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DEVELOPMENT AND CHARACTERIZATION OF A BIODEGRADABLE PACKAGING COMPOSITE FROM RECYCLED PAPER WASTE AND COCONUT FIBRE

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ABSTRACT

The growing environmental concerns associated with single-use plastic packaging have intensified the search for sustainable and biodegradable alternatives derived from renewable resources. In this study, a green composite material was developed using recycled paper waste and coconut fibre as reinforcement, bonded with a starch-based adhesive matrix, for potential application in lightweight packaging. Composite sheets of nominal thicknesses 1.5 mm, 3 mm, and 5 mm were fabricated through pulping, fibre blending, slurry casting, moulding, and ambient drying. The physical performance of the composites was evaluated through water absorption testing in accordance with ASTM D570, thickness uniformity measurements, and qualitative solubility assessment. The results revealed a strong dependence of water absorption on composite thickness, with maximum water uptake values of 252.63%, 246.19%, and 185.32% for 5 mm, 3 mm, and 1.5 mm specimens, respectively. The high moisture sensitivity was attributed to the hydrophilic nature of lingo cellulosic fibres and the porous structure formed during manual fabrication. Surface-coated specimens exhibited reduced water absorption, demonstrating the effectiveness of barrier layers in improving moisture resistance. Solubility tests confirmed rapid disintegration in aqueous media, indicating high biodegradability of the developed composite. Thickness variation was found to be within acceptable limits for manually produced sheets. Overall, the study demonstrates the feasibility of utilizing paper waste and coconut fibre to produce an environmentally benign packaging material suitable for dry and lightweight applications. The findings highlight both the potential and limitations of starch-bonded natural fibre composites, particularly with respect to moisture resistance.

KEYWORDS: *Green packaging, Paper waste, Coconut fibre, Biodegradable composites, Water absorption.*

1. INTRODUCTION

Packaging plays a critical role in modern society by ensuring product protection, preservation, transportation, and communication throughout the supply chain. However, the widespread use of petroleum-based plastic packaging has resulted in severe environmental challenges, including long-term persistence in landfills, marine pollution, and ecological toxicity. Despite increased global awareness and regulatory measures, plastic packaging continues to dominate the market due to its low cost, ease of processing, and favorable mechanical properties.[1]

In response to these challenges, research efforts have increasingly focused on the development of sustainable packaging materials derived from renewable and biodegradable resources. Paper-based materials have emerged as promising candidates due to their recyclability, low cost, and widespread availability. Nevertheless, conventional paper products often suffer from limited mechanical strength and poor resistance to moisture, restricting their broader application in packaging systems.[2]

Natural fibre–reinforced composites represent an effective approach to overcoming these limitations. By incorporating lingo cellulosic fibres such as coconut fibre (coir) into paper-based matrices, it is possible to enhance structural integrity while maintaining biodegradability. Coconut fibre is an agricultural by-product abundantly available in tropical regions and is characterized by low density, good toughness, and high lignin content, which contributes to durability. Its utilization not only improves material performance but also promotes waste valorization and circular economy principles.[3]

Starch-based adhesives are commonly employed as biodegradable binders in green composites due to their renewability, low toxicity, and strong bonding capability with cellulose-rich fibres. However, starch and natural fibres are inherently hydrophilic, which can lead to excessive moisture absorption and dimensional instability. Understanding the influence of composite thickness, porosity, and surface treatment on water absorption behavior is therefore essential for assessing the suitability of such materials for packaging applications.[4]

The present study aims to develop a biodegradable composite using recycled paper waste and coconut fibre bonded with a starch-based adhesive and to evaluate its physical performance with particular emphasis on water absorption characteristics. Unlike many studies that focus on chemically treated fibres or synthetic additives, this work emphasizes a low-cost, low-energy fabrication route using readily available materials. The study provides experimental insight into the thickness-dependent behavior of paper–coir composites and assesses their potential as sustainable alternatives to conventional plastic packaging for lightweight and dry goods.[5] [6].

2. MATERIALS AND METHODS

2.1 Materials

The materials used for the fabrication of the biodegradable composite were selected based on availability, sustainability, and biodegradability.

- Recycled paper waste: Collected from discarded office and packaging paper. The paper waste served as the primary cellulose matrix material.
- Coconut fibre (coir): Extracted from coconut husk waste and used as natural reinforcement to improve structural integrity.
- Starch-based adhesive: Prepared from natural starch and water, acting as a biodegradable binder for the composite system.
- Water: Used for pulping, adhesive preparation, and processing.

  All materials were used without chemical treatment to maintain the eco-friendly nature of the composite.

2.2 Composite Fabrication Process

The composite fabrication followed a low-energy, manual processing route suitable for small-scale and sustainable production.

Initially, waste paper was cut into small pieces and soaked in water to facilitate pulping. The soaked paper was mechanically agitated until a uniform pulp was obtained. Coconut fibres were cleaned, dried, and mechanically reduced to smaller lengths to ensure better dispersion within the matrix.

