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Investigation of mechanical properties of rattan and bamboo fiber reinforced vinyl ester composite material for automotive application

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A R T I C L E I N F O

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A B S T R A C T

In scope of this research, manufacturing and mechanical characterization of rattan and bamboo fiber reinforced vinyl ester composite material were carried out. Bamboo and rattan fiber was extracted by using retting process followed by chemical treatment to enhance mechanical properties. The composite was manufactured using bidirectional fiber mat in vacuum bag molding and hand layup process. The weight fraction between reinforcement and matrix was 24% and 76% respectively. Three types of composites were manufactured; Bamboo Fiber Composite (BFC), Rattan Fiber Composite (RFC), and Rattan (12%) and Bamboo (12%) Fiber Composite (RBFC). Different mechanical behavior of the composite was investigated, such as tensile strength, flexural strength, hardness, and impact strength. The maximum flexural and impact strength was found for RBFC with 57.66 MPa and 44.49 kJ/m2, respectively. It was found that about 29% and 17% of flexural strength and 29% and 78% of impact strength was improved for RBFC than BFC and RFC respectively. Finally, fabricated composites mechanical characteristics were compared to the Acrylonitrile Butadiene Styrene or ABS plastic materials mechanical characteristics.

1. Introduction

The natural fiber used as reinforcement is one of the most well-liked biodegradable materials. The numerous advantages are non-toxic, lightweight, low density (compared to glass fiber), great flexibility, high specific modulus, easy processing, no skin irritation, non-abrasive, and high strength-to-weight ratio. In today's world, natural fiber composites have the inherent to substitute materials, for example, metals and synthetic fiber composites. By reducing the cellulose, lignin, hemicellulose, wax, and oils that cover the external surface, the chemical treatment enhances the adherence within fibers and matrix. It increases surface roughness, increasing the fiber's mechanical characteristics [1–3].

Natural fibers include rattan, bamboo, jute, rice husk, banana, broom root, cotton, palm leaves, flax, oilseeds, pineapple, sisal, and straws (cereal). These plants are utilized for their leaves, stems, stalks, grass, fruit, and seeds. The matrix must support load directions that transverse the fiber axis since it is a transmission medium between the fibers [4]. Rattan and bamboo fibers are proposed as reinforcement among various available natural fibers. A subfamily of rattan is "*Calamoideae*," and bamboo is "*Bambusa*."

The tensile performance of sisal-reinforced composites blended with vinyl ester resins and fabricated using a hand layup process. The result is a high specific strength, high stiffness, and low weight [5]. The mechanical behavior of twisted natural fiber hybrid composites was studied using a vacuum-assisted compression molding process that alkalized the fibers to improve their mechanical properties. It was determined that the presence of twisted fibers significantly improved the mechanical properties [6]. The effect of chemical treatment (NaOH) of Areca fibers on their mechanical properties was observed. The chemical treatment was found to enhance the adhesive properties of the betel nut fiber surface [7].

Rattan fiber still has the capability to be further improved to achieve better products like automotive components [8]. A comparison of the mechanical properties was analyzed for banana fiber and rattan fiber-reinforced epoxy composites fabricated using a hand layup

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Fig. 1. Rattan cane and extracted rattan fibers.

process. It was learned that the tensile strength of banana fiber composites is higher than that of rattan fiber composites, while the bending strength of rattan fiber composites is higher [9]. Rattan composite was produced using a polyvinyl alcohol (PVA) matrix and specified thermal, mechanical, and morphological characteristics and correlated them with pure PVA. It was exhibited that better mechanical and thermal properties were obtained with 24 wt% of rattan fiber-reinforced composite [10].

There are different retting processes used to extract rattan fiber. Mechanical retting with hammers, chemical retting with chemicals and boiling, steam or vapor retting, and microbial or water retting are all examples. The retting process is essential, providing the perpetual long-life stem of the plants of bast fiber to extract fiber from rattan.

