Cement Bonded Particle Board from *Musa paradisiaca* Stalk.

Babatunde O. Ogunsile, Ph.D.* **and Jamiu A. Adepegba, M.Sc.**

Department of Chemistry, University of Ibadan, Ibadan, Nigeria.

E-mail: ogunsile@yahoo.com*
bo.ogunsile@mail.ui.edu.ng

Telephone: +234 8055373249

ABSTRACT

In order to reduce total dependence on wood materials, cement bonded particle board was made from *Musa paradisiaca* (plantain) stalk which is readily available as a waste and relatively abundant in Nigeria. The stalk was analyzed for its chemical contents. The boards were produced using three major operating conditions, namely, density (1000 to 1100kg/m^3), mixing ratio (fiber/cement: 30/70 to 40/60), and particle size (1.00-2.00 µm). About 3% $CaCl_2$ was used as chemical additive based on the weight of the cement. The effects of the operating variables were examined on the modulus of rupture and elasticity, water absorption, and thickness swelling. The results showed that water absorption and thickness swelling increases with increase in fiber content and particle geometry but a decrease in board density. The modulus of rupture and elasticity varied accordingly with the different operational variables. SEM photograph of the cut surface of the board showed good fiber/matrix adhesion.

(Keywords: *Musa paradisiaca,* plantain, particle board, board density, mixing ratio, particle size)

INTRODUCTION

Synthetic resins are used as binders in the preparation of fiberboards. A typical process of making medium density fiberboard begins with the mechanical de-fiberization of wood chips at high steam pressure followed by the addition of a suitable resin usually urea formaldehyde and a sizing agent. The fibers are then formed into sheet molds and pressed to give the desired boards (Bayasi, 2003; Shao, 1995).

Urea formaldehyde as a synthetic resin was mainly used because of its fast curing process and low cost. However, due to the release of formaldehyde into the environment, it use has become limited (Saffari *et al.*, 2011). Another formaldehyde resin, phenol formaldehyde, has little or no formaldehyde emission but it cost was high and the curing rate was slow. Besides, formaldehyde resins and other synthetic resins constitute waste disposal problem because they are non-biodegradable and not recyclable (Rokiah *et al*., 2009). In solving these problems, an alternative solution is the use of mineral binders for board manufacture and cement is the most expedient binder in terms of strength, durability and acoustic insulation properties.

The urgent need to find an effective replacement for wood in the wood based industry in Nigeria cannot be overemphasized. This becomes highly relevant in view of recent trends in deforestation. Nigeria was reported to have the highest rate of deforestation in the world (Mohammed, 2014). The only solution to this is to embark on massive plantation of wood species while exploring the non-wood resources as alternative. Non-woods and agricultural byproducts are relatively abundant in Nigeria, and are potentially cheaper than wood resources. These plants can be grown in areas that will not support trees; often with limited rainfall and low quality soil (Conklin, 1971). They mature faster and can be harvested within a year or two unlike trees that take ten to twenty years. One of such plant is *Musa species* (Jimenz, *et al*., 2005; Sankia, *et al*., 1997).

In the present study, an attempt was made to produce cement bonded particle boards from plantain stalk. The effects of density, particle size, and cement to stalk ratio were examined on the physical and mechanical properties of the boards.

MATERIALS AND METHODS

Preparation of Samples

Samples of plantain stalk were collected from a market at Ibadan. The stalks were manually cut into chips, sundried, ground with a milling machine and sieved to obtain the following different particle sizes: 1.00 µm, 1.5 µm and 2 µm.

Chemical Composition.

The proportions of the chemical constituents that affect the characteristics of the plant were determined on ground samples of the stalk using the AOAC standard methods (AOAC, 1990).

Preparation of Particle Board and Testing

The experimental design adopted for the production of the particle board is shown in Table 1.

Table 1: Experimental Design for the Particle Board Production.

