*International Conference on Mechanical, Industrial and Energy Engineering 2022*
*22-24 December, 2022, Khulna, BANGLADESH*

**ICMIEE22-208**

# Mechanical Characterization of Date Palm Rachis Fiber Reinforced Epoxy Composite

*Raju Ahammad*, Arup Kumar Debnath , Md. Mahmudur Rahman, Md. Arifuzzaman, Md. Shariful Islam*
Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna-9203, BANGLADESH

## ABSTRACT

Nowadays more and more research is being carried out to find new environment-friendly, biodegradable, and sustainable materials. These researches include investigating environment-friendly materials like natural composite materials, hybrid composite materials, and other sustainable hybrid materials. Continuous research is being carried out to find alternative reinforcement and matrix systems that can match the performance of the existing system and is more environment-friendly. An epoxy-based composite material was prepared and reinforced with Date Palm rachis fiber using the hand lay-up method. The tensile strength, flexural strength, and impact strength were investigated in this work. The flexural strength was investigated using the three-point bending method and the material had an average flexural strength of 43.242 MPa. The impact test was carried out on two types of specimens with the fibers laid up across the length of the specimen and the width of the specimens. The specimens with fibers laying across the length of the specimens had an impact strength of 224.95 $kJ/m^2$ and the specimens with fibers laying across the width of the specimens had an impact strength of 127.26 $kJ/m^2$. The tensile strength of the material was investigated using a Universal Testing Machine and the material had an average tensile strength of 42.11 MPa.

**Keywords**: Composite, Tensile strength, Flexural strength, Impact strength, Fiber.

## 1. Introduction

Due to the unique combination of outstanding performance, tremendous adaptability, and manufacturing benefits at a reasonable cost, fiber-reinforced polymer composite demand has been steadily rising over the past few decades [1]. High specific strength and stiffness, good fatigue performance, satisfactory damage tolerance, low thermal expansion, non-magnetic characteristics, corrosion resistance, and low energy consumption during fabrication are all characteristics of fiber-reinforced composites [2]. The use of carbon, boron, glass and Kevlar fibers in fiber-reinforced composites for structural and non-structural purposes has received widespread acceptance [3].

Due to growing environmental concerns, there is a growing desire for natural fibers that are biodegradable, renewable, and inexpensive to replace the synthetic fibers currently used in composite materials. Natural fibers such as sisal, jute, abaca, pineapple, coir, and date palm fiber have acceptable specific strength qualities, low density, low abrasion multi-functionality, and superior thermal values when compared to standard reinforcing materials.

Date palm fiber is a natural fiber in composite which can be used in different types of structural applications. It can be used as indoor and outdoor housing material, affordable housing for defense and rehabilitation. Date palm fiber has a very good insulation characteristic. That is why it can be used in ceiling or door panels or as a separating panel between two compartments. In addition to contributing to ecological balance, the usage of natural fibers like date palm fiber can aid rural residents of nations like Bangladesh and India, where date palm is widely available, by giving them jobs.

Faleh A.Al-Sulaiman [2] determined the mechanical properties of date palm fiber-reinforced composite where he used date palm leaves as reinforcement. Three different processes were used to construct these composites. These include Vulcan press molding, autoclaving, and wet lay-up with simple vacuum bagging. Tests were conducted using various fiber dimensions and orientations. There were two resin varieties chosen. The first was a two-component Bisphenol resin with an amine-based delayed curing agent, and the second was a high-temperature curing Phenolic (phenol-formaldehyde) resin. When compared to Phenolic laminates, the tensile strength of the Bisphenol composites was consistently 25 to 50% greater.

Ahmad Alawar et al. [3] experimented with the effect of different chemical treatments on date palm fiber composite. Raw date palm fiber was treated with different chemical treatments such as alkali treatment with concentrations of 0.5%, 1%, 1.5%, 2.5%, and 5%, and acid treatment with 0.3, 0.9, and 1.6 N. The specimen treated with 1% NaOH showed optimum mechanical properties and hydrochloric acid treatment resulted in deterioration in mechanical properties.

