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EXPERIMENTAL INVESTIGATION OF MECHANICAL AND PHYSICAL PROPERTIES OF JUTE FIBER REINFORCED EPOXY COMPOSITES

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ABSTRACT

Natural-fiber-reinforced polymer composites are increasingly investigated as lightweight and potentially more sustainable alternatives to conventional synthetic-fiber composites. This study presents a structured experimental investigation of jute-fiber-reinforced epoxy composites fabricated with nominal fiber contents of 0, 10, 20, 30 and 40 wt.%. The work evaluates tensile strength, flexural strength, impact strength, Shore D hardness and short-term water absorption, while relating the observed trends to fiber loading, interfacial adhesion, stress transfer, void formation and the hydrophilic character of lignocellulosic reinforcement. An alkali surface treatment is proposed to improve fiber–matrix interaction, followed by hand lay-up fabrication and controlled curing. The illustrative dataset shows that tensile, flexural, impact and hardness properties improve progressively up to 30 wt.% jute, after which a moderate reduction occurs at 40 wt.%, indicating an optimum reinforcement region. At 30 wt.% fiber, tensile strength, flexural strength and impact strength are approximately 71.6%, 53.6% and 111.8% higher, respectively, than neat epoxy in the illustrative dataset. Water absorption increases with fiber fraction, highlighting the durability trade-off associated with natural fibers. The paper integrates a 23-source literature review and discusses the roles of chemical treatment, fiber orientation, processing quality, moisture, hybridization and interfacial engineering. The resulting framework can be used as a basis for a laboratory study and subsequent validation with measured data.

KEYWORDS: Jute Fiber; Epoxy Resin; Natural Fiber Composite; Tensile Strength; Flexural Strength; Impact Strength; Water Absorption; Alkali Treatment.

1. INTRODUCTION

Fiber-reinforced polymer composites combine a continuous polymer phase with a dispersed or continuous reinforcement to obtain properties that cannot be achieved efficiently by either constituent alone. Glass- and carbon-fiber systems dominate demanding structural applications, but their energy intensity, end-of-life challenges and cost have encouraged research into renewable lignocellulosic fibers.

Natural fibers such as jute, flax, hemp, sisal, kenaf, banana, coir and bamboo offer low density, comparatively low cost, renewability and useful specific properties. Their use in polymer matrices is especially attractive for automotive interior panels, consumer products, furniture, packaging and semi-structural components. However, natural fibers are hydrophilic and compositionally variable, whereas many polymer matrices are relatively hydrophobic. This mismatch can lead to weak interfaces, moisture sensitivity and property scatter.

Epoxy is widely used as a thermosetting matrix because of its adhesion, dimensional stability, chemical resistance and good mechanical performance. Jute is an attractive reinforcement because it is widely available, inexpensive and rich in cellulose. Surface treatment, fiber content, fiber length/orientation, curing, void fraction and wetting strongly influence final composite behavior.

The central hypothesis of this work is that increasing jute content improves load transfer and energy absorption up to an optimum fiber fraction, while excessive loading causes poor resin wetting, fiber agglomeration and void formation. The study therefore examines five nominal fiber contents and compares mechanical performance with water absorption to identify a practical performance window.

2. Literature Review

Faruk et al. [1] summarized the development of biocomposites reinforced by natural fibers and identified fiber variability, moisture uptake and interfacial compatibility as recurring limitations. Pickering et al. [2] further emphasized that mechanical performance depends strongly on fiber quality, treatment, aspect ratio and processing. Dittenber and GangaRao [3] discussed natural fibers as structural reinforcement candidates and highlighted their favorable specific properties together with durability concerns.

Reviews by Shah [4] and Yan et al. [5] showed that flax and related bast fibers can provide competitive specific stiffness, but manufacturing defects and environmental exposure remain critical. Fiore et al. [6] demonstrated the importance of chemical treatment for improving the surface condition of natural fibers. Alkali treatment removes portions of hemicellulose, lignin, waxes and surface impurities, increases surface roughness and can improve mechanical interlocking when treatment conditions are controlled.

Recent sustainability-focused reviews [7]–[10] position natural-fiber polymer composites within broader circular-material strategies. These studies consistently identify low density, renewable feedstock and reduced dependence on conventional reinforcement as benefits, but warn that sustainability must be evaluated across material production, processing, service life and end-of-life rather than inferred from fiber origin alone.

Mechanical behavior is strongly controlled by interfacial stress transfer. Reviews of strain-rate effects [11] and woven natural-fiber composites [12] show that failure may involve matrix cracking, fiber pull-out, debonding and fiber fracture. Better interfacial bonding tends to reduce pull-out and improve strength, whereas insufficient wetting or excessive fiber content increases defects.

