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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

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

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ABSTRACT

Natural fibre-reinforced polymer composites have attracted considerable attention as sustainable alternatives to conventional synthetic composites due to their low density, renewability, biodegradability, and excellent specific mechanical properties. Among natural fibres, kenaf (*Hibiscus cannabinus* L.) has emerged as one of the most promising reinforcements because of its high tensile strength, rapid growth, low cost, and environmental compatibility. This review compiles and critically analyses published studies on kenaf-reinforced polymer composites with varying fibre contents and polymer matrices. The influence of fibre loading, fibre treatment, matrix selection, and hybrid reinforcement on tensile strength, flexural strength, impact resistance, Young's modulus, and elongation at break is discussed. Polymer matrices including epoxy, polyester, polypropylene, polyurethane, and polylactic acid are compared with respect to mechanical performance. The review demonstrates that optimum fibre loading generally ranges from 20–40 wt%, depending on matrix type and fabrication method. Hybrid composites incorporating kenaf with glass, basalt, banana, or carbon fibres exhibit superior strength and stiffness while maintaining reduced weight and improved sustainability. The compiled results indicate that kenaf-polymer composites possess significant potential for automotive, construction, aerospace interior, marine, and consumer product applications. Future developments involving nanofillers, bio-based matrices, and additive manufacturing are expected to further improve their structural performance and commercial adoption.

Keywords: Kenaf Fibre, Polymer Composites, Natural Fibre Reinforcement, Mechanical Properties, Sustainable Materials, Hybrid Composites, Polymer Matrix.

1. INTRODUCTION

The increasing demand for lightweight, environmentally friendly, and sustainable engineering materials has accelerated research into natural fibre-reinforced polymer composites (NFRPCs). Conventional synthetic reinforcements such as glass, carbon, and aramid fibres provide excellent mechanical performance but suffer from high manufacturing costs, non-biodegradability, and significant environmental impacts during production and disposal. Consequently, renewable plant-based fibres have emerged as attractive alternatives for structural and semi-structural composite applications.[1–3]

Natural fibres offer several advantages, including low density, high specific strength, biodegradability, renewability, low abrasiveness, reduced energy consumption during manufacturing, and lower production costs. These characteristics make them suitable for applications in automotive components, construction materials, packaging, consumer products, furniture, marine structures, and sporting goods.[4]

Among various natural fibres, **kenaf (*Hibiscus cannabinus* L.)** has attracted considerable attention because of its rapid

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growth, high cellulose content, excellent tensile properties, and wide availability. Kenaf belongs to the Malvaceae family and can be cultivated within four to five months under tropical and subtropical climatic conditions. The fibre consists primarily of cellulose, hemicellulose, lignin, and small quantities of waxes and pectin, which collectively determine its mechanical behaviour.[5]

Kenaf fibres possess favourable mechanical properties, including tensile strength ranging from **300–930 MPa**, Young's modulus between **14–60 GPa**, and relatively low density of approximately **1.2–1.5 g/cm³**. These characteristics provide excellent specific strength compared with many conventional engineering materials, making kenaf an attractive reinforcement for lightweight composite structures.[6]

The mechanical performance of kenaf-reinforced polymer composites depends on several factors, including fibre loading, fibre orientation, fibre length, surface treatment, matrix type, fabrication process, and fibre–matrix interfacial adhesion. Proper optimization of these parameters is essential for achieving superior mechanical properties and long-term durability.[7]

Various thermosetting and thermoplastic polymers have been investigated as matrices for kenaf fibre composites. Thermosetting matrices such as epoxy, polyester, vinyl ester, and polyurethane generally provide superior interfacial bonding and structural rigidity, whereas thermoplastic matrices including polypropylene (PP), polyethylene (PE), and polylactic acid (PLA) offer improved recyclability and manufacturing flexibility.[8]

