Innovations

Experimental Investigation of Fracture Toughness on Carbon/ S-glass Fiber Reinforced Thermoset Composites by Compact Tension Test Method

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Abstract

The characterization of the fracture toughness of fiber-reinforced hybrid polymer composites is essential to understand their mechanical properties and to predict their fracture. It is used to evaluate a material's ability to resist crack growth and propagation under applied stress. It helps to understand the behavior of polymers and the influence of hybridization on crack energy, crack propagation and failure mechanisms. These studies will provide valuable insight into the crack propagation properties of fiber reinforced hybrid polymer composites and the damaging factors that can affect them. This is a great opportunity to further research and contribute to this field of study. This test was developed to study crack propagation and its factors in composites by performing fracture toughness experiment on composite samples by performing a compact tensile test on carbon and glass fiber reinforced epoxy polymer composites with fibers arranged longitudinally, transversely and under inclined conditions. The critical fiber and matrix energy release rates for tensile cracking were determined on pre-cracked specimens under plate loading conditions. After longitudinal stretching, damage progressed progressively in the form of translaminar fiber breakage in filament-containing materials. During the transverse stretching process, fiber-matrix separation caused deformation of the materials within the layers, and irregular fiber breakage was observed during the angular stretching process. The highest critical fracture energy release rate was found in the hybrid polymer matrix composite, with the maximum value in the longitudinal tensile state.

Key words: *Crack Propagation, Fracture, Hybrid, Fibers, Polymer.*

Introduction

The significance composite is an important tool used in today's engineering applications. It is a mathematical measure used to evaluate the relative importance of different components of a system. It is used to identify and quantify the contribution of each component to the overall system performance. The composite is often used in the design process of engineering applications. It is used to identify the most important components of the system and to prioritize research and development efforts. It can also be used to assess the impact of different design parameters on the overall system performance [1].

The composite is calculated by multiplying the importance of each component by its contribution to the overall system performance. This allows engineers to identify which components are the most critical to the system and to focus their efforts on improving those components. In addition to identifying the most important components of the system, the significance composite can be used to evaluate the impact of changes in design parameters on the overall system performance. This helps engineers optimize the design of the system to achieve the desired performance. It can be used to identify the most important components of the system, prioritize research and development efforts, and evaluate the impact of design changes on the overall system performance [2].

Composite systems lack the strength and toughness that metallic systems possess, making them more prone to cracking and failure. Additionally, composite systems are more likely to experience premature fatigue due to their lack of ductility, which can lead to catastrophic failure. Furthermore, composite systems are not as thermally or electrically conductive as metallic systems, making them less efficient at dissipating heat and electricity. Lastly, composite systems are more susceptible to environmental degradation, such as exposure to humidity and extreme temperatures, which can lead to material degradation and failure [3].
The fracture toughness of a composite material is determined by the combination of its constituent material properties, such as their strength, modulus, and fracture toughness, as well as its microstructure, including fiber content, fiber orientation, fiber length, and fiber-matrix interface. Generally, the fracture toughness of a composite material increases with increasing fiber content, fiber length, and fiber orientation, as well as improved fiber-matrix interfacial adhesion. Additionally, composite materials with higher matrix strength, modulus, and fracture toughness tend to have higher fracture toughness values [4].

Fracture toughness is an important property of hybrid composite materials and is used to measure the material's ability to resist fracture under an applied load. It is an important indicator of the material's mechanical strength and durability. Fracture toughness measurements can be used to determine the energy required to initiate and propagate a crack in the material, and the amount of energy needed to cause the crack to propagate through the material. The fracture toughness of hybrid composite materials can be determined using a variety of techniques, such as the Linear Elastic Fracture Mechanics (LEFM) approach, the Double Cantilever Beam (DCB) method, and the Single Edge Notched Tensile (SENT) test. These tests measure the critical stress intensity factor (K_{IC}) of the material, which is a measure of the material's fracture toughness. By measuring the K_{IC} of the hybrid composite material, engineers can determine the material's fracture toughness and decide if it is suitable for the application [5].

