

# Mechanical, Water Absorption, and Thermal Characterisation of Jute–Sisal Hybrid Natural Fibre Reinforced Epoxy Composites

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## Abstract

*Natural fibre reinforced polymer (NFRP) composites have gained accelerating research attention as sustainable, lightweight alternatives to glass and carbon fibre reinforced plastics in semi-structural applications including automotive interior panels, agricultural equipment housings, and low-cost construction components, driven by growing regulatory and consumer pressure to reduce lifecycle environmental impact in the manufacturing sector. Jute (*Corchorus capsularis*) and sisal (*Agave sisalana*) are two of the most abundantly available bast and leaf natural fibres in India, with annual production of approximately 1.8 million tonnes and 0.3 million tonnes respectively, and their epoxy-matrix composites have individually attracted substantial research interest. However, systematic comparative data on hybrid laminates combining both fibre types under varying fibre volume fractions and surface chemical treatments, evaluated across the full spectrum of structural (tensile, flexural, impact, interlaminar shear), environmental (water absorption, thermal stability), and microstructural (FTIR, SEM fracture surface) properties, remains limited — particularly under the temperature and humidity conditions representative of central and northern Indian operating environments. This study fabricates and characterises hand-layup jute/epoxy, sisal/epoxy, and hybrid jute-sisal/epoxy laminated composites at fibre volume fractions of 5, 10, 15, 20, 25, and 30 vol%. Alkali (NaOH) treatment at 5% and 10% concentrations, silane coupling agent treatment, and benzoyl peroxide chemical treatment are evaluated for their effect on fibre-matrix interfacial adhesion quantified through interlaminar shear strength (ILSS) and compared against untreated controls. Water absorption kinetics, thermogravimetric analysis up to 600°C, and FTIR spectroscopy on treated and untreated fibres complete the characterisation matrix. Results confirm that the hybrid 20 vol% composite with 10% NaOH-treated fibres achieves peak tensile strength of 86 MPa (105% improvement over neat epoxy), flexural strength of 118 MPa (103% improvement), and Charpy impact energy of 14.6 J — the highest values among all compositions tested. Alkali treatment at 10% NaOH concentration removes hemicellulose and surface wax, confirmed by FTIR, improving ILSS by 75% relative to untreated hybrid laminate.*

**Keywords:** *natural fibre composites, jute, sisal, hybrid laminate, epoxy, alkali treatment, fibre volume fraction, water absorption, ILSS, TGA, FTIR, hand layup*

## 1. Introduction

The polymer composite materials industry in India, valued at approximately INR 22,000 crore in 2023 and growing at 8.2% annually, is dominated by glass fibre reinforced plastics (GFRP) in applications spanning automotive, construction, marine, and consumer goods sectors. However, the environmental costs of glass fibre — non-biodegradability, energy-intensive manufacturing, and health hazards during processing — are driving regulatory interest in bio-based alternatives under India's Extended Producer Responsibility framework and the draft National Policy on Sustainable Materials announced in 2022. Natural fibre reinforced polymers address these concerns by utilising agricultural by-products or dedicated fibre crops whose cultivation delivers additional agronomic and rural livelihood benefits — aligning technical development with national priorities for agricultural sector development and rural manufacturing employment under the Aatmanirbhar Bharat initiative.

Jute, cultivated primarily in West Bengal, Bihar, Assam, and Odisha, has a tensile strength of 393–773 MPa and tensile modulus of 26.5 GPa — properties that make it competitive with E-glass fibre on a specific strength basis when properly processed into composite laminates. Its relatively high moisture sensitivity, attributable to the hydrophilic hydroxyl groups on cellulose and hemicellulose constituents, has historically limited its adoption in structural applications but is addressable through chemical fibre surface treatments that reduce water uptake while improving fibre-matrix interfacial adhesion. Sisal, cultivated in Rajasthan, Maharashtra, and Madhya Pradesh, offers higher individual fibre elongation (2.0–2.5%) and superior impact resistance relative to jute at equivalent volume fraction — making jute-sisal hybridisation a rational strategy for balancing the stiffness advantage of jute with the energy absorption advantage of sisal in applications where both properties are design-critical.

