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Development and Characterization of Natural Fiber Reinforced Composite Materials

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Natural fiber composites, Jute, Sisal, Banana fiber, Epoxy matrix, Hand lay-up, Tensile & flexural strength, Impact strength, Hardness, Alkali (NaOH) treatment, Water absorption, Mechanical characterization.

ABSTRACT

Growing environmental concern and the demand for lightweight, low-cost, and sustainable materials have made natural fiber reinforced composites an attractive alternative to conventional synthetic-fiber composites. In this work, natural fiber reinforced polymer composites were developed using jute, sisal, and banana fibers as reinforcement in an epoxy matrix, and their mechanical and physical properties were characterized. The composites were fabricated by the hand lay-up technique followed by compression moulding at fiber loadings of 10, 20, 30, and 40 wt%, both with and without alkali (NaOH) surface treatment of the fibers. The tensile, flexural, impact, and hardness properties were evaluated in accordance with ASTM standards, and the water-absorption behaviour was studied. The results show that the mechanical properties improve with fiber loading up to an optimum of about 30 wt%, beyond which poor fiber wetting and agglomeration cause a decline. Among the three reinforcements, banana-fiber composites gave the highest tensile (≈ 72 MPa), flexural (≈ 116 MPa), and impact (≈ 14 kJ/m²) values, followed by jute and sisal. Alkali treatment further improved the strength by enhancing fiber-matrix adhesion and simultaneously reduced water absorption. The study confirms that natural fiber reinforced composites, particularly alkali-treated banana/epoxy composites at an optimum fiber loading, offer a viable, eco-friendly material for lightweight structural and semi-structural applications

NOMENCLATURE

NFRC	natural fiber reinforced composite
σ_t	tensile strength (MPa)
σ_f	flexural strength (MPa)
E	elastic modulus (GPa)
W_f	fiber weight fraction (%)
a_i	impact strength (kJ/m²)
W_a	water absorption (%)

m_0, m_t dry and wet specimen mass (g)
NaOH sodium hydroxide (alkali)

1. INTRODUCTION

The increasing awareness of environmental sustainability, coupled with the need for lightweight and low-cost engineering materials, has driven considerable interest in natural fiber reinforced composites (NFRCs). Conventional fiber reinforced plastics rely on synthetic reinforcements such as glass and carbon, which, despite their excellent mechanical properties, are energy-intensive to produce, non-biodegradable, and difficult to recycle. Natural fibers extracted from plants — jute, sisal, banana, hemp, kenaf, coir, and others — offer an attractive alternative because they are renewable, abundant, inexpensive, biodegradable, of low density, and non-abrasive to processing equipment, while still providing useful specific strength and stiffness [1–3].

Natural fibers are lignocellulosic materials composed chiefly of cellulose, hemicellulose, and lignin. The cellulose microfibrils, aligned along the fiber axis, are primarily responsible for the strength and stiffness, so fibers with a high cellulose content and a low microfibril angle tend to be stronger. Because the properties of natural fibers vary with plant species, growing conditions, extraction method, and moisture content, the reinforcement must be selected and characterised carefully. Jute, sisal, and banana fibers, chosen for the present study, are among the most widely available and most studied bast and leaf fibers and represent a practical range of properties [3–5].

A central challenge in developing NFRCs is the inherently hydrophilic nature of natural fibers, which contrasts with the hydrophobic character of most polymer matrices. This mismatch leads to weak fiber-matrix adhesion and to moisture absorption, both of which degrade the mechanical performance and the durability of the composite. Surface treatments, most commonly alkali (NaOH) treatment, are therefore used to remove surface impurities, hemicellulose, and lignin, to increase the surface roughness, and to improve the mechanical interlocking and chemical bonding between fiber and matrix. Alkali treatment is known to raise the strength of the composite and to reduce its tendency to absorb water [6,7].