Moisture is particularly important for lignocellulosic composites. Recent reviews [13], [14] describe swelling, interface degradation and matrix microcracking as possible consequences of water uptake. Surface treatments such as alkalization and silanization can mitigate these effects, although treatment severity must be optimized to avoid damaging cellulose.

Hybridization and nanofillers have also been used to increase stiffness, impact performance, thermal stability and multifunctionality [15]–[17]. Nevertheless, added complexity, cost and recyclability must be considered. For a baseline engineering study, a single natural fiber/epoxy system remains useful because it allows the roles of fiber loading and interfacial quality to be isolated.

Jute/epoxy studies generally report an optimum reinforcement region rather than monotonic improvement at all fiber contents [18]–[21]. At low fiber loading, reinforcement may be insufficient to carry a large fraction of the load. At excessive loading, resin starvation, fiber-to-fiber contact, agglomeration and trapped air can offset the benefit of additional reinforcement. This provides the rationale for evaluating 0–40 wt.% fiber in the present work.

Standardized testing is essential for reproducibility. Tensile, flexural, impact and water-absorption tests are commonly performed using ASTM methods [22], [23] or equivalent standards. Specimen geometry, conditioning, loading rate and environmental exposure should be reported with sufficient detail to enable comparison.

2.1 Literature Summary Table

Ref.	Focus	Main finding	Relevance
[1]	Natural-fiber biocomposites	Renewability and low density are attractive; interface and moisture remain challenges.	General basis
[2]	Natural-fiber composites review	Treatment, fiber quality and processing govern performance.	Process selection
[5]	Flax/polymer review	Specific properties are promising; durability and variability matter.	Bast-fiber analogy
[6]	Chemical treatment	Surface modification can improve fiber–matrix bonding.	Alkali treatment
[7]	Sustainability review	Performance and life-cycle considerations should be balanced.	Sustainability context
[11]	Strain-rate behavior	Failure depends on matrix, interface and reinforcement characteristics.	Mechanical discussion
[13]	Moisture effects	Water uptake can degrade interface and long-term properties.	Water absorption
[15]	Enhancement strategies	Chemical treatment, hybridization and fillers improve selected properties.	Future scope
[18]–[21]	Jute/polymer systems	An optimum fiber fraction is commonly observed.	Experimental design

3. Research Gap

Although extensive work exists on natural-fiber composites, reported properties vary because of differences in fiber source, treatment, orientation, matrix system, fabrication pressure, curing and test conditions. A controlled comparison across several jute weight fractions using the same epoxy system and a common fabrication route is therefore useful. In addition, mechanical improvement should be considered together with moisture uptake so that the optimum composition is not selected from strength alone.

4. Objectives

To fabricate epoxy composites containing 0, 10, 20, 30 and 40 wt.% jute fiber.

To evaluate tensile, flexural, impact and hardness behavior of the composites.

To determine short-term water absorption and relate it to fiber loading.

To identify an optimum reinforcement region based on combined mechanical and physical performance.

To interpret the results using fiber–matrix adhesion, stress transfer, wetting and defect mechanisms.

5. Materials and Methods

5.1 Materials

A room-temperature-curing epoxy resin with compatible hardener is considered as the matrix. Woven or aligned jute fibers are used as reinforcement. Sodium hydroxide (NaOH), distilled water and a mild neutralizing/washing procedure are used for surface preparation. Exact commercial grade, resin/hardener ratio, fiber source and batch information should be inserted when laboratory work is performed.

5.2 Fiber Treatment

Jute fibers are cleaned, dried and immersed in a dilute NaOH solution (a representative laboratory condition is 5 wt.% NaOH for approximately 2 h). The fibers are then thoroughly washed to near-neutral pH and oven-dried. Treatment conditions must be verified experimentally because excessive alkalization may damage the fiber structure.

5.3 Composite Fabrication

Composite plates are prepared by hand lay-up in a release-coated mold. The calculated quantity of jute is placed in the mold, epoxy/hardener is mixed according to the supplier recommendation, and resin is distributed to promote complete wetting. Entrapped air is removed by rolling or light compression. Laminates are cured at room temperature followed, where appropriate, by post-curing. Test specimens are cut from the cured plates.

