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Preparation and Investigation of Mechanical and Physical Properties of Flax/Glass Fabric Reinforced Polymer Hybrid Composites

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Abstract

Synthetic reinforced composites affect the environment adversely and have become a global concern, causing increased natural composite demand for sustainability and cost effectiveness. Glass is a popular material that is highly consumed in reinforced composites for its superior mechanical strength. As opposed to that, flax obtained from flax stalks can be used as an alternative reinforcing material with synthetic fibers to minimize manmade fiber consumption. Hence, this research work addresses a few flax/glass-reinforced hybrid composites by using a thermoset polyester matrix. Here, six categories of samples are made, like neat flax, neat glass, and flax/glass fabric reinforced hybrid composite, followed by different stacking layer sequences and hand layout techniques during processing. Afterwards, the mechanical behavior, thermal stability, morphological behavior, and water absorption of hybrid samples were investigated. Among the developed samples, neat glass (NG) composite exhibits superior mechanical properties, while neat flax (NF) shows the lowest result. It is apparent that the mechanical properties and thermal stability of hybrid samples are in between NF and NG because, by adding glass with flax fabric, the strength of hybrid samples is increased. Moreover, it is noticeable that, due to multiple stacking layers of flax and glass, hybrid 3 and hybrid 4 show better strength than consecutive single stacking layers in hybrid 1 and hybrid 2. Among all hybrid composites, the H4 shows comparatively better mechanical and thermal properties due to having the glass layers on the outermost surface. In summary, this research work demonstrated the feasibility of flax fabric with glass fabric as a reinforced hybrid composite that can be used in automobile inner bodies, household furnishing, and home interior decoration.

Keywords

Flax-Glass Fabric Reinforced Composites, Mechanical Properties, SEM, TGA, Polyester Resin

1. Introduction

In recent years, growing attention has been given to natural fiber polymer composites as a substitute for traditional man-made reinforcing materials. Because of their great mechanical qualities, low cost, and adaptability, glass-reinforced composite materials are often extensively employed across a wide range of fields. Energy-consuming practices and release of greenhouse gases are involved in the manufacture of glass fibers [1] as well as the inhaling glass fibers can lead to breathing problems, and handling and producing glass fibers may subject employees to severe hazards to their health. Recently, interest has migrated to biodegradable materials used in structural applications as a result of the ongoing rise in environmental concern & government obligations [2].

According to several evaluations including Mohini Saxena [3], natural fibers are a superior substitute for artificial fibers in terms of price, density, sustainability, and CO_2 emission. Several studies on natural fibers, including flax, jute, and sisal, have demonstrated that composite materials can be made from these fibers due to possess efficient reinforcement opportunity [4] [5] [6] [7] [8]. Natural fibers have had resurgence in popularity since they are more prevalent in nature and can be produced from renewable basic resources. In addition to providing a healthier working environment than a glass fibers production facility, the use of natural fibers for composite production is sustainable and eco-friendly [1]. Natural fibers also provide outstanding acoustic insulation and strong thermal qualities. Natural fibers are now used more often in the building, packaging, and automobile industries because to their benefits [9]. However, due to their poor resistance to humidity, which can result in changes in dimensions and reduced mechanical qualities, the uses for the plant-based materials in composites were still a bit confined [10] [11]. There are still some drawbacks to the natural fibre reinforced composites (NFRCs)—for example, poor interfacial adhesion between the fibre and the polymer matrix, and poor mechanical properties of the NFRCs due to the hydrophilic nature of the natural fibres as well as have high water absorption, compatibility & durability issues [12] [13]. Fiber type and quality, fiber treatment, percentage of fibers in composites, aspect ratio and orientation of fibers, matrix type and quality, composite manufacture, and composite modification are some aspects that might help improve their mechanical strength [12] [14] [15]. Several chemical and structural alterations have been employed to improve the mechanical attributes of the reinforced composite that originated from natural fibers. The bending strength of jute-biopol hybrids improved by almost 30% by using the alkali treatment, according to Mohanty *et al.* [15] [16] [17].

The silane coupling compounds are used for plant-based fiber polymer hybrid compounds, which were reviewed by Xie *et al.* [18]. By integrating natural fiber with stronger manmade fiber in a reinforced composite form, the mechanical properties can be enhanced [19]. The tensile and flexural characteristics of banana/sisal hybrid polyester composite are improved, according to Kuruvilla Joseph and Sabu Thomas' research [20]. The stacking sequences of fibers play a significant role, as examined in carbon-flax composites by Wang *et al.* Since carbon fibers become a shielding layer against moisture when they are located on the outer surface of the composite, that greatly enhances hydrothermal stability [21]. Similarly, glass fibers act as a barrier, preventing water molecules from entering the polymer matrix and thus reducing natural fiber deterioration [22].