The bamboo fiber composite's improved abundance, formability, financial savvy, sustainability, and eco-friendliness have recently received quick attention in inventive work [11]. Bamboo fibers have improved energy recovery, high toughness, low density, sufficient specific strength, and low abrasion. Compared to concrete timber and steel, bamboo fiber reinforced has a high strength-to-weight ratio [12,13]. The sisal and bamboo fiber-reinforced polyester composite containing a variety of orientation of sisal fiber and unidirectional fibers of bamboo fibers was created and described using the hand-lay-up technique. The ratio of sisal to bamboo fiber has been fixed at 3:1. Bidirectional (0°/90°) fiber orientation was shown to have more flexural strength, despite the fact that bidirectional (0°/90°) unidirectional 90° fiber orientation only had a similar value for tensile strength [14]. The mechanical properties were investigated and demonstrated that phase adhesion needs further improvement. When compared to pure LDPE (Low-Density Polyethylene), reinforcement with bamboo flour resulted in an increase in elasticity but a decrease in tensile strength and elongation at break [15]. The effects of the addition of bamboo fiber were explored in terms of its compressive properties. During compression, the treated bamboo fibers significantly increase their strength and modulus [16].

Three different methods can be used in order to extract bamboo fiber. They include the mechanical and chemical extraction processes and a combination of the mechanical and chemical extraction processes. Lignin is removed from the fibers using chemical extraction methods such as chemical retting and alkaline or acid retting. The mechanical fiber processing procedures include grinding, crushing, rolling mills, retting, and steam explosion [17].

Rattan and bamboo fiber composite give better flexural properties individually which help us to choose these fibers to fabricate composite with rattan and bamboo fibers for automotive application. Continuous rattan fiber composite materials were used to create the method for producing automobile spoiler products. The research involved assessing the strength of a composite rattan fiber, simulating it using computer software, comparing it to already-existing spoilers, and developing prototypes of spoilers [8]. In order to manufacture lightweight, affordable composite laminates from alternate natural fibers, a study was conducted comparing natural fibers (coconut coir and rattan) with Kevlar fiber for the bulletproof vest application. The analysis pointed out that coir is suitable for replacing Kevlar fiber [18].

2. Materials and methods

2.1. Materials

2.1.1. Matrix material

In this research, vinyl ester resin was used as matrix material. Vinyl ester resin and hardener W 300 were collected from a local vendor. The density of the collected resin was 1.03 g/cm^3 (25 °C), and kinematic viscosity was more significant than 20.5 mm^2/s (40 °C). The density of the hardener was 0.948 g/cm^3 (20 °C), and the boiling point was 260 °C.

2.1.2. Rattan fiber extraction

The rattan was collected from Baradargah, Rangpur, Bangladesh on July 30, 2022. There are 600 species of rattan consisting of 13 genera worldwide. There are merely two genera, *Calamus* and *Daemonorops*, grown in Bangladesh out of 13 genera. The average age of the rattan

Fig. 2. Bamboo strips and extracted bamboo fibers.

(a) (b) (c)

Fig. 3. The fiber mats (a) rattan fiber mat, (b) bamboo fiber mat, (c) rattan and bamboo fiber mat.

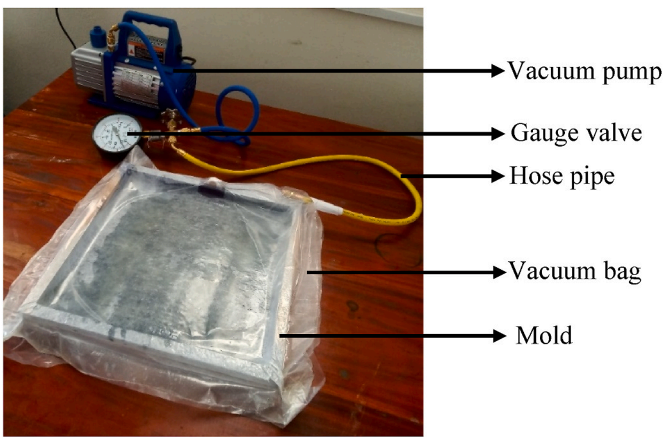

Fig. 4. Vacuum bag molding setup.

cane was more than 4.5 years, the tree's height was 25–28 feet, and the average diameter of the rattan cane was 1.4–2.0 cm. After harvesting, the rattan canes were chopped to a 29–30 cm length, as shown in Fig. 1. The cane leaves, and thrones were trimmed carefully to avoid damage to the fiber.