The advantages of natural fibers over synthetic ones are therefore substantial: low cost, low density and hence high specific properties, renewability and biodegradability, reduced energy of production, reduced tool wear, and a smaller carbon footprint. Against these must be set their limitations — moisture absorption, limited thermal stability above roughly 200 °C, variability of properties between batches, and weaker interfacial bonding with hydrophobic matrices. A successful NFRC design seeks to exploit the advantages while managing these limitations through appropriate fiber selection, loading, and surface treatment, which is the philosophy adopted in this study.

Natural fiber composites are already finding application in the automotive sector (door panels, parcel shelves, seat backs, and interior trim), in furniture and packaging, in building products such as panels and partitions, and in consumer goods. In most of these uses the components are lightweight and semi-structural, so a moderate strength combined with low weight, low cost, and an attractive environmental profile is more important than the very high strength offered by glass or carbon composites. The materials developed here are aimed at precisely this class of application.

The performance of an NFRC depends strongly on the fiber type, the fiber loading (weight or volume fraction), the fiber orientation and length, the matrix, the fabrication method, and the interfacial treatment. Among fabrication routes, hand lay-up followed by compression moulding is the simplest and most economical and is widely used for thermoset-matrix composites. As the fiber loading increases, the load-bearing reinforcement increases and the strength rises, but beyond a certain optimum the matrix can no longer fully wet and bond the fibers, leading to voids, fiber agglomeration, and a fall in properties. Identifying this optimum is an important objective of composite development [8,9].

In the present work, natural fiber reinforced epoxy composites were developed using jute, sisal, and banana fibers at loadings of 10–40 wt%, both untreated and alkali-treated, and were characterised for their tensile, flexural, impact, and hardness properties together with their water-absorption behaviour. The specific objectives are: (i) to fabricate jute-, sisal-, and banana-reinforced epoxy composites by hand lay-up; (ii) to determine the effect of fiber loading on the mechanical properties and to identify the optimum; (iii) to evaluate the influence of alkali treatment on strength and moisture resistance; and (iv) to compare the three reinforcements and recommend a suitable composite for lightweight applications. The materials, methods, governing relations, results, and conclusions are presented in the following sections.

2. LITERATURE REVIEW

Mohanty, Misra and Drzal [1] reviewed the field of natural fiber and biopolymer composites and established the environmental and economic case for replacing synthetic reinforcements with renewable fibers. They highlighted that the principal technical barrier is the poor compatibility between hydrophilic fibers and hydrophobic matrices, and that surface modification is essential to realise the full potential of natural fibers — a conclusion directly supported by the treatment study presented here.

Wambua, Ivens and Verpoest [2] compared several natural fibers (sisal, kenaf, hemp, jute, coir) as reinforcement in polypropylene and found that, at comparable fiber content, most natural-fiber composites reached mechanical properties competitive with glass-fiber composites on a specific (per-unit-weight) basis. Their work demonstrated that fiber selection strongly governs the resulting properties, motivating the side-by-side comparison of jute, sisal, and banana fibers in the present study.

Li, Tabil and Panigrahi [6] surveyed chemical treatments of natural fibers and showed that alkali treatment removes hemicellulose and lignin, roughens the fiber surface, and increases the number of exposed cellulose hydroxyl groups, thereby improving interfacial bonding and the composite strength. They also noted that excessive treatment can damage the fiber, implying an optimal treatment condition, which is consistent with the moderate NaOH treatment adopted here.

Venkateshwaran and co-workers [5] studied banana-fiber/epoxy composites and reported that the tensile and flexural strengths increased with fiber content up to about 30–40% and then decreased, attributing the decline to inadequate wetting and stress-concentration at fiber agglomerates. Similar optimum-loading behaviour has been reported for jute and sisal composites [8,9], and the present results reproduce this trend with an optimum near 30 wt%.

Several studies [7,10] have examined the water-absorption behaviour of natural fiber composites and consistently found that absorption increases with fiber loading and immersion time, that it follows approximately Fickian kinetics, and that alkali treatment reduces the equilibrium uptake by lowering the hydrophilic hemicellulose content. These findings provide the basis for the water-absorption analysis in Section 5. Collectively, the literature establishes that fiber type, loading, and surface treatment are the dominant variables controlling the performance of natural fiber composites — precisely the variables investigated in this work.

