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*Research Article*

# Mechanical Evaluation on Carbon/Basalt Fiber-Reinforced Hybrid Polymer Matrix Composite

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This work is about making hybrid composite materials out of carbon fiber mats and basalt fiber mats that are 40% reinforced with a 60% epoxy polymer matrix. Traditional hand layup has been used for the fabrication process to make five laminates of these two fibers. The mechanical properties of the hybrid composite were evaluated by measuring its tensile strength, flexural strength, impact energy, and hardness. The results showed that adding more carbon fiber layers to the composite made a big difference in its mechanical properties. In sample A, the tensile strength is 280 MPa, the flexural strength is 247 MPa, and the basalt fiber can keep more impact energy of 24 J in sample E, along with the carbon fiber and epoxy matrix. A scanning electron microscope was used to figure out how carbon/basalt fiber composite laminates break down.

## 1. Introduction

Natural origins for carbon strands include PAN (polyacrylonitrile), rayon, and pitches, with the last two being mostly used for low modulus filaments. The expressions "carbon" and "graphite" filaments are ordinarily utilized reciprocally, even though graphite indicates to fibers that are more noteworthy than 99% carbon piece, versus 93-95 percent for PAN-based carbon strands [1]. Carbon fiber offers the most noteworthy quality and firmness of all the strengthening fibers. Carbon fibers are particularly well-suited to high-temperature processing [2]. The significant downside to PAN-based fibers is their high relative cost, which is a consequence of the expense of the base material and an energy-intensified manufacturing process. Carbon fiber composites are more fragile than glass or aramid [3]. Carbon fibers can cause galvanic erosion when utilized alongside metals. Basalt fibers are biobased fibers made from basalt rocks that have superior physical and mechanical qualities over glass fibers [4, 5]. Basalt fiber-reinforced polymer composites have a long history of use in a variety of engineering sectors, including aerospace. The major materials for blades have been noncrumple fabric-based fiber-reinforced composite materials with glass and carbon fibers [6]. Sustainable composites made of naturally sourced fibers like basalt, on the other hand, are being developed to lessen the environmental effects. Basalt fibers are made without the use of chemical condiments, diluters, or destructive elements, and they are recyclable [7]. Reinforcing mats and nonwoven covering are typically portrayed by weight-per-unit-of-region. The type of reinforcement, the fiber scattering, and the measure of binder that is utilized to hold the mass or cover together directly contrast between mass items. For example, in certain procedures, hand lay-up, the folio needs to break up. In different procedures, especially in pressure embellishment and pultrusion, the fastener must withstand the water-powered powers and the dissolving activity of the matrix resin during molding. Mechanical testing is a lot simpler to be controlled; more data and information can be acquired and advantageous for the clarification contrasted and the nondestructive testing [8]. Testing machines are utilized to grow better data on known materials or to grow new materials and maintain the nature of the materials. For material providers, the mechanical properties tried by these machines are a significant proportion of item quality, and testing is required for verification. In an expansive sense, quality indicates the capacity of a structure to oppose loads without mistake [9]. Tensile properties incorporate the opposition of materials to pulling or extending powers. The two most regular small-scale hardness strategies are Vickers and Knoop hardness tests. For increasingly precise and reproducible outcomes, small-scale hardness testing needs to represent impacts of test size, planning, and condition. Samples must fit in the sample stage and be opposite to the indenter tip [10]. An amazingly rough surface may decrease the precision of space information; a validated technique for cleaning tests is prescribed. The small-scale hardness analyzer should be segregated from vibrations. Statistical information is required for tests with various stages or variations in grain sizes [11]. The mechanical properties of hybrid fiber-strengthened polymer composite utilizing hybridization. Hybrid composite materials usage has been increased due to their unique mechanical and thermal properties for traditional to current material applications. To diminish the major usage of a synthetic fiber composite for different lightweight applications, synthetic/natural fiber reinforcement hybridization can enhance the usage without changing material strength. Fiber-reinforced polymer (FRP) composite has plenty of favorable circumstances, for example, high quality, low thickness, and simple handling [12]. Plain woven basalt/polyester composites made with compression molding and aged for 24 hours in normal water and seawater showed a similar weight growth of about 2% in both mediums. Following an immersion time of approximately 100 days at 80°C in distilled water, plain woven basalt/epoxy composites made employing vacuum-assisted resin infusion with a vacuum bag revealed a weight growth of around 3.5 percent. Under the same conditions, the weight gain for plain woven E-glass/epoxy composites was around 6% [13]. The blend of support, for example, glass fiber and jute fiber in composite covers, improves the mechanical quality, and this clears a path to the expansion of the usage of characteristic fibers in different applications [14].

