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Design and Development of Low-Density Polyethylene Composites Reinforced with Coconut Fiber for Enhanced Material Properties for Composite Structures

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***Abstract*— The increasing demand for sustainable and lightweight materials in various industries has driven the exploration of natural fiber-reinforced polymer composites. This study focuses on the design and development of low-density polyethylene (LDPE) composites reinforced with coconut fiber, aiming to enhance material properties for use in composite structures. Coconut fiber, an abundant and eco-friendly material, was chosen as reinforcement due to its favorable mechanical properties, biodegradability, and cost-effectiveness. LDPE, a widely used thermoplastic, was selected as the matrix material for its low density, excellent processing capabilities, and compatibility with natural fibers. The composite materials were fabricated using a compression molding technique, incorporating coconut fiber in varying weight percentages (0%, 20%, 40%, 60%, and 80%).**

Key physical and mechanical properties, including tensile, flexural, and impact strengths, were assessed to evaluate the performance of the composites. The results demonstrated that composites with 40 wt% and 60 wt% fiber loading exhibited optimal tensile and impact strengths, making them suitable for structural applications requiring enhanced mechanical performance. Conversely, composites with 20 wt% fiber content displayed suboptimal properties due to inadequate fiber-matrix bonding, highlighting the importance of achieving proper interfacial adhesion.

Microstructural analysis using Scanning Electron Microscopy (SEM) revealed a heterogeneous distribution of fibers within the LDPE matrix, with noticeable weak interfacial bonding at higher fiber loadings. Moisture absorption tests showed that composites with lower fiber content had minimal water uptake, while those with higher fiber loadings experienced significant absorption and swelling, limiting their use in water-based environments.

However, the composites were found to be suitable for non-structural applications in moist conditions, such as partitions, false ceilings, roof tiles, and door and window frames. This study demonstrates the potential of coconut fiber-reinforced LDPE composites as lightweight, sustainable alternatives for non-structural and low-strength applications. The findings provide valuable insights into the optimization of fiber loading and processing techniques to achieve desirable mechanical and physical properties. Furthermore, the research underscores the role of natural fibers in promoting environmentally friendly materials and reducing waste in polymer composite production.

***Indexed Terms* – RCC, Composite, LDPE, Ansys, Analysis, Structures.**

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I. Introduction

The primary objective of this research is to develop and evaluate the mechanical properties of a composite material comprising low-density polyethylene (LDPE) reinforced with coconut fiber. The study focuses on understanding the effect of fiber loading on the tensile, flexural, and impact properties, as well as other characteristics such as water absorption. Composite samples were fabricated with varying coconut fiber weight percentages of 0%, 25%, 50%, and 100% to address the environmental issue of LDPE waste, commonly found in discarded water packaging materials that contribute to pollution. The coconut fibers were extracted and cleaned through a water retting process, and the LDPE-coconut fiber composites were produced using compression molding techniques. This chapter details the design and fabrication of coconut fiber-reinforced LDPE composites, highlighting the enhanced material properties achieved. The methodologies used in fiber extraction, cleaning, and composite sample preparation are presented, along with a mathematical model of the proposed system and a flow diagram of the design process. Testing procedures, including tensile, flexural, impact, water absorption modeling, and SEM analysis, are also described. The mechanical characterization of the developed composites investigates the influence of fiber reinforcement on tensile strength, flexural properties, impact resistance, and the distribution of local average strengths within the composites. Additionally, the study examines the microstructure and water absorption characteristics of the materials. The research emphasizes the optimization of processing parameters for fabricating the composites. The optimal conditions—achieved through melt blending and hot pressing techniques—were determined to be a temperature of 200°C, a pressure of 25 MPa, and a holding time of 5 minutes. Experimental results are analyzed and discussed, with justifications provided for the observations. The study concludes with remarks on the effectiveness of the developed LDPE-coconut fiber composites, highlighting their potential as environmentally sustainable materials with improved mechanical performance.

