

Effect of Pretreatment and Production Variable on the Sorption and Strength Properties of Cement Bonded Board

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Abstract

This study was carried out to investigate the effect of pretreatment on the sorption and strength properties of board manufactured from *Gliricidia sepium* sawdust. Twenty four (24) experimental boards were produced at three pretreatment levels of hot water (1 h), cold water (2 weeks and 4 weeks), three mixing ratios (1:1, 2:1 and 1:2), and one board density 700 g/m³. and test for their bonding strength by physical (water absorption-WA and thickness swelling-Th.S) and mechanical properties (modulus of elasticity-MOE, modulus of rupture-MOR). Data obtained was analyzed using analysis of variance at $\alpha = 0.05$. The result showed that board produced from mixing ratio 1:2 (sawdust to cement) of hot water for 1 h pretreatment is more dimensionally stable since it has the least mean values 44.10 and 50.23 % for water absorption and 1.17 and 2.76 % for thickness swelling in 1 and 6 h immersion and highest mean values of 68.94 and 0.33 N/mm² for modulus of rupture and elasticity respectively. However, the analysis of variance shows that pretreatment levels and production variables have a significant effect on the physical and mechanical properties examined thus increase in pretreatment and mixing ratio resulted in the improvement of dimensional stability and increase in the strength properties of the board produced.

Keywords: sawdust, pretreatment, particleboard, strength properties

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1. Introduction

Wood is a natural organic material, a composite of cellulose fiber embedded in a matrix of lignin which resists compression (Kermani 1998). Its waste is residues derived during various conversion processes and is in the form of trimmings edgings slabs shavings, sawdust, etc. These wastes or residues are generated in large quantities as reported by Ajayi (2006) and the bulk of these waste generated in Nigeria was estimated to be 1.72 million cubic meters in 2001 and we can be sure to have doubled up the figure by now.

In view of the importance of saving energy and conversion of resources, efficient recycling of all wood waste is now a global concern requiring extensive works towards exploring newer application and maximizing use of existing technologies for a sustainable and environmentally sound management. It is therefore necessary to develop ways to utilize sawdust and reduce pollution with carbon dioxide emissions. A strategy of converting this wastes into value-added products must be imbibed like pyrolytic oil (Adegoke *et al.* 2014).

According to the end uses of wood wastes and their possible reuse products, particle boards have found typical applications like flooring, wall and ceiling panels, office dividers furniture, cabinets among others (Wang & Sun 2002; Adedeji 2011). Particleboard is a composite panel product traditionally produced from wood and its wastes (Erakhrumen *et al.* 2008) as this is the most common way to reuse these wastes (Yang *et al.* 2007; Lykidis & Grigoriou 2008). To manufacture particleboards with good strength, smooth surfaces, and equal swelling, the use of homogeneous raw material is required, so wood-cement bonded boards come into play. These are made from the combination of wood particles bonded with inorganic binding agents like cement, magnetite, gypsum, and water with or without the catalyst.

Wood-cement board (WBC) despite having its advantages as a major problem which is the inhibitory effects caused by wood on the cure of the cement and the high density of the final product, this is due to mainly to the extractives and polysaccharides inherent in wood (depending on its nature) which affects reactions between it and cement resulting in boards of low quality (Jorge *et al.* 2004). To solve this problem of inhibition, inorganic accelerators are added and also pretreatment of the wood particle which is the basis of this research work. This study therefore aimed at investigating the effect of pre-treatment and mixing ratio on strength and sorption properties of cement-bonded board produced from *Gliricidia sepium* sawdust.

2. Materials and methods

2.1 Pretreatment of Sawdust

The sample was presented to remove inhibitory substance between woods, a lignocellulose material and cement, and inorganic binder before board formation. The treatments included hot water treatment and cold water treatment. Hot water treatment was carried out by boiling the water to 100°C poured unto the sawdust and leave for a period of 1 h and also for cold water treatment, the sawdust was left in cold water for a soaking period of two weeks and four weeks respectively in a plastic bowl. Thereafter, the water was drained off and the sample was air-dried to a moisture content of 12 %. It was then sieved with 2 mm mesh and kept in a sealed polythene bag against any further moisture.

