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Mechanical Performance and Hydrophilic Behavior of Jute–Glass Hybrid Composites Fabricated by Vacuum Infusion

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ABSTRACT

The demand for lighter and stronger materials has pushed research toward hybrid composites. In this work, hybrid composites combining glass and jute fibers were fabricated using the vacuum infusion process. The mechanical and hydrophilic behaviors of the prepared samples were evaluated in accordance with the relevant ASTM standard. Ten laminate configurations(S1-S10) were prepared by varying the stacking sequence of glass woven roving, glass CSM and alkali treated jute mats. Hybridization significantly improved performance relative to S9. Sample, S4 showed the highest tensile strength of 172.48 MPa and the highest hardness number of 92 (L scale) compared with the other prepared samples. It also exhibited the maximum flexural strength of 271.04 MPa. The highest impact strength was found in S8 at 64.56 kJ/m^2. The order of stacking jute and glass layers in the laminate also changed the outcome. With a different stacking sequence, tensile stress went up 11.62%, flexural modulus rose 61%, and impact strength increased 60%. Water absorption was studied in both fresh and salt water. Placing glass fiber on the outside of the laminate reduced water intake while Placing jute on the outer layers of the laminate resulted in increased water absorption (1.35%, 0.86%, 3.72%, and 1.26% in different cases). In salt water, the composites exhibited reduced absorption, recording 0.47%, 0.46%, 1.60%, and 0.80% for the corresponding hybrid laminates. The results show that jute–glass hybrids work better than only jute composites. Glass fiber provided strength, while jute gave low cost and environmental benefit. Surface treatment of fibers was also seen to improve bonding and reduce water penetration. These findings suggest that jute–glass composites can be used in cars, boats, and aerospace where strength and sustainability are both needed.

Keywords: Hybrid Composite, Vacuum Infusion, Fiber Reinforced Polymer, Stacking Sequence Effect, Mechanical Properties, Water Absorption Behavior.

1 Introduction

Hybrid composites that mix natural and synthetic fibers are receiving growing attention in research and industry [1],[2]. The main reason is that they bring together the benefits of both materials. Natural fibers are cheap, renewable, biodegradable, and help reduce the carbon footprint of composites. On the other hand, synthetic fibers such as glass or carbon provide the high strength and durability that natural fibers often lack [3],[4]. Traditional fiber-reinforced polymers (FRPs) are strong and widely used in sectors like aerospace, marine, and automotive, but they are made from nonrenewable sources and require energy-intensive processing. This combination of environmental and cost concerns has encouraged researchers to look at hybrid composites as a more sustainable option.

Natural fibers alone cannot always deliver the performance needed in engineering structures. They have lower stiffness, are sensitive to moisture, and their hydrophilic nature causes swelling and degradation over time [5]. Mixing them with synthetic fibers reduces these weaknesses. Hybridization can give better strength, stiffness, and toughness [6],[7]. In these composites, the fibers carry most of the load while the polymer matrix transfers stress and keeps the structure intact [8],[9]. Glass fiber is one of the most common synthetic reinforcements. It is cheaper and more available than carbon or aramid fibers, and it offers good strength-to-weight ratio along with durability [10] [11]. Using glass fiber with natural fibers helps balance cost, weight, and performance, and this is why such hybrids have found applications in transport and marine sectors [12],[13].

Hybrid composites are also reported to perform better than single-fiber composites in terms of weight saving and cost [14]. The interest in plant-based fibers such as jute, hemp, sisal, banana, and coir continue to rise [15],[16]. These fibers are renewable, low in density, and non-abrasive, which makes them attractive reinforcements [17]. The main drawback is water absorption, which affects their dimensional stability and mechanical behavior. Pairing them with synthetic fibers helps reduce this problem [18],[19]. Studies confirm that natural–synthetic hybrids can achieve a good balance between performance and sustainability [20],[21].

Jute is one of the most widely available natural fibers, especially in Bangladesh, and it offers a low-cost option for reinforcement [22]. Still, it absorbs moisture, and that can lower long-term strength [23]. Glass fibers do not have this problem. A hybrid of jute and glass within a polymer matrix can therefore deliver composites that are cheaper and lighter than full glass fiber systems, but stronger and more reliable than only jute-based composites [10],[11].

The manufacturing method used has a strong effect on the properties of the final product. Processes like hand layup and compression molding are simple and low-cost, but they are usually limited to prototypes or small production runs [24]. For better quality and scale-up, more advanced processes are needed. Automated tape laying, injection molding, and vacuum infusion

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*Corresponding Author Email Address: rabbi@cuet.ac.bd are three common approaches. Among them, the vacuum infusion process (VIP) is attractive because it ensures good resin flow, reduces void content, and makes laminates that are both strong and light [25]. VIP is increasingly used in applications where weight saving and performance are important, and it is also suitable for hybrid composites. Applications of these materials are already visible. In automobiles, they are used in dashboards, door panels, and interior structures. In marine and aerospace fields, they are considered for parts where moderate loads and durability are required [20],[21]. They reduce cost, save weight, and provide an alternative to fully synthetic composites.

Previous studies indicate that limited work has examined jute-glass laminates produced by the vacuum infusion process. In this study, samples were prepared at an industry scale which was not mentioned in previous investigations. The objective of this study is to evaluate how stacking sequence and vacuum infusion processing influence the mechanical and moisture related performance of jute/glass hybrid laminates. Ten laminate configurations (S1–S10) were fabricated by vacuum infusion and characterized for tensile, flexural, impact, and hardness properties both with fresh and salt water absorption.

2 Materials and Methods

2.1 Extraction and Surface Treatment of Jute Fiber

Jute fiber mats were collected from a local market in Bangladesh and then prepared for surface treatment. To improve bonding with the epoxy resin, an alkali process (mercerization) was applied. The mats, each measuring 12×12 in, were soaked in a 5% NaOH solution at 30°C for 24 hours. After that, they were rinsed with water to remove the remaining alkali and left to dry naturally in sunlight. This treatment removed hemicellulose, pectin, wax, and oil from the fiber surface, which are mainly responsible for the hydrophilic behavior of untreated jute. Sodium hydroxide also broke some hydrogen bonds in the cellulose structure, causing fiber swelling and partial rearrangement of cellulose into a more crystalline form. At the same time, the process made the surface rougher and more porous, which helps the fibers lock mechanically with the resin. Such changes improve adhesion with polymer matrices and also influence properties like moisture absorption and dye uptake. Materials used in this study are given in Table 1.

