Original Research Article

STRENGTH AND DIMENSIONAL STABILITY OF CEMENT-BONDED BOARDS MANUFACTURED FROM MIXTURE OF *Ceiba pentandra* AND *Gmelina arborea* SAWDUST

ABSTRACT

Cement bonded boards of 6 mm in thickness were produced from the mixture of *Ceiba pentandra* and *Gmelina arborea* sawdust. The influence of weight to weight proportion of *C. pentandra* and G. arborea blended at levels of 100:0, 75:25, 50:50, 25:75 and 0:100 in mass and mixing ratios of cement to wood 2:1 and 3:1 on Modulus of Rupture (MOR), Modulus of Elasticity (MOE) Water Absorption (WA) and Thickness Swelling (TS) properties of the experimental boards were examined for 24 h and 48 h immersion in cold water. The mean values for MOE and MOR were from 2479.50 to 5294.30 N/mm^2 and 0.82 N/mm^2 to 3.02 N/mm^2 respectively, while the mean values for TS and WA after 24 h in cold water were from 0.53% to 7.35% and 14.8% to 52% respectively, whereas after 48 h in cold water immersion the mean values for TS and WA were from 2.37% to 10.48% and 16.5% to 69.5% respectively. It was observed that, increase in *G. arborea* (75%) to *C. pentandra* (25%) and mixing ratio 3:1 (cement/wood) was responsible for increase in MOR and MOE and decrease in TS and WA. The result shows that cement-bonded boards can be manufactured from *Ceiba pentandra* sawdust when mixed at certain blending proportion and ratio

Keywords: *Ceiba pentandra, Gmelina arborea,* Modulus of Rupture, Modulus of Elasticity, Water Absorption and Thickness Swelling.

1.0 INTRODUCTION

Forest has always been man's resort for major raw materials needed for constructional, recreational and technological designs and fabrication. This is due to the uniqueness of the major product of the forest (e.g. Timber) and its ability to naturally regenerate itself, its durability, its workability, and adaptability to perform adequately at different environmental conditions. However, the aforesaid influence of man's dependence on the forest has over the decades caused overexploitation and great cumulative effects of in-balance in the forest environment was responsible to unabated phenomenon such as environmental degradation, earthquakes, urban flooding and other environmental problems. The high exploitation of timber species and long gestation period of tropical hardwood has stimulated interest in the production of cement-bonded particleboards from residues generated in sawmills, plantations, hardwood species from the forests and agricultural residues (Ajayi, 2006). The adequately utilization of wood and industrial wood residues for value-added panel products will thereby minimize the periodic shortage of wood raw materials, wood products and reduction in exploitation pressure exerted on the country's forest resources.

Cement-bonded board (CBB) is a versatile material that is suitable for interior and exterior use for low-cost housing construction. It can be molded into any form and shape to meet specific end use and it is resistant to freeze, thaw, fire, water, rot, termites, insects and fungi attack. Furthermore it has high insulation and durability properties and It is asbestos free, does not produce hazardous and volatiles substances, and the dust from production processing of the board is non-aggressive (Blankenhorn *et.al*, 1994; Ajayi and Badejo, 2005). It has better dimensional stability and it neither contains formaldehyde nor release poisons and toxic gases to the environment. CBB may be sawn, shaped, drilled, nailed and screwed with normal woodworking tools and machinery. Research into the development of CBB over the years by many researchers has led to the simplicity in the technologies of production techniques and the enhancement of both mechanical and dimensional stability properties to meet specific end use worldwide.
The production and uses of this boards has led to the recognition of the suitability of a wide range of raw materials for board production in order to reduce pressure on the existing forest resources; a desire to increase wood resources utilization and acceptability of the new products in the markets as alternatives to sawn timber so as to meet wood products needs on a sustainable basis (Ajayi 2006).

The suitability of some indigenous hardwood species for production of cement-bonded particleboards have been investigated by some researchers Oyagade, 1994, Badejo, 1999, Ajayi, 2000 and Ajayi, 2003;). The use of all these raw materials for CBB production will no doubt increase the industrial growth of Nigeria and economic base for National development. In addition, it will induce reduction in exploitation pressure on forest biodiversity, stabilizes ecosystems, increases sustainable management of the complex forest resources, reduces all forms of erosion in the environment and mitigates climate change and all forms of forest activities in Nigeria. Due to the high cost of synthetic resin binders, and heat energy in particleboard manufacture, the need to find an alternative source to synthetic binder is crucial mainly for non-developing countries. (Ajayi, 2000). Hence, cement is being used as binding agent in CBB particleboard manufactured (Ajayi, 2000; Ajayi, 2003).