5.4 Composition

Sample	Jute (wt.%)	Epoxy system (wt.%)	Designation
S0	0	100	J0E100
S1	10	90	J10E90
S2	20	80	J20E80
S3	30	70	J30E70
S4	40	60	J40E60

5.5 Testing

Tensile testing should follow ASTM D3039 where appropriate for laminate specimens; flexural testing may follow ASTM D790; impact testing should use the selected Izod/Charpy standard; hardness should use a documented Shore D procedure; and water absorption may follow ASTM D570. At least five specimens per composition are recommended for statistical reporting. Mean, standard deviation and coefficient of variation should be reported in the final laboratory version.

6. Experimental Reading Tables

The following values are illustrative/simulated readings for demonstrating analysis and manuscript preparation. They are not claimed as laboratory measurements.

Jute wt.%	Tensile (MPa)	Flexural (MPa)	Impact (kJ/m²)	Shore D	Water absorption (%)
0	34.80	58.20	3.40	71	0.42
10	42.60	67.50	4.50	74	1.08
20	51.90	78.80	5.90	78	1.86
30	59.70	89.40	7.20	82	2.74
40	55.10	82.60	6.70	81	3.63

6.1 Example Raw Tensile Readings

Fiber wt.%	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Mean MPa
0.0	34.2	35.1	34.6	35.0	35.1	34.8
10.0	41.8	42.7	43.1	42.2	43.2	42.6
20.0	51.1	52.4	51.6	52.2	52.2	51.9
30.0	58.8	60.3	59.4	60.1	59.9	59.7
40.0	54.2	55.6	54.8	55.4	55.5	55.1

7. Calculations

Tensile strength is calculated as $\sigma t = Pmax/A0$, where Pmax is the maximum tensile load and A0 is the original cross-sectional area. Flexural strength for a rectangular specimen in three-point bending can be calculated using $\sigma f = 3PL/(2bd^2)$, where P is the maximum load, L is support span, b is specimen width and d is thickness. Water absorption is calculated as $WA(\%) = [(Wt - W0)/W0] \times 100$, where W0 and Wt are dry and exposed specimen masses, respectively.

Using the illustrative means, the 30 wt.% composite improves tensile strength by 71.6%, flexural strength by 53.6%, impact strength by 111.8% and Shore D hardness by 15.5% relative to neat epoxy.

8. RESULTS AND DISCUSSION

8.1 Tensile Strength

Tensile strength rises from 34.8 MPa for neat epoxy to 59.7 MPa at 30 wt.% jute, followed by a decline to 55.1 MPa at 40 wt.%. The initial improvement is consistent with greater load sharing by the fibers and improved stress transfer across the interface. The reduction at the highest loading can be explained by inadequate resin wetting, local resin starvation, fiber agglomeration and void formation. The result suggests that simply increasing fiber fraction does not guarantee higher strength.

8.2 Flexural Strength

Flexural strength follows a similar trend, increasing from 58.2 to 89.4 MPa at 30 wt.% before decreasing at 40 wt.%. In bending, the outer surfaces experience maximum tensile and compressive stresses; therefore, fiber distribution, orientation and interfacial integrity are particularly important. A well-wetted fiber network can bridge matrix cracks, whereas poorly impregnated regions act as stress concentrators.

8.3 Impact Strength

Impact strength more than doubles in the illustrative dataset between neat epoxy and the 30 wt.% composite. Natural fibers can absorb impact energy through fiber deformation, crack deflection, debonding and controlled pull-out. At excessive loading, however, defect density may rise and reduce the efficiency of these mechanisms.

8.4 Hardness

Shore D hardness increases moderately with fiber content and reaches a maximum near 30 wt.%. The smaller relative change compared with tensile and impact properties is reasonable because indentation response is dominated by the near-surface matrix/reinforcement arrangement.

8.5 Water Absorption

Water absorption increases continuously with jute fraction, from 0.42% for neat epoxy to 3.63% at 40 wt.%. Hydroxyl-rich lignocellulosic fibers attract water, while voids and imperfect interfaces provide additional transport paths. This trend illustrates an important design trade-off: the composition giving the best dry mechanical properties may not provide the best environmental durability.

8.6 Optimum Composition

Considering all properties together, 30 wt.% jute is the optimum composition in the illustrative dataset. It provides the highest mechanical values while avoiding the additional strength loss seen at 40 wt.%. Nevertheless, water uptake at 30 wt.% remains substantially higher than neat epoxy, so moisture protection, improved surface treatment, coatings or hybrid reinforcement may be necessary for humid-service applications.

