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Research Article

Fabrication and Experimental Estimation of Mechanical Properties of Kevlar-Glass/Epoxy Interwoven Composite Laminate

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Hybrid composites made of natural and synthetic fibers are stronger, lighter, cheaper, biodegradable, and greener than conventional metals, and they are replacing conventional metals. The primary objective of the study was to examine the mechanical properties of interwoven hybrid composite laminates. Kevlar and glass fiber are used as reinforcement for this work. The fibers are woven together using various weaving techniques. 1×1, 3×3, and 5×5 weaving patterns are considered to explore the properties of the laminates. The composites are woven using a conventional handloom method. As a matrix, LY556 resin and HY951 hardener are combined at a ratio of 10 : 1. The composites are cured using compression molding. The cured composites are assessed for their tensile strength, flexural strength, compressive strength, interlaminar shear strength, impact strength, and fracture toughness. The highest tensile, compressive, and flexural strength were found in the 1×1 pattern, shear strength and fracture toughness were found in the 5×5 pattern, which finds applications in aerospace and defense sectors, and 3×3 dominated in impact strength; as a result, it can be used in bulletproof applications. At last, a scanning electron microscope (SEM) was used to visualize the matrix-reinforcement bonding. The microscopic images show the ripped-out fibers because of the tensile test. The shards in SEM are evident that impact force breaks the matrix elements in a brittle manner.

1. Introduction

Composites are made of two or more constituent materials. At the macroscopic level, matrix materials use reinforcement fibers to form composite structures. The composites are classified into three types based on the underlying material: ceramic, polymeric, and metallic composites. Polymeric composites are made up of two types of polymeric base materials: thermosets and thermoplastics. Reinforcing fibers are also used in short, long, and continuous forms, and their primary function is to withstand forces applied to the material and cause force transmission from one fiber to another [1].

Composite materials have proven their worth by being widely used in mechanical industries such as aerospace, marine, and automobiles. Because of their better strength, composite materials have largely supplanted metals in many industries [2]. In the aircraft sector, the use of these materials reduces structural weight and, as a result, fuel consumption. Furthermore, composite materials are more durable and resistant to fatigue, impact, and corrosion [3, 4]. Polymer-based composites, which are formed of a polymer resin as the basis and fiber reinforcements, are one of the most popular composites [2].

Due to their enhanced qualities, such as ease of manufacturing and low cost, these materials are widely produced and employed. The adhesion of the matrix and fiber is a key factor in defining the final attributes of the composite material, particularly its mechanical properties, which determines how effective the reinforcement is [5]. Epoxy resin is extensively employed in the fabrication of polymer-based composites due to its appealing mechanical properties, optimal adhesion, strong chemical resistance, and wide diversity. Because fibers like Kevlar, basalt, carbon, and glass each have their advantages and limitations in terms of mechanical characteristics and reactivity to different impacts, hybridization appears to be one of the greatest approaches for improving the overall qualities of composites [3, 6, 7].

Kevlar is an aromatic polyamide family organic fabric. The strongly aligned chains of molecules in Kevlar fibers generate a considerable anisotropy in their mechanical characteristics. Because there is no appreciable difference in mechanical properties between orientations perpendicular to the fiber axis, Kevlar fibers are commonly considered transversely isotropic, as are many other high-performance fibers. The distinctive qualities and chemical composition of fully aromatic polyamides (aramids) set them apart from other commercial, man-made fibers, particularly Kevlar. Kevlar has a one-of-a-kind combination of strength, modulus [8, 9], toughness, and thermal stability. It was created for high-stress industrial and advanced technology applications. Many different varieties of Kevlar® are now manufactured to accommodate a wide range of end purposes.

Kevlar is a material that has long been used in bulletproof [10] vests and military helmets due to its strength and excellent impact reaction (Kevlar). Kevlar fibers have high tensile strength and elastic flexibility, as well as high impact and fire resistance, and low density [3]. However, Kevlar has low chemical resistance and a weak reactivity to pressure. Although Kevlar has excellent longitudinal properties, its transverse properties are undesirable. It is beneficial to hybridize it with other fibers such as glass and carbon [3], basalt (basalt paper), and ceramics to increase these properties.

The most often used synthetic fiber for reinforcing thermoplastic and thermoset polymers is glass fiber. Glass fiber possesses a wide range of distinctive properties, such as strong bending resistance, tensile and compressive strength, non-flammability, resistance to high temperatures and humidity, resistance to chemical and biological effects, and a relatively low density. Furthermore, glass fiber is used as a constituent in various defensive elements to boost laminate strength. Because of its convenience and simplicity of access in comparison to other synthetic fibers, glass fiber is the most well-known synthetic fiber used in these hybrid composites [11, 12].

Although significantly more expensive than glass fibers, Kevlar fiber has a unique combination of high stiffness, strength, low density, and high elongation at fracture, resulting in outstanding impact resistance. Hybrid composites are produced by joining the upside of one fiber with the upside of another. For example, high modulus fibers, such as graphite, have an extremely high solidarity to weight proportion, although their effect quality is typically regarded as reasonably low in comparison [11, 13]. As a result, hybrid composites based on these Kevlar/glass fibers can be designed to achieve a reasonable balance of tensile, flexural, and impact properties [14].

Hybrid composite refers to composites comprising more than one type of fiber material. Hybrid composites are appealing structural materials because they allow designers to tailor composites and achieve properties that are not possible in binary systems. It is a more cost-effective way of using expensive fibers, such as graphite and boron, and hybrids can achieve a balance of stiffness and strength, as well as increased elongation to failure [15, 16].

The mechanical strength and stiffness of a composite can be altered depending on its type and orientation and the proportions of its constituent materials. When considering a fabric, the properties of the fibers and yarns fundamentally dictate the fabric properties [17]. But geometric criteria, such as the fabric weave structure, knitted or non-woven construction, cover factor, and yarn crimp in woven fabrics, must also be addressed, as the matrix-to-fiber connection and the underlying matrix mechanical characteristics change depending on those [18, 19]. It has been suggested that combining high-strength and high-stiffness fibers might result in fibers with improved properties [20, 21]. The mechanical and wear properties of composites can be improved through hybridization [22].

