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# Eco-Friendly Polymer Composites Using Chemically Modified Natural Fibers

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**Abstract: The increasing awareness of environmental protection and sustainability has led to the development of natural fiber-reinforced polymer composites as alternatives to conventional synthetic materials. These composites offer renewability, biodegradability, and cost-effectiveness. However, poor fiber–matrix adhesion limits their mechanical performance. This study focuses on developing eco-friendly polymer composites reinforced with chemically modified natural fibers such as jute, sisal, and banana. Alkali and silane treatments were used to enhance fiber surface characteristics. Mechanical, thermal, and morphological analyses revealed that chemical modification significantly improves tensile and flexural properties, thermal stability, and water resistance. The results demonstrate the potential of these composites in sustainable engineering applications such as automotive, packaging, and construction industries.**

***Keywords:*** *Natural Fibers, Polymer Composites, Chemical Modification, Eco-Friendly Materials, Fiber–Matrix Interface, Sustainability*

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## I. INTRODUCTION

The rapid growth of industries relying on composite materials has prompted significant research into sustainable alternatives that reduce environmental impact. Synthetic fibers such as glass, carbon, and aramid dominate the composite market due to their superior strength and stiffness. However, their production consumes large amounts of energy and relies heavily on non-renewable resources, leading to issues of recyclability and waste management.[1-4]

Natural fibers derived from plants such as jute, sisal, flax, banana, and coir are gaining attention as replacements for synthetic reinforcements. They are abundant, lightweight, renewable, biodegradable, and cost-effective. Their low density also contributes to a high specific strength-to-weight ratio, which is desirable in automotive and structural applications.[5-9]

Despite these advantages, the hydrophilic nature of natural fibers results in poor interfacial adhesion with nonpolar polymer matrices such as polypropylene (PP) or polylactic acid (PLA). This leads to reduced load transfer efficiency and degraded mechanical performance. To overcome this, chemical surface modification techniques such as alkali, silane, acetylation, and permanganate treatments are employed to remove surface impurities, alter surface energy, and introduce functional groups that enhance fiber–matrix bonding.[10-12]

This research aims to develop and characterize eco-friendly polymer composites reinforced with chemically modified natural fibers and to evaluate their structural, thermal, and water absorption characteristics for potential industrial applications.[13-16]

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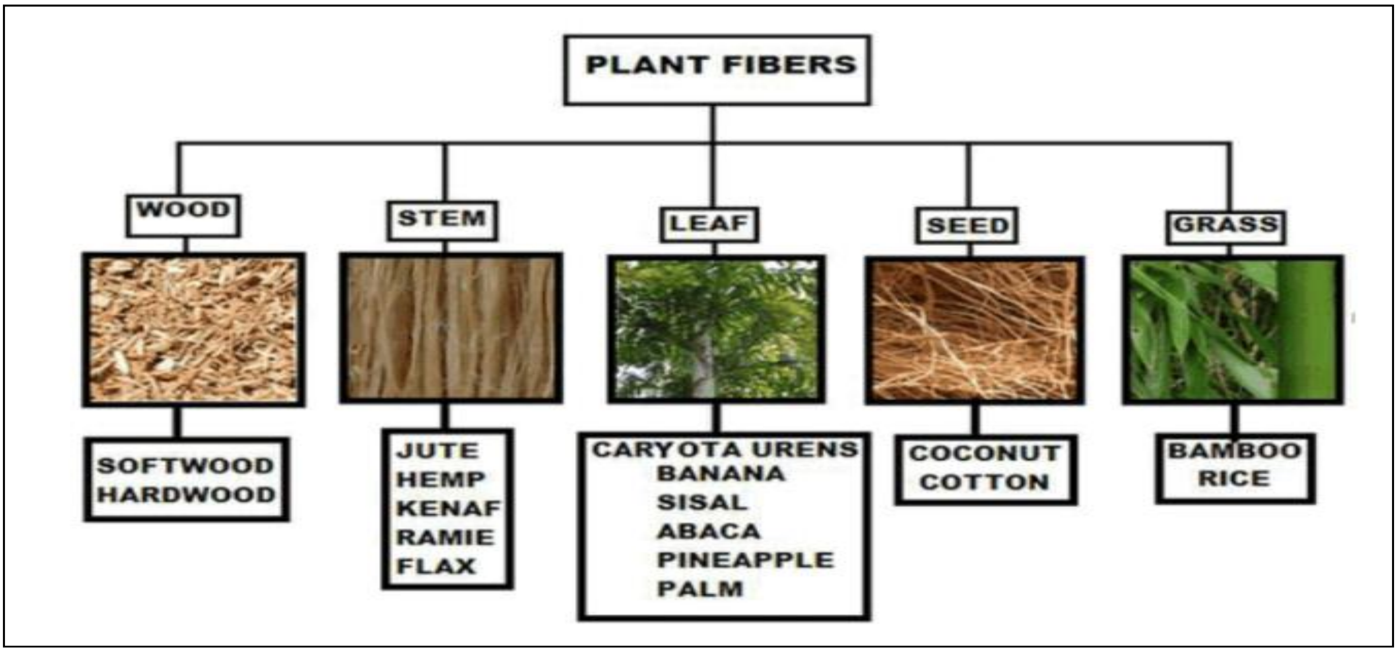


Fig 1 Classification of Plant Fibers (Image Courtesy: Researchgate.net)

## II. MATERIALS AND METHODS

### A. Materials

➢ *Matrix Materials:*

Polylactic acid (PLA) and polypropylene (PP) were chosen as polymer matrices for their distinct biodegradable and thermoplastic characteristics.

