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Development of a Polymer Matrix Composite Reinforced with Luffa Fibre and White Clay

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ABSTRACT

Luffa is a natural fiber and has found utilization for centuries in various industries, including textiles, craft, and agriculture. The poly matrix materials generally have poor tensile and flexural strength making them to be less preferred in various applications. Therefore, this research aimed to develop a polymer matrix composite reinforced with luffa fibber and clay for use in the automotive and construction sectors. The luffer fruits and white clay were collected from Ilorin and epoxy resin, hardener, and sodium hydroxide (NaOH) were purchased from Jopart Chemical Co-limited, Ilorin, Kwara State, Nigeria. The luffer fruits were stripped of the husks and cut into long fibers. Both the luffer and the white clay were then rinsed using distilled water and sun-dried for 48 hours. The dried luffa and white clay were ground into smaller particles. Eight (8) composite samples were produced from a mixture of resin (65 – 80%), luffa (10 – 70%), and clay (8 – 15%) following the design of experimental techniques. The samples were molded in molding boxes and allowed to solidify for 48 hours. Each sample was characterized for textile strength, toughness, and flexural strength using an Ultimate Tensile Machine while Rockwell hardness was used for the hardness test.

The tensile strength ranged between 4.72 and 18.07MPa, while flexural strength lies between 2.98 and 21.70MPa. The range of Brinell hardness values was 55 – 70BHN and 0.194 – 1.77Nm for toughness. The sample made from 9% clay, 11% luffa, and 80% epoxy gave the highest tensile strength (18.074MPa) and toughness (1.770Nm). Sample with the composition of 20% luffa, 15% clay, and 65% epoxy has the minimum tensile strength (4.723MPa) and hardness of 65BNH. The addition of luffa particles and white clay has been shown to enhance the tensile strength, hardness, and flexural strength of epoxy resin. The reinforced resin can be used for the production of car bumpers.

INTRODUCTION

Fibre-reinforced polymer composites have emerged in the construction industry, gradually replacing steel and concrete. Natural fibers are becoming preferred over synthetic fibers in polymer composites due to their non-toxicity, non-corrosiveness, high strength, low density, cost-effectiveness, renewability, and biodegradability, thereby positively impacting the environment (Azwa *et al.* 2013). The incorporation of biodegradable sources in polymer products may contribute to reducing carbon emissions during plastic incineration (Sahari *et al.*, 2013). However, natural fibre-based composites face challenges such as lower modulus, reduced strength, limited durability, and relatively poor moisture resistance compared to their synthetic counterparts. To overcome these limitations, blending natural fibers with stronger synthetic or natural fibers in the polymer matrix creates hybrid composites that harness the best properties of each component to yield superior, and economically viable products in the ongoing pursuit of enhanced performance materials, of reduced weight, increased strength, and lower costs, conventional materials may reach the limits of their utility. Consequently, material

researchers, engineers, and scientists remain steadfast in their efforts to either enhance traditional materials or develop entirely novel ones. Composites exemplify the latter category (Ticoalu *et al.* 2010; Sahari *et al.* 2013). Over the past three decades, composite materials, plastics, and ceramics have emerged prominently. The volume and range of applications for composite materials have steadily expanded, consistently infiltrating and capturing new markets. In the modern landscape, composite materials constitute a significant portion of the engineered materials market, spanning from everyday products to sophisticated niche applications.

While composites have already demonstrated their efficacy in weight reduction, the current challenge lies in making them cost-effective. Diligent efforts to create economically viable composite components have led to the adoption of innovative manufacturing techniques within the composites industry. Recognition within the industry suggests that the commercial applications of composites present considerably larger business opportunities than those in the aerospace sector, primarily due to the substantial size of the transportation industry (Kabir *et al.* 2012).