Table 1 Materials Used in This Study and Their Typical Properties

Category	**Material**	**Grade/Specification**	**Tensile Strength (MPa)**	**Density (g/cm^3)**
Matrix	Epoxy Resin	Araldite LY 556 + HY 951	60 – 90	1.10-1.30
Hardener	Methyl Ethyl Ketone Peroxide (MEKP)	Industrial grade	-	1.12
Fiber Reinforcement	Glass– Fiber Woven Roving Mat	600 g/m^2	2000–3500	2.55
	Glass Fiber Chopped Strand Mat (CSM)	450 g/m^2	900–1200	2.55
	Jute Fiber Mat	400 g/m^2	300–800	1.3–1.5

2.2 Flowchart of Research Methodology

In brief, the schematic flow of the research methodology for studying the mechanical and hydrophilic characteristics of hybrid composites fabricated by the vacuum infusion process is illustrated in Fig. 1.

2.3 Sequencing and Identification of the samples

Both woven and chopped glass fibers were used to investigate their synergistic effect on the mechanical and hydrophilic properties of the fabricated samples. The experimental design of the jute fiber hybrid composites was formulated considering the desired mechanical properties, part geometry, and production requirements.

Ten stacking sequences were prepared to examine the effect of fiber arrangement as shown in Table 2. Two laminates were produced entirely with glass fibers: S-1 consisted of nine layers, while S-10 consisted of five layers. One laminate, S-9, was fabricated solely with five jute fiber layers. The remaining sequences, S-2 to S-8, were hybrid designs in which jute mats were positioned at different layers within the glass fiber laminates. Fig. 2 depicted the schematic of the stacking sequences considered in this study.

Among various fabrication methods, such as, hand lay-up, compression molding, resin transfer molding (RTM), vacuum infusion process (VIP), and spray-up, VIP was selected in this study for uniform resin distribution, low void content, and reliable laminate quality. Fig. 3 showed the schematic diagram of the experimental setup whereas the real-time setup depicted in Fig. 4.

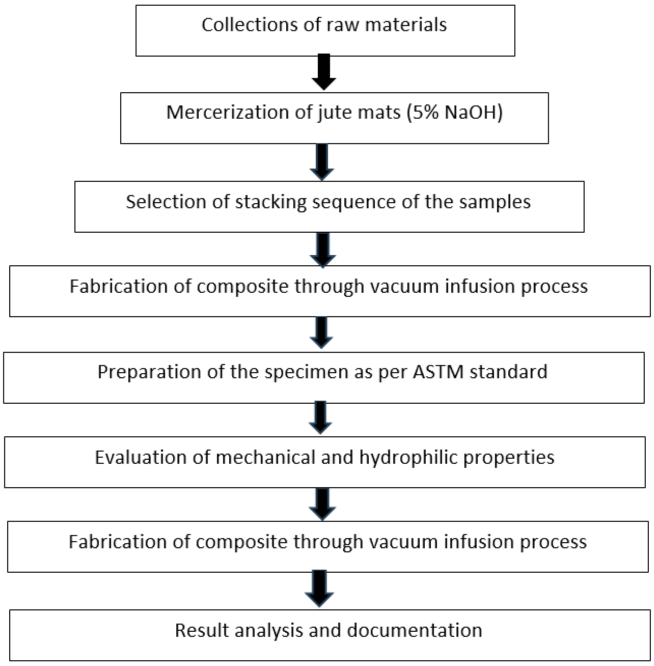


Fig. 1 Flow Chart of Research Methodology

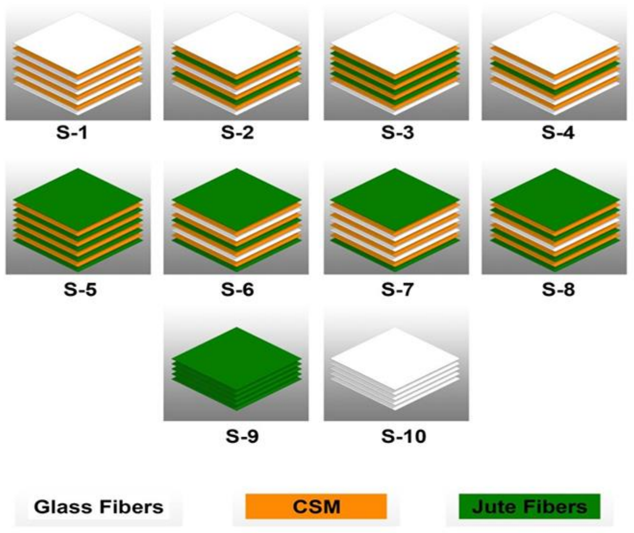


Fig. 2 Stacking sequence of hybrid composite

Table 2 Stacking sequences and the weight percentage (wt%) of the prepared samples

Sample Number	Stacking Sequence	Jute (J) wt%	Glass woven (G) wt%	Glass CSM (C) Wt%
S-1	GCGCGCGCG	0.00	62.50	37.50
S-2	GCJCGCJCG	18.18	40.91	40.91
S-3	GCJCJCJCG	28.57	28.57	42.86
S-4	GCGCJCGCG	8.70	52.17	39.13
S-5	JCJCJCJCJ	52.63	0.00	47.37
S-6	JCGCJCGCJ	28.57	28.57	42.86
S-7	JCGCGCGCJ	18.18	40.91	40.91
S-8	JCJCGCJCJ	40.00	15.00	45.00
S-9	**JJJJJ**	100.00	0.00	0.00
S-10	GGGGG	0.00	100.00	0.00

Fabrication was carried out using the Vacmobile MODULAR 4S vacuum system (New Zealand).