2.2 Board Formation

2.2.1. Calculation of Weight of Materials

The quantities of the materials used for the production of the boards having the size 200 ×200 ×10 mm was calculated and measured out according to the level of combination in the experiment. The sawdust and cement were calculated based on the sawdust/cement ratio of (1:1, 2:1, and 1:2) using the formulae:

$$Density (g/m^3) = \frac{Mass}{Volume} \quad (1)$$

Where; D = density of board produced in g/m³, M = mass in g; V = volume in m³

Water used in mixing the cement into a slurry form was also calculated.

$$Wt = W(0.30 - MC) + 0.60C \quad (2)$$

Where; Wt=Weight of water (g); W=Wood dry weight (g); MC=Moisture Content (%); C=Weight of cement (g)

2.2.2 The Blending of Production Variable, Board Formation, and Pressing

The blended stock was transferred and formed on the dimensioned mold (200×200 ×10 mm) covered with a polythene sheet to form the mat, while another polythene was placed at the top of the formed mat before it was covered with plywood at the top. The formed mat was transferred to the cold press and pressed under pressure to the required thickness for 24 h.

2.2.2.1 Curing, Condition and Trimming

The formed mat was demoulded and left to dry for 21 days to allow for proper curing of the cement. The boards were then trimmed and edged to sizes and a test specimen was cut from the boards. The boards were strengths tested for strength and sorption properties (Falemara *et al.* 2014).

2.3 Board Testing

2.3.1 Physical Properties

2.3.1.1 Water Absorption (WA)

The WA test was carried out according to the procedures of ASTM D2915 2005; Adefisan & Adesope 2012; Badejo *et al.* 2011. The test samples used were trimmed to 50 × 50 mm and immersed in cold water for 1 h and 6 h. The water absorption of the samples was measured and recorded before and after immersion in cold water. The percentage of water absorption for each sample was calculated as:

$$WA (\%) = \frac{W_2 - W_1}{W_1} \quad (3)$$

Where; WA=water absorption (%); W1=initial weight (g); W2=final weight (g)

2.3.1.2 Thickness Swelling (Th.S)

The Th.S follows the method adopted by ASTM D2915 2005; Adefisan & Adesope 2012; Badejo *et al.* 2011. The test samples used were trimmed to 50 × 50 mm and immersed in cold water. The initial thickness of the samples was measured and recorded before and after immersion in cold water. The percentage thickness swelling for each test samples were calculated as:

$$TS (\%) = \frac{T_2 - T_1}{T_1} \quad (4)$$

Where; TS = Thickness Swelling (%); T₁ = initial thickness (mm); T₂ = final thickness (mm)

2.3.2 Mechanical Properties

2.3.2.1 Modulus of Rupture (MOR) and Modulus of Elasticity (MOE)

MOR is a parameter for measuring the bending strength of wood while MOE is the measure between stress and strain within the limit of proportionality provides a convenient measure of stiffness or flexibility of a timber. The test samples were subjected to flexural tests by ASTM D1037 2003. MOR and MOE was investigated using a test specimen of 195 × 50 × 10 mm on the Electronic Universal Testing Machine Model MDW-50. The test specimens were mounted one by one on the jig and the load was applied at the center with aid of an electromechanical motor till the point where the failure occurred. The recording of the ultimate failure load (P) was estimated on the mercury meter. The Modulus of Rupture (MOR) was calculated using;

$$MOR = \frac{3pl}{2bd^2} \quad (5)$$

$$MOE = \frac{Pl^3}{4\Delta bd} \quad (6)$$

Where; MOE = modulus of elasticity, P = load of proportional limit (N); I = the span of the board sample between the machines support (mm); Δ = Deflection at beam center at proportional limit; b = width of test samples (mm); d = thickness of test sample (mm).

2.4 Data Analysis

The experiment adopted 3³ factorial experiments in completely randomize design replicated 3 times making 27 boards altogether. The mixing ratio (1:1, 2:1 and 1:2); The pretreatment (hot water for 1 h; cold water for 2 weeks cold water for 4 weeks).

Analysis of variance (ANOVA) was conducted to estimate the relative importance of various sources of variation (mixing ratio and pretreatment) on the physical and mechanical properties of cement boarded boards produced. When the ANOVA indicated a significant difference among factors and levels, a comparison of the means was conducted, employing Duncan Multiple Range Test (DMRT) to identify which groups were significantly different at $\alpha = 0.05$.

3. Results and Discussion

3.1 Physical Properties

3.1.1 Water Absorption (WA)

Water absorption gives an idea of how wood cement boards behave when used under severe humidity conditions (Noor *et al.* 2012). The mean value of water absorption property was presented in Table 1. The value ranged from 44.10 - 99.15 % and 50.23 - 101.30 % at 1 h and 6 h respectively. The values for percentage water absorption property showed that board with hot water pretreatment at mixing ratio 1: 2 (fibre cement) has the lowest value of 44.10 % at 1 h and 50.23 % at 6 h of immersion. Conversely, the range of value recorded was higher than the range obtained by Amiamdamen & Izeke (2013) who both found out that the absorption of water by sawdust board and rice husk fine board was 25.96 - 40.95 % in a ratio of cement to the particle of 70:30 while a board with the highest water absorption is from the pretreatment of cold water (4weeks) at mixing ratio of 2:1 of 99.15 % at 1 hour and 101.30 % at 6 h of immersion.

