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Mechanical Property Assessment of Hybrid Composite Laminates Composed of Jute Glass Fibers in Combination with Flax, Hemp, Sisal and Kenaf Fibers Using the Hand Layup Technique

Abdul Rehman[1,*], G.S. Lathkar[2], V. B. Suryawanshi[3], M. Zubairuddin[4]

Abstract

The present work compares the properties of various hybrid composite laminates manufactured using the hand layup technique and addresses their production process, based on glass fiber as the exterior layer and natural fibers (flax, hemp, kenaf, jute, and sisal) as interior layers, in an epoxy resin. Five stacking sequences A-GJJJJG, B-GFJJFG, C-GHJJHG, D-GKJJKG, and E-GJSSJG were used to prepare the test specimens. According to ASTM guidelines, experiments were performed to determine tensile, flexural and impact behavior. Scanning electron microscopy was employed to evaluate fracture surfaces. The mechanical performance of laminates A and C appears to be superior among all five laminates. It is found that the stacking sequence affects the mechanical performance of the hybrid laminates considerably. Hemp (GHJJHG) containing laminates had highest tensile strength, whereas the laminate having jute (GJJJJG) exhibited the highest flexural strength and impact resistance. The presence of good interfacial adhesion between the hemp fibers and the matrix, as determined from the SEM analysis, was found to contribute to the better mechanical properties observed. One of the most significant advantages of natural fiber composites is their biodegradability. Synthetic and natural fibers can be effectively combined to form composites that provide an optimum balance between strength, weight, cost and environmental consideration. It is the ability to customize these materials by choosing specific fiber types and stacking sequences that makes them even more versatile making them suitable for a wide range of applications across various industries.

Keywords: Hybridization, natural fiber, mechanical testing, SEM, hand layup.

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INTRODUCTION

Natural fiber-reinforced polymer composites have attracted substantial interest for their biodegradability, cost-effectiveness, and sustainability. However, limitations like low mechanical strength, moisture absorption and manufacturing methods hinder their application. To overcome these drawbacks, hybridization is an excellent strategy. Natural fibers (such as flax, hemp, sisal, kenaf, bamboo, and wood) and synthetic fibers are combined in composite materials through hybridization, enhancing mechanical and physical characteristics. Hybridization of natural and synthetic fibers provides an optimal balance of strength, weight, cost, and sustainability. By accurately selecting fiber types and layering sequences, composites may be adapted for specific applications such as the automobile sector, aircraft components, and sports equipment[13]. Natural fiber polymer laminated hybrid composites employing flax and glass fibers were examined for tensile, compression, impact, and flexural characteristics. The hybrid composites demonstrated enhanced mechanical performance compared to standard materials. [1] The organization and stacking sequence of fibers considerably impacts the mechanical characteristics of natural fiber composites. [2]. Putting synthetic glass fiber in extreme layers improves hybrid composites' flexural and impact resistance [3]. The mechanical strength of Kenaf/glass hybrid samples is 40-50% greater than when flax, sisal, and aloe Vera are mixed with glass fiber. [4]. When jute/glass hybrid composite substituted traditional material, weight savings of 23% and cost reductions of 20% were realized for applications in the aerospace and navy industries [5]. Produced channel sections out of carbon, glass, and flax jute hemp, natural fibre composite channels showed equivalent compression resistance compared to glass fiber composite channels [6]. Mechanical tests were carried out by varying the thickness of flax/basalt hybrid composites; thinner laminates have acceptable mechanical properties [7]. The bamboo-sisal hybrid composite was successfully fabricated; hybrid composites, such as interior panels, are excellent for lightweight vehicle applications where outstanding mechanical performance is not needed. [8]. By changing the fiber matrix ratio, banana and glass hybrid composites were evaluated for tensile and impact resistance. The mechanical characteristics of banana fiber reinforcement are comparable to those of glass fiber [9]. Studied the effect waste coffee bean addition in glass epoxy composite [23]. Several laminate stacking sequences, including jute, kenaf, and E-glass woven textiles, reveal that laminates with glass and kenaf skin and jute core layers have superior mechanical properties. [10]. Mechanical properties of jute, sisal, and hemp hybrid composites were evaluated, and jute glass hybrid laminate demonstrated better mechanical capabilities; the material has prospective uses in automobiles, aeroplanes, and sports. [11]. Hybrid laminates consisting jute, flax and glass composites absorbed more energy during impact as compared to glass epoxy laminate [14].Drop weight impact test conducted on jute glass hybrid laminates, When the amount of jute in glass/jute hybrid composites increases, the damage area decreases[15].Improvement in the thermal and mechanical properties of natural fibers have been extensively studied [24-31] .The recent literature research found that jute/glass hybridization and its effect on the mechanical and physical properties of hybrid laminates are studied by most researchers. This research aims to examine the impact of replacing a jute fabric layer with alternative natural fibers, such as flax, hemp, kenaf, or sisal, in a jute-glass hybrid composite, with a focus on their mechanical properties. To attain the best flexural and impact strength for a given fiber count, more muscular fibers are put in the outer layers and weaker fibers in the centre.