Recent research has increasingly focused on **hybrid composites**, in which kenaf fibres are combined with synthetic reinforcements such as glass fibre, basalt fibre, carbon fibre, or other natural fibres including banana, flax, jute, and sisal. Hybridization significantly enhances tensile strength, flexural stiffness, impact resistance, and fatigue performance while maintaining lower weight and improved environmental sustainability.[9]

Surface modification techniques have also been extensively investigated to improve fibre–matrix compatibility. Chemical treatments such as alkali treatment, silane coupling, acetylation, benzoylation, and maleic anhydride grafting effectively remove surface impurities, increase fibre roughness, and improve interfacial bonding, thereby enhancing stress transfer between fibre and matrix.[10]

The growing emphasis on sustainable manufacturing, circular economy principles, and carbon footprint reduction has further stimulated industrial interest in bio-based composite materials. Automotive manufacturers increasingly utilize natural fibre composites in door panels, dashboards, seat backs, interior trims, parcel shelves, and underbody components due to their lightweight characteristics and reduced environmental impact.[11]

The objective of this review is to compile and critically evaluate published data on the mechanical properties of kenaf-reinforced polymer composites with different fibre contents and polymer matrices. The review compares tensile strength, flexural strength, impact resistance, Young's modulus, and elongation at break while highlighting the influence of hybrid reinforcement, fibre treatment, and matrix selection on composite performance.

2. KENAF FIBRE AS A NATURAL REINFORCEMENT

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Kenaf fibre has become one of the most extensively investigated natural reinforcements because of its favorable balance between mechanical performance, cost, availability, and sustainability. Compared with many other natural fibres, kenaf exhibits relatively high cellulose content, contributing to superior tensile strength and stiffness.[12]

The principal chemical constituents of kenaf fibre include:

- Cellulose: **45–57%**
- Hemicellulose: **21–23%**
- Lignin: **8–13%**
- Pectin, waxes, and moisture: **remaining fraction**

The high cellulose concentration is primarily responsible for the excellent mechanical properties of kenaf composites.

2.1 Advantages of Kenaf Fibre

Major advantages include:

- Low density
- High specific strength
- Renewable resource
- Biodegradable
- Low production cost
- Good acoustic insulation
- Excellent vibration damping
- Reduced tool wear during machining
- Carbon-neutral lifecycle
- Easy availability

These characteristics make kenaf particularly suitable for lightweight structural applications.

2.2 Limitations

Despite numerous advantages, kenaf fibres possess certain limitations:

- Moisture absorption
- Hydrophilic nature
- Lower thermal stability than synthetic fibres
- Fibre property variability
- Poor fibre–matrix compatibility without treatment

These drawbacks can be significantly reduced through appropriate chemical treatments and optimized processing conditions.[13]

3. POLYMER MATRICES USED IN KENAF COMPOSITES

The matrix binds reinforcing fibres together, transfers applied loads, and protects fibres from environmental degradation. Matrix selection strongly influences the mechanical behaviour and durability of kenaf composites.

3.1 Epoxy Resin

Epoxy is among the most widely used thermosetting matrices because of its:

- Excellent adhesion
- High strength
- Low shrinkage
- Superior chemical resistance
- Excellent fatigue behaviour

Kenaf–epoxy composites generally exhibit the highest tensile and flexural properties among natural fibre composites.

3.2 Polyester Resin

Polyester resins are economical and widely employed for:

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- Automotive components
- Construction panels
- Marine products

They provide satisfactory mechanical performance with relatively low manufacturing costs.

3.3 Polypropylene (PP)

Polypropylene is a recyclable thermoplastic matrix extensively used in automotive applications because of its:

- Low density
- Good impact resistance
- Easy processing
- Excellent recyclability

However, coupling agents are often required to improve fibre–matrix adhesion.

3.4 Polylactic Acid (PLA)

PLA is a biodegradable polymer derived from renewable resources.

Major advantages include:

- Environmental sustainability
- Good stiffness
- Biocompatibility
- Suitable for additive manufacturing

Kenaf–PLA composites have attracted considerable interest for biodegradable engineering products.

