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Fabrication and Mechanical Characterization of Natural Fiber-Reinforced Polymer Composites

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Abstract

Natural fibers, which are usually discarded as agricultural waste, have a significant potential to serve as reinforcements. This paper investigates the mechanical properties of polymer composites reinforced with natural fibers like flax, hemp, and jute. Epoxy resin is used to make the matrix, and the composites were fabricated using the hand lay-up technique. Mechanical characterization of the fabricated composites reveals that hemp-reinforced natural polymers have better tensile and flexural strength compared to other jute- and flax-reinforced composites. Composites containing Jute/ Epoxy (S1) and hemp/ epoxy (S2) show the same amount of absorbed impact energy. A natural composite reinforced with hemp absorbed the maximum water.
Keywords: *Natural Fiber, Jute, Flax, Hemp, Tensile Strength, Flexural, Impact-Strength, Absorptivity.*

1. Introduction

Composite materials comprise at least two materials with distinctly different properties, one acting as a matrix element and the other as a reinforcement [1]. Applications for composite materials include structural members, automotive components, marine constructions, aircraft parts, and anti-vibration applications. The combined resilience, creep resistance, high strength-to-weight and stiffness-to-weight ratios, corrosion resistance, and superior damping qualities of composite materials form the basis of these applications. Because synthetic fibers are very expensive and only suitable for use in aircraft and military applications, scientists and researchers became interested in natural fibers such as jute, banana, hemp, coir, hemp, and sisal for use in consumer goods and civic buildings [2]. Natural fibers are sustainable materials that are good for the environment and have several benefits, including being cheap, lightweight, biodegradable, and having high specific qualities [3]. One of the most significant natural, renewable, biodegradable, and non-abrasive fibers is jute, which is also environmentally beneficial [4]. Because of its exceptional mechanical properties and ease of processing in composite construction, epoxy is widely used in a wide range of thermoset polymer composite applications despite not being biodegradable [5]. Natural fibers have benefits, but they also have several disadvantages that make them unsuitable for use in composite materials. Natural fibers, for instance, are naturally hydrophilic in damp or moist conditions. As a result, they swell after collecting moisture, affecting composites' dimensional and mechanical properties. Another disadvantage is that the individual fibers in natural fiber composites have different mechanical and physical characteristics. This will obviously restrict the industrial use of these composites on a wide scale. By using various fiber modification techniques, including graft-copolymerization, alkali treatment, and salinization, researchers have been able to address these problems with natural fibers and increase the use of their composites. This has improved the fiber-matrix interface adhesion by lowering the fiber's moisture absorption characteristics [6]. Hemp and flax fibers have different average tensile properties, which are utilized in wing boxes, randoms, aircraft panels, and

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inside applications, among other aircraft elements [7]. The matrix material is the load transfer medium by keeping the fibers together in the necessary orientation, while the fibers carry most of the weight. Additionally, the matrix shields the fibers from attacks by the outside environment [8]. Given the growing need for linen around the world, flax is a cash crop that grows well in areas with climates that are suited for it. Flax has a short growth season; in Western Europe in particular, it typically takes only 100 days from March seeding to July harvesting [9]. Bio-fibers are increasingly being used in engineering applications in place of glass fibers as reinforcement in composite materials. The increasing demand for sustainable material development and more environmental consciousness are the main reasons for this shift in choice [10]. The material dimensions, including fiber processing techniques, composite fabrication procedures, matrix materials, and their impacts on mechanical properties, have been the subject of a significant amount of prior research. Research has shown that composites made of natural fibers typically have less intrinsic mechanical capabilities than composites made of synthetic fibers, even if there may be applications for natural fiber composites that are similar to those for carbon and glass fiber composites [11]. This study analyzes the mechanical properties of epoxy composites reinforced with natural fibers. More precisely, three distinct kinds of bidirectional mats composed of flax, hemp, and jute fibers have been reinforced with epoxy. The primary objective of this work is to examine how the mechanical properties of the final materials are affected by the addition of laminated natural fiber-reinforced epoxy composites. The study includes assessing mechanical properties such as tensile, flexural, and impact strength and performing a water absorption test.