MATERIALS AND METHODS

Materials

Glass fiber along with five bidirectional natural fibers i.e. Jute, kenaf, Hemp, flax and sisal, and LY556 Epoxy resin and Aradur HY951 hardener are used in this study. The thickness of all the fabrics varies from 0.312 to 1.07 mm.

Methodology

Hybridization

The current research uses five different laminates, each with six layers. Table 1 shows Fiber with the highest tensile strength is placed at the extremity, and the lowest tensile strength fiber is kept in the middle. All laminates will contain two layers of Glass fiber at the extreme fiber. One laminate will contain 4 layers of Jute; for the remaining four laminates, two jute layers will be replaced by sisal, hemp, flax and kenaf. The weight measurement was done for all the fabrics before fabrication to calculate the fiber volume fraction of the finished laminates.

The laminate stacking sequences listed below have been used:
A-GJJJJG
B-GFJJFG
C-GHJJHG
D-GKJJKG
E-GJSSJG

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Table 1. Properties of Glass and Natural Fibers [16-20].

S no	Fiber	Young's modulus (Gpa)	Tensile strength (MPa)	Density (g/cc)	% Elongation
1	Glass	76	2000–3500 (2750)	2.5–2.59	1.8–4.8
2	flax	60	345-1500 (922.5)	1.4-1.5	2.1
3	hemp	45	550–900 (725)	1.48	3.05
4	kenaf	41	223-1191(707)	0.6-1.5	4.8
5	jute	37.5	393–800 (596.5)	1.3-1.46	2.3
6	sisal	15.5	400-700 (550)	1.33-1.5	2.45

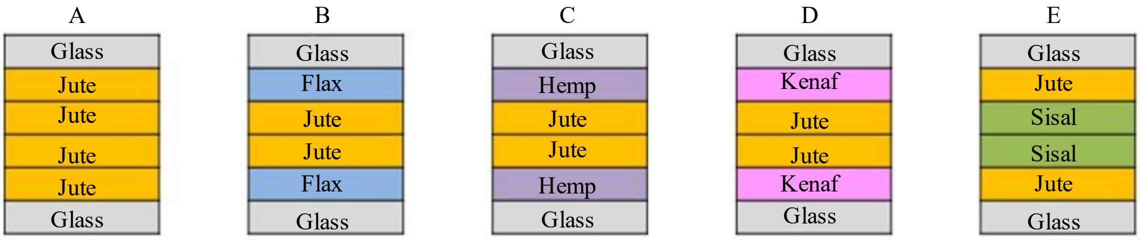

Figure 1. Laminate stacking sequence of hybrid composites.