Despite the excellent performance of wood-cement boards, many wood species will not bond well with cement to form suitable boards due to the presence of some chemical substances in the wood particles, which inhibit the proper setting of cement boards (Simatupang *et al* 1991*,* Fuwape 1992; and Ajayi, 2000). These chemical substances include sugar, starch, hemicelluloses of the sapwood and extractives of the heartwood notably phenol and other non-soluble chemical substances (Biblis and Lo, 1968, and Ajayi, 2003).The pre-treatment of the wood particles becomes necessary in order to remove water soluble extractives, to improve the bonding and compatibility of wood-cement, thereby facilitating the increase in the amount of wood species for particleboard production.

This study aimed to examine the suitability of *Ceiba pentandra* and *Gmelina arborea* sawdust for CBB and to evaluate the effect of factors of production on the dimensional stability and the bending strength of the boards.

2.0 MATERIALS AND METHOD

2.1 Materials collection

The *C. pentandra* and *G. arborea* sawdust were supplied by a sawmill industry located at Akure-Owo express way, Akure, Ondo State. This was transported to the Department of Forest Products Development and Utilization (FPD&U), Forestry Research Institute of Nigeria (FRIN), Jericho Hills, Dugbe, Ibadan, Oyo state for further processing. The cement used was Ordinary Portland Cement which conformed to the BS12 (1996) requirements.

2.2 Materials preparation

The sawdust from each wood species was screened through 6 mm mesh to remove fine particles. The coarse sawdust particles were spread out in open air for four weeks in order to allow for gradual degradation of their starches and sugars that could inhibit setting of the cement binder. After air-drying, each of the species was separately poured in aluminium bath and pre-treated in hot water at about 80 $^{\circ}$C for a soaking period of 1 hour. This pre-treatment process was carried out in order to facilitate the removal of water soluble sugars and other chemical substances that may remained after the raw material degradation. The treated particles were thereafter put in a sieve to allow for 20 minutes dipping of the water. They were later air seasoned at room temperature for two weeks to a moisture content of about 12%, bagged and stored until needed as prescribed by Ajayi (2008).

2.3 Blending of production variables

Production of boards were based on the following factors: Blending proportion in mass of *Ceiba pentandra*: *Gmelina arborea* sawdust at 100:0, 75:25; 50:50, 25:75, 0:100; Cement: wood ratio at 2.:1 and 3:1 based on oven dry weight and volume of the board. The following constant factors were observed: Board density (1200 g/cm^3), additive concentration using Calcium chloride (3% of cement weight), and Board size (350 mm × 350 mm × 6 mm).

2.4 Boards Formation, Pressing and curing

Each board was produced based on treatment combination as the amount of cement, sawdust, calcium chloride and water. Raw materials were weighed inside a mixer and mixed together thoroughly in order to prevent the formation of cement/sawdust lump. The mixture was immediately hand-formed uniformly into a mat inside a wooden mould of 350 mm× 350 mm already placed on a wooden plate covered with polyethylene sheet. The top press plate was also covered with polyethylene sheet before it was placed on the mat. This use of polyethylene sheet was done to prevent the sticking of the metal plates on the mat formed. The mat was transferred to the hydraulic press and cold-pressed for 24 h under a pressing pressure of 1.23 N/mm^2 to a targeted thickness of 6 mm. Thereafter, boards were removed and kept inside polyethylene bag and sealed up for 28 days for post curing and hardening of boards. After this, the boards were cut to test specimens.

