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Properties of cement-bonded flake-boards from *Gmelina arborea* and *Leucaena leucocephala*

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ABSTRACT

This study investigated the suitability of *Gmelina arborea*, low-density wood species and *Leucaena leucocephala*, high-density wood species for the production of 6 mm thick Inorganic-bonded flake-boards. Flake-boards were made at three levels of curing reagent and board density to get nine experimental flake-boards for each species. The flake-boards were subjected to modulus of rupture, thickness swelling, water absorption, and accelerated aging tests. Thickness swelling, water absorption and accelerated age of boards decreased as curing reagent and board density increased whereas modulus of rupture of boards from each species increased proportionately with *Gmelina arborea* having higher strength. The performance of boards produced at the highest level of curing reagent and board density were better as they showed highest resistance to dimensional movement and bending force. Flakes from both species are suitable raw materials for flake-board manufacture, which could be used as substitute to sawn timber in core and low-cost housing construction.

Keywords: Reinforced composites, Strength, Casting.

INTRODUCTION

Cement-bonded flake-board consists mainly of wood, cement, and water with or without any catalyst. In recent time, the uses of agricultural by-products as substitute to wood have been investigated and they are found suitable for board manufacturing (Ajayi, 2005 ; Ajayi, 2006b). Wood cement board is a versatile material suitable for interior and exterior use for core and low-cost housing construction. It can be molded into any form and shape to meet specific end use and has resistant to freeze, thaw, fire, water, rot, termites, insects and fungi attack. Furthermore it has high insulation and durability properties. It is asbestos free, does not contain hazardous and volatiles substances, and the dust from production processing of the board is non-aggressive (Ajayi and Badejo, 2005; Blankenhorn et. al., 1994). It has better dimensional stability and it neither contains formaldehyde nor release poisons and toxic gases. Boards may be sawn, shaped, drilled, nailed and screwed with normal woodworking tools and machinery.

Research into development, the simplicity in the technologies of production techniques and the enhancement of both strength and dimensional movement properties to meet specific end use worldwide, may be due to the following factors: 1) recognition of the suitability of a wide range of raw materials for board production in order to reduce pressure on the existing forest resources; 2) a desire to increase wood resources utilization; 3) acceptability of the new products in the markets as alternatives to sawn timber so as to meet wood products needs on a sustainable basis; and 4) the desire to protect forest biodiversity (Ajayi, 2006a). Research reports indicate that hardwoods have compatibility problems with cement than softwoods. These problems have been attributed in part, to the inhibiting properties of hydrolysable hemi cellulose and some extractives present in hardwoods which inhibit the setting and curing of cement binder in board (Blankenhorn, et al., 1994; Ajayi, 2003; Olanike et al., 2008).

The simplest means of mitigating the deteriorating effects of these chemical substances is to remove the water soluble chemicals in the wood using hot water with addition of chemical additives such as calcium chloride, carbon dioxide gas, fly ash, and sodium hydroxide (Badejo, 1999; Ajayi, 2003; Ajayi and Fuwape, 2005). Boards produced from plantation hardwood species exhibited compression stress releases when in contact with water thereby causing the springback tendency exhibited by the boards. Furthermore, the severity of the aging test may cause failure of wood flakes-cement interface and could explain the increase in thickness swelling and water absorption of boards when subjected to accelerated aging test (Ajayi, 2000). Due to the high cost of thermosetting resin in board production in Nigeria, a great deal of interest is being developed on the use of cement as a binding agent, fortified with other mineralizing agents (Ajayi, 2000).

The purpose of this study was to investigate the suitability of using *Gmelina arborea and Leucaena leucocephala* species to produce cement-bonded flake-boards, to examine the modulus of rupture (MOR), thickness swelling (TS) and water absorption (WA) of the boards and the effects of accelerated aging (AA) test on the TS and WA of the boards.

MATERIALS AND METHODS

Gmelina arborea and *Leucaena Leucocephala* logs were debarked, cut into lengths of 1.0 m and stored for three months to reduce their moisture content and the concentration of inhibitory sugar compounds. The logs were converted into slabs by circular saw and flakes by flakers. Flakes from each species were dried in open air for 14 days, and thereafter, treated with hot water at temperature of 80 °C in an aluminium pot according to standard practice. The hot water-extracted leachates from both wood species were separately removed, washed in cold water for ten minutes. The flakes were separately air dried inside controlled ambient for two weeks to attain moisture content of 12% approximately prior to use. The basic density of each wood species was assessed using wood samples of 250 mm x 75 mm x 150 mm in size. Boards were manufactured based on the experimental design which includes curing reagent ($CaCl_2$) at three levels of 1.5%, 2.5% and 3.5% and board density at three levels 1000 kg/m^3, 1100 kg/m^3 and 1200 kg/m^3. Wood flakes, solution of calcium chloride and water were mixed together to a uniform matrix free of cement/wood lumps. The amount of water used to dissolve the curing reagent was computed as shown below; $W_t = W(0.30\text{-}MC) + 0.60C$. Where: W_t= Weight of water (g), W= Wood dry weight (g), MC= Moisture Content (%) and C= Cement weight (g).