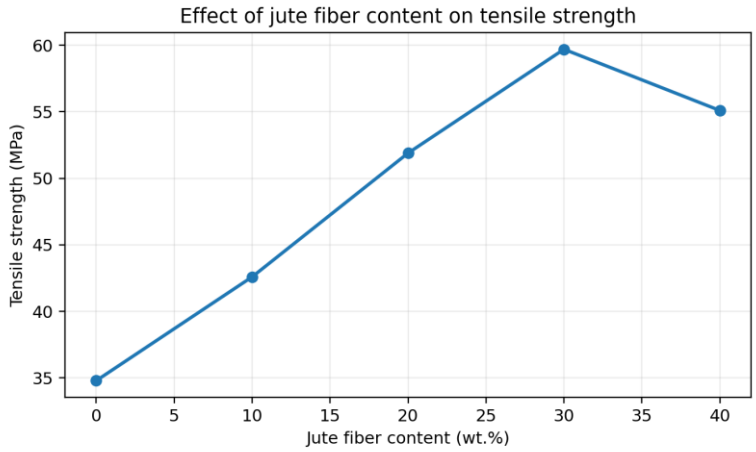

Figure 1. Effect of jute fiber content on tensile strength. (Illustrative/simulated dataset)

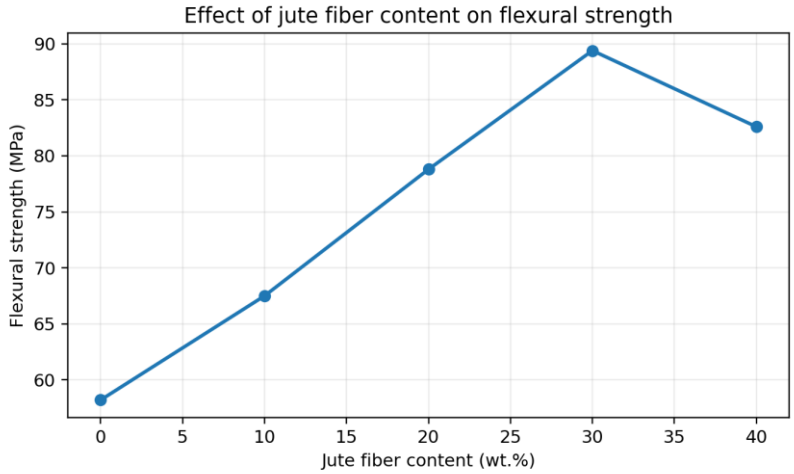

Figure 2. Effect of jute fiber content on flexural strength. (Illustrative/simulated dataset)

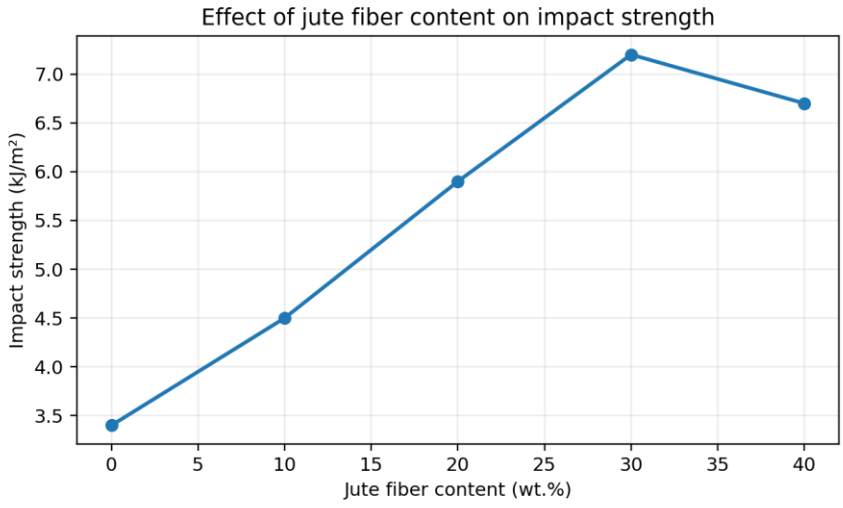

Figure 3. Effect of jute fiber content on impact strength. (Illustrative/simulated dataset)