II. Objective

The flexural and tensile properties of the developed composites were evaluated using a Hounsfield Monsanto Tensometer, while their impact properties were assessed with a Charpy impact testing machine. Microstructural analysis was conducted using Scanning Electron Microscopy (SEM), revealing a heterogeneous distribution of coir fibers within the LDPE matrix and weak interfacial bonding between the fibers and matrix. Simulation results demonstrated that water absorption decreased with lower fiber loading but increased significantly with higher fiber loading, indicating the trade-offs between fiber content and moisture resistance. This research provides valuable insights into the mechanical properties of coconut fiber-reinforced LDPE composites and highlights their potential for reducing waste and environmental pollution. The primary objective of this research was to develop and assess the mechanical properties of a composite material composed of low-density polyethylene (LDPE) reinforced with coconut fibers. Compression molding techniques were used to fabricate the composites, which were then tested for tensile, flexural, and impact strengths. Results indicated that composites with fiber loadings between 20 wt% and 80 wt% exhibited an optimal balance of mechanical properties, while composites with higher fiber content (e.g., 50 wt%) demonstrated diminished performance due to excessive fiber-matrix interaction. The microstructural analysis and moisture absorption studies further confirmed the composite's suitability for non-structural, lightweight applications, including false ceilings, window and door frames, roof tiles, and partitions. Composite materials, characterized by their two or more distinct constituents separated by an interface, are formed by embedding a discontinuous phase (fiber) into a continuous phase (matrix). Natural fibers have been increasingly utilized for reinforcement due to their abundance, low cost, and desirable mechanical properties. This research focuses on coir fiber, which is abundant, fibrous, and sustainable. Coir fiber's high elastic modulus, good stiffness, and compressive strength make it an ideal reinforcement for the LDPE matrix. This study aims to address environmental challenges by developing cost-effective composites that integrate agricultural waste (coir fiber) with recycled LDPE, promoting sustainable practices such as waste re-utilization and environmental protection. The rising interest in coir fiber as a reinforcing material stems from its biodegradability, recyclability, and compatibility with polymer matrices. While coir fibers have been successfully used in producing low-cost fiber-reinforced polymer (FRP) composites for automobile parts, recent research has explored their role in enhancing the rigidity and strength of bio-polyethylene composites. Studies have shown that hybrid reinforcements, such as combining coir fiber with basalt fibers or wood flour, can significantly improve the mechanical properties of composites. Notably, coir fiber's potential has also been demonstrated in applications such as military helmets, showcasing its ability to enhance impact strength and structural rigidity in polymer composites.

III. Composite Materials & Methodologies Developed

In this section, various types of composites material & methodologies that are incorporated & developed is presented in a nutshell. In this study, low-density polyethylene (LDPE), a thermoplastic material, was used as the matrix material (Fig. 1). LDPE has a density ranging from 0.90 to 0.95 g/cm³ and demonstrates thermal stability within the temperature range of −60°C to 90°C. Its melting temperature is approximately 140°C [6]. LDPE not only blends effectively with the reinforcing fibers but also encapsulates them, forming a cohesive composite material. The reinforcing material used in this work is coir, derived from the mesocarp of coconut fruits. Coir fibers are fine yarns with diameters between 0.15 mm and 0.65 mm, measured using a Wright & Moore micrometer vernier gauge.

These fibers have a density of 1.25 g/cm³, a tensile strength of 180 MPa, and water absorption capacity ranging from 140% to 190% [7]. The metallic mold used for fabricating the composites was constructed from mild steel, chosen for its excellent thermal conductivity (50 W/m·K), tensile strength (450 MPa), and high melting point (1300°C to 1500°C). Mild steel's high thermal conductivity facilitates rapid heat dissipation, allowing the composite material to cool quickly without deformation. The mold was fabricated using 3 mm thick mild steel sheets and designed in the form of square plates with dimensions of 200 mm × 200 mm. A perforated cavity measuring 175 mm × 175 mm was incorporated into the mold to enable precise shaping of the composite material [5].