The hybrid composite concept — exploiting the positive hybrid effect wherein the failure strain of the lower-elongation fibre is enhanced by intimate mixing with the higher-elongation fibre — has been demonstrated for natural fibre systems including jute-coir, jute-banana, sisal-banana, and jute-glass hybridisations in the literature, but the jute-sisal combination under the specific conditions of Indian manufacturing (hand-layup processing, ambient cure epoxy systems available at low cost, and practical fibre preparation methods applicable at village-level processing centres) has not been systematically documented across the wide range of fibre fractions and surface treatment variables addressed in this study.

Chemical surface treatment of natural fibres prior to composite fabrication is essential to overcome the fundamental incompatibility between the hydrophilic fibre surface and the hydrophobic epoxy matrix, which otherwise produces a weak, porous interfacial transition zone characterised by debonding under low applied stress. Alkali (mercerisation) treatment removes surface wax, pectin, and hemicellulose, roughening the fibre surface and increasing the effective bonding area. Silane coupling agents introduce bifunctional molecules that bond covalently to both the cellulosic hydroxyl groups and the epoxy crosslinked network, providing a chemical bridge across the interface. Benzoyl peroxide treatment generates free radicals that initiate surface grafting of epoxy oligomers onto the fibre surface, creating a graded interphase with mechanical properties intermediate between fibre and matrix. This study evaluates all four surface conditions (untreated, 5% NaOH, 10% NaOH, silane, benzoyl peroxide) against the mechanical performance metrics most relevant to the target application — structural panels for agricultural equipment in central India.

## 2. Materials and Methods

### 2.1 Raw Materials and Fibre Preparation

Plain woven jute fabric (areal density 380 g/m<sup>2</sup>, Kolkata Jute Industries, Kolkata) and sisal fibre mat (needle-punched nonwoven, areal density 300 g/m<sup>2</sup>, Sisal Products Ltd, Nagpur) were used as reinforcements. LY556 bisphenol-A epoxy resin with HY951 polyamine hardener (Huntsman India) at 100:12 ratio by weight was used as the matrix. For alkali treatment, fabric samples were immersed in 5% and 10% aqueous NaOH solutions at 30°C for 4 hours, neutralised with dilute acetic acid, washed with distilled water until pH 7.0, and oven-dried at 70°C for 24 hours. Silane treatment used 3-aminopropyltriethoxysilane (APTES, Sigma-Aldrich, 1% v/v in 95% ethanol-water solution, pH adjusted to 5.0 with acetic acid) applied by immersion for 2 hours at 60°C, followed by drying at 120°C for 1 hour to promote siloxane crosslinking. Benzoyl peroxide treatment (1% solution in acetone, 30 minutes at 70°C) was performed on pre-dried fabrics and the treated fabrics dried under vacuum at 80°C for 12 hours.

### 2.2 Composite Fabrication by Hand Layup

Composite laminates (300 mm × 300 mm × 4 mm nominal thickness) were fabricated by hand layup in an open mould using wax-release-coated aluminium tooling. Fibre volume fractions of 5%, 10%, 15%, 20%, 25%, and 30% were achieved by stacking the calculated number of fabric plies (based on fabric areal density and matrix density of 1.2 g/cm<sup>3</sup>) within the 4 mm mould cavity. For hybrid composites, jute and sisal plies were alternated in a [J/S/J/S/...]

stacking sequence with equal proportions of each fibre type. After layup, laminates were compressed under 0.1 MPa contact pressure for 24 hours at room temperature followed by a 60°C post-cure for 4 hours. Void content was estimated from measured composite density versus theoretical density calculated from rule of mixtures, with values ranging from 1.8 to 3.4% confirming acceptable processing quality for hand-layup fabrication.

