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REVIEW ARTICLE

Compilation of Mechanical Properties of Kenaf-Reinforced Polymer Composites with Varying Fibre Content and Matrices

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ABSTRACT:

Kenaf fibre has emerged as a promising natural reinforcement in polymer composites due to its sustainability, cost-effectiveness, and favorable mechanical properties. This review compiles and analyzes experimental data on a wide variety of kenaf-reinforced polymer composites to evaluate their mechanical performance. The composites studied include single and hybrid reinforcements combined with matrices such as epoxy, polyester, polyurethane, polylactic acid, and polypropylene. Mechanical properties such as tensile strength, flexural strength, impact strength, Young's modulus, and elongation at break were compared across different fibre loadings and composite formulations. The results indicate that the incorporation of kenaf fibres significantly enhances mechanical performance, particularly when combined with other reinforcements like glass fibre, banana fibre, or basalt. For example, hybrid kenaf-basalt epoxy composites demonstrated tensile strengths up to 150 MPa and impact strengths exceeding 29 kJ/m². Additionally, fibre loading was found to strongly influence mechanical behavior, with optimal ranges varying by matrix type. Notably, polylactic acid and epoxy-based systems generally showed superior strength and stiffness. This comprehensive dataset highlights the potential of kenaf fibre composites for structural and semi-structural applications in automotive, construction, and consumer product sectors.

KEYWORDS: Polymer matrix composites; Structural applications; Mechanical properties; Sustainable materials; Reinforcement hybridization; Fibre-matrix compatibility.

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1. INTRODUCTION

Growing environmental concern and stricter end-of-life regulations for engineering plastics have driven sustained interest in replacing synthetic reinforcements such as glass and carbon fibre with lignocellulosic natural fibres in polymer matrix composites [1]. Among the natural bast fibres, kenaf (*Hibiscus cannabinus*) has attracted particular attention because of its rapid growth cycle, low cultivation cost, low density (approximately 1.4–1.5 g/cm³), and a reported single-fibre tensile

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strength range of 223–930 MPa with a modulus of 14.5–73 GPa — values that are competitive with E-glass fibre on a specific-strength basis [2,3].

Despite this promise, the mechanical performance of a kenaf-reinforced composite is governed by a complex interplay of fibre loading, fibre architecture (chopped, woven, or unidirectional), matrix chemistry, interfacial treatment, and hybridisation with a secondary reinforcement [4,5]. Consequently, the literature reports a wide scatter of tensile, flexural, and impact properties for nominally similar kenaf composites, making it difficult for a designer to identify which combination of fibre content and matrix is best suited to a given structural or semi-structural application. Several prior reviews have surveyed subsets of this literature — for example, focusing specifically on kenaf/glass hybrids [6,7] or on general kenaf composite applications [8,9] — but a compiled, cross-matrix comparison spanning thermoset and thermoplastic systems together with hybridisation strategies remains valuable for guiding material selection.

This review compiles and compares experimentally reported mechanical property data — tensile strength, flexural strength, impact strength, Young's modulus, and elongation at break — for kenaf-reinforced polymer composites across five matrix families: epoxy, unsaturated polyester, polyurethane, polylactic acid (PLA), and polypropylene (PP), and across single-fibre and hybrid-fibre (kenaf combined with glass, basalt, banana, bamboo, or coir) formulations. The objective is to identify consistent trends in the effect of fibre loading and hybridisation on mechanical performance, to highlight the matrix systems and architectures that deliver the highest absolute properties, and to identify the principal limitations — fibre-matrix compatibility and moisture sensitivity chief among them — that constrain wider structural adoption of kenaf composites.

2. MATRIX SYSTEMS FOR KENAF-REINFORCED COMPOSITES

2.1. Thermoset Matrices: Epoxy and Polyester

Epoxy is the most extensively studied matrix for kenaf reinforcement owing to its low cure shrinkage and strong adhesive characteristics relative to unsaturated polyester [6]. At a matched fibre loading of 25 wt.%, kenaf/epoxy composites have been reported to reach a tensile strength of 93.59 MPa, compared with 86.54 MPa for the equivalent kenaf/polyester formulation, a difference attributed to the superior interfacial bonding and lower cure shrinkage of epoxy [6,10]. Alkali (NaOH) surface treatment of the kenaf fibre substantially improves this baseline performance: fibre treated with 9% NaOH for 12 hours raised flexural strength to 93.3 MPa, compared with 63.2 MPa at 3% NaOH and only 25.1 MPa for untreated fibre, reflecting improved surface roughness and fibre-matrix mechanical interlocking [6,11]. Chemical treatment strategy is therefore as influential on final composite performance as the matrix choice itself.

