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EVALUATION OF THE PHYSICAL AND MECHANICAL PROPERTIES OF COMPOSITES BOARD MADE FROM BANANA STALK (Musa sapientum) AND POZZOLAN

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ABSTRACT
The need to find alternative materials for the production of composites board has led to the use of bio-fibres among which include locally available banana stalk. These wastes are found littering local food markets and constitute environmental pollution. The boards were formed using mixing ratio of cement to pozzolan at 1:0, 1:1 and 2:1.Physical and mechanical properties of boards produced from banana stalk using ordinary portland cement and pozzolan as binders were investigated. The influence of fibre lengths (25 and 50 mm) and mixing ratio on Density, Water Absorption (WA), Thickness Swelling (TS), Linear Expansion, Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) were determined. The mean values for WA, TS and LE showed that, after water immersion for 24, 48 and 72 hours, WA, TS and LE decreased with increase in mixing ratio while observed board density increased with increase in mixing ratio. MOE mean value ranged between 473.21 and 2728.8 N/mm2 while MOR values ranged between 1.46 and 3.49 N/mm2. MOE and MOR increased with increase in mixing ratio. The study has shown that boards produced from banana stalk compared favorably with boards produced from other lignocellulosic materials and has provided avenue for recycling banana waste causing environmental menace.

KEYWORDS: Fibre Length; Pollution; Linear Expansion; Recycling; Cement.

INTRODUCTION
Pressure on forest is caused by different reasons such as high demand of forest resources; population increase, technological advancement and loss of forest lands to agricultural purposes these has widen the knowledge of man to make use of alternate material as a way to mitigate this increasing problem. Today research efforts has been focused mainly on the utilization potentials of many agricultural residues such as wheat straw (Mantanis and Berns 2001; Grigoriou 1998; Dalen and Shorma 1996), cotton stems (Ntalos 2000; Padney and Mehta 1980), maize (Ajayi 2010), maize stalk (Ajayi 2002), yam stem (Ajayi 2006), banana stem (Ajayi 2003) and kenaf (Pasialis *et al*., 1998 Grigoriou*et al*., 1997; Chow *et al*., 1992). Branches of pruning fruit trees, vine stems, sunflower, soya stems have also been studied as particleboard raw materials (Ntalos 2000; Grigoriou and Pasialis 1992). Several studies had focussed on the potentials of agricultural residues and annual plants for producing insulation and other building materials (Youngquist *et al*., 1994; Mohan 1978; Durso 1949).

Particleboard manufactured using mineral cement as the binding agent is gradually gaining importance in many countries of the world. The emergence of interest in this board, particularly among the developing nations, can be associated with the local availability of cement in many of these countries and the possibility to adapt the board manufacturing process to a low level technology. Recent effort focus on how to use agricultural wastes for ceiling board production, The production of ceiling board from wastes like banana stem with pozzolan as binder may provide a suitable alternative to sawn timber or other wood wastes like sawdust, woodchips etc. It will also reduce the demand for wood and wood products for other board production as they are available in large quantity, thereby reducing pressure on forest and ensures sustainable forest management. The pozzolan bonded board superiority to resin bonded board stability makes it a useful constructional material in areas where fire and moisture preclude the use of resin bonded particleboard (Aruwajoye 2008).

Banana Stalk is the stem of the banana plant, it has fast erupted from being an agricultural waste, to being utilized in different sectors of life, these days banana stalk is used to make toys, flower arrangement and decoration, composite materials and because of its fibrous nature, it is used to produce clothes, paper, craft and household items etc.

Pozzolanis a mixture of a material in finely divided form with cement that possesses cementitious properties (Detwiler *et al*., 1996). Examples of such materials are ash -risk husk ash (Fabiyi 2013), leaves ash, brick dust etc. Pozzolan serves as a binder produced from cement and ash (Mehta 1987). Ash used can be from different combustible materials, for the purpose of this study, the ash was from bamboo leaves. The essence of this mixture is to minimize cost and quantity of cement required. The mixing ratio of cement to ash was varied to check the strength property (Oyagade 1988) and durability of pozzolan as a binder. This research was aimed at assessing the suitability of boards produced from banana stalk which could help reduced the pressure on the forest and lower the risk of climate change in the long run.