Process variables	Specifications
Board density, BD (kg/m3)	1000, 1050 and 1100
Mixing ratio, MR (stalk / cement)	40:60, 35:65 and 30:70
Particle size, PS (µm)	1.0, 1.5 and 2.0
Board size, (m)	0.35 x 0.35 x 0.0006

The milled stalk sample was first dissolved in hot water to remove most of the extractives. It was later drained and dried to about 12% moisture content level. The dried milled stalk sample was mixed thoroughly with the appropriate amount of cement based on the specified ratio. About 3 % $CaCl_2$ (based on the weight of cement) was dissolved in water and then mixed with the stalk – cement composite to form a uniform matrix that is free of lumps. The mixture was poured into a wooden mold of 350 mm x 350mm x 6 mm, pressed and left for 24 hrs. It was then de-molded and air dried inside a polythene bag for 28 days at room temperature. The total amount of water used was calculated based on the formula:

$$W_t = 0.60C_t + (0.3 - MC)\, W \quad \textbf{(1)}$$

where W_t is the weight of water, C_t is the weight of cement, MC is the moisture content of the stalk and W is the weight of dry stalk saw dust.

The water absorption (WA) characteristic of the boards was determined manually based on the difference between the weight of test specimen soaked for 24 hours and the oven dry weight test specimen. The thickness swelling (TS) was based on the difference in their thickness. The bending modulus of elasticity (MOE) and modulus of rupture (MOR) were estimated from the load deflection curves at peak according to ASTM standard ASTM D 1037-96a (1998). A Scanning Electron Microscope (SEM) (Aspex 3020) was used to examine the stalk/cement surfaces of the particle board.

Statistical analysis

The results obtained were subjected to Univariate Analysis of Variance (ANOVA) with a 3x3x3 factorial design using the SPSS. The significant of treatment means were tested using the Duncan's Multiple Range Test at 95 % confidence level.

RESULTS AND DISCUSSION

Proximate Composition

The result of the chemical composition is shown in Table 2. The ash content of 15.08 % was an indication of high inorganic content and low volatile matter which is alright for board making. The value is less than 2.93 % obtained for oil palm waste (Elizabeth, *et al*., 2014), but similar to those of rice straw (Lam, 2001). The lignin content (13.5 %) would not have any negative effect on the particle board as lignin itself is a binder (Klapiszewskia, 2013; Laurichesse and Avérous, 2014). The cellulose content is average and tolerable of a typical raw material for particle board. However the extractive contents especially the 1% NaOH solubility which is a measure of decay is rather high because of the high moisture content of the plantain plants. The stalk should therefore be technically dried before storage.

Table 2: Chemical Composition of Plantain Stalk.

Parameter	Amount (%)
Ash	15.08
Lignin	13.50
Cellulose	46.00
1 % NaOH solubility	22.03
Cold water solubility	7.99
Hot water solubility	2.70
Ethanol solubility	2.19

<u>Effect of Process Variables on the Physical Properties of the Boards</u>

The results of the operational variables on WA and TS are depicted in Figure 1 and 2 respectively. The absorption of water by the boards decreases with a decrease in BD. The percentage of stalk in board at low BD is higher than at high BD. Since stalk has higher affinity for water than the cement, the percentage water absorption is higher at low BD where stalk is highest than at high BD. Besides, at low BD, the amount of voids that can be filled is higher than at high BD (Sotannde *et al*. 2012) leading to a higher WA than at high BD.

From the statistical analysis in Table 3, BD has significant effect on WA and TS ($p < 0.05$). For example, an increase in the BD from 1000 kg/m^3 to 1050 Kg/m^3 and 1100 kg/m^3 led to an increase in the WA by 48.94 % and 58.0 %, respectively. A similar trend was also observed for the TS which increase as BD decreases because the presence of voids increases internal swelling (Lee, 1984). On the other hand, WA increases with an increase in MR. High stalk to cement ratios increase the hydrophilic tendencies of the Board, thus leading to an increase in its water content. As for the particle size, the smaller particles of the stalk formed stronger bonds with the cement than the larger size particles, thus reducing the WA and TS at small particle size.