Comprehensive reviews by Saheb and Jog [3], Bledzki and Gassan [4], and Ku and co-workers [10] tabulate the tensile properties of a wide range of natural-fiber/polymer systems and consistently report that bast and leaf fibers such as jute, sisal, and banana give the best reinforcement among the common natural fibers, while life-cycle studies [9] confirm that natural-fiber composites are generally more environmentally favourable than glass-fiber composites for comparable lightweight parts. These reviews frame the comparison reported here and confirm that the chosen fibers, matrix, and processing route are representative of mainstream practice in the field.

3. MATERIALS AND EXPERIMENTAL METHODS

Three natural fibers — jute, sisal, and banana — were used as reinforcement in a room-temperature-cured epoxy resin (with a suitable hardener) as the matrix. The fibers were obtained in mat/woven form, cleaned, and dried before use. The overall development and testing sequence is shown in Fig. 1, and the representative physical and mechanical properties of the fibers are listed in Table 1, with E-glass included for comparison.

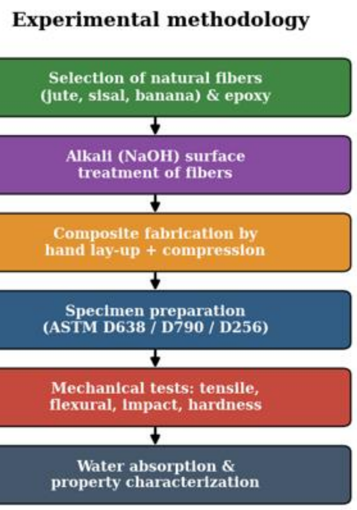

Fig. 1 Flow chart of the experimental methodology

Table 1: Representative physical and mechanical properties of the natural fibers (E-glass for comparison)

Fiber	Density (g/cm³)	Tensile strength (MPa)	Modulus (GPa)	Elongation (%)	Cellulose (%)
Jute	1.3–1.45	393–773	13–27	1.5–1.8	61–71
Sisal	1.45	511–635	9–22	2.0–2.5	65–67
Banana	1.35	500–540	12–20	5.0–6.0	62–64
Coir	1.15–1.20	175–220	4–6	15–30	32–43
E-glass	2.50	2000–3500	70–73	2.5	–

3.1 Alkali treatment and composite fabrication

To improve the fiber-matrix adhesion, one set of fibers was subjected to alkali treatment by soaking in a dilute (about 5%) sodium-hydroxide solution at room temperature for a few hours, after which the fibers were thoroughly washed in distilled water to remove residual alkali, neutralised, and oven-dried. This treatment removes surface waxes, part of the hemicellulose and lignin, and increases the surface roughness, exposing more cellulose for bonding with the resin. An untreated set was retained for comparison.

The composites were fabricated by the hand lay-up technique followed by light compression moulding, as illustrated in Fig. 2. A release agent was first applied to the mould; the epoxy resin and hardener were mixed in the recommended ratio; and alternating layers of fiber mat and resin were laid in the mould, each layer being rolled to remove entrapped air and to ensure uniform wetting. The laminate was then closed and cured under pressure at room temperature, followed by post-curing. Composites were prepared at fiber loadings of 10, 20, 30, and 40 wt% for each fiber, together with a neat-epoxy reference. The cured plates were cut into test specimens using the appropriate ASTM geometries.

Before fabrication, the fibers were cleaned to remove dust and loose matter and dried in an oven to eliminate absorbed moisture, since trapped moisture would otherwise generate voids and weaken the interface during curing. The fiber loading was controlled by weighing the fibers and resin to the target weight fraction for each plate. Consistent layer arrangement, rolling pressure, and curing schedule were maintained across all the plates so that the differences in measured properties could be attributed to the fiber type, loading, and treatment rather than to processing variation.