3.5 Polyurethane

Polyurethane provides:

- Excellent toughness
- Good impact resistance
- High flexibility
- Good abrasion resistance

These properties make polyurethane composites suitable for vibration-sensitive engineering applications.

Table 1. Common Polymer Matrices Used in Kenaf Composites

Matrix	Advantages	Typical Applications
Epoxy	High strength, excellent adhesion	Structural composites
Polyester	Economical, easy processing	Automotive panels
Polypropylene	Recyclable, lightweight	Interior automotive parts
PLA	Biodegradable	Green composites
Polyurethane	Toughness, flexibility	Impact-resistant components

4. MECHANICAL PROPERTIES OF KENAF-REINFORCED POLYMER COMPOSITES

The mechanical performance of kenaf-reinforced polymer composites is governed by several parameters, including fibre content, fibre orientation, fibre length, matrix type, manufacturing process, and fibre–matrix interfacial bonding. Appropriate optimization of these factors enables natural fibre composites to achieve mechanical properties suitable for structural and semi-structural engineering applications.[16]

4.1 Tensile Strength

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Tensile strength is one of the most important indicators of composite performance because it reflects the ability of fibres to transfer applied loads through the polymer matrix. The incorporation of kenaf fibres generally improves tensile strength up to an optimum fibre loading, beyond which fibre agglomeration, void formation, and inadequate matrix wetting reduce mechanical performance.

Published studies indicate that:

- Kenaf–epoxy composites exhibit tensile strengths ranging from **60–120 MPa**.
- Kenaf–polypropylene composites typically achieve **45–90 MPa**.
- Kenaf–PLA composites report strengths of **70–130 MPa**.
- Hybrid kenaf–glass fibre composites exceed **160 MPa**.
- Hybrid kenaf–basalt composites have demonstrated tensile strengths approaching **150 MPa**.

Chemical surface treatment significantly improves stress transfer by enhancing fibre–matrix adhesion and reducing interfacial defects. Alkali-treated kenaf fibres frequently produce tensile strength improvements of **15–30%** compared with untreated fibres.[17]

4.2 Flexural Strength

Flexural properties evaluate the ability of composites to withstand combined tensile and compressive stresses during bending. Flexural strength depends strongly on fibre orientation, fibre distribution, and matrix stiffness.

Reported values include:

- Kenaf–polyester composites: **70–120 MPa**
- Kenaf–epoxy composites: **90–150 MPa**
- Kenaf–PLA composites: **80–145 MPa**
- Hybrid kenaf–glass composites: **170 MPa or higher**

Uniform fibre dispersion and strong interfacial bonding contribute to higher flexural stiffness and reduced crack propagation.[18]

4.3 Impact Strength

Impact resistance is particularly important for automotive panels, protective structures, and consumer products subjected to dynamic loading.

Kenaf fibres improve impact behaviour through energy absorption mechanisms including:

- Fibre pull-out
- Matrix cracking
- Fibre fracture
- Crack deflection
- Delamination

Typical impact strengths reported are:

- Kenaf–epoxy composites: **10–20 kJ/m²**
- Kenaf–polypropylene composites: **8–16 kJ/m²**
- Hybrid kenaf–banana composites: **20–26 kJ/m²**
- Hybrid kenaf–basalt epoxy composites: **>29 kJ/m²**

Hybridization effectively increases toughness while maintaining lightweight characteristics.[19]

4.4 Young's Modulus

Young's modulus measures material stiffness and is strongly influenced by fibre stiffness and volume fraction.

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Typical modulus values are:

- Kenaf–polyester: **4–7 GPa**
- Kenaf–epoxy: **6–10 GPa**
- Kenaf–PLA: **5–9 GPa**
- Hybrid composites: **10–15 GPa**

Increasing fibre loading generally improves stiffness until insufficient matrix material limits effective stress transfer.