Some of the mechanical and thermal properties of the Kevlar/glass fiber interwoven hybrid composites by varying proportions of cyanate ester/benzoxazine resin blend are studied by Zegaoui et al. [23]. This research investigates the mechanical properties of a hybrid Kevlar/glass-epoxy interwoven composite laminates such as tensile, flexural, compressive, interlaminar shear, impact strengths, and the mode one fracture toughness to offer a complete comparison of these properties.

2. Materials and Methods

In this research, two different fibers consisting of Kevlar 49 and C-Glass were chosen as the reinforcement for the hybrid composite because of their higher mechanical properties compared to other variants. A GSM determines the weight and cost of the fabric to fabricate a laminate with less cost and reduced weight with good properties 240 GSM fabric fibers are selected for the study. Epoxy LY556 and hardener HY951 are used as the matrix material because of their advanced impact characteristics. The epoxy and the hardener were mixed in a 10 : 1 weight ratio. Table 1 displays the mechanical characteristics of the reinforcement and matrix components.

2.1. Weaving. The two fundamental weaving parts that convert thread or yarn into fabric are the warp and the weft. The transverse weft (often called the woof) is dragged through and inserted over and under the lengthwise or longitudinal warp strands, which are held motionless in tension on a frame or loom. The Kevlar and glass threads are woven together to create the composite lamina. Three different laminates are made by altering the Kevlar and glass fiber weaving pattern. Plain, twill, and satin weaves are the three main types. Plain weave is a 1×1 weave in which each warp strand passes over and beneath each weft strand. 3×3 twill weaves: the weft thread is passed over two or more warp threads to make a twill weave, which is then repeated one other warp thread over to create a diagonal line [24].

Table 1: Properties of reinforcement and matrix.

S. no	Density (g/cc)	Tensile strength (MPa)	Elastic modulus (GPa)	Elongation at break (%)
Kevlar 49	1.44	3,620	76	2.8
C glass	2.52	3,310	68.9	4.8
LY556	1.14	73.3	3.47	4.5
HY951	1.19	52	2.8	11

Table 2: Weaving pattern.

	S. no	Plain	Twill	Satin
Vertical	Kevlar	1	3	5
Horizontal	Glass	1	1	1

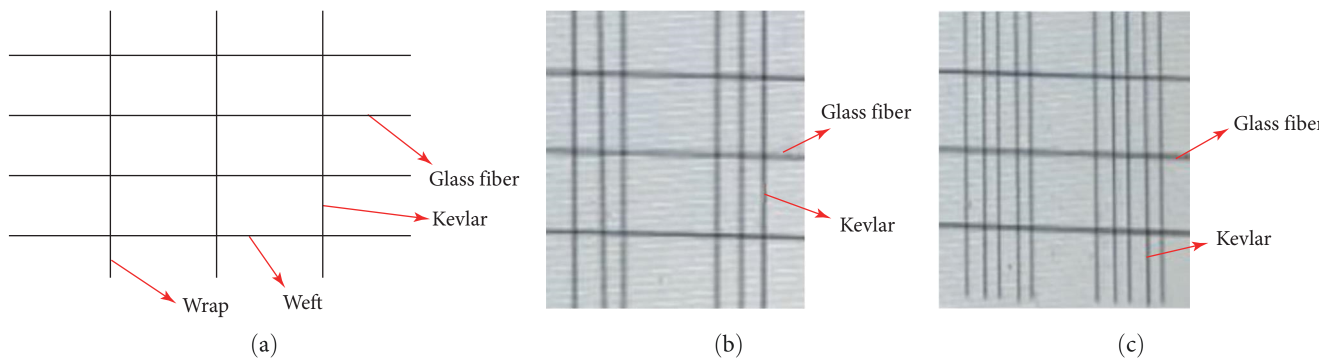

Figure 1: Weaving patterns: (a) 1 × 1 weave; (b) 3 × 3 weave; (c) 5 × 5 weave.

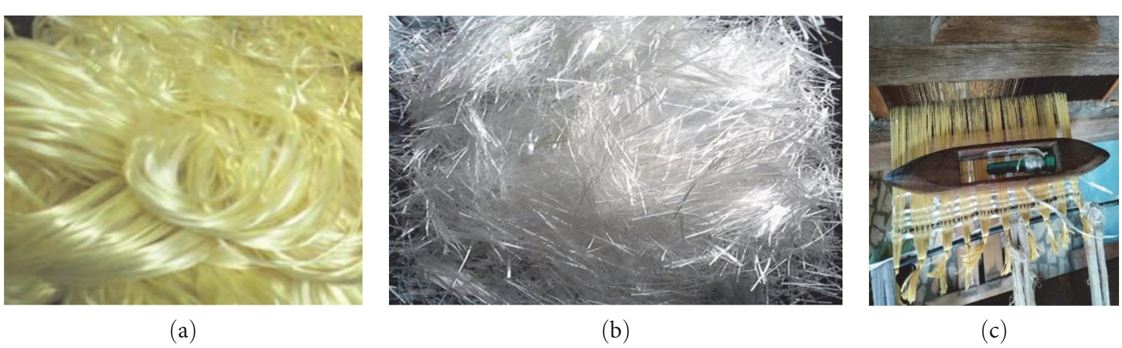

Figure 2: Reinforcement fibers: (a) reinforcement fiber (Kevlar); (b) reinforcement fiber (glass fiber); (c) weaving of fibers.

Harness satin 5 × 5 weave: each fill strand in this weave floats over five warp strands before tucking beneath one warp strand. This is more malleable than a twill weave and adapts well to intricate curves. Weaving pattern arrangements are given in Table 2, and the Weaving patterns are shown in Figure 1 1 × 1 (Figure 1(a)), 3 × 3 (Figure 1(b)), 5 × 5 (Figure 1(c)).

