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Effects of board density and mixing ratio on the physio-mechanical properties of cement-bonded particle board produced from *Ceiba pentandra* Sawdust

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ABSTRACT

The study evaluated the physical and mechanical properties of cement–bonded particleboards produced from the sawdust of *Ceiba pentandra*. The production variables investigated were two board densities (1300kg/m^3 and 1200kg/m^3) and three different mixing ratios (1:2, 1:2.5 and 1:3). Mean values of Water absorption (WA) and Thickness swelling (TS) after immersion in cold water for 24 hours ranged from 7.64 % to 9.53 % and 2.36 % to 2.99 % respectively. Board density at 1300kg/m^3 and mixing ratio 1:3 had the highest average Modulus of Rupture (MOR), Modulus of Elasticity (MOE) and Impact Bending (IMB) of 4.32 Nmm^{-2}, 1262.03 Nmm^{-2} and 12.70J/M^2 respectively. The board density had a significant influence ($P < 0.05$) on the physical and mechanical properties of the boards. Based on the result, 1300kg/m^3 board density and 1:3 mixing ratio produced the best board for mechanical properties and dimensional stability and can be used for several structural applications.

1. Introduction

Before now, asbestos fibres were generally used for construction purposes. However, arising from health and environmental concerns, efforts have been directed towards sourcing for alternative materials that would be environmentally friendly and socially acceptable. In order to solve the problems, wood and other non-wood materials in form of fibres or particles have been widely used with cement matrices to manufacture different construction materials (Asasutjarit *et al.*, 2009; Garcez *et al.*, 2016). The natural fibres are usually being incorporated into the cement matrix either in discrete or discontinuous forms. The major role of these fibres is to reinforce, i.e., to enhance tensile strength and prevent the matrix from cracking (Amel *et al.*, 2017).

One of such alternatives is the use of wastes generated in the conversion of wood. The wastes are in form of edgings, trimmings and slabs. In 2010, wastes generated in sawmill sector in Nigeria was over 1,000,000m^3, with an average recovery rate of between 45-55 % (Ogunwusi, 2014). The factors responsible for these wastes differ from one subsector to the other, but a general trend indicated that average percentage volume recovery is getting lower while waste generation is on the increase (Ogunwusi, 2014). Similarly, several studies have reported that these enormous wastes are either burnt openly, dumped in water bodies or in an open area which constitutes environmental pollution (Dosunmu and Ajayi, 2002; Aiyeloja *et al.*, 2013). Therefore, there is an increasing need to encourage the recycling and re-utilization of these wastes which will not only serve as environmental management system but also contribute positively to the economic growth of the country.

Consequently, the transformation of these wastes into cement-bonded particle board has been found to be effective in wood waste management and production of eco-friendly construction materials (Badejo, 2001; Egbewole, 2017; Ogunjobi *et al.*, 2019). This is due to its versatility such as resistance to decay and fire, good dimension stability, availability, light weight, non-corrosive nature, asbestos free, does not contain hazardous and volatile substances, the dust from the production process is non-aggressive, low cost and ease of manufacture (Blankenhorn et al., 1994; Ajayi and Badejo, 2005; Papadopoulos *et al.*, 2006). According to FAOSTAT (2019), global production of particle board increased from 64,252,021m^3 in 2000 to 96,857,066m^3 in 2018 with Europe being the highest (53.7%) producer of particle boards and Africa being the least (1.1%). Over the years, particle board has been used in various ways such as constructions, roofing, ceiling, cladding, partitioning, shuttering, and general low-cost housing as well as panel (Jorge *et al.*, 2004; Papadopoulos *et al.*, 2006).

Ceiba pentandra (L.) Gaertn that was used for this study is also known as Kapok or Silk-Cotton tree. It is a fast-growing gigantic tree which belongs to the family Bombacaceae. It is widely distributed in the tropical, inter-tropical and subtropical regions of the world and usually planted as wayside and shade trees (Alvarado *et al*., 2002). It is also an emergent tree that occurs in rainforests, and in gallery forest in drier areas (Duvall, 2011). *Ceiba pentandra* is a very large, deciduous tree which grows up to 60m tall, it is mainly used as a source of fibre and timber. Currently, the wood is mostly used in plywood manufacturing, boxes and crates, lightweight furniture, carvings, lifeboats, particle boards, papermaking etc. (Duvall, 2011).