Manufacture of Hybrid Composites

A matching die tool with a 250 × 250 mm inner cavity was utilized to make square composite laminates by hand layup. For easy removal of the laminates, a coating of wax was added to the bottom of the cavity. To make the matrix, epoxy resin and hardener were blended in a ratio of 100:13. A roller was used to apply a resin coating on the die initially, followed by the first fiber and another layer of the matrix. Each succeeding layer of the composite laminate was created using the same way refer Figure 2. To stop the formation of air bubbles, the fiber mats were thoroughly soaked. The upper die was placed over the mould with enough force to achieve a uniform thickness for the composite panel. The arrangement was left for 24 hours to be cured at 30°C room temperature and normal air pressure. After 24 hours, the composite panels were extracted from the die. Square 250mmx250mm panels have been accomplished. The specimens were carved out of the panels using water jet cutting for mechanical testing. Figure 1 shows the laminates' designations and sequencing. Hand layup resulted in a fiber volume fraction of 22%.Vacuum bagging, resin transfer molding or vacuum assisted resin transfer molding shall result in high fiber volume fraction which will lead to increased tensile and flexural strength.

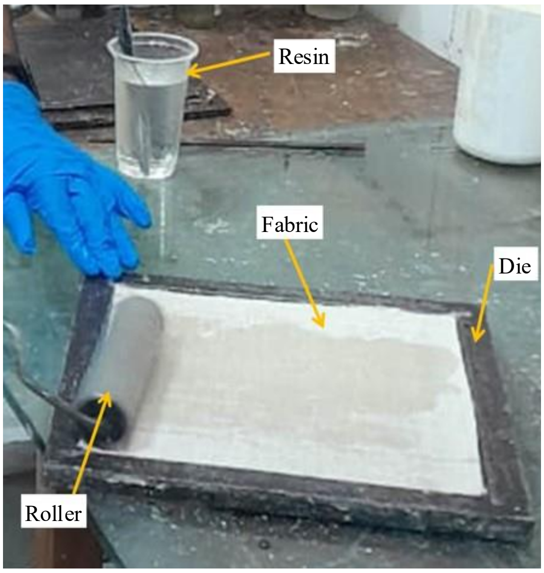

Figure 2. Hand layup process.

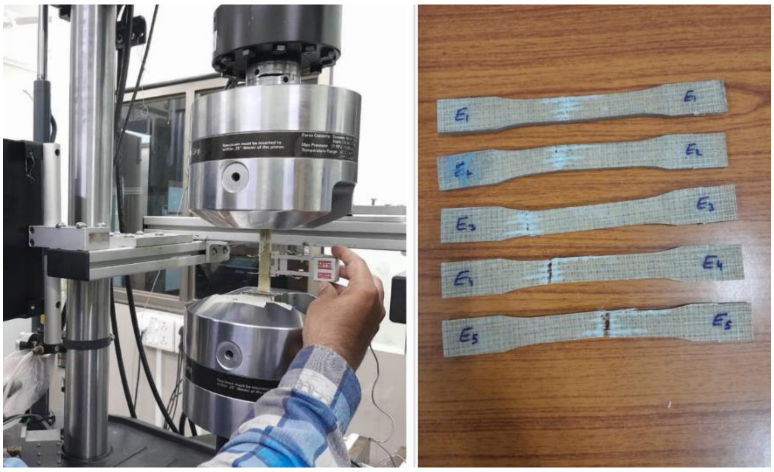

Figure 3. Tensile test setup universal testing machine.

Mechanical Tests

Tensile test

The tensile test of a composite material determines its tensile strength, modulus of elasticity, and elongation at break. MTS Landmark Servo-hydraulic Test Systems is used; the tensile test is performed as per ASTM D 638 with a uniform speed of 2 mm/min. Five samples of each panel have been tested. The test setup, samples after testing are shown in Figure 3.

