Hindawi
International Journal of Chemical Engineering
Volume 2022, Article ID 1864446, 9 pages
https://doi.org/10.1155/2022/1864446

Research Article

Experimental Investigation on Mechanical Properties of Glass Fiber Hybridized Natural Fiber Reinforced Penta-Layered Hybrid Polymer Composite

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Received 9 April 2022; Revised 20 May 2022; Accepted 13 June 2022; Published 26 June 2022

Academic Editor: G. L. Balaji

This article investigates and presents the upshots observed in the brook of hybrid composites especially, the current investigation focuses on the impact of fiber composition, sequence, and stacking pattern on composite mechanical Features. Five varied stacking sequences of hybrid composites encompassing laminates are used to create four classes of fiber with jute/bamboo/glass by utilizing a conscientious hand lay-up process with glass fiber-laced mats as their peripheral layer. For examination, fiber sequences are arranged in the combination of GJBJG, GBJBG, GJGJG, and GBGBG, where G, J, and B refer to glass fiber, jute fiber, and bamboo fiber, respectively. The position of fiber in the core layer is kept in a perpendicular direction with respect to adjacent piles which might be jute or bamboo fiber and the best position of fiber is considered due to the stacking order. Stress and strain were linear in the load versus deflection curves, and all of the samples failed quickly, it is observed that the sample containing a higher or considerable number of bamboo fiber layers exhibited increased strain and toughness. In comparison to other samples, embolism of glass fiber as the main and covering layer expressed a higher impact on the mechanical properties of the composites is observed in this investigation. The shattered sample morphology demonstrated that the matrix and reinforcements were compatible.

1. Introduction

Polymer science is being used in a variety of applications, and polymeric materials are lighter and cheaper than older materials [1]. In the composites business, carbon, boron, aramid, Kevlar, glass, and other fibers are used to reinforce polymeric resins. Natural fibers are becoming increasingly popular due to increased environmental concerns, despite their reduced strength. The abundant availability, non-corrosive qualities, decent strength, biodegradability, and low density, which

Figure 1: Fibers extracted from plants and their sources.

implies reduced weight, would benefit the consumer and industrial items [2]. Natural fibers like flax, sisal, hemp, coir, and palm have been widely utilized for reinforcing polymers for many years, and research into new fiber sources has increased in recent years [3]. Stiffness and specific strength are high in these fibers, making them appropriate for structural applications [4]. Hybridization is a technique for improving the mechanical strength of fibers and composites by combining many types of reinforcement in one matrix [5]. It is done to adjust the properties of composites to meet the needs of the application while maintaining the properties' balance [6]. Hybridization of the fiber is now done using two natural fibers blended with artificial [7] due to greater environmental consciousness and worries about renewability. The stimulus of stacking order on the properties of mechanical hybrid mixtures reinforced with kenaf and areca fibers was studied, and it was shown that hybridization considerably improves strength. Abaca-jute-glass fiber-reinforced epoxy mixtures' mechanical properties were studied, and hybrid composites were shown to have higher shear and tensile strength. Abaca fiber-reinforced mixtures, on the other hand, outperformed hybrid composites in terms of flexural and impact qualities [8]. Knitted mixtures and woven reinforced with hemp, flax, and jute fibers, commingling techniques were investigated. Knitted composites have been claimed to have superior mechanical characteristics to woven composites [9]. The primary goal of this research is to use ASTM impact test (ASTM D 256), flexural test (ASTM D790), and tensile test to investigate the mechanical properties of a jute/bamboo/glass fiber-reinforced hybrid polymer composite (ASTM D 790; in accordance with ASTM D638).

2. Materials and Methods

2.1. Bamboo. Bamboo fiber composites are becoming increasingly popular as a viable alternative to chemical-petroleum-based materials. Although there have been research into bamboo fiber removal technique, bamboo handling strategies, and carbon fiber interlacing designs that approximate the replicas we linked, there are no present studies to improve a weaving design [10]. Figure 1 depicts the plant source and obtained jute and bamboo fibers. Various comparison of mechanical property in bamboo, jute, and glass fibers is listed in Table 1 [11].

Table 1: Bamboo, jute, and glass fibers in comparison.

