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Review Article

Study on Mechanical Properties of Synthetic Fibers Reinforced Epoxy Hybrid Composites for Automobile Application

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Abstract

The current work focuses on the hand lay-up method for creating epoxy composites reinforced with S-glass fiber (S_f), carbon fiber (C_f), and E-glass fiber (E_f). The mechanical, physical, and morphological characteristics of the produced composites in various combinations were studied and compared. Mechanical tests revealed that the placing of the S-glass fiber in a specific combination in the hybrid system of the material improves tensile (206 - 227 MPa), flexural strength (289 - 364 MPa), Izod impact strength (423.36 - 466.19 J/m), Charpy impact strength (49.77 - 61.76 KJ/m^2), Shore D Hardness (74 – 91) and density (1.23 –1.47 g/cm^3). The trends for mechanical characteristics were validated by examining at the fiber-matrix interface, fiber pull-out, matrix fractures, and fiber deboning in the microstructure and fractured surface morphology of the created hybrid materials. Overall, it can be inferred from the findings analysis that by reinforcing S-glass fiber in epoxy matrix with in various fiber orientations significantly enhanced the properties of the generated hybrid composite materials. Thus, S-glass fiber with excellent strength properties, like other synthetic fibers, might be considered a good reinforcing material. The hybrid system and may be used for diverse applications in the area of automobile parts manufacturing that requires high mechanical resistance.

Keywords: Carbon, E-glass, S-glass, Epoxy, Hybrid, Hand Layup.

INTRODUCTION

Composites made of two molecular or nanometer elements are known as hybrid materials. Typically, one of these chemicals is organic in nature, and the other is inorganic. As a result, they are distinct from conventional composites, which include components that are macroscopic (at the micron to millimetre level). Microscopic mixing results in a more homogenous substance with qualities intermediate between the two original phases or perhaps new ones. Hybrid composites are more sophisticated than conventional FRP composites. A single reinforcing phase may have various matrix phases, a single reinforcing phase may have multiple matrix phases, or there may be multiple reinforcing phases. They are more flexible than other fiber reinforced composites. A high modulus fibre and a low modulus fibre are typically combined. While the low-modulus fibre makes the composite more damage-tolerant and keeps the material cost low, the high-modulus fibre provides rigidity and load bearing capabilities. By modifying the volume ratio and layer-by- layer stacking order of different plies, one may alter the mechanical properties of a hybrid composite.

When compared traditional metal components the Fiber reinforced polymer matrix (FRP) composites show wide range of advantages such as corrosion resistance, reduction in vehicle weight and internal damping. In spite of having wide range of advantages the use of composites is limited in application due to high material costs, slow production rates. Due to this the wider application in automotive industry slowdown.

S-glass, carbon, and glass fibers are the most frequently used reinforcements for polymer matrix composites. The usage of glass fiber reinforced polymer matrix (GFRP) composites as structural elements has the potential to reduce vehicle weight by 20 to 35%; more substantially. By using carbon fiber reinforced polymer matrix (CFRP) composites, weight could be decreased by 40–60%. While fuel efficiency and technological advancement are becoming more significant, cost reduction continues to be the biggest problem facing by the automotive industry. One method for reducing vehicle weight without significantly increasing costs is to add carbon fiber reinforcement to glass fiber composites and use inventive design by only selectively reinforcing along the major load direction. Multiple forms of reinforcement are used to create hybrid composites, which may be further divided into interply or laminated hybrid, interply or tow by tow hybrid, closely mixed hybrid, and other sorts of combinations.

The present study has utilized an epoxy resin as matrix with woven E-glass and carbon fiber textiles to create hybrid composite laminates.

Here is a summary of previous research on the relevant topics. The following provides a detailed description of the study on hybrid composites and the impact of different factors on the performance of composites examined by various researchers.