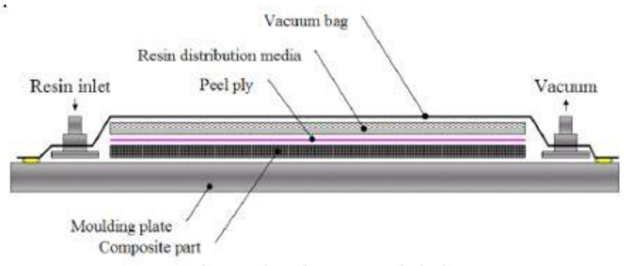


Fig. 3 Vacuum Infusion Bagging [32]

In this setup, stacked fiber mats were placed in the mold, sealed with vacuum bagging film, and infused with epoxy resin under vacuum pressure. The controlled infusion ensured complete wetting of both glass and jute fibers and provided consistent fiber–resin ratios across all laminate configurations.

2.4 Fabrication of the samples

The jute fiber–reinforced composites were made by vacuum-assisted resin infusion. A flat plywood sheet was used as the mold base. It was first cleaned and coated with a release agent so that the laminate could be taken out easily after curing. Layers of jute and glass fibers were then laid on the mold in the required sequence. On top of these, auxiliary layers such as peel ply, breather fabric, and flow media were added to help the resin pass through and cure properly. A nylon mesh was fixed with infusion and vacuum lines, and the whole setup was closed with a plastic vacuum bag. Tacky tape was used to seal the edges and keep the system airtight during infusion.

Fig. 4 Vacuum Infusion Process System Setup

The vacuum pump was turned on first to press the fiber stack and pull out trapped air. This step reduces voids and also helped the fibers sit more evenly, though a few shifts in alignment could still occur. Once the vacuum was steady, epoxy resin was allowed to enter through the inlet. Under pressure, it moved across the fabric with help from the flow media and breather, wetting the layers one after another. The whole lay-up was then left to cure in normal room conditions. During fabrication, a vacuum pressure of 90 kPa (gauge) was maintained, as monitored by the integrated vacuum regulator. This level ensured proper resin flow while preventing void formation. After complete resin infiltration, the laminates were left to cure at ambient room temperature (25 ± 2 °C) for 24 hours. After this the resin hardened, holding the fibers together and giving a solid composite plate.

Fig. 5 Curing and demolding of composite fabricated samples

After curing, the vacuum bagging materials were removed, and the composite laminate was demolded from the plywood surface (showed in Fig. 5), followed by finishing operations such as trimming and sanding to prepare the final specimens for testing.

2.5 Material Characterization

2.5.1 Tensile Test

The tensile test is one of the basic methods for checking how a material behaves under pulling load. It gives important values like stiffness, strength, ductility, and toughness. In this work, jute–glass fiber epoxy composites (S1–S10) were prepared as per ASTM D3039. The specimens were cut to size using a CNC plasma machine (Fig. 6). Tests were carried out on a universal testing machine (UTM). Each sample was held in the grips and loaded in tension until it failed. During the test, both the applied load and the elongation were recorded, which was later used to draw the stress–strain curve.

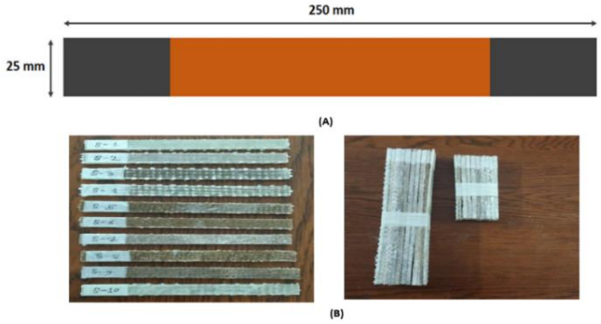


Fig. 6 (A) Tensile test specimen according to ASTM D3039 (B) Fabricated samples

2.5.2 Flexural Test

The flexural test is used to study how a material behaves when it is bent. In this condition, one side of the sample is under tension while the other is in compression. The test was done using a three- point setup according to ASTM D790 (Fig. 7). During loading, both force and deflection were measured until the specimen failed. From these data, values such as flexural strength, modulus, and toughness were obtained. These results give an idea of the stiffness of the material and its resistance to bending.

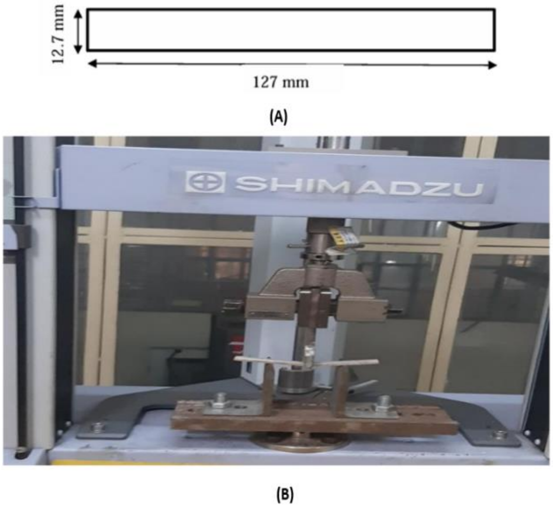


Fig. 7(A) Flexural test specimen according to ASTM D790, (B) Test setup

2.5.3 Impact Test

Impact strength shows how much energy a material can take from a sudden load before it breaks, usually given in joules per unit area. This property is important for parts used in areas such as automotive, aerospace, and construction. The Charpy test was used here, following ASTM D256, with notched specimens (Fig. 8). In general, metals and composites show higher impact resistance, while ceramics and glass are brittle. For this work, 30 notched hybrid composite samples were tested. The absorbed energy during fracture was measured and then used to calculate the impact strength with the standard equations.