Flexural Test

The flexural test is essential for understanding composite materials' behaviour under bending loads. ASTM D 790 was used to perform the flexural test. The fittings include adjustable spans and connect scales to ensure the rollers are positioned equally. The top roller's speed was fixed at 2 mm per minute. After testing five identical samples, the average values were used for analysis. The flexural strength was determined using Equation (1).

$$\sigma_f = \frac{3PL}{2bd^2} \quad (1)$$

In equation (1), d, b and L stand for the specimen's depth and width and span length in mm, respectively, and P for the flexural force placed on the composite specimens. The test setup, samples after testing are shown in Figure 4.

Figure 4. Flexural test setup UTM.

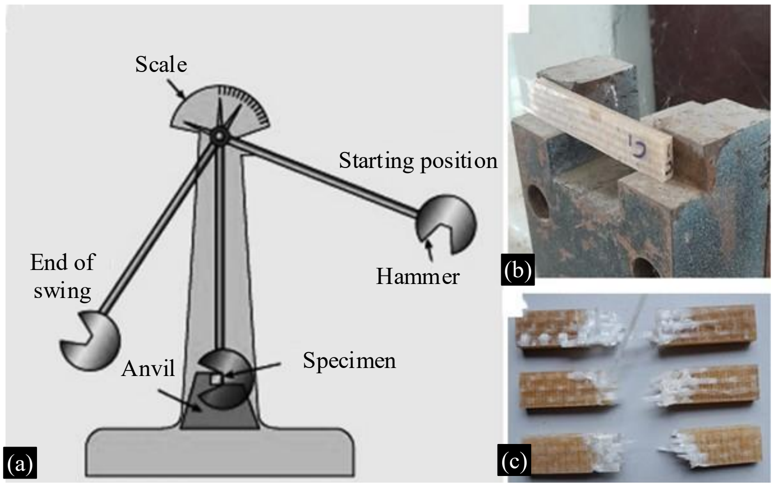

Figure 5. a) Charpy impact test schematic drawing. b) Unclamped specimen. c) composite specimens after the charpy impact test.

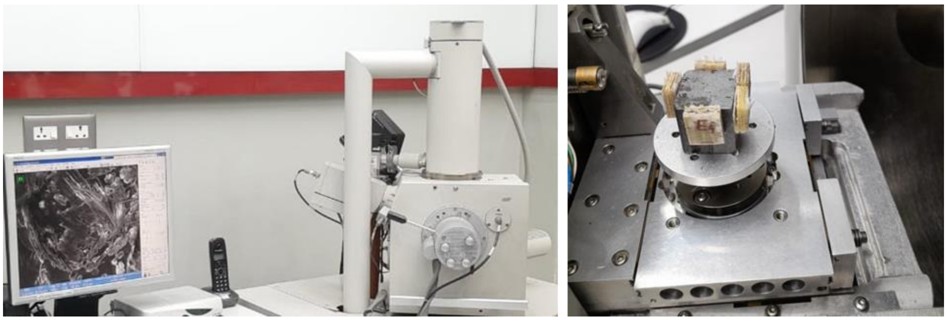

Figure 6. Quanta 200 scanning electron microscope and specimens mounted For SEM.

Charpy Impact Test

The impact test of a composite material is crucial for evaluating its ability to absorb energy and resist sudden forces. Charpy Impact is a single-point test that employs a swinging pendulum to measure a material's resistance to impact force. The kinetic energy necessary to initiate and maintain a fracture until the specimen breaks is referred to as the Charpy impact. The standard-sized specimen is supported unclamped at both ends and placed horizontally. The hammer strikes the specimen once it is released. The test setup, samples before and after testing are shown in Figure 5.

Scanning Electron Microscopy

As shown in Figure 6, A Quanta 200 Scanning Electron Microscope was used to analyze the fracture surfaces of the specimens experiencing tensile failure. Before imaging, the specimens were gold sputter coated.

