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Research Article

Physicomechanical and Thermal Properties of Particle Board Produced Using Waste Ceramic Materials and Corncob

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Waste management and recycling have led to numerous studies on particleboard production. This study attempted to use milled corncob (MCC) and waste ceramic tiles (WCTs) to produce particleboard. The MCC (100–70 wt.%) and WCT (0–30 wt.%) were mixed at different ratios, mixed and compressed at a pressure of 0.25 MPa using urea formaldehyde (UF) resin as adhesive. The physicomechanical and thermal properties of the particleboards produced were investigated. The physical properties (bulk density, water absorption, and thickness swelling) improved with composite particleboard compared to the 100% MCC particleboard. The increase in WCT yielded improved density and lowered the particleboard's water absorption and thickness swelling. The mechanical tests showed that MOE values were below the recommended standard, which makes them unsuitable for structural use. However, MOR revealed values above the recommended standard. The thermal conductivity of the particleboards was reduced with increased WCT, and the required standard was found to be met. Hence, the particleboards produced are found helpful as thermal wall insulators. Based on the experiments done, sample R7 (70% MCC and 30% WCT) was considered the most preferable since it achieved the most preferable physicomechanical and thermal conductivity performance. The particleboards produced are recommended for wall partitioning and other internal and external purposes.

1. Introduction

In recent years, there has been a growing tendency towards managing and recycling waste of all kinds. Wastes could be from domestic, industrial, animal, human, or agricultural activities and are environmental pollutants and a menace to society [1, 2]. The management and recycling of these wastes have produced numerous new products such as particleboards, biomass briquettes, car bumpers, and bio-oil and biochar [3–5]. Out of these numerous waste categories, the wastes from construction and agricultural sectors through agricultural activities are of great concern in this study.

Producing particleboards from various agroresidues (renewable materials) serving as replacements for solid wood particles has attracted more attention from researchers [5–7]. Using these agrowastes for particleboard manufacturing has served as a solution to the problem of raw material shortage for the particleboard industry. These agrowastes are utilised based on their environmental friendliness, nontoxicity, low cost, renewability, and recyclability [8, 9]. Moreover, the sustainability of forest timber consumption has led to a high deforestation rate worldwide. As a result, there is a grave consequence on the environment, thereby contributing to the global warming of the earth. Hence, a sustainable resource transition system is required majorly in developing countries [10, 11].

The enormous quantities of agricultural residues and wastes in most African countries are due to subsistence and commercial farming activities with little or no appropriate management techniques to tackle the waste. These wastes, such as the stalks of most cereal crops, palm waste, sawdust, corncob, sugarcane bagasse, mangrove bark, palm kernel shell, coconut coir, and rice husk, are primarily generated during and after harvesting of crops. These wastes have been utilised in several other applications, as reported by several studies [12–15]. Hence, it has led to a cleaner environment by preventing the indiscriminate burning of agrowaste, thus mitigating climate change [16, 17]. Among the various applications is the utilisation of the agroresidues for particleboard production.

Nigeria's estimated average corn production is around 11 million metric tons [18]. Hence, Nigeria is ranked the second largest producer of corn in Africa after South Africa. Therefore, the abundance of corn has made the residue (corncob) pose a serious environmental threat to the country. For this reason, recycling corncob with a combination of waste ceramic tiles for producing particleboards is necessary to mitigate the environmental effect on climate change. Particleboards are materials made by densifying wood chips with binders. These materials are primarily separate or different particles consolidated with resins or adhesives, compacted together under specific temperatures and pressure in the hot press process, leading to enhanced properties. Aside from lignocelluloses present in the biomass (agroresidue), adhesive is another important material for producing particleboard. Among the commonly used adhesives are urea formaldehyde (UF), phenol-formaldehyde (PF), melamine formaldehyde (MF) resins, and so on [5].

Recently, numerous studies have been done on utilising various agrowastes for producing particleboards [19–21]. For instance, the hybrid combination of sawdust and rice husk at various weight percentage ratios with the introduction of metallic chips was used to produce particleboard using UF and gelatinous starch as adhesives. The physicomechanical properties of the boards were investigated. Some mixing ratios met EN, ANSI A 208.1, and USDA standards considering the MOR, MOE, and IBS. Hence, the utilisation of both agrowastes for particle board production was recommended [5]. Jonoobi et al. [22] utilised agricultural residue and industrial waste in the development of a composite board for some interior construction works. Sawdust being the major material was blended with polypropylene plastic, where cement and expanded polystyrene serve as adhesives.

The composite panel produced fulfilled all conditions (physical and mechanical properties) for the utilisation as a partition wall. Ohijeagbon et al. [23] investigated the potential of two waste fibrous materials of straw and beech veneer splinters for particleboard production. It was found that straw and beech veneer splinters have the potential to supplement fibrous materials, in combination with wood particles, for particleboard manufacturing and indoor applications. Azizi et al. [24] studied the performance of particleboards manufactured from expanded vermiculite (VER) and date palm branches (DPBs, Phoenix dactylifera). The DPB was a viable substitute fibre material for indoor applications and particleboard manufacture. It may also partially or fully replace insulating boards in wooden buildings, absorb noise, and maintain indoor living space temperatures. Particle boards were produced in the study of Ghofrani et al. [25] using a mixture of *Eucalyptus* wood and different proportions of coconut fibre. The physical and mechanical properties investigated revealed the compatibility features of the panels for construction, furniture, and other necessary civil engineering projects. The physicomechanical properties of the hybridised grapevine and pine at different mix ratios for particleboard production were investigated by de Souza et al. [26]. The particleboard produced, especially using 90% pine and 10% grapevine, revealed vital mechanical properties higher than the global industry standard. These improved mechanical properties over the 100% pine (control) were attributed to the ability of the grapevine particles to occupy voids between the pines. As a result, there was a higher surface density gradient. More so, in a similar study by Wong et al. [27], where grapevine served as the raw material for particleboard production, the board achieved the minimum standard of strength to be helpful in construction works.