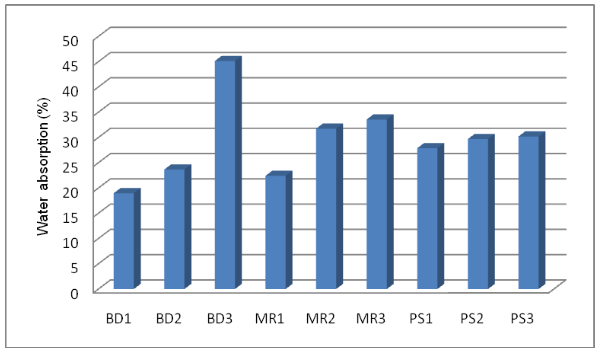

Figure 1: Effect of Process Variables on Water Absorption of the Board.

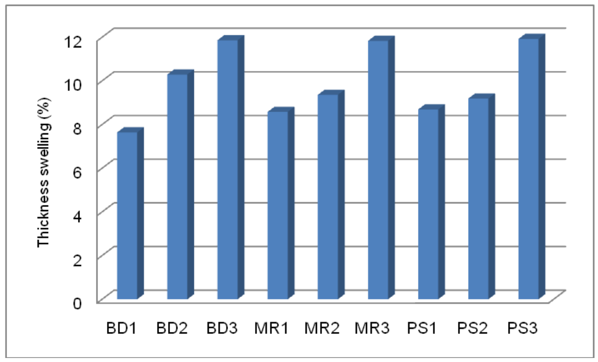

Figure 2: Effect of Process Variables on the Thickness Swelling of the Board.

<u>Effect of Process Variables on the Mechanical Properties of the Boards</u>

The results of the statistical analysis of Table 3 showed that all the process variables had significant influence on the MOR and MOE, including the two way (BD*MR, BD*PS and MR*PS) and three way (BD*MR*PS) interaction effects. The effect of the process variables on the MOR and MOE are shown in Figures 3 and 4, respectively, using average values of the results.

The actual values of the MOR obtained in this study ranged from 1.27 to 8.0 N/mm^2 while that of MOE ranged from 430 to 2953.9 N/mm^2. The highest value of MOR was slightly less than the minimum of 9.0 N/mm^2 set by the BISON type HZ for wood-cement board (Sotannde *et al*. 2012).

The pattern of variation of BD and MR as it affects the static bending properties of the board is not clearly defined. However the highest MOE and MOR correspond to the lowest BD (1000 kg/m^3) and medium stalk to cement ratio (MR = 35:75). As reported by Shotunde *et al*. (2012), as the MR was increased from 30:70 to 35:65, the MOR and the MOE also increases. The value however, dropped with further increase in MR due to the increase in the flexural property as the stalk occupied more volume in the board up to a maximum.

The static bending properties increase along with the increase in particle size. This observation supports the findings of Safarri *et al.* (2014) who reported that the highest MOE for particle boards was made from large sized chips. It was also reported elsewhere that particle size of 2.4-4 mm provided better properties (MOE, MOR, IB, and TS) for particle boards than particle size of 1-2.4 mm (Warmbier *et al*., 2010).

First – Order Factorial Design

The values obtained for the water absorption, thickness swelling, modulus of rupture and elasticity was subjected to a first order factorial design in order to evaluate and quantify the effect of the operational variables on them.

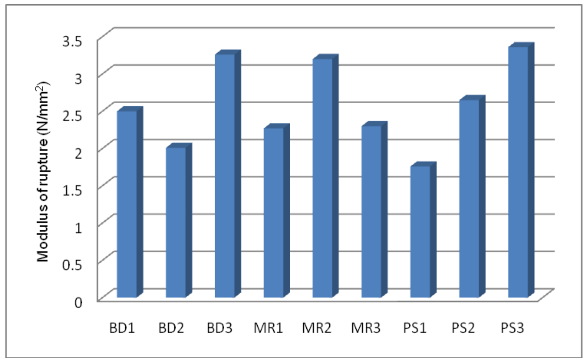

Figure 3: Effect of Process Variables on the Modulus of Rupture of the Board.