Saeed Mahdavi et al. [4] conducted research on the strength of material produced from different parts of a date palm tree. The research investigated the bulk density and fiber quality obtained from different parts of the date palm tree like the trunk, leaves, branches, and rachis. Polyethylene was used as the matrix for the composite material and the composite with 30-40% fiber content showed the maximum strength.

Abdalla Abdal-Hay et al. [5] studied the effects of alkali treatment on the properties of date palm fibers with three different size ranges of diameters (200-400, 400-600 and 600-800 mm). On both treated and

* Corresponding author. Tel.: +880-1615050099
E-mail addresses: rajuahammad009@gmail.com

untreated fibers, morphology observations (SEM), EDS density mapping (quantitative elemental analysis), X-RD, and FTIR spectroscopy were performed. Additionally, the tensile characteristics of a single fiber and composites made of discontinuous random oriented short fibers in epoxy were investigated, both with and without chemical modification. The findings demonstrated that date palm fibers, especially tiny fibers, are vulnerable to chemical alteration. Additionally, it was shown that after alkali treatment, the ultimate tensile strength and percentage elongation of a single fiber rose by 57% and 24.7%, respectively.

Salah Amroune et al. [6] worked with the chemical and thermo-physical characteristics of date palm fiber. 750 specimens were immersed in NaOH solution of different concentrations for a different amount of time. The result showed a chemical treatment can increase the mechanical property up to three times.

Ava A.Saleh et al. [7] constructed biodegradable composite material by plasticizing corn starch and chemically treating the date palm fiber and finally by compression molding. The result showed that mechanical properties like Young's modulus and tensile strength and 50% weight percentage increased by 12.5 and 7% respectively compared to thermoplastic starch. An increase in fiber percentage further deteriorates the mechanical properties, as well as moisture content, deteriorating tensile strength.

Boumedri et al. [8] extracted date palm rachis fiber for the potential reinforcement in biodegradable composite. Bezazi et al. [9] investigated the effect of alkali treatment on the physiochemical and tensile properties of date palm fiber. Alshahrani et al. [10] manufactured date palm rachis fiber reinforced poly (EPN/BA-a) composites and investigated their mechanical properties.

From the above discussion, it is clear that the date palm rachis fiber can be used to manufacture composites. However, date palm rachis fiber reinforced epoxy based composite is limited in the literature. Therefore, the aim of this work was to extract date palm rachis fiber and manufacture composite using epoxy as matrix. Finally mechanical properties of date palm fiber reinforced composites are investigated.

## 2. Methodology

### 2.1 Material

In this project fiber extracted from date palm rachis was used as the reinforcement which was collected by decomposing the date palm rachises in water and extracting the fiber as described in section 2.2. For the fabrication of the composite, Araldite (AW 106) standard epoxy resin was used as it was easily available. It also has good moisture resistance, chemical resistance, and good impact strength. 'Hardener HV 953' was used as it is compatible with Araldite (AW 106) standard epoxy resin.

