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REVIEW ARTICLE

Advances in Mechanical Properties of Jute Fibre – Reinforced Polymer Composites: A Comprehensive Review on Hybridization and Nano Fillers Effects

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ABSTRACT:

Jute fibre – reinforced polymer composites have gained substantial attention in recent years due to their biodegradability, low cost, and acceptable mechanical performance. This review paper summarizes and analyses the mechanical properties – such as tensile strength, flexural strength, modulus, impact strength, fibre content and elongation at break – of jute-based composites with various matrices and modifications. A comparative study is presented between pure jute composites, jute –glass hybrid composites, and jute composites modified with nanofillers such as carbon nanotubes. The effects of fibre content and matrix combinations on the overall performance are explored to assess the optimal configuration for different engineering applications. Among studied composites, hybrid systems like HPMC (S-glass+jute) and nano enhance jute composites demonstrated significant improvement in impact strength and flexuralproperties, indicating the benefits of hybrid reinforcement and nano – integration. Additionally, high- performance jute composites showed potential in replacing synthetic fibre composites for structural applications. Furthermore, the combination of jute with EFB and advanced epoxy formulations yields promising alternatives to conventional composites. This study provides a holistic comparison to guide the development of high-performance, eco-friendly composites materials.

KEYWORDS: Jute fibre-reinforced composites; Mechanical properties; Nanofillers; Flexural strength; Carbon nanotubes.

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1. INTRODUCTION

Jute (Corchorus spp.) is among the most widely cultivated bast fibres in South Asia, and its use as a

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polymer-composite reinforcement has grown steadily owing to its biodegradability, low density, low cost, and acceptable mechanical properties relative to glass or carbon fibre [1,2]. Jute fibre-reinforced composites (JFRCs) have been fabricated using a broad range of manufacturing routes — hand lay-up, compression moulding, injection moulding, and pultrusion — and across an equally broad range of thermoset (epoxy, polyester) and thermoplastic (polypropylene, polybutylene succinate) matrix systems [1]. Despite this promise, unmodified jute composites generally exhibit lower absolute strength and stiffness than synthetic-fibre composites, and are additionally limited by moisture sensitivity and batch-to-batch fibre variability, motivating two principal enhancement strategies: hybridisation with a secondary reinforcement, and modification with nano-scale fillers [2,3].

This review compiles and compares experimentally reported mechanical property data — tensile strength, flexural strength, modulus, impact strength, and elongation at break — for jute-based composites across fibre content, matrix type, hybridisation strategy, and nanofiller modification. Particular attention is given to jute-glass hybrid systems and to nano-enhanced jute composites incorporating carbon nanotubes (CNTs) and graphene-family fillers, since these two strategies are compiled in this review as delivering the largest reported improvements in mechanical performance. The objective is to identify the fibre content and matrix combination that optimises performance for different classes of engineering application, and to assess the extent to which enhanced jute composites can substitute for synthetic-fibre composites in structural and semi-structural roles.

2. PURE JUTE FIBRE-REINFORCED COMPOSITES

2.1. Effect of Fibre Content and Matrix Type

Across the compiled literature, jute composite mechanical properties generally increase with fibre content up to an optimum loading before declining owing to fibre agglomeration and incomplete wetting; a jute/epoxy/eggshell-filled composite reached maximum tensile strength (66.4 MPa), flexural strength (163.4 MPa), and impact strength (21.0 kJ/m²) at 25 wt.% fibre content [4]. Matrix selection materially affects the resulting properties: at a fixed 5% surface treatment level, treated jute/polyester composites exhibited better flexural properties than the corresponding jute/epoxy composites, while jute/epoxy showed superior tensile characteristics, illustrating that no single matrix universally outperforms the other across all mechanical properties [1]. Probabilistic characterisation of untreated jute/polyester composites has shown tensile strength in the 33.5–42.0 MPa range and flexural strength in the 190–275 MPa range depending on specimen thickness and fibre volume fraction, underscoring the substantial property scatter that must be accounted for for design purposes [5].