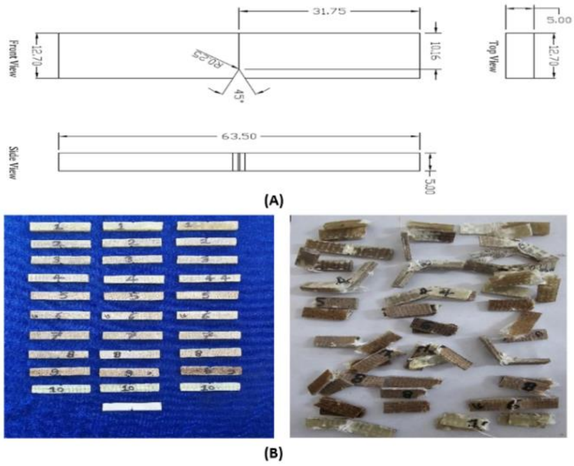


Fig. 8 (A) Test Specimen Design as per ASTM 256 Standard (B) Test Specimen Before and After Impact Test

2.5.4 Hardness Test

Hardness is the ability of a material to resist deformation and is often linked to strength, durability, and wear resistance. Different test methods are used depending on the material—Rockwell and Brinell for metals, Vickers for fine measurements, Knoop for brittle materials, Shore for polymers, and Mohs for minerals. In this work, the hybrid composite samples were tested with a Rock- well/Brinell setup (ASTM E10-18) (Fig. 9). A 1/4” steel ball indenter was used with a 60 kg load. The hardness number (HRL) was read directly from the dial gauge, which provided quick values suitable for comparing between samples.

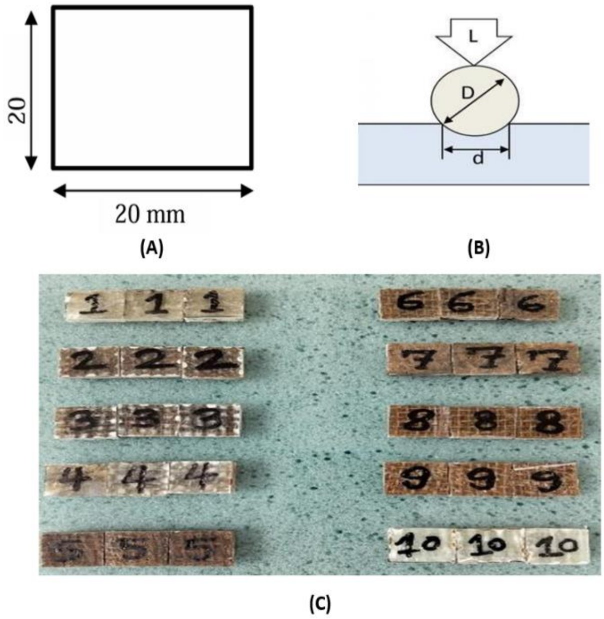


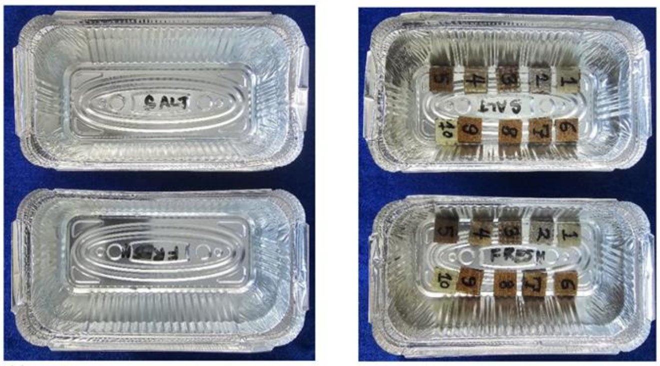
Fig. 9 (A) Test specimen (as per ASTM E10 -18) (B) Brinell Hardness Test (C) Test Specimens for hardness test

2.5.5 Water Absorption Test

Natural fibers take in water easily. Because of this, composites made with them often absorb moisture, which lowers strength and durability. To study this effect, a water absorption test was done according to ASTM D570. The test measures the weight change of a specimen after soaking and gives an idea about porosity and stability.

In this study, 20 hybrid composite samples, each 20 20 mm, were first dried and weighed. They were then soaked in fresh water and salt water for 24 hours and weighed again. The percentage of absorption was calculated from the difference between the dry and wet weights (Fig. 10).

A high value means the specimen swelled and the fiber–matrix bond weakened. A low value means the composite resisted water better. This result is important for judging performance in humid or marine environments.



(a) Fresh water and salt water (b) Specimen soaking for 48H

Fig. 10 Fresh water and salt water absorption test

3 Result and Discussion

3.1 Tensile Properties

The tensile properties of the hybrid laminates with glass and jute fibers were tested on a universal testing machine (UTM). The results showed that tensile force, stress, and stiffness changed depending on the fiber type, the amount of each fiber, and the stacking sequence used in the laminate.

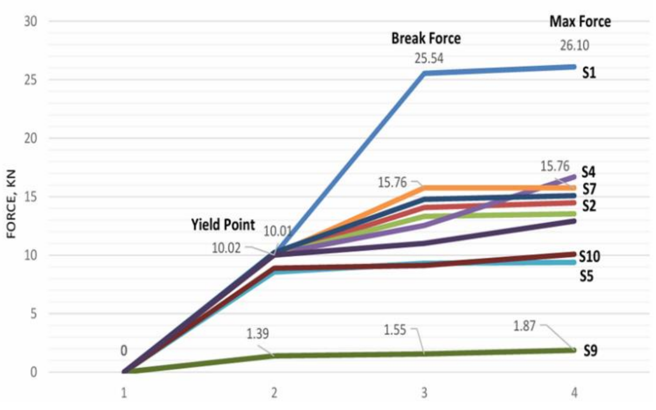


Fig. 11 Different forces acted upon hybrid composite laminates

Fig. 11 shows that the pure glass laminate (S1) carried the highest tensile force of 26.10 kN and failed at 25.54 kN. When a single jute layer was placed in the middle (S4), the tensile force dropped to 16.69 kN and the breaking load to 12.55 kN. This means about a 36% reduction, even though the jute volume was only 11.11%. Adding more jute layers lowered the strength further. S2, with two layers, showed a 44.67% drop, while S3, with three layers, showed a 48.16% drop. The loss in strength is likely from poor bonding between the jute fibers and the matrix.

