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Interlaminar Fracture of Aerospace Composites Materials

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Abstract- A fiber-polymer composite's resistance to delamination is one of its most crucial mechanical characteristics. Even partial delaminations will result in a loss of stiffness, which can be a crucial design factor. The presence of delaminations may also result in complete fracture. A fracture mechanics approach has been the obvious method for characterizing this phenomenon because delamination can be thought of as the progression of a crack. The use of fracture mechanics to determine interlaminar fracture energies, or G_C, for various fiber polymer composites using different test geometries to produce mode I, mode II, and mixed mode I/II values of G_C is therefore extensively documented in the literature. However, issues with consistency and debates over the accuracy of such results are common.

Keywords- Interlaminar fracture, Composites, Aerospace structures.

I. INTRODUCTION

Laminates made of fiber-reinforced plastics, such as carbon fiber reinforced polymer, are loaded; the resin matrices in between the plies frequently fail, leading to ply separation or delamination failure. As a result, analysis and experiment evaluation using the fracture mechanics approach have been carried out in order to comprehend the initiation and the propagation behaviour of delamination.

II. FRACTURE

Separation of a body into two or more pieces as a result of a static force applied at a temperature lower than the material's melting point is known as fracture.

- Fracture involves the start and spread of cracks.
- The degree of deformation that occurs prior to fracture is described by a material's ductility.
- The material can fail by necking down to a minute cross-section, or the surface can be totally perpendicular to the force applied, or by shear.

1. Modes of fracture:

There are three modes of fracture, Mode I, Mode II and Mode III

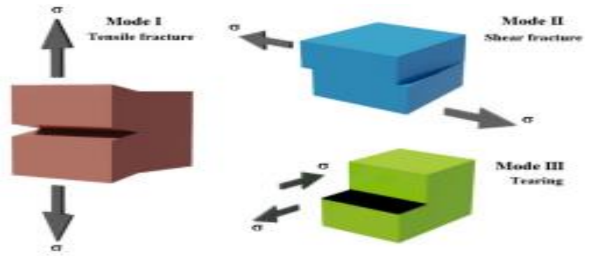

Fig 1. Mode of fractures. [2]

- Mode I - fracture plane is perpendicular to the normal force.
- Mode II - fracture occurs under the ac on of shear stress and propagates in the direc on of shear. Mode III - fracture occurs by shear mode, but it propagates in a direc on perpendicular to the direc on of shear.

Fracture toughness is given by,.

$$K_c = f\sigma\sqrt{(\pi a)} \quad 1.1$$

The plane strain fracture toughness (independent of thickness), is given by.

$$K_{Ic} = f\sigma\sqrt{(\pi a)} \quad 1.2$$

If f is equal to 1,

$$K_I = f\sigma\sqrt{(\pi a)} = \sqrt{EGc} \quad 1.3$$

Fracture Mechanics quantifies the relationship between material properties, stress level, crack length and crack propagating mechanisms.

Theoretical Fracture Strength, ≈ $^{\$}{}_{\%}$ where E is the modulus of elasticity which is vastly different from the experimentally observed ones. The presence of minute cracks or cavities in the material explains this disparity. The faults may reduce the fracture strength of the material because the crack points act as stress concentrators/raisers. If the crack is assumed to be an oval hole oriented perpendicular to the direction of load application, the maximum stress, , at the crack tip can be approximated.

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$$\sigma_m = 2\sigma_0 \sqrt{\frac{a}{\rho_t}} \quad 1.4$$

Where $_0$ is the magnitude of stress applied, * is the radius of curvature of crack tip and is half crack length of internal crack or crack length of surface crack. The stress concentration factor,

$$K_t = \frac{\sigma_m}{\sigma_0} = 2\sqrt{\frac{a}{\rho_t}} \quad 1.5$$

The double cantilever beam (DCB) is often used for measuring fracture toughness of materials. Consider the geometry shown in Figure 1.2 where b is the width of the beam, and the crack length a is much larger than h and, thus, the simple beam theory is suitable for modelling the deflection of the two split beams.

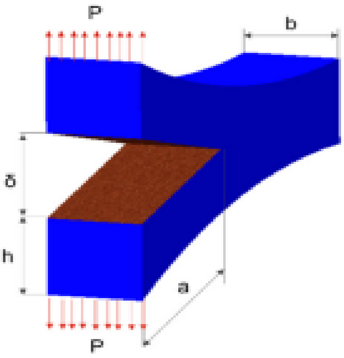

Fig 2. A double cantilever beam subjected to concentrated forces.

Noting that the unsplit portion of the DCB is not subjected to any load and that in each leg the bending moment is M = Px, we calculate the total strain energy stored in the two legs of the DCB as

$$U_T = 2\int_0^a \frac{P^2x^2}{2EI}dx = \frac{P^2a^3}{3EI} \quad 1.11$$

Where.

$$I = \frac{bh^3}{12}$$

The total strain energy per unit width is.

$$U = \frac{U_T}{b}$$

The strain energy release rate is obtained as

$$G = \frac{dU}{da} = \frac{P^2a^2}{bEI} \quad 1.12$$

If the fracture toughness Gc of the material is known, then the load that could further split the beam is,

$$P_{cr} = \frac{\sqrt{bEIG_c}}{a} \quad 1.13$$

III. ANALYSIS

Symmetric model of 0/90/45/-45/90/0 composite ply DCB material is used to analyse Mode 1 fracture evaluation with respect to effect of load on stress, shear and strain energy.

