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PREPARATION AND CHARACTERIZATION OF SAWDUST-REINFORCED POLYETHYLENE COMPOSITES FOR SUSTAINABLE APPLICATIONS

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Abstract

This research presents a comprehensive study on the development of environmentally friendly polymer composites reinforced with sawdust—a lignocellulosic waste product generated from wood processing industries. High-Density Polyethylene (HDPE) and Low-Density Polyethylene (LDPE) were selected as matrix materials due to their widespread application, ease of processing, and mechanical stability. Sawdust was incorporated as a reinforcing filler in varying proportions to fabricate hybrid composites using melt blending via twin-screw extrusion followed by injection molding. The resulting specimens were subjected to mechanical and physical characterization, including tensile, flexural, and hardness testing, along with water absorption analysis. Experimental outcomes revealed that the inclusion of sawdust significantly influenced the performance of the composites, demonstrating a trade-off between mechanical strength and sustainability. The findings emphasize the potential of bio- waste–reinforced polymers as viable materials for packaging, low-load structural components, and sustainable construction alternatives.

Keywords: HDPE, LDPE, Sawdust, Polymer Composites, Mechanical Properties, Sustainability, Extrusion, Injection Molding.

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1. INTRODUCTION

The rapid expansion of industrial activities has led to the generation of vast quantities of solid waste, including sawdust—a common byproduct of wood processing. In India alone, over 960 million tonnes of solid waste are produced annually, contributing to significant environmental challenges. Improper disposal of sawdust can result in air and water pollution, as well as fire hazards. To mitigate these issues, this study explores the use of sawdust as a reinforcing filler in thermoplastic composites based on High- Density Polyethylene (HDPE) and Low- Density Polyethylene (LDPE). These polymers are widely used due to their chemical resistance and ease of processing but are non-biodegradable. Blending them with sawdust provides a sustainable pathway to reduce plastic usage and valorize wood waste.

1.1 Wastes in Society

The industrial sector is a major contributor to solid waste, which includes diverse materials such as food scraps, office paper, yard waste, plastics, glass, textiles, chemicals, metal scrap, leather remnants, and notably, sawdust from the wood industry. The disposal and treatment of these wastes present critical environmental challenges. Among industrial wastes, sawdust stands out due to its abundant availability, low cost, and biodegradable nature. Proper waste management practices are essential to limit ecological damage and recover value from industrial byproducts. Materials like sawdust, which are often treated as low-value waste, hold the potential to be transformed into functional reinforcements in polymer composite systems.

1.2 Sawdust

Sawdust, also referred to as wood dust, is a fine particulate substance generated during the mechanical processing of wood. In addition to human activities, certain bird and insect species, like woodpeckers and carpenter ants, contribute to its natural production. Sawdust primarily consists of cellulose, hemicellulose, and lignin, making it an effective natural filler material due to its fibrous structure and compatibility with polymer matrices. Industrially, sawdust is utilized in a wide range of applications including particleboard production, wood pulp processing, mulching, fuel briquetting, animal bedding, and even as a biodegradable alternative to clay-based cat litter. Historically, it has been employed in refrigeration (as insulation in ice storage), in the manufacturing of pykrete (a slow-melting ice composite), and as a key ingredient in charcoal briquettes—a concept commercially introduced by Henry Ford. Improper disposal in open environments can lead to air and water contamination through leachates containing lignin and fatty acids. Therefore, its controlled reuse in composite applications offers both ecological and economic benefits.

1.3 Environmental Effects

Large mounds of untreated sawdust can leach toxic substances—such as phenolic compounds and fatty acids—into adjacent water bodies, adversely affecting aquatic ecosystems. These leachates can reduce oxygen levels in water and disrupt the biological balance, thereby harming biodiversity. Moreover, sawdust piles are highly

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susceptible to spontaneous combustion, posing fire hazards in industrial settings. Utilizing sawdust in composite manufacturing not only diverts it from landfills and open disposal sites but also provides a productive end-use that aligns with sustainable development goals.

1.4 High-Density Polyethylene (HDPE)

HDPE is a thermoplastic polymer derived from petroleum, known for its high tensile strength and density. Its linear molecular arrangement with minimal branching imparts superior strength, rigidity, and resistance to environmental stress cracking. HDPE is widely used in products such as bottles, piping, containers, and structural applications due to its robustness and chemical resistance. HDPE is also easily recyclable and carries the resin identification code "2." Its high melting point (up to 120°C) and moisture resistance make it suitable for long-term applications. However, its low impact strength and brittleness under dynamic loading conditions limit its performance in some applications, prompting the need for reinforcement through filler addition.

