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Synthesis of Hybrid Composites from Bio-Based Fillers: Chicken Feather, Groundnut Shell, Sawdust

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ABSTRACT

Experimental research has investigated the mechanical characteristics and water absorption performance of polyethylene-based composites reinforced with sawdust, chicken feathers and groundnut shells. Composite samples have been produced with preset volumetric ratios (20%, 30%, 40%, and 50%) at 160°C and 25 kN pressure. A compression molding machine was used to produce specimens of composite materials. The findings indicate that the composites exhibit promising mechanical properties, making them potentially suitable for various applications. However, the waste polyethylene sheet was tested for comparison. It displayed a tensile strength of 7.56 MPa, impact strength with an average energy absorption of 0.093 J, and hardness strength with an average energy value of 92.72 J. The water absorbency data showed minimal water absorption for composite samples, indicating their resistance to water penetration. Similarly, the thickness swelling data revealed no significant change in thickness after immersion, demonstrating dimensional stability in the presence of moisture. This article presents the details of these experiments conducted systematically.

1. Introduction

Composite materials have revolutionized the field of material science for their outstanding mechanical properties and extensive uses. Presently, researchers' interest has been directed towards hybrid composite materials, owing to their remarkable potential in contrast to their non-hybrid, single fiber-reinforced counterparts. Hybrid composites encompass materials wherein a solitary polymer matrix accommodates two or more diverse fiber types.

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The present work is focused on utilizing waste bio-fiber like groundnut shell, sawdust and chicken feather fiber to prepare composites. Various researchers have worked on sawdust, groundnut shells and chicken feathers. Hybridization of wood powder, groundnut husk and cashew nut fibers has been done to yield better strength, stiffness, high strength-to-weight ratio and other mechanical properties [1]. Groundnut shell ash (GSA) has been used in combination with silicon carbide at different ratios (10:0, 7.5:2.5, 5.0:5.0, 2.5:7.5 and 0:10) as reinforcement for aluminum hybrid composites to study their mechanical properties [2]. In another study, composites with alkaline treated wood sawdust ranging from 10, 20, 30, and 40 to 50 wt% by volume were manufactured by melt-mixing method followed by compression moulding and characterized for their mechanical and water absorption [3]. The mechanical properties of 10% NaOH-treated raffia palm fibre and groundnut shell particulate/epoxy hybrid composites have also been studied. The hybrid composites were produced by hand lay-up technique at 10, 20, 30, 40 and 50% reinforcements of raffia palm fibre and groundnut shell particulate in the ratio of 1:1. The tensile strength ranged from 1.88 MPa to 9.56 MPa while impact strength varied from 0.3 kJ/m^2 to 1.6 kJ/m^2 [4]. Tensile strength, hardness, and toughness of the composites were also evaluated for the reinforcement of recycled polypropylene (recycled PP) and groundnut shell powder consisting of two-particle sizes (0–250 µm and 250–420 µm) [5]. Unsaturated polyester/potash feldspar (UP/PF) composites containing various ratios of wood sawdust fiber (2, 4, and 6 phr) show that wood sawdust (WSD) fiber efficiently improves the mechanical properties of UP/PF/WSD composites and 6% of wood sawdust shows better tensile strength [6]. An investigation has also been done on the dynamic mechanical properties of composites made from groundnut shell powder and recycled high-density polyethylene [7].