A wooden mould of 350 mm x 350 mm was placed on a metal caul plate covered with polythene sheet on which the mat was formed; plywood plate was used to pre-press the formed mat and covered with another polythene sheet before the top metal caul plate was placed on it. The formed mat was transferred to the cold press and pressed under a pressing pressure of 1.23 N/mm^2 for 24 hours. Several mats were produced at once, clamped together in the press state. Thereafter, clamps were released, caul plates were removed, and the fabricated flake-boards were stored inside sealed polythene bags for 28 days for post curing.

Boards were trimmed to avoid edge effect on test specimens, stored in the laboratory environment at a temperature of 20 ± 2 °C and relative humidity of 65 ± 2% for 21 days. TS and WA were investigate using test samples of 152 mm x 152 mm and the AA passed through this test procedure: (a)

Immersion in water at 30 °C for 48 hours, (b) Storage inside freezer for 24 hours, (c) Heating in dry air at 60 °C for 1 hour, and (d) Exposure to boiled water for 1 hour. Test samples of 194 mm x 50 mm in size were used to determine the MOR; tests were carried out based on standardized procedures stated in American Standard (ASTM D1037, 1978).

The experiment was designed using 2x3x3 factorial experiment in Randomized Complete Block Design. The main factors are the wood species, board density and additive concentration. Analysis of variance was used to determine the level of significance among the factors and the effect of variables on the board's properties.

RESULTS

Table 1 presents the mean values for Modulus of Ruptures (MOR); thickness swelling (TS) and water absorption (WA); and TS and WA after the accelerated aging test. The densities of *Gmelina arborea* and *Leucaena leucocephala* were 480 kg/m^3 and 690 kg/m^3 respectively.

The mean values for MOR ranged from 8.74 N/mm^2 to 16.54 N/mm^2 for *Gmelina arborea* and 5.94 N/mm^2 to 10.79 N/mm^2 for *Leucaena leucocephala.*

The TS and WA mean values for *Gmelina arborea and Leuceana leucocephala* ranged from 2.60% to 6.61% and 2.72% to 7.79% and 19.62% to 25.53% and 16.22% to 22.98% respectively. Similarly, dimensionally stable boards were produced as the curing reagent (Figures 3 and 4) and board density increased. Boards produced at the highest level of curing reagent (3.5%) and board density (1200 kg/m^3) showed highest resistance to stresses pose by this treatment (Figures 1 and 2).

DISCUSSION

Wood density has an effect on the reactions of boards to bending test. Boards made from *Gmelina arborea,* a low-density wood species, have higher mean values and strength when compared with boards from *Leucaena leucocephala,* a high-density wood species. It shows that low-density wood produced better and stronger boards than high-density wood, the higher the wood density the lower the strength and resistant of boards to bending force. Increase in curing reagent from 1.5% to 3.5% and board density from 1000 kg/m^3 to 1200 kg/m^3 was responsible for the increase in MOR values from each species (Figures 1 and 2). Flake-boards produced from each species and at the highest levels of curing reagent (3.5%) and board density (1200 kg/m^3) were stronger and showed higher resistance to bending force than boards produced at the lowest levels of curing reagent (1.5%) and board density (1000 kg/m^3) as they contained more void spaces. Although, wood flakes were completely encased with cement but the cumulative cellulose materials in boards are smaller when compared with boards produced at higher levels. Therefore, the extent and number of void spaces at the highest levels of curing reagent (3.5%) and board density (1200 kg/m^3) were reduced.

The greater compression ratio and bonding within high density boards made at these levels probably accounted for their relatively high strength properties achieved (Ajayi, 2008; Olanike et al., 2008). In general, boards from *Gmelina arborea* were stronger than those from *Leucaena leucocephala* at all the levels of production. The loss of initial predetermined flake sizes of *Leucaena leucocephala* as against that of *Gmelina arborea* caused reduction in interflakes contact areas and number of bonds which resulted into manufacture of weaker boards. This finding is in agreement with the work of Clausen et al. (2001) and Li et al. (2004) that flake geometry has a greater control on bending strength of manufactured flake – boards. The result of the Analysis of Variance in Table 2 shows that significant differences ($p \geq 0.05$) only exists in MOR of boards at the levels of curing reagent and board density, and not with the two-factor interaction. The result of the follow-up test (LSD) in Table 3 shows the effect of each level of curing reagent and board density on MOR.