It covers the different methods and techniques used to measure the fracture toughness, as well as the advantages and limitations of each. [6,7].

1. Single-Edge Notched Tensile Test (SENT): This test measures fracture toughness by applying a sharp notched specimen to a tensile machine. It is used to determine the stress intensity factor (K_{IC}) of a material.

2. Double Cantilever Beam Test (DCB): This test applies a load to two cantilever beams and measures the fracture toughness of the material by measuring the displacement of the beam.

3. End-Notched Flexure Test (ENF): This test applies an end-notched specimen to a three-point bending machine and measures the fracture toughness of the material by measuring the displacement of the specimen.

4. Compact Tension Test (CT): This test measures fracture toughness by applying a load to a compact specimen with a notch. It is used to determine the stress intensity factor (K_{IC}) of a material.

5. Compact Specimen Test (CST): This test applies a load to a compact specimen and measures the fracture toughness of the material by measuring the displacement of the specimen.

6. Single-Edge Pre-cracked Tensile Test (SEPCT): This test measures fracture toughness by applying a pre-cracked specimen to a tensile.

The fracture behaviour of composite materials is affected by a variety of factors. These include the type and properties of the matrix and reinforcing materials, the type and geometry of the composite, the loading conditions, environmental conditions, and the manufacturing process. The matrix material of a composite has a significant effect on its fracture behaviour. This is because the matrix material serves as the main load-bearing component and has the largest influence on the stiffness, strength, and fracture toughness of the composite. The matrix material must be chosen so that it has the appropriate combination of strength and toughness for the application. The reinforcing material of a composite also has a significant impact on its fracture behaviour. The reinforcing material must be chosen so that it has the appropriate combination of stiffness, strength, and fracture toughness for the application. The reinforcing material also affects the fracture toughness of the composite, as it helps to distribute the load across the composite and prevent localized failure.

The geometry of a composite also affects its fracture behaviour. The geometry of the composite can be designed to optimize its load-bearing capacity and fracture toughness. This is done by varying the orientation of the fibers, the number of layers, and the size of the layers [8].Review of the fracture toughness properties of fiber reinforced polymer composite materials by researchers to understand the scope to fill the gaps during material characterization as follows. Interlaminar fracture modes in 0/90 cross-ply glass/epoxy laminate involve delamination of the interface between plies and is the predominant failure mode. Intralaminar fracture modes involve the failure of individual fibres or fibre bundles and are less common. Both modes are strongly dependent on the geometry and loading conditions [9].

This work provides a comprehensive overview of the effect of loading rate on the fracture toughness of fiber reinforced polymer composites. It presents the results of detailed experiments and analysis, resulting in useful conclusions. It is an excellent reference for those interested in the subject [10].Mixed-Mode Interlaminar Fracture Toughness of Glass and Carbon Fibre Powder Epoxy Composites is an extremely helpful and efficient research for the design of wind and tidal turbine blades. It provides an insight into the fracture toughness and strength of the composites, giving engineers an understanding of the material behaviour [11].A series of experiments conducted on the composites, including fatigue crack propagation tests, tensile tests, and notched beam tests. The results of these tests are then compared to theoretical models of fracture toughness in order to gain a better understanding of the material's behavior [12].In-depth analysis of the effect of matrix toughness and loading rate on the Mode I interlaminar fracture toughness of glass-fibre/vinyl ester composites.The results showed that increasing the matrix toughness and loading rate had a positive effect on the fracture toughness of the composites [13]. The Mode-I fracture toughness of glass/carbon fiber reinforced epoxy matrix polymer composite. It presents results from experimental tests and finite element simulations, and provides useful insight into the fracture behavior of the composite. The findings are highly relevant to the engineering industry and can be used to design and manufacture high-performance composite materials [14]. This work highlights the loading rate dependency on mode I interlaminar fracture toughness of unidirectional and woven carbon fibre epoxy composites. It provides a comprehensive overview of the mechanical properties of these composites under varying loading rates, and the results indicate a strong correlation between the fracture toughness and loading rate [15].