2.2. Fibre Surface Treatment

Because untreated jute fibre's hydrophilic surface chemistry limits interfacial adhesion with hydrophobic polymer matrices, alkali (NaOH) and other chemical treatments are widely used to improve fibre-matrix bonding; comparative studies of NaOH-treated jute-reinforced epoxy and polyester composites at 5% and 10% treatment concentrations found that the 5% treatment level generally produced better tensile properties than the 10% level, indicating an optimum treatment concentration beyond which fibre surface damage outweighs the adhesion benefit [1,2].

2.3. Jute-Polypropylene Thermoplastic Composites

Jute/polypropylene (PP) composites reinforced at 30, 35, and 40 wt.% fibre loading, benchmarked alongside comparable kenaf and pineapple-leaf-fibre PP composites, showed generally improving mechanical properties with increasing fibre loading, with flexural strength peaking at an intermediate ply count before declining at higher fibre content owing to reduced matrix wet-out [6]. Maleic-anhydride-grafted PP (MAPP) coupling agents were shown to improve interfacial adhesion between jute fibre and the PP matrix, evidenced by improved fracture-surface morphology under scanning electron microscopy [6].

3. JUTE-GLASS HYBRID COMPOSITES

3.1. Effect of Glass Fibre Content and Stacking Sequence

Jute/glass hybrid composites in an epoxy matrix, fabricated at glass-to-jute weight-fraction ratios of 30/70, 50/50, and 70/30, showed that tensile, flexural, and impact properties all scaled strongly with glass fibre content, identifying glass fraction as the dominant parameter governing hybrid mechanical performance [7].

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Stacking sequence further modulates this behaviour: in glass-jute polybutylene succinate (PBS) hybrids, the GJJJ configuration (glass fibre on the outer layer) showed 16% higher flexural strength and 32% higher flexural modulus than the JGJGJ configuration, while GJGJG showed 17% and 24% improvements in the same properties relative to JGGGJ, confirming that placing glass fibre at the outer layers of a hybrid laminate consistently improves flexural performance relative to jute-outer configurations [8,9].

3.2. HPMC (S-Glass + Jute) Hybrid Systems

Jute/S-glass epoxy hybrid composites fabricated by hand lay-up have shown that incorporating S-glass fibre layers into a jute/epoxy laminate produces a marked improvement in flexural strength relative to the pure jute composite, with fractographic analysis via scanning electron microscopy confirming improved interfacial load transfer at the S-glass/jute interfaces relative to the unhybridised jute laminate [10]. Compression-moulded glass/jute hybrid composites evaluated under flexural and drop-weight impact loading similarly found that increasing jute content reduced impact damage area, indicating that jute fibre contributes disproportionately to impact energy absorption in the hybrid relative to its contribution to stiffness [11].

3.3. Chemically Treated Jute-Glass Hybrids

Potassium hydroxide (KOH) treatment of the natural-fibre component in flax/glass and jute/glass hybrid epoxy composites has been shown to improve fibre-matrix bonding through removal of surface impurities and exposure of reactive hydroxyl groups, with the treated flax/glass hybrid reaching a tensile strength of 118.2 MPa, flexural strength of 168.9 MPa, and impact strength of 39.3 kJ/m², values that are broadly representative of the improvement achievable through alkaline treatment of the natural-fibre phase in a glass hybrid system [12]. Jute-glass PP hybrids evaluated across a fixed 20 wt.% total fibre loading with varying jute-to-glass ratios showed progressive improvements in strength, stiffness, and impact energy absorption with increasing glass content, alongside a heat-deflection-temperature increase from 75°C (all-jute) to 103°C (glass-rich hybrid), demonstrating that hybridisation improves thermal as well as mechanical performance [13].