2. Materials and Method

2.1. Materials

Jute, Hemp, Flax fibers, and epoxy resin were procured from the Fiber Region, Chennai (India). Bidirectional woven mats were used to fabricate composites. Figure 1 shows fiber mats of jute, hemp, Flax, and epoxy resin. Epoxy LY556(Araldite) and hardener HY951(Aradur) were chosen as the matrix for the composites. Table 1 shows the properties of the materials.

Table 1 Properties of the Reinforcements and Matrix

PROPERTIES	JUTE FIBER	HEMP FIBER	FLAX FIBER	Epoxy LY551
Density (gm/cm3)	1.46	1.3	1.5	1.15
Tensile strength (MPa)	393-800	550-900	345-1500	83
Tensile modulus (GPa)	10-30	70	27.6-80	4.2
Elongation (%)	1.5-1.8	1.6	1.2-3.2	0.2-1.4
Thickness (mm)	0.28	0.25	0.25	-

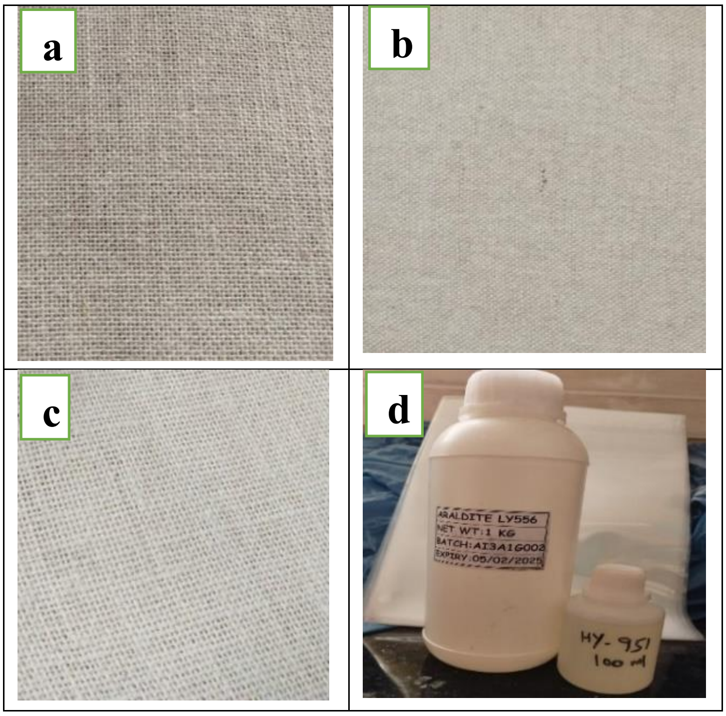

Figure 1 (A) Jute Fiber, (B) Hemp Fiber, (C) Flax Fiber, (D) Epoxy Resin

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2.2. Method to Fabricate the Composite

The Hand-layup technique fabricates the natural fiber-reinforced epoxy matrix composite. The fiber is cut into specific dimensions and used for the fabrication process. The steps involved in the fabrication of composites:

- First, fix the plastic sheet on an acrylic sheet and apply a thin layer of silicon oil to the sheet so that the composite is easy to remove after fabrication.
- Add an appropriate amount of epoxy LY556 to a borosil beaker and hardener HY951 to a measuring flask and mix them in a mixing ratio of 1:10 (% weight) by glass rod until a uniform mixture is obtained. Mixing is done until the solution's viscosity increases.
- Fibers were used to reinforce the epoxy for making the various layers and stacked them. A thin layer of epoxy was coated on each layer of fibers using a brush.
- A hand roller was used for uniform pressing and to prevent the air bubbles in the composite.
- Afterward, the load was applied to the fabricated composite and left to cure for 24 hours. The sample was then removed and cured at room temperature as post-processing.
- Sample specimens were prepared by varying the fiber layers.

