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Physico-Mechanical Characterization of Termite Mound Soil-Cement Composites Reinforced with Cylindrical Luffa Fibre

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***Abstract:** This study evaluates the physico-mechanical properties of cement-bonded composites utilizing termite mound soil as a primary matrix binder and cylindrical luffa (Luffa aegyptiaca) fibres as reinforcement. Composite boards were prepared with fibre contents of 2.5%, 5.0%, 7.5%, and 10.0%. Physical properties assessed included water absorption, thickness swelling, and density, while mechanical properties such as compressive strength, modulus of elasticity, and modulus of rupture were determined using standardized methods. Results showed that water absorption and thickness swelling increased with fibre content, reflecting the hydrophilic nature of luffa fibres. Density decreased as fibre proportion rose, indicating reduced matrix compactness and binder effectiveness. Mechanical properties improved at moderate fibre levels, particularly at 7.5%, where reinforcement was most effective. However, at 10% fibre loading, strength and stiffness declined due to fibre agglomeration, poor fibre-matrix adhesion, and micro-crack formation. Regression analyses confirmed polynomial relationships between fibre content and measured properties, with moderate correlation values, demonstrating the usefulness of statistical modelling in predicting composite performance. Overall, the study highlights luffa fibres as promising reinforcement material for sustainable composites. Optimal fibre incorporation enhances mechanical performance while maintaining acceptable physical properties, whereas excessive fibre loading compromises structural integrity. These findings provide practical guidance for developing eco-friendly composites suitable for construction applications.*

***Keywords:** Luffa fibre, Cement-bonded composite, Termite mound soil, Regression analysis, Eco-friendly construction.*

I. INTRODUCTION

The construction sector remains a vital contributor to economic growth in emerging nations such as Nigeria, where demand for roofing, ceiling boards, paneling, and furniture continues to rise. However, this industry has traditionally relied heavily on forest resources, particularly wood-based panels, leading to deforestation, biodiversity loss, and escalating costs of timber products (Abba et al., 2025). Recently studies emphasize the urgent need to adopt sustainable alternatives, including agricultural residues and earth-based binders, to mitigate environmental degradation and reduce dependence on conventional materials (Obanla, 2023).

Agricultural wastes such as rice husks, corn cobs, coconut coir, and groundnut shells are abundant and inexpensive, making them suitable raw materials for particleboards production. Their utilization not only reduces environmental pollution but also provides affordable substitutes for wood in construction applications (Obanla, 2023). Similarly, earth-based binders like termite mound soil have gained attention due to their availability. Durability, and reduced tendency to crack compared to conventional clays. Termite mound soil, formed through the secretion of termites, exhibits mineralogical properties comparable to clay and has been successfully applied in construction materials across Africa (Omofunmi and Oladipo, 2021).

In parallel, natural fibres such as cylindrical luffa (Luffa aegyptiaca) offer promising reinforcement potential. Luffa fibres are lightweight yet mechanically robust, with high cellulose content (55-90%) and significant lignin and hemicellulose fractions, which contribute to their toughness and durability. Recent investigations highlight luffa's superior performance compared to several traditional engineering materials, making it a viable candidate for composite board development (Obanla, 2023).
Despite these opportunities, Nigeria's construction industry continues to face challenges of high

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materials costs and limited availability of sustainable alternatives. This study therefore aims to develop composite boards using cylindrical luffa fibres reinforced with termite mound soil and cement, and to evaluate their physical and mechanical properties. The findings are expected to contribute to sustainable construction practices by providing affordable, eco-friendly alternatives to conventional wood-based panels.

II. METHODOLOGY

2.1 Materials

The materials employed in this study were cylindrical luffa (Luffa aegyptiaca), termite mound soil, Elephant Portland cement, and potable water.

2.2 Preparation of materials

Cylindrical luffa fibres were sourced locally from iseyin, Oke-Ogun, Oyo State, Nigeria. The fibres were cut into into 1 cm in lengths, and stored in polythene bags. Termite mound soil was collected, crushed, and sieved to 600µm for uniformity (BS 410-1:2000). The sieved soil was stored in airtight containers to prevent contamination and moisture absorption. Elephant Portland cement was purchased and stored airtight to preserve strength. Potable water was used throughout. These prepared materials formed the basis for composite particleboard production and subsequent property evaluation.