Through optimisation of the parameters used in the production of groundnut shell/rice husk-based particleboard where UF served as the binder, it was reported that the particleboard synthesised with the optimum parameters fulfilled the ANSI/A208-1999 standard for general-purpose particleboards [28]. Considering the major base agrowaste (corncob), Olawale et al. [29] investigated the properties of corncob/sawdust particleboard produced using UF as a binder. It was reported that replacing sawdust with corncob between 25% and 50% gave physical properties that are satisfactory for building interior utilisation. However, due to poor mechanical properties obtained when corncob particulates increased between 25% and 75%, the particleboard could not be recommended for load-bearing functions because it does not fulfil the European standard requirements. The 50% corncob replacement was preferable since it satisfied the physicomechanical properties evaluated. Corncob particleboards were produced using two binders in the study of Akinyemi et al. [30]. Polyvinyl acetate and Fabricol AG 222 were the binders used. The study investigated the thermal performance as well as the life cycle of the particleboards. The study revealed that the particleboard from the corncob has the potential for utilisation as a sustainable material in buildings since thermal performance showed it could serve as a good wall thermal insulator.

The literature on the utilisation of waste ceramic tiles for particle board production is scarce. More so, the low mechanical properties obtained when corncob and rice husk were used in particleboard production made it unsuitable for load-bearing function. Hence, it is essential to investigate the physicomechanical properties of particleboard produced when corncob is reinforced with waste ceramic tiles. In this study, particle board was synthesised using corn cob as the base material, while waste ceramic tile was added as an additive. The physical properties of milled corn cob and waste ceramic tiles (WCTs) were determined. Furthermore, the physicomechanical and thermal properties of the particle board produced were investigated, considering the effects of the variation of WCT addition on the particle board.

2. Materials and Methods

2.1. Raw Materials and Sample Preparation. This study utilised milled corncob (MCC), waste ceramic tiles (WCTs), and urea-formaldehyde resin as the binder for particle board production. These materials are shown in Figures 1(a)–1(c). The corncobs used were obtained from a nearby farm at *Ijare*, Ondo State, and transported to the laboratory. Sorting and cleaning of the corncobs were done. The corncobs were sundried for three (3) days to remove inherent moisture and for easy grinding. The corncob was then milled into smaller sizes and sieved using sieve number 4. The waste ceramic tile was gathered from different construction sites within the Akure metropolis. The WCT was cleaned, dried, and pulverised into powder.

2.2. Mix Design and the Production Process. The proportion of constituent materials was done by varying WCT from 0% to 30% in the mix, as shown in Table 1. The process of particle board production from material collection to the final product is displayed in Figure 2. All the materials used in the production of the particle boards, including corncob and waste ceramic tiles, were separately measured by weight using a weighing scale except for urea formaldehyde, which was measured in volume using a measuring cylinder. The urea formaldehyde used was 30% of the entire composition. The quantity of each material was calculated from Table 1 and poured into a head pan. Then, the urea formaldehyde was measured and poured into the mixture, after which the whole content was thoroughly mixed until the adhesive was uniformly distributed and a homogeneous mixture was achieved.

Before pouring, the homogeneous mixture was transferred into the lined mould and tamped properly with an iron rod to reduce air voids. The mould cover was then placed on it and moved for compression using a hydraulic jack. A metal plate was placed on the mould for uniform compression throughout the mould and then it was compressed at a pressure of 0.25 MPa to a height of 12 mm at room temperature. The pressure was applied for 30 min and then transferred into an oven to dry for one (1) hour at a temperature of 80°C. The mould was then removed from the oven and allowed to cool for 10 min before removing the panel from the mould and left for twenty-four (24) hours. Afterwards, it was placed in an oven for another three (3) hours to set properly. The particle board was removed and placed on a flat surface for cooling. The final dimension of the produced particleboard was 350 mm × 350 mm × 12 mm.

2.3. Characterisation of the Raw Materials and Particle Board

2.3.1. Specific Gravity Test. The specific gravity of a material is the weight of a certain volume of material per unit weight of an equal volume of water. This test on fine aggregates was carried out to determine the ratio between the weight of a given volume of the fine aggregates and the weight of an equal volume of water in accordance with ASTM D 854-14 standard. The specific gravity of the sample was calculated using the following equation:

$$\text{Specific gravity } (G_s) = \frac{M_2 - M_1}{((M_2 - M_1) - (M_3 - M_4))}, \quad (1)$$

where M_1 is the mass of empty pycnometer, M_2 is the mass of empty pycnometer and sample, M_3 is the mass of empty pycnometer, sample, and water, and M_4 is the mass of empty pycnometer and water only.

2.3.2. Particle Size Distribution. The sample was prepared according to the processes outlined in ASTM C136/136M-19 standard for the particle size distribution. The results were plotted on a semilogarithmic scale, and the uniformity coefficient and curvature were calculated to determine the grading and packing of the samples.

The percentage retained was calculated using the following equation:

$$\% \text{ Retained} = \frac{\text{Weight retained}}{\text{Total wt. of sample}} \times 100. \quad (2)$$

2.3.3. Bulk Density Test. The bulk density of the samples was evaluated using the ASTM D6683-19 standard, which is the mass of aggregates required to fill the container of a unit volume after aggregates were batched.

The bulk density of the sample is the total mass of the sample to the total volume of the same and is shown in equations (3)–(5).