RESULTS AND DISCUSSION

Tensile Test

Figure 7 shows Test Force-Displacement response of all five laminates. The Micro cracks in the matrix generated by tensile loading start in the weaker matrix area and move toward the fibers. There is evidence of fiber breakage. Fiber Pullout was the outcome of weak fiber-matrix adhesion areas.As predicted, the tensile strength of laminates A, C, D, and E is like that of jute, hemp, kenaf, and sisal, as found in most literature and is depicted in Table 1. The best performance is demonstrated by laminate C with the stacking pattern GHJJHG. This finding was consistent with hemp/jute/hemp composites, with increased tensile strength attributed to the jute core and hemp skin layers [21]. B has the weakest performance among hybrids; this may seem surprising given that flax has the highest strength of any natural fiber employed. In this case, the deceiving outcome is because of hemp's higher quality interface than flax [28].

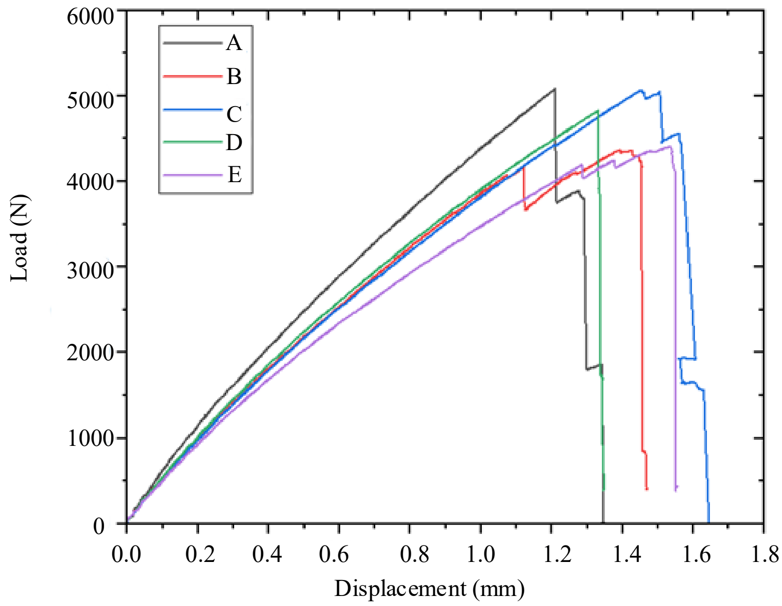

Figure 7. Tensile test force-displacement response for all five stacking sequences.

Flexural Test

Tensile failure occurs on the composite's lower surface. Under bending load, the composite's upper surface undergoes compression failure. Micro cracks in the matrix are caused by flexural stress. The force-displacement curves in Figure 8 for each of the five composites have a typically identical form. The curves show a force-displacement response that increases linearly and steadily, then yields and softens after yielding. Laminate A, consisting of jute and glass, depicts maximum flexural strength. Laminate C has shown maximum deflection before yielding. Laminate A has better flexural strength because the core jute layers prevent failure by providing good stress transfer [18]. SEM characterization of laminate C revealed that there is good interfacial adhesion between the hemp fiber and matrix, which resulted in increased flexural strength. Figure 9 depicts comparison of tensile and flexural strength of all laminates.