Rajak *et al.,* work focuses on the flexural and tensile properties of the fiber-reinforced epoxy composites with cobalt filler that are utilized in the automotive body sections. Glass fibre (GF) and carbon fibre (CF) filled with epoxy hybrid composites with cobalt contents ranging from 0.4 to 1.0 wt% were constructed by hand lay-up. The GF's tensile and flexural strengths were around 96.9 MPa and 120 MPa, respectively; whereas the reinforced CF's combined tensile and flexural strengths were 194.82 MPa and 393.34 MPa. The specimen's flexural and tensile strength was improved by 55.64% when compared to pure epoxy, which is a substantial improvement.

Nagaraja *et al.,* worked on a hybrid composite that used carbon and e-glass reinforcement in an epoxy matrix. These new hybrid composite materials are made using the resin infusion technique, which keeps each layer of fibres oriented 0°and 90°. Different stacking orders of the glass and carbon layers were created to study various mechanical characteristics. The fiber to matrix ratio is kept constant at 60:40. It is done to compare two distinct stacking. According to the results, laminates with carbon fiber on their extreme surfaces provide better flexural qualities than laminates without carbon fiber on their extreme surfaces.

The flexural properties of intra-ply structured bidirectional hybrid epoxy composites reinforced with E glass and T700S carbon fibres were studied by Donge *et al.,* According to ASTM standard, test samples are fabricated by hand lay- up, and their flexural characteristics are determined by three-point bend test. The flexural strength is decreased when glass/epoxy laminas are used to replace some of the laminas in a laminate made of carbon and epoxy. There was no discernible increase in flexural strength.

Reddy *et al.,* examined the impact of mechanical characteristics utilizing various reinforcing materials. In the current study, unidirectional T-300, T-700 12k Carbon, and E-Glass Tow Preg fibres were used to create laminates. Ovens are used to cure laminates. The fabricated laminates were cut along fiber direction that is 0º and in transverse direction that is 90º. These laminates are evaluated in accordance with ASTM standards for tensile, compressive, flexural, and modulus strength as well as inter laminar shear strength (ILSS). The Carbon T-300 12k fiber reinforced composites possess superior properties over the other composites.

Muralidhara *et al.,* conducted test on carbon fabric reinforced epoxy (CF/Ep) composites to evaluate mechanical properties. The T300CF/Ep, T700CF/Ep, and T800CF/Ep composites with various fiber topologies are studied for indentation, in-plane, tensile, and bending stresses. All composites were created utilizing hand layup followed by compression moulding with an equivalent weight proportion of carbon fiber. The high strength carbon fiber (T800) results in both tensile and flexural testing demonstrated clear strengthening effects. Density is having negligible impacted by fiber design, whereas strength and deformation of composites are greatly impacted.

Continuous carbon fiber/epoxy composites' flexural properties were explored by Hong *et al.,* and the influence of fiber content on this attribute was studied. The samples were divided into four unique fibre volume fractions from 50 to 80 vol% in incremental steps of 10 vol%. It was found that increasing fiber volume fractions in the range of 50-70 vol.% improve the flexural strength and modulus of this material. At 70 vol.% fiber volume fraction of epoxy carbon fiber composites show higher fracture strength and displacement. This is due to effective transfer of stress over the fibers. When the fiber volume fraction increase from 70-80 vol.% the reduce in flexural property was observed.

According to Mohamed *et al.,* basalt and/or glass fibre reinforced epoxy laminas boosted the tensile, flexural, and impact strengths by taking the place of partial laminas from flax fiber/epoxy laminate. In contrast to tensile qualities, high strength fibres added to the composite's outer layers improve flexural and impact resistances. The created hybrids have favorable economic and mechanical characteristics. The relative quantities of the fibers and their stacking order clearly affect the mechanical characteristics.

Kaushik *et al.,* performed experiment on the Epoxy–short glass fiber composites. Short glass fibres were combined directly with a two-pack system of Araldite (CY-230) and hardener (HY-951) to create the composites. From 2% to 10% of the total matrix weight was made up of short glass fibers. The tensile and flexural characteristics of the epoxy-glass fiber composites were enhanced. The properties also increase as the fiber content increases.