2.5 Testing

2.6 Mechanical Properties

The bending strength test was assessed using test specimen of 194 mm × 50 mm × 6 mm on universal testing machine. Specimens were separately supported equally on metal rollers at two points of 17mm away from the two ends of specimen under test. Load was applied at the centre perpendicular to the face and over the entire width of the board's specimens using a rounded metal bar. Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) were the strength properties examined. MOR and MOE data were calculated according to equation 1

$$\text{MOR (N/mm}^2\text{)} = \frac{3\rho L}{2bh^2} \qquad \textbf{(1)}$$

Where MOR = Modulus of rupture (N/mm^2), ρ = the ultimate failure load (N), L= the board span between the machine supports (mm), b = width of the board sample (mm), h = thickness of the board sample (mm)

The modulus of elasticity was determined from the bending test performed on each specimen and MOE was calculated using the equation 2

$$\text{MOE (N/mm}^2\text{)} = \frac{\rho L^3}{4\Delta bd^3} \qquad \textbf{(2)}$$

Where MOE= modulus of elasticity (N/mm^2), ρ = Load (N), L= the span of board sample between the machine supports (mm), b = width of the board sample (mm), d = thickness of the board sample (mm), Δ= slope obtained from the graph.

2.7 Physical Properties

Thickness Swelling (TS) and Water Absorption (WA) properties of boards were assessed using the test specimen of 152 mm x 152 mm. They were vertically immersed in cold water for 24 h and 48 h. All of the tests were carried out according to the procedure described in ASTM D (1978).

$$WA = \left(\frac{W_2 - W_1}{W_1}\right) \times 100 \quad \textbf{(3)}$$

Where WA = water absorption; W_1 = fresh (initial) weight (g); W_2 = Dried (final) weight (g)

$$TS = \left(\frac{T_2 - T_1}{T_1}\right) \times 100 \quad (4)$$

Where: TS= Thickness swelling (%); T_2= Final thickness (mm); T_1= Initial thickness (mm) after 28 days of curing.

2.8 Data Analysis

The experimental design was a 2×5 factorial in a Completely Randomized Design. Each of the boards were replicated three times allowing the evaluation of 30 boards.

Factor A = Two mixing ratios of cement: wood (2:1 and 3:1)

Factor B = Five (5) blending proportion of *C. pentandra: G. arborea* (100:0; 75:25, 50:50; 25:75, 0:100)

Based on the factorial experiment, a two-way analysis of variance (ANOVA) was conducted to determine the effects of main factors and its interaction factors. Mean values for board samples were compared using Duncan Multiple Range test (DMRT) at 5% probability level.

3.0 RESULTS AND DISCUSSION

Table 1. Mean Values obtained for WA, TS, MOR and MOE of Particleboard

Mixing Ratios (MR)	Blending Proportion (BP)	WA (%)		TS (%)		MOR (N/mm^2)	MOE (N/mm^2)
		24 h	48 h	24 h	48 h		
2:1	100:0	-	-	-	-	-	-
	75:25	52.0±8.70	69.5±2.90	7.35±1.23	10.48±0.52	1.02±0.10	2479.50±129.90
	50:50	32.7±5.50	48.9±2.70	4.16±0.77	8.03±0.09	1.19±0.50	2701.97±12.52
	25:75	22.2±3.70	27.1±0.80	1.59±0.27	7.54±1.04	1.36±0.11	3883.53±1971.35
	0:100	21.3±3.60	24.8±0.60	0.90±0.15	4.10±0.60	2.80±0.53	4948.63±638.67
3:1	100:0	-	-	-	-	-	-
	75:25	25.8±5.33	41.8±2.70	1.82±0.30	9.23±1.24	0.82±0.31	2114.73±46.83
	50:50	24.6±4.10	40.2±2.60	1.47±0.25	7.28±0.52	1.53±0.33	2983.27±266.43
	25:75	21.8±3.60	24.7±0.50	1.29±0.22	3.15±0.26	1.70±1.32	3345.73±1846.41
	0:100	14.8±2.40	16.5±0.30	0.53±0.09	2.37±0.43	3.02±0.55	5294.30±404.86

Table 2. Analysis of Variance (ANOVA) for MOR, MOE, WA and TS

Sources of Variation	Degree of Freedom	F. Variance Ratio					
		TS (%)		WA (%)		MOR (N/mm^2)	MOE (N/mm2)
		24 h	48 h	24 h	48 h		
MR	1	108.58*	127.33*	26.42*	3.36 ^{ns}	0.07^{ns}	0.03^{ns}
BP	4	85.38*	54.78*	63.22*	120.04*	16.53*	20.50*
MR*BP	4	36.13*	10.92*	8.57*	0.35 ^{ns}	7.21*	6.45*
Error	20						
Total	29						

*denotes significant (P<0.05); ns denotes not significant (P<0.05)