2.2. Compression Molding. Each laminate is made of seven laminae that are interwoven with reinforcement fibers in one of three possible designs using the traditional handloom process (Kanchipuram). The laminate was then put into a mold for compression molding [25] at room temperature at 5 bar pressure, and it was cured for 5 hr. Through compression molding, 250 mm × 250 mm in-plane Kevlar and Glass fiber-reinforced composite laminates of 2.8 mm thickness were manufactured. The plates from the fabrication process are cut using a high-speed hacksaw to the test specifications. The Figure 2 show reinforcement fibers (Kevlar Figure 2(a), glass fiber 2(b)).

2.3. Testing. The mechanical characteristics of the hybrid composite laminates were evaluated. The test specimens were prepared in accordance with ASTM guidelines. According to ASTM D3039, D790-03, D3410, D256, and D5528-1, the tensile, flexural, compression, impact, and mode one fracture tests were carried out [8, 26]. As the fixture is not available for the interlaminar shear test under ASTM

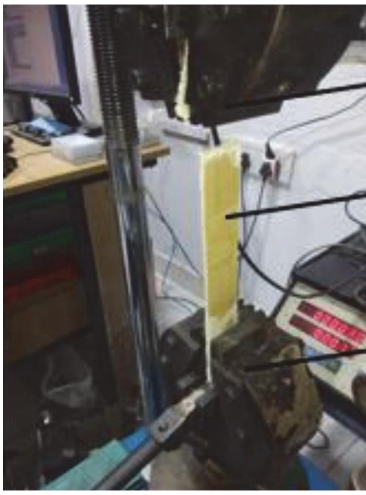

Figure 3: Tensile test setup.

Figure 4: Flexural test setup.

standards, a rectangular-shaped specimen (length × width × thickness 25 mm × 9.5 mm × 2.8 mm) where length is more significant than six times, width greater than two times the thickness of the specimen suitable for the available fixture was used for testing [27].

As the hardness test comes under physical characterization instead of the hardness test mode-1 fracture test was performed in this research. Tensile tests were conducted using a universal testing machine (UTM) with a tensile grip attached to it, as seen in Figure 3. The UTM has been used to conduct flexural, compression, and interlaminar shear tests, as shown in Figures 4–6.

Figure 7 depicts an Izod impact testing device; the sample mounted to take the impact was indicated with an arrow mark. Five samples per weaving pattern were considered for tensile, flexural, compression, and shear tests. Four samples per weaving pattern were taken for the mode-1 fracture test.

Figure 5: Compression test setup.

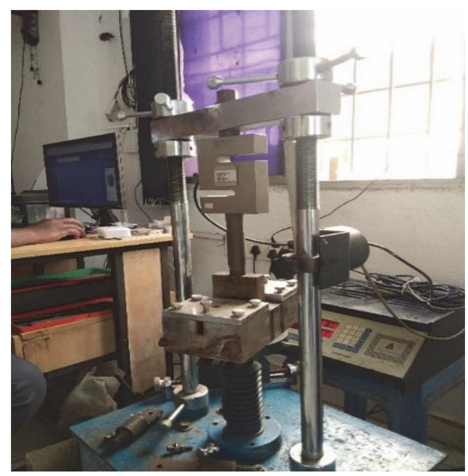

Figure 6: Interlaminar shear test setup.

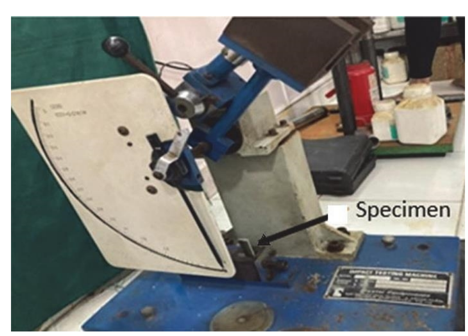

Figure 7: Izod impact test setup.

One sample for each weaving pattern was taken for the Izod impact test, as the error is less within the same weaving pattern and used [11, 28].

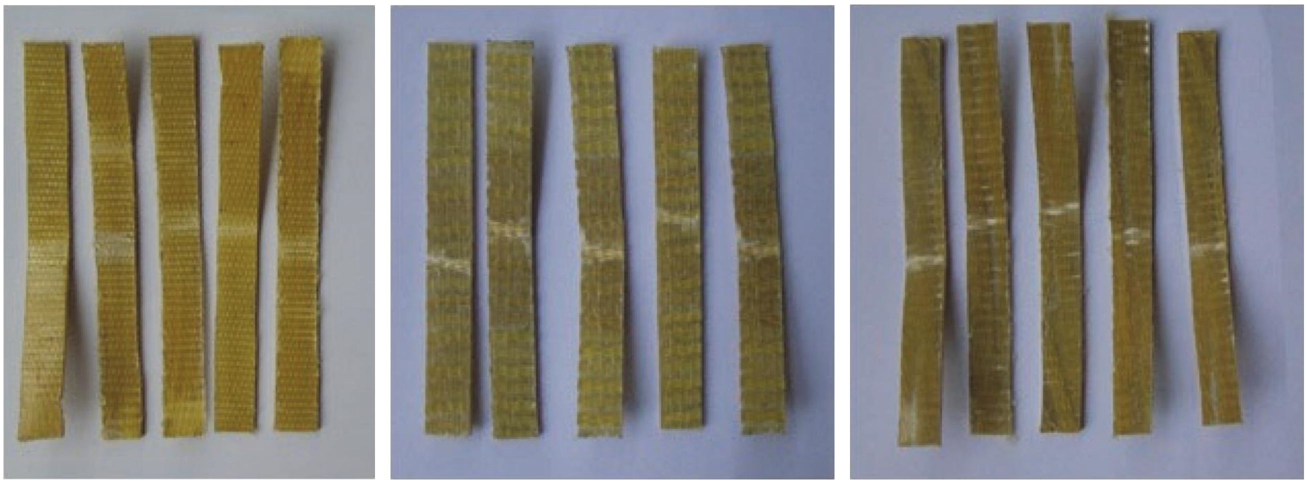

Figure 8: Specimens after flexural test.