A comparative assessment of the mechanical properties of composites with groundnut shells and rice husks as reinforcement in epoxy matrix has been reported [8]. Composites with 2.5, 5, 7.5, 10, 12.5, and 15% content of groundnut shell and rice husk were used, and impact strength, hardness, flexural and tensile strength were tested. Groundnut shell-reinforced epoxy composites exhibit impressive mechanical properties, including impact strength (7.91 J/mm^2 at 12.5%), hardness (7.8 HRF at 5%), flexural strength (43.43 N/mm^2 at 12.5%), and tensile strength (41.60 N/mm^2 at 2.5%). In contrast, the rice husk-reinforced epoxy composites demonstrate slightly lower performance with values such as impact strength (4.91 J/mm^2 at 7.5%), hardness (8.7 HRF at 2.5%), flexural strength (28.21 N/mm^2 at 5%), and tensile strength (16.67 N/mm^2 at 5%). In another study, untreated groundnut shell particles (UGP) and treated groundnut shell particles (TGP) were used to produce composites at 0, 25, 50, 75, and 100 % volumetric levels. At a loading level of 50 %, treated groundnut shell shows the best thermal response and mechanical strength [9]. The mechanical properties of wood-plastic composites, comprising sawdust, polyvinyl chloride (PVC), and calcium carbonate, were evaluated. The reported values include a tensile strength of 7.69 N/mm^2, compression strength of 11.42 N/mm^2, flexural strength of 15.264 N/mm^2, and impact strength of 0.265 N/mm^2 [10].

Plastic pollution impacts many facets of human well-being, including beach aesthetics, drainage, wastewater infrastructure systems, and disease vector breeding grounds [11]. UV light from the sun slowly breaks down plastics or even microplastics that are almost impossible to recover, disrupts food chains, and impairs natural habitats. Addressing these concerns has prompted diverse initiatives aimed at curbing plastic waste. Various treatment approaches have been deployed to mitigate environmental pollution, encompassing reuse, recycling, energy recovery, and controlled disposal in landfills. The aim is to elevate the plastic recycling rate to 55% and limit landfilling to no more than 10% by 2030 [12].

Based on the literature, no hybrid composite has been developed with groundnut shell, sawdusts, or chicken feathers [13]. This article aims to demonstrate the potential usefulness of bio-composites prepared with different agricultural wastes or by-products, such as groundnut shell powder, sawdusts and chicken feathers.

2. Methodology

2.1 Materials

This study used waste polyethylene low density polyethylene (LDPE) as the matrix, while chicken feather, groundnut shell powder and sawdust were used as reinforcements (Figure 1).

(a) (b) (c)

Fig. 1. (a) Chicken feather, (b) groundnut shell, and (c) sawdust

2.1.1 sawdust Preparation

Sawdust treatment for making composite materials typically involves several steps, such as cleaning and drying (Figure 2), before it can be integrated into a composite material. First, sawdust was collected from a sawmill, and all kinds of visible debris, such as bark or stones were removed manually. Its particle size was controlled via vibration and agitation using a sieve shaker, and particles ranging from 63.5 um to 250 um were used for composite making. Then, the sawdust was spread out under sunlight until completely dry, which was confirmed by measuring moisture content using the oven-dry method. Density was measured by weighing sawdust of a specific volume and then calculated. The average density was found to be 0.1781 g/cm^3.

Fig. 2. Sawdust preparation prior to composite making

2.1.2 Chicken Feather Preparation

Chicken feather treatment for making composite materials typically involves several steps, such as cleaning, washing, and drying (Figure 3), before they can be integrated into a composite material. Initially, chicken feathers were collected from poultry farms, and debris was removed manually.

Then, the feathers were washed thoroughly using a mild detergent solution to remove blood or any remaining contaminants. Finally, the feathers were rinsed with distilled water and spread out to dry under sunlight until completely dry.