2.3. Experimental Procedure for Fabricated Composites

For use in future applications, it is essential to test the mechanical behavior of composites during the fabrication process. In this order, samples were prepared according to ASTM standards. Each characterization test was conducted at ITS Engineering College, Ghaziabad, and I.I.T Kanpur. Tensile strength testing of the composites was performed in accordance with ASTM D3039 using a Universal Testing Machine [12]. The composites were subjected to flexural tests utilizing the Universal Testing Machine in accordance with the ASTM D790 3-point loading procedure requirements [13]. and impact test performed in accordance with ASTM D256[14]. The water absorption tests were performed in accordance with ASTM D570 criteria [15] in Figure 2- 5.

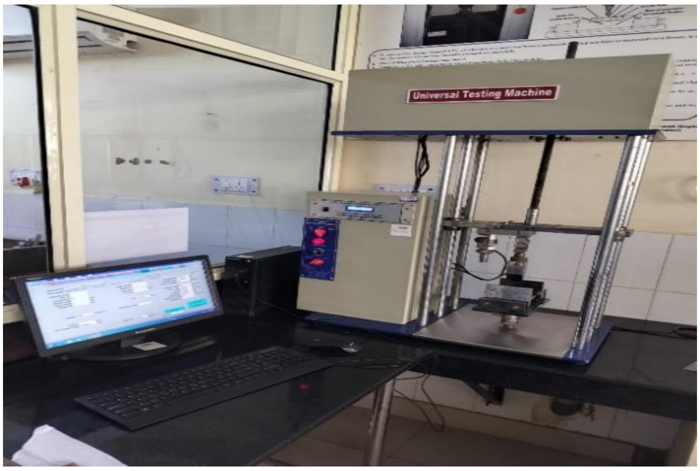

Figure 2 **Universal Testing Machine Setup**

Figure 3 **Specimen Fracture During Tensile Test**

Figure 4 **Specimen Fracture During Flexural Test**

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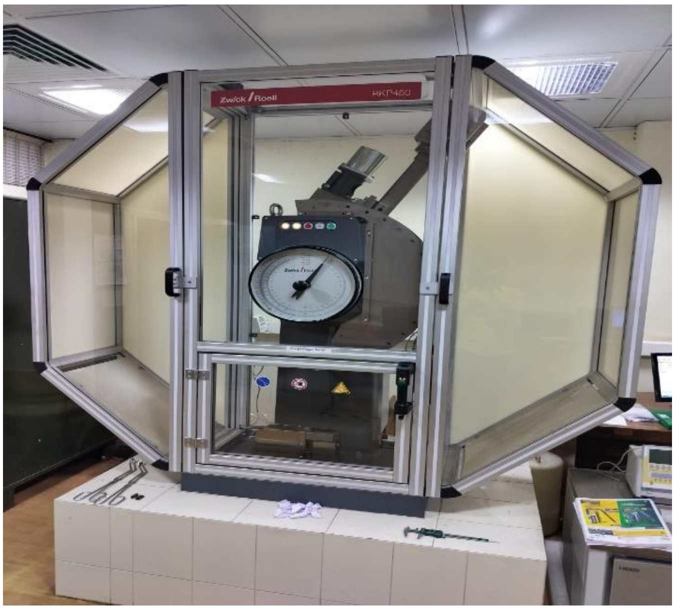

Figure 5 Zwick / Roel Impact Testing Machine

3. Results and Discussion

3.1. Tensile Test

Tensile tests of the composites were conducted according to the ASTM D3039 using a Universal Testing Machine (UTM model- WDW10, ITS Engineering College, Ghaziabad) with a crosshead speed of 6 mm/min. the test specimens were cut into rectangular strips with the dimensions of the specimens 250mm in length and 25mm in width. Tensile test data on the ductility and strength of materials under axial tensile stresses. The highest tensile stress a material can withstand before failing is its tensile strength. The findings were examined using a tensile test apparatus to determine the tensile strength of materials. Tensile forces are applied to the samples in the UTM machine until the material fails. We can determine the elongation and ultimate tensile strength using the tensile test. The experimental results of the tensile strength of the composites of different compositions are given in Table 2. The comparisons among the composites are shown in Figure 6. The results show that sample S2, with a matrix and fiber ratio of 70:30, has the highest ultimate tensile strength of 51.58 MPa compared to the other samples. All samples of the Load vs displacement graph are shown in Figure 7.