Fiber	Diameter (D) μm	Tensile strength (TS) MPa	Cellulose wt%	Elongation at break (EB) %	Density (ρ) g/cm^3	Young's modulus (E) MPa
Bamboo fibers	10–30	280	65	2.1–5	0.78	18500
Jute fibers	26–255	14–27.6	63–74.5	1.26–1.7	1.4–1.50	395–805
Glass fibers	15–25	70–73	_	2.5	2.55	2000–3500

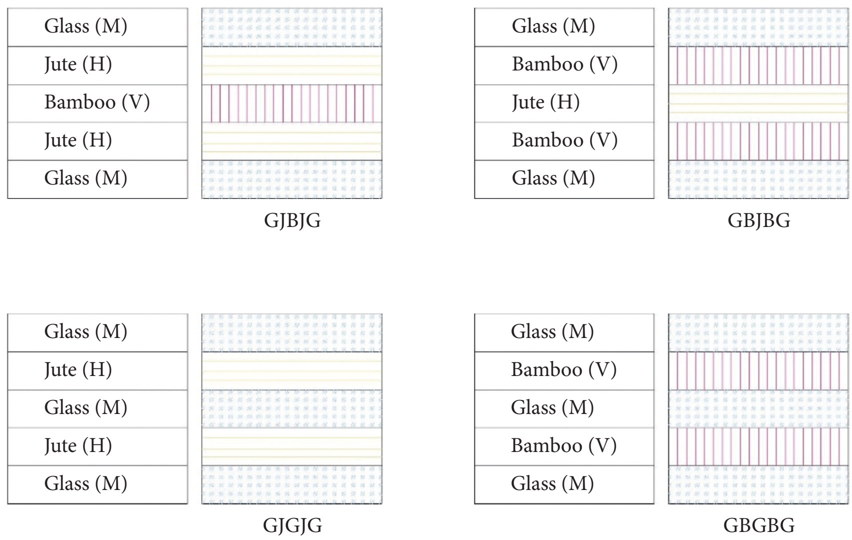

Figure 2: Depiction of the stacking sequence.

Table 2: Hybrid sample fiber-matrix ratio.

	Composition in terms of weight percent			
Samples	Epoxy	Glass fibers	Jute fibers	Bamboo fibers
GJMJG	55	15	30	16
GMJMG	55	15	14	33
GJGJG	55	23	37	—
GMGMG	55	17	—	39

2.2. Jute. Jute, also known as *Corchorus olitorius*, is a Malvaceae plant known for its fiber, which is collected from the plant's best stem. Jute is an herbaceous annual that grows to a height of about 3.5 m and has a finger-sized cylindrical stem. It is widely planted in India and Bangladesh. Fibers are light and inexpensive, and they are extensively utilized to make bags, sacks, packs, and wrappings.

2.3. Composite Fabrication Process. In this survey using a hand lay-up approach, different interaction topologies were constructed for bamboo, jute, and glass fibers which were used as reinforcement for an epoxy matrix. Each model has five layers along with the skin layer being woven glass fiber mat. Horizontally oriented fibers are found in the alternate layers, which were perpendicularly oriented fibers, are found in the core layer. GVR Enterprises in Madurai provided the epoxy hardener (HY951), resin (LY556), and glass fiber matting. B, J, and G represent bamboo, jute fibers, and glass correspondingly, in the hybrid composites GJBJG, GBJBG, GJGJG, and GBGBG, which were created in varied layer sequencing patterns. For sample production, the supplier recommended a 10:1 mix of epoxy resin (LY556) and hardener (HY951). The plies' thickness and the composites' weight ratio (55% epoxy and 55% fibers) were kept consistent throughout all samples. Figure 2 shows the stacking sequences of the various composite samples formed, and Table 2 shows the fiber-matrix ratio.

2.4. Tensile Properties. The materials' tensile qualities were investigated using an ASTM D 638 Dual Column Digital UTM with a 10 kN load located at the Associated Scientific Engineering, India. The samples were 165 mm by 19 mm by 2.5 mm, and the examinations were performed at room temperature by a crosshead swiftness of 1.1 mm/min.

2.5. Impact Strength. Using ASTM D256 standards, the impact strength of a rough specimen of 65.5, 12.7, and 3 mm was examined. The pendulum of the machine was dropped on the workpiece, and the greatest energy gained by the workpiece was measured to examine three times, with the middling value being provided each time.