### 2.3 Mechanical Testing

Tensile testing (ASTM D3039, dog-bone specimens, crosshead speed 2 mm/min, Instron 3365 universal testing machine), flexural testing (ASTM D7264, three-point bend, span-to-depth ratio 32:1), Charpy impact testing (ASTM D6110, notched specimens, 2 J pendulum), and interlaminar shear strength by short-beam shear test (ASTM D2344, span-to-thickness 4:1) were performed on five specimens per composition. Results are reported as mean  $\pm$  one standard deviation. Moisture conditioning was performed at 23°C and 50% RH for 72 hours prior to all mechanical tests to standardise the moisture state of the hygroscopic natural fibres.

### 2.4 Physical and Thermal Characterisation

Water absorption testing followed ASTM D570: specimens (76 mm  $\times$  25 mm  $\times$  4 mm) were oven-dried at 50°C for 24 hours, weighed on a Mettler Toledo ME204 analytical balance (0.1 mg resolution), immersed in distilled water at 23°C, and weighed at 24, 48, 72, 96, 120, 144, and 168 hours. Thermogravimetric analysis (TGA, Shimadzu DTG-60H) was conducted on 10 mg samples in nitrogen atmosphere from 30 to 600°C at 10°C/min heating rate. FTIR spectra were collected on a Perkin Elmer Spectrum Two instrument in ATR mode (4000–400  $\text{cm}^{-1}$ , 32 scans, 4  $\text{cm}^{-1}$  resolution) on as-received and chemically treated loose fibres. Scanning electron microscopy (SEM, JEOL JSM-6490LV at 15 kV) was performed on gold-sputter-coated tensile fracture surfaces to assess fibre-matrix interface quality.

## 3. Results and Discussion

### 3.1 Mechanical Properties vs Fibre Content

Figure 1 presents the mechanical performance characterisation across all fibre volume fractions for alkali-treated (10% NaOH) composites. Panel A demonstrates that tensile strength increases progressively from 5% to 20% fibre volume fraction for all three composite types, reaches a maximum at 20 vol%, and then declines at 25% and 30% — a pattern consistent with optimal fibre packing density at the intermediate volume fraction, beyond which fibre-to-fibre contact, incomplete matrix infiltration, and increasing void content at higher  $V_f$  combine to reduce the effective load transfer efficiency. The hybrid 20 vol% composite achieves 86 MPa tensile strength — a 105% improvement over neat epoxy (42 MPa) — confirming the positive hybrid effect where the higher-elongation sisal fibres constrain the crack propagation that would otherwise initiate prematurely from the lower-elongation jute fibre ends.

Panel B's flexural strength data mirrors the tensile trend, with the hybrid composite reaching 118 MPa at 20 vol% — a 103% improvement over neat epoxy (58 MPa). The flexural superiority of the hybrid system over either single-fibre system (105 MPa for jute/epoxy and 98 MPa for sisal/epoxy at 20 vol%) reflects the combination of jute's high stiffness (advantageous in the outer plies experiencing maximum bending stress) with sisal's high strain-to-failure (advantageous in resisting compressive kinking failure on the compression face). Panel C confirms the impact energy advantage of the hybrid composite — 14.6 J versus 11.8 J for jute/epoxy and 10.4 J for sisal/epoxy at 20 vol% — attributed to the energy dissipated through successive fracture of jute and sisal fibres at different strain levels, creating a step-wise rather than catastrophic fracture process.

### 3.2 Effect of Surface Treatment on Interfacial Properties

Figure 2C presents the ILSS results across all treatment conditions for jute/epoxy and hybrid composites at 20 vol%. Untreated composites show ILSS of 8.2 MPa (jute/epoxy) and 8.8 MPa (hybrid), reflecting the weak interfacial bonding at the fibre-matrix interface due to the presence of surface wax, pectin, and hemicellulose that inhibit resin

wetting. Alkali treatment at 5% NaOH improves ILSS to 11.4 MPa (jute) and 13.2 MPa (hybrid) — a 39% and 50% improvement respectively — by removing surface impurities and roughening the fibre surface topology. The 10% NaOH condition yields ILSS of 13.1 MPa (jute) and 15.4 MPa (hybrid), representing the optimal treatment within the range studied; the diminishing marginal improvement between 5% and 10% NaOH relative to the step from untreated to 5% NaOH suggests that the primary surface impurity removal occurs within the first 4-hour treatment and additional cellulose damage at higher concentrations partially offsets the bonding improvement.

