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Utilization of maize cobs for the production of eco-friendly composite boards

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Abstract

The rising demand for wood-based particleboards in Nigeria's construction sector has intensified deforestation, environmental degradation, and timber scarcity. Additionally, conventional particleboards use synthetic adhesives like urea-formaldehyde and phenol-formaldehyde, which emit carcinogenic formaldehyde, posing health and environmental risks.

This research investigated the effects of maize cob particles bonded with termite mound soil and cement on the physical and mechanical properties of composite boards. The study assessed parameters including density, compressive strength, flexural strength, modulus of elasticity, modulus of rupture, water absorption, and thickness swelling. Results revealed that increasing maize cob content generally reduced density and mechanical strength, while dimensional instability increased. Optimal performance was achieved at 2.5–5.0% maize cob inclusion, where composites exhibited improved strength and stability suitable for structural applications. Beyond this threshold, excessive cob loading introduced voids, weakened particle–matrix adhesion, and compromised stiffness and rupture resistance. The findings demonstrate that maize cob particles can serve as sustainable reinforcement material in eco-friendly composites, particularly in regions with abundant agricultural residues. By optimising cob proportions, composite boards can balance environmental benefits with mechanical reliability. This study highlights the potential of agricultural waste utilisation in advancing sustainable construction materials and promoting circular economy practices.

Keywords: Maize Cobs; Composite Boards; Termite Mound Soil; Eco-Friendly Construction; Agricultural Residues; Mechanical Properties

1. Introduction

The construction industry in developing countries such as Nigeria remains a vital contributor to economic growth, yet it is heavily dependent on forest resources for roofing, panelling, and furniture production. This reliance has accelerated deforestation, increased timber costs, and contributed to environmental degradation (Adebayo et al., 2021). To address these challenges, researchers have increasingly explored the use of agricultural residues as sustainable alternatives in composite board production (Okon et al., 2022).

Maize cobs, a major by-product of maize cultivation, are abundantly available in Nigeria and other maize-producing regions. Recent studies highlight their fibrous structure and potential for industrial applications, including particleboard production, bioenergy generation, and adsorbent materials (Ogunleye & Adeola, 2023). With Nigeria producing millions of tonnes of maize annually, maize cobs represent an underutilised resource that can reduce dependence on wood while promoting circular economy practices (Eze et al., 2024).

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Conventional particleboard manufacturing relies on synthetic adhesives such as urea-formaldehyde and phenol-formaldehyde, which emit carcinogenic formaldehyde and pose health risks (Barasa et al., 2025). In contrast, natural binders such as termite mound soil offer eco-friendly alternatives. Termite soil has been shown to possess high plasticity, mineral stability, and reduced cracking compared to ordinary clay, making it suitable for construction applications (Malumi et al., 2024). Its abundance across Africa further enhances its potential as a cost-effective binder in composite materials (Ojo et al., 2024).

Integrating maize cobs with termite mound soil and cement in composite board production therefore presents a promising pathway toward sustainable construction materials. This approach not only addresses environmental concerns but also leverages locally available resources to support affordable housing and infrastructure development in Nigeria. The present study aims to develop and evaluate the physical and mechanical properties of maize cob–based composite boards bound with termite mound soil and cement, thereby contributing to eco-friendly alternatives in the construction industry.

2. Methodology

2.1. Materials

The raw materials used for particleboard production included maize cobs, termite mound soil, Portland cement, and potable water. Maize cobs were sourced locally from Bodija Market, Ibadan, while termite mound soil was collected from the Polytechnic, Ibadan, compound. Portland cement was purchased from Sango Market, Ibadan.

2.2. Preparation of materials

Maize cobs were manually cut into smaller pieces with a knife, sun-dried to a moisture content below 4.5%, and milled into fine particles. The particles were sieved through a 2.36 mm British Standard sieve (BS 410-1:2000). Pre-treatment involved soaking the sieved particles in water for 20 minutes to remove debris, discarding the particles that sank to the bottom of the bowl, and boiling the floating particles for one hour to soften the particles to promote mechanical disintegration.

Termite mound soil was pulverised, air-dried, and sieved through a 600-µm sieve (BS 410-1:2000). Cement was used as an additional binder in selected mixes.