### 2.2 Fiber Extraction

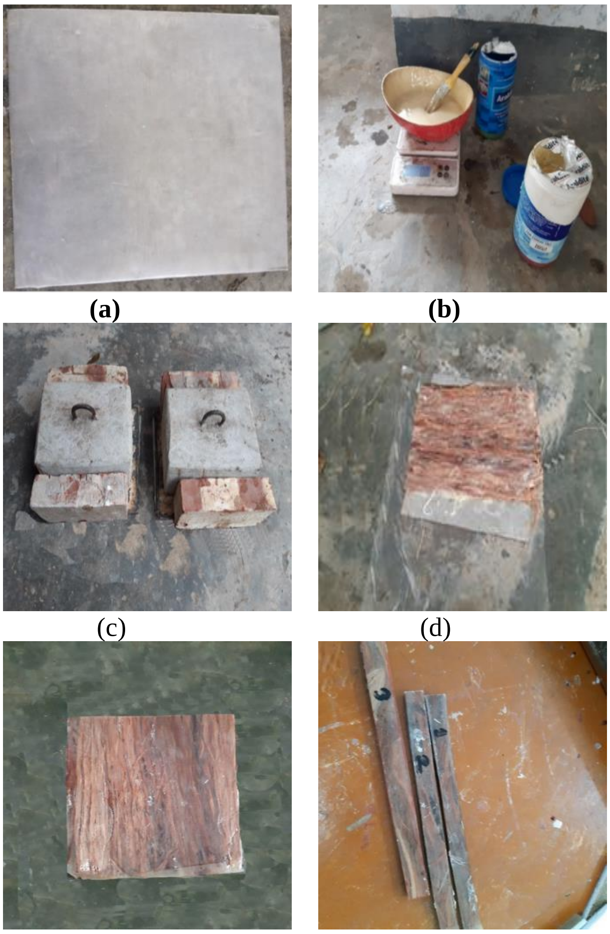
At first, date palm rachises were collected as shown in Fig. 1(a) from nearby trees and the leaves were shredded off. Then the branches were cut into 12 inches pieces. The cut pieces were bound together into a bundle which is shown in Fig. 1(b) and then submerged in pond water. The bundle was intentionally submerged in pond water as the micro-organisms in the pond would accelerate the rotting process. The bundles were taken out of the pond water after one month of the submersion and were found almost rotten. The bundles were again left in water and pulled out after a week and disintegrated. The fibers were then combed to free them from the wood pulp and rinsed several times to get silky fibers. Then the fibers were dried and made ready to fabricate the composite.


(a) (b)

**Fig. 1** (a) Date Palm Rachis collected from nearby plants; (b) Bundled Date Palm branches.

### 2.3 Fabrication of Composite

The composite material was fabricated by hand layup method which is widely used to fabricated composites [11, 12]. At first, a 30 cm×30 cm metal plate was taken and laminated with plastic wrap as shown in Fig. 2(a). Afterward, the plate surface was lubricated so that it could not stick with the epoxy resin. Then the epoxy resin and hardener mixture was made in 10:8 epoxy to hardener by the mass ratio which is recommended by the manufacturer as shown in Fig. 2(b). A layer of the epoxy mixture was then poured on the lubricated plate and it was followed by a layer of date palm fiber. The fiber layer was made as uniformly as possible so that no cracks were present after the fabrication. A further layer of epoxy was used over the fiber layer to make sure the layers stuck together which is shown in Fig. 2(c). A hand roller was used to make the surface uniform and to ensure the epoxy layer thickness was fairly uniform. This process was followed three times as three layers of fiber were used and a layer of epoxy was used between every two layers of fiber and over them. Then another metal plate was laminated with plastic and lubricated to cover the top portion of the fabricated composite material. Finally, the setup was kept under a constant heavy weight for almost 24 hours to compress and harden the material as shown in Fig. 2(d). After 24 hours the loads were removed and the composite material was obtained as shown in Fig. 2(e). The fabricated composite material had a few rough edges and uneven corners which needed to be machined to prepare for testing. Two laminates were fabricated and the fabricated laminate was cut into pieces for various testing as shown in Fig. 2(f).



**(a)** **(b)**

(c) (d)

(e) (f)

**Fig. 2** (a) Laminated plate; (b) Epoxy resin and hardener mixture; (c) Fiber layer on epoxy; (d) Composite material under the heavy weight; (e) Obtained composite material; (f) Specimen cut for testing.

## 3. Mechanical Characterization

Three mechanical tests were conducted in this project. Tensile, 3-point bending and impact tests were performed to investigate the mechanical properties of the manufactured composites.

### 3.1 Tensile Test

The tensile test was conducted according to ASTM D3039 [13] standard with a loading rate of 2 mm/min by using a universal testing machine. The specimen was prepared by following the corresponding standard and a schematic diagram is shown in Fig. 3 where the specimen thickness was 5 mm.