2.3 Board formation

Composite boards bonded with termite mound soil and cement were produced by combining cylindrical luffa fibres with a base mixture of 2000g of termite mound soil and 1000g of Portland cement. Fibre contents were varied at 2.5%, 5.0%, 7.5%, and 10.0% by weight to evaluate performance. The components were accurately batched using a digital weighing balance and thoroughly manually-mixed to ensure homogeneity and prevent fibre agglomeration. The resulting slurry was poured into moulds of standard dimensions, compacted, and allowed to set. Boards were demoulded after 24 hours and cured under moist conditions for 28 days to achieve strength.

2.4 Evaluation of the properties of composite boards produced

2.4.1 Physical properties

The physical properties evaluated included water absorption, (WA), thickness swelling (TS), and density.

2.4.1.1 Water absorption

Water absorption was determined in accordance with ASTM D-570. Three specimens of dimensions 100 x 100 x 10 mm were prepared. The specimens were oven-dried to constant mass, cooled, and weighed (M_1). They were then immersed in water at ambient temperature for 24 hours, removed, surface-dried with a lint-free cloth, and reweighed (M_2). Water absorption was expressed as the percentage increase in mass:

$$WA = \frac{M2-M1}{M1}\ x\ 100$$

Where M_1 is the oven-dry mass and M_2 is the mass after immersion.

2.4.1.2 Thickness swelling

Thickness swelling was measured following immersion tests. Three specimens of 100 x 100 x 10 mm were oven-dried to constant weight, and initial thickness (T_i) was measured using a digital vernier caliper. Specimens were immersed in water for 24 hours, removed, surface-dried, and final thickness (T_f) recorded. Thickness swelling was calculated as:

Where T_i is the initial thickness and T_f is the thickness after immersion

2.4.1.3 Density

Density was determined in accordance with BS EN 772-11 (2011). Specimens were oven-dried to constant mass, dimensions were measured to compute volume, and mass was recorded.

Density was calculated as:

$$\text{Density} = \frac{Mass}{Volume}$$

2.4.2 Mechanical properties

2.4.2.1 Compressive strength

Compressive strength was determined according to ASTM D-1037 (1978) and EN 310 (1993). Cubical specimens of 100 x 100 x 100 mm were tested using a Universal Testing Machine (UTM). Each specimen was centrally positioned between platens, and load was applied gradually until failure. Compressive strength was calculated as:

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$$CS = \frac{WC}{B \; x \; T}$$

Where Wc is the failure load (N), B is specimen breadth (mm), and T is thickness (mm).

2.4.2.2 Modulus of elasticity

The modulus of elasticity was measured according to ASTM D-1037 (1999). Specimens (195 x 50 x 10 mm to three-point bending using the UTM. Load was applied at midspan at a uniform rate until failure, and deflection was recorded. MOE was calculated as:

$$MOE = \frac{PL}{4BD3}$$

Where P is maximum load (N), L is span length (mm), B is specimen width (mm), D is thickness (mm).

2.4.2.3 Modulus of rupture

Modulus of rupture testing followed ASTM D-1037 (1999). Specimens were loaded under three-point bending until rupture, with maximum load recorded. MOR was calculated as:

$$MOR = \frac{3PL}{2bd2}$$

Where P is maximum applied load (N), L is span between supports (mm), b is specimen thickness (mm).

III. RESULTS AND DISCUSSION

3.1 Results

Table 3.1: A summary of the findings from cylindrical luffa fibres bonded with termite mound soil and cement.

Sample	2.5%	5.0%	7.5%	10.0%
Water absorption (%)	28.24	36.54	52.58	73.95
Thickness swelling (%)	4.55	5.12	6.36	7.26
Density (g/mm^3)	0.00131	0.00115	0.00093	0.00074
Compressive strength (MPa)	3.85	1.74	1.02	0.62
Modulus of Elasticity (MPa)	1052.60	3298.30	6844.71	313.33
Modulus of rupture (MPa)	0.77	1.26	3.87	11.93

3.2 Discussion

3.2.1 Effect of cylindrical luffa quantity on water absorption

The regression analysis confirmed a strong polynomial relationship between luffa fibre content and water absorption, with values increasing from 28.24% at 2.5% fibre loading to 73.95% at 10.0% in the Table 3.1. This trend reflects the hydrophilic nature of luffa fibres, which are rich in cellulose and hemicellulose, thereby enhancing moisture uptake as reported by Sasi Kumar et al. (2025). The regression equation:

y = 05228x2 – 40.82x + 25. 872 and coefficient of determination $R^2 = 0.9998$

demonstrate a reliable fit, consistent with findings that fibre loading significantly influences water absorption in bio-based composites (Singh et al., 2023). Furthermore, regression modeling in Figure 3.1 has been widely applied to predict composite behaviour, supporting its use in correlating physical and mechanical properties such as compressive strength, modulus of elasticity, and modulus of rupture (Mohammed et al., 2025).