In order to seek an alternative to the use of asbestos and to ensure the production of environmentally friendly boards and reduce the pressure on the forest, this study therefore, determined the effects of board density and mixing ratio on the physical and mechanical properties of the particle board produced using the sawdust of *Ceiba pentandra*.

2. Materials and Methods

2.1. Material collection and pre-treatment

Ceiba pentandra sawdust was collected from Surulere sawmill, Abeokuta, Ogun State, Nigeria. The collection was done by attaching the sack directly to the bandsaw so as to avoid mixture of other wood species. The collected sawdust was pulverized into fine particles, air-dried to reduce the moisture content and sieved with a 2 mm size wire mesh. The particles were pre-treated with hot water at 100°C for 30 minutes to reduce the extractive materials in the sawdust and later sundried for a week before the production.

2.2. Board Production

The cement-bonded particleboards were produced at Forestry Research Institute of Nigeria (FRIN), Ibadan, Oyo State, Nigeria. The boards were produced at two board densities (1200kg/m^3 and 1300 kg/m^3) and three different mixing ratio (1:2, 1:2.5 and 1:3) and replicated three times producing a total of 18 particle boards.

2.3. Physical Properties

Samples with dimension of 20 mm x 20 mm were prepared for evaluation of the water absorption (WA) and thickness swelling (TS) in accordance with the procedures stipulated by ASTM D 1037-93 (1995). The initial weight was measured using meter balance, and initial thickness was measured with a vernier caliper. The test samples were placed in the water and allowed to soak for 24 hours. Thereafter, the samples were removed and drained to remove excess water, then the weight and thickness were re-measured. The percentage water absorption (WA) and thickness swelling (TS) of each sample were calculated using the equation below:

$$WA = \frac{w2-w1}{w1} \ x \ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 1}$$

Where; WA = Water absorption, W1 = oven dried weight (g), W2 = weight of sample after immersion (g).

$$TS = \frac{T2-T1}{T1} \ x \ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 2}$$

Where; TS= Thickness swelling, T1= initial thickness (mm), T2= thickness of sample after immersion (mm).

2.4. Mechanical Properties

The test samples of 194 mm x 50 mm x 6 mm were cut from the board samples produced in accordance with the procedures of ASTM D 1037 – 78 (1991). To test for the MOR, the test samples were subjected to a force or load on the tensiometer with the support of a span. The forward movement of the machine leads to gradual increase of load at the middle span until failures of the test samples occurred. At the point of failure, the force exerted on the sample that caused the failure was recorded. The MOE was calculated using the amount of load required to cause a bending deflection during the MOR test. The Impact Bending (IMB) test was determined using an Impact Testing machine; it was measured in Jm^{-2}.

The following equations were used to calculate the MOR, MOE and IMB respectively.

$$MOR = \frac{3PL}{2bd^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3}$$

Where, MOR is the modulus of rupture in (Nmm^{-2}); P is the maximum or breaking load in (N); L is the length of the sample in (mm); b is the sample breadth in (mm) and d is the sample thickness in (mm).

$$MOE = \frac{PL^3}{4bd^3\Delta y} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 4}$$

Where, MOE is the modulus of elasticity (Nmm^{-2}); P is the increment in load (N); L is the length of sample or span in (mm); b is the sample breadth in (mm); d is the thickness of the specimen in (mm) and Δy is the increment in deflection corresponding to increment in load (mm).

$$IMB = \frac{Force \ x \ Load}{Area} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 5}$$

2.5. Statistical Analysis

The experimental design used was 2 × 3 factorial experiment in a completely randomized design (CRD), with the statistical model given as;

$Y_{ijk} = \mu + A_i + B_i + AB_{ij} + €_{ijk}$

Where: A and B represents the two factors of board density and mixing ratio respectively

Y_{ijk} = Individual observation A_i = Effect of board density

μ = General Mean B_i = Effect of mixing ratio

AB_{ij} = Effect of the two-way interaction between board density and mixing ratio

$€_{Ijk}$ = Experimental error.