The above works were used to select the materials of carbon/basalt fibers as reinforcement; a thermosetting epoxy polymer as matrix and hand layup technique was used to fabricate the composite and to evaluate the mechanical strength on varying carbon and basalt fiber layers; also, surface morphology of composite laminates has been conducted through SEM analysis.

## 2. Materials and Experimental Method

Reinforcement materials are carbon fiber mat and basalt fiber mat were supplied by SM composites, Chennai, India. Polymers comprised of long chains of molecules bound together by carbon atoms provide the basis for carbon fibers, which have the potential to be used in their replacement. The matrix particle is a combination ratio 10 : 1 of Biphenyl-F type LY556 Epoxy polymer with Araldite HY 951 hardener for improved natural fiber bonding capabilities supplied by Go green Pvt. Lmt. Chennai, India. The physical properties of materials used in this work was given in Table 1.

Overlay tests were created by the hand layup method in a shape and relieved under light tension at room temperature for 48 hr. It is possible to use hand lay-up to make a broad range of composites goods, from tiny to huge. All the covers were made with a sum of six layers; each layer of carbon fiber mat and basalt fiber mat is 15 g and by fluctuating the number and position of carbon and basalt layers to acquire five diverse loading arrangements [15]. Epoxy matrix is constant for all five samples, and reinforcement of carbon/basalt weight fractions are varied 75/15, 60/30, 45/45, 30/60, and 15/75 grams to fabricate the composite laminates and to conduct the mechanical experiments. There is no specific order to the fibers. The weight ratio of the carbon/basalt hybrid composite is given in Table 2.

*2.1. Testing of Hybrid Composite.* The mechanical testing of tensile test, flexural test, impact test, and hardness test to identify the mechanical properties of carbon/basalt fibers composite materials are conducted on the developed composite laminates. The tensile specimen is created from hybrid composites that have been developed. The sample was cut according to ASTM D638 specifications, and the tensile load was applied to each specimen while it was fixed between the jaws of the UTM. During the test, the results were written down [16]. The hybrid polymer matrix composite specimen for flexural investigation was prepared according to the ASTM D790 standard, with five samples are two reinforcing material compositions. The prepared specimen was placed on top of the FIE UTM clamp and bending load is applied to the specimen in a three-point bend test [17]. The Charpy impact test ASTM D256 V-notch test standardized high strain rates and the amount of energy absorbed by the material during a fracture [18]. This absorbed energy is a notch strength and stiffness measurement that may be used to look into the ductile-brittle nature of abrupt shocks. The indentation resistance of elastomeric soft plastic materials was determined using the penetration

Table 1: The physical properties of materials.

| Properties | Carbon fiber | Basalt fiber | Epoxy resin |
|---|---|---|---|
| Young's modulus (GPa) | 240 | 65 | 3.5 |
| Tensile strength (MPa) | 140 | 90 | 83 |
| Density (g/cm$^3$) | 1.67 | 1.7 | 1.15 |
| Type | Mat form | Mat form | Clear liquid |
| Elongation (%) | 1.59 | 1.3 | 4.3 |
| GSM | 200 | 200 | — |

Table 2: The weight ratio of carbon/basalt hybrid composite.

| Sample | Weight of carbon fiber mat in g | Weight of basalt fiber mat in g | Weight of epoxy matrix in g | Weight of composite laminate in g |
|---|---|---|---|---|
| A | 75 | 15 | 130 | 220 |
| B | 60 | 30 | 130 | 220 |
| C | 45 | 45 | 130 | 220 |
| D | 30 | 60 | 130 | 220 |
| E | 15 | 75 | 130 | 220 |

depth of a conical indent. The Shore A durometer was used to determine the hardness of rubber materials, whereas a Shore D durometer was used to determine the hardness of composites as per the ASTM D2240 standard of this hybrid composite [8].

## 3. Results and Discussion

The mechanical properties of tensile strength, flexural strength, impact energy, and hardness were conducted for this carbon/basalt hybrid epoxy matrix composite, and the results are taken for analyzing the mechanical stability of the hybrid composite.

*3.1. Tensile Strength.* The fabricated composite made of carbon/basalt fiber-reinforced epoxy-based hybrid composite laminates conducted the tensile strength test, and the results are plotted in Figure 1. The results revealed that carbon fiber and basalt fiber significantly improved the tensile strength, and these two fibers are bonding with an epoxy matrix is more significant. The results are observed, and sample A was given more tensile strength of 280 MPa; sample A contains high carbon fiber loading of 75 g and 15 g basalt fiber mat, and similar results are observed in the other four samples due to the presence of carbon fiber loading which can observe and retain its stable condition during the gradual axial loading condition.

