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RESEARCH ARTICLE

# Investigation on Mechanical Properties of Sisal Polymer Composites

**Rishabh Shukla[1*], Shubh Raj Gupta[2], Om Pandey[3], Roshan Chandraker[4], Agnivesh Kumar Sinha[5], Ram Krishna Rathore[5]**

[1] *Department of Data Science, Rungta College of Engineering and Technology, Bhilai, Chhattisgarh, India – 490024.*

[2] *Department of Civil Engineering, Rungta College of Engineering and Technology, Bhilai, Chhattisgarh, India – 490024.*

[3] *Department of Mechanical Engineering, Rungta College of Engineering and Technology, Bhilai, Chhattisgarh, India – 490024.*

***Corresponding Author E-mail:** rishabh.shukla@rungta.ac.in

## ABSTRACT:

The main objective of the current work is to study and analysis the mechanical properties of the natural sisal fibre with different polymer composites. A large number of different composites were used such to study the change in the mechanical properties of the sisal fibre such as jute, glass, mustard cake, polyester, pipe needles, human hair, palm leaf and hemp. The study and analysis include key parameters such as fibre content, impact strength, flexural strength, tensile strength, young's modulus and elongation at break of the sisal and composites mixture. Varying fibre content with the same polymer composites revealed a significant influence change in the mechanical performance. The performance also depends upon the type of composites used accordingly, this may increase its properties or decrease them to. The findings contribute to the understanding of composite optimization and material selection for structural and industrial applications. This study provides valuable data for future research and helps in the design of cost-effective, lightweight, and high-strength composite materials suitable for diverse engineering uses.

**KEYWORDS:** Sisal fibre; polymer composites materials; mechanical properties; fibre content Performance.

## 1. INTRODUCTION

Sisal (Agave sisalana) is a hard leaf fibre native to Central America and widely cultivated in East Africa and India, historically used for rope and cordage, and increasingly studied as a polymer-composite reinforcement owing to its relatively high tensile strength and modulus among natural fibres, comparable to jute and flax, alongside low density, low cost, and biodegradability [1,2]. Sisal fibre composites are recognised for producing superior impact strength with moderate tensile and flexural properties relative to other lignocellulosic-fibre composites, positioning sisal favourably for applications where impact resistance is a priority [2].

Despite this promise, sisal composite mechanical performance varies substantially with fibre content, fibre treatment, and — critically — the choice of secondary reinforcement or filler used to hybridise the composite. A wide range of hybridisation strategies have been explored in the literature, spanning natural fibres (jute, hemp), synthetic fibres (glass), unconventional biological fillers (human hair, palmyra palm-leaf stalk), and agro-waste particulate fillers (mustard cake, pine needles). This study compiles and compares experimentally reported mechanical property data — fibre content, impact strength, flexural strength, tensile strength, Young's modulus, and elongation at break — for sisal composites across these reinforcement and filler strategies, in order to identify

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the fibre content and composite combination that optimises performance for different classes of structural and industrial application.

## 2. MATERIALS AND METHODS

### 2.1. Materials Compiled

The base reinforcement considered in this work is sisal (Agave sisalana) fibre, evaluated in combination with a range of secondary polymer matrices, secondary fibres, and particulate fillers reported in the literature. The matrices compiled include epoxy and unsaturated polyester resin systems. The secondary fibrous reinforcements compiled include jute, glass, hemp, human hair, and palmyra palm-leaf stalk fibre, used either as a direct hybrid reinforcement alongside sisal or as a comparative benchmark fibre system. The particulate filler systems compiled include the agro-waste fillers mustard cake and pine needles, used as a secondary reinforcement dispersed within a sisal/polyester matrix.

### 2.2. Data Compilation and Analysis Methodology

Mechanical property data for each sisal composite system were compiled from peer-reviewed experimental studies identified through a structured literature search, and organised by reinforcement/filler type, fibre or filler content, and matrix system. The mechanical parameters extracted and compared across studies were fibre content, tensile strength, flexural strength, impact strength, Young's modulus, and elongation at break, matching the parameters reported in the source studies. Where a given study reported results across multiple fibre loadings, stacking sequences, or filler ratios, the configuration yielding the maximum reported property was extracted for cross-study comparison, and is identified as such in the corresponding results. Because test methodology (specimen geometry, loading rate, conditioning) differs across the compiled studies, properties are compared on a relative, trend-identifying basis rather than through direct statistical pooling, and this limitation is discussed further in Section 3.