2.6. Flexural Properties. Using an ASTM D790 universal testing equipment with a crosshead speed of 2.5 mm/min, the flexural characteristics of composite samples with dimensions of 100 mm, 12.7 mm, and 3 mm were examined.

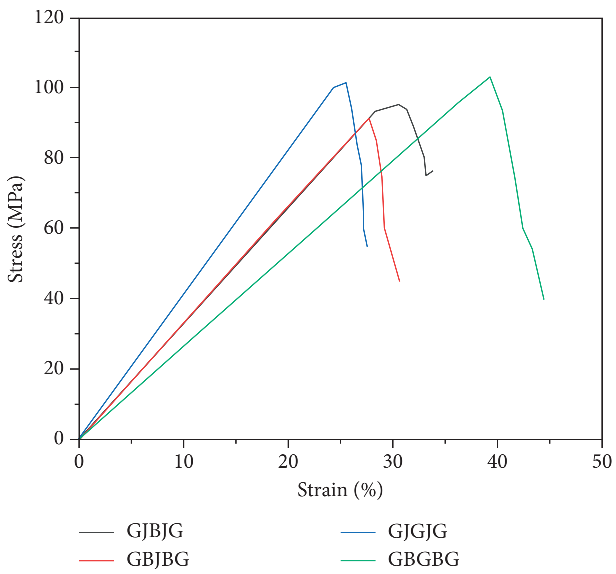

Figure 3: The composite stress-strain curve.

2.7. Morphological Analysis. To investigate the fiber/matrix interaction, an SEM was used to examine the broken surfaces of the samples. Before being inspected, the shattered samples' surfaces were gold sputtered with an ion sputter apparatus.

3. Results and Deliberation

3.1. Tensile Characteristics. The mechanical properties of composites are influenced by factors such as fiber physical attributes, fiber content, and fiber/matrix interfacial bonding. The greatest impact on the tensile strength was found in the modulus of reinforcements. In the GJBJG specimens, an examination of the tensile property was conducted in the linear connection between applied stress and strain produced. Figure 3 shows the stress versus strain arc of mixtures. The stress versus strain curve began to flatten and followed a linear trend until it reached 95.56 MPa and a 32% strain. Then, the sample becomes brittle with a rapid decline in stress and a maximum strain of 33.75%. Glass fiber plies surround jute fiber plies on both sides of this sample's outer layers, with bamboo fibers serving as the core layer. The slope of the graph steadily rose as a result of the relatively higher elongation of the bamboo fibers in the core. The sample collapsed catastrophically when the stress levels reached 91.74 MPa. This is in line with composites that have a kenaf fiber skin layer [12]. The difference between the samples is the maximum tensile stress they can withstand. This sample's tensile strength was 101.65 MPa with a strain of 30.56%, which was much lower than the GJBJG sample's tensile strength. This is owing to the lower strength, higher cellulose content, and lower elongation percentage of bamboo fibers compared with jute fibers [13]. As shown in Figure 3, the composite failure is slightly less catastrophic in this situation. The bamboo fiber distorted significantly at lower weights, failing with a maximum strain of 30.56% and a high micro-fibrillar angle [14].

The stress versus strain graph for the GJGJG sample is practically linear compared with the first two types of samples. With a strain of 27.3%, the extreme obtained TS was 101.8 MPa. Glass fiber layers assist as the covering and main layers in this specimen, with jute fiber plies implanted among the covering and main layers on both sides. The glass fibers were robust plenty to transmit the loads, and the model failed in a less dreadful way, indicating shear failure mode [15]. Because bamboo fibers are not present in this sample, it has the lowest elongation percentage among the four. GBGBG, in contrast to the further trials, shows stress and strain in a dissimilar way. The sample's strain was significantly less linear until the stress hit 61 MPa, at which point the curve begins to increase with a sharp slope. Due to its stretching nature, bamboo fibers elongate when the weight is shifted from glass fibers to them, resulting in an increase in slope. For a strain of 44.35%, the curve touched a maximum obtained TS of 103.41 MPa. The stress curve did not shift, and it will remain rectilinear with the strain until its breakdowns. The area beneath the curve is the largest, indicating the composites' toughness. Mechanical properties of hybrid composites can explain the consequences of the differential in extension to failure among jute and bamboo fibers. Figure 4 depicts the tensile strength of the samples. According to the researchers [16], the mechanical strong point of jute fiber strengthened mixtures is higher than bamboo fiber-reinforced mixtures. Stress and strain arcs show that the trials have a more or less linear performance to a certain point, after which they fail abruptly, except for GBGBG sample, which showed a pseudo-plastic disaster before reaching the maximum obtained stress value [17].