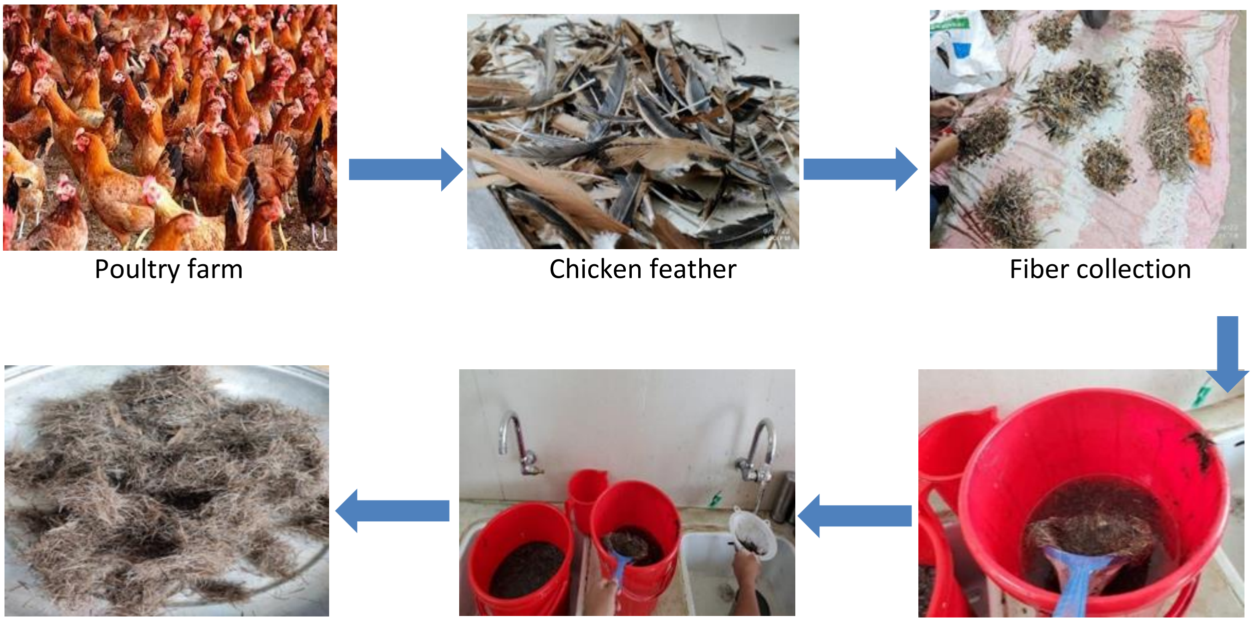

Fig. 3. Chicken feather fiber preparation

2.1.3 Groundnut Shell Preparation

At first, groundnut shells were separated from the groundnut, and dust was removed from the shells. Then, the groundnut shells were immersed in 10% sodium hydroxide (NaOH) for 2 hours and washed several times with distilled water until the pH reached 7. After washing, the groundnut shell was dried in the sunlight for a couple of days until completely dry. These dried groundnut shells were then converted into powder using a grinding machine, and particles of sizes 250, 177, 149, 89, and 63.5 um were sieved using a sieve shaker machine.

2.2 Composite Preparation

Chicken feather, sawdust and groundnut shell were mixed equally, and filler/matrix ratio was followed as Table 1. Compression moulding machine was used to produce the composites. Compression moulding machine was run at 160°C and 25 kN pressure was applied for 10 minutes.

Table 1
Ratio between matrix and filler

Specimen no.	Matrix (%)	Filler (%)
1	80	20
2	70	30
3	60	40
4	50	50

Compression was carried out carefully to avoid air gap build-up within the sample. After separating the rectangular specimen from the mould, it was cut with the help of a hand-operated saw machine to obtain specimens per testing standards.

2.3 Physical and Mechanical Testing

Table 2 lists the standards used for the physical and mechanical testing conducted. The samples were subjected to tensile, impact, hardness, water absorbency and swelling tests to determine the tensile strength, percent of elongation, impact strength, Shore D hardness, water absorbency and thickness swelling percentages.

Table 2
Testing standards for the determination of physical and mechanical properties

Properties	Testing Method
Tensile	ASTM D 638
Impact	ASTM 256
Hardness	ASTM D 2240
Water absorbency and swelling	ASTM D570

3. Results

3.1 Tensile Properties

The tensile strength of these composites was tested according to ASTM D638. As shown in Figure 4, the strength value ranges from 5.37 MPa to 8.775 MPa, while the elongation percentages are between 12.12% and 18.02%.