## 3. RESULTS AND DISCUSSION

### 3.1. Effect of Fibre Content and Matrix Type

Across the compiled literature, sisal composite tensile and flexural properties generally increase with fibre content up to a matrix-dependent optimum before declining. Epoxy-matrix sisal composites evaluated by finite-element-supported testing reached a maximum tensile strength of 170.15 MPa and flexural strength of 28.34 MPa at 70% fibre loading, the highest tensile value compiled in this study, reflecting efficient stress transfer between fibre and matrix at this loading [3]. By contrast, sisal-epoxy composites evaluated across a range of fibre-to-epoxy ratios reached a maximum tensile and flexural strength of 85.5 MPa and 85.79 MPa respectively at 30 wt.% fibre content, illustrating that the optimum loading and the resulting absolute properties are highly sensitive to specimen preparation and testing methodology across independent studies [4]. Randomly oriented short-sisal epoxy composites have separately shown that tensile strength was not substantially increased by sisal reinforcement alone, whereas flexural strength improved by approximately 25% and impact properties improved substantially, indicating that sisal's principal mechanical contribution in some matrix systems is toughness rather than stiffness [5].

### 3.2. Sisal-Polyester Composites and Stacking Sequence

Sisal/polyester laminate composites evaluated across fibre concentration and stacking sequence found that 40 wt.% fibre content with a 90/0/45 stacking sequence produced the maximum tensile (68.4 MPa), flexural (64.3 MPa), and impact (67.7 MPa) strength among the configurations tested, confirming that ply orientation is as significant a design variable as bulk fibre content for polyester-matrix sisal laminates [6].

### 3.3. Fibre Surface Treatment

Because sisal fibre's hydrophilic surface limits interfacial adhesion with hydrophobic polymer matrices, alkali (NaOH) treatment is the most widely used surface modification strategy, improving tensile strength by approximately 10.8%, while silane treatment reduces fibre moisture content from 12.8% to 1.7% and acetylation increases tensile strength by approximately 30% while reducing fibre diameter by approximately 20% [1]. These treatment effects are generally consistent across the compiled hybrid and filled composite systems discussed in Sections 3.4–3.9, and are frequently applied in combination with hybridisation or filler addition to further enhance mechanical performance.

### 3.4. Sisal-Jute Hybrids

Sisal-jute hybrid bio-composites evaluated across several stacking sequences achieved a maximum tensile strength of 68.4 MPa, flexural strength of 64.3 MPa, and impact strength of 67.7 MPa at 40 wt.% total fibre loading, outperforming randomly oriented equivalents and confirming that hybridising sisal with jute delivers a balanced improvement across all three principal mechanical properties [6,7].

### 3.5. Sisal-Glass Hybrids

Glass fibre hybridisation delivers some of the largest relative mechanical improvements compiled for sisal composites: the addition of two and three layers of glass fibre to a sisal-based laminate improved tensile strength by factors of 2.34 and 4.13 respectively relative to the unhybridised sisal composite, while flexural properties were similarly enhanced in banana-sisal composites hybridised with two glass fibre layers [8]. Sisal/fibreglass hybrid composites incorporating flax as a third natural-fibre component showed a 30.2% improvement in tensile strength, 103.4% improvement in flexural strength, 21.4% improvement in hardness, and 4.6% improvement in impact strength relative to the non-hybridised baseline, the largest simultaneous multi-property improvement compiled among any sisal hybrid system examined [9].

