Fracture Toughness and Mechanical Characterization of Synthetic Fibres Reinforced Polymer Matrix Composites

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Abstract

The advancement in composite materials has changed the view of engineering world as it has the capability toreplacesome metals for important applications. Currently, there is demand for the new materials of different grades due to their significant mechanical properties. In this paper, mechanical properties are studied on mono composites prepared using synthetic fibres namely Carbon, S- Glass and Kevlar fibres as a potential reinforcing materials been reinforced withepoxy polymer matrix composites. The composite plates were prepared with a conventional hand layup process followed by compression moulding. The specimens were testedfor Density, fracture toughness, tensile, flexural,ILSS, hardness and impact properties. According to the findings, carbon fibre reinforced epoxy matrix composites have superior characteristics than other mono composites.

Key Words: Carbon, Kevlar, Epoxy, Polymer, Hand Layup.

Introduction

Composites engineering is a field of engineering that focuses on creating composite materials by combining two or more materials in order to obtain desired properties. These materials are used in a variety of industries including aerospace, automotive, marine, medical, and sports equipment. The properties of composites are tailored to the specific application, allowing for greater performance and cost savings. The process of designing and engineering composite materials involves understanding their mechanical, thermal, electrical, and chemical properties, as well as their processing and performance characteristics [1].Composite materials science and applications is the study of the design, fabrication and use of composite materials. Composite materials are materials created from two or more distinct components that, when combined, create a material with unique properties. These materials are widely used in a variety of industries, from aerospace and automotive to medical and consumer goods. They offer a number of advantages over traditional materials, such as increased strength, lighter weight and improved corrosion resistance. The study of composite materials science and applications involves understanding the behavior of the components and how they interact, as well as the manufacturing techniques and processes used to create them [2].Hybrid carbon and glass fibre composites are composite materials that combine carbon and glass fibres in a single material. This combination of fibres provides the material with superior strength and stiffness, as well as improved fatigue and impact resistance. The carbon fibres provide strength and stiffness while the glass fibres provide improved impact resistance, while the combination of both fibres allows the material to be more lightweight and cost efficient. Hybrid carbon and glass fibre composites are used in a variety of applications, including automotive, aerospace, and sporting goods [3].The composites were subjected to cyclic loading at various levels of strain and strain rate. The results showed that the fatigue behaviour of the hybrid RTM composites was superior to that of the hand lay-up composites. The hybrid RTM composites showed higher fatigue strength and better post-fatigue behaviour than the hand lay-up composites [4].The flexural strength of the hybrid composites was found to increase with an increase in the carbon fibre content. Similarly, the tensile strength of the hybrid composites was found to increase with an increase in the glass fibre content. The results of this study can be used to optimize the properties of hybrid epoxy composites for various applications [5].Carbon/glass hybrid polymer composites have shown excellent performance in a variety of applications, due to their combination of high strength and stiffness, low weight, and excellent fatigue resistance. The material is relatively easy to work with, making it suitable for a wide range of manufacturing processes [6]. Inter-ply hybrid composites reinforced with glass and polyamide fibers offer improved mechanical properties compared to traditional monofilament glass fiber reinforced composites [7].Compressive strength of intraply and inter-intraply hybrid composites has been found to be higher than traditional composites, due to the strong bonding of the fibers. Impact resistance has been found to be improved in intraply and inter-intraply hybrid composites [8]. The effects of preheating temperature on the properties of rapid-curing carbon fibre composites fabricated by VARIM. The properties of the parts produced by VARIM can be affected by the preheating temperature in a number of ways [9].The addition of the carbon/glass fibers does not significantly improve the tensile properties of the composite. The study also provides a detailed analysis of the effects of the different parameters, such as the type of fibers, the number of layers, and the stacking sequence, on the tensile properties of the hybrid composites [10].The interlaminar shear strength (ILSS) of carbon fiber/epoxy composites is an important mechanical property and is highly dependent on the processing parameters used, such as the type of matrix, fiber orientation, and curing temperature, the ILSS of unidirectional composites can be improved by using multidirectional or hybrid fibers, which provide better interlaminar stress distribution [11].In terms of strength, carbon fiber reinforced epoxy composites have a high tensile strength and modulus of elasticity. This makes them ideal for applications where high strength and stiffness are required. Additionally, the compressive strength of carbon fiber reinforced epoxy composites is also quite high [12].The hybrid composite had better impact performance than the E-Glass/Kevlar 49 due to its higher specific energy absorption and strain at failure. The study showed that the hybrid composite had better impact performance than the E-Glass/Kevlar 49 alone, which suggests that the hybrid composite could be a suitable material for applications requiring a high level of impact resistance [13].The combination of Kevlar and epoxy matrix results in a composite material that is able to absorb much more energy when subjected to an impact, thus protecting the underlying material from damage [14].Experimental and numerical study was conducted to investigate the fracture toughness of GFRC. The experiments revealed that the fracture toughness of the GFRC was significantly higher than that of the neat polymer, and that the fracture toughness of the GFRC increased with increasing carbon fiber content [15].The various failure modes that can occur in SENB specimens and the effect of different loading conditions on fracture toughness [16].Different aspects of the fracture toughness behaviour of carbon fiber-reinforced epoxy matrix composites, including the role of interfacial adhesion and the effect of fiber–polymer interactions on the fracture toughness.