In this research, water retting was used to extract the fiber. Rattan stalks were grouped in a bundle and submerged in the 0.2096 M NaOH solution, and the bundle was submerged for 50 days. This treatment has attracted the hydroxyl group of lignin and cellulose in the fiber. Natural fibers can be surface-modified with a sodium hydroxide solution to enhance the hydroxyl group's ionization into alkoxide [19]. The retting process may require more or less time depending on the age of the rattan and microbial growth rate. The extracted fibers were dehydrated by washing them with fresh water and drying them in sunlight for 12 h at 32° to 33 °C and 70–74% relative humidity.

2.1.3. *Bamboo fiber extraction*

The bamboo [*Bambusa tulda*] was collected from Saidpur, Nilphamari, Bangladesh on August 22, 2022. The average age of the bamboo was more than two years, the tree's height was approximately 35 feet, the distance between the internodes was 30–47 cm, and the average diameter of the bamboo was 3–4.5 cm. The bamboo was chopped to a short length of 28–35 cm, as shown in Fig. 2. There were 35 internodes; for this research, 15 were used by removing 15 internodes from the bottom and five internodes from the top of the bamboo. The alkaline retting process was applied to extract the bamboo fiber from bamboo strips. After harvesting, the strips were washed adequately with tap water and dried in sunlight for 6 h. The strips were steeped in a solution of 1 N NaOH for 12 days. Adding NaOH eliminated the amorphous sections, and the lignin percentage of the core fibers was minimized [20]. The retrieved fibers were further dehydrated by washing them in fresh water and drying them in the sun. The fibers were dehydrated in direct sunlight for 12 h at 32° to 33 °C and 70–74% relative humidity (see Fig. 4) (see Fig. 5) (see Fig. 6) (see Fig. 7) (see Fig. 8) (see Fig. 3).

2.2. *Methods*

2.2.1. *Mat preparation*

Chemically treated rattan and bamboo fiber were used for preparing bidirectional fiber mats. For the rattan fiber mat and bamboo fiber mat, about 60 ± 2 gm of fiber was used. The rattan fiber mat was prepared by

(a) (b) (c)

Fig. 5. Fabricated specimens (a) RFC, (b) BFC, and (c) RBFC.

Fig. 6. Universal Testing Machine with the tensile test setup.

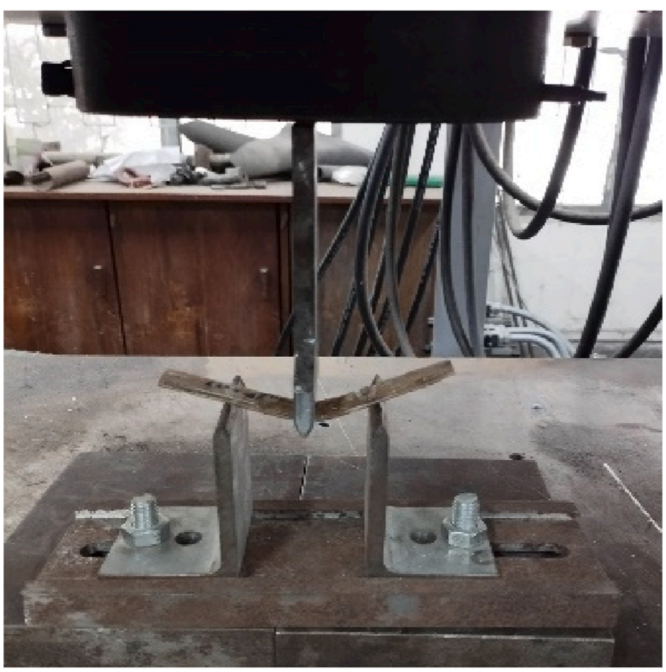

Fig. 7. Universal Testing Machine with the flexural test setup.

using the plain wave method. The twill weave method was used for the other two mats. In rattan and bamboo fiber mat 30 ± 2 gm rattan and 30 ± 2 gm of bamboo fiber was used.