Incorporating glass fiber and palmyra fiber in the structure itself would improve the composites' mechanical characteristics and reduce their susceptibility to moisture absorption [23]. The performance of sisal/glass fiber composites under tensile stress was discovered by M. Ramesh *et al.* [24]. Khalid *et al.* investigated the tensile characteristics of a hybrid composite produced from glass and jute fiber by using compression molding [25]. In relation to various fiber volume fractions (30%, 40%, and 50% in weight), hybrid composites were made of banana-pineapple leaf and woven glass with epoxy resin and studied for flexural and thermal characteristics by Mohd Hanafee *et al.* Both the banana and PALF samples exhibit the maximum results at 40 wt% [26]. S.S. Morye *et al.* investigated the mechanical properties of a glass/flax hybrid composite that was developed by differing the ratio of glass and flax constituent materials and based on variable fiber direction. It was found that the composite developed with regular fiber direction showed higher tensile strength at the same glass/flax ratio [27]. As compared to other natural fibers, flax fibers possess better mechanical qualities than E-glass and can be used as reinforcement material with glass. Natural fibers have lower elongation at break and tensile characteristics than E-glass fiber. The mass of the glass fiber is almost double that of the natural plant-based fiber. So, glass and flax fibers combined may result in a material with special properties, such as reduced weight and increased strength [28] [29].

Using the hand layup manufacturing technique, Sivakumar *et al.* conducted experiments on processed and unprocessed irregularly aligned palmyra fiber plant-based polyester resin-reinforced composites and investigated mechanical characteristics [11]. Materials developed from a chemical process involving potassium permanganate palmyra have significantly greater tensile properties than untreated fiber [30]. The influence of fiber arrangement on the efficiency of flax fiber-reinforced polymer composites was examined by Prasath *et al.* [31]. The composite was made by following the several flax layers and various directions of fiber arrangement, such as 0˚, 30˚, 45˚, 60˚ and 90˚ by hand layup techniques. The results revealed that the 0˚ and 90˚ orientations performed better. A hybrid flax and glass fiber-reinforced polyester composite was created utilizing a hand layup technique, and the mechanical parameters were evaluated by Meenakshi and Krishnamoorthy *et al.* Laminated composites were developed using various flax to glass fiber ratios, and their mechanical characteristics and water absorption nature were examined, where the hybrid composite exhibits superior outcomes than both standard glass fiber composites and composites made from natural fiber [32]. Darshill *et al.* demonstrated the feasibility of a flax structural composite that might substitute for E-glass in a tiny turbine blade [33]. Promote natural fiber polymer composites are in high demand across a variety of sectors, including automotive, electrical and electronic, building and construction, and building and renovation, which has created a highly competitive industry [34] [35]. There are several processes that are often used, including hand layout, compression molding, injection molding, and resin transfer molding (RTM) [36], The primary methods for preparing the thermoset resin-based polymer are manual lay-up and spray-up [37]. Polyester is a well-known thermoset resin that is inexpensive, has very little impact resistance, and cannot be reformed after it has been curled or polymerized [38]. Furthermore, the hand lay-up technique is a widely utilized, simple, and efficient production process that is used in the aerospace and automotive sectors. The hand-layout approach entails a one-sided, economical penetration of resin through the reinforcing fabric across the surface of the mold using a hand-layup process that is relatively comparable to other production procedures for composites [36].

The main focus of this paper is the development of new composite materials with various component stacking layers, with the goal of maximizing the use of natural fibers while minimizing the consumption of synthetic fibers. By hybridizing flax and glass fabric with thermoset polyester resin, reinforcement materials have been developed, followed by a hand-lay-up process. Finally, investigating the mechanical and thermal properties of this hybrid composite that have the potential for feasibility in the application of automobile inner bodies, household furnishing, and home interior decoration.

2. Materials and Method

2.1. Materials

Flax fabric (250 GSM) was used as reinforcement and Glass fabric non-woven (600 GSM) was sourced from Go Green Products, Chennai, India. (**Figure 1**) Research grade Unsaturated polyester resin (UPR) and Methyl ethyl ketone peroxide (MEKP) were collected from Mitali Scientific Stores, Dhaka, Bangladesh. The characteristics of flax and glass fibers are shown in **Table 1** as well as the polyester resin properties are listed in **Table 2**.

2.2. Method

Development of Composite

In recent years, a number of fundamental methods for manufacturing composites using natural fibers have been developed [19] [20]. To develop composites, hand layout techniques are followed properly due to their being basic,

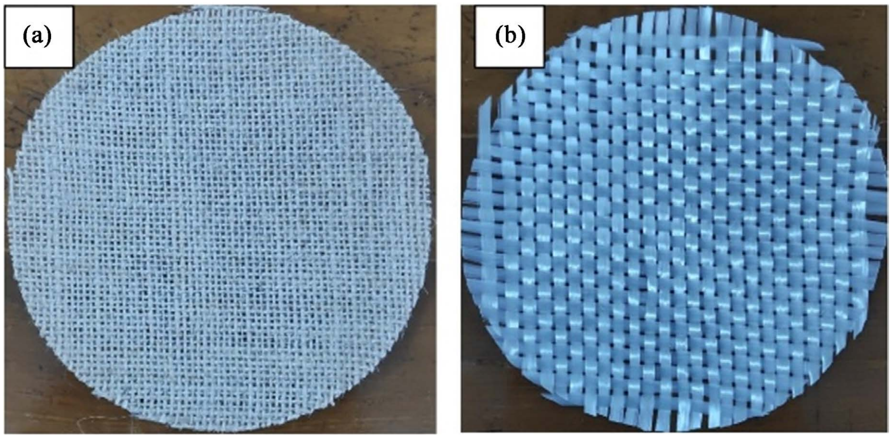

Figure 1. (a) Flax fabric & (b) Glass fabric.

Table 1. The characteristics of flax and glass fibers [11] [28] [39] [40].