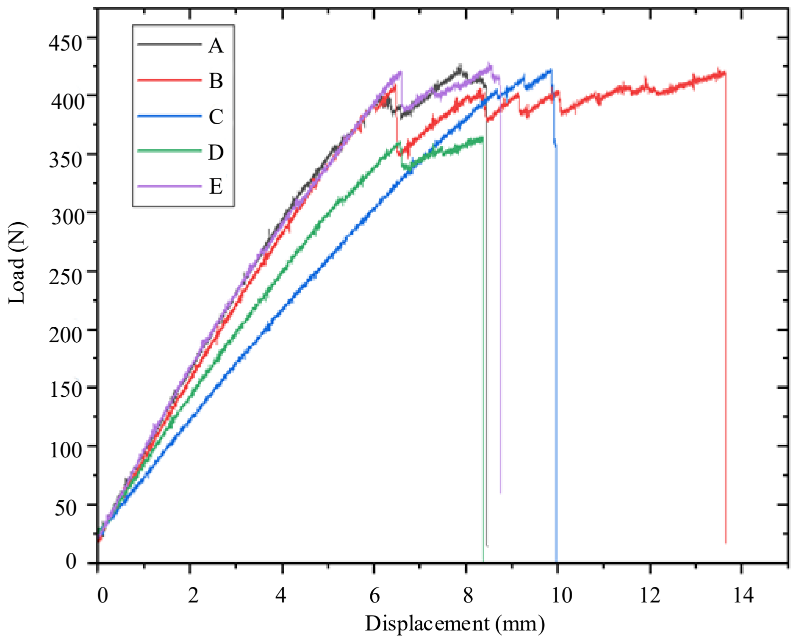

Figure 8. Flexural test force-displacement response for all five stacking sequences.

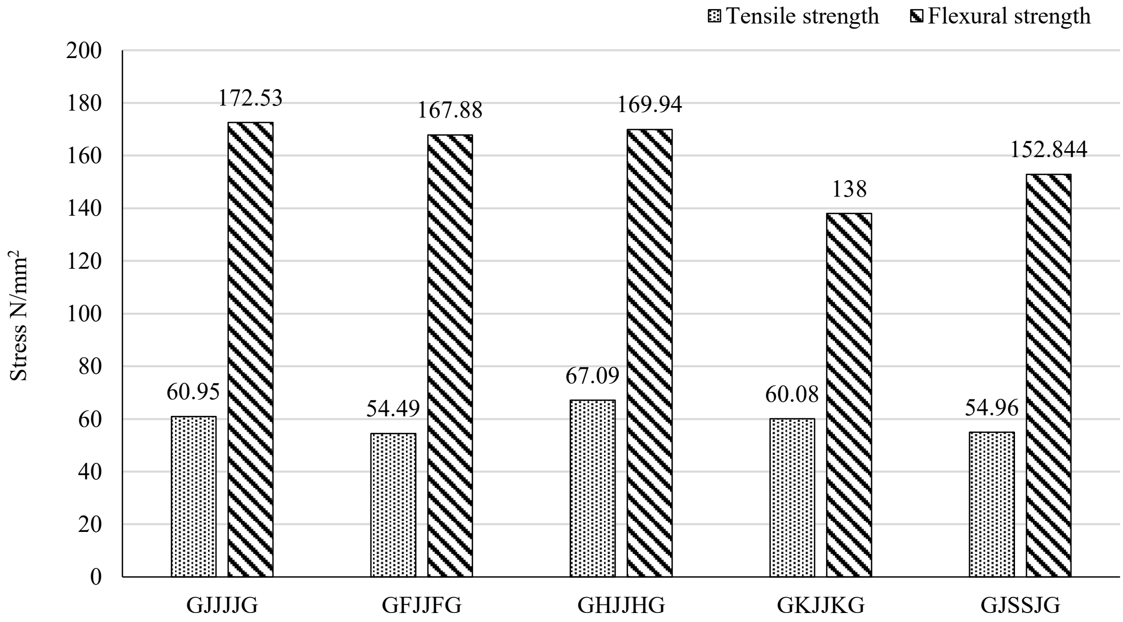

Figure 9. Tensile and flexural strength of composite laminates.

Charpy Impact Test

The failure initiated with matrix cracking followed by sudden fracture of glass fibers and progressive damage in natural fibers. The impact strength values are given in Table 2 and shown Figure 10. The laminate A, containing four jute layers, shows the best impact performance when compared with other laminates containing two jute layers. Jute fibers have high hemicellulose percentage and low cellulose percentage, which results in low stiffness and good impact resistance, as reported by [12, 21]. Several factors influence the Fiber-reinforced composite's impact strength; a significant factor is fiber-matrix interfacial adhesion. Natural fibers can be treated with alkali, silane, or plasma to increase fiber-matrix adhesion and decrease debonding under fatigue and impact scenarios. Investigate nano-coatings (such as carbon nanotubes or graphene) to improve toughness and interfacial bonding.

