designing a composite material. This work concentrates on Mode I fracture which is the dominating of the three types. To study the Mode I failure, Double Cantilever Beam (DCB) test has been conducted in UTM machine for glass fiber reinforced. Composite laminates. Epoxy is used as the matrix. These laminates are manufactured by hand layup technique as per ASTM standard D 5528-01.By using the Modified Beam Theory (MBT) method, the strain energy release rates (GIc) for the above laminates are calculated. In this work, the strain energy release rate was calculated for two different densities like 600 GMCC and 220 GMCC. Finite Element Analysis (FEA) of DCB test has been done using Ansys by including the cohesive zone model in the interface of crack propagation. The fracture toughness obtained by FEA. Nodal displacement obtained from FEA is used to calculate the GIc and compared with the experimental results. It is observed that the result of FEA closely matches with experimental results.**
Keywords: Delamination, Opening mode I test, DCB, GIc

I. INTRODUCTION

A. Composites:

Composites are materials in which two or more different materials called as reinforcement and matrix is combined together. It is defined as the sum of matrix and reinforcement. Matrix can be a thermoplastic or thermoset property and includes vinylester, epoxy, and polyester, etc. Reinforcement is the fiber like glass, aramid, carbon and graphite. The composite materials are used in wide spread application in defense industries, automobile industries, aerospace and marine. The composite structures are in the form of layers or laminates. In these laminates one of the most common failures is delamination. The evaluation and propagation of inter laminar damage leads to laminate separation. A quite typical structural failure mode is called as delamination.

B. Glass Fibres:

Glass fibers are the most of all reinforcing fibers for polymeric matrix composites (PMC). The pros of glass fibers are high tensile strength, low cost, high chemical resistance, and excellent insulating properties. The cons of glass fibers are relatively low tensile modulus and high density, sensitivity to abrasion during handling, relatively low fatigue resistance, and high hardness. The two types of glass fibers commonly used in the fiber-reinforced plastics (FRP) industry.They are are E-glass and S-glass.

C. Epoxy Matrix:

The epoxy matrix are low-molecular weight organic liquid resins. It contains a number of epoxide groups, which are three member rings of one oxygen atom and two carbon atoms. The liquid epoxy material is diglycidyl ether of bisphenol A (DGEBA). The polymerization (curing) reaction to transform the liquid resin to the solid state. It is initiated by adding small amounts of a reactive curing agent just before incorporating fibers into the liquid mix. Here we used diethylene triamine (DETA), as a curing agent.

II.SCOPE

The DCB method describes the delamination behaviour of interlaminar fracture toughness, By using double cantilever beam (DCB) test, strain energy released rate of composite laminates are calculated.

III. FAILURE MODES OF COMPOSITE

A Fiber breakage
B Matrix deformation and cracking
C Fiber de-bonding
D Delamination crack

A. Principles of Fracture Mechanics:

Materials are generrally assumed to fracture in one of the three modes, they are

1. Mode 1- (opening mode)
2. Mode 2-(shearing mode)
3. Mode 3-(tearing mode)

The fracture mechanics approach is used in composite materials for crack propagation analysis. Double cantilever beam (DCB) test is used for determining the interlaminar fracture toughness, measured in terms of the critical strain energy release rate. It is defined as the amount of strain energy released in propagating delamination by a unit length. Delamination may occur in mode-1 (opening mode or tensile mode of crack propagation).

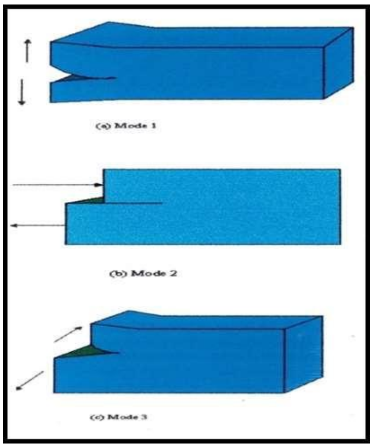

Fig. 3.1: Fundamental Modes of Failure

IV. EXPERIMENTAL WORK

A. Requirement of Composite Laminate Preparation

For preparing the composite laminate,

1) Fiber Reinforcement material (say glass fiber of 220 gmcc and 600 gmcc)
2) Matrix (Epoxy LY 556 and Hardener)
3) OHB sheet
4) Wax
5) Acetone
6) Roller
7) Gloves