A novel compact tension specimen design to prevent premature compression and buckling failure modes in fibre hybrid epoxy composites [16] The importance of loading rate on the fracture toughness and how it affects the performance of the composite materials The results are consistent and provide valuable information on the behaviour of laminates under different loading rates [17].An experimental characterization of intralaminar fracture toughness for woven composite laminates. Results of this research suggest that intralaminar fracture toughness is affected by both the interface strength and the fibre architecture [18]. The intralaminar fracture toughness characterization of woven composite laminates. The design and analysis of a compact tension (CT) specimen is discussed in detail, and the results demonstrate the potential of this specimen for characterizing intralaminar fracture toughness [19]. An analysis of the fracture toughness of epoxy composites reinforced with carbon fibers of various thickness. The results show that the fracture toughness of the composites increased with increased thickness of carbon fibers [20]. An experimental and numerical study on the fracture toughness of glass-carbon (0/90)s fiber reinforced polymer composite. It is a great effort to understand the mechanical properties of this composite material, and will be of great help in many experimental and numerical studies [21].Fracture Properties of Glass Fiber Composite Laminates and Size Effect provides an in-depth analysis of the fracture mechanisms of glass-fiber reinforced plastic laminates. It presents findings from experiments which show that the fracture toughness of these laminates is size dependent [22].

In this work, the fracture toughness of polymer fiber reinforced hybrid composite laminates was determined by compact elongation. Compact tensile tests are used to characterize crack behavior and crack growth data. The composite materials have three different fiber orientations, with an epoxy resin matrix component and carbon fiber and S-glass fabric reinforcement. The composite laminates were subjected to tensile loads with direction 90^0. Strength changes and material displacements were measured and the evolution of the damage and the critical stress intensity factor calculated. The effect of cutting the composite in three different directions on laminate cracking was compared.

2. Experimental Procedure

2.1. Material

In this study, the materials were available by the manufacturers in the form of semi-finished products. In this regard, two-step manufacturing processes were required where the first step involves hand layup technique (Figure 1) to layup the S-glass and carbon fibers with epoxy resin and then compression molding (Figure 1) during a second step.

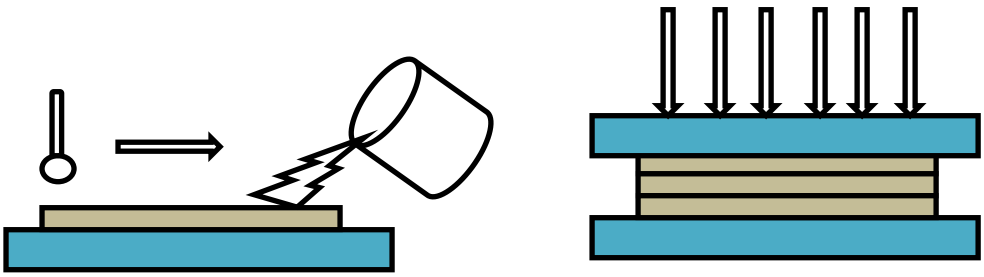

Figure 1. Hand Layup & Compression Molding Methods

The properties of the reinforcement materials used under study are given in Table 1. The composite laminates were prepared in the ratio of reinforcement: matrix of 55:45. Typical specifications of epoxy resin Lapox L-12 and hardener K-6 used in the ratio of 100:10 is shown in the Table 2. Three composite laminates were prepared with unique combinations/material configurations for the study is indicated in the Table 3.