2.3. Board formation

Composite boards were produced using maize cob particles, termite mound soil, cement, and water. The binder mass consisted of 2000 g of termite mound soil and 1000 g of Portland cement, while maize cob particles were incorporated at five inclusion levels: 2.5%, 5.0%, 7.5%, 10.0%, and 12.5% by weight. All materials were weighed with an electronic balance to ensure accuracy.

The composites were thoroughly mixed to achieve a homogeneous slurry and poured into moulds prepared to the required dimensions. After remaining in the moulds for 24 hours, the boards were carefully demoulded. Curing was carried out under controlled moisture conditions for 28 days to allow proper hydration of the cement and bonding of the maize cob particles with the termite mound soil.

2.4. Evaluation of the properties of composite boards produced

2.4.1. Physical properties

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

Water absorption

Water absorption was determined according to ASTM D-570. Specimens of 100 x 100 x 10 mm were oven-dried to constant weight, cooled in a desiccator, and weighed (M_1). They were then immersed in water at 23^0 C for 24 hours. After immersion, specimens were surface-dried with a lint-free cloth and re-weighed (M2). Water absorption was expressed as the percentage increase in mass:

$$\text{W. A (\%)} = \frac{M2-M1}{M1}\ x\ 100$$

Thickness swelling

Thickness swelling was measured following immersion of oven-dried specimens (100 x 100 x 10 mm) in distilled water at 20-250 C for 24 hours. The initial thickness (t_1) and final thickness (t_2) were recorded, and swelling was calculated as:

$$T.S\ (\%) = \frac{t2-t1}{t1}\ x\ 100$$

Density

Density was determined by dividing the mass of each specimen by its volume:

$$\rho = \frac{M}{V}$$

2.4.2. Mechanical testing

Compressive strength

Compressive strength was evaluated in accordance with ASTM D-1037 and EN 310. Cubic specimens (100 x 100 x 100 mm) were loaded in a universal testing machine until failure. Strength was calculated as:

$$\sigma_c = \frac{Wc}{b.t}$$

where Wc is the failure load (N), and b and t are specimen dimensions (mm)

Flexural strength

Flexural strength was determined using central point loading on specimens (100 x 100 x 100 mm) per ASTM D-1037. The maximum load (P) was applied until failure, and strength was calculated as:

$$\sigma_f = \frac{PL3}{4bd3}$$

Modulus of elasticity (MOE)

Modulus of elasticity was measured using specimens (195 x 50 x 50 mm) tested at midspan loading per ASTM D-1037. Deflection was recorded, and MOE was calculated as:

$$MOE = \frac{PL3}{4bd3}$$

Modulus of rupture (MOR)

Modulus of rupture was determined using specimens (195 x 50 x 50 mm) under midspan loading until failure. The maximum load (P) was used to calculate MOR:

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

3. Results

Table 1 A summary of the findings from maize cob particles bonded with termite mound soil and cement.

Sample (%)	**2.5%**	**5.0%**	**7.5%**	**10.0%**	**12.5%**
Water absorption (%)	15.07	16.05	17.21	21.85	22.34
Thickness swelling (%)	2.24	3.60	4.93	5.52	6.10
Density (g/mm^3)	0.00155	0.00133	0.00126	0.00117	0.00115
Compressive strength (MPa)	5.06	3.82	2.76	1.86	1.54

Flexural strength (MPa)	7.59	5.78	4.14	2.79	2.31
Modulus of elasticity (MPa)	2342.7	2264.1	1499.6	1056.3	787.5
Modulus of rupture (MPa)	2.61	2.93	2.12	1.67	1.26

4. Discussion

4.1. Effect of maize cob quantity on water absorption.

Table 1 presents the effect of different maize cob contents on water absorption, which displayed a non-linear trend across varying maize cob levels. The water absorption recorded an increase from 15.07% to 22.34% with higher maize cob inclusion in Figure 1, showing a nonlinear trend. Polynomial regression analysis confirmed a strong fit (R^2 = 0.921), indicating that absorption rises disproportionately at higher cob loadings. This behaviour reflects the hydrophilic nature of lignocellulosic fibres, rich in hydroxyl groups, which enhance moisture uptake and create pore channels in the cement-soil matrix (Okon et al., 2022; Ajayi et al., 2023; Ogunleye and Adeola, 2023). Thus, optimal cob content (2.5–5.0%) ensures dimensional stability, while excessive inclusion compromises water resistance.