Table 2 Result of Tensile Testing of the Composites

Composites	Max. Load (kN)	Tensile strength (MPa)
Jute/epoxy (S1)	4.920	27.33
Hemp/epoxy (S2)	8.860	51.58
Flex/epoxy (S3)	2.420	17.33

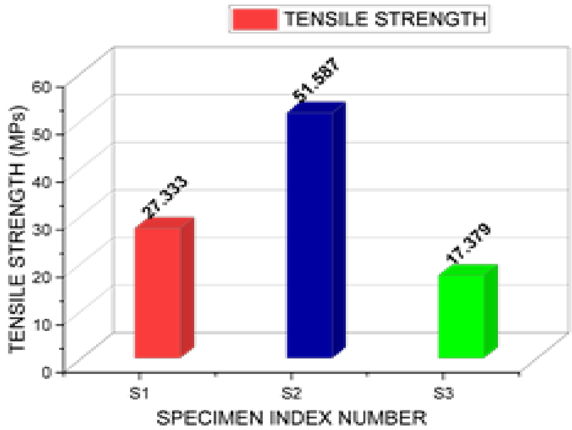

Figure 6 Comparison of Tensile Strengths of The Composites

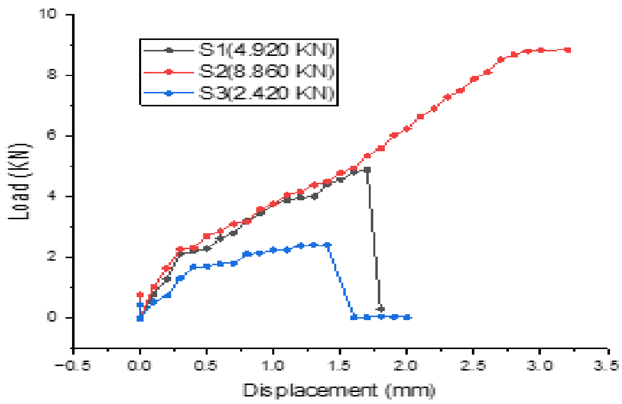

Figure 7 Load Vs Displacement Graph of Tensile Test

3.2. Flexural Test

The flexural capabilities of the composites were tested using a three-point loading arrangement with a span distance of 100 mm between the two static points and a force applied on the specimen center of the length. A 150 mm × 25 mm dimension was maintained for each type of specimen as per the ASTM D790. To ensure continuous loading, a computerized universal testing apparatus (UTM model- WDW10, ITS Engineering College, Ghaziabad) with a crosshead speed of 5 mm/min was used to conduct the three-point bending test. Table 3 shows the maximum flexural strength of sample S3(55.60 MPa), and the comparisons among the composites are shown in Figure 7. Flexural strength was calculated from Eq. (1)

$$Flexural\ strength = \frac{3PL}{2bt^2} \qquad (1)$$

Were in Table 3 & Figure 8,

P = peak load at a given point on the load-deflection curve (N),

L = support span (mm)

b = width of the samples (mm)

t = thickness of the samples (mm)

Table 3 Result of Flexural Testing of the Composites

Composites	Max. Load (N)	Flexural strength (MPa)
Jute/epoxy (S1)	480.94	47.33
Hemp/epoxy (S2)	437.38	55.60
Flex/epoxy (S3)	222.61	28.70