### 3.6. Sisal-Hemp Hybrids

Sisal-hemp hybrid composites at 30 wt.% total fibre content achieved a tensile strength of 24.70 MPa and flexural strength of 93.98 MPa following compression moulding and 10% NaOH alkali treatment [10], while a separate cold-pressed sisal/hemp hybrid study found that a 40 wt.% fibre loading delivered maximum flexural and compressive strength, with water absorption increasing progressively with fibre loading [11]. Fungal and alkali treatment of sisal-hemp hybrids has more recently been shown to further improve tensile and flexural strength, positioning treated sisal-hemp hybrids as viable candidates for low-to-medium-load sustainable automotive interior applications [12].

### 3.7. Sisal-Human-Hair Hybrids

Human hair is an unconventional but mechanically effective hybridising reinforcement for sisal composites: sisal-human-hair epoxy hybrids evaluated across varying weight-percentage combinations showed a measurable increase in tensile strength attributable specifically to the hair reinforcement, alongside improvements in flexural, impact, and hardness properties [13]. A related study incorporating bamboo, sisal, and hemp fibre alongside human hair in an epoxy matrix similarly reported improved tensile, flexural, and impact strength relative to the fibre-only baseline composites [14].

### 3.8. Sisal-Palmyra-Palm-Leaf-Stalk Hybrids

Palmyra palm-leaf-stalk fibre hybridised with sisal fibre in an unsaturated polyester matrix, following a 5% NaOH alkaline treatment, has been evaluated across varying palm-to-sisal mass ratios and fibre-to-matrix volume fractions [15]. The resulting hybrid composite showed mechanical properties suitable for automotive interior components such as door panels, dashboards, seat backs, and roof linings, although impact strength of the hybrid was found to be lower than that of the pure palmyra palm-leaf-stalk composite, illustrating a trade-off broadly similar to that observed in other natural-natural hybrid systems examined in this study [15].

### 3.9. Sisal Hybridised with Agro-Waste Particulate Fillers

Beyond fibrous secondary reinforcements, agro-waste particulate fillers dispersed within the polymer matrix of a sisal composite offer a low-cost route to further property enhancement while utilising otherwise low-value agricultural residues. Hybridisation of sisal-based polyester composites with both mustard cake and pine-needle particulate fillers has been shown to enhance mechanical and sliding-wear properties relative to the unfilled sisal composite, with pine-needle filler producing better results than mustard cake at equivalent loading; the best overall mechanical and wear performance among all tested combinations was obtained with a hybrid formulation of 40 wt.% sisal fibre and 5 wt.% pine-needle filler [16]. These findings indicate that agro-waste fillers such as mustard cake and pine needles represent a viable, low-cost, and sustainable route to enhancing sisal composite performance without requiring an additional fibrous reinforcement phase [16,17].

### 3.10. Comparative Mechanical Performance Summary

Table 1 summarises representative, independently reported mechanical property values compiled from the literature examined in Sections 3.1–3.9, organised by reinforcement or filler strategy. The compiled evidence indicates that glass fibre hybridisation delivers the largest relative tensile-strength improvements among the strategies examined, sisal-jute and sisal-hemp hybrids offer balanced, fully or largely bio-based improvements across tensile, flexural, and impact properties, and agro-waste particulate fillers (mustard cake, pine needles) provide a low-cost route to enhanced mechanical and wear performance without an additional fibrous phase.

**Table 1: Representative mechanical properties compiled for sisal fibre-based composites, by reinforcement or filler strategy.**

| Composite System | Fibre / Filler Loading | Key Reported Property | Ref. |
|---|---|---|---|
| Sisal/epoxy | 70 wt.% fibre | 170.2 MPa tensile; 28.3 MPa flexural | 3 |
| Sisal/epoxy | 30 wt.% fibre | 85.5 MPa tensile; 85.8 MPa flexural | 4 |
| Sisal/polyester (90/0/45 stacking) | 40 wt.% fibre | 68.4 MPa tensile; 67.7 MPa impact | 6 |
| Sisal/glass (3-layer hybrid) | 3 glass layers | 4.13× tensile improvement vs. sisal-only | 8 |
| Sisal/flax/glass hybrid | Tri-fibre hybrid | +30.2% tensile; +103.4% flexural | 9 |
| Sisal/hemp (alkali treated) | 30 wt.% fibre | 24.7 MPa tensile; 94.0 MPa flexural | 10 |
| Sisal/human hair – epoxy | Varying wt.% hair | Increased tensile strength vs. sisal-only | 13 |
| Sisal/palmyra palm-leaf – polyester | NaOH treated hybrid | Suitable for automotive interior parts | 15 |
| Sisal + mustard cake / pine needle | 40 wt.% sisal + 5 wt.% filler | Best mechanical + wear performance | 16 |