Sanjay *et al.,* carried out an experiment on the laminates by altering the quantity and positioning of the jute, kenaf, and glass layers to produce nine distinct stacking designs**.** The fabricated composites are compared with jute, kenaf, and E-glass laminates. Glass fibres are added to jute/kenaf fabrics-reinforced epoxy composites to increase their properties. The hybrid composites showed improved properties when subjected to in mechanical impact and inter- laminar test. The hybrid laminate with E-glass and kenaf fibre plies as skin layers and jute fibre plies as core layers shown superior properties in comparison to conventional laminates.

Jamal *et al.,* developed and investigated intraply hybrid epoxy composites for low-velocity impact and residual flexural performances. The hybrid composites were made of E-glass, aramid, high tenacity polyester (HTPES), and ultra- high molecular weight polyethylene According to the findings, the pure glass fibre composite had a flexural strength and energy that were 85-112% and 55-127% greater than those of the hybrid samples, respectively. Its flexural modulus, however, was lower than that of the hybrid glass/aramid and glass/UHMWPE composites by 18% and 27-34%, respectively. Hybrid samples, however, were significantly less impacted by the impact loads. Following the impact, the loss in flexural strength and energy for hybrid samples was 2-20% and 2.5-34%, whereas the loss was 63% and 71% for pure glass samples, respectively.

Bhagwat *et al.,* reported that the strength and stability of the material increase with addition FRP with glass fiber and carbon fiber. The hybrid composite helps to reduce the aircraft weight by 8-10%.

Suresh *et al.,* examined the mechanical characteristics of composites made of carbon fiber and e-glass. To understand more about the properties of created composites, numerous tests were conducted. The tests conducted, includes the Tensile, Compressive, Flexural, ILSS (Inter Laminar Shear Strength), Impact, and Head Deflection Test (HDT). Throughout every test, the IPN laminate with E-Glass fiber reinforcement performed less than the IPN Reinforced Carbon fiber specimen. The results show that 60%VER and 40%PU IPN display greater impact strength and maximal elongation before break.

Saravanan *et al.,* evaluated the mechanical properties of epoxy laminates produced from woven reinforcements (glass, Kevlar, and carbon) and their hybrid configurations (sandwich, intercalated). Composites were created using the compression moulding process and hand layup, and tests were performed in accordance with ASTM standards. When compared to intercalated hybrids, sandwich hybrids have superior characteristics.

One of the keys to increasing the fuel efficiency and lowering the environmental impact of transportation vehicles is the use of lightweight structures (automotive and rail). While steel has been replaced by fiber glass composites in the automotive industry. Due to their high cost, carbon fiber composites, which are lighter, stronger, and stiffer than glass fiber, are not extensively employed. By adding alternative s-glass fiber to E-glass fiber composites and carbon fiber reinforcements, vehicle weight may be reduced even further without cost increasing. Epoxy polymer matrix hybrid composite is used to strengthen the fibers, creating a novel combination. According to ASTM standards, the physical and mechanical characteristics of the aforementioned composites were examined.

EXPERIMENTAL PROCEDURE

Materials

In this study, polymer matrix; a thermoset used was epoxy resin of Lapox L-12 grade with hardener K-6. Reinforcing materials to form hybrid namely, Carbon fiber in twill form of 220 gsm, S-glass fiber in satin type form in 220 gsm and E-glass fiber in bidirectional woven form in 200 gsm were used.

Fabrication of Hybrid Composites

In this work, three distinct kinds of hybrid composites with various fiber orientations were created utilizing epoxy composites employing the hand lay-up method. The size of mold is 450 mm by 450 mm by 3 mm with 55% of fiber weight is kept constant for the all the composites. The samples were cut according ASTM standards for physical and mechanical tests using abrasive water jet machining followed by oven drying is shown in the figure 1.

