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Effect of wood particle geometry and pre-treatments on the strength and sorption properties of cement-bonded particle boards

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Abstract: The effect of particle geometry and pretreatments on the strength and sorption properties of wood particle cement composite boards was investigated. Wood particles (flakes and sawdust) of *Gmelina arborea* were mixed with cement and water in the production of composite boards. The wood particles were pretreated with hot water, calcium chloride and a combination of both treatments to enhance bonding with cement. The slurry was poured into rectangular moulds for board formation. After demoulding, the boards formed were tested for modulus of rupture (MOR), modulus of elasticity (MOE), water absorption (WA) and thickness swelling (TS). The results revealed that the mean MOR for flakes boards was 3.23N mm^{-2} while the mean MOR for sawdust boards was 3.01N mm^{-2}. Hot water and calcium chloride treatment produced the best effect in flake composite boards with MOR and MOE values of 6.90 N/mm^2 and 1897.36 N mm^{-2} while sawdust composite boards had mean MOR and MOE values of 5.69N mm^{-2} and 1664.31N mm^{-2} respectively. The WA rate after 24 hours of flakes and sawdust boards treated with hot water and calcium chloride was 3.63% and 4.28% while the TS rate was 0.69% and 1.44% respectively. Particle geometry and pretreatments significantly improved strength and sorption properties of wood particle cement composite boards ($p<0.05$).

Keywords: Composite boards, Particle geometry, Pretreatments, Sorption properties, Strength properties

INTRODUCTION

Cement-bonded particle board (CBPB) is a composite product that is made with wood particles/flour and Portland cement as the binding agent. Particle geometry which is the size or shape of the wood particles used in cement-bonded particle board production is of vital importance in the mechanical and physical properties of the CBPBs (Olorunnisola, 2007 and Badejo *et al.*, 2011). Particle geometries include strands, flakes, chips and fibres. Wood composite properties can be engineered to a certain extent by adjusting particle geometry (Li *et al.*, 2004).

In recent years, some products for structural applications have been developed such as cement-strand slab (Miyatake *et al.*, 2000), cement-bonded composite beams (Bejo *et al.*, 2005) and cement-bonded oriented strand boards (Papadopoulos *et al.*, 2006). In comparison to wood and conventional wood products, cement-bonded particle boards are highly fire resistant, water and insects resistant especially in warm and humid environment where such materials are demanded for construction materials (Wolfe and Gjinolli 1996; Eusebio 2003). The increasing interests and prospects of CBPBs in the building construction industries have been explained by the low costs and availability of the raw materials for production (Olorunnisola, 2007). Raw materials for the production of CBPBs range from agricultural residues (Rowell, 2007) to forest biomass, bamboo, wood wastes (sawmill wastes, logging wastes), construction wastes and recycled wood materials (Zhou and Kamdem, 2002). The addition of wood particles/flour to cement improves fracture toughness by blocking crack propagation which permits the composite to carry load to a higher strain limit (Wolfe and Gjinolli, 1996). Although, the incorporation of large particles has been found to impact greater flexural properties in wood-cement composites, poor interfacial bonding occurring between large particles and cement often results in low strength properties (Adefisan, 2013) and affects composite durability (Kerade *et al.*, 2003). The effect of different pretreatments on the properties of wood composites has also been investigated (Badejo, 1988 and Olorunnisola, 2008). The objective of this study was to determine the effect of different particle geometry and pretreatments on the strength and sorption properties of wood cement composite boards.

MATERIALS AND METHODS

Raw material preparation: Gmelina (*Gmelina arborea* Roxb.) sawdust and wood shavings were collected from Forestry Research Institute of Nigeria (FRIN) Ibadan. The materials were air-dried to a moisture content of about

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12%. Sieves of diameters 2.00 mm and 1.00 mm were used to obtain the sawdust-geometry which passes through the 2mm mesh and was retained by the 1mm mesh. The wood shavings were milled to flakes with an attrition mill. The flake-type geometry generated had average length, width, and thickness of 12 mm, 2 mm and 1 mm respectively.