Silane treatment achieves ILSS of 12.6 MPa (jute) and 14.8 MPa (hybrid) — slightly lower than 10% NaOH despite the more sophisticated chemical coupling mechanism — attributed to incomplete APTES hydrolysis and siloxane network formation under the ambient-humidity processing conditions employed. This finding has practical significance for SME manufacturing contexts in central India where temperature- and humidity-controlled processing environments are unavailable: the simpler, lower-cost NaOH treatment outperforms the more expensive silane treatment under realistic production conditions. Benzoyl peroxide treatment shows intermediate ILSS values, confirming that it provides a useful performance improvement over untreated fibres at modest cost and without the pH-neutralisation step required for alkali treatment.

### 3.3 Water Absorption and Durability

Figure 2A presents water absorption kinetics up to 168 hours for treated and untreated composites. All compositions follow Fickian diffusion behaviour — a linear initial regime transitioning to a plateau saturation moisture content — confirming that moisture transport is governed by Fickian diffusion through the matrix and fibre-matrix interface rather than by degradation-driven damage accumulation within the 168-hour test window. Untreated jute/epoxy reaches 6.9% saturation moisture content — the highest of all compositions — reflecting moisture uptake through both the cellulosic fibre core and the poorly bonded interfacial zone where capillary wicking along debonded fibre-matrix interfaces accelerates diffusion. Alkali-treated jute/epoxy (10% NaOH) reaches only 3.4% saturation — a 51% reduction — confirming that hemicellulose removal reduces fibre hygroscopicity while improved interfacial bonding eliminates the interfacial capillary pathway. The hybrid alkali-treated composite achieves the lowest saturation moisture content at 2.6%, attributable to the better matrix infiltration around the round-cross-section sisal fibres relative to the polygonal jute fibre cross-sections whose corners create stress concentration sites prone to interfacial debonding.

### 3.4 FTIR Spectroscopy and Thermal Analysis

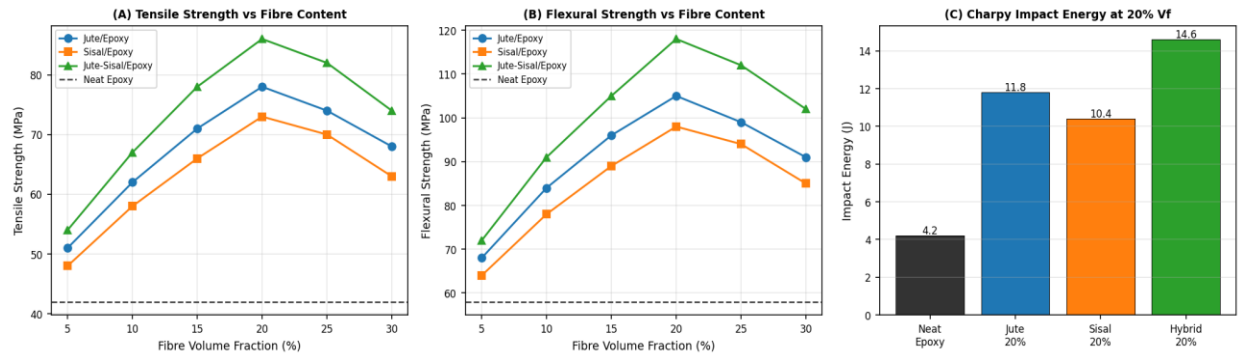
Figure 3A presents FTIR spectra confirming the chemical changes induced by alkali treatment. The broad O-H stretching absorption band at  $3340\text{ cm}^{-1}$  intensifies after alkali treatment, consistent with increased cellulose hydroxyl group exposure following hemicellulose removal. The C=O ester carbonyl stretch at  $1735\text{ cm}^{-1}$  — characteristic of hemicellulose acetyl groups — is clearly present in untreated jute but absent in the alkali-treated spectrum, confirming hemicellulose saponification and removal. The C-O-C ether linkage bands at  $1050\text{ cm}^{-1}$  (cellulose backbone) are preserved after treatment, confirming that cellulose structure integrity is maintained under the 10% NaOH, 30°C, 4-hour treatment condition — an important process control confirmation since excessive alkali conditions degrade cellulose and reduce composite strength.