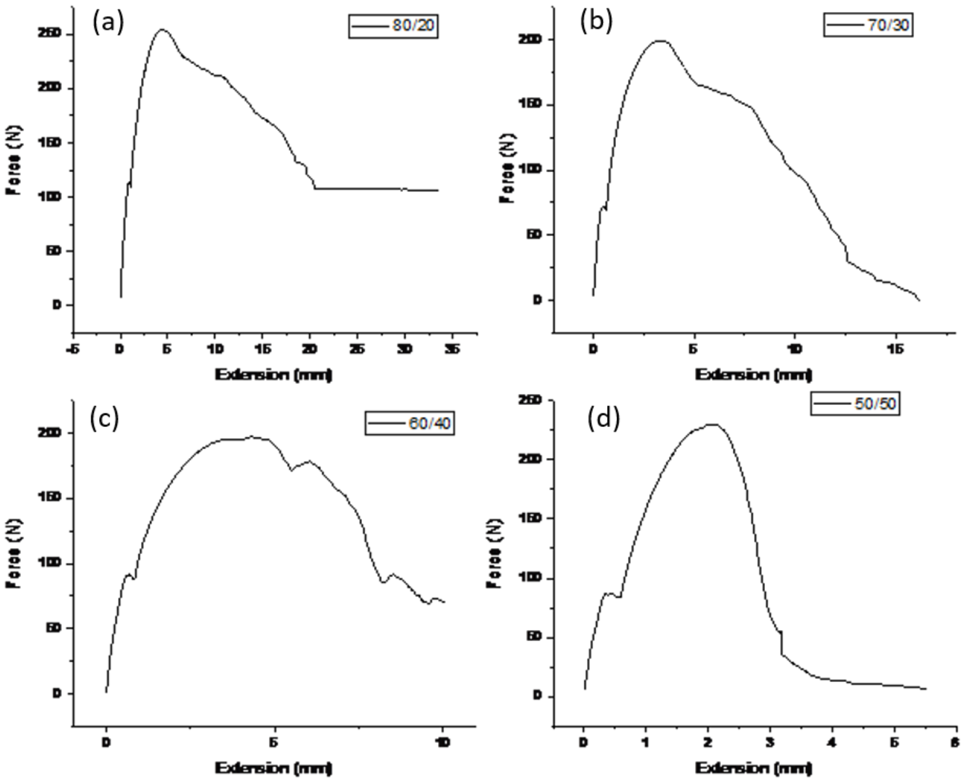

Fig. 4. Force vs elongation of (a) composite 80/20, (b) composite 70/30, (c) composite 60/40 and (d) composite 50/50

Tensile strength increases with adding filler content up to 30% wt. This is due to strong interfacial bonding between the sawdust, groundnut shell powder, chicken feather and the LDPE matrix. This increase in tensile strength results from filler materials incorporation and can be attributed to the intrinsic adhesion of the filler-matrix interface [14].

However, the composite's tensile strength starts decreasing with further addition of sawdust, groundnut shell, and chicken feather content above 30%. Tensile strength reduces as the filler content increases; this can also be attributed to the weak interfacial bonding between the filler (hydrophilic) and the matrix polymer (hydrophobic) at a larger filler content. In general, this weak interfacial bond forms micro-cracks and fiber agglomerates due to preferential fibre-fibre interaction as well as no uniform stress transfer from the fiber to the matrix [15].

3.2 Impact Strength

The impact strength of the composites, as shown in Figure 5, has impact energy ranging from 0.025 joules to 0.045 joules, which is lower than 100% polyethylene (0.09 J). It was established that the impact strength was reduced with increased sawdust, groundnut shell, and chicken feather loading. The loading of fillers reduces elasticity and constrains matrix deformation. Excessive filler content diminishes the energy absorption capacity of the matrix material, resulting in reduced toughness and, consequently, a decrease in impact strength [16].