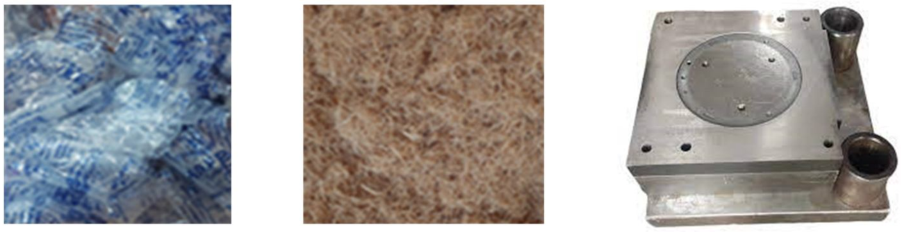

Fig. 1: General the materials – LDPE matrix, Coconut Coil Fibres, Metallic Mould

Fig. 2: General Cleaning & extraction of the coconut coil fibres – Soaked coconuts, separation of the mesocarp coirs from exocarps, soaked coco coirs, dried coirs in the sun

IV. Extraction of Fibres & Its Cleaning Process

The coir fibers were obtained from coconut husks through a water retting process. Initially, the husks were soaked in water for 24 hours to loosen the bonds between the mesocarp and exocarp layers. Subsequently, the separated coir fibers were soaked for an additional four days to further soften them. The softened husks were then lightly beaten to remove any pithy substances and clean the fibers thoroughly. To eliminate wax and impurities, the fibers underwent a boiling process in a hot detergent solution for 2 hours. After rinsing, the cleaned fibers were sun-dried for approximately 10 hours to ensure complete drying. Once dried, the fibers were stored in polyethylene bags for later use, as illustrated in Fig.1.

V. Preparation of the Sample for the Experimentation Purposes

The composite materials were fabricated by combining coconut fibers and LDPE in specific weight percentages. The coconut fiber content was varied across five categories: 0%, 20%, 40%, 60%, and 80%, while the corresponding LDPE content was adjusted to 100%, 80%, 60%, 40%, and 20%, respectively. During sample preparation, key physical properties such as density, volume, mass, and fiber volume fraction of both the matrix

(LDPE) and the fiber (coir) were carefully measured and accounted for. The Fig. 2 illustrates the general process of cleaning and extracting coconut coir fibers. This includes soaking coconuts, separating the mesocarp coir from the exocarp, soaking the coir fibers, and sun-drying the cleaned coir fibers.

VI. Mathematical Model Development

In this section, the mathematical model that is used for the experimentation is presented. The developing of the coconut fibre based RF less density poly-ethylene materials can be described by the following mathematical model shown in the equation below as [11]

$$V_f = \left(\frac{V_c + W_c}{W_{c + W_f}}\right)$$

Here , V_f is the faction of volume of the composite fibre, V_c is polyethylene's low density volume (LDPE), W_c will be the weight of the LDPEs & W_f is the coconut fibre's weight. Material properties of the composite material is determined from the equation [10]

Tensile strengths :

$$\sigma\, t = \left(\frac{P_{max}}{b}\right) * \left(\frac{d}{t}\right)$$

where σ *t* is strength of the tensile, P_{max} is maximum load, *b* is the sample's width *d* is the sample thickness, and *t* is the grip separation [9].

Tensile modulus :

$$E\, t = \left\{ {(P/A)} \Big/ {\left({\delta l}/{l} \right)} \right\}$$

where *E t* is the tensile modulus, *P* will be load, sample's c/s *A*, δ*l* is the change in length, and *l* is the original length [12].

Flexural strength:

$$\sigma\, t = \left(\frac{3 \times P_{max} \times L}{2 \times b \times t^2}\right)$$

Here, σ is the strength of the flexure, P_{max} is maximum load, *L* the length of span, *b* the sample's width, and *t* the thickness of the sample [12].