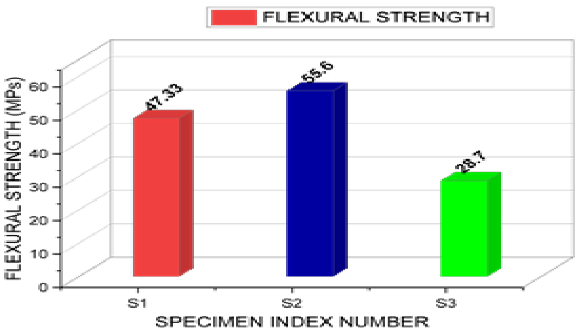

Figure 8 Comparison of Flexural Strengths of the Composites

3.3. Impact Test

The impact test is conducted based on the energy absorption capacity of the composite. "Absorbed impact energy" refers to the energy required to break the composite specimen. The preparation of specimens measuring 65 mm by 12 mm follows ASTM D256. The impact strength of the composites depends on the fibers and matrix composition. The impact test results for the samples are shown in Table 4. A comparison of the absorbed impact energy of the composites is shown in Figure 9. Sample S1 and S2 have the same absorbed impact energy. the highest impact strength of sample S3 (1.25J), as shown in Table 4.

Table 4 Result of Absorbed Impact Energy

Composites	Absorbed Impact energy (J)
Jute/epoxy (S1)	1.836
Hemp/epoxy (S2)	1.836
Flex/epoxy (S3)	1.255

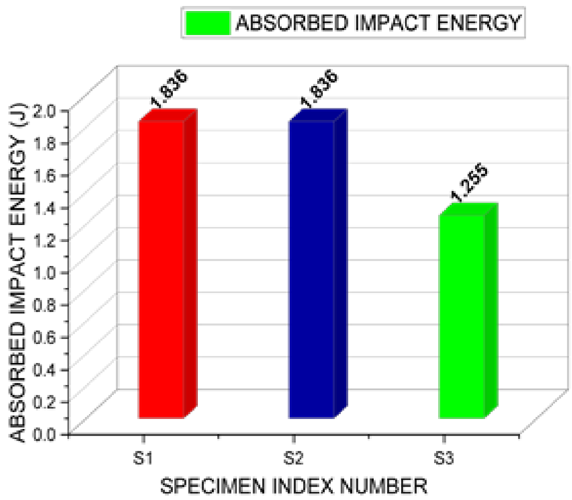

Figure 9 Comparison of Absorbed Impact Energy of The Composites

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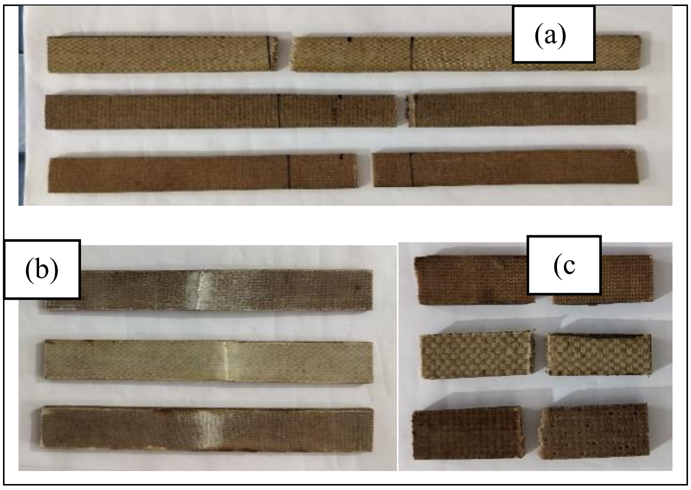

Figure 10 Tested Specimens of Fabricated Composite After Failure (A) Tensile Test, (B) Flexural Test, (C) Impact Test

3.4. Water Absorption Test

The water absorption test was conducted according to an ASTM-D570 (shown in Figure 12) with specimen dimension- 76mm × 25 mm. The composite sample was dried at 32°C in the sun for four to five hours. The samples were then all weighed before being submerged in a water jar to determine their original weights. After that, the composite samples were kept separately for a duration of 15 days at room temperature in jars containing distilled water. Samples were removed from the water jar and regularly dried with tissue paper. The composite samples were reweighed after drying to determine the percentage of water absorption. The percentage of water absorption was calculated by using the following equation (2)

$$water\ absorption(\%) = \frac{w_t - w_0}{w_0} \times 100 \qquad (2)$$

where,

- w_t = weight of the composite sample after submerged in water in Figure 11 and Table 5.
- w_o = weight of the composite sample before submerged in water.