Table1. Properties of Reinforcing Materials

Particulars	S-glass Fiber	Carbon Fiber
Fiber Aerial Density (gsm)	195	195
Thickness (mm)	0.25	0.20
Filament Diameter (microns)	8	7
Weaving Style	Satin	Twill
Tensile Strength (MPa)	330	345
Tensile Modulus (GPa)	-	230

Table2. Specifications of Polymer Matrix Materials

Particulars	Epoxy Lapox L-12	Hardener K-6
Appearance	Visual Clear, viscous liquid	Visual Clear Liquid
Viscosity at 25°C m Pas	9,000 - 12,000	5 - 20
Density at 25°C g/cm^3	1.1 - 1.2	0.95 - 1.10

Table 3. Material Configurations/Combinations

Material	S-glass Fiber (wt%.)	Carbon Fiber (wt%.)	Epoxy Resin (wt%.)	Material Code
S-glass Epoxy Composite	55	0	45	S-E-C
Carbon Epoxy Composite	55	0	45	C-E-C
Hybrid Composite	27.5	27.5	45	C-S-E-C

2.2 Methods

Samples were cut at three different directions is shown in the figure 2, on the composite laminates that were fabricated for examination using abrasive water jet machining as per ASTM D 5054 [25] standard and later samples were dried in the oven for removal of water and moisture content. The Test specimens were prepared using the water-jet technique in accordance with the dimensions shown in Figure 3 (Compact Tension Specimen – Wikipedia Source).