Sample preparation: The samples were pretreated to remove the inhibitory substance between wood, a ligno-cellulosic material and cement, an inorganic binder prior to board formation. The treatments included hot water treatment, calcium chloride ($CaCl_2$) treatment, a combination of hot water and $CaCl_2$ treatment and a control. Hot water treatment was carried out in a water bath at 100°C for a period of 1 hour. Thereafter, the water was drained and the samples air-dried to a moisture content of about 12%. $CaCl_2$ was added as additives during board manufacture.

A cement-wood ratio of 3:1 by weight was used for this research. Giving a board density of 1200kg/m^3 and a board size of 350mm (length) by 350mm (width) by 6mm (thickness), the mass of the composite board was calculated as 882g. Thereafter, 661.5g Portland cement and 220.5g wood particles were weighed for board formation. The wood particles include the sawdust and flake geometries prepared with different treatments. Each category was prepared in four replicates making a total of 32 samples. These were packaged in a labeled polythene bag to avoid moisture absorption and easy identification. The quantity of water required for the mix was adopted from the procedure outlined by Badejo (1998) as follows:

$$0.6\,Z + (0.3 - R)\,H$$

Where Z= Weight of cement in the board, R= Moisture Content of the material, H= Weight of wood in the board This was calculated as 432.36ml, which was mixed with wood particles and cement until homogenous slurry was formed. However for chemical pretreatment, a solution of 3% calcium chloride (i.e. 19.85 g based on weight of cement) was dissolved in 432.36 ml of water prior to mixing with wood and cement.

Board formation: Wooden moulds of 350 mm × 350 mm were placed on caul plate and were covered with a polythene sheet to prevent sticking of the formed boards on to the plate. The slurry was spread out on the plate in the mould and pre-pressed using a wood press to enhance uniform mat formation and reduce the thickness of the formed mat. The formed mat was labeled to distinguish boards of different particle geometry and treatments. The labeled mat was covered with another polythene sheet with a top metal plate placed on it, and cold pressed at a pressure of 1.23 N/mm^2 for a period of 24hours using the hydraulic press. The final thickness of the boards was 6mm before demoulding. The demoulded boards were stored in a sealed polythene bags for 28days for curing of the cement. After curing, the boards were tested for strength and sorption properties.

Modulus of rupture (MOR) and Modulus of elasticity (MOE) test : Test samples were cut into 50mm (width) × 195mm (length) and were subjected to three point flexural test on Hounsfield Tensiometer machine equipped with a 125 lb load cell and tested at cross-head speed in accordance with British standard (1989). The MOR and MOE were thereafter calculated.

Water absorption and thickness swelling test: The board samples were cut into 100mm (width) by (100mm) length for water sorption test. The samples were completely submerged in distilled water at a temperature of about 20 ± 2^0C for 24 hours. The initial weight and thickness of the test samples were measured. At the end of the submersion period, the samples were drained for about 10 minutes and re-measured. Water absorption and thickness swelling after 24 hours was calculated from the increase in weight and thickness of the samples during submersion.

Data analysis: The experiment was carried out as a 2x4 factorial in a completely randomized design with four replicates. Analysis of variance procedure was used to estimate the effects of the sources of variation on the strength and sorption properties of the boards. Factor A represents particle geometry at two levels while Factor B represents pretreatments at four levels. Mean separation was carried out using Duncan's Multiple Range Tests.