4.5 Elongation at Break

Unlike tensile strength, elongation at break generally decreases as fibre loading increases because natural fibres are less ductile than polymer matrices.

Typical elongation values include:

- Polyester composites: **2–4%**
- Epoxy composites: **1.5–3%**
- Polypropylene composites: **3–6%**
- PLA composites: **2–5%**

Maintaining an appropriate balance between stiffness and ductility is essential for engineering applications subjected to impact and cyclic loading.[20]

5. EFFECT OF FIBRE CONTENT AND HYBRID REINFORCEMENT

The proportion of reinforcing fibre is one of the most influential factors affecting composite performance. Mechanical properties generally improve with increasing fibre loading until an optimum level is reached. Beyond this level, insufficient matrix material results in fibre agglomeration, void formation, poor wetting, and reduced load transfer efficiency.[21]

Most published studies report optimum kenaf fibre loading between **20–40 wt%**, depending on matrix type and processing technique.

5.1 Low Fibre Content (<20 wt%)

Characteristics include:

- Excellent matrix continuity
- Good surface finish
- Lower stiffness
- Reduced tensile strength
- Higher ductility

Such composites are suitable for lightweight interior components.

5.2 Medium Fibre Content (20–40 wt%)

This range generally provides the best balance between strength and manufacturability.

Advantages include:

- Maximum tensile strength
- Improved flexural behaviour
- High stiffness
- Better impact resistance
- Good fibre dispersion

Consequently, most structural applications employ fibre contents within this range.

5.3 High Fibre Content (>40 wt%)

Excessive fibre loading often results in:

- Fibre clustering
- Matrix starvation
- Increased porosity
- Poor interfacial bonding
- Reduced mechanical performance

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Therefore, optimization of fibre loading is critical for maximizing composite properties.[22]

5.4 Hybrid Reinforcement

Hybrid composites combine kenaf with synthetic or other natural fibres to overcome the limitations of single-fibre composites.

Common hybrid systems include:

- Kenaf–Glass
- Kenaf–Basalt
- Kenaf–Carbon
- Kenaf–Banana
- Kenaf–Flax
- Kenaf–Jute
- Kenaf–Sisal

Hybridization provides:

- Higher tensile strength
- Improved impact resistance
- Greater fatigue life
- Enhanced dimensional stability
- Better moisture resistance
- Reduced crack propagation

Among these, **kenaf–basalt epoxy composites** have demonstrated particularly attractive mechanical properties, combining high strength with improved environmental sustainability.[23]

6. STRUCTURAL APPLICATIONS

Kenaf-reinforced polymer composites have emerged as promising engineering materials owing to their lightweight nature, excellent specific strength, biodegradability, and low manufacturing cost. Their favorable mechanical properties have enabled their application across automotive, construction, aerospace, marine, packaging, and consumer product industries. Continuous improvements in fibre treatment, hybrid reinforcement, and polymer matrices have further expanded their engineering applications.[31]

6.1 Automotive Industry

The automotive sector is the largest consumer of natural fibre composites due to stringent regulations on vehicle weight reduction and greenhouse gas emissions. Kenaf composites are increasingly replacing glass fibre composites in non-load-bearing and semi-structural components.

Typical automotive applications include:

- Door panels
- Dashboard structures
- Parcel shelves
- Seat backs
- Interior trim panels
- Boot liners
- Roof liners
- Battery compartment covers for electric vehicles

Compared with conventional materials, kenaf composites reduce component weight by **20–30%**, thereby improving fuel efficiency and extending the driving range of electric vehicles.[32]

6.2 Construction Industry

In civil engineering, kenaf-polymer composites are increasingly employed as sustainable construction materials due to their excellent strength-to-weight ratio and corrosion resistance.

Applications include:

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- Wall panels
- Ceiling boards
- Partition panels
- Decorative laminates
- Roofing sheets
- Modular housing components

Hybrid kenaf composites also exhibit good acoustic and thermal insulation properties, making them suitable for energy-efficient buildings.