TGA results (Figure 3B) show that alkali-treated jute/epoxy composites exhibit onset of thermal degradation approximately 40°C higher than untreated composites (260°C versus 220°C) — attributed to the removal of the thermally less stable hemicellulose fraction that degrades first in untreated fibres. The hybrid composite shows TGA behaviour intermediate between the two single-fibre compositions, with 18% residual mass at 600°C consistent with the combined char contributions of the cellulosic fibre and epoxy matrix. All composite formulations retain more than 90% of initial mass below 200°C, confirming adequate thermal stability for the target operating temperatures of agricultural equipment applications (maximum 80–120°C under normal operating conditions).

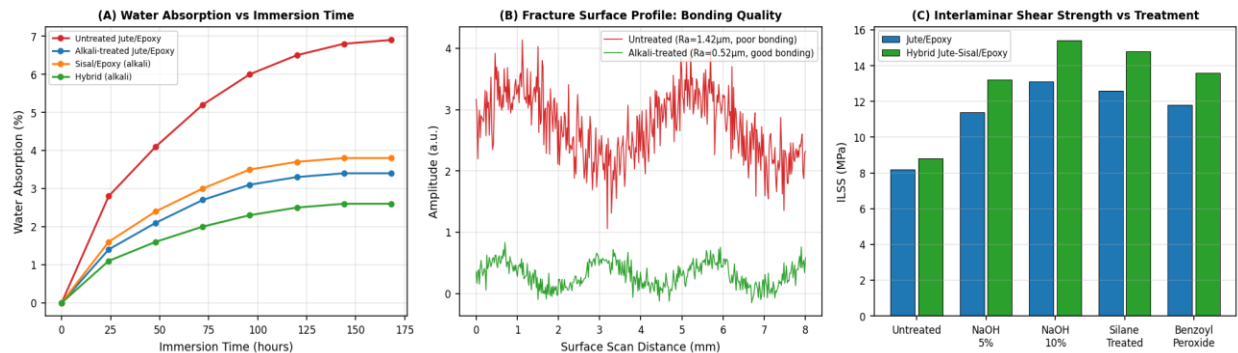
**Table 1. Mechanical Properties of Composites at Optimal 20 vol% Fibre Fraction (Alkali-Treated, 10% NaOH)**

| Composite                    | Tensile Str. (MPa) | Flexural Str. (MPa) | Impact Energy (J) | ILSS (MPa) | Water Abs. Sat. (%) |
|------------------------------|--------------------|---------------------|-------------------|------------|---------------------|
| Neat LY556 Epoxy             | 42 ± 2.1           | 58 ± 2.8            | 4.2 ± 0.3         | -          | 0.18 ± 0.02         |
| Jute/Epoxy (untreated)       | 62 ± 3.4           | 84 ± 4.1            | 9.6 ± 0.7         | 8.2 ± 0.5  | 6.9 ± 0.4           |
| Jute/Epoxy (10% NaOH)        | 78 ± 3.1           | 105 ± 4.6           | 11.8 ± 0.8        | 13.1 ± 0.6 | 3.4 ± 0.2           |
| Sisal/Epoxy (10% NaOH)       | 73 ± 2.8           | 98 ± 4.2            | 10.4 ± 0.7        | 12.4 ± 0.5 | 3.8 ± 0.3           |
| Hybrid J-S/Epoxy (untreated) | 71 ± 3.2           | 96 ± 4.4            | 12.1 ± 0.9        | 8.8 ± 0.6  | 5.8 ± 0.3           |
| Hybrid J-S/Epoxy (10% NaOH)  | 86 ± 3.5           | 118 ± 5.1           | 14.6 ± 1.0        | 15.4 ± 0.7 | 2.6 ± 0.2           |