Table 3: Tensile test results.

Orientation	Cross sectional length (l) (mm)	Cross sectional breadth (b) (mm)	Cross sectional area (A) ($l \times b$) (mm^2)	Load (P) (N)	Tensile strength ($\sigma_t = P/A$) (MPa)	Average tensile strength (MPa)
	3.9	27	105.3	7,000	66.48	
	3.8	26	98.8	7,370	74.60	
1 × 1	3.6	27.5	99	7,690	77.68	74.80
	3.7	26.5	98.05	7,520	76.70	
	3.7	27	99.9	7,850	78.58	
	3.7	27	99.9	6,740	67.47	
	3.8	27.2	103.36	7,350	71.11	
3 × 3	3.9	26.9	104.91	6,690	63.77	68.71
	3.8	26.5	100.7	7,180	71.30	
	3.6	27.5	99	6,920	69.90	
	3.7	29	107.3	6,660	62.07	
	3.8	28	106.4	6,580	61.84	
5 × 5	3.6	28.6	102.96	7,410	71.97	66.45
	3.9	27.5	107.25	6,940	64.71	
	3.7	27	99.9	7,160	71.67	

The 15 specimens undergone flexural tests are shown in Figure 8. Scanning electron microscopy (SEM) was used to examine the cracked surfaces of the tested specimens (VEGA3 TESCAN). SEM examination was done on the shattered surface of the specimens put through the mechanical testing. This was done to evaluate the material's quality and identify the type of failure that occurred when the appropriate test's load was applied.

3. Results and Discussion

3.1. Tensile Test. The tensile test determines the maximum load (tensile strength) that a material can withstand without breaking [29]. Five samples of each type (1 × 1, 3 × 3, and 5 × 5) were used in the tensile testing, yielding 15 readings. Five values of every composite are averaged to provide an average value for each laminate suggested by Felipe et al. [13]. The results are presented in Table 3. The three hybrid composite laminates employed in the current study's tensile strengths comparison are shown in Figure 9.

The 1 × 1 pattern laminate produced the maximum tensile strength of these three distinct composites, measuring 74.80 MPa. The 5 × 5 pattern had the weakest tensile strength of all, measuring 66.45 MPa. The 3 × 3 pattern achieved a tensile strength of 68.71 MPa. The mechanical properties of the latter are comparable to those of pure laminates, according to the theory behind the characteristics of hybrid composite laminates. The same is true for the current study [9, 30].

One of the test specimens is shown in Figure 10. The specimens cracked at the gauge region and between the tensile grips, as seen in Figure 10. These cracks appear when

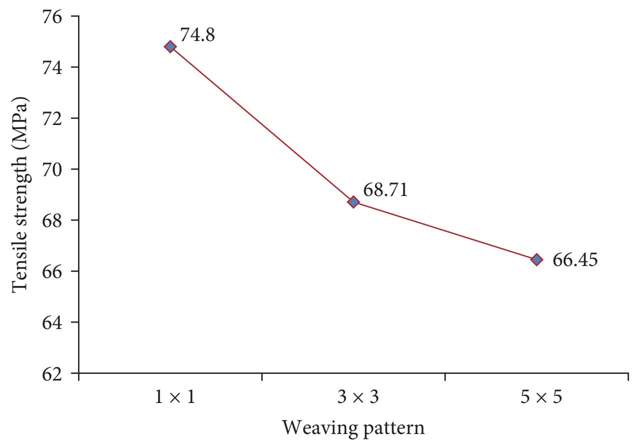

FIGURE 9: Tensile strength vs. specimens orientation.

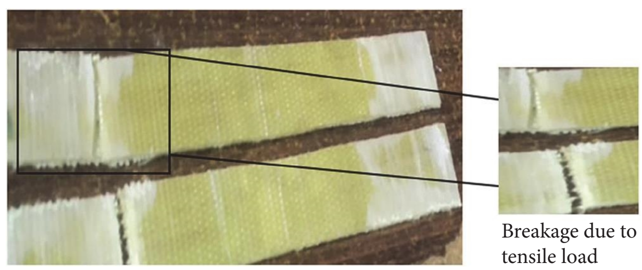

FIGURE 10: Test specimens after tensile test.

TABLE 4: Flexural test results.

Orientation	Gauge length $L = 4 \times b$ (mm)	Breadth (b) (mm)	Thickness (t) (mm)	Load (P) (N)	Flexural strength ($F = 3PL/2bt^2$) (MPa)	Average flexural strength (MPa)
	55.2	13.8	3.2	1,390	814.45	
	55.2	13.4	2.8	1,310	1,032.48	
1 × 1	56	14.1	3.1	1,430	886.49	905.68
	56.4	14	3.2	1,380	814.37	
	55.8	13.6	2.9	1,340	980.61	
	56	14	3.3	1,480	815.43	
	55.2	13.8	3.2	1,410	826.17	
3 × 3	54	13.5	3.1	1,390	867.85	860.86
	55.7	14.2	2.9	1,430	1,000.46	
	56.3	13.6	3.2	1,310	794.39	
	52.8	13.2	3.2	1,440	843.75	
	55.6	13.9	3.1	1,310	817.90	
5 × 5	54.8	13.7	3	1,390	926.67	859.79
	55.3	14.3	3.3	1,410	751.05	
	53.8	13.6	2.9	1,360	959.57	

tensile testing occurs at the gauge region under constant stress. Additionally, it is clear from Figure 10 that the complete specimen always fails to be brittle, which is proper under the same stress and strain behavior.

The plain weave specimen is less pliable and holds wrap and weft well. The number of crossover points is more in plain fabric and less porous. As a result, it can withstand more tensile load than any other pattern [30]. The tensile strength of the 1 × 1 pattern is 8.1% higher than the 3 × 3 pattern and 11.2% higher than the 5 × 5 pattern.