6.3 Aerospace Applications

Although natural fibre composites cannot fully replace carbon fibre in primary aircraft structures, they are increasingly utilized for secondary structural components.

Applications include:

- Cabin interior panels
- Seat structures
- Overhead luggage compartments
- Cabin partitions
- Decorative interior components

The reduced weight and improved sustainability of kenaf composites contribute to lower aircraft operating costs and reduced carbon emissions.

6.4 Marine Applications

Kenaf-reinforced polymer composites demonstrate good corrosion resistance and low density, making them suitable for several marine engineering applications.

Examples include:

- Boat interior panels
- Deck flooring
- Storage compartments
- Floating structures
- Marine furniture

Proper resin selection and fibre surface treatment significantly improve moisture resistance in marine environments.

6.5 Consumer Products

Kenaf composites are increasingly employed in environmentally friendly consumer products such as:

- Furniture
- Sports equipment
- Laptop casings
- Mobile phone covers
- Helmets
- Luggage
- Household appliances

These products benefit from reduced environmental impact while maintaining adequate mechanical performance.

Table 2. Engineering Applications of Kenaf-Reinforced Polymer Composites

Industry	Typical Components	Major Benefits
Automotive	Door panels, dashboards, parcel shelves	Lightweight, fuel efficiency
Construction	Wall panels, roofing sheets	Sustainability, corrosion resistance
Aerospace	Interior cabin panels	Weight reduction
Marine	Boat interiors, deck panels	Corrosion resistance

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Consumer Products	Furniture, sporting goods	Eco-friendly materials

7. CHALLENGES AND FUTURE PERSPECTIVES

Despite significant progress, several technical challenges continue to limit the widespread structural application of kenaf-reinforced polymer composites.

7.1 Current Challenges

Major challenges include:

- Moisture absorption due to hydrophilic cellulose fibres.
- Poor fibre–matrix compatibility.
- Variability in natural fibre properties.
- Reduced thermal stability.
- Long-term environmental degradation.
- Limited fire resistance.
- Difficulty in predicting long-term fatigue behaviour.

Advanced chemical treatments and improved manufacturing techniques are therefore essential to achieve consistent mechanical performance.[33]

7.2 Future Perspectives

Current research is focused on improving both the mechanical performance and sustainability of kenaf composites.

Emerging research areas include:

- Nano-cellulose reinforced kenaf composites.
- Graphene and carbon nanotube hybrid composites.
- Bio-based epoxy resins.
- Self-healing polymer composites.
- Additive manufacturing (3D printing).
- Artificial Intelligence-assisted composite design.
- Machine learning prediction of composite properties.
- Topology optimization for lightweight structures.
- Circular economy and recyclable composites.
- Smart composites incorporating embedded sensors.

These emerging technologies are expected to significantly enhance the structural reliability and commercial adoption of kenaf composites in future engineering applications.[34]

8. CONCLUSION

Kenaf-reinforced polymer composites represent a sustainable and lightweight alternative to conventional synthetic fibre composites for numerous engineering applications. This review demonstrates that the mechanical performance of these composites is strongly influenced by fibre loading, matrix selection, fibre treatment, and hybrid reinforcement. Optimum fibre contents of approximately **20–40 wt%** generally provide the best balance between tensile strength, flexural strength, stiffness, and impact resistance. Epoxy- and polylactic acid-based composites exhibit superior mechanical performance, while hybrid reinforcement with glass, basalt, or banana fibres further enhances structural properties. Although challenges such as moisture absorption, fibre variability, and interfacial compatibility remain, ongoing advances in surface modification, nanotechnology, bio-based polymers, and additive manufacturing are expected to overcome these limitations. Overall, kenaf-reinforced polymer composites offer significant potential as

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environmentally friendly materials for automotive, construction, aerospace, marine, and consumer product applications.

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