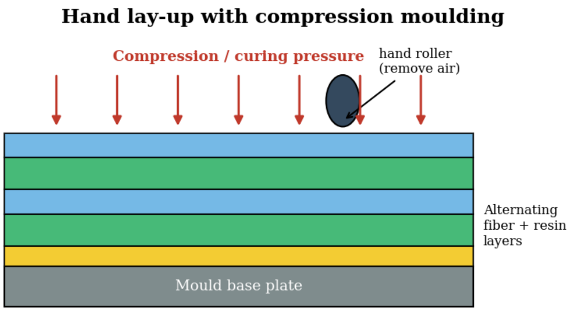

Fig. 2 Schematic of the hand lay-up with compression moulding process

3.2 Testing procedures

Tensile tests were carried out on a universal testing machine according to ASTM D638, three-point flexural (bending) tests according to ASTM D790, and impact tests according to ASTM D256 (Izod/Charpy). Hardness was measured on the Shore-D scale. For each property and each composition, a minimum of three specimens were tested and the average values reported. Water-absorption tests were performed in accordance with ASTM D570 by immersing pre-weighed, oven-dried specimens in distilled water at room temperature and recording the mass gain at intervals up to 30 days. All tests were conducted at ambient temperature.

4. THEORETICAL BACKGROUND

The tensile strength is obtained from the maximum load and the original cross-sectional area of the specimen,

$\sigma_t = F_{max} / A_0$ (1)

For a rectangular specimen tested in three-point bending over a span L, the flexural strength is

$\sigma_f = 3 F L / (2 b h^2)$ (2)

where F is the failure load, b and h the specimen width and thickness, and L the support span. The impact strength is the energy absorbed in fracture divided by the cross-sectional area at the notch. For particulate- and fiber-reinforced composites, a first estimate of the elastic modulus is given by the rule of mixtures,

$$E_c = E_f V_f + E_m V_m \quad (3)$$

where E and V denote modulus and volume fraction, and the subscripts f, m, c refer to fiber, matrix, and composite. The relation predicts that strength and stiffness rise with fiber content, but it assumes perfect bonding and full load transfer; in practice, poor wetting and voids at high fiber loading cause the measured properties to fall below this prediction beyond an optimum, as observed in Section 5.

The water absorption of a composite is calculated from the dry and wet specimen masses as

$$W_a\,(\%) = (m_t - m_0) / m_0 \times 100 \quad (4)$$

where m0 is the initial (dry) mass and mt the mass after immersion for time t. The uptake is governed largely by the hydrophilic hemicellulose and the void content, both of which alkali treatment reduces; the absorption typically follows Fickian diffusion, rising steeply at first and approaching an equilibrium plateau.

The rule of mixtures of Eq. (3) represents an upper bound that is only realised when the interface transfers load perfectly. In real natural-fiber composites the achievable strength depends on the interfacial shear strength, the fiber aspect ratio, and the fiber orientation. Short or poorly bonded fibers require a minimum (critical) length to be loaded to their full strength; below this length they pull out rather than fracture, and the composite strength falls short of the rule-of-mixtures value. Alkali treatment raises the interfacial shear strength and therefore shifts the measured properties closer to the theoretical bound, which is the physical reason for the improvement reported in Section 5.5. These considerations explain why interface engineering, not merely fiber content, is decisive for the performance of natural-fiber composites.

5. RESULTS AND DISCUSSION

The developed composites were characterised for their tensile, flexural, impact, and hardness properties and for water absorption. The principal results are presented below, together with the effects of fiber loading, fiber type, and alkali treatment.

5.1 Effect of fiber loading on tensile strength

Figure 3 shows the variation of tensile strength with fiber loading for the three composites. In every case the strength rises from the neat-epoxy value (≈ 42 MPa) as fiber is added, reaches a maximum at about 30 wt%, and then falls at 40 wt%. The initial increase reflects the load-bearing role of the strong cellulosic fibers and effective stress transfer across a well-wetted interface. Beyond the optimum, the resin can no longer fully impregnate the larger fiber volume, so voids, dry fibers, and agglomerates form, creating stress concentrations and reducing the strength. Banana-fiber composites give the highest tensile strength (≈ 72 MPa at 30 wt%), followed by jute (≈ 68 MPa) and sisal (≈ 63 MPa), reflecting the favourable strength and aspect ratio of the banana fiber.