Characteristics	Flax	E-glass
Density (g/cm^3)	1 - 1.5	2.5 - 2.7
Lumen size (mm)	5	-
Toughness (MJ/m^3)	5 - 35	40 - 50
Young's modulus (GPa)	60 - 80	70
Eb%	4.5 - 6.5	3 - 5
Tensile strength (GPa)	0.4 - 1.5	2 - 3.7
Tensile modulus (GPa)	-	68 - 75
Fiber length (cm)	33	33 (continuous)
Fiber diameter (μm)	160 - 230	-

Table 2. The characteristics of unsaturated polyester resin [41].

Characteristics	Values
Viscosity at 30˚C	4 - 5
Appearance	Opaque
Eb%	3.2
Bending strength (kgf/mm^2)	8.4
Bending modulus (kgf/mm^2)	536.1
Heat distortion temperature (˚C)	67.3
TS (kgf/mm^2)	3
Impact strength (kgf-cm/cm)	3.9

cost-effective, and having the key benefit of not being constrained by the size and shape of the products. The production procedures utilized in this process are comparatively simpler to understand than those employed in other molding techniques. This gives designers the freedom to add and reinforce materials at various points throughout the product to satisfy certain design requirements. It is crucial to keep in mind that the procedure has some inherent defects that could affect the end product's stability and quality. However, the overall quality of the composites can be preserved as long as they adhere to the fundamental requirements for technological applications. The hand layup heat press molding procedure was used to fabricate composite plates for this experiment. The first process involves cutting 6 × 6 inch^2 pieces of reinforcing materials, such flax fabric and glass fabric. To get rid of moisture, the flax fabric was then dried for 60 minutes at 100˚C in the oven. The resin system for impregnating the fibers was then made by gently stirring the necessary quantity of polyester resin for several minutes with a small amount (1% - 2%) of MEKP in a plastic container. In order to encourage curing, fiber impregnation, and laminate consolidation, the wet laid-up composite laminates were next exposed to hot-pressing in a hydraulic press at 90˚C for 10 minutes. The samples were post-cured for 24 hours at room temperature. (Figure 2, Table 3)

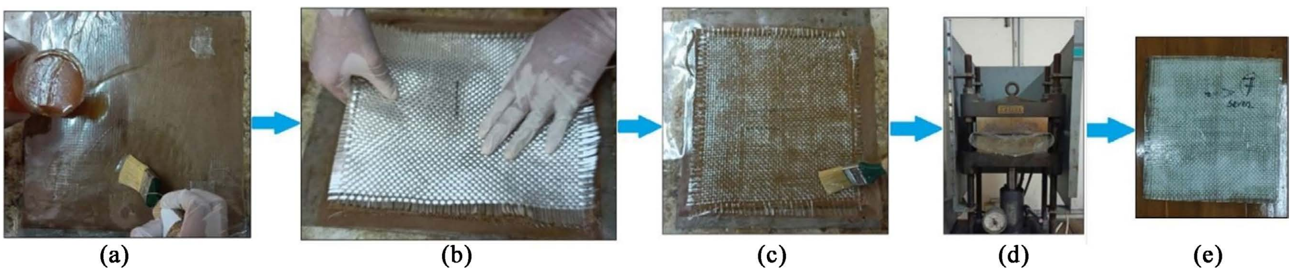

Figure 2. Fabrication of composite materials. (a) Resin pouring; (b) Placing fabric lay; (c) Finishing resin pouring; (d) Heat pressing the composite; (e) Final composite sample.

Table 3. Stacking Sequences of fabricated composites.

Designation	Sample Code	Stacking sequence	Ply number ratio (flax/glass)
Neat flax	NF	☆☆☆☆☆☆☆☆☆☆☆☆	12/0
Neat glass	NG	✧✧✧✧✧✧✧✧✧✧✧✧	0/12
Hybrid 1	H1	☆✧☆✧☆✧✧☆✧☆✧☆	6/6
Hybrid 2	H2	✧☆✧☆✧☆☆✧☆✧☆✧☆	6/6
Hybrid 3	H3	☆☆☆✧✧✧✧✧✧☆☆☆	6/6
Hybrid 4	H4	✧✧✧☆☆☆☆☆☆✧✧✧	6/6

☆: flax; ✧: glass.

2.3. Characterization

2.3.1. Tensile Strength

A universal testing machine (UTM) was used to test the tensile strength (ASTM D63803) of the composite materials. Machine jaw speed was 10 mm/minute and gauge length were 50 mm. The specimens were 120 mm in length and 15 mm in width.

2.3.2. Flexural Strength

Flexural testing (ISO 14125) was carried out using the aforementioned Universal Testing Machine. The machine jaw speed was 60 mm/minute and gauge length were 25 mm. The samples had dimensions of 60 × 15 mm.

2.3.3. Impact Testing

A Universal Impact Tester was used to perform impact testing on the composite specimens. Impact testing was conducted in accordance with ASTM D611097 standard. With a lift angle of 150˚, a gravity distance of 30.68 mm, and a mass of 2.63 kg, a hammer weighing 2.63 kg was employed.

2.3.4. Hardness Test

A Brinell hardness tester device was used to determine the specimen hardness. ASTM E10-18 standards were followed during the testing process. A 2.6 mm-diameter indenter ball was used to apply a load of 100 kgf for 30 seconds to the material surface.