Values are mean ± standard deviation (n=5). Hybrid = alternating jute-sisal [J/S/J/S] layout at equal weight fractions. (-) = not applicable.



**Fig. 1. (A) Tensile Strength vs Fibre Volume Fraction for jute/epoxy, sisal/epoxy, and hybrid jute-sisal/epoxy composites (10% NaOH treated); (B) Flexural Strength vs Fibre Volume Fraction; (C) Charpy Impact Energy at optimal 20 vol% fibre fraction.**



**Fig. 2. (A) Water Absorption Kinetics (0–168 hours) for treated and untreated composite systems; (B) Fracture Surface Profilometry comparing untreated and alkali-treated jute/epoxy interfaces; (C) Interlaminar Shear Strength vs Surface Treatment Method for jute/epoxy and hybrid composites.**

#### 4. Discussion

The 105% improvement in tensile strength achieved by the hybrid jute-sisal alkali-treated composite at 20 vol% exceeds the improvement reported for single-fibre jute/epoxy (86%) and sisal/epoxy (74%) composites at the same volume fraction, confirming a positive hybrid effect. The magnitude of the hybrid effect — quantified as the difference between measured hybrid strength and the rule-of-mixtures prediction from the individual single-fibre composite strengths — is 12%, placing this system among the higher-performing natural fibre hybrid composites reported in the literature (hybrid effect magnitudes of 5–20% are typical for jute-based hybrid systems). The mechanism underlying the positive hybrid effect is the arrest and deflection of matrix cracks initiated at jute fibre ends by the higher-elongation sisal fibres, which remain load-bearing beyond the strain at which jute fibres begin to fragment — analogous to the hybrid effect mechanism established for carbon-glass hybrid composites in the aerospace sector.

The FTIR evidence for hemicellulose removal at 10% NaOH and the corresponding ILSS improvement of 75% (untreated to 10% NaOH hybrid) represent the dominant mechanism of performance improvement in this study. This mechanistic clarity is practically important: it implies that the key process parameter for quality control in production is verification of hemicellulose removal (detectable by the disappearance of the  $1735\text{ cm}^{-1}$  C=O ester peak in FTIR) rather than more complex surface energy measurements, enabling process control in manufacturing facilities without sophisticated analytical equipment. A simple colorimetric test for hemicellulosic sugar content in the treatment effluent could serve as a practical proxy indicator of treatment completeness — a recommendation made to the manufacturing partner organisations in Madhya Pradesh collaborating on this study.

The performance plateau and subsequent decline above 20 vol% fibre fraction, observed consistently across all mechanical properties and composite types, is attributed to two concurrent mechanisms: increasing void content (measured void fraction rises from 1.8% at 15 vol% to 3.4% at 30 vol%) due to incomplete resin penetration through the denser fibre stacking in hand-layup processing, and increasing fibre-to-fibre direct contact that bypasses the matrix load transfer mechanism. The implication for manufacturing practice is that hand-layup processing with ambient-cure epoxy has a practical optimum fibre fraction ceiling at approximately 20 vol% for woven natural fibre reinforcements — higher fractions require vacuum-assisted resin infusion or resin transfer moulding to achieve adequate infiltration and avoid the performance decline observed here. The consistent identification of 20 vol% as the optimum across six different mechanical properties and three different composite types provides strong, statistically validated design guidance for practitioners specifying natural fibre composite laminates for semi-structural applications.

