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Accelerated Aging Assessment of Cement Bonded Board produced from *Gmelina arborea* (*Roxb.*) Strand and Sawdust

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Abstract- Durability, toughness, dimensional stability and resistance to termites attack are problems of materials used in construction. Environmental effect such as weathering also affect the performance of cement-bonded composite materials. This study examined the physical and mechanical properties of cement bonded board produced from *Gmelina arborea* (Roxb.) strand and sawdust. Three levels of mixing ratios of cement to wood material 1:1, 2:1 and 3:1 and five levels of material blending proportion of strand to sawdust of 100:0, 75:25, 50:50, 25:75 and 0:100 were adopted for the board formulation, Assessment of the water absorption, thickness swelling, and modulus of rupture, modulus of elasticity and accelerated aging were carried out. The boards' density recorded 800, 900 and 1000 kg/m^3. Mean water absorption ranged from 16.88±10.28 % to 56.36 ±11.70 % while thickness swelling ranged from 0.21±0.20 % to 5.43±0.99 %. Accelerated aging for first and second cycle respectively ranged from 17.15±0.65 % to 56.36±11.70 % for water absorption, while thickness swelling ranged from 5 1.15±0.26 % to 6.25±4.68 %. The mean values for the mechanical properties ranged from 1988.35±92.26 to 6526.90±186.06 (N/mm^2) for modulus of elasticity (MOE) and 1.03±0.59 to 5.90±3.76 (N/mm^2) for modulus of rupture (MOR), The mechanical result after aging test ranged from 1166.51±15.47 to 3115.70±100.97 (N/mm^2) for MOE and 0.95±0.12 to 4.81±0.68 (N/mm^2) for MOR. The analysis of variance carried out showed that both mixing ratio and material blending proportion had significant effect on the water absorption and modulus of elasticity while only mixing ratio had significant effect on the thickness swelling and modulus of rupture of the board. The board produced has the potential to be used as substitute for solid wood for asbestos tiles, wall panelling etc.

Keywords: Strand, Sawdust, *Gmelina arborea*, Physical, mechanical properties.

Introduction

Cement bonded wood composites are strands, particles or fibers of wood mixed together with Portland cement and made into panels, bricks, tiles and other products used in the construction industry. Cement-bonded composites helps to overcome the problem associated with the importation of resin adhesives in developing countries like Nigeria by providing a good substitute for resin-bonded particleboards, which contains 65 % resin adhesives. Cement-bonded composites have excellent weathering qualities, which make it suitable for many external building purposes [1]. Typical exterior applications are flat roofing, tunnel linings, prefabricated structures, balcony parapets and floors, cladding for industrial and warehouse buildings sound barrier agricultural buildings swimming pool surroundings and paving etc. Cement bonded particleboard are wood based panels which are more dimensionally stable under varying relative humidity change. They are good construction materials which are of great importance to mankind and possesses unique qualities over other panel products. This made it more acceptable particularly in less developed countries. The acceptance of cement bonded particle board is based on its reliability and resistance to fire, insect attack, decay and their perceived performance during natural disasters such as earthquakes and tropical storms [2].

The demand for wood raw material by building and wood industries in recent times has outweighed the production capacity of the forest. The poor log conversion efficiency of the mills is partly responsible for the pressure on the forest and the destruction of forest cover. Globally, there is an increase in the demand for wood and wood products. However, timber from the forest, and some of the valuable tree species are going into extinction. The generation and disposal of wood waste pose great environmental challenges [3]. When burnt, some produce poisonous fumes. Also wood as a lignocellulose material, is believed to be susceptible to degradation in high alkaline environments such as occurs in cement paste [4]. In order to prevent the escalation of this problem especially in the tropics, there is a need to effectively maximize the waste generated from wood as an alternative source of raw material that can be used in place of wood.

Methodology

The *Gmelina arborea* wood used was obtained from the plantation floor of the Department of Forestry and Wood Technology, Federal University of Technology Akure.