1.5 Low-Density Polyethylene (LDPE)

LDPE, another widely used polyethylene variant, differs from HDPE in molecular structure. Its high degree of branching reduces density and crystallinity, resulting in a softer, more flexible polymer. LDPE exhibits excellent processability, elongation, and impact resistance, making it ideal for film applications, squeeze bottles, and cable insulation. Despite its advantages, LDPE has lower tensile strength and thermal stability compared to HDPE. It is chemically inert under standard conditions but may swell in contact with some solvents. Like HDPE, LDPE is recyclable (resin code "4") and often incorporated in composites to improve flexibility and reduce stiffness.

1.6 Waste Management

The adoption of reduce–reuse–recycle strategies has been central to modern waste management policies. Integrating waste materials like sawdust into polymeric composites exemplifies the reuse principle, transforming a low-value byproduct into a high-performance engineering material. The use of natural fillers in thermoplastics not only reduces reliance on virgin polymer but also decreases the carbon footprint of the final product. Furthermore, composite fabrication processes such as extrusion and injection molding allow for the efficient and scalable production of such sustainable materials.

1.7 Composite Materials

Composite materials are engineered systems comprising two or more distinct constituents—typically a matrix and a reinforcement—that synergistically enhance mechanical and physical properties. In polymer-based composites, thermoplastics like HDPE or LDPE serve as the matrix, while fillers such as sawdust act as the reinforcing phase. This combination improves strength, stiffness, dimensional stability, and in some cases, reduces overall material cost. The heterogeneous structure of composites allows for customized performance by adjusting parameters such as filler content, particle size, and processing conditions. Wood–polymer composites, in particular, offer a unique

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balance of mechanical strength and environmental responsibility, making them suitable for applications in construction, packaging, and furniture.

2. LITERATURE REVIEW

The utilization of lignocellulosic fillers such as sawdust in polymer composites has been extensively studied as a sustainable alternative to conventional synthetic reinforcements. The resulting wood–polymer composites (WPCs) are known for their biodegradability, cost-effectiveness, and adequate mechanical strength for low-load structural applications. This section reviews key research studies relevant to sawdust- based polymer composites, particularly those involving HDPE and LDPE matrices.

2.1 Sawdust as Reinforcement in Polymer Matrices

Hossain et al. (2013) found that NaOH-treated sawdust enhanced the tensile strength of polyethylene composites by improving filler– matrix adhesion. However, beyond optimal loading, sawdust tended to agglomerate, weakening the mechanical performance. This highlights the importance of surface treatment and controlled filler content.

2.2 LDPE–Wood Composites with Degraded LDPE

Ndlovu et al. (2013) used degraded LDPE (dLDPE) as a compatibilizer to improve bonding in LDPE–wood flour composites. The oxidative treatment introduced polar groups, enhancing interfacial adhesion and leading to better dispersion and mechanical properties.

2.3 Dimensional Stability and Mechanical Behavior of HDPE-Based Composites

Adhikary et al. (2007) compared virgin and recycled HDPE reinforced with *Pinus radiata* wood flour. Both systems showed comparable mechanical strength when compatibilized with MAPP, proving the feasibility of using recycled HDPE while maintaining dimensional stability.

2.4 Nanoclay-Reinforced HDPE Composites

Faruk et al. (2008) demonstrated that pre- blending nanoclay into HDPE before adding wood flour enhanced tensile and flexural properties. Improved dispersion of nanoclay particles led to better filler–matrix interaction and overall strength.

2.5 Mechanical Properties of Wood Dust–Epoxy Composites

Kumar et al. (2014) tested sundi wood dust– epoxy composites and observed increased tensile and flexural strength up to a critical filler percentage. Beyond this point, filler clumping reduced mechanical efficiency, underlining the importance of optimal filler ratios.

2.6 PLA-Based Biocomposites with Rubberwood Sawdust

Petchwattana et al. (2014) reinforced PLA with rubberwood sawdust and core-shell rubber (CSR). The sawdust improved stiffness while CSR increased impact resistance. However, excessive filler led to brittleness, revealing a trade-off between rigidity and

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flexibility.