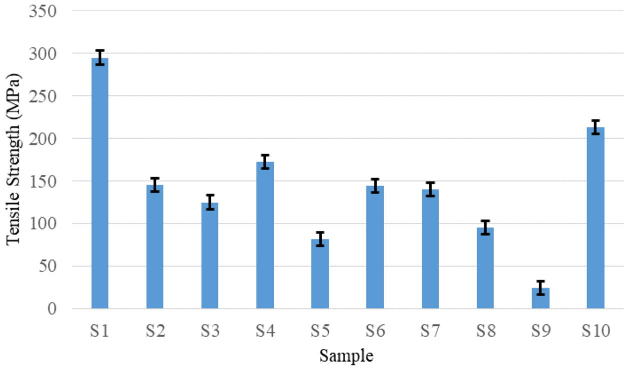


Fig. 12 Tensile Strength of the prepared samples

Fig. 12 shows that the five-layer glass laminate (S10) had the highest tensile stress, 213.28 MPa. In contrast, the jute laminate (S9) gave the lowest value of 24.17 MPa. The best hybrid reached 172 MPa in tensile stress, which is much higher than the 83.02 MPa reported by Turjo et al. [27] for a hand lay-up hybrid. Adding glass layers clearly raised the load-carrying capacity of the hybrids (S2–S7) compared with pure jute, showing that combining the two fibers is effective.

The order of stacking also changed the behavior. For example, S7, which had two jute layers at the outer surface, carried more load than S2, where the same layers were placed at the core. A similar trend was reported by Yusoff et al. [26], where putting low modulus and ductile fibers on the outside improved tensile strength.

3.2 Flexural Properties

Fig. 13 shows that the pure jute fiber composite (S9) exhibited the lowest flexural strength (22.12 MPa) and modulus (0.45 GPa), while the pure glass fiber composite (S10) achieved the highest values (311.47 MPa, 16.73 GPa). Hybrid composites (S2–S7) demonstrated intermediate flexural strength (93–271 MPa) depending on fiber sequence.

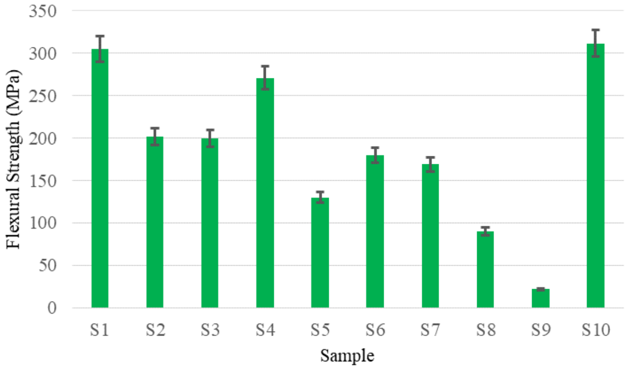


Fig. 13 Flexural properties of the prepared samples.

Sequencing had a clear effect on flexural properties. S2, with two jute layers placed in the inner core, showed higher flexural strength (202.02 MPa) compared with S7, where the jute was on the outer core (169.25 MPa). This suggests that keeping jute inside the laminate helps resist bending. The better performance also comes from good fiber–matrix bonding provided by the vacuum infusion process.

Jute fibers, because of their lower adhesion and natural ductility, led to larger displacements of 6-9 mm before failure. This shows their role in absorbing more energy. Overall, the results confirm that both the fiber type and how the layers are stacked strongly affect the flexural behavior of these hybrids.

The hybrids performed better. For example, S4, which had a single jute layer in the middle, reached 271.04 MPa in flexural strength, even higher than the pure glass laminate. The ductile nature of jute allowed plastic deformation and extra energy absorption, while the glass provided stiffness and strength. In these hybrids, the jute layers fail first because of their lower strength, then the load shifts to the glass and matrix. This prevents sudden failure. The combination of ductile jute and brittle glass gave both higher load capacity and larger displacement, showing that the hybrid design is effective in improving flexural behavior.

3.3 Impact Properties

The impact strength (IS) of pure jute, pure glass, and hybrid jute–glass fiber composites are presented in Fig. 14. Pure glass fiber composite (S1, 9 layers) exhibited the highest IS of 39.27 kJ/m^2, while pure jute fiber composite (S9, 5 layers) showed the lowest value of 2.10 kJ/m^2, confirming the relatively low impact absorption capacity of jute fibers.

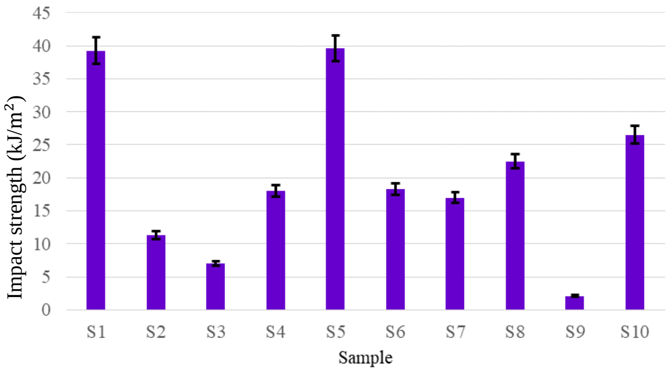


Fig. 14 Impact strength of the prepared samples.

The hybrid laminates (S2–S8) showed a wide range of impact strength values depending on how the layers were stacked and how much jute was added. Adding jute helped absorb more energy because of its viscoelastic and ductile behavior, which deflects cracks and slows down their growth. For example, S3, with three inner jute layers (GCJCJCJCG), reached 11.32 kJ/m^2. S6, with one jute core and two outer jute layers (JCGCJCGCJ), showed a higher value of 18.29 kJ/m^2. When the jute content was raised further, as in S5 (JCJCJCJCJ, 55% jute), the impact strength increased to 39.65 kJ/m^2, which is close to that of the pure glass laminate S1. A similar pattern was reported by Sujon et al. [28], who found 30 kJ/m^2 for a C2J6C2 hybrid.

From these results, it is clear that glass fibers mainly give stiffness, while jute fibers improve impact resistance by deforming and deflecting cracks. At the same time, using too much jute, although it raises impact strength, can lower tensile strength because jute is less stiff than glass. This shows that stacking sequence is important for balancing strength and impact performance in hybrid composites.