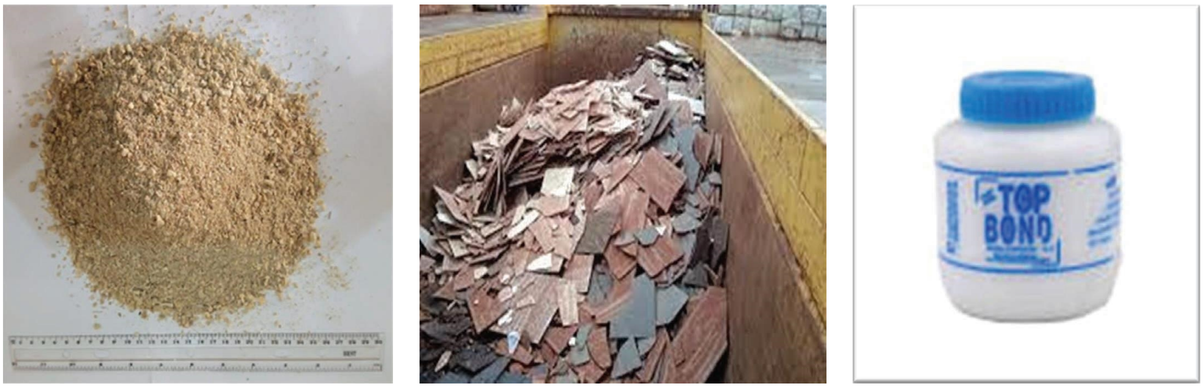
$$\text{Bulk density} = \frac{\text{Weight of sample } (W_s)}{\text{Volume of sample } (V_s)}, \quad (3)$$

$$\text{Weight of sample } (W_s) = W_2 - W_1, \quad (4)$$

$$\text{Volume of ring } (V_r) = \pi r^2 h, \quad (5)$$

where W_1 is the weight of the container, and W_2 is the weight of the container and sample.

2.3.4. Water Absorption Test. A water absorption test was carried out to determine the amount of water the particle board can absorb within a particular time frame and also to determine the dimensional stability of the board, according to the ASTM D570 standard. The samples cut to the previously stated size were measured as initial weight (Wi) and then soaked in water at room temperature for 2 and 24 h for final weight (W_f). The water absorption (in percentage) was then calculated using the following equation:



(a) (b) (c)

Figure 1: Major materials for particle board production: (a) milled corncob, (b) waste ceramic tile, and (c) urea-formaldehyde (UF) resin.

Table 1: Particle board mix design.

S/N	Corncob (%)	Waste ceramic tiles (%)
R1	100	0
R2	95	5
R3	90	10
R4	85	15
R5	80	20
R6	75	25
R7	70	30

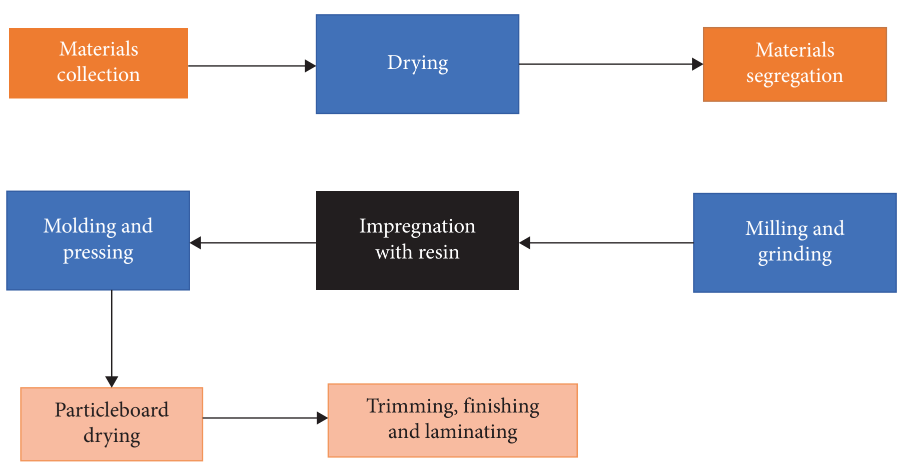


Figure 2: Schematic diagram of the production process of particle board.

$$\text{Water absorption } (WA) = \frac{W_f - W_i}{W_i}, \tag{6}$$

where W_i is the initial weight of the sample before water immersion, and W_f is the final weight of the sample after water immersion.

2.3.5. Thickness Swelling Test. It is a dimensional test used to determine the change in thickness of the particle board samples after immersion in water for a particular period. This test was done using the ASTM D1037-12 standard. The initial thickness of the samples was measured using a digital Vernier caliper before immersing them in water at room temperature. The thickness of the boards was measured using Vernier caliper before and after soaking for 2 and 24 hours at room temperature. The thickness swelling was expressed as the percentage of increase in thickness of the board over the original thickness according to Fono-Tamo et al. [14] using the following equation:

$$\text{TS} = \frac{T_2 - T_1}{T_1}, \tag{7}$$

where TS = thickness swelling; T_2 = final thickness, and T_1 = initial thickness.

2.3.6. Bending Strength. The 290 mm × 50 mm × 12 mm board test specimens were subjected to a load on the universal testing machine according to the ASTM D1037-03 standard. Two rollers at each end supported the specimen and loaded at the centre. The forward movement of the machine leads to a gradual increase of load at the middle span until failures of the test specimens occurred. The force exerted on the specimen that caused the failure was recorded at the point of failure. The modulus of rupture (MOR) of the test specimens was evaluated using the following equation (8) [14]:

$$\text{MOR} = \frac{3\rho L}{2bd^2}, \tag{8}$$

where MOR = modulus of rupture; ρ = failing load; L = span between centres of support (mm) = 20 × d; b = width of the test specimen (mm); and d = mean thickness of the specimen (mm).

The panel's stiffness, modulus of elasticity (MOE), will be determined from the bending test performed on each specimen, and MOE was determined using the following equation according to Fono-Tamo et al. [14]:

$$\text{MOE} = \frac{\rho L^3}{4bd^3 H}, \tag{9}$$

where MOE = modulus of elasticity of panel stiffness; ρ = load at proportional limit, L = span between centres of support (mm), b = width of the test specimen (mm), d = mean thickness of the specimen (mm); and H = increment in deflection (mm).

2.3.7. Compressive Strength. The compressive strengths test was conducted according to ASTM C349 [21]. The strengths were determined using a universal testing machine with a load capacity of 2000 kN on a 100 mm^3 specimen. The reported test results were the average of three measurements. The compressive strength of the specimen was expressed as the maximum crushing load in Newton (N) divided by the effective area in millimetres (mm), as shown in the following equation:

$$F_{cu} = \frac{\text{Force}, F}{\text{Area}, A}, \tag{10}$$

where F_{cu} is the compressive strength.