The authors also discuss the various testing methods and approaches used to measure the fracture toughness of these materials [17].

The various toughening mechanisms and approaches to improve interlaminar fracture toughness. The review further discusses the types of laminated composite materials and the different types of toughening techniques, such as chemical, physical, and mechanical treatments. It also discusses the application of these techniques, such as the use of fibers, structural reinforcements, coatings, and chemical treatments [18].The Mode I fracture toughness of FRPs and discusses the various factors that affect it, such as fiber type, fiber orientation, fiber volume fraction, matrix properties, surface treatment, and environmental conditions. Additionally, the review summarizes recent advances in the field of FRP fracture toughness and discusses future research directions [19].In the on-going project, an effort has been made to hand-lay mono composites and evaluates their fracture toughness and mechanical performance.

2. Materials and Method

2.1. Materials

Reinforcing materials used are S- glass fiber of 195 gsm, carbon fiber plain weave of 220 gsm, Kevlar fiber of 200 gsm. The polymer matrix used was a thermoset, epoxy resin namedLapox L-12 and k-6 hardener.

2.2. Fabrication

Figure 1 illustrates the hand layup procedure that was used to create the laminates, which was followed by compression moulding.To fabricate the mono composites, epoxy and hardener were combined in a weight-to-weight ratio of 100:10.The Table 1 show the composite laminates that were prepared and there sample code.

Table 1. Material Configuration

Sl. No	Material Configuration	Sample Code
1	Neat Epoxy Composite	N-E-C
2	Kevlar/Epoxy Composite	K-E-C
3	S-Glass/Epoxy Composite	S-E-C
4	Carbon/Epoxy Composite	C-E-C

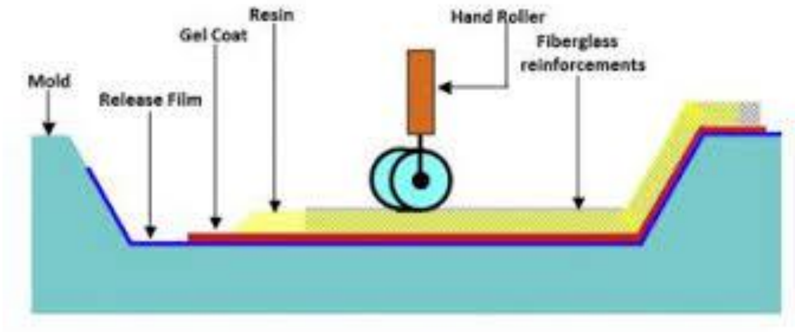

Fig. 1Fabrication of Composites

The fabricated hybrid laminates were allowed to cure for up to 24 hours in room temperature.For cutting the specimens in accordance with ASTM requirements, the abrasive water jet process is used. Later the samples were dried in micro. Figure 2 shows the composite sample cut from the hybrid laminates.

