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Influences of cement brands and mixing ratio on the physico-mechanical properties of cement bonded particleboards made of wood particles of *Gmelina arborea*, *Afzelia africana* and *Triplochiton scleroxylon*

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Abstract

Cement bonded particleboards (CBPs) were produced of wood particles of *Gmelina arborea*, *Afzelia africana* and *Triplochiton scleroxylon* using two brands of ordinary portland cement manufactured by two different domestic cement companies operating in Nigeria known as Dangote PLC and Lafarge Company. The admixture of wood particles and cement for production of the CBPs were done at mixing ratio of 1:1, 1:1.5 and 1:2 (weight to weight basis). The properties such as water absorption and thickness swelling at 24 hours, density, modulus of rupture (MOR), modulus of elasticity (MOE) and impact bending strength were determined. The results of the study reveal that the density ranged from 0.61 to 0.92 g/cm^3. Meanwhile, water absorption and thickness swelling were found to be 30.34 to 72.44% and 11.43 to 10.77% at 24 hours, respectively. The bending properties obtained from the laboratory tests ranged from 115.77 to 826.55 N/mm^2 and from 1,157.70 to 4,773.38 N/mm^2 for MOR and MOE, respectively, while impact bending strength ranged from 41.70 to 238.49 N/mm^2, respectively. As the cementious content increases from 50% to 66.3% and wood content decreases from 50% to 33.4%, the properties such as density, MOR, MOE and impact bending strength increased, while water absorption and thickness swelling decreases. The statistical results showed that such factors as wood species, cement type and mixing ratio had significant influence on the physical and mechanical properties of CBPs. The study reveals that CBPs made of wood particles of *Triplochiton scleroxylon* and Dangote cement brand at the ratio of 1:2 were more dimensionally stable, denser and stronger while CBPs of wood particles of *Afzelia africana* were stiffest and most rigid. As concluded, cement brand had significant importance in qualities of CBPs, which can be attributed to chemical compositions found in materials used.

Keywords: cement, physical, mechanical, wood, particleboards, mixing ratio

Introduction

The wood-based panel industries comprise of plywood, fibreboard and particleboards, these are composed of wood particles, resins and water. These composites have been in service for several decades and most widely were in use in the developed countries than in the developing countries. In Africa, particleboards suffer setback in production and usage due to type of binders which are costlier due to cost of importation. Thereby making the panel products unaffordable to low-income earners, this reason necessitated more research on using cement as a binder. According to European Committee for Standardization (2011), cement is a hydraulic binder, a finely ground inorganic material that when mixed with water, forms a paste, sets and hardens through hydration reactions. These processes after hardening, gains its strength and retain it stability even under water. Many studies have focused on understanding the complex behaviour of a wood-cement –water mixture (Hamdon 2008, Sotannde et al. 2012). The flexural strength of wood-cement composites has been extensively investigated (Vo and Navard 2016). The behaviour of wood-cement bonded particleboards to mositure up-taken and bio-deteriorating agents were also investigated (Sudin and Swamy 2006, Dadile et al. 2019). Wood-cement bonded particleboards are mainly used in building industry for flooring and ceiling due to properties displayed (Papadopoulos 2006, Dadile et al. 2019). The chemical constituents which are present in wood and cement play a key role in determining the inert properties of the composite (Sam et al. 2013). Cement as a binding material can influence and dictate the quality of building products due to its chemistry constituents (Bhanumathidas and Kalidas 2003). The use of wood particles as reinforcement in concrete cement also plays great significant roles in achieving good network of strong bond formation. However, there has been issue with the use of cement with wood particles as regards its compatibility; the chemical substances which are organic interfere in wood-cement bonding capacity. Vo and Navard (2016) reported various chemical compounds found in wood that is responsible for inhibitory effect of wood in cement setting. The wood chemical compound varies in wood types, which are more abundant in hardwoods than in softwoods (Hamdon 2008). Many Nigerian wood species with cement have been investigated (Fan et al. 2012). Nigeria has 6,000 wood plants species many of which contain variety of chemical constituents which cause problems in cement setting may have not being investigated. Due to availability of wood and cement in many countries, the production of wood-cement particleboards may likely increase in the future. There is a need to investigate wood of different species with different brands of cement placed on the Nigerian market for production of cement bonded particleboards. A literature review revealed that qualities and chemical analyses of cement brands available in the Nigeria markets were not made known to the consumers (Faleye et al. 2009). There is a complete lack of information on suitability of different types of cement in the Nigerian market for production of cement bonded particleboards and cement influence on their properties. As the reviewed literature revealed, chemical constituents of wood differ, and chemical constituents of each cement brand also differs. Hence, there is a great need to investigate the effect of cements, wood species and wood-cement mix on properties of particleboards made of two cement brands widely and highly used by consumers in Nigeria.

Therefore, the present study reports the physico-mechanical properties and fractured surfaces in fibre-to-fibre arrangement in composition of particleboards as influenced by the cements, wood species and wood-cement proportions. Properties such as density, water absorption, thickness swelling, modulus of rupture, modulus of elasticity and compressive strength were investigated.