2.3.8. Thermal Conductivity. The k-value, or thermal conductivity (W/m°C), is among the crucial properties to be considered when determining whether a substance may be used as a thermal insulator or may stand the test of time under fire conditions. Using the guarded hot-plate technique, the thermal conductivity of the samples was assessed. This technique requires the guarded hot-plate equipment to be used in a steady state (controlled environment). The test was conducted on the 28th day of curing by vertically stacking the samples (Figure 3), which resulted in a thin wall that could pass through the hot-plate chamber's entrance, which measured 150 mm × 100 mm between the hot and cold chambers. Two surface temperature sensors, as well as a heat flux plate sensor on the sample facing the hot side compartment, were employed in the test. A surface temperature sensor was attached to the sample facing the cold side compartment. The sensors were linked to a multichannel data recorder, which recorded the information gathered.

Figure 3: Arrangement of sample into the guarded hot plate plugged with the stabiliser.

Using the general equation shown in equations (11)–(13), as provided by Fourier's law, the data from the data logger were used to calculate the material's thermal conductivity.

$$Q^{\circ} = -kA\frac{dT}{dx}, \tag{11}$$

$$P = kA\frac{(T_1 - T_2)}{dx}, \tag{12}$$

$$k = P \times \frac{dx}{A} \times \frac{1}{(T_1 - T_2)}, \tag{13}$$

where Q° = rate of heat transfer, T_1 = temperature of the heating chamber, T_2 = temperature of the sample after 1 hour, k = thermal conductivity (W/mk), P = power supplied to the heating chamber = (watts), dx = thickness of sample (m), A = cross-sectional area, m^2 = length × breadth, and dT = $T_1 - T_2$.

2.3.9. Thermal Diffusivity. The quantity of heat that moves over a unit area of a layer with a unit thickness and a unit temperature difference between its faces in a unit amount of time generates a change in temperature in the material's unit volume, measured by thermal diffusivity. For a homogeneous and isotropic medium with temperature-independent thermal properties and no internal heat generation, the differential equation of heat conduction can be written as the following equation:

$$A = \frac{k}{\rho c_p}, \tag{14}$$

where A = thermal diffusivity, K = thermal conductivity, ρ = density, and C_p = specific heat capacity.

2.3.10. Specific Heat Capacity. For a thermally isolated material of mass (m), the relationship between heat deposition and temperature increase is depicted by equations (15)–(17).

$$Q = mC_p\Delta T, \tag{15}$$

$$C_p = \frac{Q}{m\Delta T}, \tag{16}$$

$$C_p = \frac{Q^{\circ}}{m\Delta T}, \tag{17}$$

where Q = energy (J), m = mass (kg), ΔT = temperature difference, and Q° = rate of heat transfer.

2.4. Effects of Mix Proportion on the Particleboard Properties. The response surface methodology (RSM) has proven to be a reliable tool for understanding the behaviour of composite materials [31]. The RSM helps to simultaneously examine design elements to identify the critical factor influencing the response in a single experiment [33]. To study the effects of the mix proportion on the particleboard properties, the central composite design (CCD) of RSM was used to analyse the experiment results. The desired responses considered for analysis are bending strengths and compressive strengths.

3. Results and Discussion

3.1. Raw Materials Characterisation and Sieve Analysis. The sieve analysis carried out on waste ceramic tiles (WCTs) and milled corncob (MCC) is presented in Figure 4. The result shows that the raw samples are well graded with the particle size obtained. Table 2 presents that the bulk density for WCT (1826 kg/m^3) was higher than that of MCC (342 kg/m^3). The higher density of the WCT is expected, considering that WCT is heavier than MCC in every respect. The specific gravity of the two materials was 2.88 (WCT) and 1.88 (MCC).

3.2. Physical Properties of Particle Boards

3.2.1. Bulk Density. The bulk density results of the particleboard produced in this study are presented in Figure 5. The lowest density (1120 kg/m^3) was obtained with sample R1 (100% MCC), while the highest density (1760 kg/m^3) was obtained with sample R7 (70% MCC: 30% WCT). It can be observed that as the percentage of WCT increased with decreasing amount of MCC, the density of the particleboard increased. The increase in density resulted from the rise in WCT, which can be attributed to bulk density of the raw material as presented in Table 2, where WCT was denser than MCC. This implies that the amount of WCT greatly influences the density value in the mixture. This result agrees with the study of Atoyebi et al. [13]. A similar trend was obtained in the study of Jonoobi et al. [22], where the density of the particleboard produced using wood, plastic, and cement was reduced with a reduced quantity of cement. Based on the ANSI 208 [33] standard, all the particleboards produced in this study are classified as high-density boards. According to the standard, low-density boards have densities below 640 kg/m^3, while high-density boards are classified as having densities above 800 kg/m^3. Particleboards could be stronger when denser materials are utilised. However, the particleboard produced when sawdust and corncob were used revealed low-density particleboard, making the particleboard produced not beneficial for load-bearing function [29].

3.2.2. Water Absorption. Figure 6 illustrates the water absorption of the particleboards at 2 and 24 h water immersion, respectively. The sample R1 gave the highest water absorption value at 2 and 24 h of immersion in water. This high water absorption value could be attributed to the hydrophilic nature of the corncob material [22]. Biomass materials are hydrophilic, so they tend to absorb water. It can be observed that there was a reduction in the water absorption of the particleboards as the percentage content of MCC was reduced with an increase in the value of WCT. The decrease in the water absorption of the particleboard with increasing WCT could be attributed to the hydrophobic nature of the WCT [6]. Hydrophilicity reduces with MCC reduction, while hydrophobicity increases with increasing WCT. However, an unusual increase was noticed in sample R4, which was later reduced. This could be due to the decreased compaction of the panel during synthesis. Hence, there is more room for water penetration [29]. The particle size of the MCC and WCT and the resin utilised were responsible for the highest WA percentage obtained in this study. The highest value obtained implied that the composition of the materials for the production of the particleboards led to pore reduction in the board, which hindered excessive absorption of water by the board. Hence, the particleboard can be said to be water resistant. According to the IS3087 standard, an excellent water-resistant capacity of particleboard should not exceed 40% [22]. The result revealed that lignocellulosic materials tend to raise the hydrophilic nature of particleboards due to huge pores that could lead to much water penetration via capillarity action [22, 34]. This was also observed in the study of Ohijeagbon et al. [6].