Since Nigeria, is blessed with abundant natural fibers such as bamboo, ramie, jute, sisal, pineapple, coir, and banana, has shifted its focus toward advancing natural fiber composites for value-added applications. These natural fiber composites serve as suitable alternatives to wood in the housing and building sector. The development of natural fiber composites in Nigeria follows a dual strategy aimed at preventing the depletion of forest resources while ensuring favourable economic returns for the cultivation of natural fibers. Therefore, the use of White-clay reinforced Luffa sponge on the performance of polymer matrix composite was studied.

The automotive industry faces significant challenges with the durability and performance of car bumpers, which frequently suffer from damage due to minor collisions and adverse road conditions. Traditional materials such as plastics and metal alloys used in bumpers often exhibit inadequate impact resistance and poor environmental sustainability, resulting in high repair and replacement costs. To address these issues, there is a pressing need for innovative, cost-effective, and environmentally friendly materials. This research aims to develop a polymer matrix composite reinforced with luffa fiber and white clay to enhance bumper performance. Despite the advantages of natural fiber-reinforced polymers (NFRPs), such as sustainability and potential cost benefits, they are prone to moisture absorption, variability in fiber properties, and lower fire resistance compared to synthetic materials. This study will explore these challenges and leverage locally available luffa fiber and white clay to create a composite that aims to overcome these limitations, improve durability, and contribute to more sustainable automotive components. The paper is sectioned into five, with the introduction in section one, literature and materials are presented in sections two and three, respectively. Section four has results and discussions on why conclusions and future scope are presented in section five.

MATERIALS AND METHODS

The primary materials used in this study were luffa fibers,white-clay powder, and epoxy resin. The epoxy resin and HV-953-IN hardener were sourced from Jopart Chemical Co-limited, Ilorin, Kwara State, Nigeria, while the dried luffa shown (Figure 1) and white clay (Figure 2) were obtained from local markets in Galadima, and Akerebiata, Ilorin, The hardner played a crucial role in catalyzing and enhancing the curing process of the epoxy resin

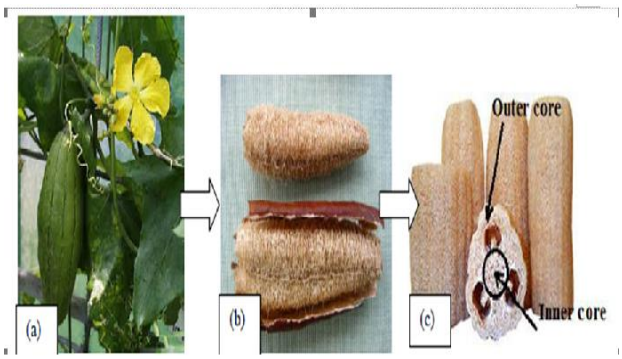

Figure 1: Picture of the Purchase Luffa Fibers

The dried luffas pod was first stripped of their husks, with the seeds carefully removed, the fruits were then cut into long fibers using scissors. To eliminate impurities, the sponge gourd fibers were treated with sodium hydroxide (NaOH), dried at room temperature for 12 hours, rinsed thoroughly with water to remove excess NaOH, and further dried at room temperature for 48 hours. Once dried, the fibers were ground into micro-sized particles using a mechanical milling machine at Oja-Tuntun Market in Ilorin, Kwara State.