Materials and methods

Materials

Sawdust of *Gmelina arborea, Triplochiton scleroxylon* and *Afzelia africana* were used in this study. The trees of these wood species were felled from the Research plot situated at Onigambari forest reserve at the coordinates 7°25′ and 7°55′ N, 3°53′ and 3°9′ E within the lowland semi-deciduous forest belt of Nigeria and covers a total land area of 17,984 ha. At the sawmill section of the Department of Forest Products Development and Utilization, Forestry Research Institute of Nigeria, Ibadan, Oyo State, the harvested wood logs were sawn on planks while produced wood particles were collected. The particles of these wood species were to serve as filler to the matrix (cement). With this aim two brands of Ordinary Portland Cement (O.P.C.) manufactured by Dangote PLC and Lafarge Company, Nigeria, were purchased and used in this study.

Materials processing, boards formation and boards production

$CaCl_2$ was used as an additive to accelerate the curing period of cement in the boards and was supplied by the Institute. Prior to board production, particles of each wood species were thoroughly screened with sieve mesh of size 2.0 mm. This was done to remove unwanted materials that may hinder the fibre-to-fibre internal arrangement of the particles and to obtain homogenous particle size. The particles were pre-treated by soaking them in hot water at 100°C for an hour to de-polymerize the chemical compositions imbedded in the wood particles by removing some unwanted water-soluble chemical substances like starch, compounds of phenol, lignin and extractives. The wood particles were squeezed to dry and then air-dried to attain 12% moisture content. After that, the wood chips and cement brands were measured at various proportions namely of 1:1, 1:1.5 and 1:2 (wood-cement ratio) and at constant nominal density of 1.00 g/cm^3. The same procedure was applied to both brands of the above-mentioned cement used in this study and 3% of $CaCl_2$ was added based on the weight of cement used as an additive. However, the quantity of water used was determined by using Equation 1 (Atoyebi et al. 2018). The mixture was hand fed into caul plate with frame sized 35 × 35 cm. However, stoppers of 10 cm were used to guide the sides to obtain uniform thickness. The mixture fed into caul plate with frame was pre-pressed and further subjected to hydraulic jack press under pressure of 1.75 N/mm^2 for 24 h. The boards were released from the hydraulic jack press and stacked in the laboratory to dry under room temperature to ensure good setting of the cement with the wood material, and then exposed to the open air to dry for 7 days. Each specimen was cut in pieces with sizes of 15.4 × 15.4 cm and 17.8 cm × 5.1 cm for physical and mechanical properties tests in accordance with standard ASTM D 1037 (American Society for Testing and Materials 2006).

$$W_t = 0.60C_t + (0.3 - MC) \cdot W, \qquad (1)$$

where:
W_t – weight of water (g);
C_t – weight of cement (g);
MC – moisture content (oven dried sawdust of each wood species, %), and
W – weight of sawdust (g).

Physical and mechanical properties

In accordance with standard BS EN 12390-7: 2009 (British Standards Institute 2009), the bulk density of the CBPs was obtained by dividing the mass of the test sample by its volume. The board specimens were dried under room temperature of 26°C for 24 hours and such parameters as weight, length, width and thickness were measured to obtain the bulk density as adopted by the Equation 2.

$$Density\ (\mathrm{g/cm^3}) = \frac{W_a}{V_a}, \qquad (2)$$

where:
W_a – air dried weight (g);
V_a – air dried volume (cm^3).

Similarly, square-shaped test samples with size of 15.4 × 15.4 cm each were immersed in water at 26 ± 2°C for 24 h to test them for moisture resistance. In accordance with standards BS 1881-122 (British Standards Institute 2011) and ASTM D 1037 (American Society for Testing and Materials 2006), the weight and thickness of the sample were measured before and after immersion into cold water under room temperature of 26°C for 24 hours to calculate water absorption and thickness swelling of the boards using Equations 3 and 4.

$$Water\ absorption\ (\%) = \frac{W_f - W_i}{W_i} \cdot 100, \qquad (3)$$

where:
W_f – final weight of sample (g);
W_i – initial weight of sample (g).

$$Thickness\ swelling\ (\%) = \frac{T_f - T_i}{T_i} \cdot 100, \qquad (4)$$

where:
T_f – final thickness (cm);
T_i – initial thickness of sample (cm).

In accordance with standard ASTM D 1037 (American Society for Testing and Materials 2006), the specimens with size of 17.8 cm × 5.1 cm were subjected to three-point bending on a universal testing machine, model WDW-50 (Jinan Hensgrand Instrument Co. Ltd., Jinan, China) with a moveable crosshead speed of 5 mm/min to obtain data for modulus of rupture and modulus of elasticity. Meanwhile, specimens with size of 15.4 × 15.4 cm were subjected to successive blows of an impact machine in accordance with standard ASTM D 143-2009 (American Society for Testing and Materials 2009) to determine the impact bending strength. The specimens were freely supported along all four edges and the hemisphere of 22.5 kg hammer was made to strike the centre of the specimen. The rod dropped through the height of 1.3 cm in increments of 1.3 cm until fracture occurs. To calculate the impact bending strength, A_w, of the samples, Equation 5 was adopted:

$$A_W = \frac{Q}{bxh}, \qquad (5)$$

where:
A_w – impact bending strength (J/cm^2);
Q – work needed to break the test specimen (J);
b – width of the sample (cm);
h – thickness of the sample (cm).

The methods adopted for presentation of data include bar chart and analysis of variance. The graphical analysis was employed to provide an easy means of observing the trend of any relationship among the study variables and properties. The experimental design adopted for this study was 2 × 3 × 3 factorial experiments in completely randomized design using an IBM SPSS Statistics 20 software package (IBM Corp. 2021), to determine the level of significance for the main factors and interacting factors emerged. The main factors are wood species, cement brand and wood-cement ratio. As well as a follow-up test using Duncan's multiple range test was conducted at significant level of 5%.