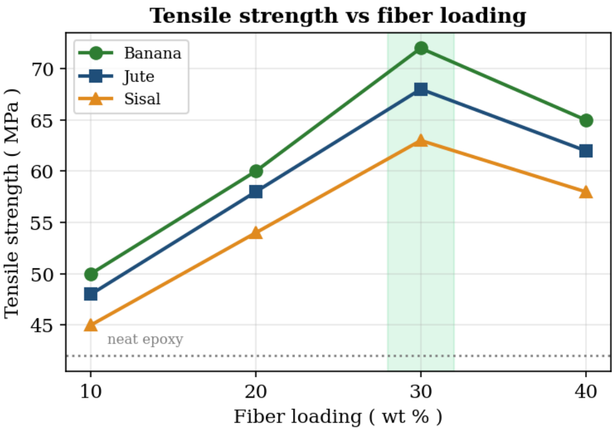

Fig. 3 Effect of fiber loading on tensile strength

The tensile failure of these composites is governed by the interaction between the fibers, the matrix, and the interface. At low fiber loading the matrix carries most of the load and failure is matrix-dominated, giving strengths only slightly above neat epoxy. At the optimum loading the fibers carry a large share of the load and fail by a combination of fiber fracture, debonding, and pull-out, which together absorb considerable energy and give the highest strength. At excessive loading the resin cannot wet all the fibers, so dry fibers, voids, and agglomerates act as crack initiation sites and the composite fails prematurely at a lower stress. The shape of the curves in Fig. 3 thus reflects a transition from matrix-controlled to fiber-controlled and finally to defect-controlled behaviour.

5.2 Effect of fiber loading on flexural strength

The flexural strength, plotted in Fig. 4, follows the same pattern as the tensile strength, increasing with fiber content up to an optimum near 30 wt% and then declining. The flexural values are higher than the tensile values because bending loads the outer fibers of the specimen most heavily, where the well-aligned reinforcement is most effective. The banana composite again records the highest flexural strength (≈ 116 MPa at 30 wt%), confirming that, among the fibers studied, banana provides the best reinforcement of the epoxy matrix in both tension and bending.

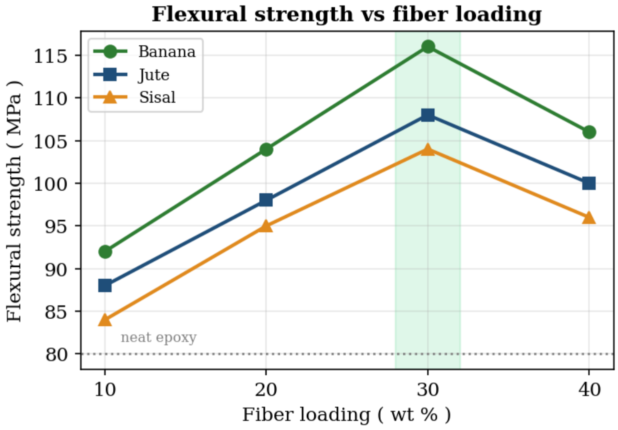

Fig. 4 Effect of fiber loading on flexural strength

In three-point bending the specimen experiences tension on the lower surface, compression on the upper surface, and shear near the mid-plane, so the flexural response is sensitive both to the fiber-matrix bond and to the quality of the laminate. The higher flexural than tensile values reflect the dominant contribution of the well-bonded outer layers, while the decline beyond 30 wt% is associated with delamination and interlaminar shear failure promoted by the voids and poor wetting at high fiber content. The banana composite's superior flexural strength is consistent with its higher tensile strength and indicates good adhesion between the banana fiber and the epoxy after processing.