2.3.5. Water Uptake

The water absorption (wt%) of the composites was calculated in accordance with ASTM D5229. A 105˚C oven was prepared to bake test specimens for one hour with dimensions of around 100 mm in length and 100 mm in breadth. The specimens were immediately weighed after being taken out of the oven and this weight was noted as W_f and initial weight was W_i. The following formula was then used to determine how much water was taken in:

$$\text{Water uptake}(\%) = \frac{W_f - W_i}{W_f} \times 100\%$$

2.3.6. Thermal Analysis

The thermogravimetric analysis (TGA) was used to examine the thermal behavior of the generated composite. The tests were carried out using a thermal analyzer (SDT 650, Discovery, USA), with the materials heated continuously at 5˚C/minute. In order to assess its thermal qualities, a sample of the composite material that ranged in weight from 10 to 45 grams (depending on volume) was created.

2.3.7. Morphological Analysis

On a Hitachi, Japan-made SU 1510 scanning electron microscope (SEM), the morphological organization of fibers inside composite materials, fracture behavior and polyester resin adherence were examined. For a thorough investigation, the samples were magnified three times by 0.5 K, 1.0 K and 10.0 K under 15 kV.

3. Results

3.1. Tensile Strength

Figure 3 reveals the TS 170.76, 677.98, 389.85, 462.75, 494.42, and 538.81 MPa for neat flax, neat glass, and hybrid 1, 2, 3, and 4, respectively. It is apparent that the TS of hybrid samples is in between that of neat flax and neat glass because, by adding glass with flax fabric, the strength of hybrid samples increases but is lower than that of neat glass. Also, it is noticeable that, due to multiple stacking layers of flax and glass, hybrid 3 and hybrid 4 show better strength than consecutive single stacking layers in hybrid 1 and hybrid 2. Among all, the hybrid 4 shows a comparatively better TS (538.81 MPa), due to having the glass layers on the outermost surface [42].

In **Figure 4**, it can be seen that the TM of flax-glass neat and hybrid 1 to hybrid 4 composites are 2.1, 5.8, 2.7, 3.5, 3.3, and 4.1 GPa, respectively. Here, neat flax shows less TM because flax fibers have a tendency to absorb moisture from the surrounding environment, which can weaken their mechanical properties, including the tensile modulus, due to the hydrophobic nature of glass [43]. In the case of hybrid samples, hybrid 2 and hybrid 4 show comparatively better TM due to the glass laminate in the outer layer.

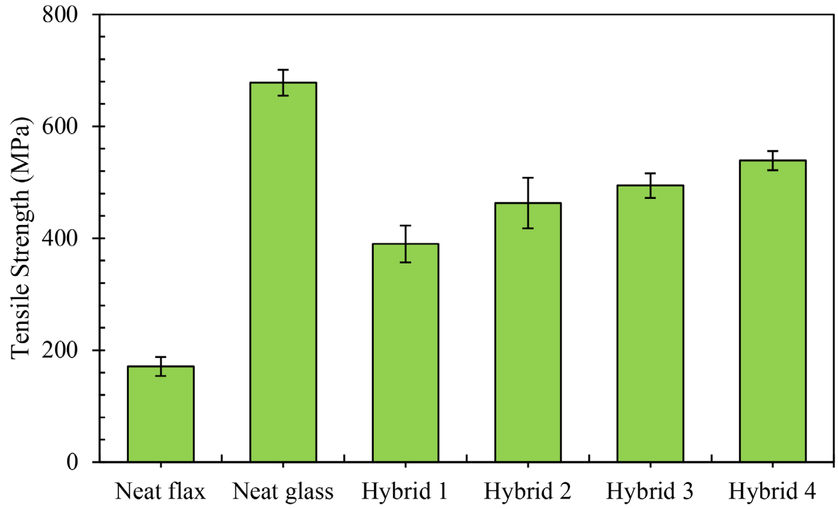

Figure 3. Tensile Strength (TS) of neat flax, neat glass and hybrid composites.

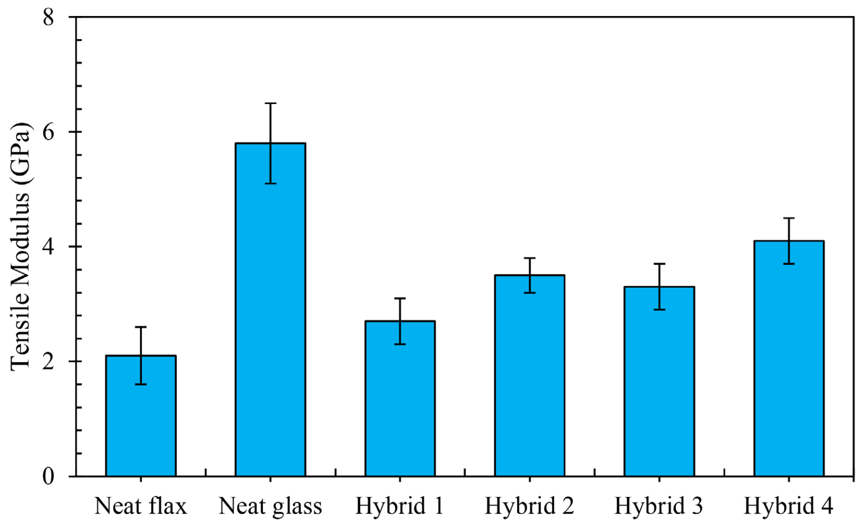

Figure 4. Tensile Modulus (TM) of neat flax, neat glass and hybrid composites.