B. Preparation of Laminates by Hand Lay Up Technique:

1) Initially, the fiber mats are cut into 200 x 200 mm size.
2) Epoxy LY556 and Hardener mixed in the ratio of 1:10.
3) Three OHB sheets be placed in the floor and the wax is applied in the sheets.
4) Apply the mixed matrix on the OHB sheets.
5) Then, the fibre mat kept as a first layer and roller be rolled properly on the mat.
6) Again mixed matrix appied on the first layer of fiber and rolled properly.
7) Then second layer of fiber mats kept above the first layer and mixed matrix applied again and rolled properly.
8) Similarly the consecutive layer can be formed up to required thickness.
9) For 220 gmcc, need 16 layers and for 600 gmcc, need 8 layers to get required thickness.
10) The 50mm initial crack is formed by keep the OHB sheet in exact mid plane of the layers.
11) Then allow the laminates for curing in atmospheric condition for two days.

In this work, we prepared 220 gmcc and 600gmcc bi-directional laminates

C. Specimen Preparation:

The specimen is prepared as per ASTM dimension D 5528-01 in which specimens is nearly 125 mm (5.0 in.) long and nominally from 20 to 25 mm (0.8 to 1.0 in.) wide, The laminate thickness shall normally be between 3 and 5 mm (0.12 and 0.2 in.), The distance corresponds to an initial delamination length of approximately 50 mm (2.0 in.) plus the extra length required to bond the hinges or load blocks. The end of the insert should be accurately located and marked on the panel before cutting specimens. The initial delamination length, measured from the load line to the end of the panel insert. Hinged metal tabs are bonded at thedelaminated end of the specimen.

D. Specification of Laminates:

1.*Specimen Details of 220 GMCC Bi-Directional Laminates:*

- No of layers 16.
- Specimen is approximately 125mm long, 25mm wide and 3 to 5 mm thickness.
- Initial crack length is 50mm.

2. *Specimen Details of 600 GMCC Bi-Directional Laminates:*

(1)No of layers 8

(2)Specimen is approximately 125mm long, 25mm wide and 3 to 5 mm thickness. Initial crack length is 50mm


Fig. 4.4.2.1: Laminated Specimen with Supports

V. Test Method

The delamination test is carried in Universal tensile machine in CIPET, Chennai. In double cantilever beam subjected to the specimen by two tensile opposite forces. The UTM machine is making of Lloyd Instruments. The UTM is controlled by Nexygen software. The movement of ram speed is 50mm/min. By using nexygen software, just take the load and displacement values in the corresponding crack length. The values for 600gmcc is tabulated below.

VI. Calculation

Modified Beam Theory (MBT) Method is used for calculating GIc. The strain energy release rate GIc for various tested specimen was calculated by plotting the curve between load and crack opening displacement. The locations of instantaneous front are marked for different intervals of delamination growth. The Mode I critical strain energy release rate was calculated using (MBT) method as given in equation (1)

$$GI_C = 3P\delta/2b\,(a + \Delta)$$

Where:
P = Load
δ = Load point displacement
b = Specimen width [b = 25mm]
a = Delamination length. [a = 50mm initial crack]
Δ =Effective delamination extension, Δ = [δ/P]1/3

E. Experimental Results:

DCB test was conducted for 600gmcc and 220 gmcc in UTM machine. The strain energy release rate GIc can be calculated by using modified beam theory method. The applied tensile load and the load point deflection of Bi-directional laminate with increasing crack length at 5 mm interval are shown in Table. Load and load point deflection are obtained from the UTM machine while conducting the test. The experimental results show that the load required for each 5 mm crack extension is reducing.

VII.FINITE ELEMENT ANALYSIS

Finite element analysis of delamination test has been conduct by using cohesive zone model. The FEA model is developed as per

Table - 6.1.