3.2. Analysis of Morphology. Using morphological analysis of the shattered sample, the microstructure of the mixture's specimen, line among fibers, and gum in the progress of interlinking is examined. In Figure 5(a), model GJBJG shows glass filaments in the microstructure of a broken sample with broken ends, suggesting that gum has controlled the fibers. The high interfacial bond between the fibers and the matrix gives the composites their strength [18]. The morphology demonstrates that the fibers in the corresponding plies are completely connected with the matrix. Figure 5(b) shows fragmented fibers, indicating that the fibers are completely maintained in the matrix and do not pull out under external force, as shown in Figure 5(a). This indicates that the fibers are entirely linked to the matrix and unable to bear the forces, as a result, the fibers broke catastrophically without necking [19]. In the shattered sample of GJGJG, Figure 5(c) shows the presence of fibers maintained in the matrix with their ends spread out in the microstructure. This could be owing to the strong external forces that they are subjected to. In the microstructure of sample GJBJG, Figure 5(d) clearly reveals the presence of distinct layers of fibers in different orientations.

Among the length and direction, it is equally vertical. Fibers were kept in their original orientation during composite manufacture and after curing. The fibers kept their orientations after fracture, however, they were bent or

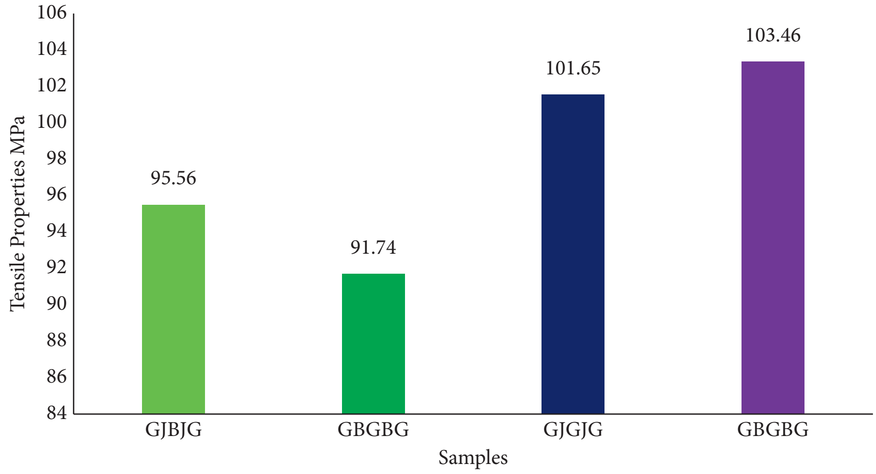

Figure 4: The composites' tensile strength.