3.2. Flexural Test. The flexural test results are given in Table 4. Figure 11 compares the flexural strengths of three hybrid composite laminates used in this study.

The photographs of the test specimens following the flexural testing are displayed in Figure 12. It can be seen

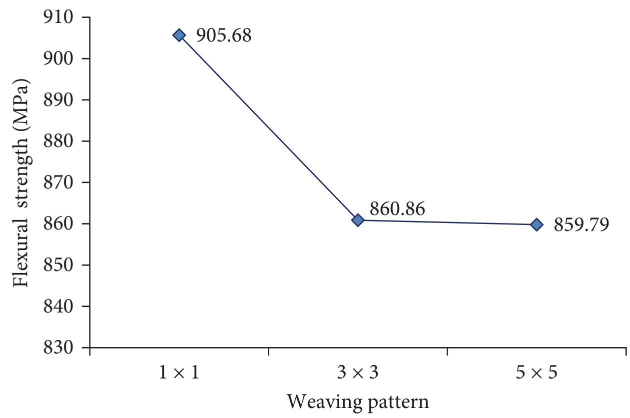

Figure 11: Flexural strength vs. specimens orientation.

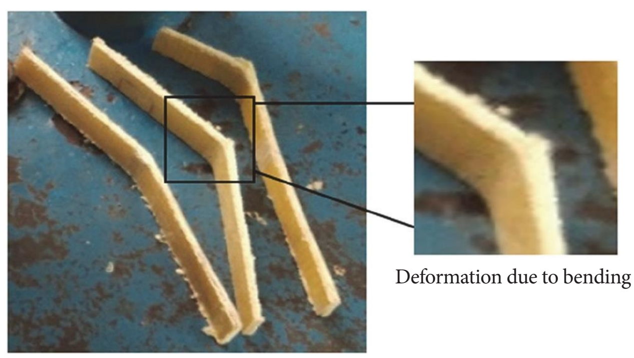

Figure 12: Test specimens after flexural test.

Table 5: Compression test results.

Orientation	Cross sectional length (l) (mm)	Cross sectional breadth (b) (mm)	Cross sectional area (A) ($l \times b$) (mm^2)	Load (P) (N)	Compressive strength ($\sigma_c = P/A$) (MPa)	Average compressive strength (MPa)
	3	14	42	6,170	146.90	
	3.3	13.8	45.54	6,250	137.24	
1 × 1	3.5	13.6	47.6	6,530	137.18	136.05
	3.7	14.1	52.17	6,380	122.29	
	3.6	13.4	48.24	6,590	136.61	
	3.4	14.4	48.96	6,380	130.31	
	3.7	13.9	51.43	6,050	117.64	
3 × 3	3.6	13.7	49.32	6,010	121.86	122.54
	3.5	14.1	49.35	6,140	124.42	
	3.7	14.3	52.91	6,270	118.50	
	3.7	13.8	51.06	6,280	122.99	
	3.5	13.7	47.95	6,580	137.23	
5 × 5	3.7	13.9	51.43	6,110	118.80	123.94
	3.9	14.1	54.99	6,370	115.84	
	3.7	13.4	49.58	6,190	124.85	

that under the influence of the three-point bending force, all of the 1 × 1, 3 × 3, and 5 × 5 patterns bowed differently. This demonstrates that the properties exhibited by the composites were significantly influenced by the order in which the reinforcing fibers were woven into the composite materials. However, the figures did not represent the magnitude of the flexural load on the specimens. Instead, it was investigated using the test's quantitative data.

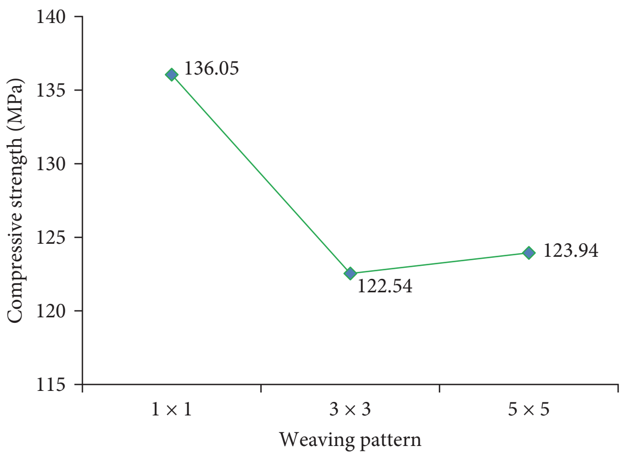

Figure 13: Compressive strength vs. specimens orientation.

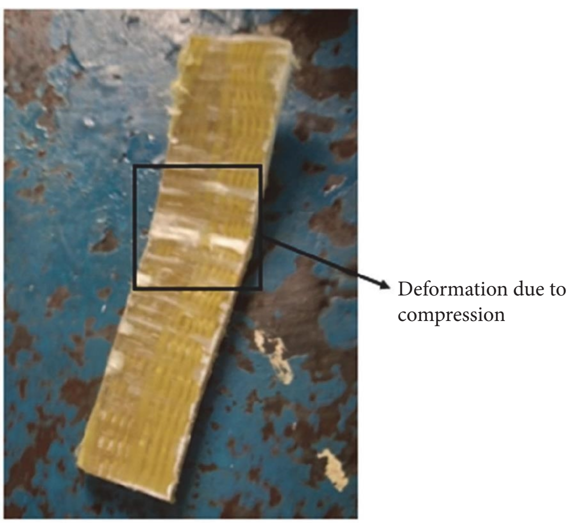

Figure 14: Test specimens after compression test.