Scanning electron microscopy (SEM) analysis

The fracture surfaces of the CBP specimens were characterized with high resolution field emission scanning electron microscopy aided with JSM 7600F Schottky FE-SEM (USA). The JEOL-JSM 7600F was operated at an accelerating voltage of 15 kV and emission current of 10 µA. The fracture surfaces were sputter-coated with gold of approximately 20 nm thick. The scanning data were analysed at magnification of 9,000×. For each CBP formulation, approximately 6 SEM images were taken and analysed.

RESULTS

Physical properties

The results of the physical properties of the boards are illustrated by Figures 1, 2 and 3, respectively. The densities of the particleboards were obtained to be 0.80 g/cm^3 and 0.81 g/cm^3 for Lafarge and Dangote cements, respectively. Meanwhile, higher values of 45.15% and 3.25% were obtained for water absorption and thickness swelling of the boards and low values of 41.68 and 0.95% for Lafarge and Dangote cements, respectively. The values obtained for water absorption and thickness swellings in 24 hours of water soak test were 45.15% and 41.68%; and 3.25% and 0.95% for CBPs made of Lafarge and Dangote cements, respectively (Figure 1). As illustrated in Figure 1, water absorption and thickness swelling values were less in Dangote cement than Lafarge cement; this implies that CBPs made of Dangote cement brand were denser.