3.2. Flexural Strength (FS)

Figure 5 illustrates that the FS of flax-glass neat and hybrid composites is 55, 16.4, 5.9, 6.5, 9.8, and 11.2 GPa, respectively. It is observable that neat glass composite can withstand the maximum load because of its high length-to-width ratio and polymer-ordered orientation, compared to neat flax composite. Besides, in the case of hybrid composites, variant 4 shows the highest flexural strength (11.2 GPa) due to triple glass layers on both outer surfaces. In Figure 6, the FM of different composites is shown, where hybrid variant 4 shows good results due to the same reasons.

3.3. Impact Strength

Figure 7 displays that the IS of flax-glass neat and hybrid composites is 54.74, 178.11, 68.55, 80.32, 110.43 and 127.55 kJ/m^2, respectively. The maximum value is 178.11 kJ/m^2 for neat glass layer composite, and the minimum value is 54.74

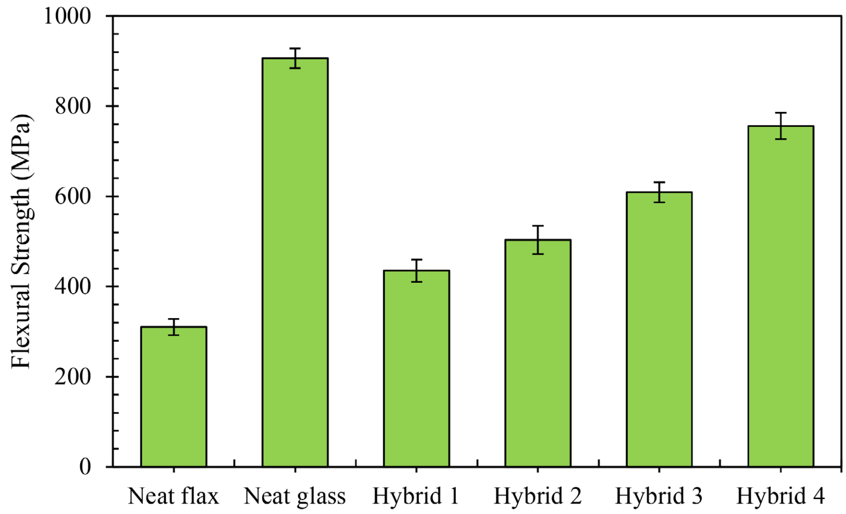

Figure 5. Flexural Strength (FS) of neat flax, neat glass and hybrid composites.

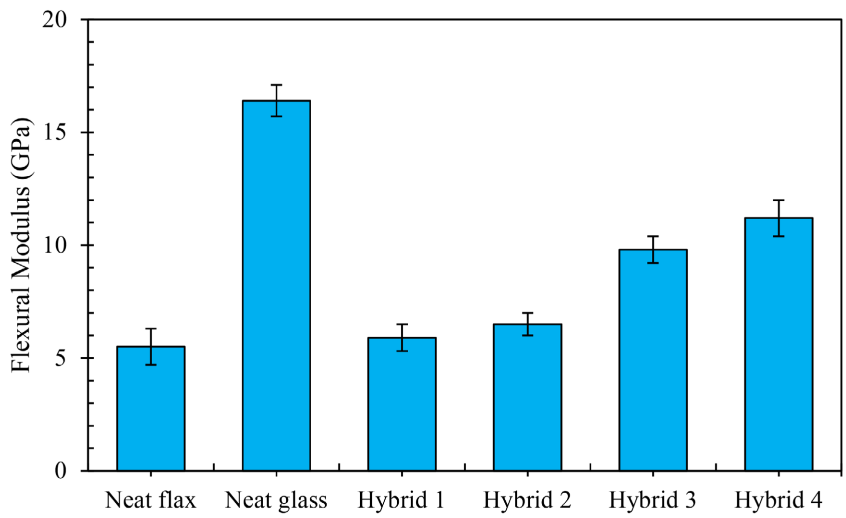

Figure 6. Flexural Modulus (FM) of neat flax, neat glass and hybrid composites.

kJ/m^2 for neat flax composite. For hybrid composites, the maximum value is 127.55 kJ/m^2 for variant 4 due to the triple layer of glass on the outer side of the composites. It is apparent that impact strength is increased with multiple layers rather than single layers.

3.4. Hardness Test

Figure 8, exhibits the hardness (BHN) of neat flax, neat glass, and flax/glass hybrid samples is 89.41, 305.26, 170.85, 230.66, 243.06, and 278.09, respectively. Where, neat glass composite reached the highest hardness (BHN 305.26), and among hybrid composites, variant 4 showed the best hardness as it had three glass fabric layers on the outer side of composite laminates. It has also been observed that hardness increases with increasing stacking sequences and glass layer content, resulting in higher values.