2.2.2. Manufacturing process

The reinforcing matrix composite was manufactured using a neat and dry fiber mat. In order to be employed in the manufacturing process, vinyl ester resin and hardener were combined in a matrix at a weight ratio of 100:1.25 and homogeneously mixed for 3–5 min. Vacuum bag molding and hand layup molding were used for the fabrication

Fig. 8. Charpy impact test setup.

processes. The vacuum bag molding was conducted for BFC and RBFC and RFC was prepared by using hand lay-up. Two fabrication processes were followed because rattan fiber cannot be fabricated in the vacuum bag molding process.

Due to its unique physical and chemical characteristics, rattan fiber cannot be efficiently produced using the vacuum bag molding technique. The finished product of vacuum bag molding may have voids and flaws since rattan fiber is a somewhat thick and dense material that does not adhere well to the mold shape.

A wood frame mold with a polyethene sheet on top was used to prevent vinyl ester resin from sticking to the frame's surface and help remove the mat after fabrication. Peel ply was put on the polyethene. First, a mixer of vinyl ester and hardener was brushed on the peel-ply cover. Next, the fiber mat was laid down and brushed resin on it. The procedure was repeated until a necessary number of layers were applied. In this work, two layers of fiber mat were used in fabrication. Peel ply, as well as a breathing cloth, were placed at the top in order to prepare for vacuum bag molding. The mold was then placed inside a vacuum bag and sealed. Under 50–60 cmHg vacuum pressure, the bag's existing air was continuously sucked out for 6 h before being kept at room temperature for 14–18 h. The excess vinyl ester, hardener solution, and air gap were also removed in the vacuum pump molding process. Peel ply and breathing cloth were also applied in the hand layup molding process. In hand layup, A surface plate weighing around 220 kg was placed on top of the mold surface and left at room temperature for 24 h.

The specimens were categorized on the volume fraction of the fiber. The specimens are as follows.

2.2.3. Composite specimen preparation

The vacuum bag molding process prepared all the specimens according to ASTM standards.

2.2.4. Mechanical characterization

The tensile test was carried out at Shimadzu AGS-X Universal Testing Machine. The capacity of the machine was 5 kN. The specimens had a rectangular cross-section of 175 mm × 25 mm x 5 mm. The jaw speed was 2 mm/min, and the gauge length was 61.3 mm. The flexural test was carried out at Shimadzu UH-F1000$_{kN}$X Universal Testing Machine by using the three-point bending method. The machine's capacity was 123 kg, and jaw speed was 1 mm/min. The distance between the supported pin ends was 66.10 mm, and the force was applied at the middle span of the beam.

The Charpy impact test was done using Universal Impact Testing Machine (Capacity: 30 kgfm) with a simple pendulum hammer. The impact load was 8.446 kg to break the specimen. Impact toughness for material depends on the existence of groves, grove radius, etc. The

Fig. 9. Rockwell hardness test setup.

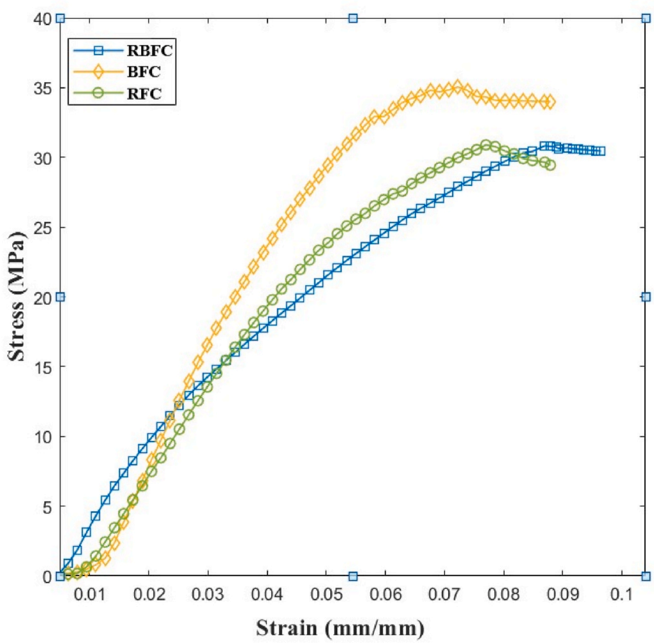

Fig. 10. Stress-strain curve of the fabricated composites.