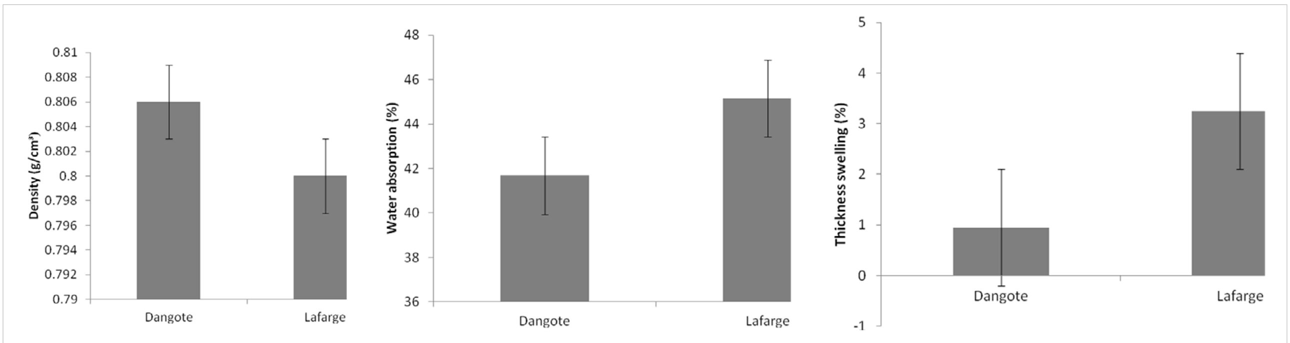


Figure 1. Influence of cement types on physical properties of CBPs

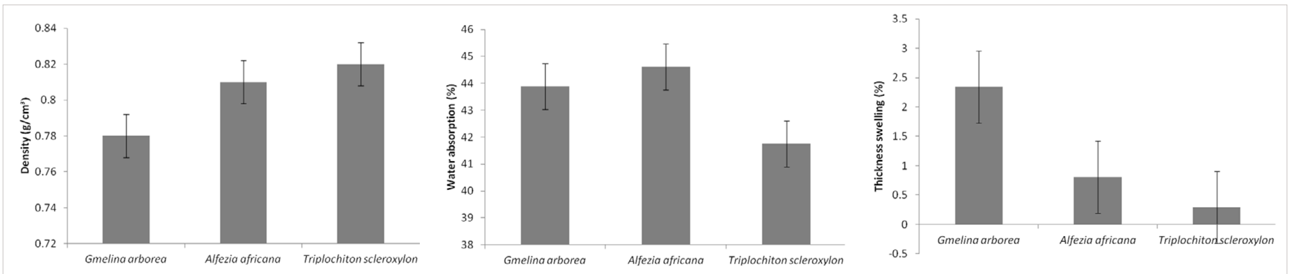


Figure 2. Influence of wood species on physical properties of CBPs

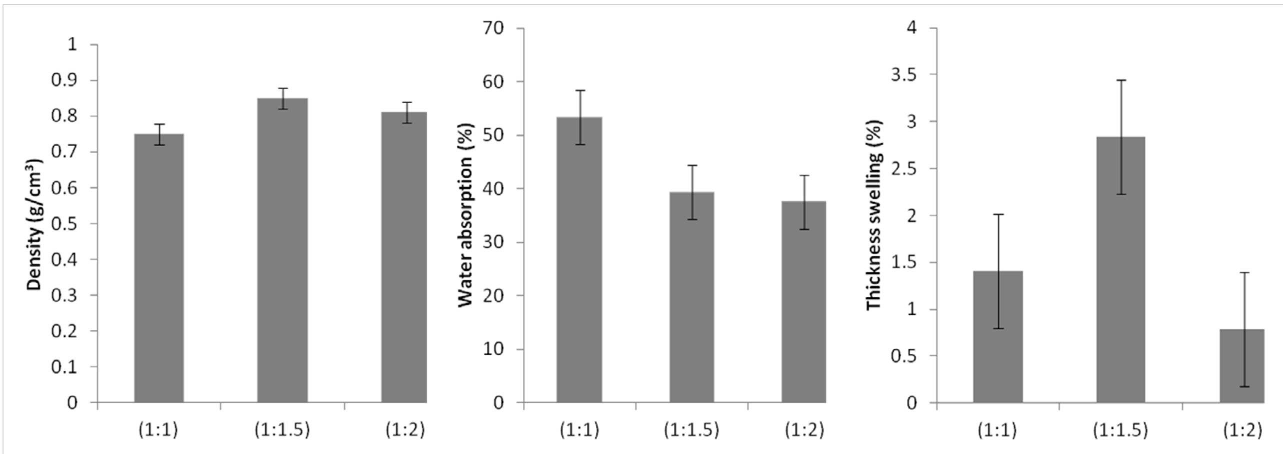


Figure 3. Influence of mixing ratio on physical properties of CBPs

The physical properties values obtained of CBPs made from particles of three indigenous wood species from Nigeria are presented in Table 1 and the density values obtained are as follows: 0.78 g/cm^3, 0.81 g/cm^3 and 0.82 g/cm^3 for *Gmelina arborea*, *Afzelia africana* and *Triplochiton scleroxylon*, respectively. As it is demonstrated in Table 1, CBPs of *Afzelia africana* had higher density value than CBPs of *Triplochiton scleroxylon* and *Gmelina arborea*. The outcome of other values for water absorption and thickness swelling were 43.89%, 44.61%, 41.75% and 2.34%, 0.81%, 0.29% for *Gmelina arborea*, *Afzelia africana* and *Triplochiton scleroxylon*, respectively. As it is shown in Table 1, *Triplochiton scleroxylon* of natural density 0.32 g/cm^3 had the highest board density observed and the lowest dimensional stability values. The values obtained compared favourably with values obtained in different studies of CBPs made of indigenous and exotic wood species (Onuaguluchi and Banthia 2016, Ferrandez-Villena et al. 2020).

Furthermore, density values obtained for the boards at mixing ratio 1:1, 1:1.5 and 1:2 were 0.75 g/cm^3, 0.81 g/cm^3 and 0.85 g/cm^3. As illustrated by Figure 3, as the cement content increased in mixing ratio from 1:1 to 1:2, the densities obtained also increases by 50.0% to 66.2%. However, as the cement content is increasing from 1:1 to 1:1.5 to 1:2, water absorption values also decrease by 53.36% to 39.35% and to 37.54%, respectively. Similarly, trend was also witnessed for thickness swelling values, as the cement content is increasing from 1:1 to 1:1.5 and to 1:2, thickness swelling also decreases by 2.41% to 1.84% and to 0.79%, respectively.

Mechanical properties

The effect of production variables on mechanical properties of CBPs are illustrated by Figures 4, 5 and 6. As it is depicted in Figures 4, 5 and 6, the average mechanical properties values obtained for CBPs made of Lafarge and Dangote cement were 2,660.12 N/mm^2 and 4,000.45 N/mm^2 for modulus of elasticity, 2.15 N/mm^2 and 2.57 N/mm^2 for modulus of rupture; and 131.08 N/mm and 156.60 N/mm for impact bending strength, respectively (Table 2). Similarly, the average modulus of elasticity, modulus of rupture and internal bonding strength values obtained for CBPs made of each wood species were 2,026.50 N/mm^2, 2.09 N/mm^2, 107.70 N/mm for *Gmelina arborea*; 4,597.70 N/mm^2, 3.22 N/mm^2, 142.26 N/mm for *Afzelia africana* and 3,374.30 N/mm^2, 1.78 N/mm^2, 181.38 N/mm for *Triplochiton scleroxylon* (Table 2), respectively. Finally, the average modulus of elasticity, modulus of rupture and impact bending values obtained for CBPs at different ratio were 2,624.70 N/mm^2, 1.44 N/mm^2, 93.51 N/mm for 1:1, 2,600.40 N/mm^2, 2.62 N/mm^2 and 156.16 N/mm for 1:1.5 and 4,773.40 N/mm^2; 3.02 N/mm^2 and 181.87 N/mm for 1:2, respectively (Table 2). The summary of the result of analysis of variance conducted for physical and mechanical properties for such factors as (a) cement type, (b) wood species and (c) mixing ratio are presented in Tables 3 and 4. The outcome shows that all the main factors at various levels were significantly different at 5% level of probability. This implies that cement brand, wood species and mixing ratio have influence on density, thickness swelling and water absorption at 24 hours of water immersion, modulus of rupture, modulus of elasticity and impact bending strength. As it is proven in Tables 1 and 2, the outcome of the result of Duncan's multiple range tests conducted on mean values obtained for all the production factors. As denoted in Tables 1 and 2 with letters, particleboards made of *Triplochiton scleroxylon* was found to be most compacted, dimensionally stable and dense than the other wood species due to the highest mean values recorded with letter 'a' while *Afzelia africana* was also dense, rigid and stronger. Similarly, mean values of particleboards made at mixing ratio 1:2 had letter 'a', it was found to be most dimensionally stable, rigid and strongest among others (Tables 1 and 2). Meanwhile, the mean val-