2.7 Adhesion Enhancement with Ethylene-Vinyl Alcohol (EVAL)

Kim et al. (2005) improved the tensile strength of LLDPE–sawdust composites using EVAL copolymer as a compatibilizer. Composites with 15 mol% vinyl alcohol showed better bonding, although higher contents reduced elongation, indicating an inverse relationship between strength and ductility.

2.8 Effect of Fiber Characteristics on WPC Performance

Bouafif et al. (2009) showed that fiber size, origin, and surface condition impact strength and moisture resistance in HDPE–wood composites. Smaller, treated fibers improved mechanical performance, while higher filler content increased water uptake, affecting durability.

3. MATERIALS AND METHODOLOGY

This study aims to develop and evaluate polymer composites using High-Density Polyethylene (HDPE) and Low-Density Polyethylene (LDPE) as matrix materials, reinforced with sawdust derived from teak wood. A systematic experimental approach was followed for material selection, preprocessing, blending, compounding, and specimen fabrication for mechanical characterization.

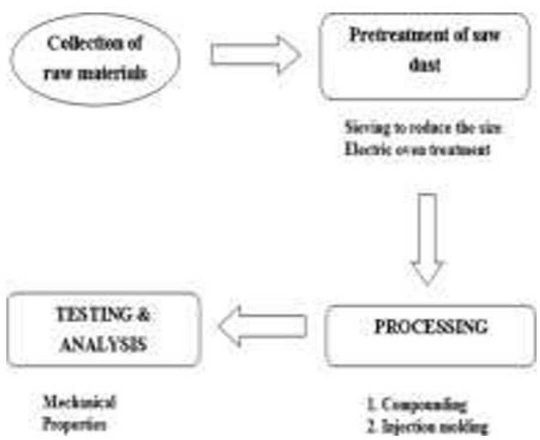

Fig 1: Materials and Methodology

3.1 Materials

The composite system developed in this study consists of two principal phases:

- **Matrix phase**: Virgin HDPE and LDPE granules
- **Reinforcement phase**: Untreated teak wood sawdust

The matrix materials serve as the continuous phase, binding and encapsulating the dispersed reinforcement particles. The reinforcement phase provides rigidity, dimensional stability.

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3.2 Sawdust

Sawdust used in this study was collected as a byproduct of teak wood cutting operations. It primarily consists of fine wood particles with an average particle size below 500 microns. This lignocellulosic material offers natural compatibility with polymer matrices and contributes to environmental sustainability by utilizing wood waste. However, due to its hydrophilic nature and potential moisture content, pre-treatment is essential.

3.3 Reinforcement Phase

The teak wood sawdust acts as the reinforcing component in the polymer composite system. The incorporation of sawdust not only reduces the polymer content but also contributes to improved stiffness and hardness. The use of a naturally derived filler such as sawdust aligns with the sustainable materials approach.

3.4 Matrix Phase

The thermoplastic matrix is composed of:

- **HDPE (High-Density Polyethylene)**: Known for its high tensile strength, chemical resistance, and low permeability.
- **LDPE (Low-Density Polyethylene)**: Offers superior flexibility, impact resistance, and processability due to its branched molecular structure.

Both polymers were used in granular form and blended in various proportions with sawdust to study the effects of filler content on composite behavior. Blending HDPE and LDPE enables a controlled variation in mechanical flexibility and stiffness.

3.4.1 Properties of HDPE

- Density: 0.93–0.97 g/cm^3
- High crystallinity with minimal branching
- Good tensile strength and moisture resistance

3.4.2 Properties of LDPE

- Density: 0.91–0.94 g/cm^3
- High impact resistance and ductility
- Better flexibility compared to HDPE
- Lower melting point and higher processability

3.5 Methodology Overview

A systematic methodology was followed to ensure the homogeneity of the composites and the reliability of results. The process steps include:

1) Raw material preparation
2) Sawdust preprocessing (sieving and drying)

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3) Manual mixing with silicone oil (for compatibility)

4) Twin-screw extrusion for compounding

5) Injection molding for specimen fabrication

6) ASTM-standard mechanical testing

3.6 Sawdust Preprocessing

To enhance the interface compatibility between the hydrophilic sawdust and hydrophobic polymer, the following preprocessing steps were conducted:

3.6.1 Sieving

The collected sawdust was passed through a mesh sieve to ensure consistent particle size distribution. Particles retained were below

500µm to allow uniform dispersion and

avoid agglomeration in the polymer matrix.