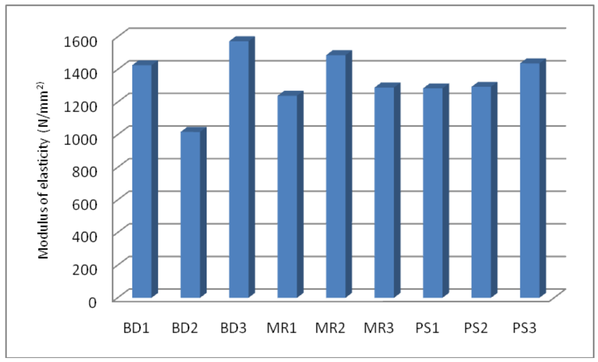

Figure 4: Effect of Process Variables on the Modulus of Elasticity of the Board.

Table 3: Analysis of Variance showing the Effect of the Process Variables on the Physical and Mechanical Properties of the Boards.

Variables	df	WA (%)	TS (%)	MOR (N/mm^2)	MOE (N/mm^2)
BD	2	72.51	11.10	3.27	1496.63
MR	2	31.19	(8.82)	2.75	682.73
PS	2	(6.34)	(9.05)	4.15	446.04
BD*MR	4	(11.44)	(5.44)	2.62	1736.29
BD*PS	4	(5.13)	(4.10)	2.19	1707.03
MR*PS	4	(5.56)	(7.63)	1.32	1230.13
BD*MR*PS	8	(7.85)	(4.00)	1.33	579.69
Error	54				
Total	81				

Some of the experimental data were fitted to a first order polynomial regression equation as implemented in the "SPSS" statistical package. Individual and second order interaction influences over the response surface of the independent variables were evaluated (Aknazarova and Kafarov, 1982; Ogunsile *et al*., 2006; Jimenez *et al.,* 2008).

The mathematical model was:

$$Y = a_0 + a_1 X_1 + a_2 X_2 + a_3 X_3 + a_{12} X_1 X_2 + a_{13} X_1 X_3 + a_{23} X_2 X_3 \quad \textbf{(2)}$$

The response variable Y represents the physical (WA and TS) and mechanical properties (MOR and MOE). The independent variables X_1, X_2 and X_3 correspond to the BD, MR and PS respectively. The values of the independent variables were normalized from –1 to +1 by using the equation:

$$X_n = 2(\bar{X} - X)/(X_{max} - X_{min}) \quad \textbf{(3)}$$

Where X_n is the normalized value of BD, MR and PS, X is the absolute experimental value of the variable, $\bar{X}$ is the mean of all the experimental values for the variable in question, X_{max} and X_{min} are the maximum and minimum values respectively of the variable.

Experiments 1-15 of Table 4 allowed the calculation of different parameters in the regression equations a_i and a_{ij}. These were subsequently subjected to a T - test to check their significance at 90-95 % confidence level. The central point of the design corresponds to the following reaction conditions:

Board Density, BD = 1050kg/m^3
Mixing Ratio, MR = 35:65
Particle Size, PS = 1.5 µm

The coefficients of the model equations and the statistical parameters establishing their validity are summarized in Table 5. The dependent variables (i.e. thickness swelling, water absorption, modulus of rupture and elasticity) were related to the independent variables through equations 4 – 7.

$$WA = 26.16 - 13.4X_1 - 7.08X_2 + 10.5X_1X_1 \quad \textbf{(4)}$$

$$TS = 15.07 \quad \textbf{(5)}$$

$$MOR = 2.61 + 0.65X_3 - 1.34X_1X_1 \quad \textbf{(6)}$$

$$MOE = 1244.97 \quad \textbf{(7)}$$

Equations 5 and 7 showed that none of the operational variables had any significant effect on the physical and the mechanical properties of the cement bonded particle board. Thus the factorial design failed to predict the experimental data for the thickness swelling and the modulus of elasticity. The design however gave expressions for the experimental data for the water absorption and the modulus of rupture as seen in Equation 5 and 7.