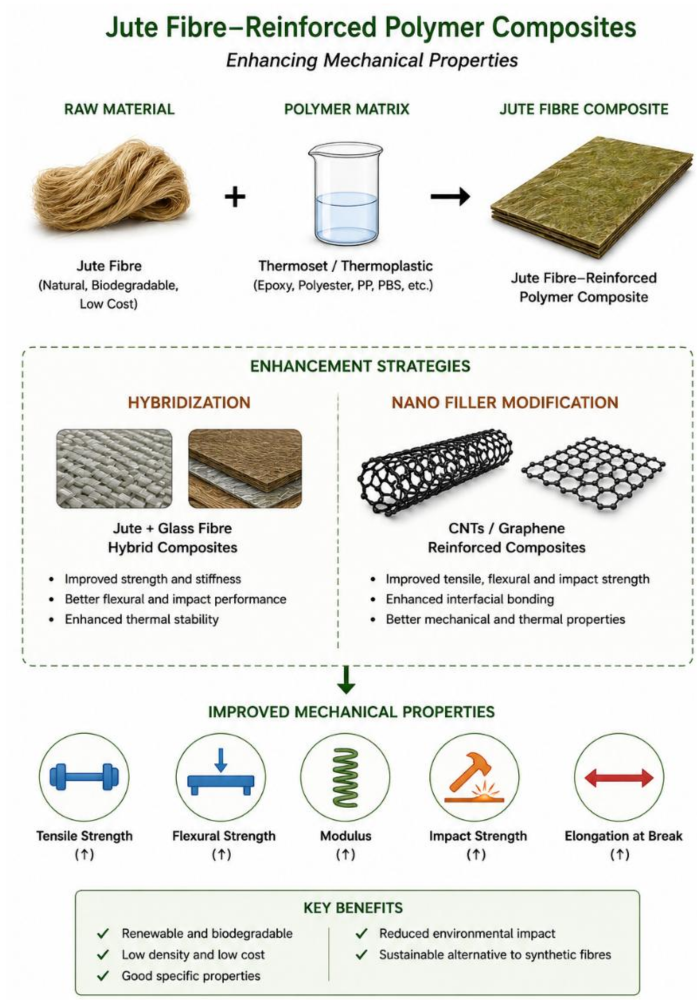

Figure 1: Jute fibre-reinforced polymer composites overview.

4. NANOFILLER-MODIFIED JUTE COMPOSITES

4.1. Carbon Nanotube (CNT) Modification

Multi-walled carbon nanotube (MWCNT) modification of jute/unsaturated-polyester-resin (JFUPR) composites at 2–10 wt.% MWCNT loading raised tensile strength from a baseline minimum of 3.37 MPa to a maximum of 19.86 MPa, alongside measured improvements in flexural strength, impact strength, and hardness, with the tensile property increasing progressively with MWCNT weight percentage across the tested range [14]. Hierarchical CNT modification directly onto the jute fibre surface (rather than dispersion in the bulk matrix) has separately been shown to improve the hydrophobic character of the

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fibre and to introduce a nanostructured surface roughness that promotes mechanical interlocking with the matrix, resulting in considerably higher tensile properties and thermal stability relative to unmodified-jute composites at the same bulk filler loading [15].

4.2. Graphene and Graphene Oxide Modification

A direct comparison of functionalised graphene (FG) and graphene oxide (GO) as nanofillers in jute-reinforced composites at 0.5, 0.75, and 1.0 wt.% loading found that both fillers enhanced impact strength, tensile strength, heat deflection, flexural strength, and hardness relative to the unfilled jute composite, with 0.75 wt.% GO producing the best overall surface and bulk property balance among the GO-filled samples, while FG produced greater strength and heat-deflection improvement than GO at equivalent loading [16]. The same comparative study found that cenosphere filler addition at 5–10 wt.% raised jute/epoxy tensile strength by approximately 43% and flexural strength by approximately 22%, indicating that particulate micro-fillers can deliver improvements of a similar order of magnitude to nano-scale carbon fillers in jute systems, at potentially lower material cost [16].