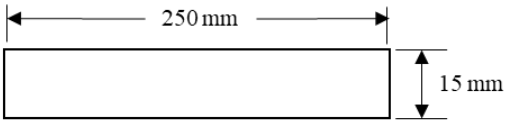


**Fig. 3** Schematic diagram of the tensile test specimen.

Stress-strain responses were recorded and used to calculate the modulus of elasticity. The following equation was used to calculate the modulus of elasticity (E) -

$$E = \Delta\sigma/\Delta\varepsilon \tag{1}$$

The two chosen strain points were 0.001 and 0.003 as recommended by the standard.

### 3.1 Flexural Test

Three-point bending test was performed to investigate the flexural properties of the manufactured composite. Specimens for the three-point bending test were prepared by following the ASTM D7264 [14] standard with a loading rate of 1 mm/min. The specimen dimension is shown in Fig. 4.

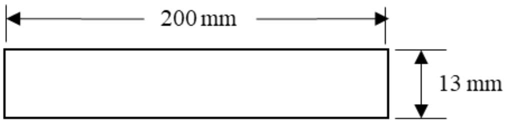


**Fig. 4** Schematic diagram of the three-point bending test specimen.

Load-deflection response was recorded and used to calculate flexural strength and modulus. The following equation was used to calculate flexural strength-

$$\sigma = \frac{3PL}{2bh^2} \tag{2}$$

The flexural modulus of elasticity was calculated using the following equation-

$$E_f = \frac{L^3 m}{4bh^3} \tag{3}$$

### 3.3 Impact Test

Charpy impact test was performed to determine the impact strength of the manufactured composite. This test was conducted according to ASTM D6110 standard. The schematic diagram of the test specimen is shown in Fig. 5.

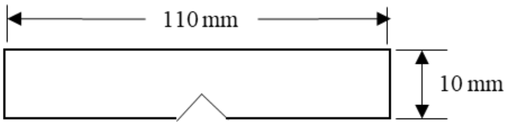


**Fig. 5** Schematic diagram of the impact test specimen.

The following formula was used to calculate the impact strength per unit area-

$$\frac{E}{A} = \frac{Mg(h_1 - h_2)}{bt} \tag{4}$$

In this project, the Charpy test was conducted in the laboratory of the Industrial Engineering & Management department of KUET which is shown in Fig. 6(a). Two types of specimens were used for the testing as shown in Fig. 6(b). In the first type of specimen, the fibers were laid up across the width of the samples (parallel to the V notch) whereas, for the second type, the fibers were laid up across the length of the samples (perpendicular to the V notch). The samples were then set in the Charpy test machine one by one and the height of the swing was calculated before and after the impact on the sample which is shown in Fig. 6(c).

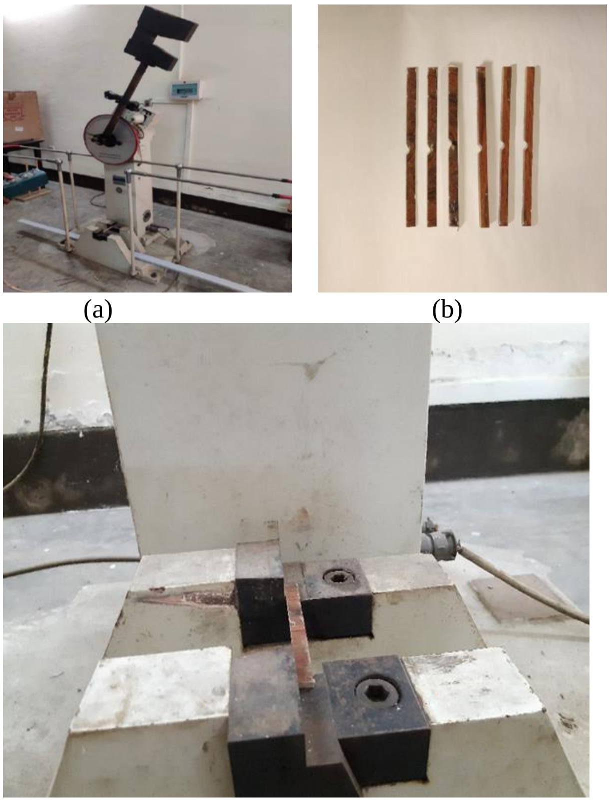

(a)
(b)
(c)

**Fig. 6** (a) Charpy test machine; (b) Two types of impact test specimen; (c) Specimen set in the machine.

## 4. Result and Discussion

### 4.1 Tensile Test

Three samples were tested to determine the tensile strength and modulus of elasticity. Fig. 7 shows the stress-strain responses of the tested specimens. It is observed from this figure that the stress-strain responses of all the specimens are consistent.