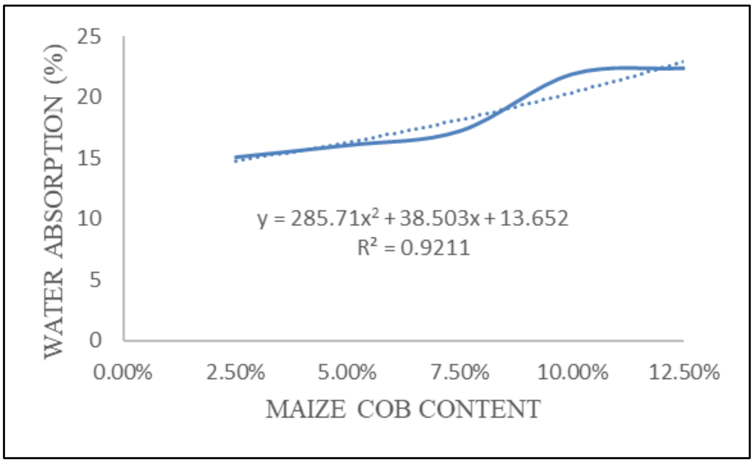

Figure 1 Effect of maize cob on water absorption

4.2. Effect of maize cob content on thickness swelling

Table 1 illustrates the effect of different maize cob contents on thickness swelling. The thickness swelling increased with maize cob content, ranging from 2.24% to 6.10% after 24 hours. The rise in swelling at higher cob loadings reflects reduced binder availability and poor particle-matrix adhesion, which facilitates water penetration. Similar nonlinear increases in swelling have been reported in agrowaste composites, where lignocellulosic fibres introduce porosity and dimensional instability (Isam et al., 2020; Ajayi et al., 2023; Eze et al., 2024). Lower cob inclusion (2.5-5.0%) maintained better dimensional stability, while excessive loading (>7.5%) accelerated swelling. The polynomial regression graph in Figure 3.2 shows the relationship between maize cob content (%) and thickness swelling (%). It highlights the nonlinear increase in swelling as cob inclusion rises, with the regression curve fitting strongly ($R^2 \approx 0.997$). This visualisation confirms that low maize cob inclusion (2.5-5.0%) maintains dimensional stability, while higher inclusion levels (>7.5%) lead to accelerated thickness swelling due to pore formation and fibre-matrix incompatibility. This trend is consistent with recent studies on agrowaste composites (Okon et al., 2022; Ogunleye and Adeola, 2023; Eze et al., 2024).

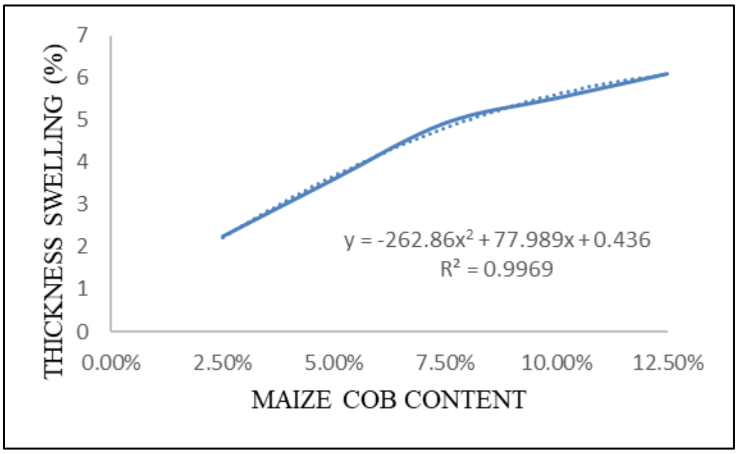

Figure 2 Effect of maize cob on thickness swelling

4.2.1. Effect of maize cob content on density

Table 1 demonstrates the effect of different maize cob contents on density. The composites decreased with increasing maize cob content, ranging from 0.00155 g/mm^3 at 2.5% to 0.00115 g/mm^3 at 12.5%. This reduction reflects the lower density of maize cob compared to termite mound soil and cement, which reduces the compactness of the matrix. Similar findings were reported in studies on agrowaste composites, where higher fibre inclusion reduced density due to increased porosity and weaker packing (Isam et al., 2020; Okon et al., 2022; Ajayi et al., 2023; Eze et al., 2024).