3.2.3. Thickness Swelling. The thickness swelling percentage of the particleboards is presented in Figure 7. Figure 7 shows that the highest thickness swelling percentage was in sample R1 and the lowest in sample R7. More thickness swelling was obtained at 24 h than at 2 h of water immersion. This implies that the more time spent in immersion, the more thick the swelling of the particleboard is and the more WCT there is in the particleboard composition, the lower the thickness swelling. This is attributed to fewer pores achieved as WCT increased in the composition. The more the MCC in the composition, the faster the particleboard becomes saturated with water [29]. Sample R7 performed the best in terms of thickness swelling.

American National Standards Institute [33] stipulated that thickness swelling must not exceed 8%. The values obtained in this study for the particleboard with the mixture

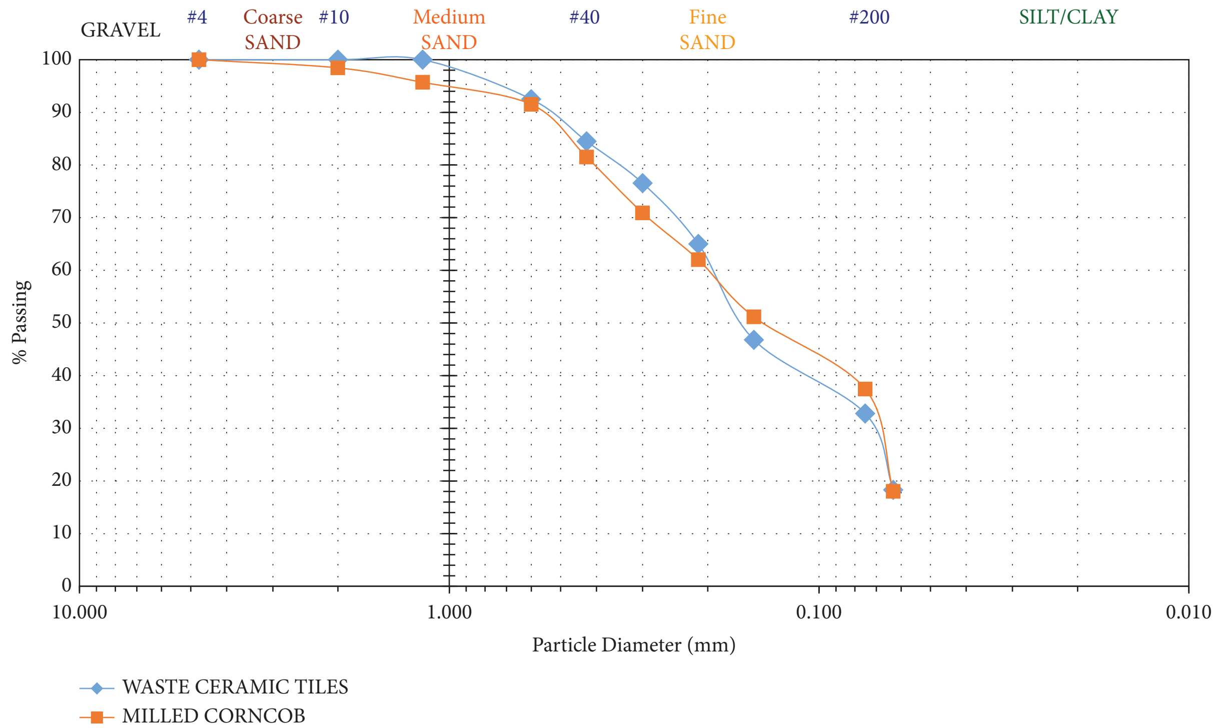


Figure 4: Sieve analysis for WCT and MCC.

Table 2: Result for bulk density of different materials used.

Materials	Bulk density (kg/m^3)	Specific gravity
WCT	1826	2.88
MCC	342	1.88

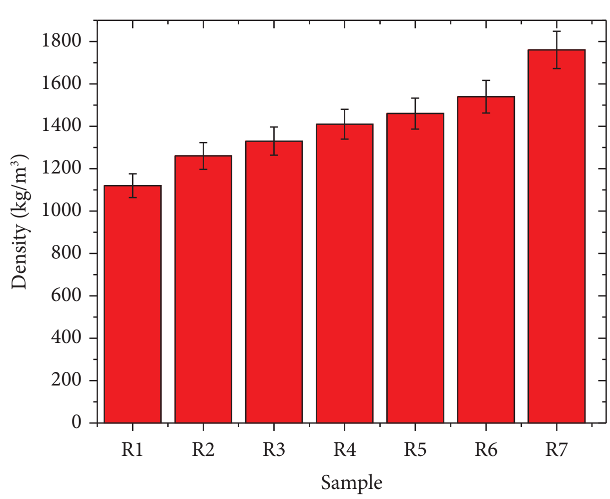


Figure 5: Bulk density for particle boards at different compositions.