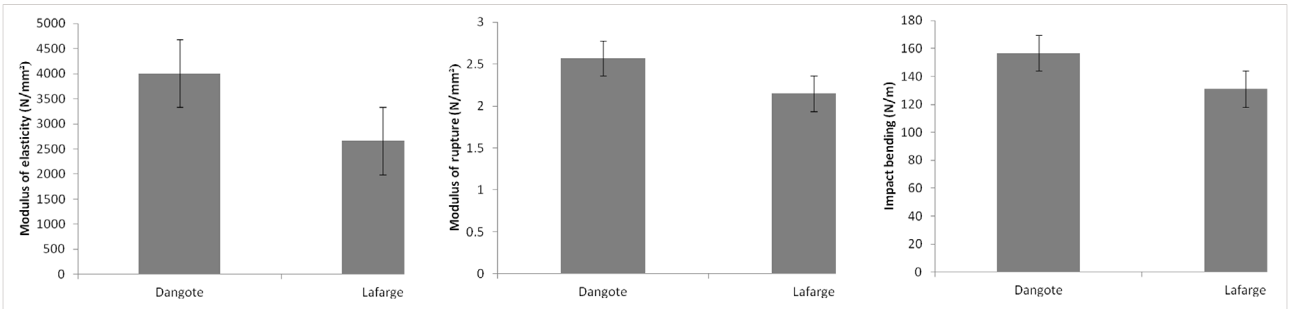


Figure 4. Influence of cement types on mechanical properties of CBPs

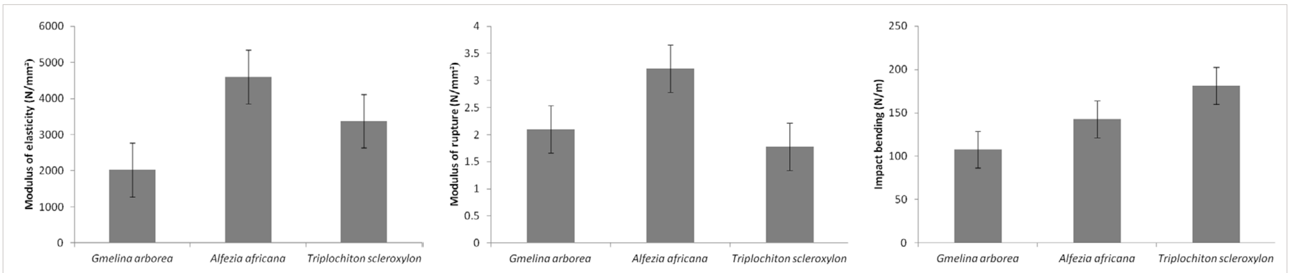


Figure 5. Influence of wood species on mechanical properties of CBPs

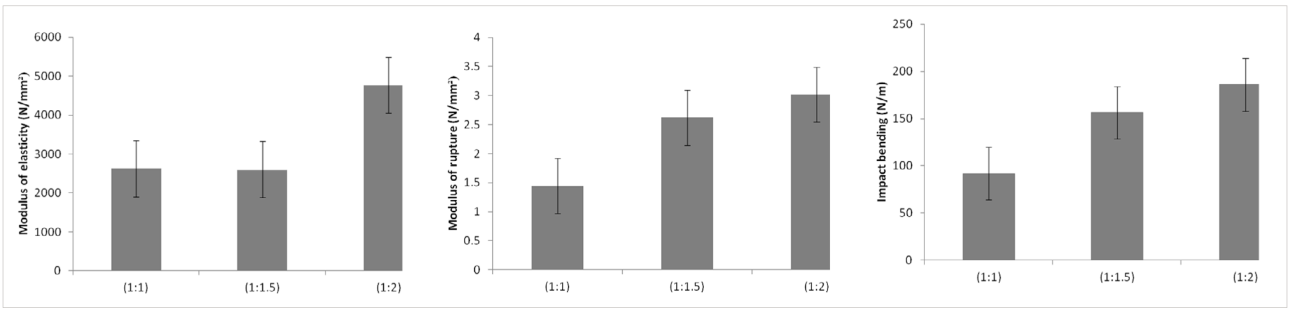


Figure 6. Influence of mixing ratio on mechanical properties of CBPs

Table 1. Results of Duncan's Multiple Range Test for physical properties

Factors	Levels	Water sorption (%)	Thickness swelling (%)	Density (g/cm3)
Wood species	*Gmelina arborea*	43.89b	2.34c	0.78b
	Afzelia africana	44.61c	0.81b	0.81a
	Triplochiton scleroxylon	41.75a	0.30a	0.82a
Mixing proportion	1:1	53.36c	1.40b	0.75c
	1:1.5	39.35b	2.84c	0.85a
	1:2	37.54a	0.79a	0.81b
Cement brand	Lafarge	45.15b	3.25b	0.80b
	Dangote	41.68a	0.95a	0.81a

Note: Each value reps mean with character.

Table 2. Results of Duncan's Multiple Range Test for mechanical properties

Factors	Levels	Modulus of elasticity (N/mm^2)	Modulus of rupture (N/mm^2)	Impact bending (N/mm)
Wood species	*Gmelina arborea*	2026.52c	2.10b	107.69c
	Afzelia africana	4597.69a	3.22a	142.46b
	Triplochiton scleroxylon	3374.25b	1.78c	181.38a
Mixing proportion	1:1	2624.73b	1.44c	181.87a
	1:1.5	2600.35c	2.62b	93.51c
	1:2	4773.38a	3.02a	156.16b
Cement brand	Lafarge	2661.16b	2.15b	131.08b
	Dangote	4004.48a	2.57a	156.60a

Note: Each value reps mean with character.