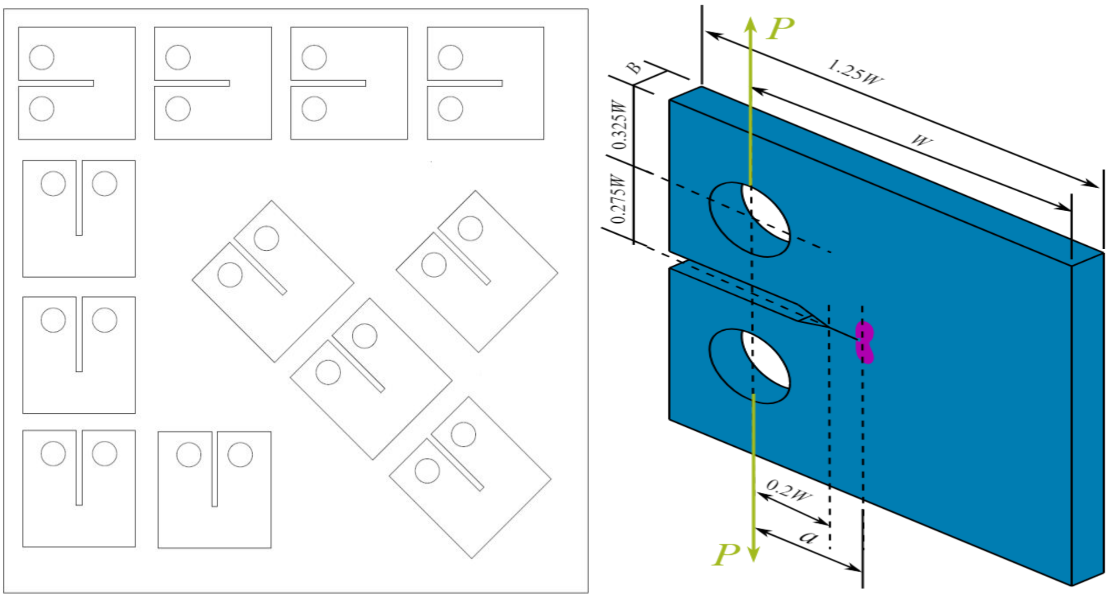

Figure 2. CT Specimen Model & Samples Drawing

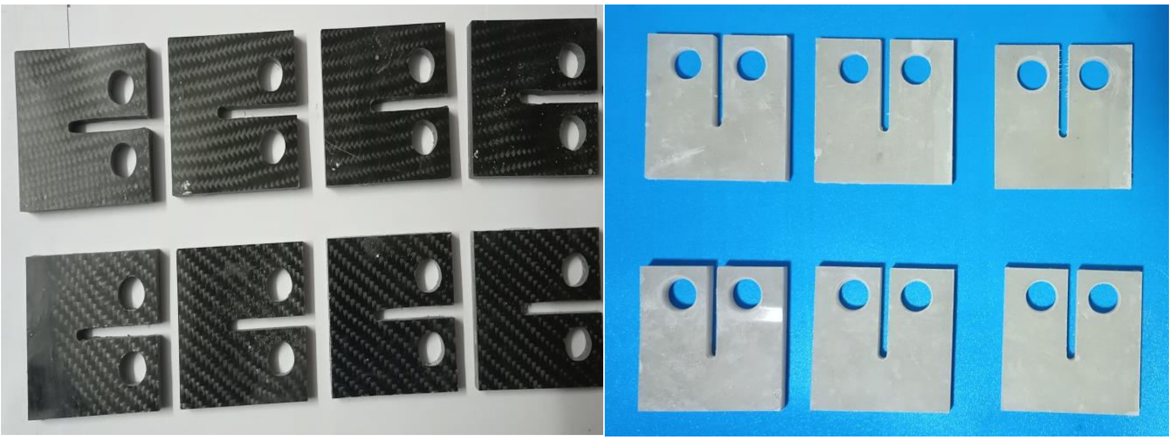

Figure 3. CT Specimen Samples

2.3 Fracture Toughness Testing

The sample meets the requirements of the fracture mechanics test method described in ASTM E-399 and ISO-13586 (Figure 3). Compact tension specimens are designed with a pre-opened notch to allow crack propagation [23]. The examples shown in Figure 3 show the initial error. This settlement represents the pre-stress which ensures that settlements begin immediately [23]. The toughness test was carried out with a force of 100 kN Kalpak brand computer controlled universal testing machine.All specimens were tested at a lateral loading rate of 1mm/min [26].

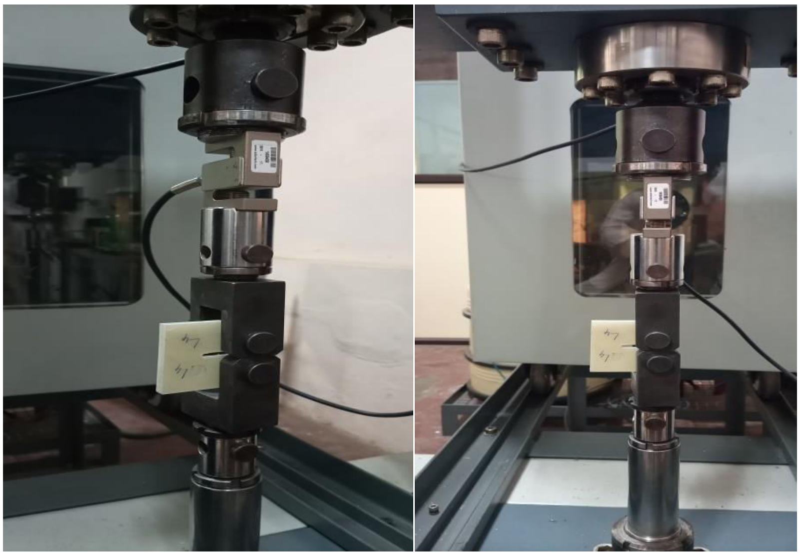

Figure 4. CT Sample under Fracture Toughness Testing

3. Results & Discussions

Table 4. Fracture Toughness Test Results of Composites - Longitudinal Cut CT Specimens

Sl.No	Material Configuration	Peak Load (N)	K_{IC} (MPa.m$^{1/2}$)
1	S-Glass Epoxy Composite	1776.45	13.00±1.5
2	Carbon Epoxy Composite	2850.40	17.23±1.4
3	Hybrid Composite	3828.31	23.64±1.6

Table 5. Fracture Toughness Test Results of Composites -Transversely Cut CT Specimens

Sl. No	Material Configuration	Peak Load (N)	K_{IC} (MPa.m$^{1/2}$)
1	S-Glass Epoxy Composite	1771.61	12.16±2.5
2	Carbon Epoxy Composite	2791.12	16.57±1.7
3	Hybrid Composite	3371.76	21.04±1.5

Table 6. Fracture Toughness Test Results of Composites - Angularly Cut CT Specimens