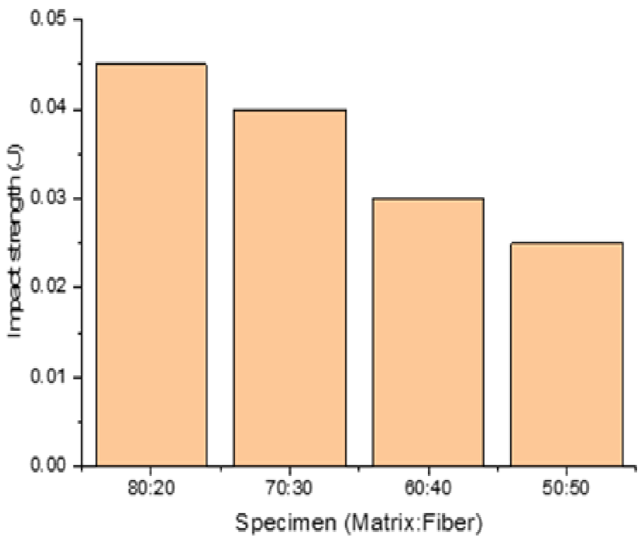

Fig. 5. Impact strength of the composites

3.3 Hardness

The hardness of the composites (Figure 6) with filler fractions of 20%, 30%, 40%, and 50% are 88.2, 92.7, 94.5 and 86.6 Shore D, respectively. The hardness increases with the increase of fiber weight fraction of the composites.

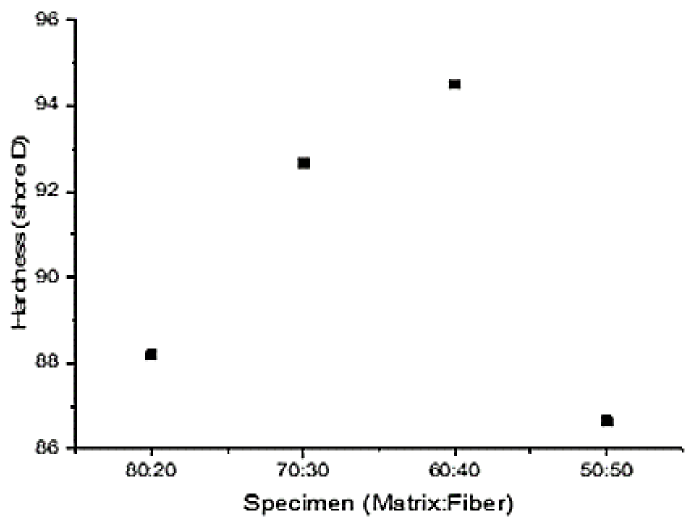

Fig. 6. Hardness of the composites

3.4 Water Absorbency

Water absorption is the amount of water taken up under specified conditions. The formula [(Wet weight - Dry weight) / Dry weight] x 100% is used to calculate the per cent water absorption. For example, if the dry weight of the material is 2.35 grams and the wet weight after absorption is 2.44 grams, the water absorption would be [(2.44 - 2.35) / 2.35] x 100 = 21.15%. The average values of the water absorption of the new composites ranged from 3.24 – 3.82%. The results revealed that the water absorption of the developed composite is very low, as depicted in Figure 7. The considerably low absorption rates of the WPC specimens may be due to the hydrophobic nature of LDPE, as observed by Youssef, El-Gendy et al. [17]. Water absorption increased with increasing fiber content. This could be due to the hydrophilic nature of the sawdust, which leads to high moisture absorption [18].