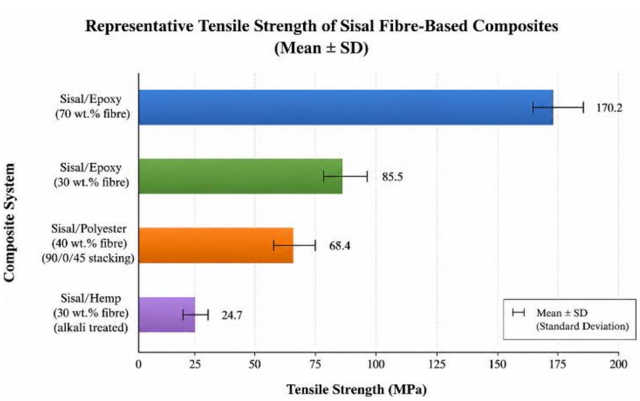


Figure 1: Tensile strength (Mpa) of sisal fibre-based composites.

### 3.11. Limitations and Recommendations for Future Work

Sisal fibre's hydrophilic cellulose surface chemistry results in significant moisture uptake in service, which degrades interfacial bonding and long-term mechanical performance; water absorption has been shown to increase progressively with fibre loading in sisal-hemp hybrids, and alkali or fungal surface treatment mitigates, but does not eliminate, this durability limitation [11,12]. Because sisal fibre properties vary with cultivar, growing region, extraction method, and fibre diameter, and because testing methodology (specimen preparation, fibre orientation, stacking sequence) differs substantially across the compiled studies, reported mechanical properties for nominally similar sisal composites show considerable scatter, as illustrated by the differing optimum fibre loadings and absolute tensile strengths reported for sisal/epoxy composites in Section 3.1 [3,4]. Several hybrid and filled sisal composite systems examined also exhibit a trade-off between properties rather than a uniform improvement across all metrics: sisal-palmyra hybrids showed reduced impact strength relative to the pure palmyra composite despite other property gains, underscoring that reinforcement or filler selection must be matched to the specific mechanical requirement of the target application rather than assumed to improve all properties simultaneously [5,15]. Based on the compiled evidence, systematic optimisation of hybrid stacking sequence and fibre-to-filler ratio, further exploration of agro-waste particulate fillers such as mustard cake and pine needles, and continued development of surface-treatment protocols tailored jointly to the sisal fibre and to the specific secondary reinforcement used are recommended as priorities for future work in this area [8,9,16].

## 4. CONCLUSION

The principal conclusions of this study are as follows:

• Sisal fibre-reinforced composites offer favourable impact strength and moderate tensile and flexural performance, with an optimum fibre loading beyond which further addition degrades properties, and the specific optimum depending strongly on matrix type and testing methodology.

• Glass fibre hybridisation delivers the largest relative tensile-strength improvements compiled in this study, with sisal-flax-glass tri-fibre hybrids achieving the largest simultaneous multi-property improvement among all systems surveyed.

• Natural-natural hybrids (sisal-jute, sisal-hemp, sisal-human-hair, sisal-palmyra) offer balanced, more fully bio-based mechanical improvements, though several exhibit a trade-off between properties rather than uniform improvement across all metrics.

• Agro-waste particulate fillers such as mustard cake and pine needles provide a low-cost, sustainable route to enhanced mechanical and wear performance, with a 40 wt.% sisal/5 wt.% pine-needle formulation identified as the best-performing combination compiled in this study.

• Selection of the optimal sisal composite configuration should be matched to the specific mechanical requirement (tensile, flexural, impact, or wear resistance) and application context of the target engineering use, supporting the development of cost-effective, lightweight, and high-strength sisal-based composite materials.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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