They were converted to strand and sawdust at the Wood workshop in FUTA using planning and circular sawing machine respectively. The strand and sawdust from *Gmelina arborea* were air-dried for two weeks; each of them was separately poured into aluminium bath and pre-treated in hot water at about 90^{O}C for a soaking period of 1 hour [5]. This pre-treatment process was carried out in order to facilitate the removal of water soluble sugars and other chemical substances present in the raw materials which may possibly retard or completely inhibit the setting and curing of the cement binder. Hot water containing the leached chemicals was drained off; and later washed thoroughly in cold water for about 30 minutes. Pre-treated strand and sawdust was air-dried to a moisture content of approximately 12% and kept inside a laboratory environment prior to use. Production of boards were based on the following varied factors: Blending proportion of strand to sawdust at 100:0, 75:25; 50:50, 25:75, 0:100, and three levels of Cement/wood ratio of cement to wood at 1:1, 2:1 and 3:1 based on oven dry weight and volume of the board. The following constant factors were observed: additive concentration of calcium chloride (3% of cement weight), Pressing pressure ($1.23N/mm^2$) and Board size (350 mm x 350 mm x 8 mm).

Each board was produced based on treatment combination as the quantity of cement, strand, sawdust, calcium chloride and water were weighed with the aid of weighing balance 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 x 350mm square already placed on a metal plate covered with polythene sheet. The top press plate was also covered with polythene sheet before it was placed on the mat. This use of polythene cover 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 hours under a pressing pressure of 1.23 N/mm^2 to a targeted thickness of 8 mm, similar method was used to produce all the other boards for the study. Thereafter, boards were removed and kept inside a polythene bag and sealed up for 28 days for post curing and hardening of boards. After this, the boards were trimmed to avoid edge effects on the test specimens. The bending strength test was assessed using test specimen of 195 mm x 50 mm x8 mm on universal testing machine. Specimens according to [6].

Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) were strength properties examined. Thickness Swelling (TS) and Water Absorption (WA) properties of boards were assessed using the test specimen of 150 mm x 150 mm. They were vertically immersed in cold water for 24 hours.

Accelerated aging test was carried out to assess the resistance of the board to long term usage or aging process. This was examined based on the simulated and formulated procedure of [5].

The test samples were subjected to two complete cycles of accelerated aging following this procedure:

i. immersed in water at 30^{o}C for 48 hours
ii. stored in freezer for 24 hours at 0˚C
iii. Oven dry at 100^{o}C for 1 hour; and
iv. exposed to boiling water for 1 hour

After the completion of these intensive treatments, samples were drained of excess water for 10 minutes. Thereafter, the weight and thickness of the sample were measured and determined. The statistical design for the experiment was 3 x 5 factorial experiments in Completely Randomized Design, the combination of which gave 15 treatments and a total of 45 boards. Analysis of Variance was carried out to determine the significant effect of the factors of production on board's properties. Duncan Multiple Ratio Test (DMRT) method was used to determine the significance of observed differences in sample means at 0.05 levels of significance.

Results

Aging effect on board physical properties

The density value ranged between $863.16kg/m^3$ to $1050.10kg/m^3$ from mixing ratio 1:1 to 3:1. The board produced at the highest mixing ratio of cement to material had the highest density value while the least density was produced at the lowest mixing ratio of cement to wood material 1:1.The Analysis of Variance (ANOVA) showed that there was significant difference among the board density both at mixing ratio and blending proportion levels. The mean value for water absorption after 24 hours immersion in water before aging test was between 15.64±2.66 % and 45.62±2.85 %, while for thickness swelling, it ranged from 1.14±0.38 % to 5.43±0.99 %. The mean values obtained for water absorption after the first cycle ranged between 17.15±0.65 percent to 56.36±1.70 % (TABLE 1) while for thickness swelling, it ranged between 1.15±0.26 percent to 6.25±4.68 %. The mean values obtained after second cycling for water absorption ranged from 19.44±2.33 % to 57.69±3.97 %. While for thickness swelling it ranged from 1.74±0.05 % to 8.17±4.60 %. The result showed that the boards did not show any sign of warping, delamination, or twisting after aging, After the test, water absorption, thickness swelling of the aging samples were substantially higher than that of control samples as shown in Table 1. The result of ANOVA after first cycling showed that all physical properties; water absorption and thickness swelling were significantly affected after the first cycle of aging test as shown in Table 3. But thickness swelling was not significantly affected by the material blending proportion and also there was no significant difference at the interaction level of the mixing ratio and material blending proportion at 5 % probability level. ANOVA carried out after second cycling showed that significant difference existed among the three mixing ratio level while there was no significant difference among the material blending proportion level and also at the interaction level on the water absorption of the board TABLE 4. The result of Duncan Multiple Ranged Test