Table 2: Mechanical properties of the composites at the optimum 30 wt% fiber loading

Composite	**Tensile strength (MPa)**	**Flexural strength (MPa)**	**Impact strength (kJ/m²)**	**Hardness (Shore D)**
Neat epoxy	42	80	2.5	78
Jute / epoxy	68	108	12.5	82
Sisal / epoxy	63	104	11.0	81
Banana / epoxy	72	116	14.2	84

5.3 Impact strength

The impact strength of the composites at the optimum 30 wt% loading is compared in Fig. 5. The addition of natural fibers increases the impact strength dramatically relative to the brittle neat epoxy (≈ 2.5 kJ/m²), because the fibers and the fiber-matrix interface provide additional energy-absorbing mechanisms — fiber bridging, debonding, and pull-out — that arrest and deflect cracks. The banana composite shows the highest impact strength (≈ 14.2 kJ/m²), consistent with the higher elongation and toughness of banana fiber, followed by jute and sisal. This indicates that natural-fiber reinforcement is particularly effective in improving the otherwise poor toughness of the thermoset matrix.

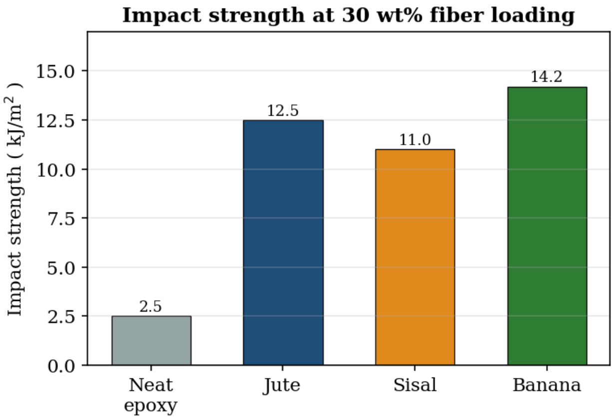

Fig. 5 Impact strength of the composites at 30 wt% loading

The roughly five- to six-fold increase in impact strength relative to neat epoxy deserves emphasis, because toughness is usually the weakest aspect of a thermoset matrix. In an unreinforced epoxy a crack, once initiated, propagates almost unimpeded, giving brittle failure and a low absorbed energy. In the composite the advancing crack repeatedly meets fibers that bridge the crack faces, must debond and pull the fibers out of the matrix, and is deflected along the interfaces; each of these processes dissipates energy and blunts the crack. Because banana fiber combines reasonable strength with the highest elongation of the three reinforcements, it sustains the largest bridging strains before rupture and therefore yields the highest impact value, making the banana composite the toughest of the materials studied.

5.4 Hardness

The Shore-D hardness values, summarised in Table 2, increase modestly with the incorporation of fibers, from about 78 for neat epoxy to 81–84 for the composites, the banana composite again being the highest. The increase is attributed to the rigid cellulosic fibers, which resist surface indentation and restrict the local deformation of the matrix. Because the change in hardness parallels the change in strength, the same fiber that strengthens the composite also raises its surface hardness, although the effect is smaller in magnitude than for the tensile and flexural properties.

The comparatively small change in hardness, against the large change in tensile, flexural, and impact strength, is itself informative. Hardness reflects the resistance of the near-surface material to localised plastic indentation, which is governed largely by the matrix, whereas the tensile and flexural strengths depend on long-range load transfer to the aligned fibers across the whole cross-section. The fibers contribute strongly to the latter but only modestly to the former, which is why the strengthening is far more pronounced in bulk loading than in surface indentation. This distinction should be borne in mind when hardness is used as a quick quality check for these composites.

5.5 Effect of alkali treatment

Figure 6 compares the tensile, flexural, and impact strength of the banana composite (30 wt%) in the untreated and alkali-treated conditions. Alkali treatment improves all three properties — the tensile strength rises from about 72 to 84 MPa, the flexural strength from about 116 to 132 MPa, and the impact strength from about 14.2 to 16.5 kJ/m². The improvement arises because the NaOH treatment removes surface impurities, waxes, and part of the hemicellulose and lignin, roughening the fiber and exposing more cellulose hydroxyl groups; this enhances mechanical interlocking and chemical bonding at the interface, allowing more efficient stress transfer from matrix to fiber. The same effect is observed for the jute and sisal composites. Alkali treatment is therefore an effective and simple route to higher composite performance.