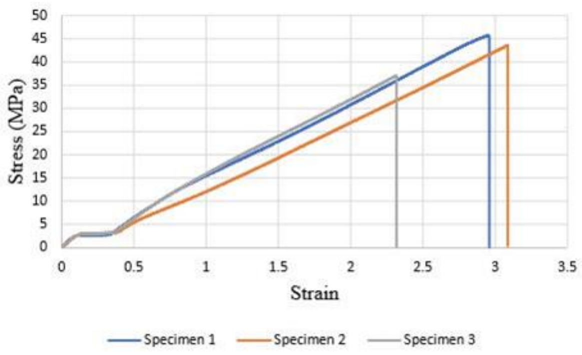


**Fig. 7** Stress vs strain diagram for the three specimens.

The stress vs strain diagram of the material shows the specimens showed almost no plastic deformation. After a uniform elongation for a certain amount of stress, the specimens failed like a brittle material.

Fig. 8 shows the tensile strength and modulus of elasticity of the tested specimens. Among the three specimens, specimen 1 showed maximum tensile strength with 45.65 MPa and specimen 3 showed minimum tensile strength with 37.08 MPa. The average tensile strength of the material is found as 42.11 MPa.

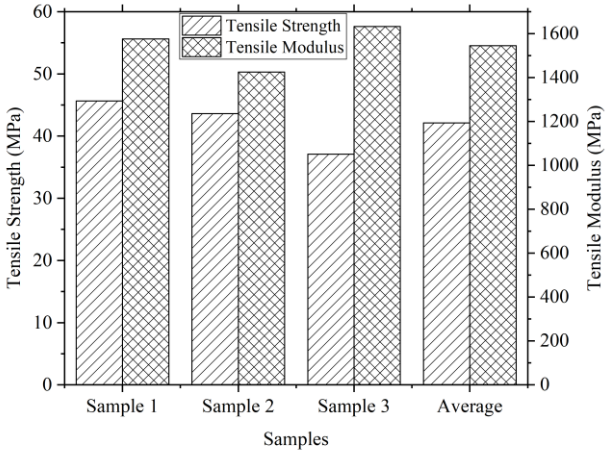


**Fig. 8** Tensile strength and tensile modulus of the specimens.

Among the three specimens, specimen 3 showed a maximum modulus of elasticity of 1633 MPa, and specimen 2 showed a minimum modulus of elasticity of 1425 MPa.

### 4.2 Flexural Strength

Three-point bending test was conducted as described earlier to determine the flexural strength and modulus. Fig. 9 shows the flexural strength and modulus of the specimens. Three samples were also tested in this case. Specimen 1 showed maximum flexural strength with 52 MPa and specimen 2 showed minimum flexural strength with 33.45 MPa. The average flexural strength of the material was 43.24 MPa.

Among the three specimens, specimen 2 showed maximum flexural modulus with 1492.51 MPa and specimen 3 showed minimum flexural modulus with 1177.76 MPa. The flexural strength and flexural modulus of the specimens are shown in Fig. 9.

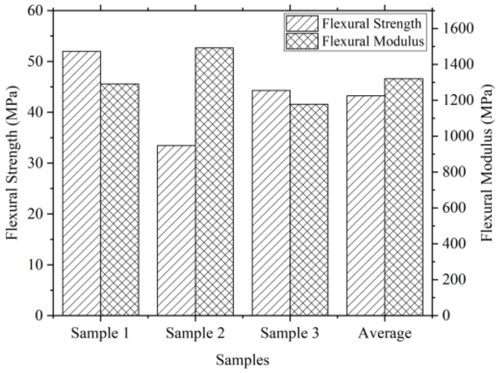


**Fig. 9** Flexural strength and flexural modulus of the specimens.

4.3 Impact Test

Three specimens were tested to determine the impact strength of the manufactured composites. The impact strength of the specimens was determined with fibers laid up across the width (across weft) of the specimen and fibers laid up across the length (across warp) of the specimen.