Table 3: Multiple comparisons for MOR, MOE, WA and TS of cement-bonded board

Notation	Blending proportion	WA		TS		MOR	MOE
		24 h	48 h	24 h	48 h		
BP_5	0:100	18.05^{a}	2.60^{a}	0.72^{a}	2.52^{a}	1.10^{a}	2842.62^{b}
BP_4	25:75	21.80^{a}	3.90^{a}	1.44^{b}	3.91^{b}	1.45^{ab}	2999.13^{b}
BP_3	50:50	28.65^{b}	15.90^{b}	3.04^{c}	4.84^{c}	1.91^{b}	3886.90^{ab}
BP_2	75:25	38.90^{c}	16.75^{b}	4.59^{b}	5.27^{c}	2.36^{b}	4147.18^{a}
BP_1	100:0	-	-	-	-	-	-

Data followed by the same letter in the same column are not significantly different

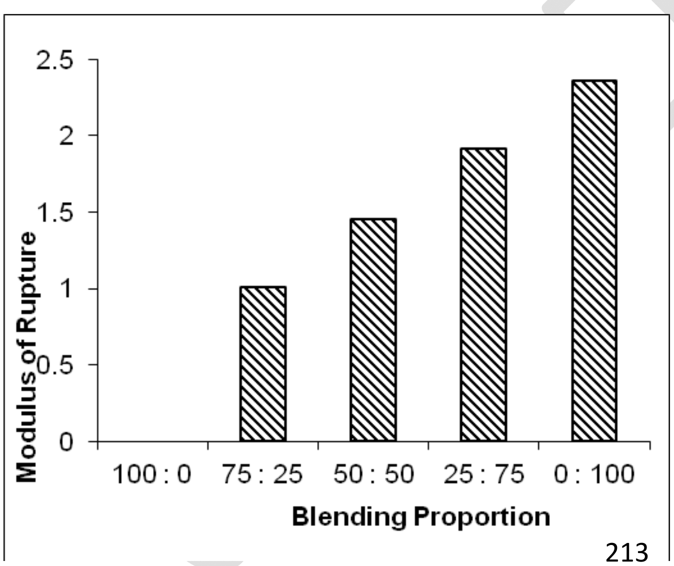
Modulus of Rupture and Modulus of Elasticity

Table 1 presents the average values for Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) as they ranged from 1.02 to 3.02 N/mm^2 (MOR) and from 2479.50 to 5294.30 N/mm^2 (MOE), respectively. The result shows that the boards formed from pure *C. pentandra* sawdust failed at the point of removing from the press. This might be due to the nature of the sawdust (fines and density) and the high contents of extractives present in the sawdust, which can inhibit and retard the setting and curing properties of the cement. Boards made from *G. arborea*, a high density wood species (0.45+ g/cm^3), have higher average strength when compared with boards from *C. pentandra* a lower density wood species (0.23 g/cm^3) (Gisel *et al*., 2014). The result in this study contradict the findings of Ajayi (2008) who stated that low-density wood produced better and stronger boards than high-density wood.

The results also shows that MOR and MOE depends on blending proportion (BP) and cement/wood mixing ratio as they were directly influenced by each level of combination. As the contents of *G. arborea* increases in blending proportion related *to C. pentandra* sawdust and for higher cement to wood contents (mixing ratio), there was increase in MOR and MOE values as shown in Figures 1, 2, 3 and 4. Result further revealed that strong experimental boards were produced at the highest levels of BP of *G. arborea* (75%) to *C. pentandra* (25%) and cement/wood mixing ratio 3:1. The influence of BP becomes increasingly significant as the ratio of *G. arborea* and those of the cement content increased (Oyagade 1990, Giemer *et al.* 1993, Ajayi, 2006). Higher board compaction of boards was achieved because of increased number of bonds, inter particles contact areas and adequate encapsulating of the wood particles by the binder. This study confirm the findings of Ajayi (2006), that greater bonding quality and cohesive strength inherent in the boards manufactured from high cement/wood ratio and high blending proportion of materials accounts for the flexural strength observed in such boards.

According to the general properties of low-density cement wood composites in a specific gravity range of 0.5 to 1.0, the modulus of rupture was 1.7 to 5.5 N/mm^2 and the modulus of elasticity 621 to 1241 N/mm^2 (Wang and Xu, 1994). The data of MOR and MOE obtained in this study satisfies the specified property in a ratio of 25:75 for cement bonded sawdust particleboard. The results obtained for the MOR of the panels in this study were significantly lower than the European standard (>9 N/mm^2) when the density ranges from 1200 to 1300 kg/m^3 (Anon, 1996).