Flexural modulus:

$$E\, f = \frac{(P \times L^4)}{(5 \times b \times t^4 \times \delta f)}$$

Here, *E f* is flexural modulus, *P* will be load, *L* will be the length of the span, *b* being the width of the sample, *t* is the thickness of the sample, and δ *f* is the deflection [1].

Impact strength:

$$I = \frac{P}{h}$$

where *I* is the impact strengths, *P* will be load, and *h* the sample's height [13].

Water absorption:

$$W_a = \left(\frac{W_w - W_d}{W_d}\right) \times 100$$

where W_a is the absorption in water, W_w is the sample's weight after water immersion of the sample, and W_d will be the dry sample's weight [12].

One can use these equations to assess the material properties of the composite made from coconut fiber and low-density polyethylene. The digital weighing scale was employed to measure the weight of the samples, and the laminate formulae were used to calculate the equivalent fiber weight fraction. The formula below can be used to compute the Fiber's Volume Fraction (FVF) based on the Fiber Weight's Fraction (FWF) [15]

$$FVF = FWF \times \left(\frac{\rho_m}{\rho_f}\right)$$

where FWF - the Fibre's Weight Fractions, ρ_m – matrix material's density & ρf the fibre material's density. For example, let's assume that we have a composite material with a Fibre Weight Fraction of 40% and the matrix material's density is 1.94 gms per cm^3, similarly, the density of the fibre material is 1.25 gms per cm^3. Then, we can calculate the Fibre Volume Fraction as follows [15].

$$FVF = 0.4 \times 0.94 / 1.25 = 0.3016 \text{ or } 30.16\%$$

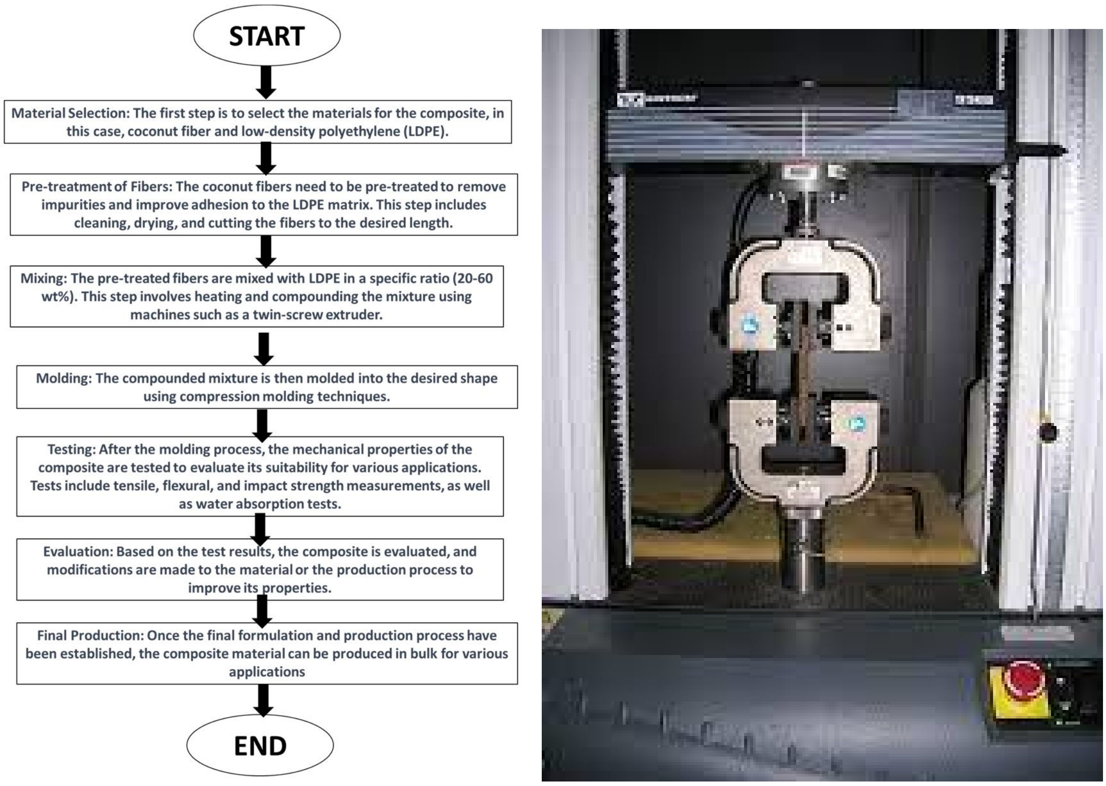

Fig. 3: Flow chart / DFD for the design process of the composite material & Machine used for tensile testing – Elastomer / UTM