The board with the lowest water absorption might be possibly due to its maximum binding force between the sawdust and the cement and nearly complete filling of the pores by the cement which could limit the absorption by capillary action (Davies & Davies 2017). The board with higher water absorption was detected to be more porous and absorbed more water. This phenomenon was attributed to the void spaces created by a small quantity of cement available to blind the sawdust fiber. These void spaces are easily stocked by penetrating water thus increasing the board's weight after soaking.

In general, it was observed that the behavior of the boards to water intake revealed that increase in pretreatment level (hot water at 1 h) and maxing ratio (1:2) produced boards that re more dimensionally stable than others and it showed highest resistant to movements; as similarly observed by Ajayi & Aina (2012). Boards with a pretreatment level (cold water at 4 weeks) and mixing ratio of 2:1 were observed to be more permeable and absorbed more water.

Table 2 and 3 show the results of the analysis of variance conducted on the water absorption after 1 h and 6 h water immersion. The results show that all factors are significant in water absorption at 1 h and only mixing ratio is significant in 6 h immersion but pretreatment and interaction of the two factors is not significant at 5 % probability level in 6 h immersion.

3.1.2 Thickness Swelling (Th.S)

The result after 1hr and 6 hrs of cold water immersion is shown on the Table 1 which ranges from 1.17 - 4.37 % at 1 h, then 2.76 - 6.52% at 6 h immersion. The high results obtained can be attributed to high compression ratio and compatibility, and also strong bond formation (Ajayi (2013) due to the quantity of binder present in the board. This is similar to what was obtained by Kaplon, 2009 & Terry 2011). The analysis of variance conducted on thickness swelling after 1 and 6 h of cold water immersion at 5% level of probability shown in Table 3 shows that there is a significant difference at the mixing ratio level of 1 h but none between pre-treatment, mixing ratio and interaction between the two factors at 1 and 6 h of immersion.

Table 1. Mean values obtained for water absorption and thickness swelling of particleboards produced from sawdust of *G. sepium* and cement

Pretreatments	Mixing ratio	Water absorption (%)		Thickness Swelling (%)	
		1 h	6 h	1 h	6 h
Hot (1 h)	1.01	44.48±39.84a	71.22±5.45abc	2.70±1.54ab	4.21±2.24ab
	2.01	65.66±5.21ab	83.95±21.96bc	3.15±1.54ab	4.28±1.45ab
	1.02	44.10±2.36a	50.23±8.21a	1.17±0.80a	3.75±0.92a
Cold (2wks)	1.01	71.45±0.93abc	70.30±5.21abc	1.75±1.06a	3.48±1.31a
	2.01	89.09±19.50bc	95.07±17.11c	2.87±1.56ab	4.36±1.60ab
	1.02	47.11±2.49a	61.54±14.31ab	1.72±0.53a	3.01±0.65a
Cold (4wks)	1.01	73.24±6.70abc	94.24±35.45c	2.09±1.20a	2.81±1.39a
	2.01	99.15±2.11c	101.30±2.15c	4.73±1.57b	6.52±1.31b
	1.02	47.04±4.31a	54.27±3.37ab	1.34±0.59a	2.76±0.83a

Mean, Standard Error in parenthesis, values followed by the same alphabet in columns are not significantly different ($p \leq 0.05$).

Table 2. Analysis of variance table for WA particleboards produced

1 h				
Source of variation	df	Sum of Square	Mean Square	F-cal
Pretreatment (PT)	2	2413.8	1206.9	5.24*
Mixing Ratio (MR)	2	4873.14	2436.57	10.57*
PT*MR	4	2778.18	694.55	3.01*
Error	18	4149.48	230.53	
Total	26	14214.61		
6 h				
Source of variation	df	Sum of Square	Mean Square	F-cal
Pretreatment (PT)	2	986.89	493.44	1.87*
Mixing Ratio (MR)	2	6635.46	3317.73	12.56*
PT*MR	4	778.14	194.53	0.74ns
Error	18	4753.26	264.07	
Total	26	13153.74		

*significant ($p \leq 0.05$); ns-not significant ($p > 0.05$)