Table 2 shows that significant differences exists in the MOR and MOE, at the levels of BP and the two factor interactions, whereas MR had no significant effect on MOR and MOE. Table 3 shows significant difference exists in Modulus of rupture (MOR) at blending proportion levels between 100:0 and 25:75; 100:0 and 50:50; 100:0 and 75:25, respectively, while the comparison between 50:50 and 75:25; 50:50 and 75:25 are not significant. For MOE, there is no significant difference between the BP 100:0 and 25:75, but significant difference exists between BP 100:0 and 50:50; 100:0 and 75:25 and between 25:75 and 50:50, 25:75, and75:25; 50:50 and 75:25.



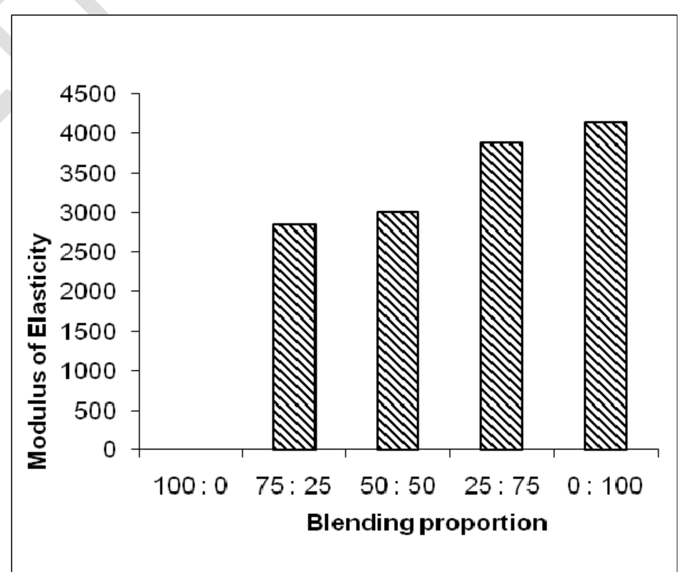
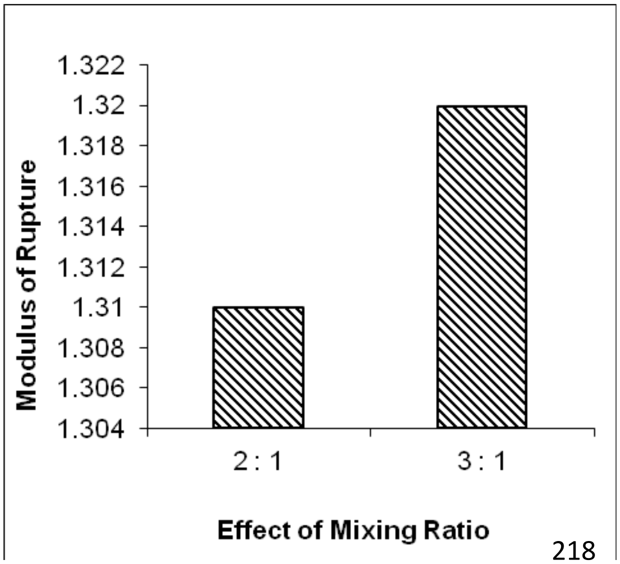


Figure 1: Effect of Blending Proportion on MOR

Figure 2: Effect of Blending Proportion on MOE



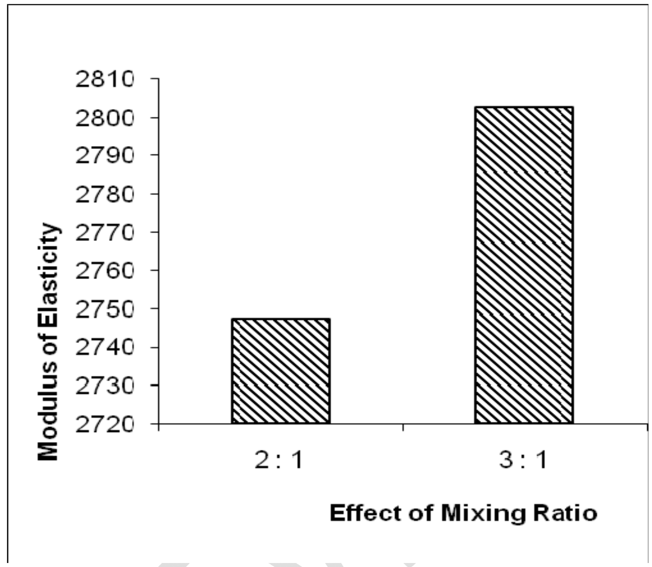


Figure 3: Effect of Mixing Ratio on MOR **Figure 4**: Effect on Mixing Ratio on MOE