IV. MATERIALS

Table 1. Material properties. [19]

Material	Density	Youngs modulus- E- "Pa"			Poisson's Ratio "ν"			Shear Modulus -G-"Pa"		
		X	Y	Z	XY	YZ	XZ	XY	YZ	XZ
Carbon fiber -230	1800	$2.3e^{11}$	$2.3e^{10}$	$2.3e^{10}$	0.2	0.4	0.2	$9e^{10}$	$8.21e^{9}$	$9e^{10}$
Epoxy Carbon fiber -230	1490	$1.21e^{11}$	$8.6e^{9}$	$8.6e^{9}$	0.27	0.4	0.27	$4.7e^{10}$	$3.1e^{9}$	$4.7e^{10}$

V. RESULTS

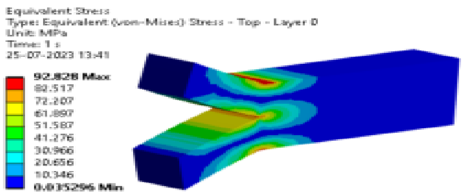

Fig 3. Max vonMises Stress "MPa".

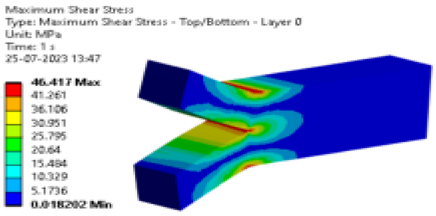

Fig 4. Max Shear Stress "MPa".

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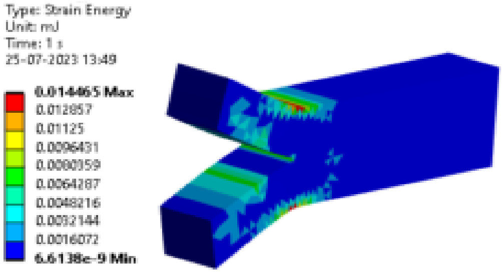

Fig 5. Strain Energy “mJ”.

Table 2. vonMises stress.

Stress "MPa"		
Load	Carbon fiber 230	Epoxy Carbon fiber 230
10	9.28	9.51
20	18.57	19.03
40	37.13	38.06
60	55.69	57.08
80	74.26	76.11
100	92.82	95.14

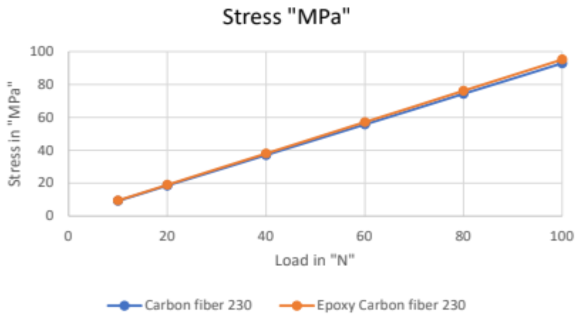

Fig 6. Graph 1.1 Load v/s vonMises stress.

Table 3. Shear Stress.

Shear Stress “MPa”		
Load	Carbon fiber 230	Epoxy Carbon fiber 230
10	4.65	4.76
20	9.28	9.54
40	18.56	19.07
60	27.85	28.61
80	37.13	38.15
100	46.41	47.68

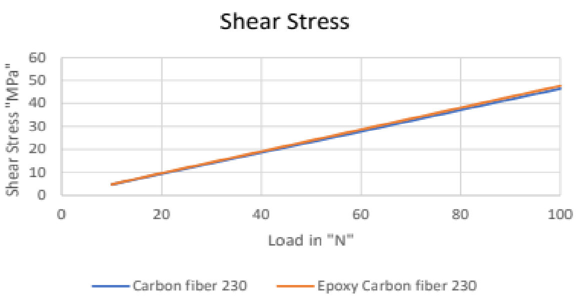

Fig 7. Graph 1.2 Load v/s Shear stress.
Table 4. Strain Energy.

Shear Stress “MPa”		
Load	Carbon fiber 230	Epoxy Carbon fiber 230
10	4.65	4.76
20	9.28	9.54
40	18.56	19.07
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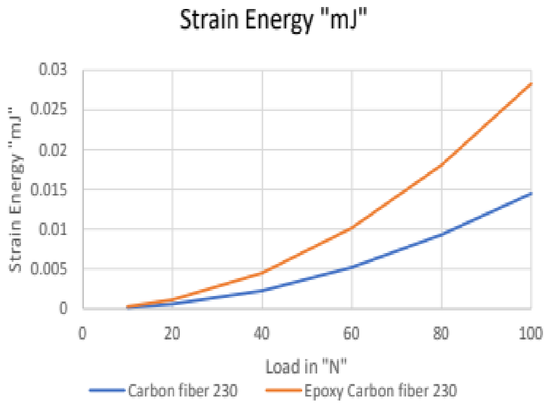

Fig 8. Graph 1.3 Load v/s Strain energy.

VI. CONCLUSION

Stress is behaving linear with respect to Carbon fiber and Epoxy carbon fiber. Shear stress is behaving linear with respect to Carbon fiber and Epoxy carbon fiber. Strain energy is exponential with respect to Carbon fiber and Epoxy carbon fiber. Material exhibits ductile state by using of composition of materials. Increased strain energy makes carbon epoxy fiber more resilient. The crack propagation decreases with the increase of strain.

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