Rockwell hardness test was done at L scale using P.A. Hilton Rockwell and Brinell Hardness Tester (Capacity: 60–250 kg) during the test the pre-load or minor load was 10 kg-f, and the major load was 60 kg-f used.

3. Result and discussion

3.1. Mechanical characterizations

3.1.1. Tensile strength

The stress-strain curve shows the average data of three specimens for RFC, BFC, and RBFC respectively given in Fig. 9 (see Fig. 10).

The ultimate tensile strength was maximum for BFC, and the value was 35.0565 MPa. For RBFC, the ultimate tensile strength was minimum. The value of ultimate tensile strength for RFC and RBFC was quite similar. Young's modulus represents the general stiffness of the material. Higher Young's modulus corresponds to stiffer materials. BFC had maximum Young's modulus, making it stiffer than other composites. Among all the fabricated composites, RBFC was more ductile than others as it has a maximum elongation at break with 8.69%.

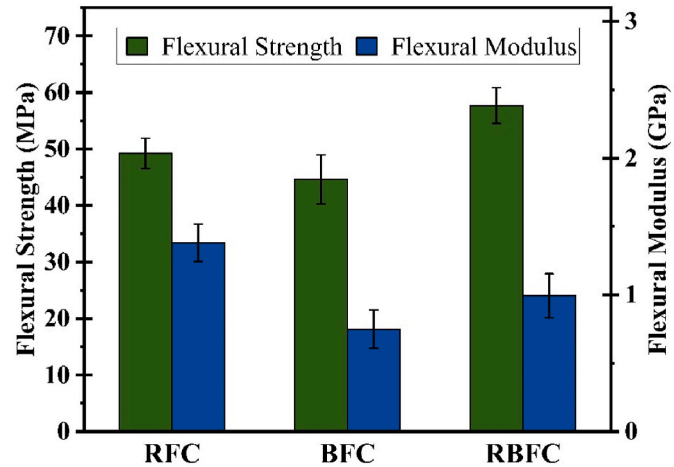

Fig. 11. Flexural strength of the fabricated composites.

3.1.2. Flexural strength

Fig. 11 shows the average data of three specimens of the flexural test for RFC, BFC, and RBFC respectively.

The flexural strength of RBFC was higher than other fabricated composites. Maximum flexural strength was 57.66 MPa. The difficulty of bending a material increases with its flexural modulus. Flexural modulus was maximum and minimum for RFC and BFC with 1.38 GPa and 0.75 GPa respectively. The flexural test is more sensitive than the tensile test, which can be significantly affected by specimen size, strain rate, and other geometrical factors. All specimens, however, exhibit more substantial flexural properties than tensile properties.

3.1.3. Impact strength

The specimen ought to be positioned so that the specimen's notch faces away from the pendulum's impact direction. The pendulum was released, and noted down the reading of the deflection angle on the dial was. The impact strength was calculated by the following equations,

$$K = MgR(\cos \boldsymbol{\alpha} - \cos \boldsymbol{\beta}) \tag{1}$$

$$I = K / A_n \tag{2}$$

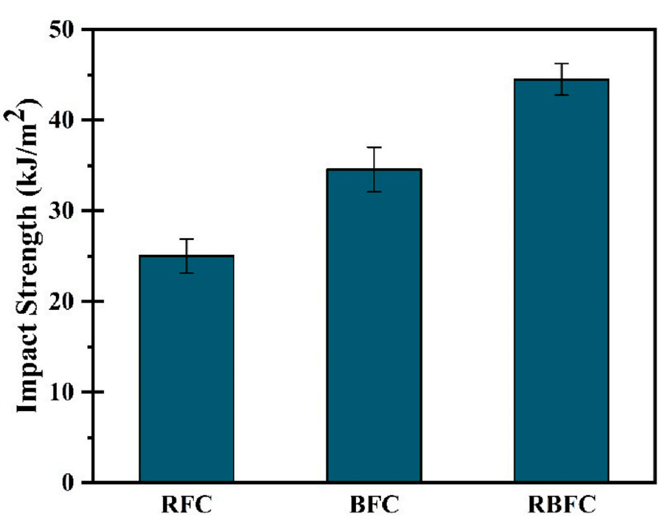

Fig. 12. Impact strength of the fabricated composites.