Thickness Swelling and Water Absorption

Table 1 shows the average values for Water Absorption (WA) and Thickness Swelling (TS) after 24 and 48 h of immersion in cold water. The average values for WA ranged from 14.8% to 52.0% and from 16.5% to 69.5% after 24 h and 48 h cold water immersion, respectively, and for TS, the values ranged from 0.53% to 7.35% and 2.37% to 10.48% after 24hours and 48 h immersion in cold water. The result shows that increasing blending proportion of *G. arborea*: *C. Pentandra* and the cement/wood mixing ratio caused decrease in WA and TS properties. The lowest values were obtained from the boards produced at 0:100 (*C. pentandra: G. arborea* sawdust) and 3:1 cement/wood ratio, 25:75 (*Ceiba pentandra: Gmelina arborea* Sawdust) blending proportion and 3:1 cement/wood ratio. Because of this, more dimensionally stable boards were produced at these levels as they showed relatively better performance of WA and TS of the manufactured boards.

Generally, board with high resistance to water intake and thickness increase was produced at the highest proportion of *G. arborea* (75%) to *C. pentandra* (25%), and cement/wood ratio of 3:1 as the board exhibited less spring back tendency, lowest thickness swelling, and weight gain during immersion in cold water. Similar results as previously reported by Fuwape (1992), Oyagade (1990), Ajayi (2000) and Ajayi 2008,). As a result, a low spring back characteristic exhibited was due to the reduction in the release of compression stress after demolding and when boards were put in water. The higher the cement/wood, the higher the board density, better inter-particle contact and improvement in quality and quantity of bonds in boards to resist the spring back of boards (Ajayi, 2000).