3.6.2 Oven Drying

Sieved sawdust was subjected to thermal treatment in a convection oven at 80°C for several hours to remove inherent moisture and volatile content. This step is essential to prevent vapor-induced defects during extrusion and to improve matrix–filler adhesion.

3.7 Processing Methods

3.7.1 Manual Mixing

Before extrusion, the sawdust and polymer granules were premixed manually with a small quantity of silicone oil. This oil acts as a temporary coupling agent to assist in achieving preliminary compatibility and to reduce friction during melt compounding.

3.8 Composite Formulation

Composite formulations were prepared with varying weight ratios of HDPE, LDPE, and sawdust. The total filler content (sawdust) ranged from 10% to 30% by weight. Each formulation was labeled and documented for downstream testing and analysis.

3.9 Compounding Process

A twin-screw extruder was used to melt- blend the polymer-sawdust mixture. Extrusion parameters were optimized as follows:

- Barrel temperature: 160°C to 190°C (in zones)
- Screw speed: 80–100 rpm
- Residence time: ~3 minutes

The extrusion ensured uniform mixing, melting, and pelletizing of the composite blend. These pellets were air-cooled and collected for molding.

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3.10 Injection Molding

Pellets obtained from the extrusion process were fed into an injection molding machine to fabricate standardized test specimens. Molding parameters included:

- Injection temperature: ~190°C
- Mold temperature: ~60°C
- Injection pressure: 80–100 bar

4. TESTING

The mechanical and physical characterization of the developed polyethylene–sawdust composites was carried out to evaluate their performance and suitability for structural and sustainable material applications. Standardized testing protocols were adopted to determine key properties such as tensile strength, flexural strength, hardness, and water absorption. All tests were conducted on injection-molded specimens prepared in accordance with ASTM standards.

4.1 Tensile Strength Test

Standard followed: ASTM D638 **Equipment used:** Universal Testing Machine (UTM)

Tensile strength was evaluated using a computer-controlled UTM. Specimens were loaded in tension at a constant crosshead speed until fracture. The test provides data on:

- Ultimate tensile strength (UTS)
- Elongation at break
- Modulus of elasticity

This test is critical to assess the composite's ability to resist pulling forces. Sawdust inclusion generally leads to reduced elongation but can improve stiffness.

4.2 Flexural Strength Test

Standard followed: ASTM D790 **Equipment used:** UTM with three-point bending fixture

The flexural test measures the material's resistance to bending forces. Rectangular specimens were supported on two ends and loaded at the center until deformation or fracture. Parameters obtained include:

- Flexural strength
- Flexural modulus
- Strain at yield

The incorporation of sawdust was found to increase the flexural rigidity of the composites. This is attributed to the fibrous nature of the filler.

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4.3 Hardness Test

Standard followed: ASTM D2240

Scale used: Shore D

The flat surfaces of molded specimens were used for testing, and multiple readings were averaged for accuracy.

Higher sawdust content resulted in an increase in Shore D hardness values. This trend confirms the role of lignocellulosic fillers in increasing the surface rigidity of polyethylene composites

4.4 Water Absorption Test

Standard followed: ASTM D570

Procedure: Immersion in water for 24 hours

Specimens were weighed before and after immersion in distilled water for 24 hours at room temperature. Water absorption percentage was calculated using

$$\text{Water Absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100$$

The presence of sawdust increased the water uptake due to the hygroscopic nature of lignocellulosic fillers. Composites with higher filler loading showed greater moisture absorption. Although this affects dimensional stability, it remains within acceptable limits for indoor and semi-structural applications.

4.3 Visual Inspection and Morphological Observations

Preliminary observations were made regarding surface finish, uniformity, and filler dispersion. Specimens with 10% and 20% sawdust appeared homogeneous and free from visible defects. At 30% filler content, minor voids and surface irregularities were noted, indicating the onset of filler agglomeration and reduced flow during molding.

5. RESULTS AND DISCUSSION

This chapter outlines the key outcomes from mechanical testing of the sawdust-reinforced HDPE–LDPE composite, including tensile strength, flexural strength, surface hardness, and impact resistance. All tests followed ASTM standards and were conducted on injection-molded specimens.