The 1 × 1 pattern has the highest flexural strength of 905.68 MPa [9]. The flexural strength of the 3 × 3 pattern was 860.86 MPa, while the flexural strength of the 5 × 5 pattern was 859.79 MPa. The plain weaving pattern is less flexible and has more crossovers, so it has more bending resistance [30]. As a result, it can withstand a higher load before its deformation. The flexural strength of the 1 × 1 pattern is 4.9% higher than the 3 × 3 and 5.1% higher than the 5 × 5 pattern.

3.3. Compression Test. A compression test is used to determine the compressive force acting on a material. The specimen is pushed against it while it is being held in the fixture. The compressive strength needed to push the specimen to the point where it tends to crack is calculated. The results of compression testing are tabulated in Table 5. Figure 13 compares the compressive strengths of three hybrid composite laminates used in this study.

A sample undergoing a compression test is shown in Figure 14. Out of the three interwoven hybrid composite laminates, the 1 × 1 pattern has the highest compression strength of 136.05 MPa. The 3 × 3 pattern has the lowest compression strength of 122.54 MPa, and the 5 × 5 pattern has a compression strength of 123.94 MPa.

To withstand higher compressive loads, the material must be rigid enough. The twill and satin patterns are flexible and have fewer crossovers than the plain pattern. As a result, the plain pattern can withstand higher compressive loads [30]. The compressive strength of 1 × 1 pattern is 8.9% higher than the 5 × 5 pattern and 9.9% higher than the 3 × 3 pattern laminate.

3.4. Interlaminar Shear Test. The interlaminar shear strength test evaluates the composite's resistance to delaminating under shear forces parallel to the layers of the laminate and, consequently, to the interface between the adhesive and adherent [31]. The results of the interlaminar shear test are tabulated in Table 6. Figure 15 shows the variation of the interlaminar shear strengths of the three interwoven composite laminates used in this study.

The 5 × 5 hybrid composite laminate has the highest shear strength of the three interwoven hybrid composite laminates, measuring 132.66 MPa, and the 1 × 1 pattern has the lowest shear strength, measuring 129.37 MPa. 130.91 MPa is the shear strength of the 3 × 3 pattern. The interlacing is significantly less, the fabric is loose in satin weave compared to other parameters, and the density is high. As a result, fabric yarns move easily and bunch together [32]. The shear strength of the 5 × 5 pattern is 1.3% higher than the 3 × 3 pattern and 2.5% higher than the 1 × 1 pattern.

3.5. Izod Impact Test. The Izod impact strength test is a technique for evaluating a material's impact resistance [26]. The pivoting arm (pendulum) of weight 5 kg is released from a height of 150 mm at an angle of 90° to impact the specimen. The notch angle of the specimen is 45°. The sample is broken when the arm swings downward and strikes a notched sample. The material's resistance to impact is computed. The results of the impact test are tabulated in Table 7. Figure 16 compares the Izod impact strengths of the three hybrid laminates.

Figure 17 shows the specimen undergoing the Izod impact test. According to the study, the 3 × 3 pattern has an impact strength of 7.3 J, which is higher than the 4.5 and 4.8 J impact strengths of the 1 × 1 and 5 × 5 patterns, respectively.

When an arm hits the sample, the fibers take the impact to resist the breakage. The twill weave pattern absorbs more energy before failure as its crossovers are limited, and the weft is aligned diagonally [32]. The satin pattern is also flexible, but it does not have a more robust diagonal line in it; as a result, it has less impact strength than the 3 × 3 pattern. The impact strength of the 3 × 3 pattern is 34.2% higher than the 5 × 5 pattern and 38.3% higher than the 1 × 1 pattern.

3.6. Mode-1 Fracture Test. The decomposition of crack tip stresses into three loadings, or "modes," is referred to as modes of fracture. The modes are Mode-1 stress orthogonal to the crack surface's local plane. Mode-1 fracture test is performed to measure the material's fracture toughness. The specimen is held vertically in the fixture by two bolts, one on each side. The specimen is then permitted to be

Table 6: Interlaminar shear test results.

Orientation	Breadth (b) (mm)	Thickness (t) (mm)	Load (P) (N)	Shear strength ($\tau = 3P/4bt$) (MPa)	Average shear strength (MPa)
	9.4	3.1	4,970	127.92	
	9.6	3.2	4,960	121.09	
1 × 1	9.6	2.9	5,070	136.58	129.37
	9.5	3	5,210	137.11	
	9.4	3.2	4,980	124.17	
	9.2	3.2	5,105	130.05	
	9.4	3.1	5,015	129.08	
3 × 3	9.5	2.9	4,810	130.94	130.91
	9.3	3.1	5,040	131.11	
	9.6	2.8	4,780	133.37	
	9.1	3.1	4,680	124.42	
	9.3	2.8	5,120	147.47	
5 × 5	9.6	3	4,730	123.18	132.66
	9.5	3.1	5,070	129.12	
	9.3	2.8	4,830	139.11	

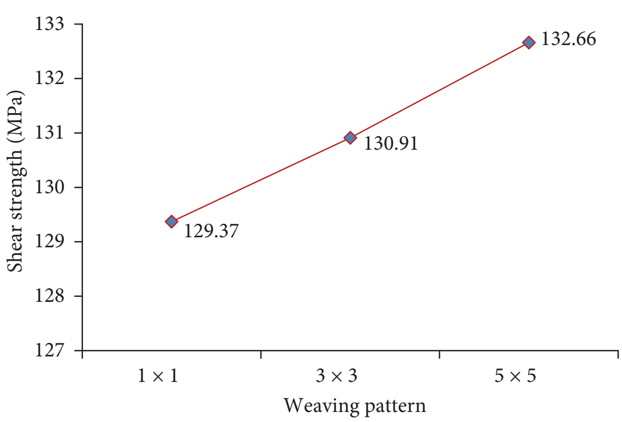

Figure 15: Shear strength vs. specimens orientation.