Table 1: MOR, TS, WA, AA (TS and WA) of Boards from the Two Hardwood Species [a] .

Factors curing reagent	/Level board density	MOR N/mm^2		TS %		WA %		TS % (AA)		WA % (AA)	
		G	L	G	L	G	L	G	L	G	L
1.5	1000	8.74 ± 01	5.94± 1.98	4.22±2.27	4.79±1.43	22.37 ± 1.32	22.99±0.40	6.61± 0.23	7.79± 0.10	25.53±0.53	22.98 ± 0.47
1.5	1100	9.84±3.45	7.08± 1.35	4.20 ± 0.74	4.48±1.15	20.61± 0.28	20.82±0.49	6.14± 0.23	5.84± 0.42	21.94±0.40	20.37 ± 0.51
1.5	1200	10.86±1.28	9.84± 1.08	3.70 ± 2.04	3.74±1.18	20.01 ± 0.03	20.93±0.24	2.03± 0.21	3.03± 0.05	20.39±0.63	18.00 ± 0.16
2.5	1000	9.57± 0.57	9.78± 2.14	2.91 ± 0.21	3.95±0.30	21.18 ± 1.14	21.77±0.22	5.47± 0.15	7.34± 0.26	23.83±2.15	21.73 ± 0.70
2.5	1100	11.56±2.78	7.95± 1.57	2.83 ± 0.80	2.94±0.36	20.50 ± 0.19	20.86±0.19	4.58± 0.46	4.17± 0.05	21.69±0.81	19.91 ± 0.39
2.5	1200	12.47±3.24	9.73± 0.97	2.80± 0.11	2.18±0.18	18.92 ± 1.48	19.15±0.07	3.38 ± 040	2.34±0.33	20.07±0.07	17.55 ± 0.32
3.5	1000	11.61±1.76	9.92± 1.20	1.41 ± 0.47	2.06±0.21	19.64 ± 2.62	20.54±0.66	4.64± 1.11	5.46±0.39	23.13±2.24	21.06 ± 0.06
3.5	1100	15.01±1.14	8.74± 0.97	1.31 ± 0.74	1.95±1.46	18.03 ± 1.81	19.22±0.23	3.36± 0.06	4.23±0.36	21.34±1.23	18.31 ± 0.31
3.5	1200	16.54±1.11	10.79±0.87	1.13 ± 0.45	1.58±0.73	17.81 ± 1.93	18.77±1.09	2.60± 0.56	2.72±0.52	19.62±0.12	16.22 ± 0.19

a- values are means of three replicates, G = Gmelina arborea, L = Leuceana leucocephala ,

Table 2: Analysis of variance for MOR, TS, WA and AA (TA and WA) from the two hardwood species.

Source of variation	Degree of freedom	F Values									
		MOR (N/mm^2)		TS %		WA %		AA (TS %)		AA (WA %)	
		G	L	G	L	G	L	G	L	G	L
CR	2	11.70*	5.70*	14.18*	16.25*	6.89*	39.05*	21.16*	41.95*	2.57ns	117.63*
BD	2	6.17*	5.75*	0.19ns	3.23ns	4.79*	43.96*	92.84*	380.36*	27.75*	680.99*
CR*BD	4	0.43ns	1.73ns	0.04ns	0.41ns	0.22ns	2.97*	13.01*	14.91*	0.60ns	3.18*
Error	18										
Total	27										

ns= Not significant ($p \geq 0.05$). * = Significant at ($p \leq 0.05$) level. *G = Gmelina arborea, L = Leuceana leucocephala*

Table 3: Least Significant Difference Test for MOR, TS, WA, and AA (TS and WA) from the two hardwood species *.