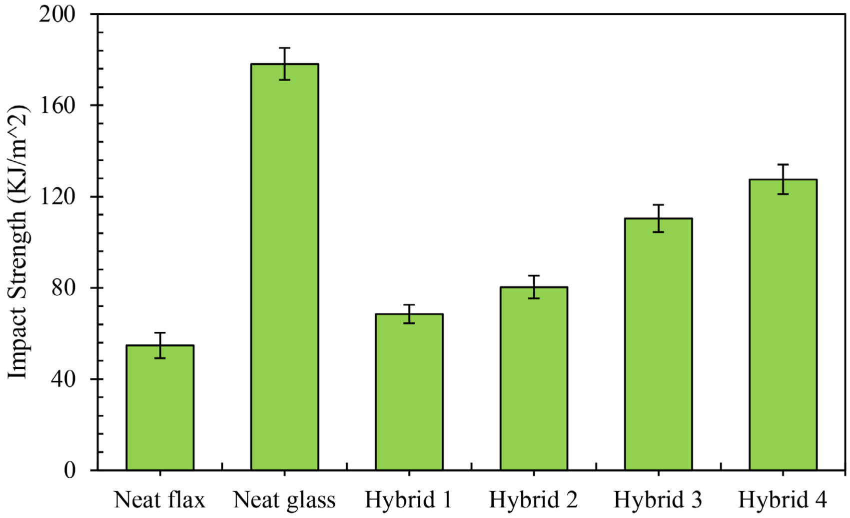

Figure 7. Impact strength (IS) of neat flax, neat glass and hybrid composites.

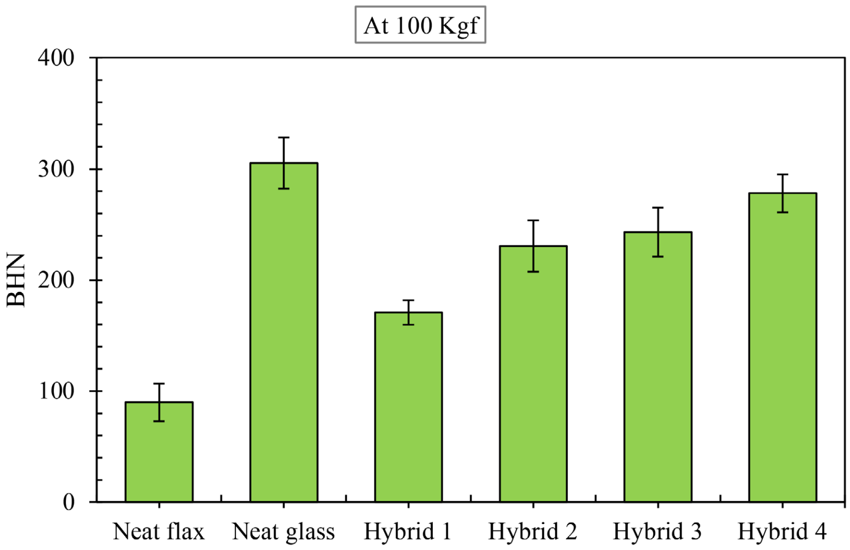

Figure 8. Hardness of neat flax, neat glass and hybrid composites.

3.5. Water Absorption

Figure 9 shows the water-uptake nature of flax-glass fabric composites. For neat flax, the composite began to quickly absorb water after only 10 minutes, after which the rate gradually grew by 21.43% over the course of 1500 minutes (or 25 hours), and after that it began to slow down.

For neat glass, it is revealed that glass fiber does not take water up to the first 180 minutes, then it takes a very negligible amount of water up to 1500 minutes, which is 0.01% for 240 minutes, 0.02% for 1440 minutes, and 0.02% for 1500 minutes. So, we can say that the water absorption rate of glass composite is negligible as it is hydrophobic.

Figure 10 indicates the water-uptake nature of flax-glass fiber polyester hybrid composites. It has been found that the water absorption rate of the composite is very slow, less than 1% up to 1500 minutes, due to the glass fiber's hydrophobicity and the use of polyester resin. In the Figure, composites absorb no water up to the first 30 minutes; hybrid 2 and hybrid 4 showed better results than hybrid 1 and Hybrid 3. It has been noticed that having flax fabric layers on

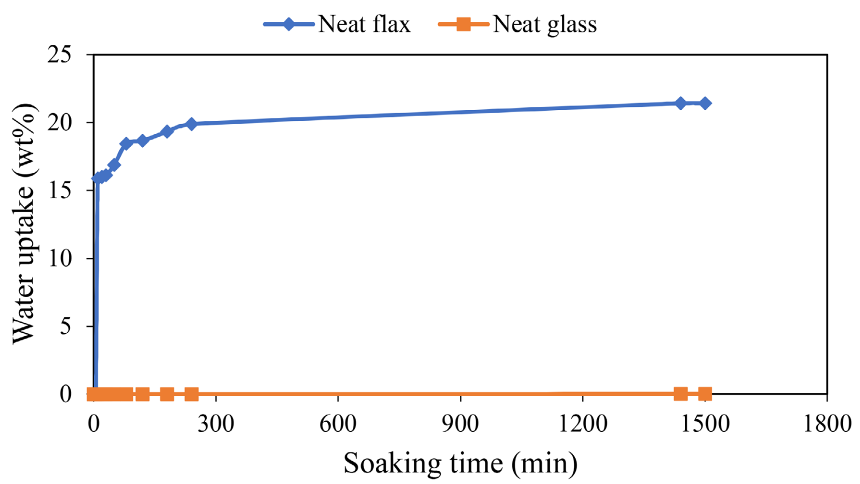

Figure 9. Water uptake (%) of neat flax and neat glass composites.