5.1 Tensile Strength

Tensile testing yielded values of 23.12 MPa, 24.01 MPa, and 23.66 MPa, with an average of **23.60 MPa**. These results fall within the acceptable range for polymer composites and suggest good load-bearing capacity. The consistency across samples indicates effective dispersion of sawdust and uniform blending.

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5.2 Flexural Strength

Flexural strength was measured as 79.88 MPa, 81.42 MPa, and 87.36 MPa, averaging **82.89 MPa** with a standard deviation of ±3.23 MPa. The improvement in bending resistance reflects the contribution of sawdust in restricting deformation, reinforcing the matrix against flexural loads.

5.3 Surface Hardness (Shore D)

Hardness values ranged from 70.67 to 72.33, with an average of **71.33 Shore D**. The increased hardness indicates enhanced surface durability due to the rigid sawdust filler. The composite can therefore withstand moderate surface wear.

5.4 Water Absorption Test

Water absorption was measured over a 24- hour period following ASTM D570. Results showed a moderate increase in mass, consistent with the hydrophilic nature of sawdust. Water uptake increased with higher filler content, though remained within acceptable limits for indoor applications.

5.5 Summary of Results

The composite demonstrated balanced mechanical properties: a tensile strength of **23.60 MPa**, flexural strength of **82.89 MPa**, surface hardness of **71.33 Shore D**, and impact energy of **3.59 J**. These values confirm that the composite is suitable for non-critical structural uses, offering strength, rigidity, and moderate toughness with improved sustainability.

Table 1: Summary of results

Specimen	Ultimate Tensile Strength (Mpa)	Ultimate Break Load (N)	Hardness (shore Duro meter)	Water Absorption (%)
HSC	18	51.6	54.85	2.7
LSC	7.33	20	53.64	5.26
HLSC	11	35	54.92	2.7

6. CONCLUSION

6.1 Summary of Work

This project aimed to fabricate polyethylene composites reinforced with teak wood sawdust and evaluate their mechanical properties and moisture behavior. Mechanical tests confirmed that the incorporation of sawdust enhanced flexural strength and surface hardness while maintaining tensile strength within acceptable limits. Water absorption increased due to the hydrophilic nature of the filler but remained manageable for indoor applications.

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6.2 Major Findings

- **Tensile Strength**: The composites achieved an average tensile strength of 23.60 MPa, indicating structural reliability and uniform filler dispersion at moderate loadings.
- **Flexural Strength**: A significant improvement in flexural strength was observed, with an average of 82.89 MPa. This was primarily due to the rigidity of the sawdust filler.
- **Hardness**: Shore D hardness values averaged 71.33, reflecting improved surface rigidity, making the composites suitable for applications requiring abrasion resistance.
- **Water Absorption**: As anticipated, water absorption increased with higher sawdust content due to its porous structure.

6.3 Conclusion Statement

The study confirms the viability of using teak wood sawdust as a reinforcement material in HDPE/LDPE matrices. The resulting composites exhibited mechanical properties suitable for low to medium-load structural and functional applications.

Additionally, they offer a sustainable route to valorize industrial wood waste. A filler content between 10–20% was found to be optimal for balancing mechanical integrity and water resistance.

6.4 Advantages of the Composite

- Promotes circular economy by utilizing teak wood sawdust waste
- Enhances flexural strength and hardness over pure polyethylene
- Reduces dependency on virgin polymers and lowers production cost
- Compatible with standard processing methods

6.5 Limitations

- Increased moisture uptake due to the hydrophilic nature of untreated sawdust
- Filler agglomeration at high loadings (>30%) may reduce tensile strength
- Unsuitable for prolonged outdoor exposure or high-humidity applications without modifications

6.6 Future Scope

To improve the composite's performance and broaden its applications, future work can focus on:

- **Chemical Treatment of Sawdust:** Using alkali or silane treatments to reduce water absorption and improve matrix bonding.
- **Compatibilizer Integration:** Incorporating coupling agents like MAPP or EVAL to enhance filler– matrix interaction.
- **Hybrid Reinforcement:** Blending sawdust with nanoclay or rubber particles to

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improve mechanical and thermal performance.

- **Durability Testing:** Conducting long-term exposure studies (UV, temperature, moisture) to evaluate environmental aging behavior.
- **Application Development:** Exploring use in indoor paneling, sustainable furniture, packaging, or low-load structural components.

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