The least tensile strength is observed in sample E contains more basalt fiber loading is 112 MPa, and the results are based on tensile loading which can show that the stress transfer between the fibers and matrix are evenly distributed which is more mechanical stability compared to basalt fiber loading. Another research also revealed a similar path for tensile strength of carbon/kenaf fiber-reinforced hybrid composite improved tensile strength of 249 MPa due to

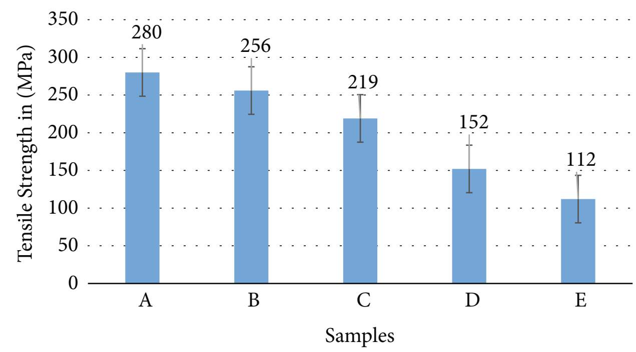


Figure 1: Tensile strength of carbon/basalt fiber hybrid epoxy composite.

more carbon fiber loading in composite and can withstand tension loading; carbon fibers are normally having higher mechanical strength compared to other synthetic fiber [19]. Therefore, a positive influence of composite laminates was observed when increasing carbon fiber loading into the composite.

*3.2. Flexural Strength.* The carbon/basalt fiber composite flexural results can show the same as tensile strength results, the flexural strength results revealed the maximum value observed in sample A, and the least value is observed in sample E; applying the bending load during this flexural test also can withstand more loading in carbon fiber compared to basalt fibers. The flexural strength of the hybrid composite is plotted in Figure 2.

The linear variation in carbon and basalt fiber can improve the stability during this bending load, and in sample A, it is 247 MPa flexural strength, and in sample E, it is 97 MPa; the variation between these two samples is very high. In the comparison of basalt fiber with kenaf fiber, basalt fiber can improve the mechanical stability due to the less variation in stress distribution, and the results based on gradual loading can absorb 38% more in basalt fiber compared to kenaf fiber and at the same time 40% more in carbon fiber [20] compared to basalt fiber loading into the hybrid composite. This shows that the basalt fibers acting as cladding inhibited the carbon fiber's characteristics.

*3.3. Impact Energy Absorption.* The Charpy impact test is performed on the hybrid composite to determine the impact energy absorption capability of the hybrid composite as a function of fiber weight fraction. The graphical results of impact energy absorption for carbon/basalt hybrid composite laminates are shown in Figure 3.

The results from the Charpy impact test reveal that basalt fiber can resist sudden force more compared to carbon fiber, and particles are strongly bonded with each other in carbon fiber; however, in basalt fiber, it has more impact resistant; therefore, when increasing basalt fiber loading, it consequently improves the impact energy absorption in results. A similar work was carried out with the development of kevlar/carbon fiber-reinforced hybrid composite, and the results show kevlar fiber is resistant to a more sudden load average of 15% compared to carbon fiber loading in

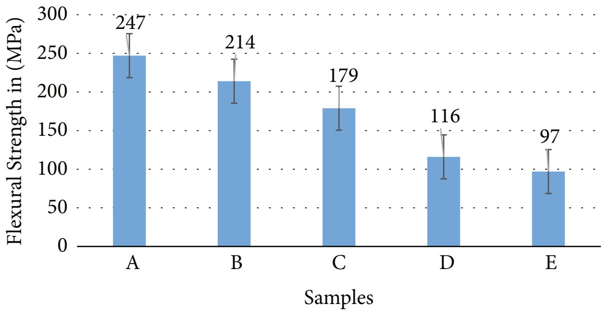


Figure 2: Flexural strength of carbon/basalt fiber hybrid composite.

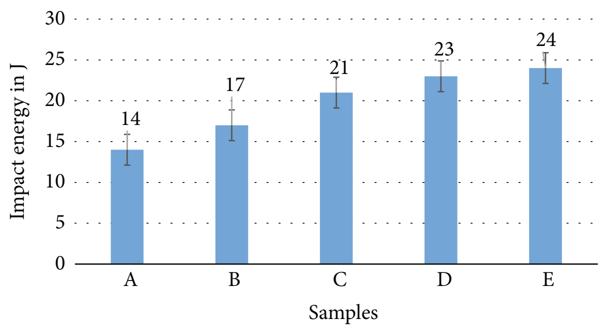


Figure 3: Impact energy of carbon/basalt fiber hybrid composite.

fabricated laminates [21]. In sample E, it was given maximum impact energy of 24 J, and in a sample A, it is 14 J, and the increasing of carbon fiber mat layer consequently reduces the impact energy absorption in this hybrid composite laminates.