3.4 Hardness Properties

The Rockwell Hardness Number (HRL) of jute–glass fiber hybrid composites is influenced by fiber type, arrangement, and stacking sequence. Jute fibers contribute environmental advantages and improved toughness, while glass fibers enhance stiffness and hardness. Measurements were taken on the Rockwell L scale (Fig. 15).

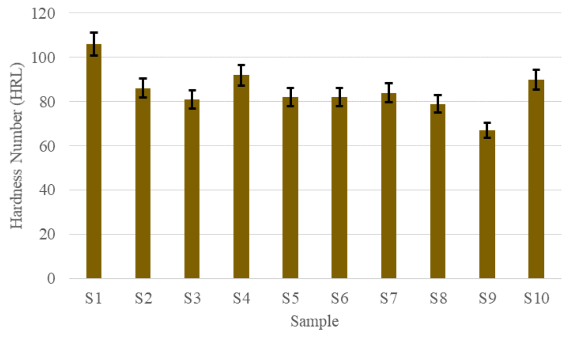


Fig. 15 Rockwell hardness (HRL) number of the prepared samples.

The pure glass laminate (S1, 9 layers) had the highest hardness at 106 HRL. Adding jute reduced the values. With one central jute layer (S4), hardness dropped to 92 HRL, about a 13.2% decrease. Two jute layers inside (S2) gave 86 HRL, and two jute layers on the outside (S7) gave 84 HRL. When the layers were alternated, as in S5 (JCJCJCJCJ), the hardness went down to 82 HRL. This arrangement, however, showed better load distribution. Similar results were reported by Nadondu et al. [29], who found 74.16 HRL for injection-molded hybrids.

The lower hardness comes from the lower stiffness and modulus of jute compared with glass, which makes softer zones in the laminate. Still, adding jute also improves toughness and impact strength, giving a more balanced set of properties. Changing the fiber ratio, adjusting the stacking sequence, and using surface treatments can reduce the loss in hardness while keeping the advantages of hybridization.

3.5 Water Absorption

Water absorption of the fabricated composites was evaluated by immersing specimens in fresh and salt water for 24 hours (Fig. 16). Pure glass fiber laminates (S1, S10) showed no absorption, confirming their hydrophobic nature. In contrast, composites containing jute exhibited measurable uptake due to the hydrophilic character of lignocellulosic fibers.

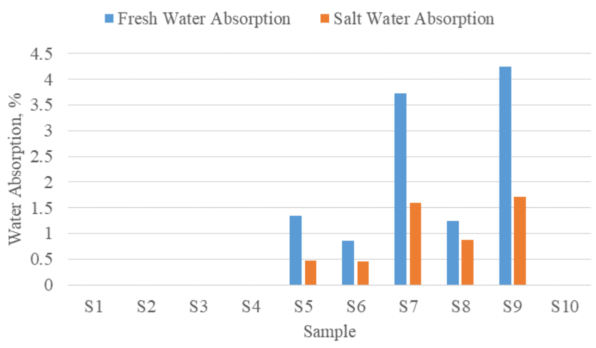


Fig. 16 Water absorption pattern of jute and glass fiber hybrid composites

Hybrid laminates with glass fiber on the outer layers (S2–S4) showed good resistance to water absorption. In contrast, when jute was placed on the outside (S7), absorption reached 3.72% in fresh water and 1.6% in salt water. The pure jute laminate (S9) had the highest values, 4.24% in fresh water and 1.72% in salt water. Overall, fresh water absorption was higher than salt water, since dissolved salts lower the activity of water and limit fiber swelling.

Moisture uptake was also affected by porosity in the resin and small defects in the laminate. Jute layers increased water intake and reduced durability, which is more critical for marine use. To improve resistance while keeping the advantages of hybrid design, surface treatments and better stacking sequences are needed.

3.6 Comparative Study

The mechanical properties and hydrophilic behavior of jute–glass fiber hybrids made by vacuum infusion were studied, and stacking sequence was found to be an important factor. Turjo et al. [27] noted that vacuum infusion composites usually contain about ~3% voids, which gives better performance than hand layup or injection-molded products. The results from this work support that observation when compared with earlier reports.

Tensile properties: Among the nine-layer laminates, S4 (GCGCJCGCG) with one jute layer at the center gave the highest tensile strength at 172.48 MPa. This was followed by S2 at 145.19 MPa and S6 at 144.46 MPa. When three or more jute layers were added, as in S3, S5, and S8, the strength dropped. The lowest was S5 at 81.55 MPa. For comparison, Hasan et al. [30] reported tensile strengths of 121.13, 115.28, and 109.90 MPa for four-layer hybrids made by hand layup, while Mahmud et al. [31] reported only 67.83 MPa for GJJG laminates. These results show that the vacuum infusion method gives better performance than the hand layup process.

Flexural properties: S4 also gave the highest flexural strength at 271.04 MPa. S2 (202.02 MPa) and S3 (202.38 MPa) also showed good bending resistance compared with the other sequences. On the other hand, S5 and S8 had much lower values, 136.64 MPa and 93.53 MPa. For reference, Hasan et al. [30] reported a maximum of 217.47 MPa in hand layup composites, while Mahmud et al. [31] reported 103.28 MPa. These comparisons make clear that the vacuum infusion process produces laminates with higher flexural strength.

Impact strength: Impact resistance went up with more jute in the laminates. The highest value was found in S8 at 64.56 kJ/m^2. S6 (18.29 kJ/m^2) and S7 (16.81 kJ/m^2) also showed better resistance than S2, which was only 5.67 kJ/m^2. These results are different from those of Hasan et al. [30], who reported much higher impact values, 365–378 kJ/m^2, for hand layup laminates. The difference may be due to the smaller number of fiber layers in their samples, which allowed more deformation and energy absorption.