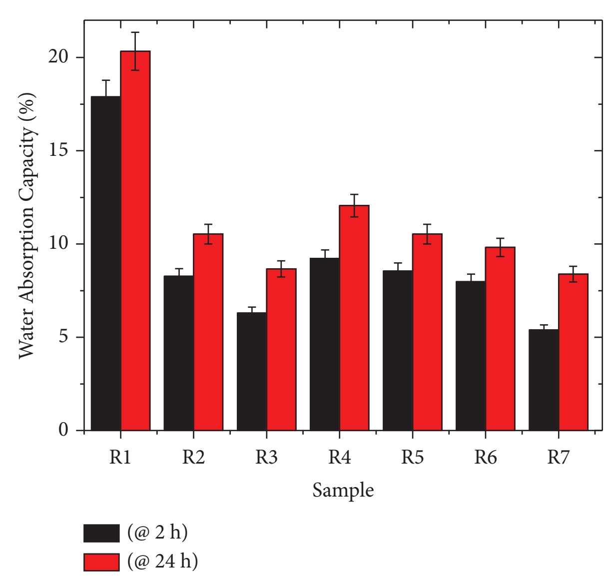


Figure 6: Water absorption for 2 and 24 h for particleboards at different compositions.

of WCT and MCC are between 1.75 and 6%, except for sample R1 with 10% thickness swelling at 2 h. More so, the thickness swelling of sample R2–sample R7 was between 3.25 and 9.50%, while sample R1 was 19.00% at 24 h. The optimum acceptable thickness swelling value at 24 h water immersion should not exceed 16% according to the EN 312 [35] standard. Therefore, all the samples (R2–R7) met the requirements except for the control sample (R1).

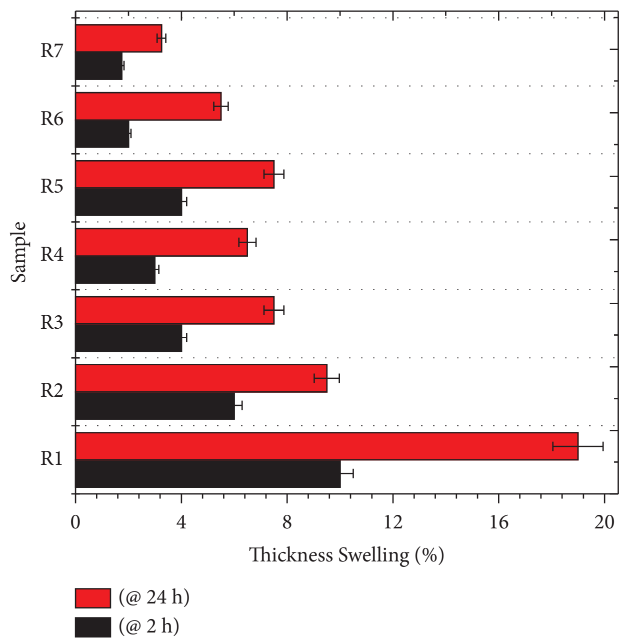


Figure 7: Thickness swelling for 2 and 24 h for particleboards at different compositions.

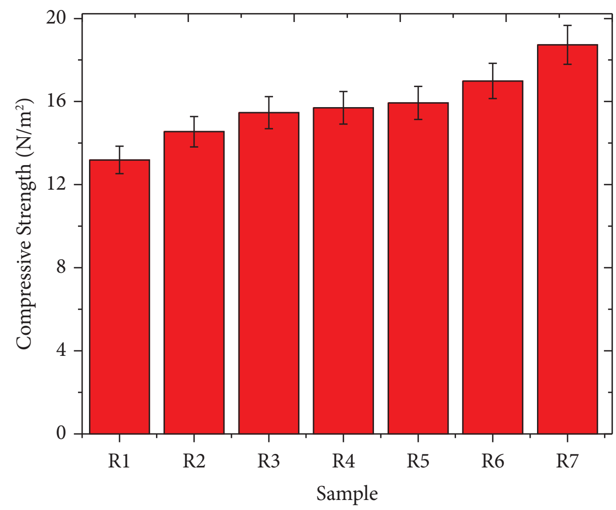


Figure 8: Compressive strength for particleboards at different compositions.

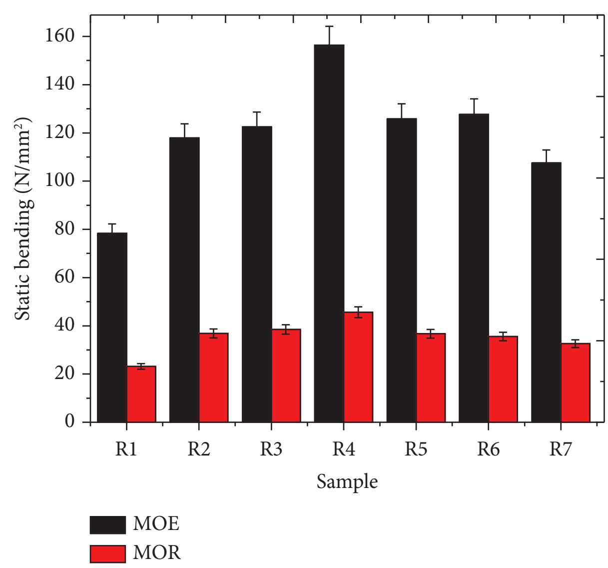


Figure 9: Modulus of rupture and modulus of elasticity for particleboards at different compositions.

3.3. Mechanical Properties

3.3.1. Compressive Strength. Figure 8 displays the compressive strength obtained for the particleboards at different compositions. It can be observed that the compressive strength ranged from 13.19 N/mm^2 to 18.73 N/mm^2. The lowest compressive strength was obtained at sample R1, while sample R7 gave the highest compressive strength. It was also observed that the compressive strength increased with increased WCT and reduced MCC content in the composition. The increased compressive strength as the WCT increased could be attributed to the cementitious nature and density of the WCT, which tend to lower the pores in the particleboard, thereby increasing the strength. These particleboards are to be able to withstand load bearing due to the amount of compressive strength they possess. As a result of this result, the particleboard is recommended for wall partitioning in buildings and for other load-bearing applications. All particleboards surpassed the minimum recommended value (2.5 MPa) benchmarked for composite boards useful for wall partitioning [36].