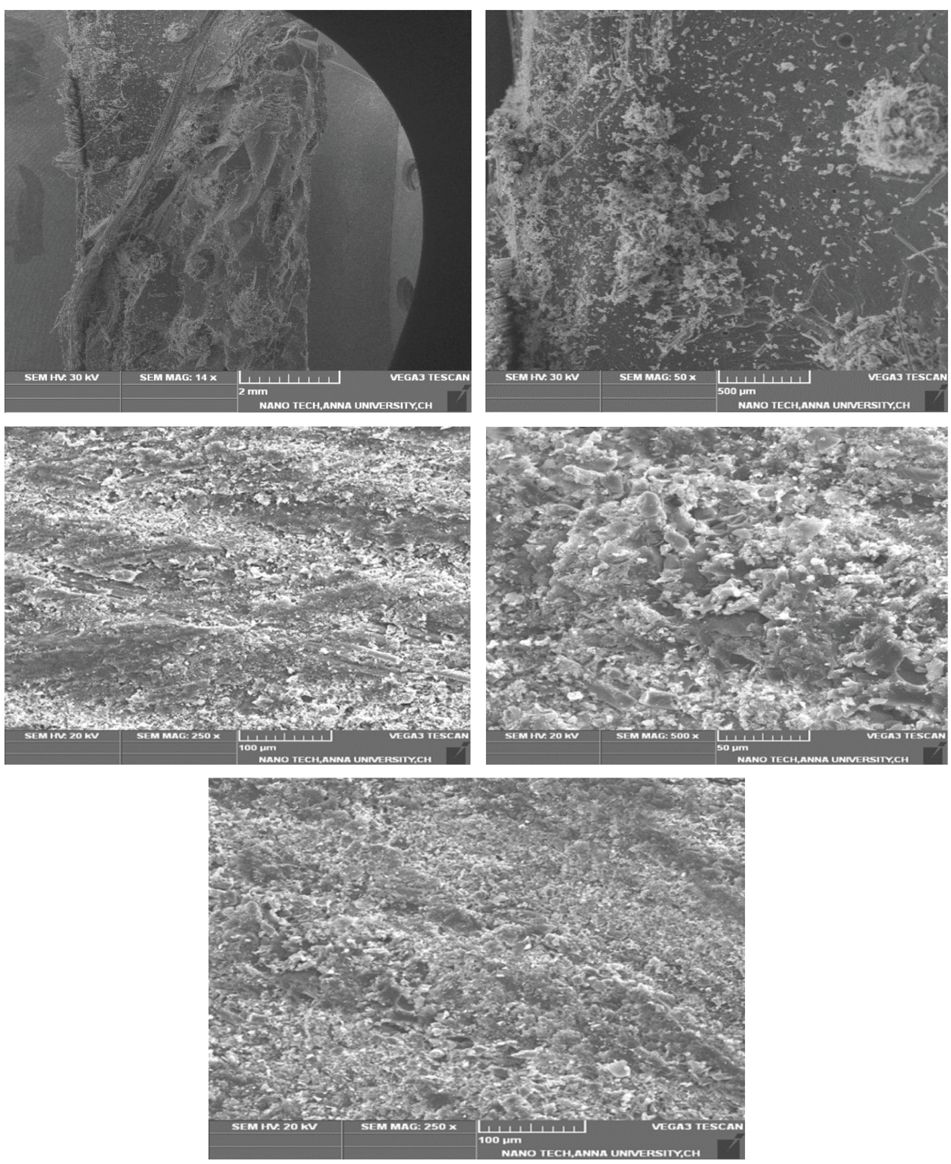

Figure 5: Tensile failure morphology.

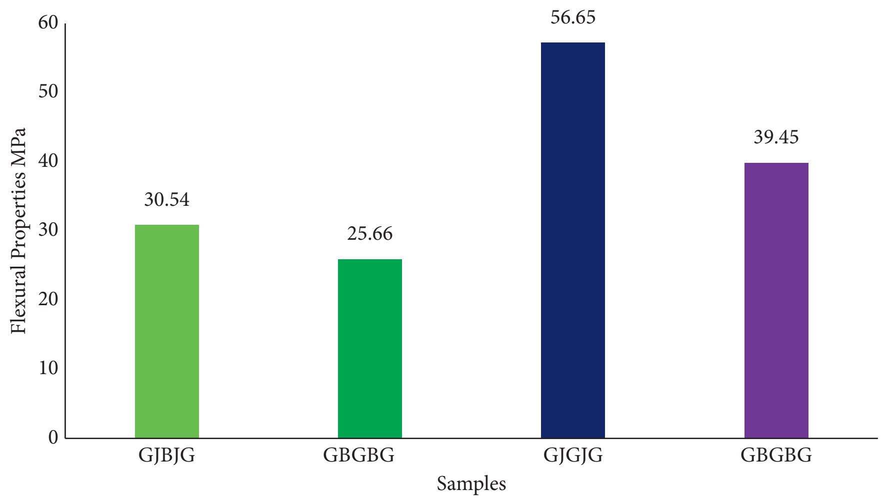

Figure 6: The composites flexural strength.

snapped due to external stresses. In Figure 5(e) of sample GBGBG, glass fibers and biofibers are visible on uniform and less uniform surfaces. Clusters of biofibers were seen; however, they have few non-linearity in their alignment due to peripheral loading, which has led them to reposition. Bending fibers indicates mechanical strength, and they can absorb greater energy during impact tests [20].