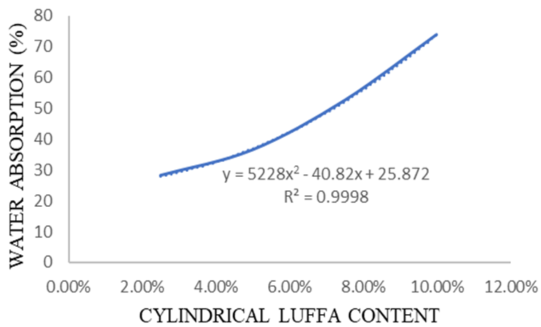

Fig. 3.1: Effect of cylindrical luffa on water absorption

3.2.2 Effect of cylindrical luffa quantity on thickness swelling

Table 3.1 presents the effect of different cylindrical luffa contents on thickness swelling. The thickness swelling of the composite boards increased progressively with higher luffa fibre content, ranging from 4.55% at 2.5% fibre loading to 7.26% at 10.0%. This behavior is attributed to the hydrophilic nature of luffa fibres, which absorb moisture and expand when immersed in water (Sasi Kumar et al., 2025). The presence of cellulose and hemicellulose in luffa fibres enhances water uptake, thereby influencing dimensional stability (Singh et

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al., 2023). Similar findings were reported by Mohammed et al. (2025), who observed that fibre-matrix adhesion and void content significantly affect swelling in natural fibre composites. The results confirm that increasing fibre proportion reduces dimensional stability, highlighting the need for fibre treatment or hybridization to improve performance. The regression equation:

y = 132x2 + 20.98x + 3.8925 and coefficient of determination $R^2 = 0.9886$

Regression analysis indicated a strong positive relationship between luffa fibre content and thickness swelling in Figure 3.2, confirming that dimensional expansion increases with fibre loading. The polynomial model produced a high coefficient of determination ($R^2 > 0.9886$), demonstrating reliable predictive accuracy. This response is attributed to the hydrophilic nature of luffa fibres, which promotes moisture absorption and fibre expansion within the composite matrix. The result is consistent with recent studies showing that natural fibre content plays a critical role in governing dimensional stability through water uptake and fibre–matrix interaction effects (Sasi Kumar et al., 2025; Singh et al., 2023).

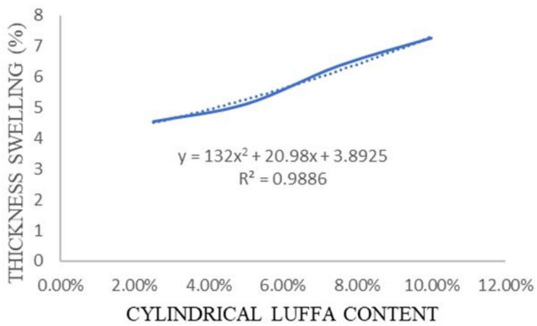

Fig. 3.2: Effect of cylindrical luffa on thickness swelling

3.2.3 Effect of cylindrical luffa quantity on density

Table 3.1 illustrates the effect of different cylindrical luffa contents on density. Density of the cement-bonded luffa fibre composites decreased steadily with increasing fibre content, ranging from 0.00131 g/mm³ at 2.5% fibre loading to 0.00074 g/mm³ at 10.0%. This reduction is attributed to the lower density of luffa fibres compared to the matrix, which reduces packing efficiency and weakens binder effectiveness (Sasi Kumar et al., 2025). Similar findings were reported by Singh et al. (2023), who observed density reduction in bio-based composites with higher fibre volume. The regression equation:

$y = -0.021x^2 – 0.0062x + 0.0015$ and coefficient of determination $R^2 = 0.9978$

Regression analysis of density revealed a negative correlation in Figure 3.3 between fibre content and composite compactness, with $R^2 = 0.9978$ confirming model reliability. This agrees with Alhijazi et al. (2020), who reported that increasing natural fibre volume reduces density due to poor fibre-matrix adhesion and void formation in bio-composites.