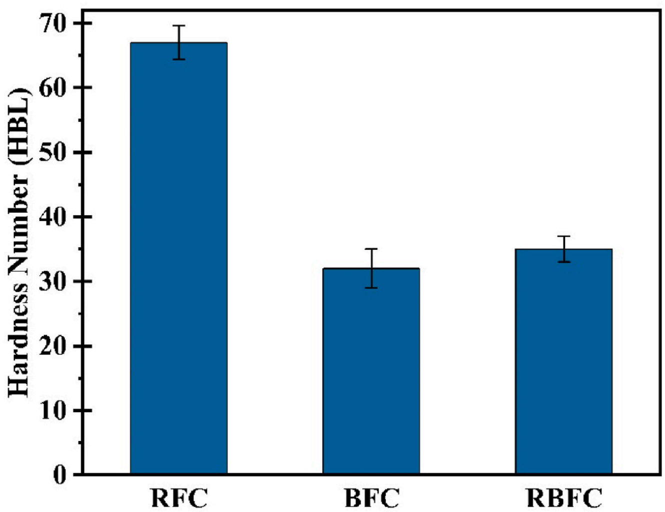

Fig. 13. Rockwell hardness number of the fabricated composites.

Table 1
Material content of composites.

Specimen Name	Percentage of Fibers	Percentage of Resin and Hardener
RFC	24% Rattan Fiber	76%
BFC	24% Bamboo Fiber	76%
RBFC	12% Rattan Fiber+12% Bamboo Fiber	76%

Where:

K = Absorbed energy.
M = Mass of the pendulum
g = Acceleration of gravity.
R = Radius of pendulum
$\boldsymbol{\alpha}$ = Angle of pendulum before release
$\boldsymbol{\beta}$ = Maximum angle of pendulum after release.
I = Impact strength.
K = the energy absorbed by the specimen.
A_n = Area of cross-section of the specimen below the notch.

Fig. 12 shows the average data of three specimens of the Charpy impact strength for RFC, BFC, and RBFC respectively (see Fig. 13).

From the Charpy impact strength experimental result, it was found that the impact strength of RBFC was high. The flexural strength of the RBFC was maximum, so the impact strength of the RBFC was maximum. Because high flexural strength indicates a more impacting force material can withstand. The impact strength of RBFC was found to be 44.49 kJ/m^2. Besides, the impact strength for RFC was lower, which was 25.04 kJ/m^2.

3.1.4. Hardness number

Figure shows the average data of three specimens of the Brinell hardness number for RFC, BFC, and RBFC respectively.

The Rockwell hardness number was maximum for RFC and minimum for BFC. The maximum and minimum hardness number was 67 and 32, respectively. The Rockwell hardness number for RBFC was 35.

4. Comparison of mechanical characteristics with other composites and material

The comparisons between the results of the present and previous investigations are presented in this part. Comparisons are made between tensile strength, flexural strength, and impact strength (see Table 1).

Table 2
ASTM standards for mechanical characterization [21–23].

Sl. No	Tests Name	Standards	Reference
1	Tensile Test	ASTM D3039	[21]
2	Flexural Test	ASTM D7264	[22]
3	Impact Test	ASTM D256	[23]
4	Hardness Test	–	–

Table 3
Tensile characteristics of the fabricated composites.

Composite Material	Tensile Strength (MPa)	Young's Modulus (GPa)	Elongation at Break (%)
RFC	30.89 ± 0.74	0.33 ± 0.23	5.94 ± 1.16
BFC	35.06 ± 0.67	0.57 ± 0.07	6.26 ± 0.97
RBFC	30.82 ± 1.85	0.37 ± 0.12	8.69 ± 1.43

4.1.1. Comparison of rattan fiber composite

A comparison of rattan fiber-reinforced composites with previous work is shown in Table 4 (see Table 3) (see Table 2).

From Table 4 it is clear that, though RFC had better flexural and impact strength than others, tensile properties were significantly lower.

4.1.2. Comparison of bamboo fiber composite

A comparison of bamboo fiber-reinforced composite with previous works is shown in Table 5.