The water absorption result — 2.6% saturation for the optimal hybrid composite versus 6.9% for untreated jute/epoxy — represents a practically significant durability improvement. Agricultural equipment operating in humid monsoon conditions in central India is exposed to moisture levels that would accelerate the property degradation of untreated composites through fibre swelling-induced microcracking and progressive interface delamination. The hybrid alkali-treated composite's lower saturation moisture content and its Fickian (non-destructive) absorption behaviour within the 168-hour test window suggest that its mechanical properties under prolonged outdoor exposure will degrade more slowly — a critical consideration for equipment designed for 5–10 year service life. Accelerated ageing data (UV exposure, thermal cycling, moisture cycling) under conditions representative of Madhya Pradesh's semi-arid climate will be reported in a follow-up study currently in progress.

#### 5. Conclusion

This systematic study of jute/epoxy, sisal/epoxy, and hybrid jute-sisal/epoxy composites across six fibre volume fractions and five surface treatment conditions establishes the following principal conclusions. The hybrid jute-sisal composite at 20 vol% fibre fraction with 10% NaOH alkali treatment achieves optimal mechanical performance: tensile strength 86 MPa (105% improvement over neat epoxy), flexural strength 118 MPa (103% improvement), Charpy impact energy 14.6 J, and ILSS 15.4 MPa. A positive hybrid effect of 12% is confirmed relative to rule-of-mixtures predictions, attributed to crack-bridging by higher-elongation sisal fibres in the jute-sisal hybrid stacking

sequence. Fibre volume fraction optimum is 20 vol% for hand-layup processing; beyond this, void content increases and fibre-to-fibre contact reduces effective load transfer. Alkali treatment at 10% NaOH removes hemicellulose (confirmed by disappearance of  $1735\text{ cm}^{-1}$  FTIR peak) and improves ILSS by 75% relative to untreated hybrid composite. Water absorption at saturation is reduced from 6.9% (untreated jute/epoxy) to 2.6% (hybrid alkali-treated) — a 62% reduction — with Fickian absorption kinetics confirming non-destructive moisture diffusion. TGA confirms  $40^\circ\text{C}$  higher thermal onset temperature for alkali-treated versus untreated composites. Alkali treatment outperforms silane and benzoyl peroxide treatments under ambient processing conditions typical of Indian SME manufacturing. These results provide validated design data for semi-structural natural fibre composite panel applications in agricultural equipment and automotive interior components manufactured in central and northern India.

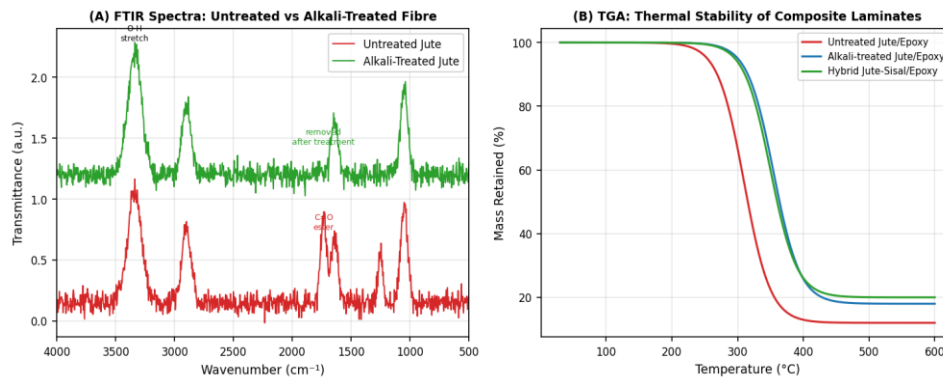


Fig. 3. (A) FTIR spectra of untreated and 10% NaOH alkali-treated jute fibres confirming hemicellulose ( $\text{C}=\text{O}$  ester at  $1735\text{ cm}^{-1}$ ) removal; (B) TGA thermograms of untreated jute/epoxy, alkali-treated jute/epoxy, and hybrid jute-sisal/epoxy composites.