The polynomial regression graph in Figure 3.3 shows how density decreases with increasing maize cob content. The curve demonstrates a strong fit ($R^2 \approx 0.985$), confirming that higher maize cob inclusion reduces composite density due to its lower mass compared to cement and termite mound soil. Low cob inclusion (2.5–5.0%) maintains higher density, while excessive loading (>7.5%) reduces compactness and increases porosity, consistent with recent agrowaste composite studies (Isam et al., 2020; Okon et al., 2022).

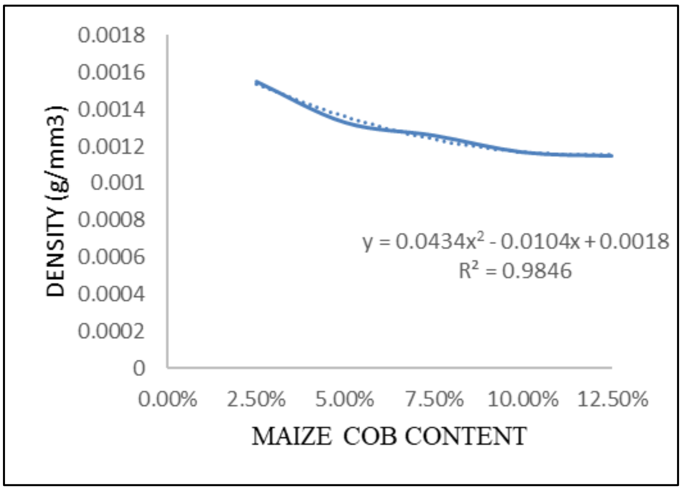

Figure 3 Effect of maize cob on density

4.3. Effect of maize cob content on compressive strength

The results of compressive strength in Table 1 show the effect of different maize cob contents on compressive strength. The compressive strength of composites decreased with increasing maize cob content, ranging from 5.06 MPa at 2.5% to 1.54 MPa at 12.5%. The reduction is attributed to weaker particle-matrix bonding and an increased water-cement ratio, which reduced compactness and workability. Similar declines in strength with higher agrowaste inclusion have been reported in cement-bonded composites (Isam et al., 2020; Okon et al., 2020). Thus, optimal cob inclusion is necessary to balance ecofriendliness with mechanical performance

The polynomial regression graph in Figure 4 shows how compressive strength decreases with increasing maize cob content. The curve demonstrates a strong fit ($R^2 \approx 0.998$), confirming that higher maize cob inclusion weakens the cement-soil matrix due to reduced bonding and an increased water–cement ratio. Low cob inclusion (2.5 - 5.0%) maintains higher compressive strength, while excessive loading (>7.5%) significantly reduces mechanical performance. These findings align with recent studies on agrowaste composites (Ajayi et al., 2023 and Eze et al., 2024).

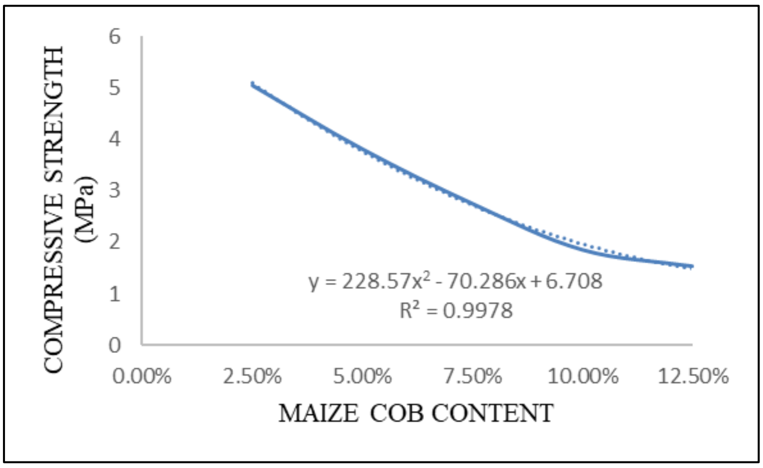

Figure 4 Effect of maize cob on compressive strength

4.4. Effect of maize cob content on flexural strength

Table 1 shows the effect of different maize cob contents on flexural strength. Flexural strength decreased with increasing maize cob content, ranging from 7.59 MPa at 2.5% to 2.31 MPa at 12.5%. The reduction is attributed to poor particle–matrix adhesion, increased voids, and the low density of maize cob, which weakened load transfer. Similar declines in flexural strength with higher agrowaste inclusion have been reported in cement-bonded composites and earth blocks (Okon et al., 2022). Thus, minimal cob inclusion enhances bending resistance, while excessive loading compromises mechanical performance.