3.3.2. Static Bending. The modulus of rupture (MOR) and modulus of elasticity (MOE) of the composite particleboards at different compositions are presented in Figure 9. The MOR and MOE followed the same trend. The MOR values ranged between 23.12 N/mm^2 (sample R1) and 45.61 N/mm^2 (sample R4), while MOE values ranged from 80.42 N/mm^2 (sample R1) to 156.38 N/mm^2 (sample R4). Based on the BS EN 13353 standard [37], the minimum values for MOR and MOE should be 5 N/mm^2 and 400 N/mm^2, respectively. Therefore, all the particleboards met the MOR standard. However, the MOE values obtained for all the particleboards in this study fell below the MOE requirement. The high MOR and low MOE could be attributed to the relationship among the bond quantity of the materials. Curing and heating methods could have been responsible for the low MOE performance. Hydrated products, such as boards, disintegrate when heated, leading to breakage of bonds. With this, MOE is reduced. However, the extent of the reduction could be linked to the moisture loss, aggregate type of the materials, and high temperature. Several studies have reported the significant effect of temperature on MOE [38–40]. However, based on the good MOR result, the particleboard can be used for interior construction works in buildings.

3.4. Thermal Properties. Thermal property determination is essential to ascertain the particleboard insulation ability. The particleboards' thermal conductivity and specific heat capacity were obtained, as shown in Figures 10 and 11.

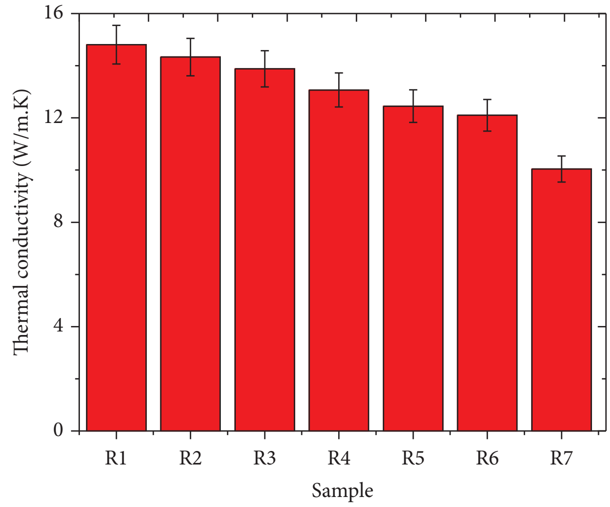


Figure 10: Thermal conductivity for particleboards at different compositions.

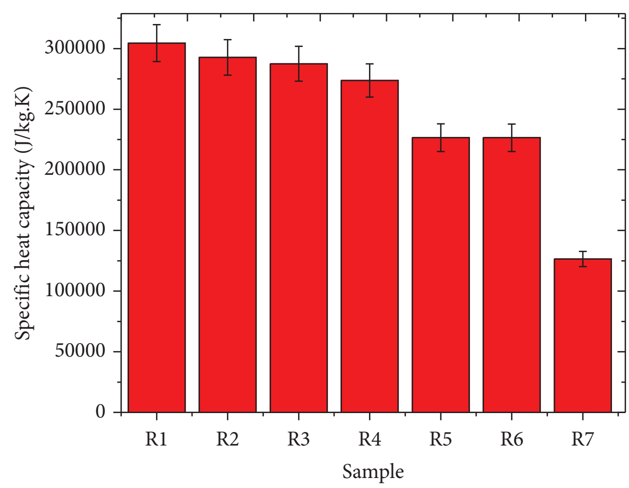


Figure 11: Specific heat capacity for particleboards at different compositions.

In Figure 10, as the quantity of WCT increased while MCC reduced, the thermal conductivity of the samples reduced. This implied that the reduction in thermal conductivity is directly linked to the WCT. The WCT in the particleboard could act as an insulator. Also, the specific heat capacity of the samples declined as the WCT increased in composition, as shown in Figure 11. It can be observed that the values of thermal conductivity and specific heat capacity reduced as the quantity of WCT increased in the composition of the particleboard materials. The reduction in the thermal conductivity value implies an improved thermal insulation property. The lowest thermal conductivity value means a superior thermal insulator, offering more building insulation. The exceptional thermal insulator in this study was obtained at sample R7. Lower thermal transmission results in lower thermal conductivity and higher thermal resistance [30]. This implies that all the particleboards produced will exhibit good insulation when used for general-purpose functions in buildings.

3.5. Effects of Production Variables on the Particle Board Properties. The relationships between the independent variables and the responses are presented by the response surface plot, as shown in Figure 12, and the ANOVA results are shown in Table 3. The surface plot for the MOE (Figure 12(a)) indicates that the MOE value increases with the increase in the MCC. On the other hand, a decrease in the MOE values was observed with increased WCT proportion, indicating that the presence of WCT reduces the MOE. Also, the ANOVA results (Table 5) show that WCT and MCC-WCT significantly affect the MOE, displaying a *P* value less than 0.05. From Figure 12(b), the MOR values were observed to reduce with an increase in the percentages of MCC and WCT. However, the plot demonstrates that a maximum MOR value of 45.6 N/mm^2 can be achieved with an MCC and WCT content of 85% and 15%, respectively. The ANOVA results for the MOR revealed that whilst the MCC and WCT had no significant effect on the MOR, their binary blend is substantial. The plot for the compressive strength (Figure 12(c)) shows a decrease in the