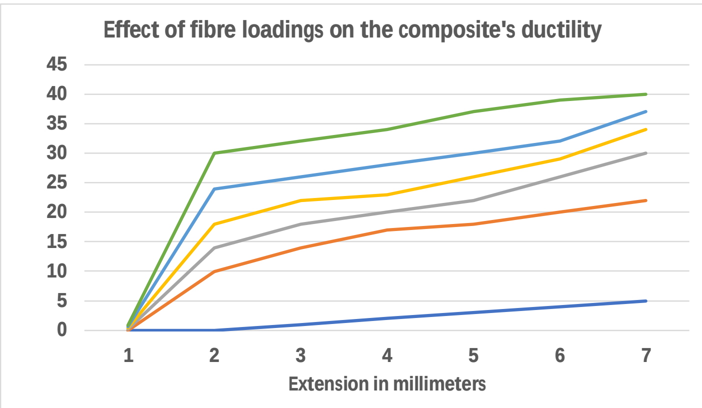

Fig. 4. Impact of fibre loadings on the ductility of the composite

VII. Impact of Fibre Reinforcement on Flexural Characteristics of the Composite Structures

The figures 1 and 2 illustrate the flexural properties of the Coir-LDPE composite with varying weight percentages of coir fiber. The composite with 20 wt% fiber loading showed the highest flexural strength of 12

MPa, while the lowest flexural strength of 6.75 MPa was observed at 20 wt% fiber fractions. The flexural strength of the composite slightly increased with fiber loading up to 40 wt% compared to pure LDPE, but then decreased as the fiber content increased. The reduction in flexural strength may be attributed to incomplete filling of the melted LDPE resin in the natural fibers during composite processing, as described by [11]. On the other hand, the incorporation of coir fiber generally improved the flexural modulus of pure LDPE, as shown in Fig. 3.11. The highest flexural modulus of the Coir-LDPE composite was obtained at 20 wt% fiber loading, while the lowest was recorded at 30 wt% fiber loading. The sudden decrease in flexural modulii is due to incomplete fillings of the matrix in the composite, which is consistent with the findings of [12].

VIII. CONCLUSIONS

The study successfully developed and evaluated coconut fiber-reinforced low-density polyethylene (LDPE) composite materials using compression molding. The investigation focused on mechanical properties such as tensile, flexural, and impact strengths. The results indicated that composites with 40 wt% and 60 wt% fiber loading provided the best combination of tensile and impact strengths. However, composites with lower fiber content, such as 20 wt%, exhibited poor mechanical properties due to weak bonding between the coir fibers and the LDPE matrix. Microstructural analysis revealed a homogeneous distribution of fibers within the matrix, though interfacial bonding between the fibers and LDPE was observed to be weak. These findings highlight the potential for optimal fiber loading to achieve enhanced mechanical properties while balancing structural integrity. The moisture absorption analysis showed that composites with low fiber loading had minimal water absorption, whereas higher fiber loading led to increased absorptivity and noticeable thickness swelling. This makes the composites unsuitable for direct water applications but viable for use in moist environments. Despite having lower strength compared to synthetic fiber-reinforced composites, the developed material is suitable for lightweight, low-strength, and non-structural applications. Examples include partition panels, false ceilings, roof tiles, and window and door frames. Overall, the study demonstrates the feasibility of using coconut fiber and LDPE to create sustainable, eco-friendly composite materials for specific applications.

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