Among the three specimens across the weft, specimen 3 showed maximum impact strength with 156.96 kJ/m$^2$ and specimen 1 showed minimum impact strength with 102.19 kJ/m$^2$.

Among the three specimens across the warp, specimen 3 showed maximum impact strength with 353.16 kJ/m$^2$ and specimen 1 showed minimum impact strength with 140.14 kJ/m$^2$.

Specimen 3 for this set has shown significantly more impact strength than the other two specimens. Since the composite material was made in the hand lay-up method, maintaining fiber uniformity across the material was challenging. The difference in impact energy of specimen 3 from the other two specimens may be caused by the non-uniform distribution of the fibers of the material.

The two types of specimens have shown different types of results upon testing. The difference will be visible when the results are viewed together. The impact strength of the specimens across warp and weft positions is shown in Fig. 10.

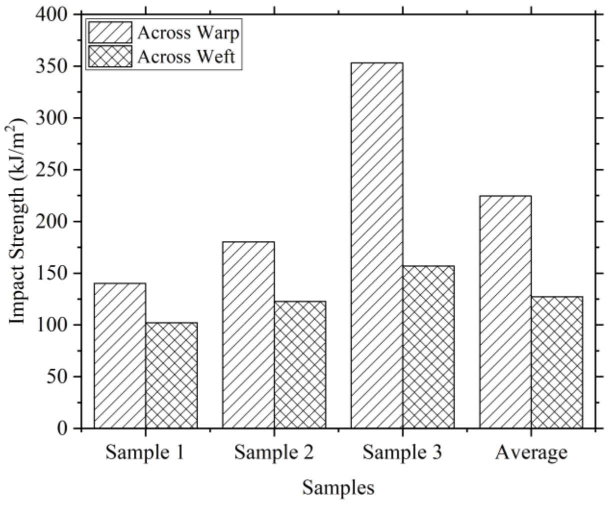


**Fig. 10** Impact strength of the specimen across warp and weft.

From Fig. 10, it is visible that the specimens, where the fibers were laid up across the length of the specimen showed more impact strength than the specimens where the fibers were laid up across the width of the specimen.

4.4 Comparison

Table 1 shows a comparison of mechanical properties of date palm rachis fiber reinforced composite with other natural fiber reinforced composites. It is observed form this table that the manufactured date palm rachis fiber properties in this paper are comparable with similar type of natural fiber reinforced epoxy based composites.

**Table 1** Comparison of mechanical properties.

| Properties | Date palm rachis (this paper) | Banana | Rattan [15] | Luffa [12] |
|---|---|---|---|---|
| Tensile strength (MPa) | 42.11 | 35.86 [16]<br>33.46 [15] | 13.01 | 11.43 |
| Tensile modulus (MPa) | 1545 | 6080 | | 2370 |
| Flexural strength (MPa) | 43.24 | 15.86 [16]<br>128.47 [15] | 131.56 | 26.29 |
| Flexural modulus (MPa) | 1320.4 | 830 [16] | | 2020 |

## 5. Conclusion

Date palm rachis fiber reinforced epoxy composite was manufactured by extracting fiber from date palm rachis. Tensile, three-point bending and impact tests were performed to determine the mechanical properties of the manufactured composites. The average tensile strength and modulus were 42.11 MPa and 1600 MPa while the flexural strength and modulus were 43.24 MPa and 1300 MPa respectively. The average impact strength across warp direction is found to be 225 kJ/m2, on the other hand the average impact strength across weft direction is 125 kJ/m2. The mechanical properties found in this research is comparable to the properties of other natural fiber reinforced composites.

## 6. Acknowledgement

The authors would like to express their sincere gratitude and acknowledgment to the Department of Mechanical Engineering, KUET, and the Department of Industrial Engineering, KUET for all kinds of help and support to properly conduct this experimental work.