2.2. Biodegradable Thermoplastic Matrices: Polylactic Acid

Among the matrices compiled in this review, unidirectional continuous kenaf/PLA systems reported some of the highest absolute mechanical properties. Ochi's classic study of unidirectional kenaf/PLA composites reported a tensile strength of 223 MPa and a flexural strength of 254 MPa [12], while a later study of unidirectional continuous kenaf/PLA at a 0° fibre orientation reported an ultimate tensile strength of approximately 190 MPa and a flexural strength of approximately 235 MPa, with strength retained up to 120°C [13]. By contrast, short/woven kenaf mat reinforcement of PLA yields substantially lower absolute properties — a 40 wt.% woven kenaf/PLA composite reached a tensile strength of 61 MPa, a flexural strength of 62 MPa, and an impact strength of 48 kJ/m² [14] — illustrating that fibre architecture (continuous, aligned fibre versus randomly oriented short fibre) is as significant a variable as fibre content when comparing across studies. Hybridising kenaf with bamboo and coir within a PLA matrix has been reported to raise tensile strength to 187 MPa in a kenaf-bamboo-coir/PLA system, approximately 20% and 78% higher than the corresponding bamboo-coir/PLA and kenaf-coir/PLA composites, respectively [15].

2.3. Polypropylene and Other Thermoplastic Matrices

Kenaf/polypropylene (PP) composites are of interest for high-volume compression-moulded and thermoformed automotive components. Fibre contents of 30–40 wt.% have been reported to provide sufficient reinforcement to substantially improve the strength of the PP matrix, with kenaf/PP sheets exhibiting superior flexural and tensile strength relative to coir- or sisal-reinforced thermoplastics processed under comparable conditions

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[16]. Maleated (maleic-anhydride-grafted) PP coupling agents further improve the specific modulus of kenaf/PP composites relative to untreated systems, giving kenaf/PP an advantageous modulus-to-cost ratio compared with coir, sisal, and even E-glass-reinforced thermoplastics on a specific-property basis [16,17].

2.4. Polyurethane Matrix Systems

Kenaf-reinforced polyurethane composites remain comparatively less studied than epoxy or PLA systems, but soil-burial durability studies of kenaf/thermoplastic-polyurethane (TPU) composites at 30% fibre loading have shown that tensile strength drops to approximately 16.14 MPa after 80 days of soil burial, underscoring a moisture- and biodegradation-related durability limitation that is particularly pronounced for flexible polyurethane matrices relative to rigid thermosets [18].

3. EFFECT OF FIBRE LOADING ON MECHANICAL PERFORMANCE

Across the matrices compiled in this review, mechanical performance generally increases with fibre loading up to an optimum content, beyond which performance plateaus or declines owing to fibre agglomeration, incomplete wetting, and void formation. A recurring finding across multiple independent studies is that no single fibre-loading percentage is universally optimal; rather, 40 wt.% is frequently reported as a favourable loading for thermoset matrices, whereas thermoplastic systems tend to saturate at lower loadings of 25–30 wt.% because of the higher melt viscosity restricting fibre wet-out at higher fibre fractions [6,19]. For example, increasing kenaf loading from 10% to 40% in one flexural study increased flexural strength progressively, but a further increase to 50% caused a decline, attributed to a saturated fibre-polymer mixture that could no longer be held tightly enough by the matrix to transfer load effectively [6,20].

Fibre loading also interacts with fibre architecture: in PLA systems, a 10% fibre content was reported to give optimum tensile (20 MPa) and flexural (28 MPa) properties for one short-fibre formulation [21], figures far below the 190–223 MPa achieved by unidirectional continuous-fibre kenaf/PLA at comparable or even lower nominal fibre volume fractions [12,13], reinforcing that fibre orientation and continuity, not loading percentage alone, dominate the upper bound of achievable strength.

4. HYBRIDIZATION STRATEGIES

4.1. Kenaf-Glass Hybrids

Hybridising kenaf with glass fibre is the most extensively reported strategy for boosting the mechanical performance of kenaf composites toward levels competitive with fully synthetic laminates while still displacing a substantial fraction of glass fibre by mass. Stacking-sequence studies of kenaf/glass/epoxy laminates report tensile strengths spanning 75–159 MPa depending on the position and number of glass plies, with a glass-core-and-outer-kenaf configuration reaching approximately 150 MPa [22], while hybridisation of non-hybrid kenaf composites (49.48 MPa tensile, 77.63 MPa flexural) with glass raised these values to 65.29 MPa and 115.71 MPa respectively [7]. Kenaf/glass/polyester structural profiles have achieved tensile strengths within roughly 8% of pure fibreglass laminates while replacing a substantial glass fraction with kenaf [23].