RESULTS AND DISCUSSION

Mechanical properties

Effect of particle geometry and pretreatments on MOR: The mean values of the MOR of the wood particles are shown in Table 1. It was observed that flake-particles composite boards have greater MOR values than sawdust composites. In flakes boards, the mean MOR was 3.23N mm^{-2} while the mean MOR for sawdust boards was 3.01N mm^{-2}. This situation can be attributed to the high slenderness ratio in flakes particles. This finding is in agreement with the report of Frybort *et al.* (2008) that the use of long particles is important for high MOR. Badejo (1988) reported improvement in MOR with increase in flake dimensions of hardwood cement composites. Although, the incorporation of large particles has been found to impart greater flexural properties in wood-cement composites, poor interfacial bonding occurring between large particles and cement often results in low strength properties (Adefisan, 2013) and affects composite durability (Kerade *et al*., 2003). Hot water and $CaCl_2$ treatment produce the best effect in MOR of the flakes board with a mean value of 6.90N mm^{-2}, followed by $CaCl_2$ only with a mean value of 2.71N mm^{-2} while the untreated

Table 1. Mechanical properties of cement-bonded particle boards.

Particle geometry	Pretreatment	MOR (N mm^{-2})	MOE (N mm^{-2})
Flakes	Hot water only	2.22 ± 0.03	1674.34 ± 145.13
	$CaCl_2$	2.71 ± 0.07	1517.53 ± 19.57
	Hot water + $CaCl_2$	6.90 ± 0.65	1897.36 ± 37.45
	No pretreatment	1.08 ± 0.05	1115.59 ± 133.85
	Mean	3.23 ± 1.27	1551.21 ± 164.79
Sawdust	Hot water only	2.40 ± 4.04	877.16 ± 46.39
	$CaCl_2$	2.80 ± 0.007	1312.58 ± 25.79
	Hot water + $CaCl_2$	5.69 ± 0.50	1664.31 ± 33.56
	No pretreatment	1.15 ± 0.05	864.99 ± 40.9
	Mean	3.01 ± 0.96	1179.76 ± 192.15

Each value represents M±SD of 4 replicates

Table 2. Variance ratio table from the results of various ANOVA for properties tested on the boards.

Source of variation	Variance ratio (F-Cal)					F-Tab
	df	MOR	MOE	WA	TS	
Particle geometry	1	4.48*	190.31*	96.02*	6.96*	4.26
Pre-treatment	3	465.75*	148.88*	582.44*	30.76*	3.01
Particle geometry × pre-treatments	3	10.34*	27.90*	14.46*	0.54^{ns}	3.01
Error	24					
Total	31					

*significant at ($p < 0.05$) probability level, ns not significant at ($p < 0.05$) probability level

boards had the least value of 1.08N mm^{-2}. This same pattern of variation in MOR was obtained in the sawdust boards. Pretreatments enhanced the MOR of the composites by removing the inhibitory components that impair bond formation in composites, thereby improving the formation of strong crystalline bonds towards high flexural performance of composites.

Effect of particle geometry and pretreatments on MOE: The mean values of MOE of the wood particles are presented in Table 1. The mean MOE values for sawdust boards ranged from 864.99N mm^{-2} for untreated to 1664.31N mm^{-2} for boards treated with hot water and $CaCl_2$. For flakes board, the mean MOE ranged from 1115.59 N/mm^2 for untreated to 1897.36 N/mm^2 for boards treated with hot water and $CaCl_2$. It would be observed that hot water and $CaCl_2$ treatment produce the best effect in MOE of the particle geometries. Flakes boards have mean MOE value of 1551.21N mm^{-2} while the mean MOE value of sawdust boards was 1179.76N mm^{-2}. This finding is in agreement with the report of Badejo (1988) who worked on improvement in MOE with increase in flake dimensions of hardwood cement composites. Further, Clausen *et al.* (2001) and Li *et al.* (2004) reported that flake geometry has a greater control on stiffness of manufactured flake boards. It would be observed that hot water treatment produces a better result than $CaCl_2$ treatment in the MOE of flakes boards while the reverse was observed in sawdust-cement bonded boards. This indicates that the effect of pretreatments is a function of the particle geometry in the stiffness of composite boards.