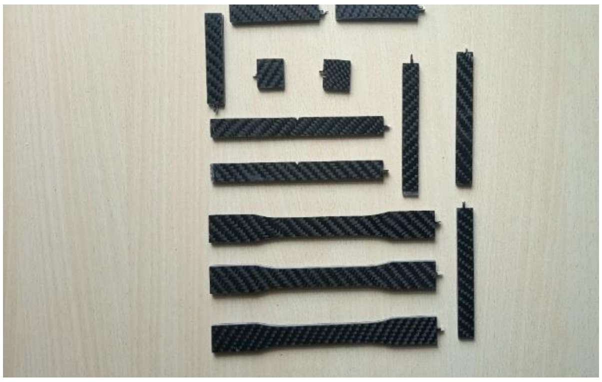

Fig. 1: Shows hybrid Composite Samples

Tensile Test

The Computerized Universal Testing Machine (UTM) (Kalpak India) used for the tensile testing has a maximum load cell capacity of 10 kN. According to ASTM D-638 standards, the specimen was cut. Five identical specimens total, each measuring 165 mm by

19 mm by 3 mm, were run at a crosshead speed of 10 mm/min and a gauge length of 57 mm.

Flexural Test

The five identical type rectangular hybrid composite specimens with dimensions of 90 mm x 12.5 mm x 3 mm were subjected to three-point bending flexural tests using a Computerized UTM (Kalpak India) in accordance with ASTM D-790 standard. The load of 10-kN capacity at normal room temperature of 27ºC, a crosshead speed of 5 mm/min, with the gauge length of 50 mm.

Impact Test

Computerized impact tester 0-25 J is used to conduct both izod and charpy test. The ASTM standard for izod test is ASTM D-256 and the sample dimensions are 64 mm x12 mm x 3 mm. Similarly, ASTM standard for charpy test is ASTM D-6110 and sample dimensions of 126 mm x12.7 mm x 3 mm. Both V and U -shaped notches were made by Notch Cutter. Five identical samples are used during each test. The samples are subjected to impact load by the pendulum as the specimen are break the toughness and impact energy is recorded.

Hardness Test

The hardness of the soft materials like plastic and rubber is obtained by the Durometer Hardness. The hardness value is frequently used to identify or specify a specific elastomer's hardness. The test gauges how deeply a specific indenter can penetrate a material when applied under particular force and duration. According to ASTM D2240, a Shore D hardness test is conducted. The specimen is initially set down on a sturdy, level surface. The instrument's indenter is then pushed into the specimen.

Density Test

The mass of a particular volume of material at 23°C compared to the same amount of deionized water is measured by specific gravity. Because plastic is marketed on a cost per pound basis, specific gravity and density are very important. ASTM D-790 is followed while conducting density tests.

RESULTS AND DISCUSSION ON

Tensile Properties of Hybrid Composites

The table 1 shows the tensile test results of hybrid composites. The tensile strength of the laminated composites is of 206 MPa, 227 MPa and 216MPa was observed for 1st, 2nd & 3rd composition respectively. Different fiber loading directions are to responsible for these variable tensile properties. By the tensile results it is easy to understand the impact of fiber orientation. Comparing the tensile strength to existing hybrid fiber-reinforced composite laminates reveals a considerable increase in strength. The high tensile strength of the carbon fibers is majorly influencing really tensile strength. Compared to glass and s-glass fibers, carbon fiber has almost twice the tensile strength. When the hybrid composite with, configurations 2C-4E-2S-4E-2C performs well when compared to 2C-1S-6E-1S-2C and 2C-2E-1S-2E- 1S-2E-2C configuration. The peak load of 11445 N with 3.7 mm extension was observed and tensile modulus of 7292 MPa. Due to the existence of stronger fibres in the external layers of the hybrids, there has been a notable increase in the tensile strength of sandwich hybrid composites. Due to the operational parameter and uneven gripping of the specimen results in breaking at end of the dog bone shape. Non-uniform stress distribution in the specimen is caused by the uneven gripping. Among all the composites being studied, hybrids have the highest tensile strength. Depending on the fibre architecture, the tensile strength varied greatly. The characteristics of composites have been perfectly affected by the number of layers used in their fabrication.

Table 1: Shows tensile Properties of Hybrid Composites

Sample Configuration	Peak Load (N)	Maxi. Elongation (mm)	Maxi. Tensile Strength (MPa)	Tensile Modulus (MPa)
2C-1S-6E-1S-2C	10360	3.1	206	6.864
2C-4E-2S-4E-2C	11445	3.7	227	7.292
2C-2E-1S-2E-1S-2E-2C	10883	3.5	216	6.875

Flexural Properties of Hybrid Composites

The flexural characteristics of the hybrid composites are shown in Table 2. The composites are subjected to tensile and compressive loads in the case of flexural loading.