Hardness: Rockwell hardness went down as the jute content increased. Among the hybrids, S4 had the highest value at 92 HRL, followed by S2 at 86 HRL and S6 at 82 HRL. Laminates with more jute, such as S5 and S8, gave the lowest readings at 82 and 79 HRL. For comparison, Nadondu et al. [29] reported 74.16 HRL (Rockwell E) for injection-molded glass–carbon–durian skin hybrids. That value is lower than what was measured here with vacuum infusion, which again points to the advantage of this process.

Hydrophilic behavior: Pure glass laminates (S1, S10) and the hybrids with glass on the outer surfaces (S2–S4) showed good resistance to water uptake. Hybrids with jute on the outside absorbed much more. For example, S7 took in 3.72% in fresh water and 1.6% in salt water. The pure jute laminate (S9) absorbed the most, 4.24% in fresh and 1.72% in salt. In every case, fresh water absorption was higher than salt water, which is linked to the greater activity of fresh water. Sujon et al. [28] reported about 3.8% absorption for jute–carbon composites made by vacuum-assisted resin infusion, which is close to the present results.

From the results, S4, with one jute layer at the center, gave the best overall performance in tensile, flexural, and hardness tests. S2 came next, showing a good balance of properties, while S6 and S3 performed at moderate levels. Impact strength went up as more jute was added, with the highest value in S8, but hardness dropped as a trade-off. In terms of moisture resistance, S2–S4 were the best because the glass outer layers reduced water absorption.

4 Conclusions

This study shows that stacking sequence has a strong effect on the mechanical and hydrophilic behavior of jute–glass fiber hybrids made by vacuum infusion. The laminate with a single central jute layer (S4) gave the best results, with 172.48 MPa in tensile strength, 271.04 MPa in flexural strength, and 92 HRL in hardness. Adding more jute increased impact resistance, with S8 reaching 64.56 kJ/m^2 , but this came at the cost of lower tensile strength and hardness. Laminates with glass on the outside (S2–S4) resisted water absorption well, while those with jute on the surface absorbed more.

Overall, the findings confirm that hybridization combines the stiffness of glass with the ductility of jute, giving a more balanced composite. By changing the stacking sequence, the properties can be adjusted toward strength, toughness, or durability depending on the use. More research should look into fiber surface treatment and barrier coatings to cut down moisture uptake and improve long-term performance of these sustainable, low-cost materials.

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Author Contributions

A. A. Chowdhury: Methodology, Investigation, Data Curation, Writing – Original Draft, **Abdullah-Al-Mamun**: Writing – Original Draft, **M S Rabbi**: Conceptualization, Supervision, Writing – Reviewing and Editing, **Shifat Hasan Naim**: Software, Visualization

Conflict of Interest Statement

The authors declare no competing financial or non-financial interests, nor any personal relationships, that could influence the work reported herein.

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Data Availability Statement

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

References

[1] Haq, E., Saifullah, A., Habib, A., Azim, A.Y.M.A., Alimuzzaman, S., Dhakal, H.N. and Sarker, F., 2024. Improved mechanical properties of environmentally friendly jute fibre reinforced metal laminate sandwich composite through enhanced interface. *Heliyon*, *10*(2).

[2] Parvez, M.M.H., Rupom, S.M.N., Adil, M.M., Tasnim, T., Rabbi, M.S. and Ahmed, I., 2023. Investigation of mechanical properties of rattan and bamboo fiber reinforced vinyl ester composite material for automotive application. *Results in Materials*, *19*, p.100437.

[3] Atiqah, A., Jawaid, M., Sapuan, S.M., Ishak, M.R., Ansari, M.N.M. and Ilyas, R.A., 2019. Physical and thermal properties of treated sugar palm/glass fibre reinforced thermoplastic polyurethane hybrid composites. Journal of Materials Research and Technology, 8(5), pp.3726-3732..

[4] Rafat, M.T., Shuchi, T.Z., Evan, F.R. and Rahman, M.A., 2024. Mechanical and absorption properties of carbon-basalt and glass fiber reinforced composites: a comprehensive study with implications for advanced manufacturing technology. *Results in Materials*, *23*, p.100615..

[5] Spencer, M. and Chen, X., 2023. Static and fatigue cracking of thick carbon/glass hybrid composite laminates with complex wrinkle defects. *International Journal of Fatigue*, *177*, p.107963..

[6] Wang, A., Liu, X., Yue, Q. and Xian, G., 2023. Tensile properties hybrid effect of unidirectional flax/carbon fiber hybrid reinforced polymer composites. *Journal of Materials Research and Technology-JMR&T*, *24*, pp.1373-1389..

[7] Maung, P.T., Prusty, B.G., Shamsuddoha, M., Phillips, A.W. and St John, N.A., 2021. Static and dynamic response of a carbon composite full-scale hydrofoil manufactured using automated fibre placement. Composites Part C: Open Access, 6, p.100218..

[8] Abolfazli, M., Bazli, M., Rajabipour, A., Heitzmann, M., Pourasiabi, H., Wang, H. and Arashpour, M., 2023. Residual compressive strength of filament wound hybrid glass/carbon fibre reinforced polymer tubes after exposure to elevated temperature. *Composite Structures*, *316*, p.117050..

[9] Rajesh, M., Pitchaimani, J. and Rajini, N.J.P.E., 2016. Free vibration characteristics of banana/sisal natural fibers reinforced hybrid polymer composite beam. *Procedia Engineering*, *144*, pp.1055-1059..

[10] Rajeshkumar, G., Nagaraja, K.C., Ravikumar, P., Rangappa, S.M. and Siengchin, S., 2024. Effect of halloysite addition on the dynamic mechanical and tribological properties of carbon and glass fiber reinforced hybrid composites. *Heliyon*, *10*(15).

[11] Andoko, A., Gapsari, F., Wijatmiko, I., Diharjo, K., Rangappa, S.M. and Siengchin, S., 2023. Performance of carbon fiber (CF)/Ceiba petandra fiber (CPF) reinforced hybrid polymer composites for lightweight high-performance applications. *Journal of Materials Research and Technology*, *27*, pp.7636-7644..