Physical properties of cement bonded particle boards

Effect of particle geometry and pretreatments on water absorption: The result of the water absorption (WA) test after 24 hours of immersion is shown in Fig. 1. It was

Table 3. Duncan grouping for the properties evaluated.

Pre-Treatments	MOR	MOE	WA	TS
Hot water only	2.31^b	1275.75^b	13.40^c	6.70^b
$CaCl_2$ only	2.76^c	1415.05^c	6.09^b	1.66^a
Hot water and $CaCl_2$	6.29^d	1780.84^d	3.95^a	1.07^a
No pre-treatment	1.12^a	990.29^a	21.59^d	8.57^b
Particle geometry				
Flakes	3.23^b	1551.21^b	9.64^a	3.62^a
Sawdust	3.01^a	1179.76^a	12.88^b	5.38^b

Means in column with the same letters are not significantly different ($p < 0.05$)

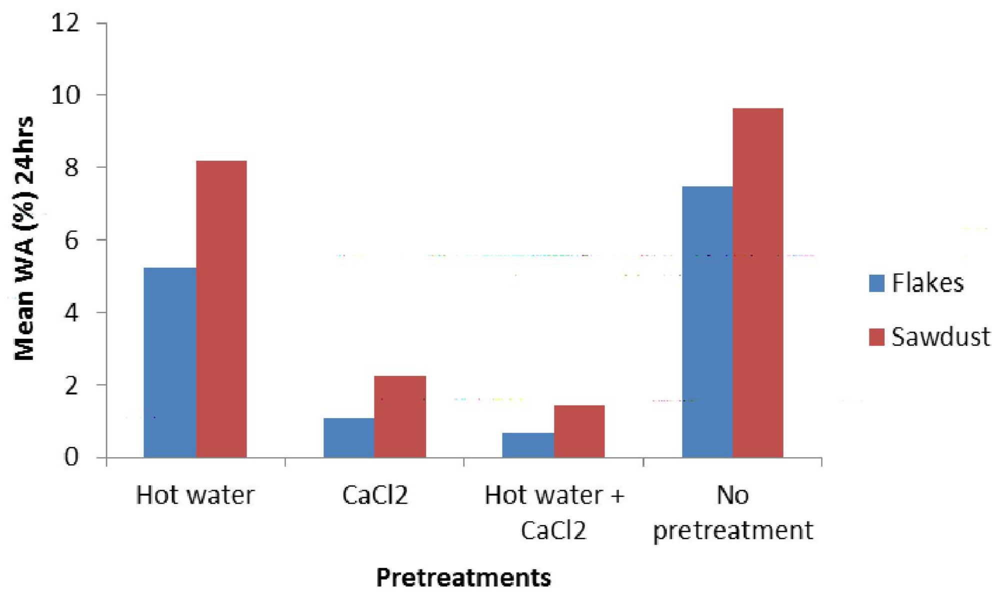

Fig. 1. *Effect of particle geometry and pretreatments on WA.*

observed that for all treatments and control, WA was highest for sawdust boards than flake boards. This could be attributed to the fact that the fibrous particles in sawdust expose a larger surface area for absorption of moisture and this resulted in volume increase of the boards during submersion. Boards treated with both hot water and $CaCl_2$ have the least WA rates of 3.63% for flakes and 4.28% for sawdust, while untreated boards have the highest WA rates of 18.79% and 24.4% for flakes and sawdust boards respectively. This pattern of variation has also been reported in literature (Badejo *et al*., 2011; Morteza *et al*., 2011) in wood cement particle boards.