In previous work, 30% of bamboo fiber was used to investigate the mechanical properties. But in the present work, for 24% bamboo fiber, more tensile, flexural, and impact strength was found.

4.1.3. Comparison of the mechanical characteristics of a material

For the present work, the comparison of the mechanical properties of the fabricated composite with ABS plastic which is used in automotive body parts such as dashboards, shrouds, spoilers, etc. is shown in Table 6.

The flexural and impact strength was more than ABS plastic material for RBFC. But the tensile strength was less than ABS plastic. Only for BFC, tensile strength was relatively equal.

5. Conclusion

The research was conducted to manufacture and characterize rattan and bamboo fiber-reinforced vinyl ester composite material for engineering applications. Chemical retting process of raw fibers helped to reduce the percentage of non-cellulosic material such as lignin and pectin effectively without damaging the cellulose. Vacuum bag manufacturing process helped to reduce the air void inside the composite materials which enhanced the mechanical properties. It was found that the flexural strength of RBFC was higher than the other fabricated composite. With increasing flexural strength, the impact strength also increases which is evident from the investigation. Hardness of RFC was significantly greater than others but impact strength was comparatively lower. Compared with ABS plastic material, RBFC has better mechanical properties. So, it can be used in automotive applications.

Authorship contributions

Md Mahadi Hassan Parvez: Conception and design of study, acquisition of data, analysis and/or interpretation of data, Drafting the manuscript, Shah Misbabun Nur Rupom: Conception and design of study, acquisition of data, analysis and/or interpretation of data, Drafting the manuscript, M.M. Adil: Conception and design of study, analysis and/or interpretation of data, Supervision, Project

Table 4
Comparison of rattan fiber reinforced composite with previous works [2,10].

Fiber	Matrix	Fiber Percentage	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (kJ/m^2)	Ref.
Previous Works						
Rattan	Epoxy	24	48.72	45. 72	5.89	[10]
		30	42.65	40.21	5.30	
Rattan	Polypropylene	20	46.04	50.2	17.48	[2]
		30	52.45	54.86	19.78	
Present Work						
Rattan	Vinyl Ester	24	30.89 ± 0.74	49.26 ± 2.69	25.04 ± 1.87	–

Table 5
Comparison of bamboo fiber reinforced composite with previous works [24–26].

Fiber	Matrix	Fiber Percentage	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (kJ/m^2)	Ref.
Previous Works						
Bamboo	Polypropylene	0	24.50	38.00	2.52 [25]	[25]
		30	25.80	45.49	18.38 [25]	[26]
Bamboo	High-Density Polyethylene (HDPE)	20	22.03	26.78	–	[24]
		30	25.47	27.86	–	
Present Work						
Bamboo	Vinyl Ester	24	35.06 ± 0.67	44.65 ± 4.32	34.56 ± 2.45	–

Table 6
The comparison of mechanical properties of the fabricated composite with ABS plastic [27].

Mechanical Characteristics	ABS plastic material [27]	Rattan fiber composite material (RFC)	Bamboo fiber composite material (BFC)	Rattan Bamboo fiber composite material (RBFC)
Tensile strength (MPa)	35	30.89 ± 0.74	35.06 ± 0.67	30.82 ± 1.85
Flexural strength (MPa)	56	49.26 ± 2.69	44.65 ± 4.32	57.66 ± 3.14
Impact strength (kJ/m^2)	31	25.04 ± 1.87	34.56 ± 2.45	44.49 ± 1.75
Density (gm/cm^3)	1.0–1.05	0.95–1.04	0.94–0.97	1.08–1.09

administration, revising the manuscript critically for important intellectual content and editing, Tasfia Tasnim: Supervision, revising the manuscript critically for important intellectual content, Approval of the version of the manuscript to be published, M S Rabbi: revising the manuscript critically for important intellectual content, Approval of the version of the manuscript to be published, Irfan Ahmed: Revising the manuscript critically for important intellectual content, Approval of the version of the manuscript to be published.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: The authors affirm that they have no known financial or interpersonal conflicts that would have appeared to have an impact on the research presented in this study.

Data availability

Data will be made available on request.

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