3.3. Flexural Properties. Flexural tests are performed to measure the materials' flexibility by subjecting the specimen to solidity, shear, and tensile loads. High flexural strength (FS) materials are firm and fragile to work with. The FS of GJBJG model is 30.7 MPa, which is determined by fiber percentage, ply kind, and then fiber loading sequence. When the horizontal load is applied bamboo fibers enclosing jute fibers in the base layer resist twisting transmission stress from the bamboo fibers to the jute fibers, which is subsequently transferred to glass fibers in the composite's covering layer [21]. GBJBG sample's jute fibers, essential layer resist twisting and transmission stress to end-to-end bamboo fiber layers on both sides. The bamboo fibers bent and transferred the stress to the glass fibers as a result of the tension, subsequent in a slightly lower FS of 25.7 MPa. *Cocos nucifera* composites have flexural strength comparable to this [22]. Due to their lower cellulose content, bamboo fibers have a lower flexural strength than jute fibers [23]. The GJGJG sample, which contains glass fibers at its main and covering layers with jute fibers layered among them, resists bending and has an ideal flexural strength of 56.65 MPa. The glass/bamboo fibers layered GBGBG sample struggles with twisting force and the bamboo fibers layer among the core and skin bends when subjected to stresses, yielding a flexural strength of 39.45 MPa. Lower flexural strength indicates that less stress was moved from the matrix to the fibers, according to earlier studies [24]. Samples GJGJG and GBGBG have a higher FS than samples GJBJG and GBJBG, which is attributed to the presence of a considerable fraction of glass fibers [25]. FS and stiffness are provided by these fibers in the skin layers [26]. Bamboo fiber plies have lower flexural strength than jute fiber plies models because of their extensible nature. The FS of the hybrid composite samples is shown in Figure 6.

3.4. Impact Strength. The low-velocity impact test is used to assess the impact strength of a composite specimen because it can induce matrix cracking, fiber breakage, fiber misrepresentation, retreats, delamination, and debonding of fiber and matrix [27]. If this type of damage goes unchecked, it might lead to disastrous failures. When the mixture sample is distorted by a low-velocity impression, the impact generator's dynamic vigor is absorbed, resulting in damage. Specimen absorbs the same amount of energy that was used to destroy it. The amount of energy required to completely shatter the specimen is known as the absorbed energy. The kinetic energy of the bullet can be efficiently dispersed away from the impact zone by using a material with maximum impact toughness. High energy absorbed specimens are more damaged as associated with other specimens. The composite's higher impact strength, which is reliant on the properties of the composite's constituents as well as the strength of the interlinking bond among the fiber and matrix [28], is ascribed to its ability to absorb energy. GJBJG, GBJBG, GJGJG, and GBGBG have impact strengths of 5.4, 3.6, 6.8, and 6.2 J, respectively, in this study [29]. Sample GBJBG exhibited the lowest impact strength due to the low strength of the bamboo fiber plies around the core jute fiber ply [30]. They have a lesser strength due to their lower cellulose content and strength [31].

Sample GJBJG has a 63.5% higher impact strength than sample GBJBG, which has a solo bamboo layer as the core and is surrounded by jute fiber layers. The impact strengths of samples GJGJG and GBGBG are 102% and 88.5% higher than those of sample GBJBG, respectively, and 22% and 14.4% higher than those of sample GJBJG [32]. The HS glass fiber sheets at the covering [33] and main captivate more vigor than the jute and bamboo fiber sheets crammed among them in examples GJGJG & GBGBG, correspondingly [34], increasing the composite samples' impact strength. The