In this situation, the top surface of the composite region, directly above the neutral axis, is where the composites experience stress. Failure strain rises and failure probability fall as a result. As a result, the composites' flexural strength was greater than their tensile strength. The flexural strength of 356 MPa was recorded for the fabricated hybrid composites at the fiber orientation of 2C-4E-2S-4E-2C, which was 20% and 15% more than the other composites. The flexural modulus of 23051 MPa 2C-4E-2S-4E-2C fibre orientations composite. The maximum Load and modulus were noted on the 2C-4E-2S-4E-2C composite and this is due to fiber orientation.

Table 2: Flexural Properties of Hybrid Composites

Sample Configuration	Peak Load (N)	Maxi. Elongation (mm)	Maxi. Flexural Strength (MPa)	Flexural Modulus (MPa)
2C-1S-6E-1S-2C	533	2.22	289	17913
2C-4E-2S-4E-2C	672	2.55	364	23051
2C-2E-1S-2E-1S-2E-2C	574	2.48	308	19666

Impact Strength of Hybrid Composites

The impact strength of the hybrid composites is determined by the adhesion of fiber-matrix interface, strength, and fiber shape. The hybrid composite's impact strength is displayed in Table 3.

For the 2C-4E-2S-4E-2C hybrid composite, the impact strengths were 450.5 J/m and 53.3 KJ/m2, respectively, under Charpy and Izod impact testing conditions. The improvement in performance of the 2C-4E-2S-4E-2C composite is attributable to the inclusion of high-performance s-glass fibres in the core layer of sandwich hybrid composites and adjacent stacked layers of carbon with glass fibres.

Table 3: Show impact Strength of Hybrid Composites

Sample Configuration	Izod Impact Strength (J/m)	Charpy Impact Strength (kJ/m^2)
2C-1S-6E-1S-2C	423.36	49.77
2C-4E-2S-4E-2C	466.19	61.76
2C-2E-1S-2E-1S-2E-2C	427.79	57.4

Hardness of Hybrid Composites

Table 4 displays the hybrid composites' hardness on a shore D scale. Fiber-reinforced epoxy composites made of glass, carbon, and s-glass has hardness ratings of 74 SD, 91 SD, and 87 SD, respectively. The hybrid laminates in the 2C-4E-2S-4E-2C configuration had a higher hardness values over the other composites. The composites outermost layers have an impact on the hardness of laminates. The hybrid composites have a high hardness value because of placing carbon fiber in the outermost layer. Hardness is also improved by the fibers being distributed uniformly throughout the matrix and having few voids.

Table 4: Shows Shore D Hardness Value of Hybrid Composites

Sample Configuration	Shore D Hardness
2C-1S-6E-1S-2C	74
2C-4E-2S-4E-2C	91
2C-2E-1S-2E-1S-2E-2C	87

Density of Hybrid Composites

In many weight-sensitive applications, density is a material property that is crucial. The relative proportions of the matrix and reinforcing materials determine the density of a composite. Greater sensitivity to weathering, water penetration, and reduced fatigue resistance are often associated with higher void contents. For estimating the quality of composites, knowledge of void content is desirable. Table 5 displays the measured density of hybrid composites. Table 5 makes clear that the density of the composite arrangement with the 2C-4E-2S-4E-2C ratio is greater.

Table 4: Shows Density of Hybrid Composites

Sample Configuration	Density
2C-1S-6E-1S-2C	1.23
2C-4E-2S-4E-2C	1.47
2C-2E-1S-2E-1S-2E-2C	1.30

SEM of Hybrid Composites

Figure 2 depicts the SEM morphology. The tensile tested sample's fractured region was used for the SEM analysis. SEM can detect fiber fractures, fiber pullouts, and fiber matrix breaks with fiber bonding and matrix debris on fiber. The epoxy resin matrix completely covers the s-Glass fiber filaments, as seen by SEM pictures. The figure demonstrates the strong bonding and the fact that there is no parting of the s-glass fibers from the epoxy. There is also no matrix cracking or interface deboning can be seen.