[12] Yahaya, R., Sapuan, S.M., Jawaid, M., Leman, Z. and Zainudin, E.S.B., 2015. Effect of layering sequence and chemical treatment on the mechanical properties of woven kenaf–aramid hybrid laminated composites. *Materials & Design*, *67*, pp.173-179..

[13] Dong, C., 2024. Flexural properties and optimisation of hybrid composites reinforced by carbon, glass and flax fibres. *Hybrid Advances*, *7*, p.100302..

[14] Wang, A., Wang, X. and Xian, G., 2021. The influence of stacking sequence on the low-velocity impact response and damping behavior of carbon and flax fabric reinforced hybrid composites. *Polymer Testing*, *104*, p.107384..

[15] Velmurugan, G. and Natrayan, L., 2023. Experimental investigations of moisture diffusion and mechanical properties of interply rearrangement of glass/Kevlar-based hybrid composites under cryogenic environment. *Journal of Materials Research and Technology*, *23*, pp.4513-4526..

[16] Azhary, T. and Wildan, M.W., 2022. Mechanical, morphological, and thermal characteristics of epoxy/glass fiber/cellulose nanofiber hybrid composites. *Polymer Testing*, *110*, p.107560..

[17] Okafor, C.E., Sunday, I., Ani, O.I., Akçakale, N., Ekwueme, G.O., Ugwu, P.C., Nwanna, E.C. and Onovo, A.C., 2023. Biobased hybrid composite design for optimum hardness and wear resistance. *Composites Part C: Open Access*, *10*, p.100338..

[18] Singh, M.K., Tewari, R., Zafar, S., Rangappa, S.M. and Siengchin, S., 2023. A comprehensive review of various factors for application feasibility of natural fiber-reinforced polymer composites. *Results in Materials*, *17*, p.100355..

[19] Rajesh, M., Jayakrishna, K., Sultan, M.T.H., Manikandan, M., Mugeshkannan, V., Shah, A.U.M. and Safri, S.N.A., 2020. The hydroscopic effect on dynamic and thermal properties of woven jute, banana, and intra-ply hybrid natural fiber composites. *Journal of Materials Research and Technology*, *9*(5), pp.10305-10315..

[20] Mandal, A., Habib, A., Paul, B., Islam, M., Ahamed, B., Islam, S. and Sarker, F., 2024. Integration of recycled denim waste cotton fibre and jute fibre in thermoplastic bio composite applications. *Results in Materials*, *23*, p.100611..

[21] Abir, N., Siddique, A.B., Begum, H.A., Gafur, M.A., Khan, A.N. and Mahmud, M.A., 2023. Effect of fibre loading on mechanical properties of jute fibre bundle reinforced gypsum composites. *Heliyon*, *9*(7)..

[22] da Silva Batista, M., Teixeira, L.A. and da Luz, S.M., 2023. Hygrothermal exposure and residual strength after cyclic loading on epoxy composites reinforced with sisal fibers. *Polymer Testing*, *127*, p.108192..

[23] Raj, J.I.D., Geethan, K.A.V., Rajan, A.J. and Ananth, S.V., 2023. Characterization of epoxy resin based banana fiber reinforced composite with waste CD powder filler. *Materials Today: Proceedings*, *90*, pp.19-23..

[24] Huzaifa, M., Zahoor, S., Akhtar, N., Abdullah, M.H., Haider, S., Khan, S.U. and Alam, K., 2024. Exploring mechanical properties of eco-friendly hybrid epoxy composites reinforced with sisal, hemp, and glass fibers. Journal of Materials Research and Technology, 33, pp.2785-2793..

[25] Radzi, A.M., Sapuan, S.M., Jawaid, M. and Mansor, M.R., 2019. Water absorption, thickness swelling and thermal properties of roselle/sugar palm fibre reinforced thermoplastic polyurethane hybrid composites. *Journal of Materials Research and Technology*, *8*(5), pp.3988-3994..

[26] Yusoff, R.B., Takagi, H. and Nakagaito, A.N., 2023. A comparative study of polylactic acid (PLA)-Based unidirectional green hybrid composites reinforced with natural fibers such as kenaf, bamboo and coir. Hybrid Advances, 3, p.100073.

[27] Turjo, S.K.S., Hossain, M.F., Rana, M.S., Al-Mamun, M. and Ferdous, M.S., 2024. Durability and mechanical characteristics of unidirectional jute/banana and synthetic fiber reinforcement epoxy composite. *Hybrid Advances*, *6*, p.100232..

[28] Sujon, M.A.S., Habib, M.A. and Abedin, M.Z., 2020. Experimental investigation of the mechanical and water absorption properties on fiber stacking sequence and orientation of jute/carbon epoxy hybrid composites. *Journal of Materials Research and Technology*, *9*(5), pp.10970-10981.

[29] Nadondu, B., Surin, P. and Deeying, J., 2022. Multi-objective optimization on mechanical properties of glass-carbon and durian skin fiber reinforced poly (lactic acid) hybrid composites using the extreme mixture design response surface methodology. *Case Studies in Construction Materials*, *17*, p.e01675..

[30] Hasan, M.M., Islam, M.A. and Hassan, T., 2024. Analysis of jute-glass fiber reinforced epoxy hybrid composite. *Heliyon*, *10*(24)..

[31] Mahmud, S.H., Akram, M.W., Ferdous, S.M.R., Islam, D., Fatema, K., Chowdhury, M.S.A., Das, A. and Ovi, S.M., 2024. Fabrication and mechanical performance investigation of jute/glass fiber hybridized polymer composites: Effect of stacking sequences. *Next Materials*, *5*, p.100236..

[32] Mahmud, S.H., Akram, M.W., Ferdous, S.M.R., Islam, D., Fatema, K., Chowdhury, M.S.A., Das, A. and Ovi, S.M., 2024. Fabrication and mechanical performance investigation of jute/glass fiber hybridized polymer composites: Effect of stacking sequences. *Next Materials*, *5*, p.100236..

[33] Abdurohman, K. and Siahaan, M., 2018, April. Effect of mesh-peel ply variation on mechanical properties of E-glas composite by infusion vacuum method. In *Journal of Physics: Conference Series* (Vol. 1005, No. 1, p. 012009). IOP Publishing.