4.2. Kenaf-Basalt Hybrids

Basalt fibre, an inorganic mineral fibre with glass-like mechanical properties but improved thermal and chemical resistance, has more recently been explored as a hybrid partner for kenaf. A kenaf/basalt/epoxy hybrid composite has been reported to achieve a tensile strength of 94.85 MPa, a flexural strength of 98.26 MPa, and an impact strength of 29.97 kJ/m², values that were framed by the authors as demonstrating the composite's capability to withstand substantial combined mechanical loading [24]. By contrast, a stacking-sequence study of basalt/kenaf/polyester found that an all-basalt configuration reached the highest tensile strength (85 MPa) and lowest void content, while an all-kenaf configuration was lowest on both measures (42 MPa tensile, highest void content), illustrating that hybrid stacking sequence — not merely the presence of basalt — governs the realised improvement [25].

4.3. Kenaf-Banana and Other Natural-Natural Hybrids

Hybridising kenaf with a second natural fibre such as banana offers a fully bio-based composite, trading some absolute strength for improved sustainability credentials. Kenaf/banana/epoxy hybrid composites at 40 wt.% total fibre content have been reported to reach a tensile strength of approximately 139.5–171.3 MPa

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depending on fibre ratio and moisture-conditioning state, substantially exceeding banana/jute epoxy hybrids at comparable loadings (27.02 MPa tensile) [26], while retaining more than 90% of as-fabricated tensile and flexural strength after water saturation [26]. Kenaf-bamboo hybrids in an epoxy matrix have similarly shown a 50:50 kenaf:bamboo ratio to maximise tensile strength (55.18 MPa) and elongation at break among the ratios tested [27], while a kenaf-sisal hybridisation strategy was reported to increase tensile strength, flexural strength, and impact toughness relative to the unhybridised sisal composite [28].

5. COMPARATIVE MECHANICAL PERFORMANCE SUMMARY

Table 1 summarises representative, independently reported mechanical property ranges compiled from the literature surveyed in Sections 2–4, organised by matrix/reinforcement system.

The compiled data show that the highest absolute tensile and flexural strengths are associated with continuous, unidirectional fibre architecture in a PLA matrix, that kenaf-glass and kenaf-basalt hybridisation in an epoxy matrix offer the best balance of tensile, flexural, and impact performance for randomly oriented or woven fibre architectures, and that unhybridised, low-loading thermoplastic (PP) systems generally occupy the lower end of the compiled property range.

Table 1: Representative mechanical property ranges compiled for kenaf-reinforced polymer composites by matrix/reinforcement system. *Property ranges reported across multiple fibre loadings and testing conditions; values are illustrative of the compiled trend, not a single-study result.

System (Matrix/Reinforcement)	Tensile Strength (MPa)	Flexural Strength (MPa)	Impact Strength (kJ/m²)	Ref.
Kenaf/epoxy (25 wt.%)	93.6	—	—	6,10
Kenaf/polyester (25 wt.%)	86.5	—	—	6,10
Kenaf/PLA, unidirectional	190–223	235–254	—	12,13
Kenaf/PLA, woven mat (40 wt.%)	61	62	48	14
Kenaf/PP (30–40 wt.%)	32–45*	60–85*	15–35 J*	16,17
Kenaf/glass/epoxy (hybrid)	65–159	115.7	—	7,22
Kenaf/basalt/epoxy (hybrid)	94.9	98.3	30.0	24
Kenaf/banana/epoxy (hybrid, 40 wt.%)	139.5–171.3	73.7–145.4	—	26
Kenaf/bamboo/epoxy (50:50 hybrid)	55.2	—	—	27

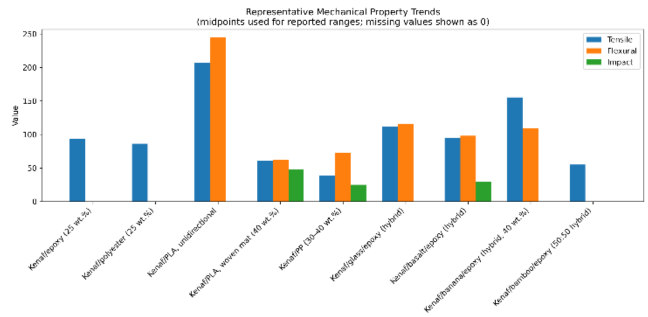

Figure 1: Representative mechanical property trends of kenaf-reinforced polymer composites across different matrix and hybrid reinforcement systems.