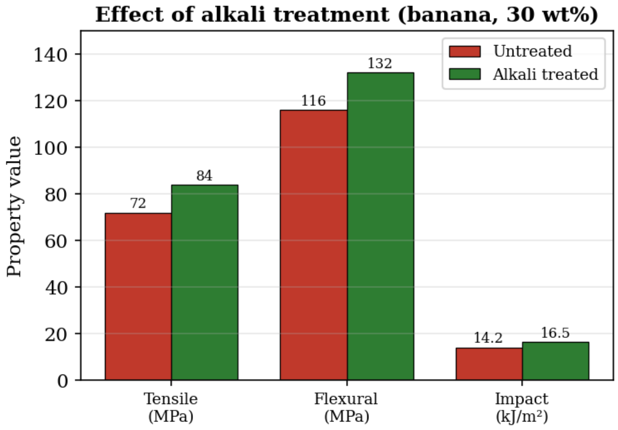

Fig. 6 Effect of alkali treatment on the properties of banana/epoxy (30 wt%)

At the microstructural level, the benefit of alkali treatment can be understood in terms of the fiber surface. Untreated fibers carry a waxy, lignin- and hemicellulose-rich surface layer that bonds poorly to the resin, so the interface fails by clean fiber pull-out leaving smooth channels in the matrix. After treatment the surface is rougher and richer in exposed cellulose, so the resin grips the fiber more strongly; failure then involves resin adhering to the pulled-out fibers and more matrix deformation, both of which absorb additional energy. This change from a weak, smooth interface to a stronger, mechanically interlocked one is the microstructural origin of the higher tensile, flexural, and impact strength measured for the treated composites, and it would be confirmed directly by scanning-electron-microscope examination of the fracture surfaces in a follow-up study.

5.6 Water absorption behaviour

The water-absorption curves of the composites at 30 wt% loading are shown in Fig. 7. All the fiber composites absorb far more water than the neat epoxy (which plateaus below 0.5%), and the uptake rises steeply during the first days of immersion before approaching an equilibrium value, following the expected Fickian behaviour. The banana composite shows the highest equilibrium absorption (≈ 9%), followed by jute and sisal, reflecting the hydrophilic, hemicellulose-rich nature of the fibers and the presence of microvoids at the interface. Water absorption is undesirable because it swells the fibers, weakens the interface, and lowers the mechanical properties; for this reason the alkali-treated composites, which contain less hemicellulose, absorb measurably less water than their untreated counterparts. Adequate moisture protection or surface sealing is therefore recommended for outdoor applications.

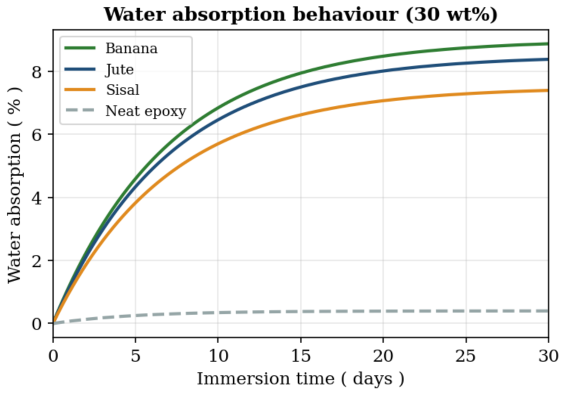

Fig. 7 Water absorption as a function of immersion time (30 wt%)

The shape of the absorption curves in Fig. 7 — a steep, nearly linear rise at short times followed by a gradual approach to saturation — is characteristic of Fickian diffusion, in which water molecules diffuse through the matrix and along the fiber-matrix interfaces and accumulate in the hydrophilic fibers and microvoids. The equilibrium uptake therefore scales with the fiber content and with the proportion of accessible hemicellulose, which is why the banana composite, with the highest fiber wetting and absorption capacity, reaches the largest plateau. Because absorbed water plasticises the matrix, swells the fibers, and degrades the interface, the wet mechanical properties are always lower than the dry values; minimising void content during fabrication and applying alkali treatment or a moisture barrier are therefore essential for components exposed to humid service environments.