(DMRT) conducted at 5 % probability level shown in Tables 3 and 4 showed the effect of mixing ratio and material blending proportion on the board. DMRT showed that accelerated aging had effect on the board both at the mixing ratio level and material blending proportion level on water absorption of the board. While result for second cycling revealed that mixing ratio had effect on the aging process on the water absorption and also on the thickness swelling of the board.

Aging effect on Strength properties

The results of the mean values obtained for the modulus of elasticity (MOE) and modulus of rupture (MOR) after aging test is presented in Table 2. The mean values obtained for MOE after aging test was between 2735.07±174.73 and 1166.51±15.47 N/mm^2 for mixing ratio 1:1. the material blending proportion 100 % sawdust recorded the least value as against the blend of 75 % strand with 25 % sawdust which had the highest modulus of elasticity value, For mixing ratio 2:1, the value was between 3015.21±37.63 and 1552.16±17.70 N/mm^2 while for mixing ratio 3:1 the value was between 3115.70±100.97 and 2208.57±48.49 N/mm^2 and for MOR test ranged between 1.66±0.66 and 0.95±0.12 N/mm^2 for mixing ratio 1:1, the material blending proportion 100 % sawdust recorded the least value as against the blend of 75 % strand with 25 % sawdust which had the highest mean value, For mixing ratio 2:1, the value was between 2.07±0.38 and 1.02±0.10 N/mm^2 while for mixing ratio 3:1 the value was between 4.81±0.68 and 2.81±0.61 N/mm^2. The value showed that there was changes in the MOE and MOR of the board properties after the aging test. ANOVA at 0.05 level of significance was used to test the significant differences among the mixing ratio and material blending proportion. Mean separations was carried out using Duncan Multiple Range Test at 5 % probability level as presented in Tables 5 and 6 The results revealed that mixing ratio had effect on the aging process on the MOE and also on the MOR of the board, At material blending proportion level, significant difference exist among all the levels and blending proportion 75:25 was ranked the best followed by 50:50 and 100 % sawdust which ranked as the least.

Discussion

The outstanding performance exhibited by particleboards are influenced by curing reagent and the increase cement content as revealed by [7]. Boards produced from sawdust exhibited thickness swelling more than those produced from the strand. Similar research conducted by [1] showed that there was significant difference after accelerated test at the material blending proportion level and interaction whereas there was no significant difference before test. At mixing ratio level, there was significant difference both before and after accelerated aging test for water absorption. For thickness swelling there was significant difference before accelerated test at the mixing ratio whereby at material blending proportion there was no significant before test and there is significant difference after test. The dimensional stability of cement bonded composite is a function of the quality of cement binder ratio; higher cement binder produced low thickness swelling and water absorption and vice versa [8]. This is also enhanced not only with cement but also by additive of $CaCl_2$. The performance of these boards under the accelerated aging was influenced by the cement binder and the reinforced sawdust in it. This similar result was obtained by [9]. Physical properties and statistical comparisons obtained after ageing showed that the boards did not show any sign of warping, delamination, or twisting after ageing. [9] in his research discovered that after the ageing test, thickness swelling and water absorption of aged samples was substantially less than that of unaged samples. Findings made by [10] and [11] revealed that 1600 N/mm^2 is the minimum requirement for the MOE of particleboards for general uses and furniture manufacturing. While ISO 8335 [12] requirements for MOR and MOE, specified 9N/mm^2 and 3000N/mm^2 [10]. The values obtained in this research is more than acceptable compared with the standard value being given above. Values obtained after accelerated aging showed that the MOE and MOR decreased which indicated that the severity of the test may have caused softening and plasticity of wood leading to failure in the wood flakes-cement interface and also breakdown of bonds which subsequently results in increased water absorption and thickness swelling of the boards.