4.3. Comparative Effectiveness of Nanofiller Strategies

Comparing across the compiled nanofiller literature, CNT modification delivers the largest relative tensile-strength improvement reported for jute composites, while graphene/GO modification delivers more balanced improvements across tensile, flexural, impact, and thermal (heat-deflection) properties simultaneously [14,16]. Sisal-jute composites incorporating CNTs have independently confirmed statistically significant tensile-strength improvements attributable to nanotube reinforcement, using analysis-of-variance testing to establish significance across composite formulations [17], supporting the generality of the CNT-enhancement effect across different natural-fibre matrices beyond jute alone.

5. JUTE-EFB AND OTHER NATURAL-NATURAL HYBRIDS

Oil-palm empty fruit bunch (EFB)/jute epoxy hybrid composites, fabricated in EFB/jute/EFB and jute/EFB/jute layering configurations, showed that the jute/EFB/jute configuration achieved higher flexural strength than the EFB/jute/EFB configuration and than neat epoxy, with pure jute composite flexural strength (75.5 MPa) exceeding that of neat epoxy (33.5 MPa) by a wide margin; however, pure EFB composite retained a substantially higher impact strength than any of the hybrid configurations tested, illustrating a trade-off between flexural and impact performance in jute-EFB hybridisation [18]. EFB/woven-jute hybrids at a fixed 4:1 EFB-to-jute weight ratio showed that hybridisation reduced void content and improved density, moisture resistance, and dynamic mechanical properties relative to pure EFB composite, with the oil-palm:jute (1:4) configuration showing the highest damping behaviour and tensile properties among the hybrid ratios tested [19,20]. Surface treatment of both EFB and jute fibres with 2-hydroxy ethyl acrylate prior to hybridisation has further been shown to improve flexural and impact properties relative to untreated hybrid composites through improved fibre-matrix interfacial bonding [21].

6. COMPARATIVE MECHANICAL PERFORMANCE SUMMARY

Table 1 summarises representative, independently reported mechanical property values compiled from the literature surveyed in Sections 2–5, organised by reinforcement strategy. The compiled evidence indicates that jute-glass hybrids (particularly HPMC/S-glass systems with glass fibre positioned at the outer laminate layers) and CNT/graphene-modified jute composites deliver the largest absolute and relative mechanical improvements among the strategies compiled, while pure jute and jute-EFB systems offer a more fully bio-based, lower-cost alternative with correspondingly more moderate mechanical performance.

Table 1: Representative mechanical properties compiled for jute fibre-based composites, by reinforcement strategy and loading.

Composite System	Reinforcement / Loading	Key Reported Property	Ref.
Jute/epoxy + eggshell filler	25 wt.% fibre	66.4 MPa tensile; 163.4 MPa flexural	4
Jute/polyester (untreated)	Varying volume fraction	33.5–42.0 MPa tensile; 190–275 MPa flexural	5
Jute/PP	30–40 wt.% fibre	Improving strength with fibre loading	6
Jute/glass – epoxy (GJJJ)	Glass outer layers	+16% flexural strength vs. JGJGJ	8,9
Jute/S-glass (HPMC) – epoxy	Hand lay-up hybrid	Marked flexural strength improvement	10
Flax/glass – epoxy (KOH treated)	T-F2G2 hybrid	118.2 MPa tensile; 39.3 kJ/m² impact	12

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Composite System	Reinforcement / Loading	Key Reported Property	Ref.
Jute/UPR + MWCNT	2–10 wt.% MWCNT	3.37→19.86 MPa tensile	14
Jute + GO/FG nanofiller	0.5–1.0 wt.%	Improved tensile, flexural, impact, heat deflection	16
Jute/EFB – epoxy (J/EFB/J)	4:1 EFB:jute	Highest flexural among hybrid configurations	18,19

7. CHALLENGES AND LIMITATIONS

7.1. Moisture Absorption and Durability

Jute fibre's hydrophilic cellulose surface chemistry results in significant moisture uptake in service, which degrades interfacial bonding and reduces mechanical performance over time; hybridisation with a lower-absorption reinforcement (glass fibre or EFB) and epoxy matrices with inherently better water resistance than polyester have both been shown to partially mitigate, though not eliminate, this durability limitation [19,20].