600 GMCC - Crack length (mm)		55	60	65	70
SAMPLE 1	Load (N)	18.52	10.64	4.83	3.38
	Load point deflection (mm)	8.91	12.87	16.39	20.6
	GIc(kJ/m^2)	194.7	160.7	92.1	80.6
SAMPLE 2	Load (N)	18.75	10.53	4.78	3.58
	Load point deflection (mm)	8.98	13.23	17.11	23.1
	GIc(kJ/m^2)	198.72	163.4	95.12	95.8

1600 GMCC- Bi-Directional Laminates

220 GMCC - Crack length (mm)		55	60	65	70
SAMPLE 1	Load (N)	15.1	10.8	3.11	2.25
	Load point deflection (mm)	8.12	10.75	14.25	18.94
	GIc(kJ/m^2)	137.0	137.1	51.5	49.16
SAMPLE 2	Load (N)	15.25	11.21	3.45	2.36
	Load point deflection (mm)	8.15	10.9	14.37	19.25
	GIc(kJ/m^2)	145.82	143.2	57.64	52.41

Table - 6.1.2
600 GMCC- Bi-directional laminates

ASTM standard D 5528-01. Material properties are defined for glass fiber and the model is meshed. Displacement load is applied on one end and another end is arrested.

1) Structural analysis
2) Geometric dimensions
   1) Length = 125 mm
   2) Width = 25 mm
   3) Thickness = 4.8 mm,4.5 mm & 3.6 mm
   4) Crack length = 50 mm
3) Material properties
   1) Element type: solid 182, Inter 202
   2) Young's modulus: EX=37.9E5, EY=14.3E3, EZ=14.3E3, GXY=5.6E3 GYZ=5.6E3, GXZ=5.24E3
   3) Poison ratio PRXY=0.29, PRXZ=0.29, PRYZ=0.36.
4) Meshing
5) Boundary conditions
6) Delamination results

The analysis of delamination of composite fiber is to be in under process

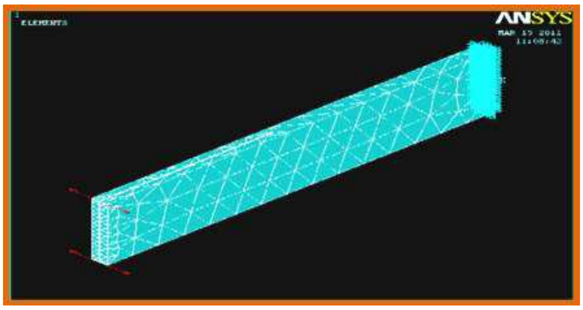

Fig. 7.1: Boundary Conditions and Load Applied (600 GMCC)

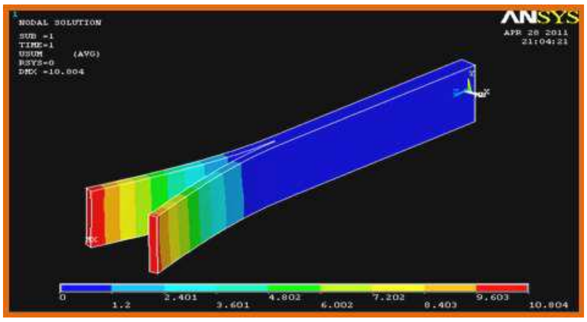

Fig. 7.2: Delamination Face Displacement (F55 = 18.63n)

VIII. CONCLUSION

In this work, the mechanical properties of composite materials and the opening mode fracture toughness of glass fiber composite laminates are studied. Two different Laminates of 220 and 600 GMCC were manufactured by hand lay-up technique. 50 mm initial crack also developed in the two specimens. Specimens were prepared as per ASTM standard D 5528-01. I observed that, the Delamination studies on FRP laminates will carry in the DCB test. Lloyd Instruments UTM machine is used for the DCB test for calculating the delamination growth. Modified Beam Theory technique is used for Strain energy release rate (*G*Ic) calculation. The strain energy release rates for both the specimen using modified beam theory method are calculated. In Ansys, cohesive zone model is used to calculate the value of strain energy. This work is in under process. Finally compare the experimental results and also analysis results to find the maximum stress behavior between two laminates

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