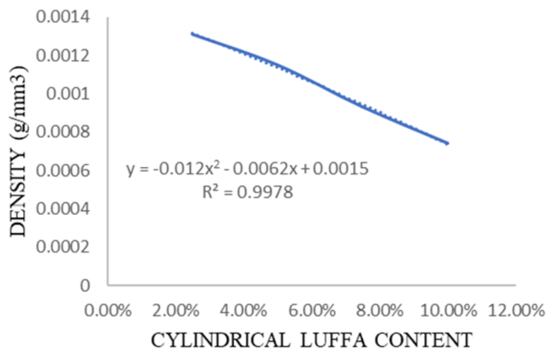

Fig. 3.3: Effect of cylindrical luffa on density

3.2.4 Effect of cylindrical luffa quantity on compressive strength

Table 3.1 demonstrates the effect of different cylindrical luffa contents on compressive strength. Compressive strength of the cement-bonded luffa fibre composites decreased with increasing fibre content, ranging from 3.85 MPa at 2.5% fibre loading to 0.62 MPa at 10.0%. This reduction is attributed to poor fibre–matrix adhesion and the porous nature of luffa fibres, which weaken load transfer efficiency (Alhijazi et al., 2020). Similar reductions in compressive strength with higher fibre volume were reported by Sahu and Gupta (2022), who emphasized the role of void content and hydrophilicity in limiting mechanical performance of bio-composites. The regression equation:

$y = 684x^2 – 127.14x + 6.5475$ and coefficient of determination $R^2 = 0.9908$

Regression analysis of compressive strength indicated a clear negative correlation with fibre loading in Figure 3.4, confirming reduced strength as fibre proportion increased. The polynomial fit showed moderate reliability ($R^2 \approx 0.9908$). Similar regression-based findings were reported by Zhang et al. (2021), highlighting fibre-matrix incompatibility and voids as key factors in strength reduction.

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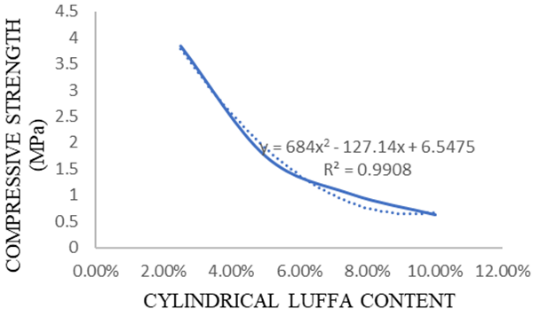

Fig. 3.4: Effect of cylindrical luffa on compressive strength

3.2.5 Effect of cylindrical luffa content on modulus of elasticity

Table 3.1 demonstrates the effect of different cylindrical luffa contents on modulus of elasticity. The modulus of elasticity of cement-bonded luffa fibre composites varied between 313.33 MPa and 6844.71 MPa. MOE increased from 2.5% to 7.5% fibre loading, indicating effective reinforcement, but decreased at 10% due to fibre agglomeration and poor fibre–matrix adhesion. This reduction is linked to micro-crack formation and non-uniform stress transfer. Similar trends were reported by Zhang et al. (2021), who observed reduced stiffness at higher fibre volumes in natural fibre composites. The polynomial regression model (R^2 = 0.7493) confirmed moderate correlation between fibre content and modulus of elasticity. The regression equation:

y = -4E-06 + 444169x – 8426.3 and coefficient of determination R^2 = 0.7493

Regression analysis of modulus of elasticity revealed a non-linear trend in Figure 3.5, with maximum reinforcement at 7.5% fibre loading and decline at 10%. The polynomial fit (R^2 = 0.7493) showed moderate reliability. Similar regression-based observations were reported by Li et al. (2020), emphasizing fibre agglomeration effects on stiffness reduction.