Table 3. Analysis of variance table for Th.S particleboards produced

1 h				
Source of variation	df	Sum of Square	Mean Square	F-cal
Pretreatment (PT)	2	1.71	0.85	0.57ns
Mixing Ratio (MR)	2	14.94	7.47	5.00*
PT*MR	4	13.13	3.28	2.20ns
Error	18	26.9	1.5	
Total	26	56.68		
6 h				
Source of variation	Df	Sum of Square	Mean Square	F-cal
Pretreatment (PT)	2	1.18	0.59	0.31ns
Mixing Ratio (MR)	2	11.51	5.75	3.04ns
PT*MR	4	19.77	4.94	2.61ns
Error	18	34.04	1.89	
Total	26	66.49		

*significant ($p \leq 0.05$); ns-not significant ($p > 0.05$)

3.2 Mechanical Properties

3.2.1 Modulus of Rupture (MOR)

The Modulus of Rupture (MOR) conducted on the experiment boards is presented in Table 4 below with mean values ranging from 0.1 - 0.33 N/mm². The highest value was observed to be from the mixing ratio level of 1:2 at hot water (1hr) pretreatment while the lowest was observed at a mixing ratio level 2:1 at cold water (4wks). However, it was observed that these values obtained were far lower than those observed by Ma *et al.* (2012) whose values range from 3 - 3.5 N/mm² which may be due to the high resin content of the sawdust sample used. This result obtained is far lower even compared with the standard or minimum required for panels of general-purpose

and interior fittings (Gokay & Aytak 2007). ANOVA revealed that MOR at 5 % probability level was not significantly different for both the pretreatment and mixing ratio but significant at the interaction of the two.

3.1.2. Modulus of Elasticity

This is also presented in Table 4, and it ranges from 26.16 - 68.94 N/mm². The MOE values were high boards produced with hot water pretreatment (1 h) and mixing ratio 1:2 while its lowest at cold water pretreatment (4 wks) and mixing ratio 2:1. This may be because reinforcing particles being stiffer than the binder matrix which is contrary to most reports by several authors (Mehmet & Ayhan 2008). This may also be due to the high resin content of the sawdust used.

The ANOVA result shows that MOE wasn't significant at a 5 % level of probability in pretreatment and mixing ratio but only significant in the interaction between the two factors (Table no. 5).

Table 4. Mean values obtained for modulus of elasticity and rupture of particleboards produced from sawdust of *G. sepium* and cement.

Pretreatments	Mixing Ratio	Modulus of Elasticity (N/mm ²)	Modulus of Rupture (N/mm ²)
Hot water(1hr)	1.01	60.61±11.68ab	0.31±0.07c
	2.01	55.21±22.45ab	0.29±0.15bc
	1.02	68.94±19.66b	0.33±0.09c
Cold water(2wks)	1.01	45.87±2.58ab	0.19±0.06abc
	2.01	32.26±17.06ab	0.14±0.09a
	1.02	49.77±45.67ab	0.19±0.13abc
Cold water(4wks)	1.01	32.38±14.37ab	0.18±0.06abc
	2.01	26.16±7.59a	0.10±0.03a
	1.02	65.19±4.55ab	0.31±0.03c

Mean, Standard Error in parenthesis, values followed by the same alphabet in columns are not significantly different (p≤0.05)

Table 5. Analysis of variance table for modulus of rupture and elasticity particleboards produced

Modulus of rupture				
Source of variation	df	Sum of Square	Mean Square	F-cal
Pretreatment (PT)	2	0.04	0.02	2.50ns
Mixing Ratio (MR)	2	0.02	0.01	1.25ns
PT*MR	4	0.11	0.03	3.60*
Error	18	0.14	0.01	
Total	26	0.32		
Modulus of elasticity				
Source of variation	df	Sum of Square	Mean Square	F-cal
Pretreatment (PT)	2	473.32	236.66	0.58ns
Mixing Ratio (MR)	2	841.57	420.79	1.03ns
PT*MR	4	4443.24	1110.81	2.71ns
Error	18	7391.05	410.61	
Total	26	13149.18		

*significant (p≤0.05); ns-not significant (p>0.05)

5. Conclusion

The present study investigated the effect of pre-treatment and mixing ratio on strength and sorption properties of cement-bonded board produced from *G. sepium* sawdust hence it was observed that the board produced from the mixing ratio 1:2 (sawdust to cement) with the pretreatment level of hot water (1hr) has more dimensional stability and strength properties. This shows that mixing ratio and pretreatments has a positive influence on both dimensional stability and strength properties of the board, but the sawdust to be used should be less resinous.

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