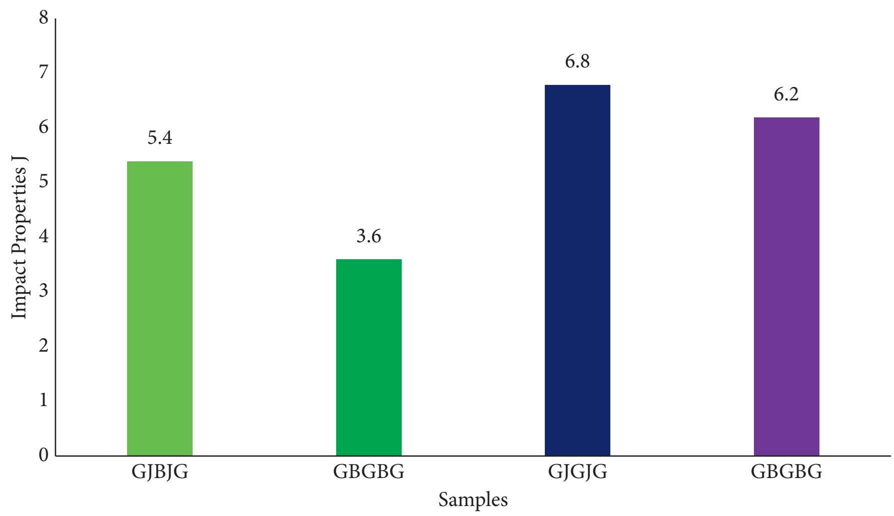

Figure 7: The composites impact resistance.

impact strength values obtained in this study are comparable to that of jute and glass fiber composites [35]. These glass fibers have a more homogenous structure than biofibers and uphold a robust interlinking bond with the matrix [36]. Glass fibers are more effective at preventing crack growth than biofibers. Glass fibers are more impact resistant [37] and transmit weight from the relatively weak biofibers to the robust covering and main glass fiber layers [38]. In general, woven fabrics feature threads are joined in both the warp and weft directions [39]. A perpendicular crack occurs when a fracture spreads through the fiber-matrix border in a way where it will come in contact with fibers in the opposite direction [40]. This causes the fracture to deviate from its intended path, or the break will be stopped by the fiber's strength. Figure 7 depicts the FS of the hybrid mixtures model.

4. Conclusions

This research upshot aimed in presenting the peripheral outline and mechanical performance of penta-layered hybrid epoxy composite-based fiber content. Hybrid reinforcing is done amid glass fiber with jute and bamboo fibers as major constituents. The results and observations of the proposed research work are as follows.

(i) Hybrid composition glass fiber mats along with samples reinforced using jute and bamboo fibers exhibited superior mechanical characteristics. The strength of the composites in the periphery and core is greatly influencing tensile strength, impact, and flexural strength of composites. Predominant bamboo constituted fiber sample exhibited comparatively higher strain and toughness compared with other composites, whereas higher load withstanding capacity, energy absorption capacity and relatively more strength are attained in jute fiber.

(ii) Total samples prepared and analyzed, demonstrated comparative linear stress-strain behavior and it failed brusquely but the sample with more bamboo fiber constituents withstanding more than normal on applying loads. The enclosing layer of the fiber and less amount of extensible fiber at the periphery controlled the flexural strength of the composite vindicating the consequence of the stacking sequence. The efficacy of bamboo, jute, and glass reinforcing are arranged in ascending manner.

Certainly from hybridization, we can deduce the most effective and successful techniques to prepare composites based on synthetic fibers which yield strength, and biodegradability is accomplished by using natural fibers. Comparatively, jute fiber exhibits more strength than bamboo fibers and can survive more stress and strain profile. Observations made from the derived results are voluble that natural fibers are quite active in polymer reinforcing and possess comparatively similar or higher characteristics than glass fiber. Depending on loading, the mechanical response of the composite is also determined by the source of natural fiber. Mechanical properties of hybrid fiber are greatly influenced by their stacking order and strength.

4.1. Scope of Future Work. To prepare a superior composite synthetic fiber that possesses and exhibits superior extreme toughness with biodegradability, hybridization is the most effective technique for investigating all reported techniques. For future scope, we premeditated to work on waste-free processing of natural resources for multi-disciplinary applications [40].

Nomenclature

G:	Glass fiber matting
J:	Jute fibers
B:	Bamboo fibers
ASTM:	American society for testing and materials
LY556:	Epoxy resin
HY951:	Hardener.

Data Availability

The data used to support the findings of this study are included within the article. Further data or information can be obtained 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.

Acknowledgments

The authors thank and acknowledge the management of Vel Tech Rangarajan Dr. Sagunthala, R & D Institute of Science and Technology, Chennai, for their support to carry out this research work. The authors appreciate the supports from Saveetha School of Engineering, SIMATS, Chennai, and Mettu University, Ethiopia.

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