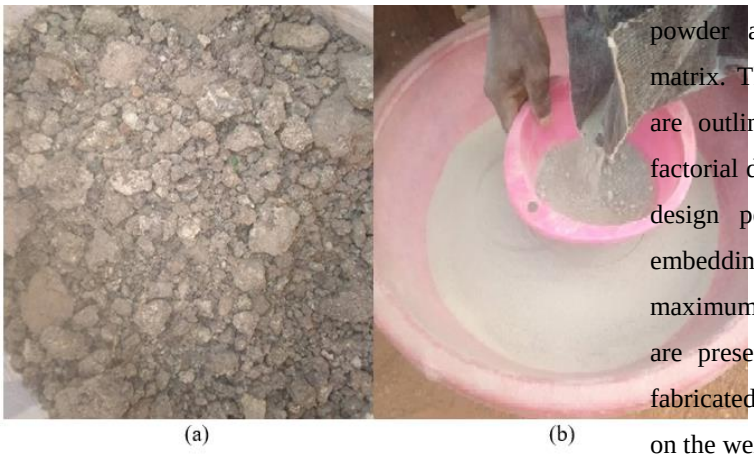

Figure 2: (a) As-received white clay (b) Sieving after grinding

The clay was dried at room temperature for 12 hours, mechanically milled at 300 rpm, and sieved [Figure 2] 20 µm (particles 20 µm and –100 to +20 µm at the metallurgical laboratory, University of Ilorin, to obtain the desired particle size. Three (3) kg of Luffa fiber samples were treated with diluted 0.1 M of NaOH solution for one hour at room temperature. After the treatment, the fiber was thoroughly washed with distilled water to remove any residual impurities and then sun-dried for 48 hours to ensure complete dryness. The dried fibers were mechanically milled at 300 revolutions per minute for 2 hours to break them down into smaller particles. The milled particles were then sieved using sieve sizes ranging from 20 to 100 µm to obtain micro-sized luffa particles. Similarly, six [6] kg of white clay underwent a purification process to eliminate impurities and organic matter. The clay was washed, dried, and ground into a fine powder. It was then mechanically milled at 300 rpm for 12 hours to achieve a uniform particle size, as depicted in Figure 2. This process ensured the clay particles were refined and ready for further use in the study.

The composite samples were designed using Design Expert version 6.0.8 to investigate the effects and interactions of micro-sized Luffa powder and white clay powder on the epoxy matrix. The experimental ranges for the variables are outlined in Table 2. A two-level fractional factorial design was employed to select the optimal design points from the set generated by the embedding algorithm, resulting in eight (8) maximum model points. The results of this design are presented in Table 3. The composites were fabricated using the hand-lay-up technique. Based on the weight percentages of the epoxy resin matrix specified in Table 2, the epoxy resin and curing agent (hardener) were mixed in a ratio of 10:1 (v/v). The required weight proportions of Luffa fiber and clay powder were measured and sequentially mixed with the epoxy resin/hardener blend. The mixture was gently stirred for 5 minutes to ensure homogeneity and then poured into a

prepared wooden mold. All experiments were conducted at room temperature, following the same procedure to maintain consistency. This step is critical for achieving optimal reinforcement properties in the composite material.

Table 1: Experimental processing parameters and levels

Factors	Level	
	I	II
A: Luffa fiber powder (g)	0	2
B: Clay powder (g)	0	5
C: Diglycidyl epoxy (g)	100	70

Table 2: Experimental Model for Polymer Composite Formation

	Component Mixture		
Samples	**Factor A: Luffa Fiber Powder (wt.%)**	**Factor B: White-Clay Powder (wt.%)**	**Factor C: Diglycidyl Epoxy (wt.%)**
S0	0	0	100
S1	12	8	80
S2	15	10	75
S3	13	12	75
S4	10	10	80
S5	20	15	65
S6	12	13	75
S7	10	15	75
S8	11	9	80

A wooden mould with dimensions of 150 mm × 100 mm × 5 mm was used to cast the composite samples. Additionally, cylindrical specimens with dimensions of Ø10 mm × 20 mm length were prepared for hardness testing and phase analysis. These specimens were carefully fabricated to ensure uniformity and accuracy in testing. The tensile strength of the developed Luffa fibre-epoxy resin composite samples was evaluated using a Universal Testing Machine (UTM) in compliance with the ASTM D 3039-76 standard. All specimens were prepared in a dog bone shape with dimensions of 140 mm × 10 mm × 5 mm.

RESULT AND DISCUSSION

Tensile Strength

The results for tensile strength, yield strength, and Young's Modulus for each sample are presented in Table 4. The findings reveal that Sample S1 exhibited a tensile strength of 9.491 MPa, while Samples S2 and S3 showed lower tensile strengths of 7.317 MPa and 7.436 MPa, respectively. The incorporation of Luffa fibre significantly enhanced the maximum load-bearing capacity of the composites. Among all samples, Sample S8, which contained 9 wt.% of white clay powder, demonstrated the highest tensile strength, indicating the beneficial effect of clay reinforcement on the mechanical properties of the composite.