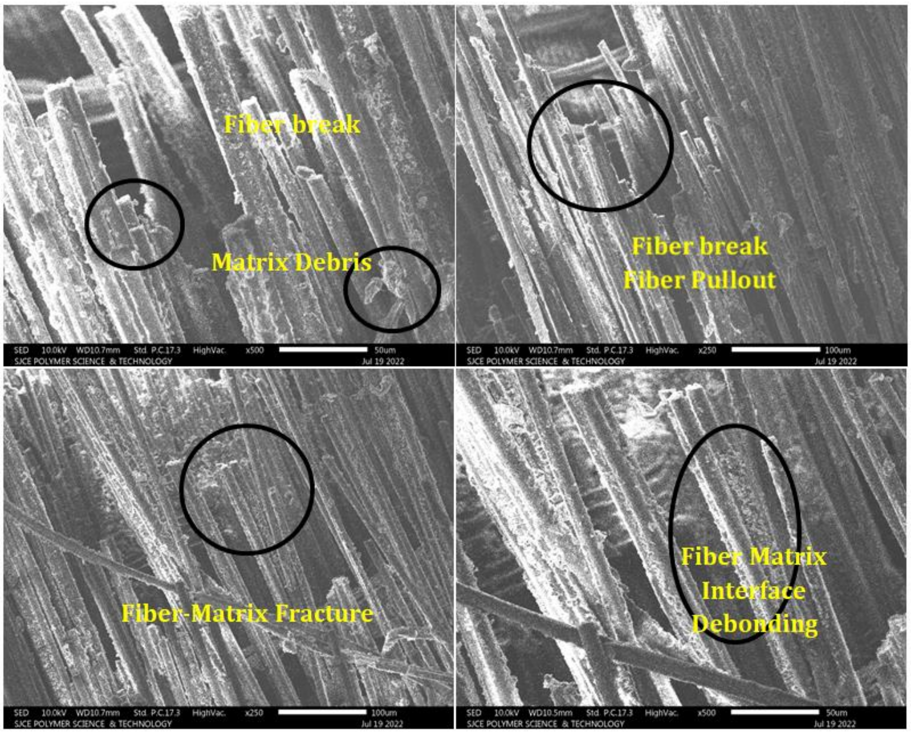

Fig. 2: SEM images of Tensile Tested Sample

CONCLUSION

The hybrid composite materials are made with three reinforcements in a thermoset epoxy matrix that are used to examine the effects of hybrid configuration and untreated reinforcement on mechanical characteristics. Through hand layup technique the hybrid composites are successfully fabricated. By analyzing the reports following conclusions are drawn:

1. Better interfacial adhesion between the fiber layers is achieved using the hand layup approach.
2. The density of 2C-4E-2S-4E-2C hybrid composite is denser than the other combination.
3. The hybrid composites 2C-4E-2S-4E-2C registered maximum tensile strength of 227 MPa and maximum tensile modulus of 7292 MPa
4. When compared to other fiber orientated composites, the 2C-4E-2S-4E-2C fiber oriented composite had excellent flexural characteristics. The higher strength and modulus, of 364 MPa and 23051 MPa respectively were seen.
5. When compared to conventional composites, hybrid composites constructed with the combination of 2C-4E-2S-4E-2C demonstrated better impact strength.
6. The inclusion of carbon at their extreme end in their composition makes the 2C-4E-2S-4E-2C composite harder than all the hybrid composites under examination.
7. Fiber and matrix adhesion has a significant effect in enhancing the strength of the composites, as evidenced by examinations of the broken surfaces of the specimen. Debris from the matrix, fiber pull-out, and delamination are also seen. The deterioration in the mechanical characteristics of sandwich composites is caused by delamination, fiber pullout, fractured fiber, and matrix fractures.
8. The mechanical properties of the composites 2C-4E-2S-4E-2C may enable them the ideal option for use in structural and other applications, such as those for cars and buildings.

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