Sl.No	Material Configuration	Peak Load (N)	K_{IC} (MPa.m$^{1/2}$)
1	S-Glass Epoxy Composite	1695.55	11.20±1.2
2	Carbon Epoxy Composite	2684.02	15.98±2.3
3	Hybrid Composite	3126.92	19.31±2.5

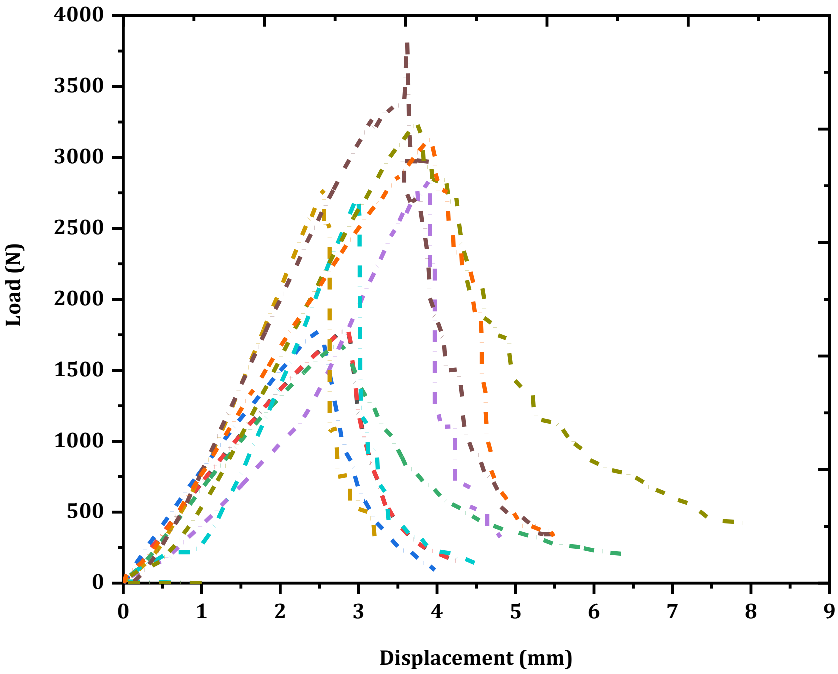

Figure 5. Overall Fracture Curves – Load Vs Displacement

The initial and maximum fracture load values were recorded during the tension compression test for each specimen put under study. When the damage is started, the crack growth model controlled the composite material response. The fiber-reinforced composites have four types of failure including breaking of fibers under stress; curl of fibers under pressure; matrix cracking in transverse shear and stress; matrix crushing under transverse shear and compression stress. To examine the effect of the fiber reinforcement on the fracture toughness, the force-displacement curves obtained from the test. Load versus displacement curves obtained by overall testing the samples for fracture toughness using compact tension test method is shown in Figure 5. As the tensile force increased, the amount of displacement where the maximum load occurred increased too. The sample which was cut longitudinally from a hybrid laminate was taken as the material having the highest force since it contained reinforcement placed in 90^0, the progress of the damage of the hybrid composite resulted from the hard break due to carbon fiber present at extreme ends of the hybrid and the continuous fiber density, which showed highresistance to the breakage, a sharp change was observed after the fiber breakage [23,24].

Tables 4-6 and figure 6 show that samples made from a laminate of hybrid composite, have a higher critical stress intensity factor K_{IC} = 23.16 MPa.m$^{1/2}$. Due to the influence of laminate direction, longitudinal performance was better than transverse or angular directions.

Because the direction of metal rolling, the direction of plastic molding, and then the direction of production composites improve mechanical properties Depending on the composite type, the fracture energies in the longitudinal direction differed significantly from the other direction [23,24].