Polynomial regression graph showing the relationship between maize cob content (%) and flexural strength (MPa) in Figure 5. The curve highlights the nonlinear decline in strength, with the regression fit ($R^2 \approx 0.997$) confirming that higher cob inclusion weakens particle–matrix bonding and increases voids. Low cob inclusion (2.5–5.0%) maintains higher flexural strength, while excessive loading (>7.5%) reduces bending resistance. These findings align with recent agrowaste composite studies (Isam et al., 2020).

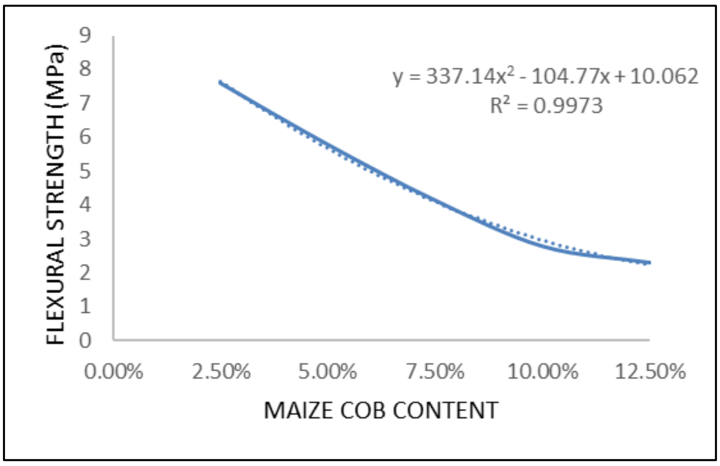

Figure 5 Effect of maize cob on flexural strength

4.5. Effect of maize cob content on modulus of elasticity

Table 1 illustrates the effect of different maize cob contents on the modulus of elasticity. The modulus of elasticity decreased with increasing maize cob content, ranging from 2342.75 MPa at 2.5% to 787.50 MPa at 12.5%. This reduction is linked to insufficient adhesive coverage over larger cob particle surfaces, which weakened interfacial bonding and mechanical performance. Similar declines in stiffness have been reported in agrowaste composites, where higher fibre inclusion reduces matrix cohesion and elasticity (Ishimwe et al., 2021; Abetie, 2021; Ajayi et al., 2023; Eze et al., 2024). Thus, minimal cob inclusion enhances stiffness, while excessive loading compromises structural integrity.

The polynomial regression graph showing the relationship between maize cob content (%) and modulus of elasticity (MPa) in Figure 6. The curve demonstrates a strong nonlinear decline, with the regression fit ($R^2 \approx 0.953$) confirming that higher cob inclusion reduces stiffness due to weaker particle–matrix bonding. Low cob inclusion (2.5–5.0%) maintains higher modulus of elasticity, while excessive loading (>7.5%) compromises mechanical performance. These findings align with recent agrowaste composite studies (Ishimwe et al., 2021; Abetie, 2021; Ajayi et al., 2023; Eze et al., 2024).