The water absorption test is run to saturation. All manufactured composites absorb more water continuously. Sample S2 absorbed the maximum proportion of water during the experiment. Figures 10 and Table 5 show the percentage change of water absorption with time for natural fiber-reinforced polymer composites.

Table 5 Result of Water Absorption of Different Samples

Time (in days)	%water absorbed (S1)	%water absorbed (S2)	%water Absorbed (S3)
1	3.44	8.65	5.57
2	5.84	12.68	8.49
3	6.49	13.43	9.17
4	6.82	13.73	9.51
5	7.53	14.1	10.54
6	7.73	14.25	10.63
7	8.05	14.02	11.06
8	8.96	14.92	11.32
9	9.42	15.22	11.57
10	9.16	15.29	11.14
11	9.16	15.37	11.57
12	9.29	15.37	11.23
13	9.29	15.37	11.23

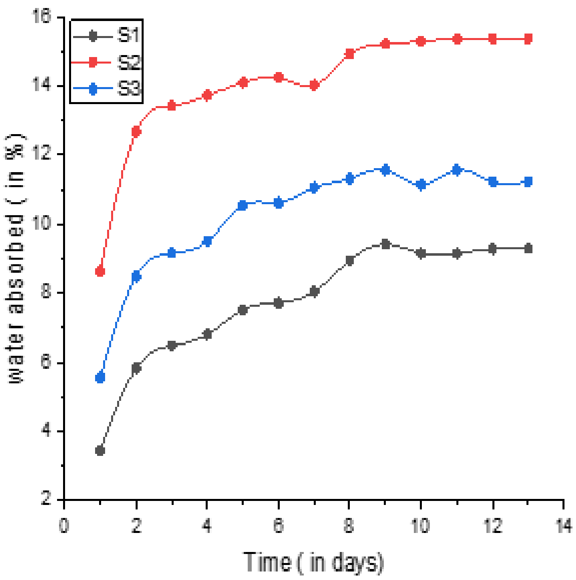

Figure 11 Graph of Time Vs Water Absorption

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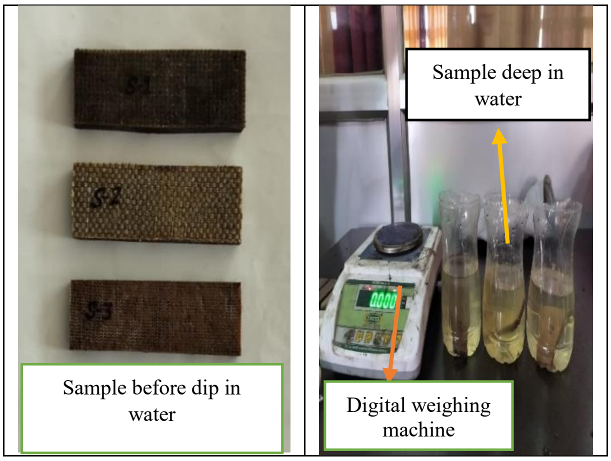

Figure 12 Water Absorption Test

Conclusion

Regarding mechanical characteristics, the hemp-reinforced polymer composite (S2) performs better than the other samples. In particular, sample S2 has greater tensile and flexural strengths than other composite materials, measuring 51.58 MPa and 55.60 MPa, respectively. The chemical composition of natural fibers determines their tensile strength. As the amount of cellulose in the fibers rises, the resulting composite material has a higher tensile strength. Conversely, as lignin content increases, tensile strength falls. Composites containing Jute/ Epoxy (S1) and hemp/ epoxy (S2) show the same amount of absorbed impact energy. At 1.25 J, sample S3, containing flax/epoxy, has the highest impact strength. A natural composite reinforced with hemp in epoxy (S2) absorbed the maximum water due to its hydrophilic nature.

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