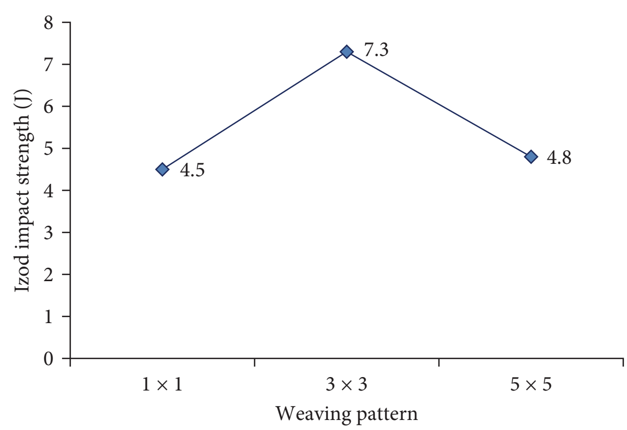

Figure 16: Impact strength vs. specimens orientation.

Table 7: Izod impact test results.

Orientation	Izod impact strength (J)
1 × 1	4.5
3 × 3	7.3
5 × 5	4.8

pulled in both the $+y$ and $-y$ axes by the fixture until it appears to fracture. The material's fracture toughness is calculated. An average value from four values per laminate type is calculated under testing. The results of Mode-1 fracture test are tabulated in Table 8. Figure 18 compares the facture toughness of three interwoven composites.

Figure 19 shows one of the specimens of Mode-1 fracture test. Out of all the specimens, the 5 × 5 pattern has a higher fracture toughness of 589.94 MPa, followed by the 1 × 1 pattern with 552.43 MPa. The 3 × 3 pattern has the lowest fracture toughness of 513.13 MPa.

The fibers in the 5 × 5 pattern are easily movable; it resists the propagation of cracks [30, 32]. The fracture toughness of the 5 × 5 pattern is 6.3% higher than the 1 × 1 pattern and 13.02% higher than the 3 × 3 pattern.

4. SEM Study

SEM images are taken to examine the interfacial properties, internal cracks, and internal structure of the fractured surfaces of the specimens [33]. SEM images of tensile, flexural, and impact tests were examined. The SEM images of the pattern having intermediate results (second highest results) from respective experiments were considered, as they might be used for further morphological studies. For tensile, flexural, and impact tests, 3 × 3, 3 × 3, and 5 × 5 patterns showed intermediate results; as a result, these SEM images were examined. Figure 20 depicts the SEM images obtained from the tensile test of the 3 × 3 pattern.

According to the SEM study, the matrix element bonded well with the reinforcing fibers. The fibers, however, were

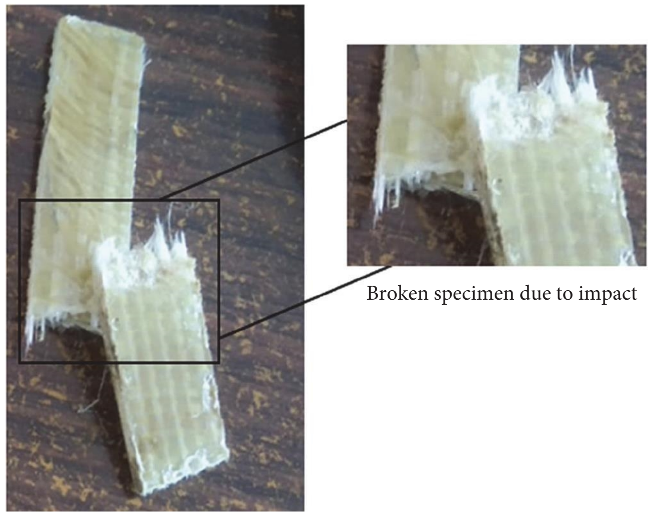

FIGURE 17: A test specimens completing izod impact test.

TABLE 8: Mode-1 fracture test results.

Orientation	Load P (N)	Length W (mm)	Thickness B (mm)	Crack length A (mm)	Fracture toughness K (MPa)	Average fracture toughness (MPa)
1 × 1	1,410	31.6	3.2	14	373.27	552.43
	1,455	32.5	2.8	13.2	668.17	
	1,470	31.3	3	11	555.04	
	1,355	32.9	3.1	14.7	613.24	
3 × 3	1,365	32.5	3.1	11	464.61	513.13
	1750	31.6	2.8	10	635.09	
	1,035	32.2	3	14.5	504.28	
	1,055	32.6	2.9	13	448.54	
5 × 5	1520	32.5	2.9	14	720.11	589.94
	1,180	31.2	2.8	11	478.04	
	1905	31.8	3	12	769.23	
	1,190	32.5	3.2	10.9	392.39	

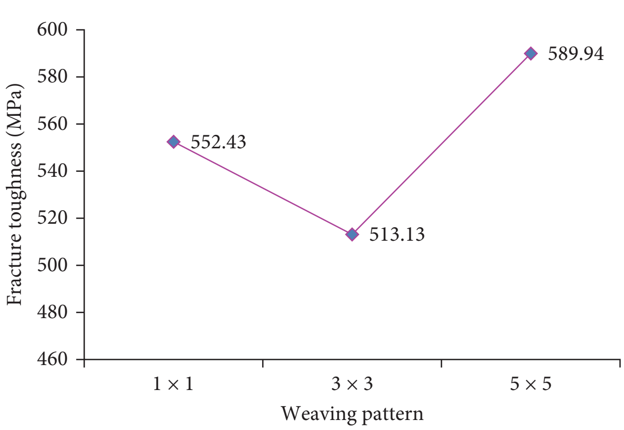

FIGURE 18: Fracture toughness vs. specimens orientation.

FIGURE 19: A test specimen undergone Mode-1 facture test.

ripped out due to the tensile load. Due to the applied tensile force, the reinforcing fibers were pushed out of the matrix and fractured by snapping in a brittle way. It is also deduced that during the tensile load, the fibers contribute primarily to the resistance to the imposed tensile load.