Table 3: Result of Tensile Test

Samples	White-Clay Powder (wt.%)	Tensile strength	Yield strength	Young's modulus
S1	8	9.491	9.491	1199.746
S2	10	7.317	7.317	684.956
S3	12	7.436	1.884	590.705
S4	10	12.820	12.820	1415.504
S5	15	4.723	1.175	357.704
S6	13	9.821	9.821	552.994
S7	15	9.752	2.826	986.475
S8	9	18.074	18.074	1604.300

The enhanced tensile strength, yield strength, and modulus can be attributed to the strong and harmonious bonding between the micro-sized Luffa fibers, white clay powder, and the epoxy resin matrix. This effective interfacial adhesion

contributes to improved stiffness, strength, and load-bearing capacity of the composite material. Furthermore, as the percentage of Luffa fiber increases, a corresponding rise in stiffness is observed, indicating that the fiber reinforcement plays a critical role in enhancing the mechanical properties of the composite.

Flexural Strength Test

The variations in flexural strength and the corresponding deflections are presented in Table 5. With the addition of white clay powder reinforcement, the flexural strength of Sample S2 was found to be higher than that of Sample S1. Specifically, Sample S5 exhibited a flexural strength of 15.264 N/mm² and deflected over a length of 1.607 mm.

Table 4: Results of the Flexural Strength Test

Samples	White-Clay Powder (wt.%)	Flexural strength (N/mm²)	Deflection (mm)
S1	8	2.976	0.744
S2	10	3.627	1.102
S3	12	4.371	1.333
S4	10	12.291	1.593
S5	15	15.264	1.607
S6	13	16.418	1.811
S7	15	17.712	2.024
S8	9	21.699	2.506

The flexural strength increased progressively across the samples, with Sample S8 demonstrating the highest flexural strength of 21.699 N/mm² at 9 wt.% white clay powder. These results indicate relatively improved flexural properties, which can be attributed to the strong interfacial bonding between the reinforcements (Luffa fibers and white clay powder) and the epoxy resin matrix. This effective bonding enhances the overall mechanical performance of the composite material.

Hardness Test

The hardness of the fabricated samples was measured using a Rockwell Hardness Testing Machine, and the results are presented in Table 6. The data reveals an arithmetic variation in hardness across the samples, with Sample S6 exhibiting the highest hardness value of 70 BHN, closely followed by Sample S4 with a hardness value of 68 BHN. The corresponding toughness values for these samples range between 0.194 to 1.77 Nm

Table 5: Result of Hardness Test

Samples	Micro-sized Luffa Fiber (wt.%)	Hardness (BHN)	Toughness (N.m)
S1	12	59	0.194
S2	15	55	0.289
S3	13	59	0.431
S4	10	68	0.949
S5	20	65	0.341
S6	12	70	0.542
S7	10	57	0.894
S8	11	58	1.770

The results demonstrate a clear trend: higher hardness correlates with greater strength but reduced ductility, stiffness, and flexural strength. This inverse relationship is consistently observed across all tested samples, highlighting the trade-off between hardness and other mechanical properties in the composite materials.

CONCLUSION

The research highlights Luffa fiber as an eco-friendly material with promising applications. Surface modification using 0.1M NaOH improved fiber-matrix adhesion, enhancing flexural properties. While fiber addition reduced tensile strength, it increased bending modulus in epoxy/polyester composites. Treated fibers absorbed more water than untreated ones, making the composites suitable for foot mats and partitions.

Tensile strength varied with fiber and white-clay content, with Sample S8 (9 wt.% white clay) showing the highest load-bearing capacity. Flexural strength improved with increased white-clay reinforcement, indicating strong bonding with the epoxy matrix. Hardness and mechanical properties also increased, demonstrating the potential of these composites for high-performance structural applications.

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