6. CHALLENGES AND LIMITATIONS

6.1. Fibre-Matrix Compatibility

The hydrophilic surface chemistry of kenaf fibre, dominated by cellulose hydroxyl groups, is fundamentally incompatible with the hydrophobic character of most thermoset and thermoplastic matrices, resulting in weak interfacial adhesion, fibre pull-out, and premature debonding under load unless the fibre surface is chemically modified [6,11]. Alkali treatment, silane coupling agents, and maleation of thermoplastic matrices are the most widely reported mitigation strategies, but treatment efficacy varies with concentration, duration, and matrix chemistry, meaning that treatment protocols cannot be transferred directly between studies without re-optimisation [11].

6.2. Moisture Absorption and Durability

Because kenaf fibre readily absorbs moisture, composite mechanical properties degrade progressively under humid service conditions or direct water exposure. Soil-burial testing of kenaf/TPU composites showed a tensile-strength decline to 16.14 MPa after 80 days [18], while water-immersion testing of kenaf/glass/polyester composites showed general deterioration of mechanical strength with prolonged moisture ingress, albeit with an initial rise in strain to failure before a sharp late-stage drop [29]. Kenaf/banana hybrid composites were comparatively more resilient, retaining over 90% of tensile and flexural strength after water saturation [26], suggesting that hybridisation with a lower-absorption fibre or matrix can partially offset this limitation.

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6.3. Variability and Standardisation

Because kenaf fibre properties vary with cultivar, growing region, retting method, and extraction process, single-fibre and composite mechanical properties reported across studies show wide scatter even at nominally identical fibre loadings, complicating direct cross-study comparison and standardised design allowables of the kind routinely available for synthetic fibres [2,3].

7. FUTURE DIRECTIONS

Based on the compiled evidence, three directions appear most promising for advancing kenaf composites toward broader structural adoption. First, standardised fibre surface treatment protocols correlated directly against composite mechanical outcomes would reduce the current scatter in reported properties and enable more reliable design allowables. Second, continued development of continuous/unidirectional kenaf fabric preforms, which this review's compiled data show substantially outperform short or woven mat architectures, would allow kenaf composites to approach the mechanical performance of fully synthetic laminates in load-bearing applications. Third, further hybridisation research combining kenaf with basalt or other inorganic fibres, which retain many of basalt's favourable stiffness and thermal-stability characteristics while displacing a large fraction of synthetic fibre by mass, represents an attractive route to durable, semi-structural composites for the automotive and construction sectors [24,25].

8. CONCLUSION

The principal conclusions of this compiled review are as follows:

• Kenaf fibre reinforcement consistently improves the tensile, flexural, and impact properties of polymer matrices relative to the neat resin, with the magnitude of improvement strongly dependent on fibre loading, architecture, and matrix chemistry.

• Unidirectional, continuous-fibre kenaf/PLA composites report the highest absolute tensile (190–223 MPa) and flexural (235–254 MPa) strengths compiled in this review, exceeding short/woven-mat kenaf composites in any matrix by a wide margin.

• Hybridisation with glass or basalt fibre in an epoxy matrix offers the best balance of tensile strength (up to ~150–160 MPa for kenaf-glass, ~95 MPa with ~30 kJ/m² impact strength for kenaf-basalt) for randomly oriented or woven kenaf architectures.

• Optimum fibre loading is matrix-dependent: thermoset systems tolerate loadings up to approximately 40 wt.% before saturation, while thermoplastic systems such as PP and PLA short-fibre composites tend to saturate at lower loadings of 25–30 wt.%.

• Fibre-matrix compatibility (requiring alkali, silane, or maleation treatment) and moisture-driven durability loss remain the two most significant barriers to wider structural use of kenaf composites, and should be prioritised in future standardisation efforts.

• The compiled dataset supports the viability of kenaf-reinforced and kenaf-hybrid polymer composites for structural and semi-structural applications in the automotive, construction, and consumer-product sectors, provided fibre treatment and architecture are matched appropriately to the target matrix and loading regime.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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