Figure 21 illustrates the SEM images obtained from the flexural test of the 3 × 3 pattern. According to the SEM examination, the reinforcement fibers deflected due to the shear

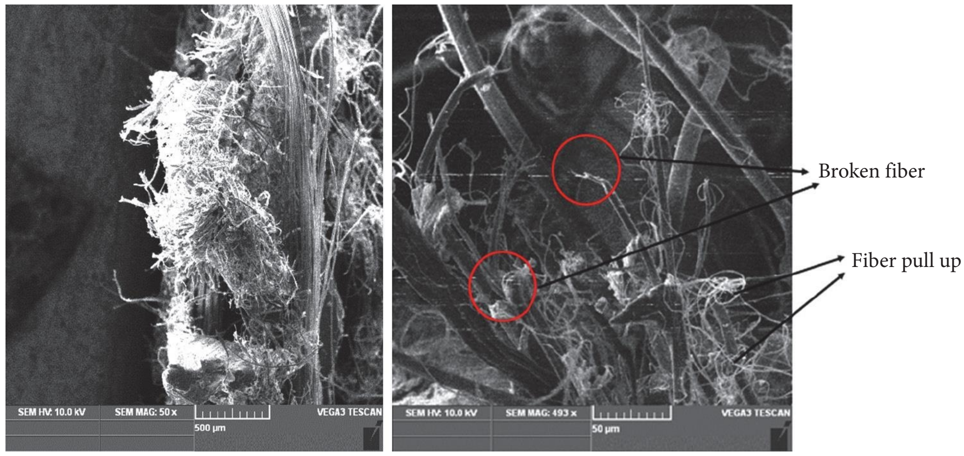

Figure 20: 3×3 Tensile test SEM images.

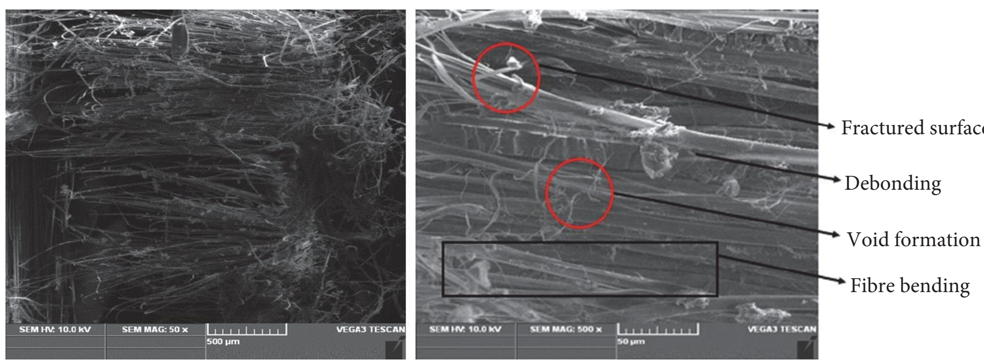

Figure 21: 3×3 Flexural test SEM images.

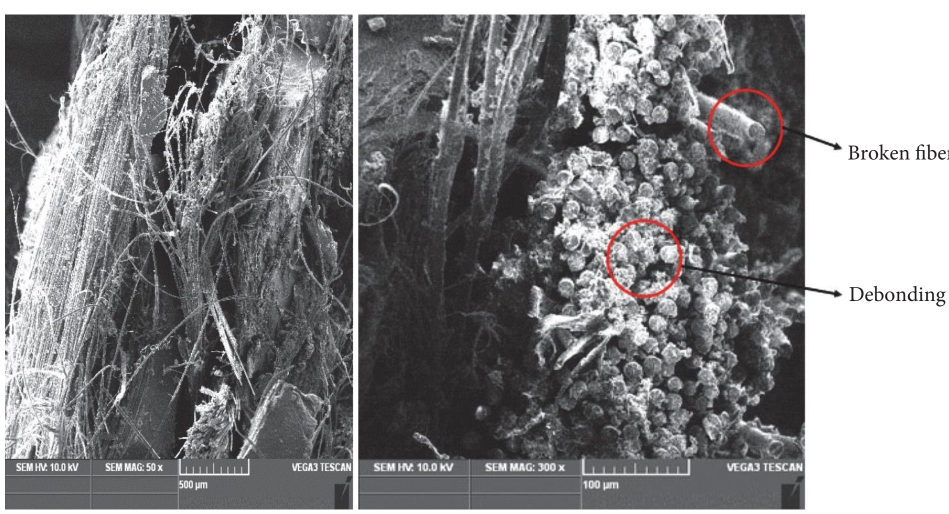

Figure 22: 5×5 Impact test SEM images.

force communicated through the three-point bending load. The matrix element crumbled due to the shear force, causing the reinforcing fibers to become misaligned. As a result, the fiber strands were intertwined. On the other hand, a layer of reinforcement fiber directly above the three-point bending load was unaffected. This demonstrates that the bending load affected the locations with higher shear strength.

Figure 22 shows the SEM images obtained from the impact test 5×5 pattern. The impact force caused the matrix element to break into a brittle mode due to the impact force, as observed via the fragments of the material in the SEM image. All the matrix elements along the impact path of the impact were crushed into smaller bits. Shear distortion caused the fibers in the middle layers to be pulled from their weave. The fibers were also extensively damaged when the matrix element burst due to the impact force. The images are evident that delamination and fiber breakage occurred due to impact.

5. Conclusion

The tensile, compression, flexural, shear, impact, and Mode-1 fracture response of Kevlar/glass-reinforced interwoven epoxy laminates of different weaving patterns were investigated.

Overall 1×1 weaving pattern showed its dominance as the plain weave is less pliable and holds wrap and weft well.

The highest tensile, compressive, and flexural strength is found in the 1×1 pattern; plain fabric has a higher number of crossover points and is less porous.

As a result, the 1×1 pattern finds applications in the aerospace and transportation sectors. The shear strength and fracture toughness were found to be higher in the 5×5 pattern.

In the case of impact strength, the 3×3 pattern demonstrated its dominance as it has high impact strength; this laminate can be used in bulletproof applications and applications in the Aerospace industry, such as constituents of fighter aircraft.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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