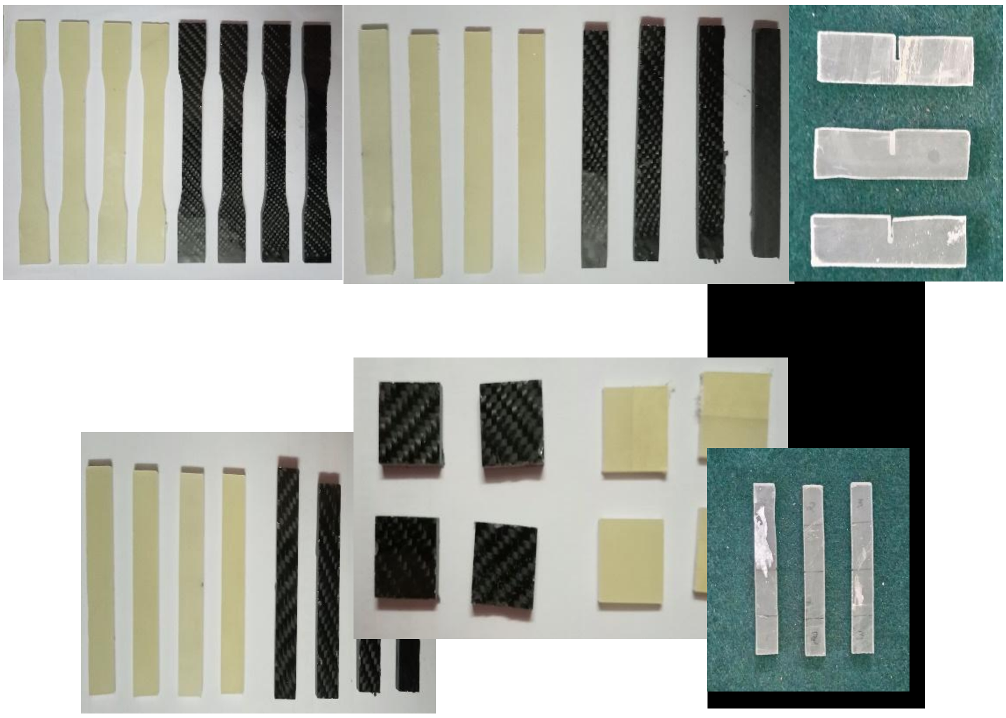

Fig. 2 Composite Specimens

2.3. Mechanical Characterizations

The mechanical testing of advanced fibre composites involves a variety of techniques and tests that are used to measure the properties of composite materials such as strength, stiffness, fatigue, and fracture toughness. The tests are used to evaluate the composite material’s performance in different applications.

The mechanical testing of advanced fibre composites is essential for understanding the performance of the composite material in different applications. The tests can be used to determine the mechanical properties of the material and can be used to design components [20].The Fracture toughness and mechanical tests were carried out on the prepared samples according to ASTM standards. The test and respective ASTM code are mentioned in table 2.

Table 2. Shows the test names with ASTM standards

Sl. No	Test	ASTM Standard	References
1	Density	ASTM D792	[21]
2	Tensile	ASTM D638	[22]
3	Flexural	ASTM D790	[23]
4	ILSS	ASTM D2344	[24]
5	Fracture Toughness	ASTM D5054	[25]
6	Impact	ASTM D256	[26]
7	Shore D Hardness	ASTM D2240	[27]
8	Barcol Hardness	ASTM D2583	[28]

3. Results & Discussion

Table 3. Physical &Mechanical Properties of Synthetic Fibres Reinforced Epoxy Composites.

Sample Code	Density	Ultimate Tensile Strength (MPa)	Tensile Modulus (GPa)	Maxi. Flexural Strength (MPa)	Flexural Modulus (GPa)	Interlaminar Shear Strength (MPa)	Izod Impact Strength (J/m)	Shore-D Hardness Value	Barcol Hardness Value
N-E-C	1.160	19.453	0.560	63.810	6.680	4.230	32.900	86	20
K-E-C	1.166	240.45	6.62	136.60	13.78	5.70	1878.70	76	40
S-E-C	1.423	318.74	12.80	472.57	22.43	23.45	1260.40	82	44
C-E-C	1.335	408.12	13.26	626.74	31.82	27.70	901.40	85	49

3.1 Density Test

The density of the prepared samples is determined using the Mettler Toledo, Model AX 205.Composite’s density is significantly affected by the parameters of glass fibre such as type, geometry, fibre angle and resin quantity.

The s-glass fibreepoxy composite showed higher density with a value of 1.423. The s-glass fibre has higher density than compared with other fibres and the results are shown in the figure 3.