Values calculated from the respective polynomial equations above were plotted with the experimental results for WA and MOR. The results as shown in Figure 5 gave good correlation (r^2 = 0.919) between the experimental values and those predicted by the model for WA. The correlation (r^2 = 0.657) was however weak for the MOR as shown in Figure 6.

According to Equation 4, the board density, the mixing ratio and the interactions of the board density have significant influence on the water absorption of the cement board. The highest value of water absorbed was about 57 % which was obtained at the lowest values (-1 for all) of the operation variables. Operating at the highest values (i.e., +1 for all) of the board `density and mixing ratio will reduce the amount of water absorbed to 16 %.

Equation 6 revealed that besides the interaction of the board density, the particle size have significant effect on the modulus of rupture. The lowest value of the MOR was about 3.3 N/mm^2. This value can be increased to 4.6 N/mm^2 by operating at the highest value of the particle size (i.e., 2 µm).

SEM Analysis

Analysis of the morphological features of fracture surfaces by SEM is important for observing the surface morphology of fiber/matrix. The SEM images of the cement bonded particle board taking at different magnification are shown in Figure 6. The result showed that the composites produced good adhesion of stalk saw dust to the cement matrix

Table 4: Experimental Design and Result for the Cement Bonded Particle Board.

Experiment	x1 BD	x2 MR	x3 PS	WA (%)	TS (%)	MOR (N/mm^2)	MOE (N/mm^2)
1	1	1	1	19.57	8.53	1561.93	3.27
2	1	1	-1	8.44	7.74	2921.07	1.97
3	1	-1	1	21.67	7.63	1398.48	2.77
4	1	-1	-1	19.87	6.86	2120.17	2.14
5	-1	1	1	32.67	10.11	983.87	3.14
6	-1	1	-1	35.43	9.58	808.87	1.38
7	-1	-1	1	56	10.92	2169.8	3.4
8	-1	-1	-1	50.67	10.9	853.7	1.55
9	1	0	0	20.87	7.51	692.03	2.76
10	-1	0	0	49.67	23.45	2666.87	5.24
11	0	1	0	10.66	9.32	1537.33	2.14
12	0	-1	0	29.32	9.9	992.77	2.05
13	0	0	1	21.47	10.19	1051.93	2.25
14	0	0	-1	24.67	8.87	430.1	1.27
15	0	0	0	31.75	20.67	1745.47	2.37

Table 5: Significant Regression Parameters for the Board.

	WA	TS	MOR	MOE
a_0	26.16	15.07	2.61	1244.97
a_1	-13.4	(-2.67)	(-0.18)	(121.06)
a_2	-7.08	(-0.093)	(0.0)	(27.82)
a_3	(1.23)	(0.34)	0.65	(3.21)
a_{12}	(0.16)	(0.49)	(0.095)	(274.39)
a_{13}	(1.30)	(0.13)	(-0.21)	(-446.49)
a_{23}	(0.155)	(0.066)	(-0.073)	(-222.32)
a_{11}	10.52	(1.81)	1.336	(559.61)
a_{22}	(-4.78)	(-4.06)	(-0.57)	(145.21)
a_{33}	(-1.70)	(-4.14)	(-0.904)	-378.83)

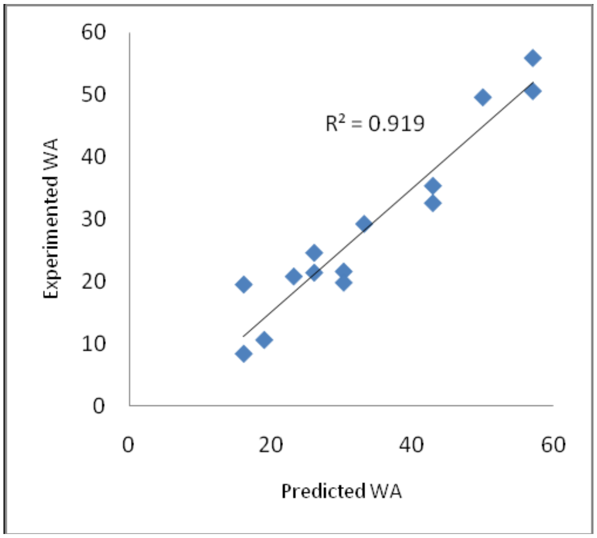

Figure 5: Correlation between Predicted and Experimental Values of Water Absorption.