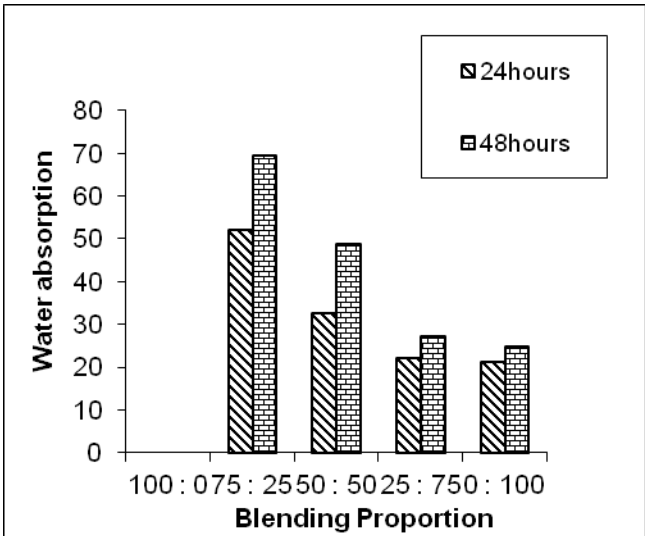


Figure 5: Effect of Blending Proportion on WA

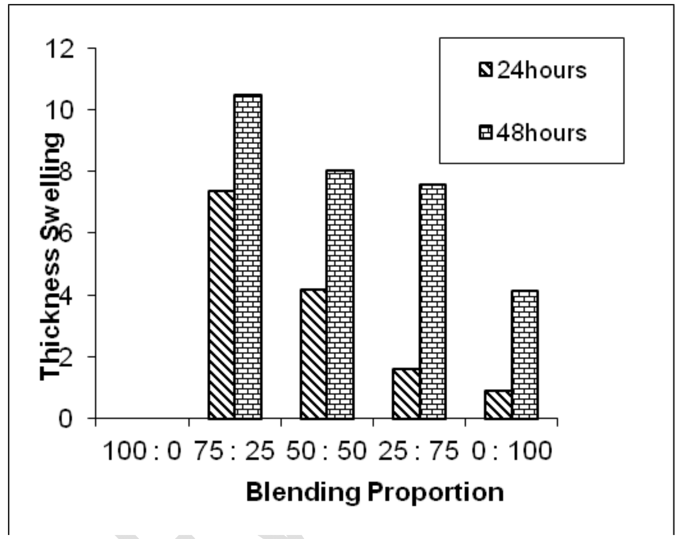


Figure 6: Effect of Blending Proportion on TS

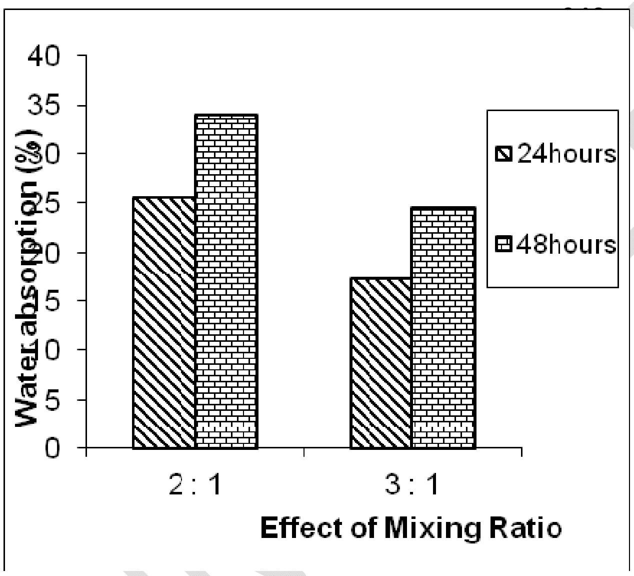


Figure 7: Effect of Mixing Ratio on WA

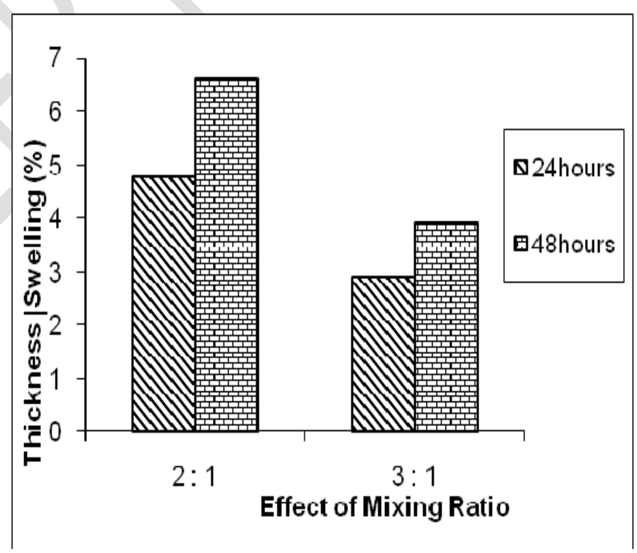


Figure 8: Effect of Mixing Ratio on TS

The result of the ANOVA in Table 2 shows that WA and TS properties were significantly affected by the BP, cement/wood ratio and the two-factor interaction. Each level of blending proportion having the same letter at 24 h and 48 h in cold water immersion has no significant effects, whereas those with different letter have significant effects on TS and WA (Table 3).

However, despite of the low compatibility of hardwood species as *C. pentandra of* low density with cement, they can be used for manufacturing cement-bonded composites when blended with high density wood species such as *G. arborea*. This blending process has helped to produced dimensional stable boards and improves their chemical compatibility using cement and setting accelerators such as calcium chloride as described by Ajayi, (2000).

CONCLUSION

This study revealed that cement-bonded particleboard could be manufactured from mixture of *C. pentandra* and *G. arborea* sawdust. Boards produced showed resistance to compression stress releases as a result of contact with water, indicating that they were structurally stable. Although the dimensional stability and mechanical strength properties of the boards were affected by the blending proportion and cement/wood ratio, however, increasing the blending proportion (*C. pentandra/G. arborea*) and cement/wood (2:1 to 3:1) could be attributed to increase in MOR and MOE, and decrease in WA and TS properties. Boards produced at the highest levels of the two variables were stronger than other boards. The follow-up test established the level of significant effect of blending proportion and cement/wood ratio on MOR, MOE, WA and TS, of cement-bonded boards produced.

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