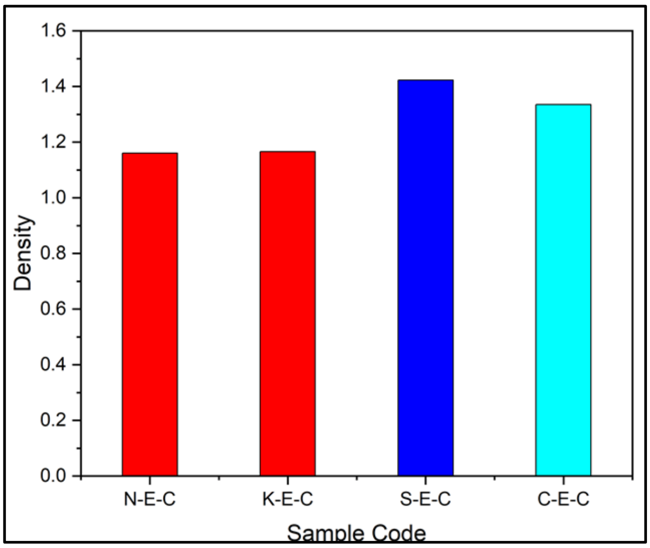

Fig. 3 shows the density of fabricated Composites

3.2. Tensile Test

Tensile test was performed using 100 Kg capacity Kalpak Computerized Universal testing machine(UTM)and the cross head speed is 10 mm/min. The tensile test results of different mono composites are shown inFigure 4 &Table 3.The carbon fibre reinforced epoxy composite, which measured 408.12 MPa and 13.26 GPa, has the highest tensile strength and modulus over mono composites.Increased interfacial bonding between the matrix and the fibres is the reason of the higher characteristics.

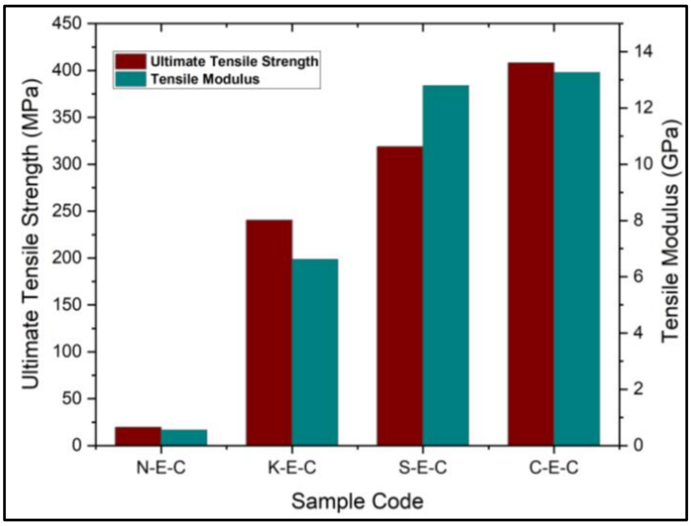

Fig. 4 Tensile Properties of Composites

3.3. Flexural Test

Flexural testing enables the evaluation of fiber-reinforced polymers' compressive and tensile characteristics.Flexural tests were performed at a cross head speed of 5 mm/min using a Kalpak Computerized UTM with a 100 Kg weight capacity.The flexural strength and modulus of 626.74 MPa and 31.82 GPa which is highest for the carbon epoxy composite. These results are tabulated Table 3 and displayed in Figure 5. During the bending load tensile and de-lamination type of failure are observed. The factors like fibre orientations, adhesion between fiber-matrix, stress transmission at the interface, and mixing temperatures would affect the flexural characteristics of composites. The compressive fracture was observed on all the samples after flexural test.