Factors	/Levels	MOR (N/mm)^2		TS %		WA %		Accelerated aging			
								TS %		WA %	
		G	L	G	L	G	L	G	L	G	L
	1.5	9.81a	7.62a	4.04a	4.34a	21.00a	21.58a	4.93a	5.55a	22.62a	20.45a
CR	2.5	11.30a	9,15b	2.82b	3.02b	20.20a	20.59b	4.48a	4.62b	21.86b	19.73b
	3.5	14.39b	9.82b	1.28c	1.86c	18.49b	1951c	3.53b	4.20c	21.36a	18.53c
	1000	9.97a	8.55a	2.84a	3.60a	21.06a	2177a	5.57a	6.86a	24.16a	21.92a
BD	1100	12.24b	7.92a	2.78a	3.12b	19.71b	2030b	4.69b	4.81b	21.66b	1953b
	1200	13.29b	10.12b	2.54a	2.50a	18.91a	19.62c	2.67c	2.70c	20.03c	17.26c

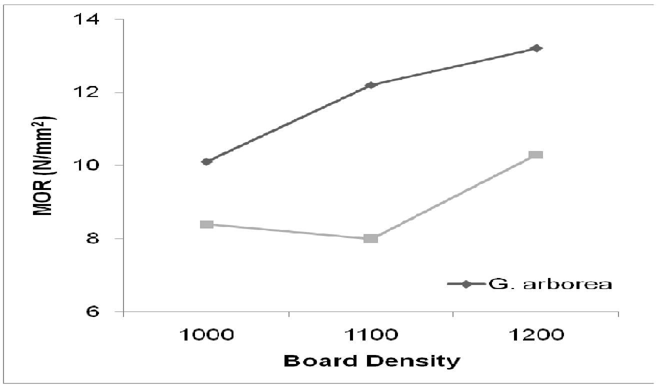

Figure 1: MOR of boards with *G. arborea* and *L. leucocephala* using different density.

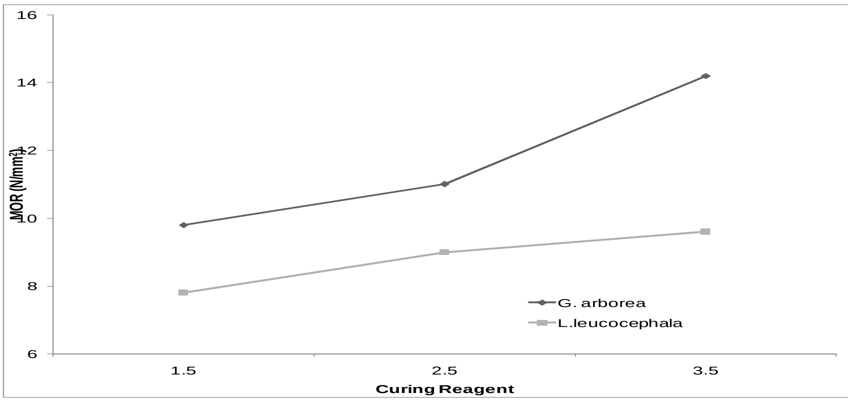

Figure 2: MOR of boards with *G. arborea* and *L. leucocephala* using different curing reagents.

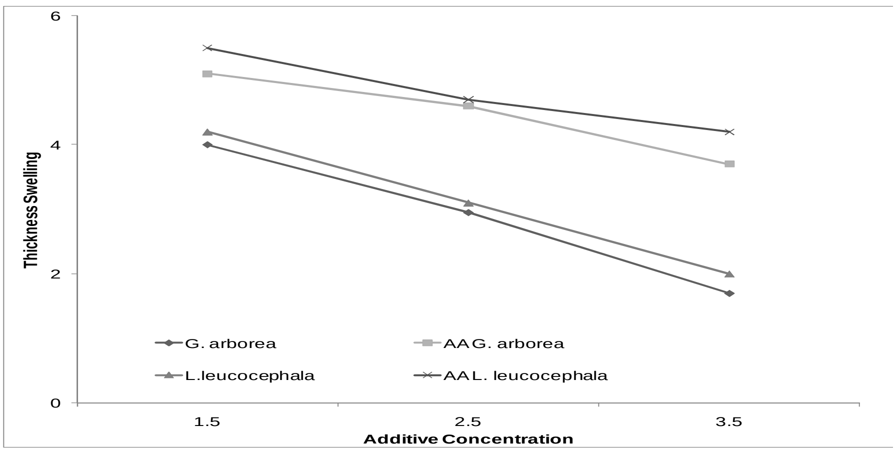

Figure 3: Thickness swelling of boards using different additive concentration.