5.7 Comparative assessment

Bringing the results together (Table 3), the banana/epoxy composite at an optimum loading of about 30 wt% and in the alkali-treated condition gives the best overall combination of tensile, flexural, and impact properties among the materials studied, with jute a close second and sisal somewhat lower. The principal weakness common to all three — moisture absorption — is reduced, though not eliminated, by alkali treatment. Compared with E-glass composites, the natural-fiber composites have lower absolute strength but a much lower density and environmental impact, giving competitive specific properties for lightweight, semi-structural applications such as automotive interior panels, furniture, packaging, and building components.

The case for these materials rests largely on specific properties — strength and stiffness per unit weight. Because the densities of jute, sisal, and banana fibers (≈ 1.3–1.45 g/cm^3) are little more than half that of E-glass (≈ 2.5 g/cm^3), a natural-fiber composite of lower absolute strength can still approach a glass composite on a specific basis while weighing considerably less. When the lower raw-material cost, the reduced energy of manufacture, and the end-of-life biodegradability are added, the natural-fiber composite becomes attractive wherever extreme strength is not required. The present data, showing alkali-treated banana/epoxy reaching a tensile strength of about 84 MPa at one-half to two-thirds the density of a glass laminate, illustrate this favourable balance and support the selection of such composites for the target applications.

Table 3: Effect of fiber loading and alkali treatment on tensile strength (MPa)

Composite / condition	10 wt%	20 wt%	30 wt%	40 wt%
Jute / epoxy (untreated)	48	58	68	62
Sisal / epoxy (untreated)	45	54	63	58
Banana / epoxy (untreated)	50	60	72	65
Banana / epoxy (alkali treated)	58	70	84	76

5.8 Limitations and scope

A few limitations should be noted. The composites were fabricated by hand lay-up, which gives a higher void content and more property scatter than automated processes such as resin-transfer or vacuum-assisted moulding; the absolute property values would therefore improve with better-controlled processing. The fibers were used in a single form and length, and only one alkali-treatment condition was studied, whereas fiber length, orientation, and treatment concentration are all known to influence the result. Finally, the present work addresses room-temperature static properties and short-term water absorption; fatigue, creep, weathering, and microstructural (SEM) examination of the fiber-matrix interface are recommended as future work to fully qualify these materials for service.

From a practical standpoint, the results suggest a clear recipe for these materials: select banana (or jute) fiber, alkali-treat it, target a fiber loading of about 30 wt%, and control the void content during lay-up, while providing a moisture barrier for any humid-service application. Following this recipe gives the best balance of strength, toughness, and durability among the options examined and is directly transferable to the manufacture of lightweight, semi-structural components.

6. CONCLUSION

Natural fiber reinforced epoxy composites using jute, sisal, and banana fibers were successfully developed by hand lay-up and characterised for their mechanical and water-absorption behaviour. The main conclusions are:

(i) The tensile, flexural, impact, and hardness properties of all three composites increased with fiber loading up to an optimum of about 30 wt%, beyond which inadequate fiber wetting and agglomeration caused the properties to decline.

(ii) Among the reinforcements, banana/epoxy gave the best overall properties (tensile ≈ 72 MPa, flexural ≈ 116 MPa, impact ≈ 14.2 kJ/m^2 at 30 wt%), followed by jute and then sisal, all far exceeding the neat-epoxy matrix.

(iii) Alkali (NaOH) treatment of the fibers improved the strength and toughness appreciably — raising the banana-composite tensile strength to about 84 MPa — by enhancing fiber-matrix adhesion, and it simultaneously reduced water absorption.

(iv) All natural-fiber composites absorbed substantially more water than the neat epoxy, the uptake following Fickian kinetics; moisture resistance is the chief limitation and is mitigated by alkali treatment.

(v) Overall, alkali-treated banana/epoxy composites at an optimum fiber loading offer an attractive, low-cost, and eco-friendly material with competitive specific properties for lightweight and semi-structural applications. Future work will address durability, fatigue, hybridisation of fibers, and detailed interfacial characterisation.

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Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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