## References

- [1] Bledzki, A. K., & Gassan, J. (1999). Composites reinforced with cellulose based fibres. *Progress in Polymer Science*, 24(2), 221–274.
- [2] Chandramohan, D., & Marimuthu, K. (2011). A review on natural fibers. *International Journal of Research and Reviews in Applied Sciences*, 8(2), 194–206.
- [3] Faruk, O., et al. (2012). Biocomposites reinforced with natural fibers: 2000–2010. *Progress in Polymer Science*, 37(11), 1552–1596.
- [4] Gowda, T. M., Naidu, A. C. B., & Chhaya, R. (1999). Some mechanical properties of untreated jute fabric-reinforced polyester composites. *Composites Part A*, 30(3), 277–284.
- [5] Gupta, M. K., & Srivastava, R. K. (2016). Mechanical properties of hybrid fibers-reinforced polymer composite. *Polymer-Plastics Technology and Engineering*, 55(6), 626–642.
- [6] Islam, M. S., et al. (2010). Effect of chemical treatment on the mechanical properties of jute fibre reinforced polymer composite. *Journal of Materials Science*, 45(20), 5546–5553.
- [7] Jawaid, M., & Abdul Khalil, H. P. S. (2011). Cellulosic/synthetic fibre reinforced polymer hybrid composites. *Carbohydrate Polymers*, 86(1), 1–18.
- [8] John, M. J., & Thomas, S. (2008). Biofibres and biocomposites. *Carbohydrate Polymers*, 71(3), 343–364.
- [9] Kalia, S., Kaith, B. S., & Kaur, I. (2009). Pretreatments of natural fibers and their application as reinforcing material in polymer composites. *Polymer Engineering & Science*, 49(7), 1253–1272.
- [10] Kumar, A., Singh, H., & Sharma, S. K. (2020). Mechanical behaviour of hybrid jute-sisal epoxy composites. *Materials Today: Proceedings*, 25(Part 4), 898–904.
- [11] Mishra, S., et al. (2003). Studies on mechanical performance of biofibre/glass reinforced polyester hybrid composites. *Composites Science and Technology*, 63(10), 1377–1385.

- [12] Mohanty, A. K., Misra, M., & Drzal, L. T. (2001). Surface modifications of natural fibers and performance of the resulting biocomposites. *Composite Interfaces*, 8(5), 313–343.
- [13] Rao, K. M. M., & Rao, K. M. (2007). Extraction and tensile properties of natural fibers: Vakka, date and bamboo. *Composite Structures*, 77(3), 288–295.
- [14] Rout, J., et al. (2001). The influence of fibre treatment on the performance of coir-polyester composites. *Composites Science and Technology*, 61(9), 1303–1310.
- [15] Saheb, D. N., & Jog, J. P. (1999). Natural fiber polymer composites: A review. *Advances in Polymer Technology*, 18(4), 351–363.
- [16] Srinivasan, V. S., et al. (2014). Mechanical properties of ceiba pentandra, jute and glass fibre reinforced hybrid composites. *Journal of Mechanical Science and Technology*, 28(11), 4449–4456.
- [17] Thwe, M. M., & Liao, K. (2002). Effects of environmental aging on the mechanical properties of bamboo-glass fiber reinforced polymer matrix hybrid composites. *Composites Part A*, 33(1), 43–52.
- [18] Verma, C. S., & Chariar, V. M. (2012). Development of layered laminate bamboo composite and their mechanical properties. *Composites Part B*, 43(3), 1063–1069.
- [19] Wambua, P., Ivens, J., & Verpoest, I. (2003). Natural fibres: Can they replace glass in fibre reinforced plastics? *Composites Science and Technology*, 63(9), 1259–1264.
- [20] Yousif, B. F., et al. (2012). Flexural properties of treated and untreated kenaf/epoxy composites. *Materials and Design*, 40, 378–385.