## 7. References

[1]. Zaman, H.U., et al., *Preparation and characterization of jute fabrics reinforced urethane based thermoset composites: Effect of UV radiation.* Fibers and Polymers, 2010. **11**(2): p. 258-265.

[2]. Al-Sulaiman, F.A., *Applied Composite Materials*. 2001, Kluwer Academic Publishers: Kingdom of Saudi Arabia. p. 369-377.

[3]. Alawar, A., A.M. Hamed, and K. Al-Kaabi, *Characterization of treated date palm tree fiber as composite reinforcement.* Composites: Part B, 2009: p. 601-606.

[4]. Mahdavi, S., H. Kermanian, and A. Varshoei, *Comparison of mechanical properties of date*

*palm fiber- polyethelene composite.* BioResources, 2010. **5**(4).

[5]. Abdal-Hay, A., et al., *Effect of diameters and alkali treatment on the tensile properties of date palm fiber reinforced epoxy composites.* International Journal of Precision Engineering and Manufacturing, 2012. **13**(7): p. 1199-1206.

[6]. Amroune, S., et al., *Investigation of the Date Palm Fiber for Green Composites Reinforcement: Thermo-physical and Mechanical Properties of the Fiber.* Journal of natural fibers, 2019.

[7]. Saleh, A.A., et al., *Insights into the effect of moisture absorption and fiber content on the mechanical behavior of starch‐date‐palm fiber composites.* Starch in Health and Disease, 2017. **69**(7-8).

[8]. Boumediri, H., et al., *Extraction and characterization of vascular bundle and fiber strand from date palm rachis as potential bio-reinforcement in composite.* Carbohydrate Polymers, 2019. **222**: p. 114997.

[9]. Bezazi, A., et al., *Alkali treatment effect on physicochemical and tensile properties of date palm rachis fibers.* Journal of Natural Fibers, 2022. **19**(10): p. 3770-3787.

[10]. Alshahrani, H., et al., *Development of Hybrid Composite Utilizing Micro-Cellulose Fibers Extracted from Date Palm Rachis in the Najran Region.* Polymers, 2022. **14**(21): p. 4687.

[11]. Asif, M., et al., *Comparative study on mechanical properties of bamboo strip and bamboo strip-glass fiber reinforced hybrid composites.* Journal of Engineering Advancements, 2020. **1**(01): p. 06-10.

[12]. Chakrabarti, D., et al., *Effect of chemical treatment on the mechanical properties of luffa fiber reinforced epoxy composite.* Journal of Engineering Advancements, 2020. **1**(02): p. 37-42.

[13]. International, A., *Standard test method for tensile properties of polymer matrix composite materials*. 2007: ASTM international.

[14]. International, A., *Standard test method for flexural properties of polymer matrix composite materials*. 2007: ASTM International.

[15]. Islam, M.S., S. Azmy, and A. Almamun, *Comparative study on mechanical properties of banana and rattan fiber reinforced epoxy composites.* American Journal of Engineering Research (AJER), 2019. **8**(2): p. 1-6.

[16]. Jubair, K., M.S. Islam, and D. Chakraborty, *Investigation of Mechanical Properties of Banana-Glass Fiber Reinforced Hybrid Composites.* Journal of Engineering Advancements, 2021. **2**(04): p. 175-179.

## NOMENCLATURE

$L$ : length of the support span, mm
$B$ : width of the testing specimen
$t$ : thickness of the testing specimen
$m$ : slope of the load vs displacement curve, N/mm
$E$ : impact energy, kJ
$g$ : gravitational force, m/s$^2$
$M$ : mass of the swing, kg
$h_1$ : initial height before impact, m
$h_2$ : height after impact, m
$\Delta\sigma$ : difference in applied stress at two strain points, MPa
$\Delta\varepsilon$ : difference in two strain points.
$E_f$ : flexural modulus of elasticity, MPa
$\sigma$ : stress at the outer surface at mid-span, MPa
$P$ : applied load, N
$h$ : specimen thickness, mm