Effect of particle geometry and pretreatments on TticKness swelling (TS): The results of the thickness swelling of the board after 24 hours of water immersion is shown in Fig.2. It was observed that sawdust-particle geometry exhibited greater increase in thickness after submersion irrespective of the pretreatments as a result of water uptake by the air spaces and voids in the fine particles composites (Adefisan and Amiandamhen, 2012). This invariably implies that sawdust boards may not be suitable for exterior applications since they are not dimensionally stable. Untreated boards had highest values for both particle types with TS rates of 7.49% and 9.66% for flakes and sawdust respectively. Boards treated with hot water and $CaCl_2$ are more dimensionally stable with rates of 0.69% and 1.44% for flakes and sawdust respectively. This finding agrees with earlier report (Semple and Evans 2004) that hot water, $CaCl_2$ and $MgCl_2$

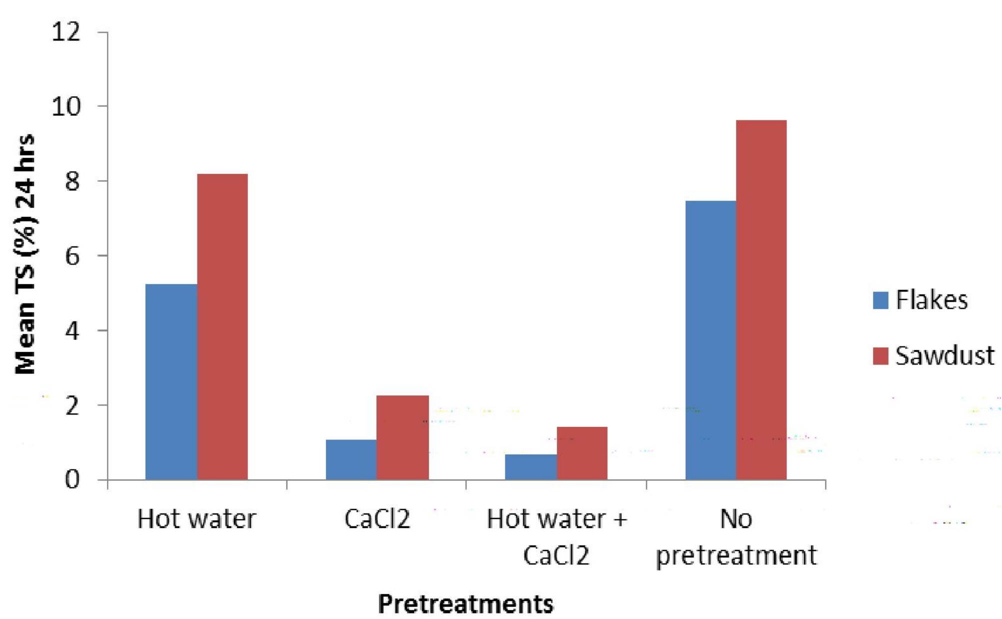

Fig. 2. *Effect of particle geometry and pretreatments on TS.*

are effective methods of reducing thickness swelling.

The results of the analysis of variance carried out at 5% level of probability to test for significant differences among particle geometry and pretreatment on the mechanical and physical properties of cement bonded particle boards are presented in Table 2. The results showed that there were significant differences in cement bonded particle boards produced from different particle geometry and pretreatment. The interaction between particle geometry and pretreatment were not significant at 5% probability level.

Duncan New Multiple Range Test was used in the separation of means at 5% probability level where significant differences exist (Table 3). The results showed that cement bonded particle board produced from different pretreatment and particle geometry of wood flakes and sawdust were significant.

Conclusion

MOR, MOE, TS and WA were the mechanical and physical properties considered in investigating the effects of wood particle geometry and pretreatment on the strength and sorption properties of cement-bonded particle boards. It was observed from the study that cements bonded particle boards produced from flakes exhibited the best effects in strength and water sorption properties. A combined pretreatment of hot water and $CaCl_2$ in the manufacture of the composite boards produces highest strength properties and dimensional stability. Therefore, the resultant properties of flakes bonded composites pretreated with hot water and $CaCl_2$ could be used as a structural index for material with an adequate tolerance of moisture.

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