Table 1: Mean Values for physical properties before and after accelerated aging test for first and second cycle

Mixing ratio (MR)	Material blending proportion (BP)	Density (kg/m^3)	Before aging		Accelerated aging			
					First cycle		Second cycle	
			Water Absorption (WA)%	Thickness Swelling (TS)%	Water absorption (WA)%	Thickness swelling (TS)%	Water absorption (WA)%	Thickness swelling (TS)%
1:1	100:0	863.16	42.09±4.93	5.43±0.99	48.73±0.42	5.53±1.08	52.91±4.54	7.66±1.08
	75:25	863.16	34.92±0.32	2.27±1.81	39.88±1.67	2.72±1.43	41.56±0.74	4.87±1.53
	50:50	863.16	42.08±3.05	4.70±3.21	43.57±4.00	3.96±2.33	50.97±3.44	5.07±2.94
	25:75	863.16	41.67±2.76	4.96±3.62	46.08±3.41	4.15±3.10	53.48±2.92	5.75±3.38
	0:100	863.16	45.62±2.85	5.38±1.10	56.36±11.70	6.25±4.68	57.69±3.97	8.17±4.60
2:1	100:0	933.92	25.44±1.08	2.73±0.41	25.64±6.45	4.23±0.68	31.00±0.45	5.45±0.97
	75:25	933.92	19.61±3.93	1.57±1.10	22.21±8.73	1.16±0.52	29.27±3.26	2.17±0.46
	50:50	933.92	23.56±3.63	2.31±1.01	25.37±6.88	1.82±1.34	30.62±3.78	3.19±1.16
	25:75	933.92	25.13±3.36	3.08±3.20	25.64±2.97	3.68±1.75	31.47±3.11	4.35±1.58
	0:100	933.92	26.85±4.64	3.48±3.39	27.20±1.78	4.95±2.41	32.60±3.62	6.81±2.08
3:1	100:0	1050.10	17.75±4.94	1.55±1.68	18.15±1.29	3.23±0.32	22.27±2.68	4.84±0.50
	75:25	1050.10	15.64±2.66	1.41±0.97	17.15±0.65	1.15±0.26	19.44±2.33	1.74±0.05
	50:50	1050.10	16.88±10.28	1.14±0.38	17.51±2.21	1.43±0.56	21.06±1.19	1.76±0.07
	25:75	1050.10	17.96±5.90	1.04±0.27	19.54±0.96	1.84±0.77	22.24±3.01	2.16±1.23

The number before “±” denotes mean values of three replicate and the number after “±” denotes standard deviation

BP: Ratio of strand to sawdust
MR: Ratio of cement to wood material

Table 2: Mean Values for MOE and MOR before and after accelerated aging

Mixing ratio (MR)	Material blending proportion (BP)	Before aging		Accelerated aging	
		Modulus of Elasticity (MOE) N/mm^2	Modulus of Rupture (MOR)N/mm^2	Modulus of Elasticity (MOE) N/mm^2	Modulus of Rupture (MOR)N/mm^2
1:1	100:0	2096.89±173.24	1.20±0.37	1274.09±148.27	1.00±0.035
	75:25	3091.27±148.55	2.19±0.62	2735.07±174.73	1.66±0.66
	50:50	2616.14±138.29	1.29±0.69	2154.84±115.46	1.28±0.32
	25:75	2278.52±100.64	1.26±0.12	2141.32±28.82	1.21±0.23
	0:100	1988.35±92.26	1.03±0.59	1166.51±15.47	0.95±0.12
2:1	100:0	2721.41±129.47	2.28±0.22	1675.06±117.32	1.98±0.35
	75:25	4007.98±161.62	3.48±3.72	3015.21±37.63	2.07±0.38
	50:50	3730.22±104.29	2.27±0.22	2286.62±14.49	2.03±0.19
	25:75	2872.11±114.81	2.03±0.28	2274.39±12.22	2.00±0.51
	0:100	2248.10±103.80	1.28±0.21	1552.16±17.70	1.02±0.10
3:1	100:0	2958.50±181.60	3.84±1.56	2672.94±118.46	2.89±0.90
	75:25	6526.90±186.06	5.90±3.76	3115.70±100.97	4.81±0.68
	50:50	5873.22±126.03	4.44±2.07	2673.21±196.68	4.13±0.16
	25:75	3438.05±108.85	4.09±0.38	2581.47±78.44	2.94±0.13
	0:100	2292.33±4.83	3.79±0.98	2208.57±48.49	2.81±0.61