Table 3. Results of analysis of variance for physical properties

Variable factors	Density		Water sorption		Thickness swelling	
	F-value	*Sig*	*F*-value	*Sig*	*F*-value	*Sig*
Cement brand	124.12	0.00 *	3281.10	0.00 *	152.85	0.00 *
Wood species	16.45	0.00 *	802.65	0.00 *	13.01	0.00 *
Mixing ratio	46.15	0.00 *	27345.05	0.00 *	38.74	0.00 *

* Significance at $p \leq 0.05$ level of probability.

Table 4. Results of analysis of variance for mechanical properties

Variable factors	Modulus of elasticity		Modulus of rupture		Impact bending	
	F-value	*Sig*	*F*-value	*Sig*	*F*-value	*Sig*
Cement brand	22969.87	0.00 *	1468.62	0.00 *	1882.24	0.00 *
Wood species	28072.41	0.00 *	6426.18	0.00 *	5235.84	0.00 *
Mixing ratio	26418.33	0.00 *	7561.41	0.00 *	7959.71	0.00 *

* Significance at $p \leq 0.05$ level of probability.

ues for boards made of Dangote cement had letter 'a' and this denoted that CPBs of Dangote cement was found to be more dimensionally stable, more compacted, stronger, more rigid and dense than CPBs made of Lafarge cement (Tables 1 and 2).

The effect of cement brands on properties particleboards

The outcome of physical properties values is in conformity with assertions that the denser the particleboards, the stronger it becomes (Geimer et al. 1993, Fuwape 1995). The two cement brand particleboards were of the same density range with little variation, which may be attributed to the difference in percentage of $Al_2(SO_3)$ found in each of the cement used. Al_2SO_3 is known to be hygroscopic in nature, its inability to form sufficient bonds with phenol groups in wood caused the little variation witnessed in density of the CBPs. Also, spring back might have occurred after the pressing period too, according to Roger (2005). Dangote cement has lower specific surface area (358 m^2/kg) and setting time (195 s), this might have strongly affected early compressive strength of materials which allows spring back to occur. Zhou and Kandem (2002) stated that thickness changes always occur due to spring back after pressing process of particleboard, which may have significant effect on dimensional instability of the boards. According to BS EN 634-2:2007 (European Committee for Standardization 2007), the maximum standard and accepted value of thickness swelling for CBPs should be $\leq 1.5\%$ and the values obtained in this study for thickness swelling of CBPs produced of Dangote and Lafarge cement brands at higher content than wood content conformed to standard BS EN 634-2.

An earlier study revealed that corroborated results have shown that curing accelerator and cement brands influence the mechanical properties of the particleboards (Ara et al. 2019). According to BS EN 634-2:2007 (European Committee for Standardization 2007), the standard and accepted values for modulus of rupture and modulus of elasticity should be of 9 N/mm^2 and 4,000 N/mm^2, respectively. The modulus of rupture values obtained for the CBPs made of these two cement brands were lower to the above mentioned standard but in conformity with the standard value accepted for modulus of elasticity. The strength values obtained for the CBPs of Dangote cement were higher than the values obtained for the CBPs of Lafarge cement. This variation can be attributed to the activities of free CaO, silicate ratio, setting time and MgO of the cement to wood particles. The free CaO in cement accounts for compressive strength and the higher value of free CaO, the lower the compressive strength. Literatures revealed that Lafarge cement has higher free CaO of 1.34% while Dangote cement has 0.95% (Roger 2005, Faleye et al. 2009). An increase in free CaO reduces the total silicate that formed the main strength phase in hardened cement concrete (Akanni et al. 2014). Free CaO values > 3% should be avoided as not only the strength will be reduced but also risk of dimensional instability will be particularly high if CaO > 3% (Roger 2005).