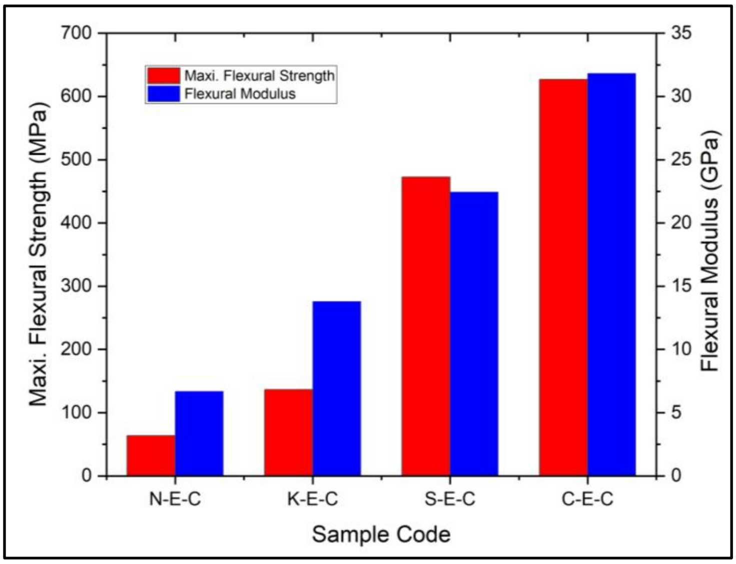

Fig. 5Flexural Properties of Composites

3.4. Impact Test

the toughness of the materials is measured by Izod impact test.The manufacturing flaws serve as stress points and lead to reduction in laminate's fracture toughness. The prepared samples were tested using the Digital Instron Model Ceast 9050. With different fibres and their orientations, the composites' impact properties varied greatly.The results show that a sample of an epoxy composite reinforced with Kevlar fibre has an impact strength of 1878.70 J/m and is seen in Figure 6 and Table 3.

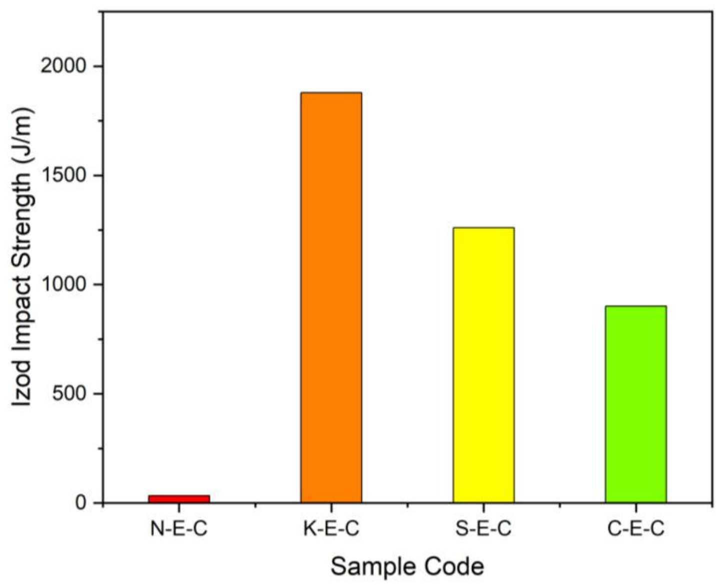

Fig. 6shows the Izod Impact Strength of Composites results

3.5 Hardness Test

Employing a Shore-D hardness tester, the prepared composites' hardness is determined. Table 3 and Figure 7 display the compositesshore D hardness value.When compared to fibre reinforced composites, the plain epoxy composite's shore D hardness value has increased to a higher value of 86. This rise in hardness is caused by the brittle character of epoxy in the materials system.

The Barcol hardness for various mono composites reinforced epoxy matrix is shown in Figure 7 and Table 3. When compared to other material systems, carbon epoxy composite was shown to have a greater Barcol hardness.The hardness value of carbon epoxy composite was 46. When squeezed together, the fibre phase and thermosetting epoxy matrix phase provide resistance. The interface can efficiently transmit load because of this. This contributes to the carbon epoxy composite's improved hardness.Due to the distribution of the test load on the fibres, the hardness value will significantly rise when the resin is reinforced with carbon fibres. Test ball penetration into the surface of composite materials has decreased, and therebyincrease the hardness of the material.