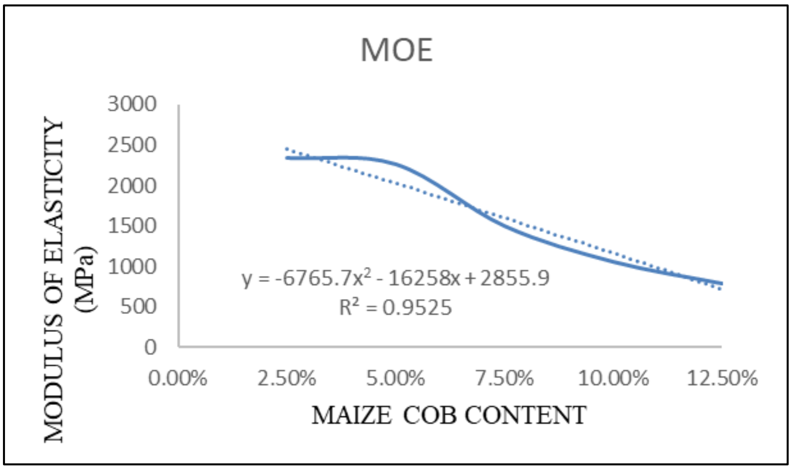

Figure 6 Effect of maize cob on modulus of elasticity

4.6. Effect of maize cob content on modulus of rupture

Table 1 demonstrates the effect of different maize cob contents on modulus of rupture (MOR). The modulus of rupture ranged from 2.93 MPa at 5.0% to 1.26 MPa at 12.5%, showing an initial increase followed by a decline. The optimum strength at 5.0% reflects improved load transfer, while higher cob inclusion reduced bonding, created voids, and weakened stiffness. Similar nonlinear MOR behaviour has been reported in agrowaste composites, where excessive fibre loading compromises mechanical integrity (Ishimwe et al., 2021; Abetie, 2021; Ajayi et al., 2023; Eze et al., 2024). Thus, moderate cob content enhances rupture resistance, but excessive loading reduces strength.

the polynomial regression graph showing the relationship between maize cob content (%) and modulus of rupture (MPa). The curve highlights the nonlinear trend, with MOR peaking at 5.0% cob inclusion before declining, and the regression fit ($R^2 \approx 0.96$) confirms the observed behaviour. Moderate cob inclusion (around 5.0%) enhances rupture resistance, while higher loadings (>7.5%) weaken bonding, create voids, and reduce mechanical strength. These findings align with recent agrowaste composite studies (Ishimwe et al., 2021; Abetie, 2021; Ajayi et al., 2023; Eze et al., 2024).

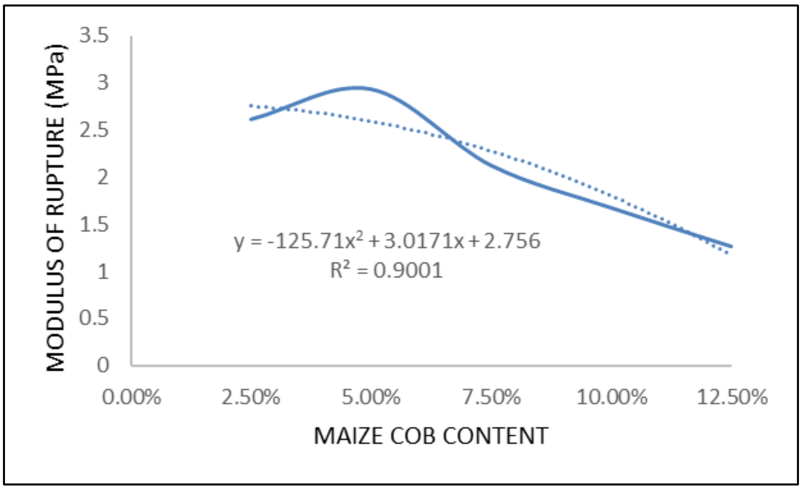

Figure 7 Effect of maize cob on modulus of rupture

5. Conclusion

This study examined the effects of maize cob particles bonded with termite mound soil and cement on composite board properties. Results showed that increasing maize cob inclusion reduced density, compressive strength, flexural strength, modulus of elasticity, and modulus of rupture, while water absorption and thickness swelling increased. Optimal performance was achieved at 2.5–5.0% cob content, where mechanical strength and dimensional stability were maintained. Beyond this level, excessive cob loading introduced voids, weakened particle–matrix adhesion, and compromised structural integrity. The findings highlight that maize cob particles can serve as sustainable raw material for eco-friendly composite production, provided their proportion is carefully optimised to balance environmental benefits with mechanical performance. This demonstrates the potential of agricultural residues in advancing sustainable construction materials while reducing waste.

5.1. Recommendations

Based on the findings of this study, it is recommended that maize cob particles be incorporated into composite board production at controlled proportions, ideally between 2.5% and 5.0%, to achieve optimal mechanical strength and dimensional stability. Excessive inclusion beyond this threshold significantly reduces density, compressive strength, flexural strength, modulus of elasticity, and modulus of rupture, while increasing water absorption and thickness swelling. For sustainable applications, maize cob particles should be pretreated to improve adhesion with termite mound soil and cement, thereby minimising void formation and enhancing bonding. Future research should explore hybrid reinforcement using maize cob in combination with other agrowastes or additives to optimise performance. Industrial adoption of maize cob composites can reduce environmental waste, promote circular economy practices, and provide affordable alternatives for construction materials, particularly in regions with abundant agricultural residues. This approach supports eco-friendly innovation while maintaining structural reliability.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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