A starch-based adhesive was prepared separately by mixing starch with water and heating until a viscous binder was formed. The paper pulp and coconut fibres were then blended with the starch adhesive to obtain a homogeneous slurry. The prepared slurry was poured into moulds of predefined dimensions and spread uniformly to achieve target thicknesses of 1.5 mm, 3 mm, and 5 mm. Figure1 shown the samples of different thickness.

5mm thickness 3mm thickness 1.5mm thickness

Figure: 1 Composite samples of different thickness

The moulded samples were subjected to light manual pressing to remove excess water and improve fibre bonding. The composite sheets were then dried under ambient conditions for approximately one week until complete moisture removal was achieved. Multiple trials were conducted to ensure repeatability and uniformity of the fabricated samples.[7]

2.3 Surface Coating

To evaluate the influence of surface protection on moisture resistance, selected composite specimens were coated with a thin protective layer using a commercial paint-based coating. The coated samples were allowed to dry completely before testing. This step was intended to assess the effectiveness of surface barriers in reducing water absorption.

3. Experimental Procedure

3.1 Water Absorption Test

Water absorption behavior was evaluated in accordance with ASTM D570, which is commonly used for polymeric and composite materials.

Square specimens of dimensions 50 mm × 50 mm were cut from each composite sheet. The samples were oven-dried at low temperature and cooled to room temperature prior to testing. The initial dry weight (W_1) of each specimen was recorded using an analytical balance with an accuracy of ±0.001 g. [8]

The specimens were completely immersed in distilled water at room temperature for approximately 17–24 hours. After immersion, the samples were removed, gently wiped with a soft cloth to eliminate surface water, and immediately weighed to obtain the wet weight (W_2).

The percentage water absorption was calculated using:

Water Absorption (%)= $\frac{W2-W1}{W1}\times 100$

3.2 Thickness Uniformity Measurement

Thickness uniformity was assessed by measuring the thickness of each composite sheet at multiple locations using a vernier caliper. The measured values were compared with the nominal thickness to evaluate dimensional consistency and fabrication quality.

3.3 Solubility and Biodegradability Assessment

A qualitative solubility test was conducted to assess the biodegradability of the composite material. Small specimens of known weight were immersed in water and observed over time for disintegration and dissolution. Visual confirmation of material breakdown without harmful residues was used as an indicator of biodegradability.

4. RESULTS AND DISCUSSION

4.1 Water Absorption Behaviour

The water absorption results for the uncoated composites revealed a strong dependence on specimen thickness. The 5 mm thick composite exhibited the highest water absorption (252.63%), followed by the 3 mm (246.19%) and 1.5 mm (185.32%) samples. Figure 2 shows the samples of composites after immersing in water for 17-24 hours.

5mm thickness 3mm thickness 1.5mm thickness

Figure: 2 Composite samples after immersion in water.

The increased water uptake in thicker samples can be attributed to higher internal porosity and greater availability of hydrophilic sites within the lingo cellulosic structure. The starch-based matrix and natural fibres contain abundant hydroxyl groups, which readily form hydrogen bonds with water molecules, leading to swelling and mass increase. Thinner composites exhibited comparatively lower porosity and improved fibre packing, resulting in reduced moisture penetration.

These findings are consistent with previous studies on natural fibre–reinforced biocomposites, where increased thickness and void content were associated with higher moisture absorption.

4.2 Effect of Surface Coating

Surface-coated specimens showed a noticeable reduction in water absorption compared to uncoated samples. The coating acted as a physical barrier, limiting direct water contact with the hydrophilic fibre–matrix network. Among the coated samples, the 1.5 mm composite demonstrated the lowest water uptake, indicating improved dimensional stability. Figure 3 shows the composite samples after coated with epoxy.

		
5mm thickness	3mm thickness	1.5mm thickness

Figure: 3 Composite samples after coated with epoxy.

Although coating enhanced moisture resistance, the composites still exhibited higher absorption than synthetic polymer-based packaging materials. This highlights the inherent limitation of starch-bonded natural fibre systems and emphasizes the importance of surface modification for packaging applications exposed to humid environments.

4.3 Thickness Uniformity and Solubility

Thickness measurements showed variations within ±0.5 mm, which is acceptable for manually fabricated composite sheets. Minor deviations were attributed to uneven slurry distribution and manual pressing during moulding.

The solubility assessment confirmed rapid disintegration of the composite material in water, validating its biodegradable nature. The starch-based adhesive dissolved readily, leading to fibre separation and breakdown of the composite structure. This behavior supports environmentally safe disposal and compostability, making the material suitable for short-life packaging applications.

6. CONCLUSION

A biodegradable composite packaging material was successfully developed using recycled paper waste and coconut fibre bonded with a starch-based adhesive. Experimental results demonstrated that composite thickness significantly influences water absorption behavior, with thinner samples exhibiting improved stability and lower moisture uptake. Surface coating was found to enhance water resistance, though moisture sensitivity remains a key limitation.

The study confirms the feasibility of converting agricultural and paper waste into environmentally benign packaging materials suitable for lightweight and dry goods. While the composite cannot directly replace plastic packaging in moisture-intensive applications, it presents a sustainable alternative for short-term and low-load packaging needs.

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