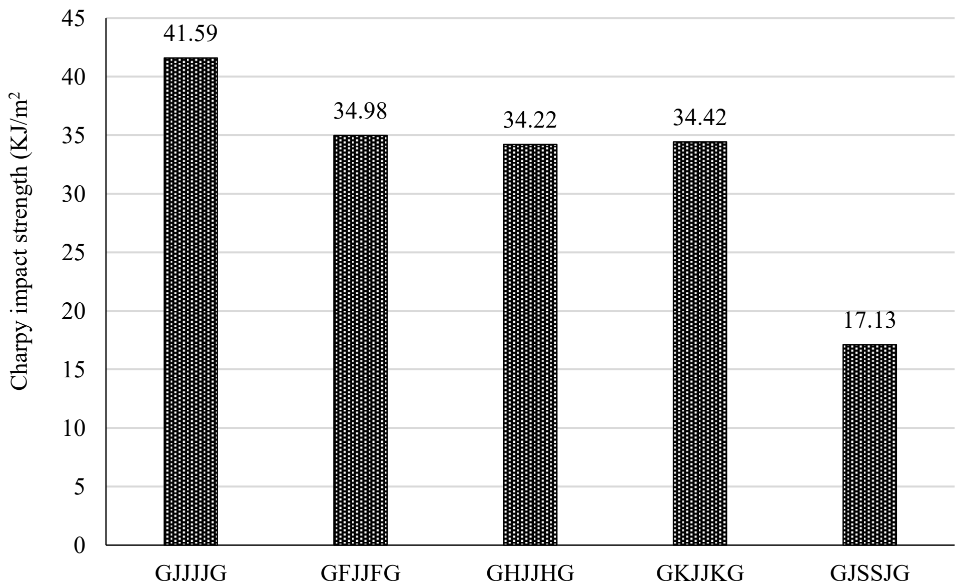

Figure 10. Impact strength values of composite laminates.

Table 2. Composite Laminates' Mechanical Properties.

S no	Laminate stacking sequence	Tensile strength MPa	Young's modulus (GPa)	Flexural strength MPa	Charpy impact kJ/m^2
1.	A-GJJJJG	60.95	5.34	172.53	41.59
2.	B-GFJJFG	54.49	5.31	167.88	34.98
3.	C-GHJJHG	67.09	5.08	169.94	34.22
4.	D-GKJJKG	60.80	4.92	138.00	34.42
5.	E-GJSSJG	54.96	4.64	152.84	17.13

Scanning Electron Microscopy

All samples failed due to fiber breaking when the tensile force was applied. Figure 11 shows SEM micrographs of broken hybrid composite laminate specimens under tensile pressure. Laminate C demonstrated excellent strength; Figure 11 (a) demonstrates substantial interfacial adhesion between the matrix and hemp fiber. The same phenomenon was found in the pure hemp composite [21]. SEM analysis of laminate B containing flax reveals a brittle fracture with a weak interface (Figure 11 d); comparable findings were reported by Petrucci. et. al [22].