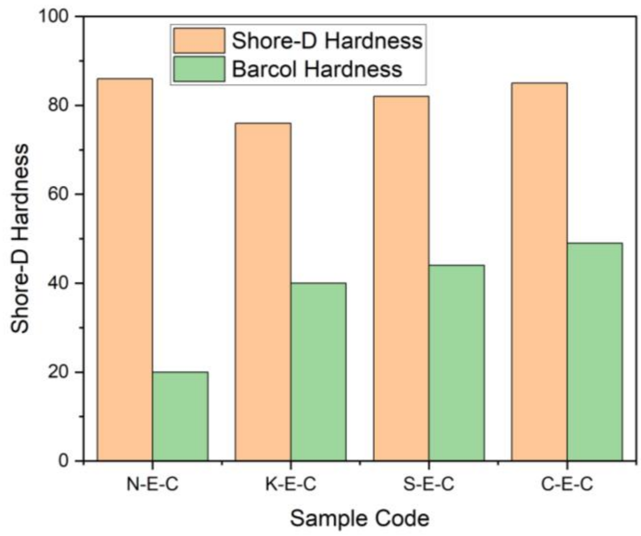

Fig. 7Hardness Valuesof Composites

3.6Interlaminar Shear Test

The interlaminar-shear test especially evaluates the characteristics in the interlaminar areas of the mono composites under study, i.e. between the matrix and fibre reinforcement.The tests were performed using the three-point short-beam bending test technique specified in ASTM standard at room temperature using a computerised universal testing equipment (100 Kg capacity Kalpak Make).After the test, the ILSS for carbon epoxy composite was computed, and the findings are displayed in figure 8 and table 3 with a value of 27.70 MPa, which is higher in the batch.Due to their excellent resistance to delamination under shear loads, carbon fibre reinforced epoxy composites are superior to those fabricated by utilizing other fibre types.

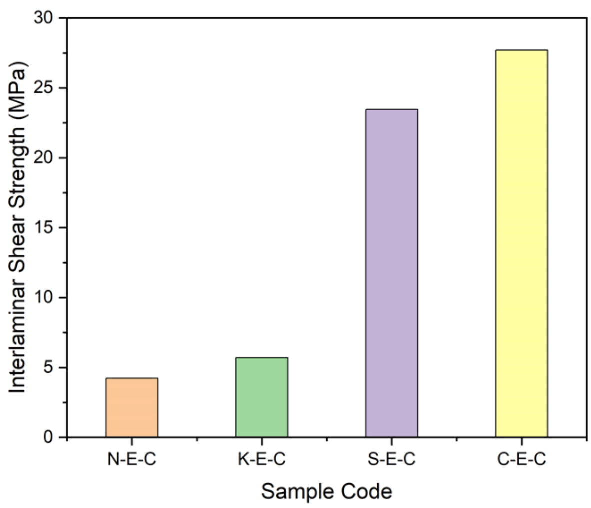

Fig. 8Interlaminar Shear Strength of Composites

3.6 Fracture Toughness Test

When assessing a composite material for a practical application, fracture toughness is a crucial factor to take into account. The test reveals the specimen's resistance under load.Figure 9 depicts the sample during a fracture toughness test .The three-point bending test for the critical stress intensity factor can be used to gauge the fracture toughness of composites with rectangular cross sections (K_{IC}). The value of (K_{IC}) for the SENB fracture toughness test is computed by

$$\mathbf{K_{IC}} = \frac{P_Q}{(BxW)^{1/2}} f(x) \ \ldots \mathbf{MPa.m^{1/2}}$$

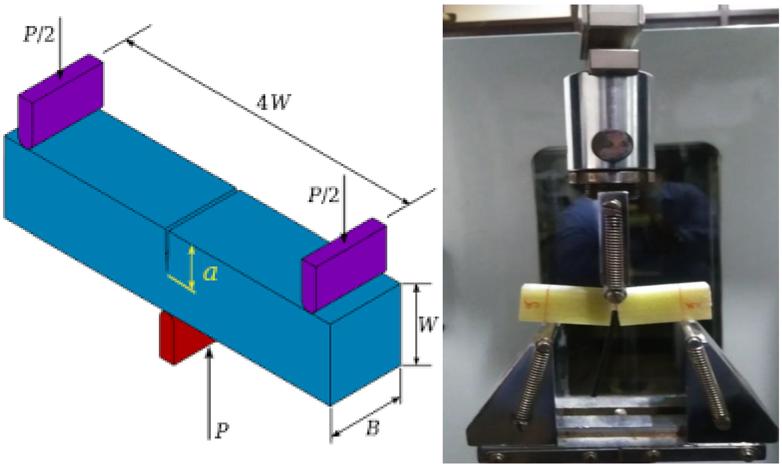

Fig. 9Sample during the fracture Test

According to ASTM D 5045, an epoxy matrix composite reinforced with synthetic fibres underwent a fracture toughness test. In this test process, a notched specimen that had already been cracked was loaded in three-point bending mode.The fracture resistance of the developed material was tested using the computerizedUTM (100 Kg capacity Kalpak Make). In the test on pre-cracked samples, a cross-head loading rate of 1 mm/min was applied to the samples.The standard equation, which was developed on the basis of the elastic stress analysis described in ASTM D 5045, was used to obtain the K_{IC} value. Table 2 shows the results obtainedfrom the fracture toughness test.