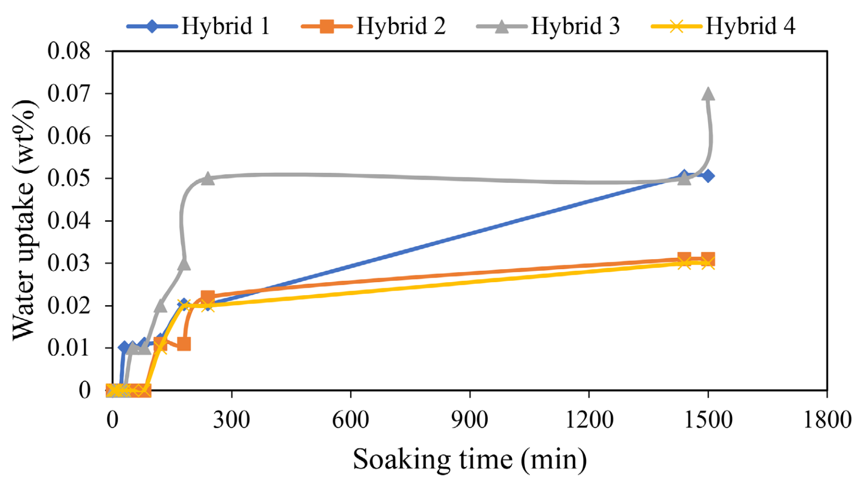

Figure 10. Water uptake (%) of hybrid composites.

the outer side leads to more water absorption, while having glass does the opposite. Hybrid 4 started to absorb water from 120 minutes (0.01%) up to 1550 minutes (0.03%) and then had very negligible water uptake.

3.6. Thermogravimetric Analysis

In the below, **Figure 11** displays the temperature behavior of neat flax, neat glass, flax/glass fabric-reinforced polyester hybrid 4 composites. The degradation of neat flax/polyester composite is initiated at around 100˚C - 130˚C and evaporate the liquid moisture content. At 230˚C - 240˚C polyester resin starts to melts. The significant decomposition begins between 340˚C - 400˚C, where the degradation of the lignin, hemicelluloses and cellulose occurs and significant weight declined from 80% to 30%. The final decomposition and complete weight loss of the composite is found at 590˚C - 600˚C.

On the other hand, the plain glass/polyester composites break down and remove volatile elements between 180˚C - 190˚C. At 230˚C, the resin state changes to a molten state, its weight progressively decreases, and the intermolecular connections grow weaker. Significant weight loss and the fastest rate of breakdown were seen at 485˚C, and the linear polymer's backbone chain broke up into tiny pieces at higher temperatures. Finally, the residue that remained after the whole polyester matrix burned at between 800˚C - 1000˚C. The flax/glass hybrid polyester composites, disintegrate over a short period of time. At first, water

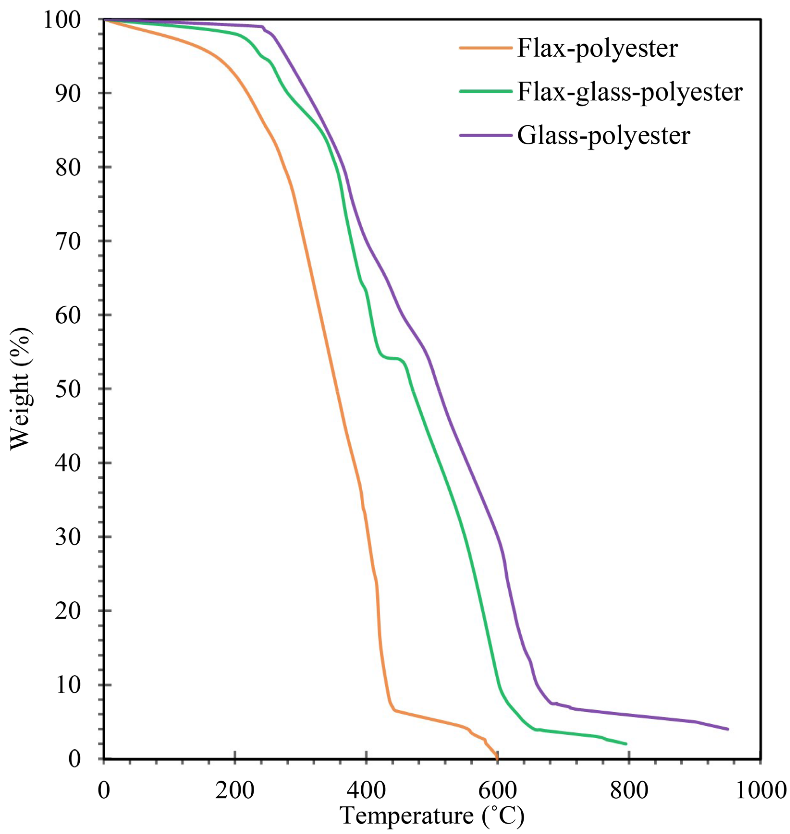

Figure 11. TGA of neat flax, glass and hybrid composites.

evaporates between 140˚C - 170˚C, then resins begin to melt at 230˚C with steady weight loss & volatile material removal. Second phase considerable weight declined from 50% to 10% at 440˚C - 450˚C, deforming the crystal structure. At 780˚C - 790˚C, the whole matrix burned away and some residue was left behind. It is obvious that the thermal stability of the hybrid flax-glass composite is higher than that of the pure flax-polyester composite [44] [45].