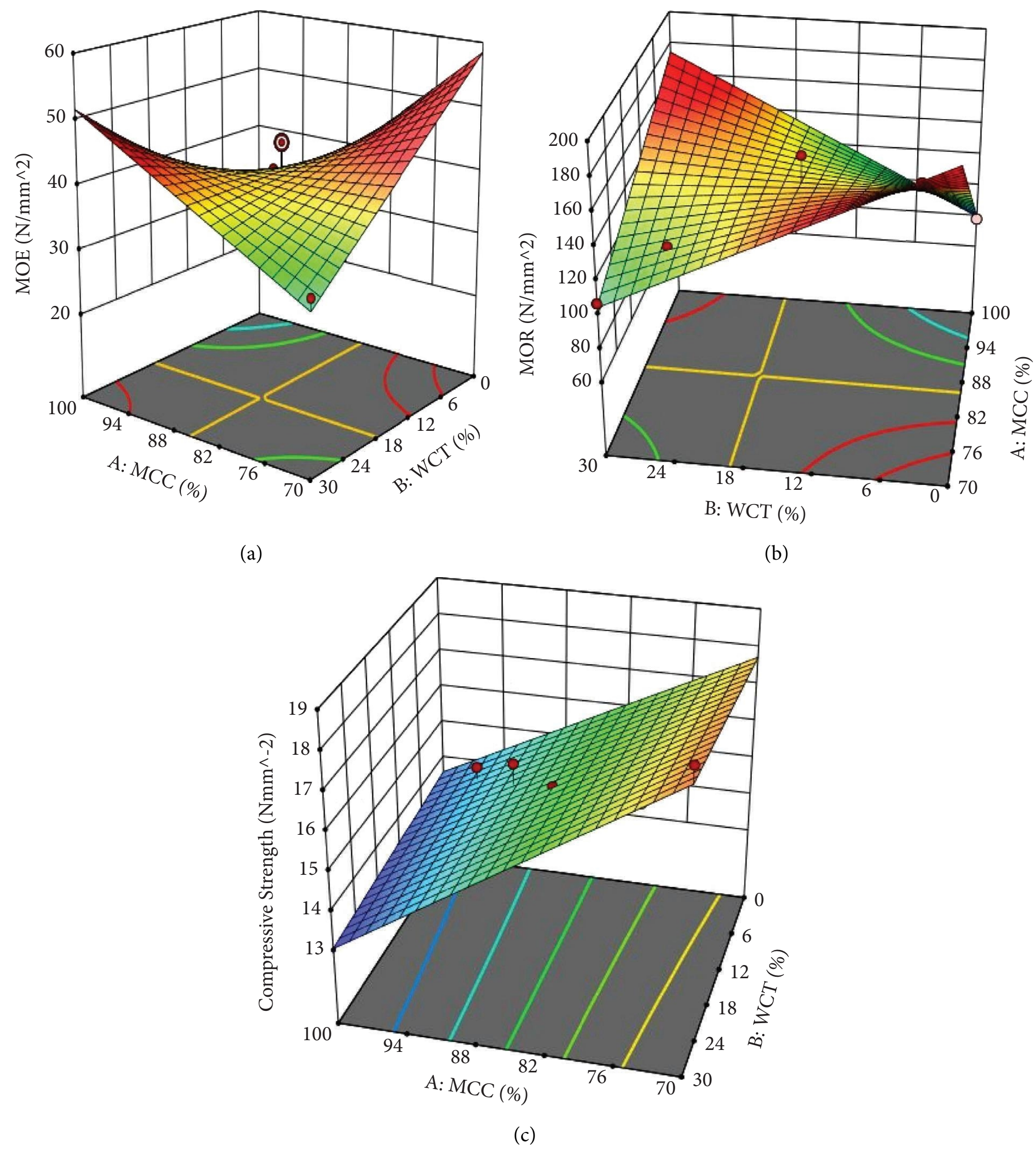


Figure 12: Response surface plots for the (a) MOE, (b) MOR, and (c) compressive strengths.

Table 3: ANOVA for the particleboard properties.

Sources	DF	MOE			MOR			Compressive strength		
		SS	*F* value	*P* value	SS	*F* value	*P* value	SS	*F* value	*P* value
Model	2	236.45	10.95	0.0239	2794.73	10.48	0.0257	17.30	28.65	0.0043
A	1	36.80	3.41	0.1386	484.72	3.64	0.1292	17.22	57.04	0.0016
B	1	7.82	0.67	0.0159	2.89	0.11	0.0623	0.0026	0.0244	0.3400
AB	1	191.83	18.49	0.0126	2307.11	17.33	0.00141	0.00779	0.2665	0.6329
Residual	4		43.19			533.33			1.21	
R^2			0.8455			0.8397			0.9348	
Adj. R^2			0.7683			0.7596			0.9021	
Mean			35.00			119.04			15.79	
SD			3.29			11.55			0.5495	
AP			8.0484			7.8948			13.0813	
CV %			9.39			9.70			3.48	

DF: degree of freedom; SS: sum of squares; SD: standard deviation; R^2: coefficient of determination; AP: adequate precision; Adj. R^2: adjusted coefficient of determination; A = MCC, and B = WCT.

compressive strength as the MCC increases. However, the plot demonstrates that a maximum flexural strength value of 18.73 N/mm^2 can be achieved with MCC and WCT content of 70% and 30%, respectively. The ANOVA results in Table 3 revealed that only MCC significantly affects the compressive strength.

This work used the optimisation tool of RSM to optimise design variables. The design variables and responses were defined as maximum to attain the best mechanical performance of the particleboard. From the optimisation results, 70.0% of MCC and 30.0% of WCT were the optimum input parameter percentage.

4. Conclusions

In this study, the possibility of producing particleboards from milled corncob and waste ceramic tiles using less sophisticated techniques and equipment has been achieved with the realisation of reliable physical properties. The results revealed increased bulk density, reduced water absorption, and thickness swelling with increased waste ceramic tiles in the composition. With an increase in WCT, the boards' density rose. Both water absorption and thickness swelling fell within the permitted limits for standardised commercial particleboard. Due to the dimensional stability features acquired for the various board requirements, these boards had little to no risk of experiencing excessive moisture changes. All of the manufactured boards had favourable physical characteristics that are suggested for both indoor and outdoor uses in structures. The results on modulus of rupture (MOR) and modulus of elasticity (MOE) may suggest that the particleboards cannot be used for load-carrying or structural purposes. Although the MOR attained the minimum standard requirement, the MOE fell below the minimum requirement. The static bending requirement for general-purpose boards per EN 312-2 is 11.5 N/mm^2, while the BS EN 13353 states that panels intended for structural use should have densities of at least 420 kg/m^3 and minimum values of MOR and MOE to be 5 N/mm^2 and 600 N/mm^2, respectively. Hence, only nonstructural applications, such as liners, partitions, and other internal and external uses, are permitted for boards made to this specification.

Data Availability

All data generated or analyzed during this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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