➢ *Reinforcing Fibers:*

Jute, sisal, and banana fibers were sourced locally, washed, and dried prior to treatment.

➢ *Chemical Reagents:*

Sodium hydroxide (NaOH), silane coupling agent (3-aminopropyltriethoxy-silane), acetic acid, ethanol, and distilled water were used for surface modification.[17-21]

### B. Chemical Treatment of Fibers

➢ *Alkali Treatment (Mercerization):*

Fibers were immersed in a 5 wt% NaOH solution for 4 h at room temperature. The process removes lignin, hemicellulose, pectin, and waxy substances from the fiber surface. This increases surface roughness, exposes cellulose fibrils, and enhances the number of active hydroxyl sites for bonding. After treatment, fibers were washed with distilled water until neutral pH was achieved and oven-dried at 80°C for 24 h.

➢ *Silane Treatment:*

Alkali-treated fibers were further soaked in a 2% silane solution prepared in an ethanol–water mixture (pH ≈ 4.5) for 1 h. Silane acts as a coupling agent that forms siloxane linkages with the hydroxyl groups of the fiber and covalent bonds with the polymer matrix, thereby enhancing interfacial adhesion. The fibers were subsequently dried at 60°C for 12 h before use.[22-25]

### C. Composite Fabrication

Composites were fabricated using compression molding technique. The treated and untreated fibers were mixed with the polymer matrix at different fiber loadings (10%, 20%, and 30% by weight).

The mixture was preheated and pressed at 180°C for PLA and 200°C for PP, under 5 MPa pressure for 10 minutes. After cooling, specimens were cut according to ASTM standards for mechanical and physical testing.[26-29]

### D. Characterization Methods

➢ *Mechanical Properties:*

Tensile (ASTM D638) and flexural (ASTM D790) tests were performed using a universal testing machine (UTM).

➢ *Thermal Properties:*

Thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) were conducted to assess thermal degradation and crystallinity.

➢ *Morphological Analysis:*

Scanning Electron Microscopy (SEM) was employed to examine fiber–matrix interface and fracture surfaces.

➢ *Moisture Absorption Test:*

Samples were immersed in distilled water for 48 h at room temperature; moisture uptake (%) was determined from weight gain.[30-32]

## III. RESULTS AND DISCUSSION

➢ *Mechanical Properties*

Treated fiber composites exhibited substantial improvements in mechanical performance compared to untreated composites.

For 20% silane-treated jute fiber composites, tensile strength increased by approximately 38%, and flexural

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strength by 32% over untreated samples. This is due to improved interfacial adhesion that facilitates efficient stress transfer between the matrix and fibers. Alkali treatment is also enhanced interlocking at the fiber surface, while silane provided chemical bonding, thereby combining mechanical and chemical reinforcement effects.[33-37]

➢ *Thermal Stability*

TGA results indicated that untreated composites began degradation at 290°C, while silane-treated fiber composites showed onset degradation around 305–315°C. This improvement in thermal stability can be attributed to better matrix encapsulation of fibers and reduced micro-void formation. DSC analysis revealed a slight increase in crystallization temperature, suggesting enhanced nucleation due to treated fiber surfaces.[38-40]

➢ *Morphological Analysis*

SEM micrographs revealed that untreated composites displayed voids, fiber pull-out, and poor adhesion at the interface. In contrast, chemically treated fibers were well-embedded within the matrix, with smooth fracture surfaces and minimal voids. The improved compatibility is evident from the cohesive fracture behavior, validating the effectiveness of surface modification in promoting interfacial bonding.[41]

➢ *Water Absorption Behavior*

Moisture uptake in untreated fiber composites reached 8–10% by weight after 48 h immersion, whereas silane-treated composites absorbed only 4–5%. The reduction in hydrophilicity is due to the substitution of hydroxyl groups and the presence of silane layers that prevent water penetration. Lower moisture absorption enhances dimensional stability, which is crucial for outdoor and packaging applications.[42, 43]

➢ *Comparative Performance*

Among all fiber types, jute fiber composites showed the best mechanical performance, while sisal composites exhibited superior toughness. Banana fiber composites had excellent impact resistance due to their flexible structure. Overall, chemically modified fibers consistently outperformed untreated fibers in every property evaluated.[44-48]

## IV. APPLICATIONS

The improved eco-friendly composites are ideal for replacing traditional glass-fiber composites in semi-structural and consumer applications, such as:

- Automotive: Door panels, dashboards, seat backs, and insulation boards.
- Construction: Ceiling tiles, wall partitions, and decorative laminates.
- Packaging: Biodegradable trays, films, and containers.
- Consumer goods: Furniture panels, sporting goods, and luggage shells.

Their biodegradability and low environmental impact also make them attractive for green manufacturing and circular economy initiatives.[49-54]

## V. CONCLUSION

This study successfully demonstrates the potential of chemically modified natural fibers as reinforcements for eco-friendly polymer composites. Alkali and silane treatments significantly improved fiber–matrix adhesion, leading to notable enhancements in mechanical, thermal, and moisture-resistance properties. The treated composites showed up to 40% improvement in strength, higher thermal stability, and reduced hydrophilicity. The findings confirm that natural fiber-based composites are viable, sustainable alternatives to synthetic materials, promoting both environmental conservation and material innovation. Future work will focus on hybridization with nanofillers and exploring biodegradable polymer matrices to further enhance performance and reduce environmental footprint.

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