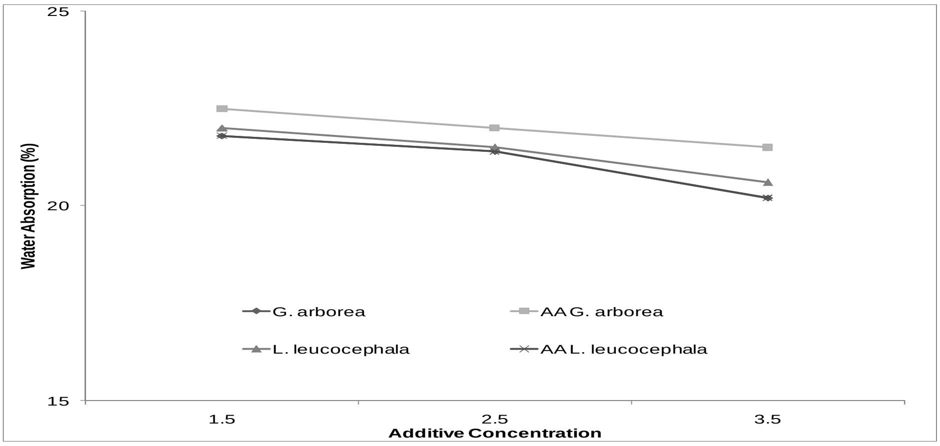

Figure 4: Water absorption of boards using different additive concentration.

Generally, in spite of the low compatibility of hardwood species and the variations in the densities of *Gmelina arborea* (480 kg/m^3) and *Leuceana leucocephala* (690 kg/m^3), they can be used for manufacturing of cement-bonded composites, increase the board's density to manufacture high quality panel products and also improve their compatibility using cement setting accelerators such as calcium chloride (Ajayi, 2000) and carbon dioxide (Geimer et al., 1993). The statistical analysis of data for TS and WA shows that curing reagent and board density have significant effects on TS and WA of both *Gmelina arborea* and *Leuceana leucocephala* boards. The two-factor interaction has significant effect on WA of boards produced from both species but not on their TS (Table 2). The LSD test in Table 3 shows the effect of each level of curing reagent and board density on TS and WA.

Accelerated aging test (AA) test was used to evaluate the inherent ability of bonds to withstand severe exposure conditions, this provided immediate and likely information on the behaviours of particle board in a critical long-term use and to give insight into degradation that could take place while in service. It explains the resistance of boards to weathering or degradation due to moisture, heat, springback and shrinkage stresses.

The increase in AA test values over the 48 hrs soak in water may be due to swelling forces which caused wood flakes delaminating, destruction of the binder and degradation of the bonds.

The freezing, followed by hot water treatment, caused evolution of air bubbles indicating that the newly created void spaces evolved were brought about by board's exfoliation, delamination and further enlargement under freezing condition. The severity of the test may have caused softening and plasticity of wood leading to failure in the wood flakes-cement interface, breakdown of bonds and increase in TS and WA of boards. However, the outstanding performance exhibited by these boards was influenced by curing reagent and the reinforced wood materials in them (Moslemi and Lim, 1984; Ajayi, 2000). Thickness swelling values obtained for the boards were within the acceptable EN standard (ESC, 1993b) compared with the work carried out by Nemli et al. (2004). He reported an average thickness swelling ranging from 17.0 to 24.9% for boards produced from urea formaldehyde resin as binder and 1% ammonium chloride as hardener. The damage done to cement-bonded board after long-term exposure was caused by chemical degradation of particles and mechanical stress on the binder induced by swelling forces from the wood particles.

Boards produced from *Leuceana leucocephala* increased thickness-wise than those from *Gmelina arborea,* but boards from *Gmelina arborea* swell more. While the *Leuceana leucocephala* boards were saturated with water, the newly visible void spaces created in *Gmelina arborea* based-boards were filled with water thereby causing more increase in the weight of boards.

Curing reagent and board density, and two-factor interaction have significant effect on TS of boards from both species, and WA of boards from *Leuceana leucocephala,* but the effect of board density on WA of *Gmelina arborea* based-boards was significant but the effects of curing reagent and two-factor interaction were not significant (Table 2). The question of the ability of accelerated aging exposure to predict the long-term durability of board cannot be answered presently until the results of longer weather exposure periods are available for possible comparison.

Conclusion

The TS and WA assert the behaviours of cement-bonded flake-boards under the effect of moisture; accelerated aging imposes stress on the structure and bonds of the boards. The more severe the test procedures the greater the degrading effects on the bonds, wood components and the binding agents. Increase in board density and curing reagent concentration caused increase in MOR but decrease in TS and WA even under normal moisture exposure and accelerated aging treatments. Boards produced at the highest levels of board density and curing reagent were the strongest, most stable and resisted the stress posed by both treatments. The accelerated aging test can be used to predict the long-term durability of cement-bonded flake-boards in practical use under normal weathering exposure.

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