The data collected were analyzed using the Statistical Package for the Social Sciences (SPSS) software. Analysis of Variance (ANOVA) was used to test for significant difference among the parameters at $P \leq 0.05$

3. Results and Discussion

3.1. Physical Properties

Water absorption (WA) and Thickness swelling (TS) are the most important physical properties related to dimensional stability of the boards. They give an idea of how wood cement boards behave when used under severe humidity conditions (Sotannde *et al.*, 2012). They are especially important in boards for external use. Table 1 shows the mean values of water absorption (WA) which ranges from 7.64 % to 9.53 %. The response of the boards to water intake shows that increase in mixing ratio (1:2 to 1:3) and board density (1200kg/m^3 to 1300kg/m$^{3)}$ of cement bonded particleboard produced caused a decrease in water absorption. This is in agreement with Ajayi (2003), who reported that board produced at the highest level board density resist hydrostatic force against the bonds. Papadopoulos (2008) also attributed this phenomenon to the greater volume of material consolidated into the higher-density board, which resulted in a higher board compaction ratio and consequently, little or no empty space within the boards to retain water.

The lowest value obtained from the board was 1300 kg/m^3 and 1:3 mixing ratio for 24 hours of cold water immersion. The boards with a mixing ratio of 1:2 and board density 1200 kg/m^3 was discovered to be more porous and seems to absorb more water faster. The downward trend of the values of %WA as shown in Table 1 was due to the gradual increase in the quantity of the two production variables (board density and mixing ratio) used in the manufacturing process.

Table 1. Average values obtained for Thickness swelling and Water absorption**.**

Board density (kg/m^3)	Mixing ratios	Thickness swelling (%)	Water absorption (%)
1200	1:2	2.99± 0.17	9.53±0.25
1200	1:2:5	2.96± 0.37	8.62±0.10
1200	1:3	2.85± 0.11	8.50±0.47
1300	1:2	2.71±0.18	8.15±2.56
1300	1:2.5	2.57± 0.07	7.87±0.59
1300	1:3	2.36± 0.19	7.64±0.11

These observations agreed with Bamisaye (2007), Ajayi *et al.* (2008), Badejo *et al*. (2011), Sotannde *et al.* (2012) and Egbewole (2017). It was deduced that when the board is exposed to wet conditions, the compression stress is released, which caused the boards' springback leading to structural deformation, breakdown of bonds, fragility of boards and reduction in board's stability (Hiziroglu *et al.*, 1993). Thickness swelling also followed the same pattern as water absorption as shown in Table 1. Increase in mixing ratio (1:2 to 1:3) and board density (1200 kg/m^3 and 1300 kg/m^3) affected the thickness of the board due to the quantity of cement and wood particle present. The lowest thickness swelling value was obtained from the board with 1300kg/m^3 and mixing ratio 1:3 while the highest value was obtained from 1200 kg/m^3 and 1:2 mixing for 24 hours cold water immersion. This may be as a result of variation in density of the boards produced. Hence, the higher the board density, the lower the swelling of the board and vice – versa. Analysis of variance for the thickness swelling of cement – bonded particleboard produced from *Ceiba pentandra* sawdust showed that effect of board density was significant (P<0.05) as presented in Table 2.