7.2. Nanofiller Dispersion

As with other nano-scale reinforcement systems, CNTs and graphene-family fillers are prone to agglomeration within the polymer matrix at higher loadings, which can offset the mechanical benefits observed at low loadings; achieving uniform dispersion in jute composite fabrication typically requires additional processing steps (mechanical stirring, sonication) beyond the simple hand lay-up methods commonly used for pure jute or jute-glass hybrid fabrication [14,16].

7.3. Property Variability and Standardisation

Because jute fibre properties vary with cultivar, growing region, retting method, and extraction process, mechanical properties reported across independent studies at nominally similar fibre loadings show considerable scatter, as illustrated by the wide tensile and flexural strength ranges compiled in Table 1 even for ostensibly similar pure jute/polyester systems, complicating direct design-allowable comparisons across the literature [5].

8. FUTURE DIRECTIONS

Based on the compiled evidence, three directions appear most promising for future development of jute-based composites. First, systematic optimisation of hybrid stacking sequence and glass-to-jute ratio, building on the consistent finding that outer-layer glass placement improves flexural performance, would help establish clearer hybrid-composite design guidelines [8,9]. Second, further development of standardised nanofiller dispersion protocols for CNT- and graphene-modified jute composites would help translate the substantial laboratory-scale property improvements already demonstrated into more consistent, reproducible composite performance [14,16]. Third, continued exploration of fully bio-based hybrid systems such as jute-EFB, potentially combined with nano-scale filler modification, may offer a route to composites that retain strong sustainability credentials while approaching the mechanical performance currently achievable only with synthetic-fibre hybridisation.

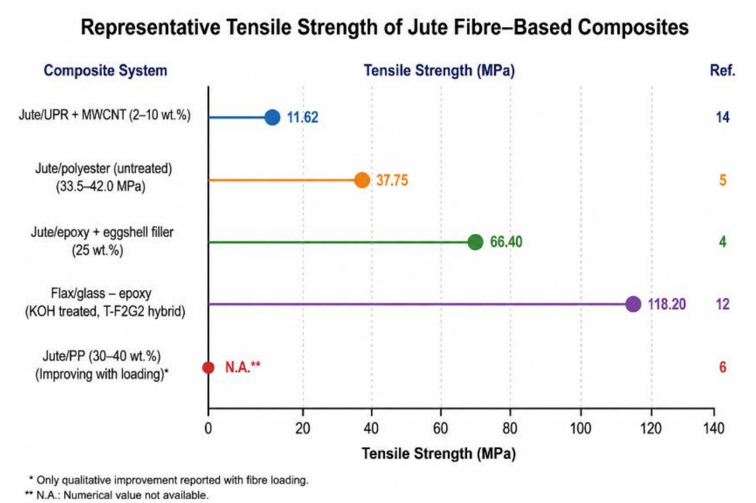

Figure 2. Representative tensile strength of jute fibre-based composites presented as a horizontal lollipop plot.

9. CONCLUSION

The principal conclusions of this compiled review are as follows:

- Jute fibre-reinforced composites offer acceptable baseline mechanical performance that is strongly dependent on fibre content, matrix type, and surface treatment, with an optimum fibre loading beyond which further addition degrades properties.
- Jute-glass hybridisation, particularly HPMC (S-glass + jute) systems with glass fibre positioned at the outer

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laminate layers, delivers substantial improvements in flexural and impact properties relative to pure jute composites.

• Nanofiller modification with carbon nanotubes delivers the largest relative tensile-strength improvements compiled in this review, while graphene and graphene oxide fillers deliver more balanced improvements across tensile, flexural, impact, and thermal properties simultaneously.

• Jute-EFB and related natural-natural hybrids offer a more fully bio-based alternative with a trade-off between flexural and impact performance depending on layering configuration, and represent a promising direction for further sustainability-focused development.

• High-performance jute-glass hybrid and nano-enhanced jute composites show clear potential for partially replacing synthetic-fibre composites in select structural and semi-structural applications, supporting the development of cost-effective, eco-friendly composite materials for diverse engineering uses.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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