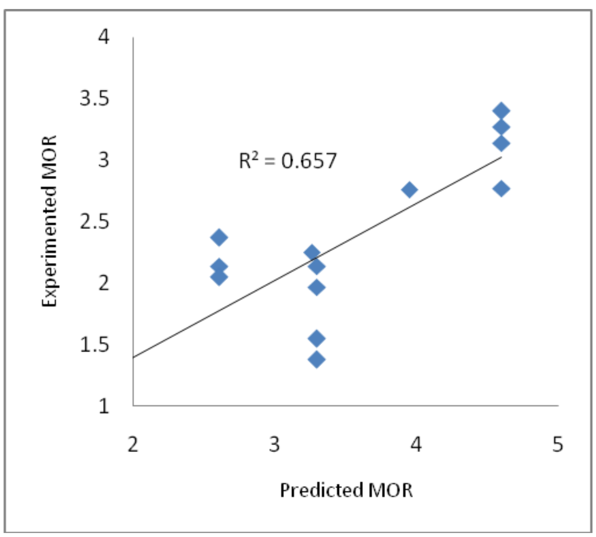

Figure 6: Correlation between Predicted and Experimental Values of Modulus of Rupture.

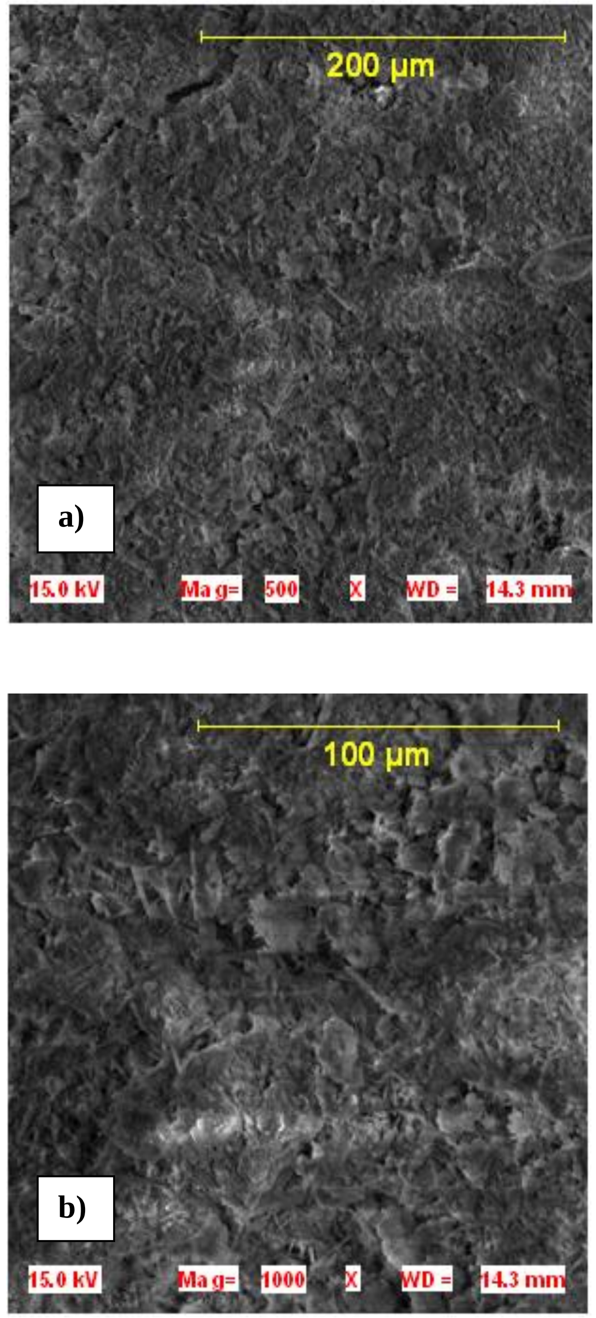

Figure 7: SEM Images of the Cement Bonded Particle Board at (a) x500 and (b) x1000 Magnification.