Table 4. Fracture Toughness Propertiesof Composites

Sample Code	Peak Load (N)	K_{IC} ($MPa.m^{1/2}$)
N-E-C	120.34	1.683
K-E-C	607.51	8.50
S-E-C	721.51	10.10
C-E-C	2260.20	13.66

The peak load and K_{IC} responses for several synthetic fiber-reinforced epoxy composites are shown in figure 10.It can be seen that the carbon epoxy composite, under an average peak load of 2260.20 N, had a highest critical stress intensity factor (K_{IC}) of 13.66 MPa.√m While a clean epoxy composite has a measured average minimal $K_{IC}$of 1.683 MPa√m at a measured average peak load of 120.34 N.The mode-I fracture surface exhibits very slight debonding between the fibre and matrix showing brittle cleavage failure.

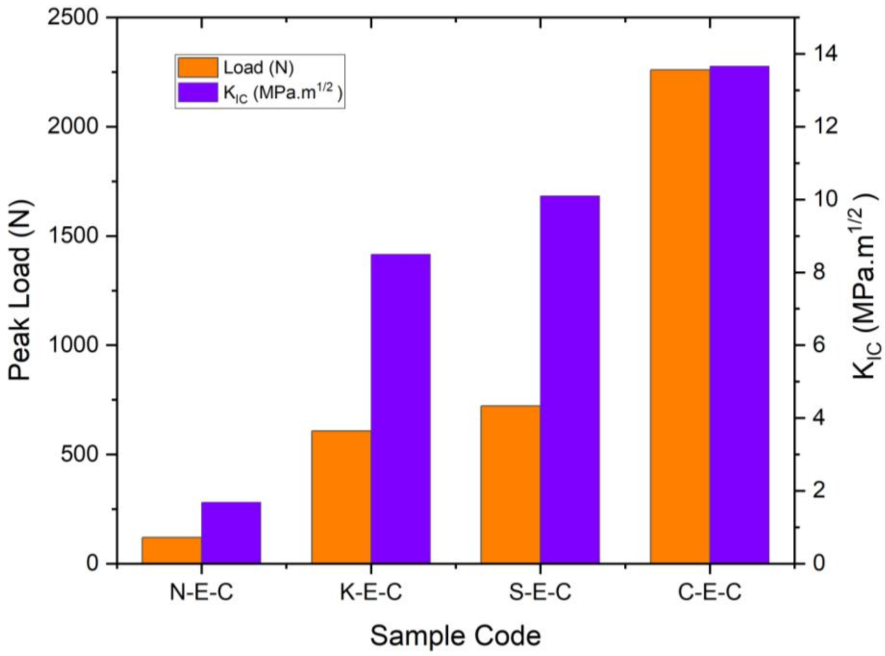

Fig. 10Fracture Toughness Properties of Composites

4. Conclusion

The paper presents the results of comprehensive testing of different synthetic fibres reinforced epoxy polymer matrix under different mechanical loading conditions and fracture toughness.

- Adding carbon fibre in epoxy has improved the mechanical properties of developed composites.
- The tensile strength, flexural strength, interlaminar shear strength of carbon epoxy composite resulted in optimal levels when compared with other mono composites respectively.
- Density of S-glass fibre reinforced epoxy composite resulted in higher value as more silica content is present in the fibre making the fibre much denser than others.
- The brittleness of the material made the impact resistance of the neat epoxy composite poor, but after adding Kevlar fiber reinforcement, the impact resistance increased because Kevlar fibers absorb more energy than other fibers.
- Due to the brittle nature of epoxy resin, which makes the material relatively hard under test, the neat epoxy composite was found to have a high Shore D Hardness value.Because carbon is renowned for having a very high hardness and with the proportion of carbon fibre reinforcement in the material system, the Barcol hardness of carbon fibre reinforced epoxy composite demonstrated higher hardness when compared to other mono fibres based composites.
- A superior critical stress intensity factor for carbon epoxy composite was obtained from a fracture toughness test.Additionally, it was shown that the stress intensity factor K_{IC} for fibre reinforced composites diminishes as crack direction increases. The crack increase due to debonding, resin degradation and also fiber breakage.

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