3.7. Morphological Analysis

In Figure 12, the SEM micrographs of the neat flax, neat glass, and flax-glass hybrid composite samples are presented. Figure 12(a) reveals the fractured fiber and fiber pull out of neat flax by loading, showing poor mechanical performance. Figure 12(b) shows the fiber orientation and resin adhesion with a neat glass composite that is indicating good mechanical performance, In the case of hybrid flax/glass composites Figure 12(c), clearly visible thermoset polyester resin's proper adhesion to the flax/glass-reinforced composite due to the good hydrophilic nature of flax that improved mechanical strength. Finally, Figure 12(d) reveals the surface roughness of the fabricated hybrid composite that may be happened due to the hand lay-up techniques during fabrication [46]. Roughness of the fabricated hybrid composite could be improved by polishing the surface using a polishing wheel as well as can be incorporated filler materials into the composite [47].

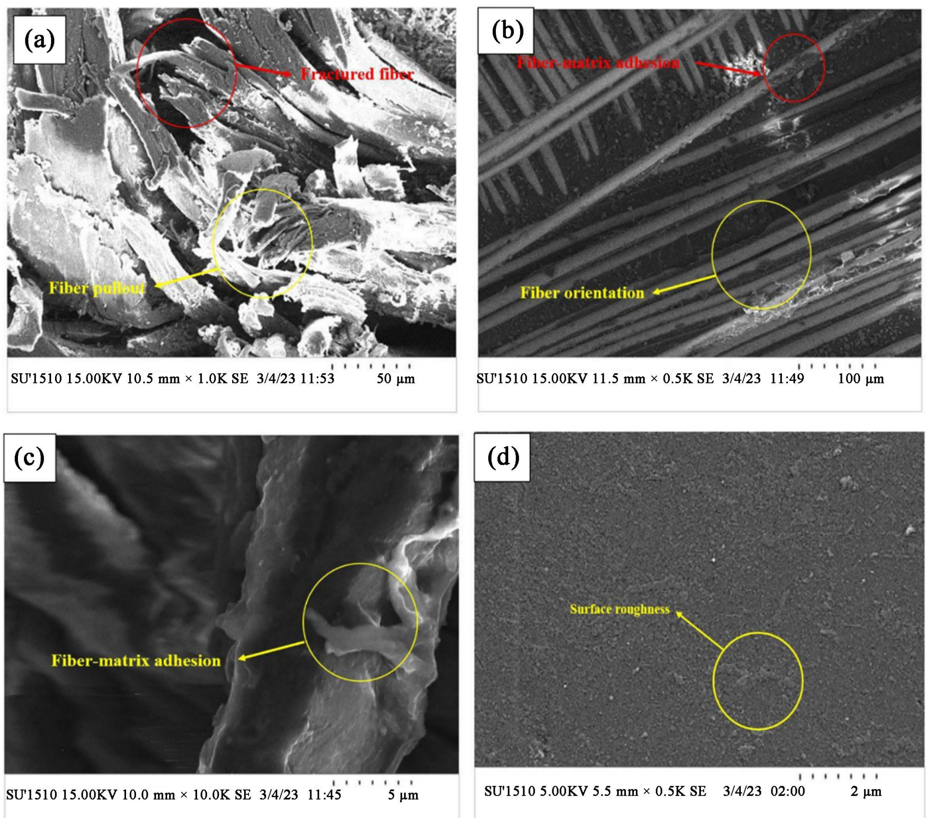

Figure 12. Morphological analysis of neat flax, glass and hybrid composites.

4. Conclusion

In this experimental study, flax-glass fabric-reinforced hybrid composites have been prepared by maintaining optimal parameters. Six categories of samples have been made, with each sample consisting of 12 layers of flax and glass fabric, following the different stacking sequences. Tensile strength, flexural strength, impact strength, and hardness of these composites have all been evaluated in terms of their mechanical properties. The neat glass composite outperforms the other evaluated composite samples in terms of mechanical qualities, whereas the neat flax composite performs the least well. It is apparent that the mechanical properties and thermal stability of hybrid samples are in between those of neat flax and neat glass because, by adding glass with flax fabric, the strength of hybrid samples is increased. Also, it is noticeable that, due to multiple stacking layers of flax and glass, hybrid 3 and hybrid 4 show better strength than consecutive single stacking layers in hybrid 1 and hybrid 2. Among all hybrid composites, the hybrid 4 shows comparatively better mechanical and thermal properties due to having the glass layers on the outermost surface. In the case of water absorption, it has been noticed that having flax fabric layers on the outer side leads to more water absorption, while having glass does the opposite. In conclusion, the researcher recommends that flax/glass hybrid composites can be employed in the interior décor of homes as well as the inner bodies of automobiles. Additionally, flax fiber may be used with glass fiber to make reinforced composites at a lower cost while reducing the need for glass demand for a more sustainable future.

5. Future Scope

Future studies on flax-glass fiber reinforced polymer composites can target strengthening interfacial bonding, enhancing hybridization, investigating functional additives, highlighting sustainability, and assessing structural applications.

Author Contribution Statement

Sayed Hasan Mahmud: Conceived and designed the experiments; performed the experiments; wrote the paper.

Md. Washim Akram: Analyzed and interpreted the data; wrote the paper.

Md. Fuad Ahmed, Md. Atik Bin Habib: Contributed reagents, materials, analysis tools or data.

Data availability Statement

No data was used for the research described in the article.

Conflicts of Interest

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

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