*3.4. Shore D Hardness of Hybrid Composite.* Shore D hardness test ASTM D2240 are carried out on the fabricated composite laminates, and the graphical results are shown in Figure 4. The hardness of composite materials is majorly based on the outer surface of the laminates due to the impression on the hybrid composite, and at the same time, bonding between the carbon and basalt fibers with an epoxy matrix is quite well, and the delamination is less in this hybrid composite during this experiment. The maximum hardness capacity was observed in sample C is 74, which contains an equal amount of carbon, and basalt fibers are reinforced with epoxy matrix. The outer layer of carbon can resist more the impression during this test compared to the outer layer of basalt fiber presents in composite laminates shown in samples D and E are 68 and 70 evident of hybrid composite.

A similar test was done for sisal/carbon fiber hybrid composite which also shows the same mode of results; the outer layer of carbon fiber can resist 3% more gradual impression on the hybrid composite [22]. Therefore, the bonding capacity of carbon/basalt fibers with an epoxy polymer is significant with less variation in all five samples of hybrid composite.

*3.5. SEM Analysis of Hybrid Composite.* The SEM analysis was conducted for fractured samples in tensile loading, and

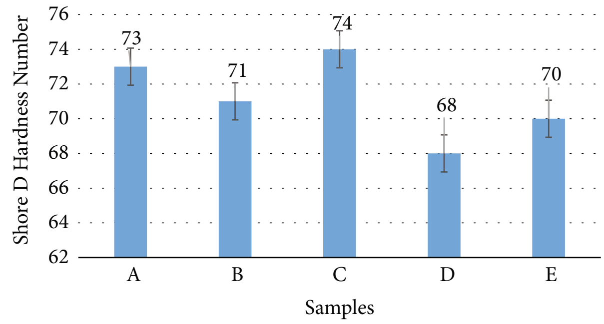


Figure 4: Shore D hardness number of carbon/basalt fiber hybrid composite.

it is evident to identify the failure mode of carbon/basalt fiber hybrid composite [23]. As seen in the SEM micrograph of the shattered surface of the hybrid composites, fiber pullouts are insignificant in the larger weight fraction of carbon fiber-reinforced hybrid composites. However, in all five samples, bonding strength with an epoxy matrix is significant and fiber pullouts and fiber cracks also minimal, and the epoxy matrix bonding with carbon fiber is a little bit more compared to basalt fiber bonding shown in the SEM output image. The SEM micrographs of carbon/basalt fiber hybrid epoxy composite are shown in Figure 5.

## 4. Conclusion

The developed composite is made of carbon fiber mat, basalt fiber mat is reinforced with epoxy polymer matrix, and mechanical properties of this hybrid has been evaluated; also, the SEM analysis of fracture surface has identified the mode of failure presents in this hybrid composite. The following points are the important findings of hybrid composite:

(i) The bonding capacity of this carbon/basalt with an epoxy matrix is significant, and it can suitable to fabricate the composite materials for lightweight applications

(ii) The tensile strength of this hybrid composite in sample A is 280 which is 60% more than sample E, and it reveals the positive influence of composite materials during tensile loading with increasing of the carbon fiber layer into the sequence of hybrid composite

(iii) Increasing of 7% more carbon fiber reinforcement in sample A compared to sample B can reflect the 13% more flexural strength is 247 MPa during the three-point bending analysis

(iv) The impact energy absorption is more when increasing of the basalt fiber layer in sample E is 24 J which is 41% higher impact energy compared to sample A; increasing of basalt fiber layer 35% can reflect 41% higher in results competed for 6% more energy output during this Charpy test of hybrid composite

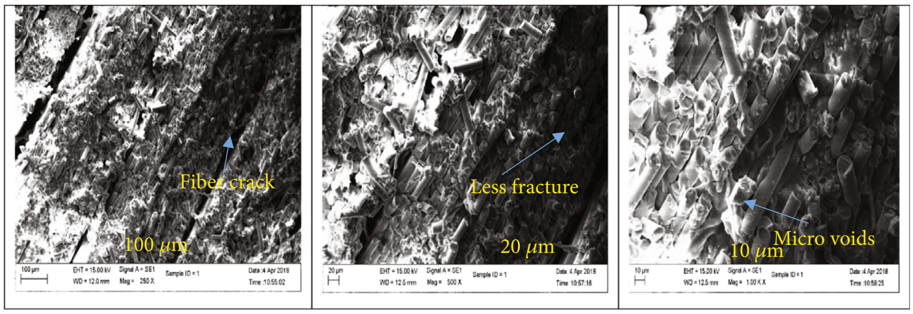


FIGURE 5: SEM micrographs of carbon/basalt fiber hybrid composite.

(v) The Shore D hardness capacity is also more when laminates contain the outer layer of carbon fiber, and during the SEM analysis, the fiber fracture and pullouts are very minimal as observed, and it can improve the mechanical stability of hybrid composite; also, the sample A weight fraction can be suitable for static application materials with gradual loading condition

## Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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