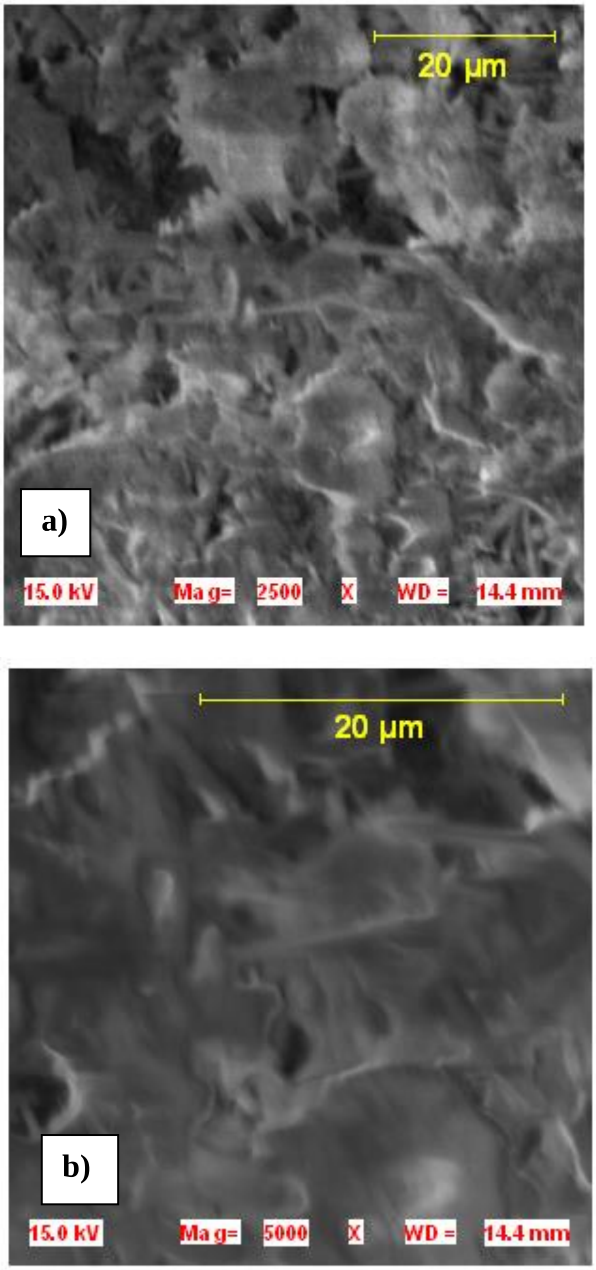

Figure 8: SEM images of the Cement Bonded Particle Board at (a) x 2500 and (b) x5000 Magnification.

CONCLUSIONS

Cement bonded particle boards were made from *Musa paradisiaca* (plantain) stalk. The physical and mechanical properties were influenced by the board density, stalk to cement mixing ratio and particle size. Water absorption and thickness swelling increased with an increase in the plantain stalk to cement mixing ratio but decreased with an increase in the board density. The highest modulus of rupture and elasticity correspond to the lowest board density, medium stalk to cement ratio and highest particle size.

ACKNOWLEDGMENTS

The authors acknowledge the technical assistance rendered by Mr. Aina of the Forestry Research Institute of Nigeria, FRIN, Ibadan.

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SUGGESTED CITATION

Ogunsile, B.O. and J.A. Adepegba. 2015. "Cement Bonded Particle Board from *Musa paradisiaca* Stalk". *Pacific Journal of Science and Technology*. 16(1):12-20.

Pacific Journal of Science and Technology