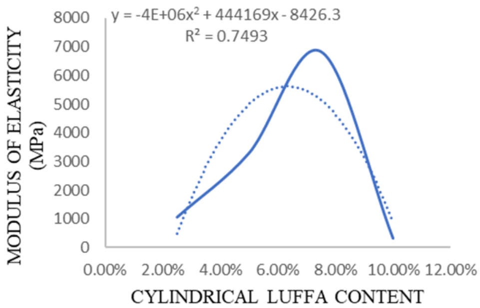

Fig. 3.5: Effect of cylindrical luffa on modulus of elasticity

3.2.6 Effect of cylindrical luffa content on modulus of rupture

Table 3.1 presents the effect of different cylindrical luffa contents on modulus of rupture. The modulus of rupture of cement-bonded luffa fibre composites varied widely, ranging from 0.77 MPa at 2.5% fibre loading to 11.93 MPa at 10.0%. MOR increased with fibre addition up to 7.5%, indicating effective reinforcement, but declined at higher fibre content due to fibre agglomeration and weak fibre-matrix bonding. This reduction is consistent with regression-based findings by Prasad et al. (2021), who reported decreased flexural strength in natural fibre composites at elevated fibre volumes. The polynomial regression model confirmed moderate correlation between fibre content and modulus of rupture. The regression equation:

y = 3028x2 – 234.14x + 4.8975 and coefficient of determination R^2 = 0.9931

Regression analysis of modulus of rupture demonstrated a non-linear relationship in Figure 3.6, with strength peaking at 7.5% fibre loading before declining. The polynomial fit ($R^2 \approx 0.9931$) indicated moderate predictive accuracy. Similar regression-based findings were reported by Das et al. (2020), highlighting fibre agglomeration and weak bonding as critical factors reducing flexural strength.

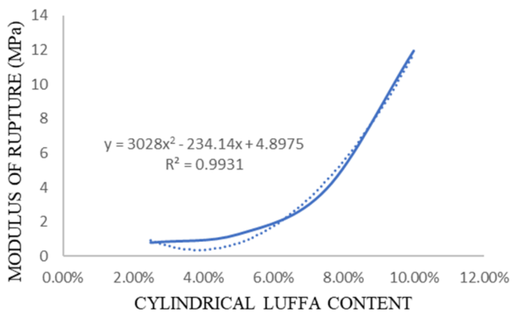

Fig. 3.6: Effect of cylindrical luffa on modulus of rupture

IV. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

The investigation into cement-bonded composites reinforced with cylindrical luffa fibres has demonstrated clear relationships between fibre content and the physical as well as mechanical properties of the material. Water absorption and thickness swelling increased progressively with higher fibre loading, reflecting the hydrophilic nature of luffa fibres. Density values decreased as fibre proportion rose, indicating reduced matrix compactness and binder effectiveness. Mechanical properties such as compressive strength, modulus of elasticity, and modulus of rupture showed an initial improvement at moderate fibre levels, particularly around 7.5%, before declining at 10% due to fibre agglomeration, poor adhesion, and micro-crack formation. Regression analyses confirmed polynomial trends across all properties, with varying degrees of correlation, highlighting the predictive potential of statistical modelling in composite design. Overall, the study reveals that luffa fibres can serve as effective reinforcement when optimally incorporated, but excessive fibre content compromises structural integrity. The findings emphasize the importance of balancing fibre volume with matrix compatibility to achieve composites that combine sustainability with desirable mechanical performance, offering potential for eco-friendly construction applications.

4.2 Recommendations

Based on the findings of this study, several recommendations can be made to enhance the performance of termite mound soil and cement-bonded luffa fibre composites.

Firstly, fibre loading should be optimized around moderate levels, particularly near 7.5%, where mechanical properties such as modulus of elasticity and modulus of rupture showed improvement before declining at higher fibre content. Excessive fibre addition should be avoided, as it leads to poor fibre-matrix adhesion, agglomeration, and reduced density, which compromise structural integrity.

Secondly, fibre treatment methods such as alkali or chemical modification are recommended to reduce hydrophilicity, thereby minimizing water absorption and thickness swelling. Improved fibre surface compatibility will enhance bonding with the cement matrix and promote uniform stress transfer.

Thirdly, hybridization with other natural or synthetic fibres may be explored to balance mechanical strength and dimensional stability. Additionally, careful control of processing parameters, including mixing ratios and curing conditions, is essential to achieve consistent composite quality.

Finally, future research should investigate long-term durability under varying environmental conditions to establish the suitability of luffa fibre composites for sustainable construction applications.

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