The effect of wood species on properties of particleboards

The observations seen in Figures 1, 2 and 3 for density of the CBPs could be attributed to the bulk density of individual wood species used as filler to matrix. If the matrix contains filler of low bulk density, it may have high compaction ratio than matrix that contains high bulk density (Hamdon 2008). However, lower bulk density materials do give high compaction of high strength cement bonded particle boards (Hamdon 2008). As reported in literature, the bulk density of each wood species used varies as follows: *Gmelina arborea* had 0.40–0.51 g/cm^3, *Afzelia africana* had 0.72–0.85 g/cm^3 while *Triplochiton scleroxylon* had 0.32–0.44 g/cm^3 (Adam and Krampah 2005, Bosu and Krampah 2005, Gerard and Louppe 2011). It has also been stated by that physical and chemical properties of wood species play a major role in compatibility of particleboard (Hamdon 2008). As displayed in Figure 2, *Triplochiton scleroxylon* of the lowest bulk density had the highest density values followed by *Alfezia africana* and *Gmelina arborea*. It was seen that wood particles of *Alfezia africana* has higher bulk density than those of *Gmelina arborea* of lesser bulk density; this was not in agreement with previous findings of Hamdon (2008). This study confirmed that some indigenous high density wood species could still perform better than low bulk density wood species in terms of properties. Particles of *Alfezia africana* might see to be high in water absorption but still maintained low thickness swelling when compared to *Gmelina arborea* (Figure 2). Past studies attributed the conditions of cement bonded particleboards in connection to hydration temperature of wood to cement mixture and this condition varies in species, between sapwood and hardwood (Fan et al. 2012, Onuaguluchi and Banthia 2016, Ferrandez-Villena et al. 2020). The extractive contents and substances present in the cell wall of wood species gave different compatibility results with cement (Chen et al. 1998, Sudin and Swamy 2006). The chemical components of each wood species also contributed to bonding mechanism in CBPs. As reported by Adam and Krampah (2005), Gerard and Louppe (2011), and Bosu and Krampah (2005), wood of *Triplochiton scleroxylon* had the lowest extractives content compared to those of *Alfezia africana* and *Gmelina arborea*. Also, the hemicellulose content was found to be low in wood of *Alfezia africana* comparing to that of *Triplochiton scleroxylon* and *Gmelina arborea* (Adam and Krampah 2005, Bosu and Krampah 2005, Gerard and Louppe 2011). During cement hydration, CaOH is produced, and pH increases to 12.5 to formed alkalinity, which dissolves easily in cement paste, since the hemicelluloses are non-crystalline and alkali-soluble, they affect cement crystallization (Miller and Moslemi 1991). The nature and quantity of wood chemical components critically affect the cement hydration and strength. The chemical components such as soluble sugars, arabinogalactans, phenolic compounds and other extractives found in wood are mostly responsible for the inhibitory effect of wood to cement setting. Wood sugars such as hydroxylic and carboxylic acid functional groups react with Ca^{2+}, Al^{4+} and Fe^{3+} in cement to retard its setting and disrupt the crystallization reaction. As depicted in Figure 4, CBPs made of *Afzelia africana* particles had the highest modulus of elasticity and modulus of rupture, they were also high in impact bending strength. This implies that particles of *Afzelia africana* reacted well with cement to give high fibre to fibre hydrogen bond that allows increase in the stress concentration. Despite the strength properties displayed by *Afzelia africana*, it still shows that boards made of this wood can still be better in terms of physical and mechanical properties than those made of other wood species with lower strength properties values. It could be that properties displayed for *Afzelia africana* wood could be within the tolerable properties meant for wood species to be used for CBPs production.

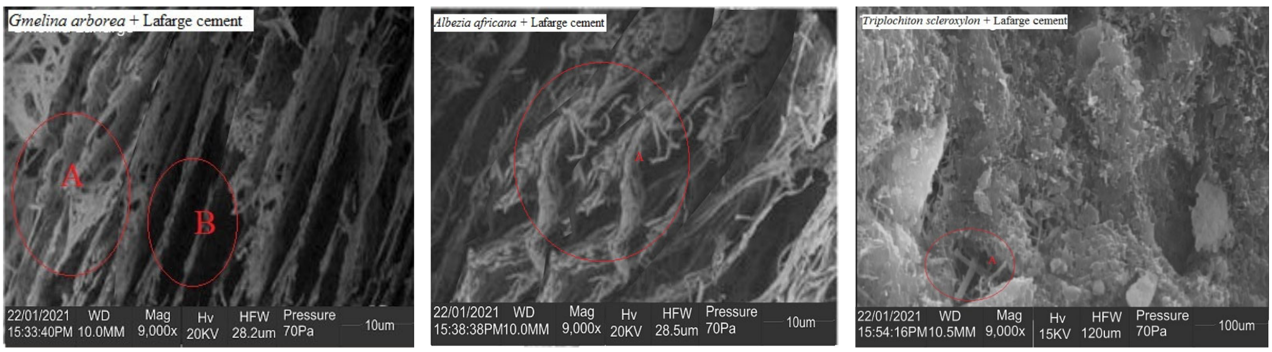
Effect of mixing proportion on properties of particleboards

Mixing of cement to wood at different proportion has influence on properties of particleboards as shown in Figures 3 and 6. As can be seen, it was observed that increase in cement content is associated with better physical and mechanical properties (Figures 3 and 6). This observation agrees with the findings of Ibrahim (1995) that stated that compressive strength is correlated to the density of individual wood species and adhesive used as binder. As it appears from Figure 3, water absorption and thickness swelling values reduce as the cement content increases. As the cement content increases, more to wood particles in the matrix, pores were filled while fibres were encased to restrict internal moisture movement in the CBPs. In this study, the water absorption and thickness swelling values obtained for the CBPs as affected by wood/cement ratio was higher than the maximum value of 25% for 24 hours recommended by Indian standard IS 14276 (Bureau of Indian Standards 1995), and the values obtained for thickness swelling also falls below 8% maximum value for thickness swelling recommended by ANSI A208.1-1999 (American National Standards Institute 1999).

It was also noticed that cement content in wood content ratio for CBPs induces stress concentration at wood-cement interface. When cement content increases, the internal stresses over specific surface per unit volume increases, thereby increasing the areas of high stress concentration. As it follows from Figure 6, strength values increase as the cement content increases, this is a sign of complete matrix formation and this observation agree with data obtained by Garcia (2020) and Oyagade et al. (1995). The CBPs got stronger and stiffer with increase in cement content to wood content. The strength values obtained in this study falls within the recommended minimum standard value of 3 N/mm^2 for particleboards of general purpose according to American National Standards Institute (1999).