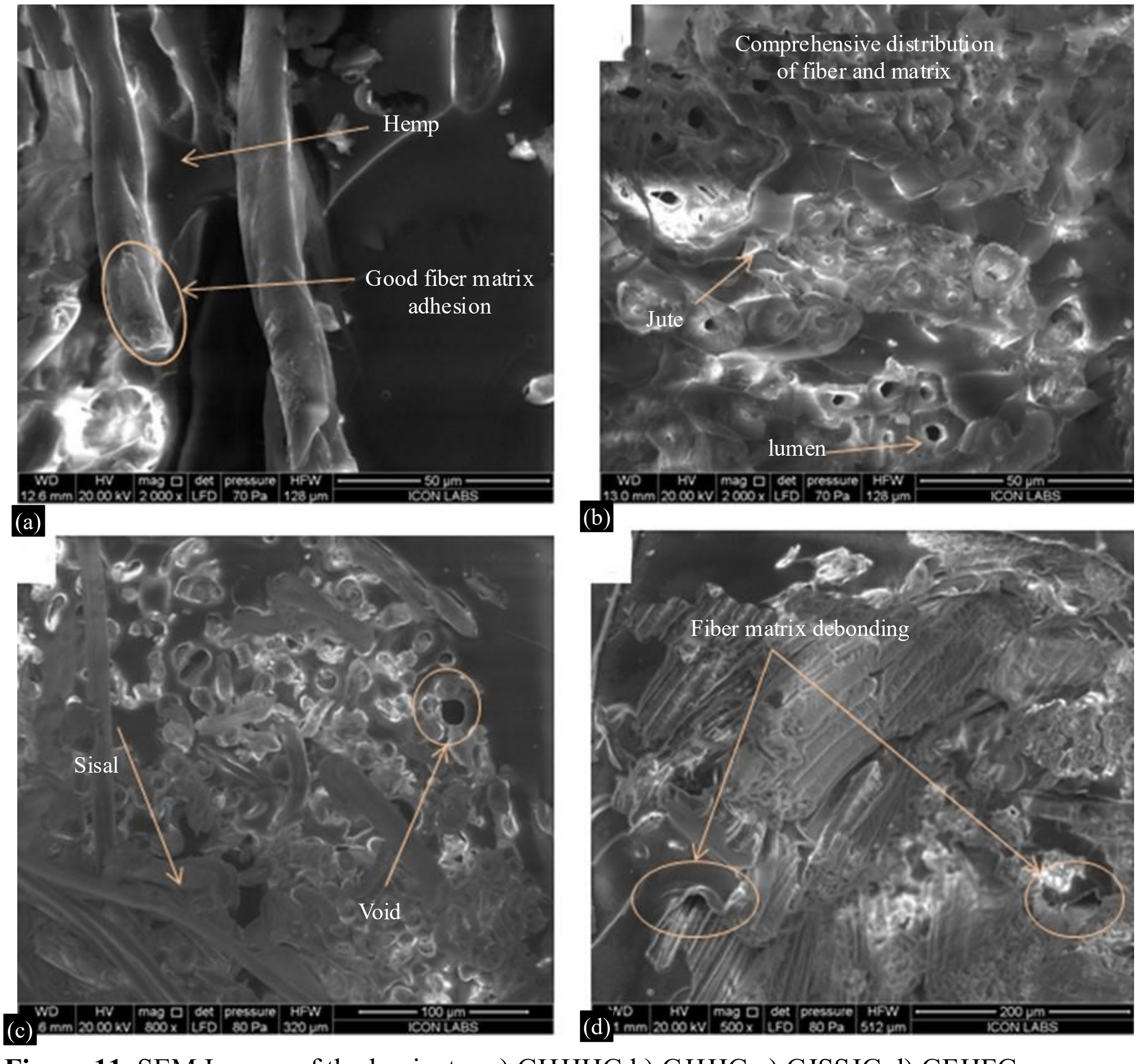

Figure 11. SEM Images of the laminates a) GHJJHG b) GJJJJG c) GJSSJG d) GFJJFG.

CONCLUSION

Glass and natural fiber hybrid composites are thoroughly investigated through mechanical testing. The Hand layup method successfully fabricates the composite material. The fabric of Jute, flax, hemp, kenaf, sisal and glass, with epoxy resin, is employed to create the hybrid composites. Laminate C, containing hemp with jute/glass combination, has shown the best overall performance, with laminate A which has only one natural fiber, i.e. Jute with glass fiber following closely behind. SEM micrographs demonstrate that compared to other natural fibers used in this study, hemp exhibits a superior interfacial interaction between the fiber and the matrix, improving the laminate's mechanical characteristics incorporating hemp fiber. Natural and synthetic fibers are hybridized to balance strength, weight, affordability, and sustainability. Engineers may adapt composites to specific purposes by selectively choosing fiber kinds and stacking sequences. However, future studies should focus on durability, moisture resistance, and recyclability to improve hybrid composites.

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