Table 2. ANOVA result for Thickness swelling and Water absorption

Sources of variation	Df	F	
		TS	WA
Board density	1	19.00*	3.69^{ns}
Mixing ratio	2	2.60^{ns}	0.816^{ns}
D × M	2	0.457^{ns}	0.144^{ns}
Error	12		
Total	17		

* denotes significant at *P<0.05*, "ns" denotes not significant

3.2. Mechanical Properties

The mean values of MOE from this study ranges from 442.26 Nmm^{-2} to 1262.03 Nmm^{-2} which is lower than values reported by Erakhrumen et al. (2008), Badejo et al. (2011) and Amel et al. (2017) respectively but compared favorably with the report of Bamisaye (2007), who reported mean values of 391.68 Nmm^{-2} – 1339.29 Nmm^{-2} using rice husk as the lignocellulosic material. The average values of MOR ranges from 1.41 Nmm^{-2} to 4.32 Nmm^{-2} which is lower than the values reported by Erakhrumen et al. (2008), Badejo et al. (2011) and Amel *et al.* (2017),. The highest board density (1300kg/m^3) and mixing ratio (1:3) had the highest average MOR and MOE of 4.32 Nmm^{-2} and 1262.03 Nmm^{-2} respectively while the least MOR and MOE was obtained at the 1200kg/m^3 board density and 1:2 mixing ratio as presented in Table 3.

Table 3. Mean values obtained for MOR, MOE and IMB.

Board density (kg/m3	Mixing ratios	Modulus of Elasticity (Nmm^{-2})	Modulus of Rupture (Nmm^{-2})	Impact bending(J/m^2)
1200	1:2	636.61± 254.70	2.65±1.06	7.04±2.46
1200	1:2:5	442.26±143.84	1.41±0.61	8.43±4.25
1200	1:3	581.03±228.44	3.01±1.71	11.27±2.48
1300	1:2	987.73±230.96	4.12±1.06	8.44±4.24
1300	1:2.5	1026.09±1083.78	3.73±1.07	11.27±2.48
1300	1:3	1262.03±208.16	4.32±1.08	12.70±0.00

It is possible to produce the strongest experimental board at the highest levels of board density (1300kg/m^3) and mixing ratio (1:3). This is in agreement with earlier conclusions that heavier, stronger and stiffer boards could be manufactured by progressively increasing the board density (Badejo *et al.*, 2011) and mixing ratio (Fuwape, 1995; Badejo, 1999). Board density had significant effects ($P<0.05$) on both MOR and MOE as shown in Table 4.

Table 4. Analysis of variance of MOR, MOE and impact bending

Sources of variation	Df	F		
		MOR	MOE	IMB
Board density	1	9.597*	5.56*	1.77^{ns}
Mixing ratio	2	1.41^{ns}	0.23^{ns}	2.98^{ns}
D × M	2	0.267^{ns}	0.18^{ns}	0.11^{ns}
Error	12			
Total	17			

* denotes significant at $P<0.05$, "ns" denotes not significant

The mean values of Impact bending (IMB) for the boards produced ranged from 7.04 J/m^2 to 12.70 J/m^2. From this result, it was observed that the shock resistance of the samples was affected by the mixing ratio and board density. The impact bending of the boards increased with increase in *Ceiba pentandra* sawdust ratio from 1:2 to 1:3 and board density 1200kg/m^3 to 1300 kg/m^3. This observation is in agreement with the report of Badejo (1999), Sedano-Mendoza et al. (2010), Sotannde et al. (2012), Adejoba et al. (2015). The board that had the highest shock resistance was produced at highest *Ceiba pentandra*/cement ratio and the highest board density 1300 kg/m^3 as shown in Table 3. The result is in agreement with the conclusion of Adejoba et al. (2015) that at higher density, strong inter-particles bond exist between the cement and sawdust particles which resulted to better compatibility.

4. Conclusion

This result obtained from this study showed that board production is feasible in *Ceiba pentandra* sawdust when mixed with cement in a considerable ratio. The study further revealed that only the board density influenced the dimensional stability and strength of the board. The values obtained for water absorption and thicknesses swelling following 24 hours water soak cycle ranged from 7.64% to 9.53% and 2.36% to 2.99% respectively. These results showed the boards were structurally stable. Also, the values obtained from impact bending, modulus of rupture and modulus of elasticity ranged from 7.04% to 12.70%, 636.61% to 1262.03% and 2.65% to 4.12% respectively. The result obtained from this study shows that the strongest experimental board was produced at the highest level of board density (1300kg/m^3) and mixing ratio (1:3).

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