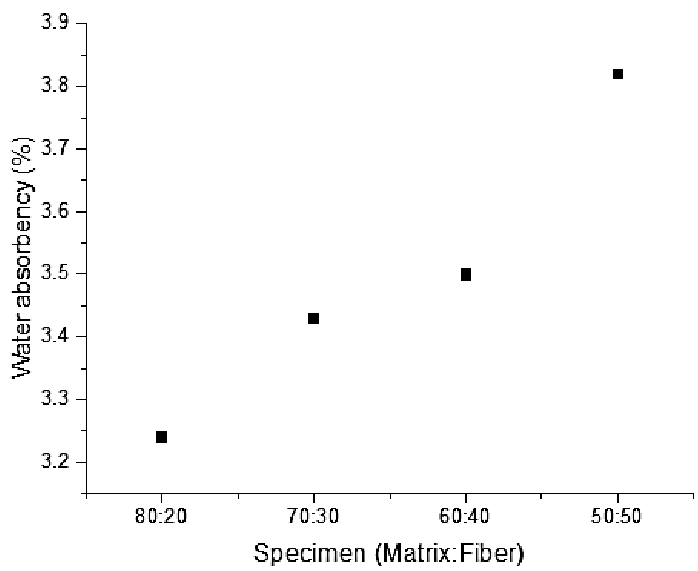

Fig. 7. Water absorbency of the composites

3.5 Thickness Swelling

Overall, these composites experienced no significant swelling when immersed in water. The swelling percentages recorded were less than 1% (Figure 8), indicating that these materials maintain their dimensional stability even in the presence of moisture. Similar to the water absorption trend, the thickness swelling also increased with increasing wt% of fillers in recycled polyethylene-based composite.

However, the 50/50 composite shows 2.7% swelling, probably due to more fibres in the composite sheets. This high volume of fibers has led to a marginal void fraction with micro-particles that promoted the swelling of composite materials. It also helps to correlate the thickness swelling and water absorption effect in the prepared samples. The thickness swelling and high-water absorption have been considered problems in maintaining particleboards. When subjected to water, particleboards with high lignocellulosic content undergo drastic degradation in mechanical properties. The hydrophilicity of wood particles is attributed to hydroxyl groups in the cellulose, hemicellulose and lignin components in wood fibers, which allow hydrogen bonding with water [19]. By replacing the fiber content with hydrophobic LDPE, moisture resistance is consequently improved. As a result, WPCs provide better application in moist or humid environments than high-fiber boards [20].

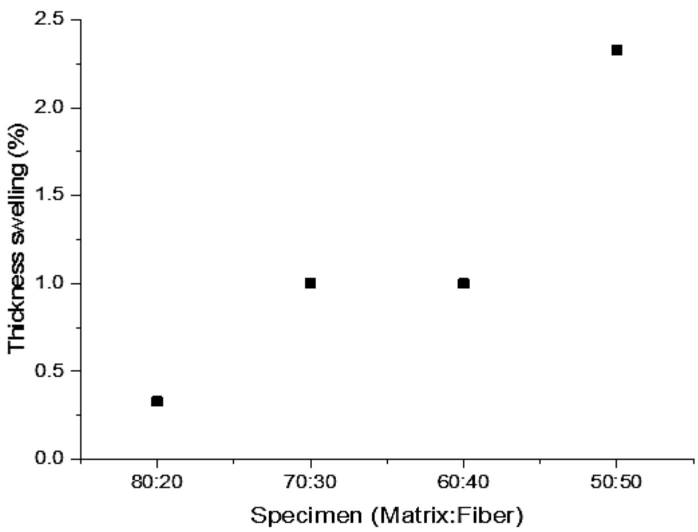

Fig. 8. Thickness swelling of the composites

4. Conclusions

The possibility of using a bio-based filler, i.e., groundnut shell powder, chicken feather and sawdust, was established for the formulation of polymer composites. The optimum reinforcement content in the polymer composite material was revealed to be 30 wt%. Findings of this work reveal that polyethylene reinforced with varying filler contents of sawdust, chicken feather, and groundnut shell mixture exhibited tensile strength from 5.37 MPa to 8.78 MPa, hardness from 86.6 Shore D to 94.5 shore D and low amount of water absorption and thickness swelling. The new composite materials could be used as furniture, panels, walls, and ceilings as they possess the necessary mechanical, low water absorbent (hydrophobic surface of composites) characteristics. These can potentially replace traditionally used wood materials. Future research will focus on expanding the types of plant-based fillers for polymer composites.

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