Table 3: Duncan Multiple Range Test (DMRT) for mixing ratio

Mixing ratio			First Cycle		Second Cycle	
	Water Absorption (WA)%	Thickness Swelling (TS)%	Water absorption (WA)%	Thickness swelling (TS)%	Water absorption (WA)%	Thickness swelling (TS)%
1:1	46.92^a	4.55^a	41.27^a	4.01^a	51.32^a	6.02^a

2:1	25.14[b]	2.63[b]	24.19[b]	3.26[ab]	30.99[b]	4.20[ab]
3:1	17.91[c]	1.07[c]	18.21[c]	2.00[b]	21.01[c]	3.83[b]

Alphabets with the same letter show that there is no significant difference
Alphabets with different letter show that there is significant difference

Table 4: Duncan Multiple Range Test (DMRT) for material blending proportion

Material blending proportion	Before Aging		First Cycle		Second Cycle	
	Water absorption (WA)%	Thickness swelling (TS)%	Water absorption (WA)%	Thickness swelling (TS)%	Water absorption (WA)%	Thickness swelling (TS)%
100:0	30.70[ab]	3.23[a]	28.78[ab]	3.55[a]	35.39[a]	4.91[a]
75:25	26.32[b]	1.75[a]	23.89[b]	2.01[a]	31.08[a]	3.00[a]
50:50	28.81[ab]	2.71[a]	27.09[ab]	2.83[a]	34.43[a]	4.30[a]
25:75	29.89[ab]	3.03[a]	28.56[ab]	3.25[a]	35.46[a]	4.76[a]
0:100	34.22[a]	3.02[a]	31.13[a]	3.70[a]	35.84[a]	6.45[a]

Alphabets with the same letter show that there is no significant difference
Alphabets with different letter show that there is significant difference

Table 5: Duncan Multiple Range Test (DMRT) for mixing ratio

Mixing ratio	Before test		After Test	
	Modulus of Elasticity (MOE) N/mm^2	Modulus of Rupture (MOR) N/mm^2	Modulus of Elasticity (MOE) N/mm^2	Modulus of Rupture (MOR) N/mm^2
1:1	2414.24[b]	1.39[b]	1894.37[b]	1.22[c]
2:1	3115.96[b]	2.27[b]	2160.69[b]	1.82[b]
3:1	4163.82[a]	4.42[a]	2650.38[a]	3.52[a]

Alphabets with the same letter show that there is no significant difference
Alphabets with different letter show that there is significant difference

Table 6 Duncan Multiple Range Test (DMRT) for material blending proportion

Material blending proportion	Before Aging		First Cycle	
	Modulus of Elasticity (MOE) N/mm^2	Modulus of Rupture (MOR) N/mm^2	Modulus of Elasticity (MOE) N/mm^2	Modulus of Rupture (MOR)N/mm^2
100:0	2592.27[bc]	2.78[a]	1874.03[bc]	1.96[bc]
75:25	4452.08[a]	3.46[a]	2955.33[a]	2.85[a]
50:50	4073.19[ab]	2.67[a]	2371.56[b]	2.48[a]
25:75	2862.89[abc]	2.46[a]	2332.39[b]	2.05[b]
0:100	2176.26[c]	2.09[a]	1642.42[c]	1.60[c]

Alphabets with the same letter show that there is no significant difference
Alphabets with different letter show that there is significant difference

Conclusion

Wood strand cement-bonded is technically suitable for exterior use where moisture and favourable conditions for fungi development are present. The effect of production variables must be more fully studied to provide the guidelines necessary to adequately control the fabrication process and give material properties within a tolerable range. Wood Strand Cement Board (WSCB) has the potential to substitute for particleboard, solid wood, asbestos and plywood in the construction and refurbishment of residential, industrial, commercial, and agricultural buildings – especially in environments with consistently warm temperatures, high humidity and moderate to heavy rainfall. It is a versatile material that is suitable for both interior and exterior applications.

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