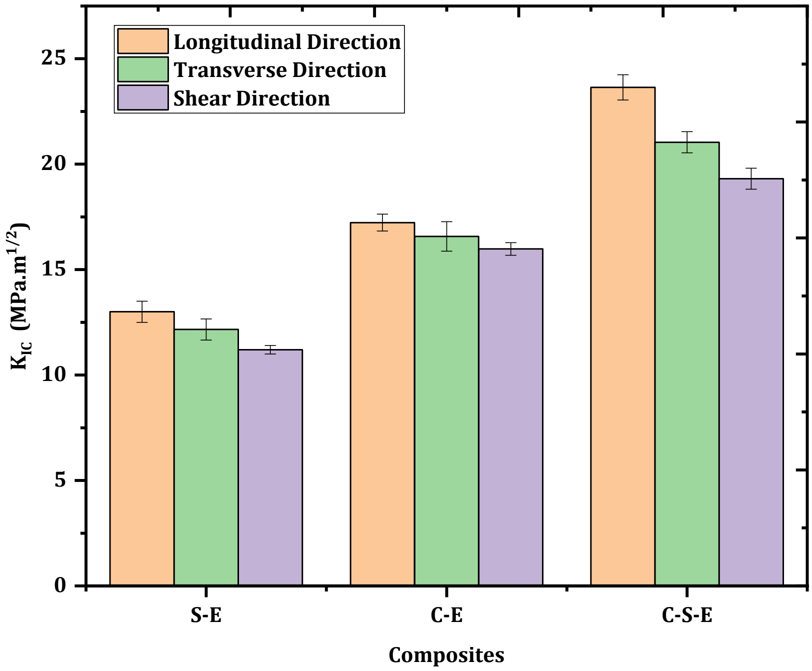

Figure 6. Graph: Critical Stress Intensity Factor Vs Composites

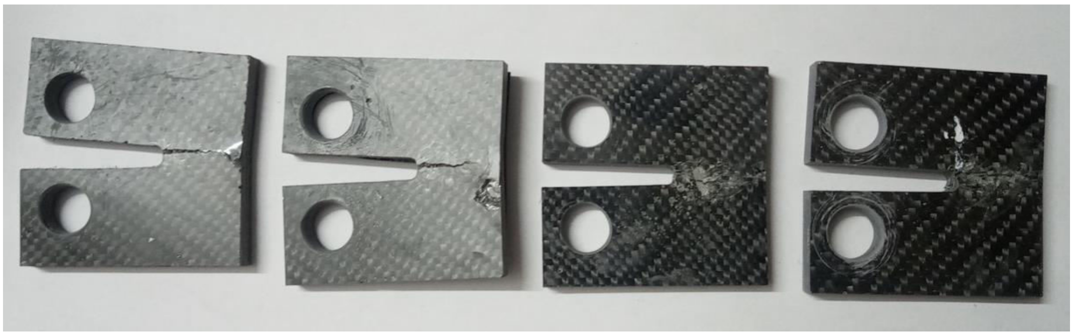

Fig. 7 Photos of the specimens undergone Compact tension test of Hybrid Composites (Longitudinal Cut)

From the figure 7, it is shown that, the samples showed a linear crack progression, but in some cases, the direction of the crack changed gradually due to the high resistance of the continuous fiber density to breakage. However, a sharp change occurred after the fiber broke. The marked regions experienced damage from partial compressive load, with the matrix undergoing shear force parallel to the continuous fiber until the fiber broke, causing pull-outs. [23].

Conclusion

In this investigation, a compact tension test was performed to determine the fracture toughness of carbon/s-glass fiber reinforced epoxy composite laminates in three different directions tested and rated by fiber type and direction. As a result of longitudinal elongating, impairment in the form of cracking of the translaminar fibers in composites with unremitting fibers steadily established. In longitudinal compression, settlement evolved as fiber buckling in the upper filament composite and as intra-layer shear in other materials. The highest fracture toughness was found in the hybrid composite at the maximum load of 3828.31 N and K_{IC} = 23 was achieved.16 MPa.m$^{1/2}$ for elongation. The lowest toughness was determined to be 13 MPa.m$^{1/2}$ for the glass fiber reinforced epoxy polymer matrix composite.

Longitudinal fracture toughness was found to be greater than transverse or angular fracture toughness, and the orientation of the fabric fibers played a dominant role in material system.

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Conflict of Interest No

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