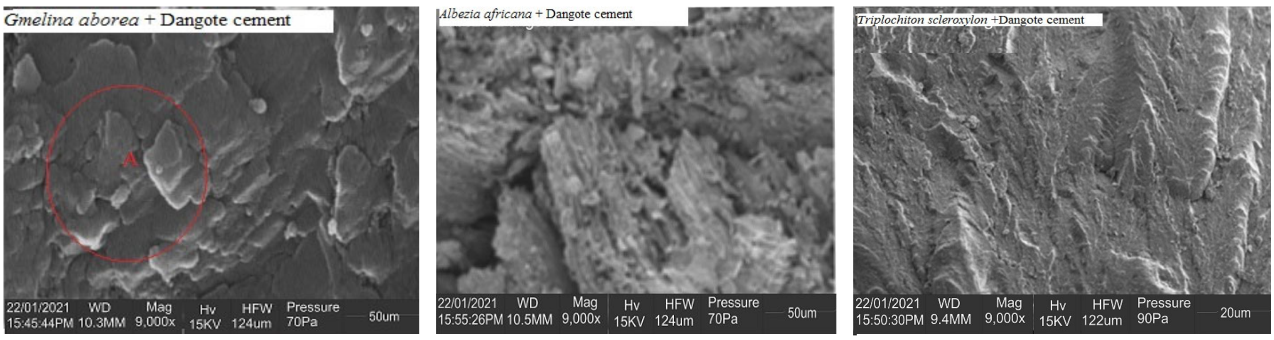
Analysis of fractured surface of CBPs by Scanning Electron Microscopy (SEM)

The relationship of fibre to cement in internal structure of the CBPs made of the above-mentioned three wood species at certain wood/cement ratio are shown in Figures 7 and 8 using the CBPs with wood to cement ratio of 1:2 which demonstrates their outstanding performance in dimensional stability and strength properties. The micrographs in Figures 7 and 8 revealed that the inter-relationship between the particles of wood and cements in the CBPs could also be responsible to the properties displayed by the CBPs made of wood particles of different wood species and cement brands at the ratio of 1:2. As it can be seen in Figure 7, the wood particles from different species reacted differently with Lafarge cement. The CBPs made of wood particles of *Afzelia africana* had evenly distributed fibre to fibre interwoven arrangement structure while unevenly arrangement of fibre to fibre was noticed in the CBPs made of wood particles of *Gmelina arborea* and *Triplochiton scleroxylon*. The fibre-to-fibre arrangement within the internal structure of the CBPs made of wood particles of *Gmelina arborea* and *Triplochiton scleroxylon* shows presence of voids that allows moisture to penetrate and increase water absorption rate of the boards (Figures 7a-b). However, as it appears from Figure 8, all boards made of Dangote cement shows high compatibility which implies existence of good bonding relationship between the fibres and cement. No fibre fallout was seen and that is an indication of the presence of very high adhesive binding forces in the CBPs (Figure 8a-c). The particles of *Afzelia africana* were well interwoven laid with Dangote cement than Lafarge cement because the presence of the fibre can be seen (Figure 8b). The cement was evenly mixed with wood fibres which were well encapsulated with Dangote cement to prevent any fibre fall out (Figure 8b). The presence of interbonding force occurs because of fibre-to-fibre interwoven arrangement in the CBPs made of wood particles of *Afzelia africana* which increase stress concentration within the internal structure of the boards to give higher strength and better rigidity to the CBPs than in other CBPs made of fibres of *Triplochiton scleroxylon* and *Gmelina arborea*.



(a) *Gmelina arborea* (b) *Afzelia africana* (c) *Triplochiton scleroxylon*

Figure 7. SEM images (9000x) of structural surface of CBPs made of Lafarge cement



(a) *Gmelina arborea* (b) *Afzelia africana* (c) *Triplochiton scleroxylon*

Figure 8. SEM images (9000x) of structural surface of CBPs made from Dangote cement

Conclusion

The production and evaluation of the properties of the CBPs made of wood particles of three indigenously grown wood species, using two brands of domestic cement at three mixing ratios were successfully done. The following conclusions were drawn from this study.

The nature and brand of cement influence the properties of CBP. The CBPs made of cement (OPC) manufactured by Dangote PLC and Lafarge Company conformed to BS EN 634-2:2007 standard while the CBPs made of cement produced by Dangote PLC were better in dimensional stability, stronger and stiffer than the CBPs made of Lafarge cement.

The properties of CBPs vary accordingly to indigenous wood species used. In such a manner the CBPs made of *Triplochiton scleroxylon* had the lowest values of water absorption and thickness swelling, 41.75% and 0.29%, respectively.

With respect to mechanical properties, the CBPs made of wood particles of *Afzelia africana* had better modulus of rupture and elasticity than those made of wood particles of other species, while the CBPs made of wood particles of *Triplochiton scleroxylon* had the highest value of shock resistance.

The interfacial bonding of the CBPs made at mixing ratio of 1:2 (wood to cement) were better than those made with the other ratios, their internal fibre-to-fibre arrangement was evenly distributed in interwoven arrangement leading to improved qualities of the products.

Cement manufacturers in Nigeria must be made to conform to specific standards of infrastructure in developed countries, and this study revealed that cement type has great influence on properties of particleboards. In such a case Dangote cement was occurred to be better for production of particleboards than Lafarge one.

Declaration of competing interest

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