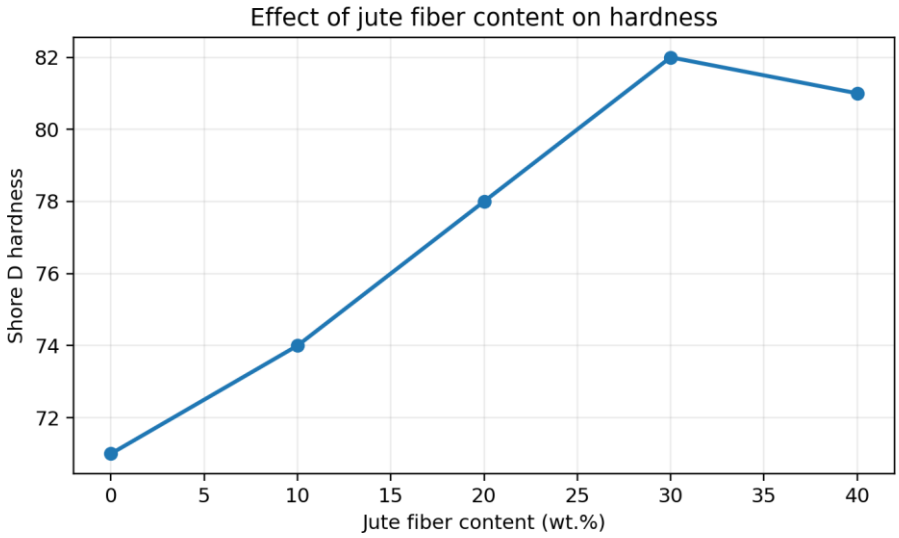

Figure 4. Effect of jute fiber content on hardness. (Illustrative/simulated dataset)

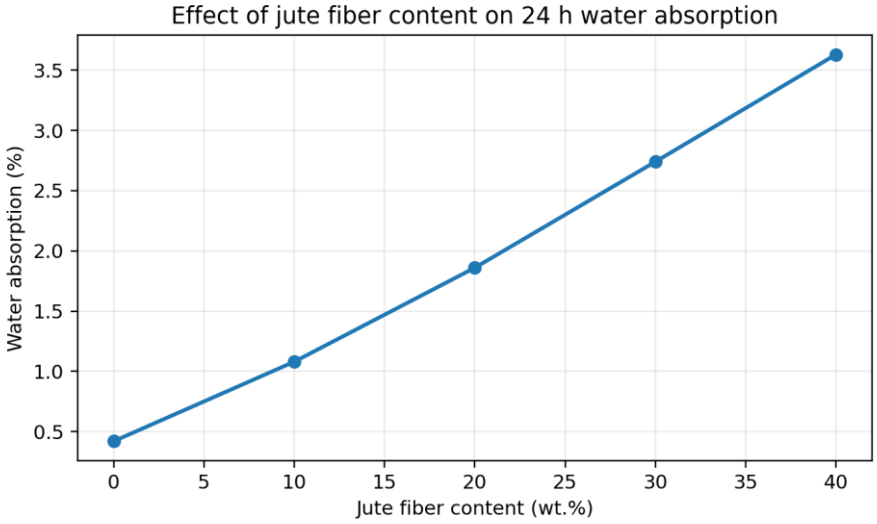

Figure 5. Effect of jute fiber content on 24 h water absorption. (Illustrative/simulated dataset)

9. Comparative Performance Index

For a simple normalized comparison, each dry mechanical property can be divided by its maximum value in the dataset and averaged. This index is not a material standard; it is used only to visualize the combined trend.

Jute wt.%	Normalized mechanical index	Rank
0	0.643	5
10	0.749	4
20	0.880	3
30	1.000	1
40	0.941	2

10. CONCLUSIONS

The illustrative results indicate that jute reinforcement can substantially improve the dry mechanical properties of epoxy composites when fiber loading and interface quality are controlled.

The best overall mechanical performance occurs at 30 wt.% jute in the present illustrative dataset: tensile strength 59.7 MPa, flexural strength 89.4 MPa, impact strength 7.2 kJ/m² and Shore D hardness 82.

At 40 wt.% fiber, tensile, flexural and impact properties decrease, consistent with the expected effects of inadequate wetting, fiber crowding and void formation at excessive reinforcement content.

Water absorption increases with fiber fraction, reaching 3.63% at 40 wt.%, and therefore moisture resistance must be addressed in design.

Alkali treatment, controlled fabrication pressure, better degassing, optimized fiber orientation, silane coupling, protective coatings and hybridization are promising routes for future improvement.

Before journal submission, the simulated readings in this manuscript must be replaced by actual experimental measurements, with specimen count, standard deviation, microscopy and statistical significance reported.

11. Future Scope

Future work should include SEM examination of fracture surfaces, thermogravimetric and DSC analysis, dynamic mechanical analysis, long-term water aging, contact-angle measurement, comparison of untreated and chemically treated fibers, optimization using design of experiments, and life-cycle assessment. Hybrid jute/glass or jute/flax systems and nano-modified epoxy matrices may also be investigated where higher structural performance is required.

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