MATERIALS AND METHODS

Preparation of raw materials

Banana stalk was obtained from Owena, Ondo State. It was cut to two fibre lengths (25 and 50mm), milled and dried. Binder used (pozzolan) was produced by mixing cement to ash in different ratio (1:0, 1:1, 2:1). Ash was obtained by burning bamboo leaves (*Bambusa vulgaris*). Other materials used were Ordinary Portland Cement (OPC), Water, Caul plates and Press.

Board formation

After the collection and processing of banana stalk into various fibre lengths, the required quantity of banana stalk and the binding agent (pozzolan) to be used was taken, after which it was mixed together in the stated ratio and filled into the metal plate moulds frame (350 × 350 × 8mm). They were pre-pressed for easy laying to get a smooth and balanced density size board and pressed in the press with hydraulic jack. The board (350 × 350 × 8mm) was later removed from the mould for further curing as shown in the production processes (a – o). All sample boards were produced according to the stated method with three replicates each per treatment. The effect of production variables of the board was determined to know which of the board produced will have the most suitable physical and mechanical property when in use.

Production processes

a. Collection of banana stalk	b. Collection of bamboo leaves	c. Soaking of banana stalk
d. Extracting of fibres	e. Cutting into fibre lengths	f. Crushing of fibres
g. Milling of the fibre	h. Pretreating using hot water	i. Weighing of materials
j. Mixing of the materials	k. Pre pressing	l. Pressing of board
m.Cutting to sizes after curing	n. compression	o. immersion in water

Parameters tested

The board edges were trimmed with circular saw to avoid edge effect and were cut into the required sizes of 50 × 50 × 8mm and 195 ×50 × 8mm for physical and mechanical tests respectively according to the ASTM (2005).

Physical test

Water Absorption

The percentage water absorption for the test samples was calculated after immersion in water for 24, 48 and 72 hours using:

$$WA = \frac{W_2 - W_1}{W_1} \times 100 \qquad (1)$$

Where
WA = Water Absorption (%)
W_1 = Initial Weight of the board (g)
W_2 = Weight of board after immersion in water (g)

Thickness Swelling

For the thickness swelling (TS) tests, boards was immersed in water for 24, 48, 72 hrs. The changes in thickness and weight of the specimens were measured after the immersion. The percentage thickness swelling (TS %) was calculated using the formula:

$$TS = \frac{T_2 - T_1}{T_1} \times 100 \qquad (2)$$

Where:
TS = Thickness swelling (%)
T_2 = is thickness of the board after water immersion (mm)
T_1 = is the initial thickness of the board (mm).

Linear expansion

For the Linear expansion test, boards was immersed in water for 24, 48, 72 hrs. The Linear change in each sample was measured after immersion. The percentage linear expansion was calculated using the formula:

$$L.E = \frac{L_2 - L_1}{L_1} \times 100 \qquad (3)$$

Where
$L.E$ = linear expansion (%)

L_2 = is length of the board after water immersion (mm)
L_1 = is the initial length of the board (mm).

Density
For the observed density, each sample was measured. The density was calculated using the formula:

$$\text{Density (kg/m}^3) = \frac{weight}{volume} \quad (4)$$

Mechanical test
Modulus of Rupture (MOR)
This was carried out using the Universal Testing Machine available at the Wood Testing Laboratory, Forestry and Wood Technology Department, Federal University of Technology, Akure. The specimens were mounted one by one on the machine and load was applied at the centre with the aid of an electro-mechanical motor till the point when failure occurred. The ultimate load (P) and slope was recorded and estimated using the following formula

$$MOR = \frac{3PL}{2BH^2} \quad (5)$$

Where
MOR = Modulus of Rupture
L = Span between center of support (mm)
B = Width of test specimen (mm)
H = Thickness of test specimen (mm)
P = Ultimate failure load (N)

Modulus of elasticity (MOE)

$$MOE = \frac{PL^3}{4BHD^3} \quad (6)$$

Where
MOE = Modulus of Elasticity
L = Span between center of support (mm)
B = Width of test specimen (mm)
H = Increase in deflection
P = Ultimate failure load (N)
D = Thickness of the specimen

Experimental design
The experimental design used was 2 × 3 factorial experiment in Completely Randomized Design with 2 levels of factor B (fibre length), 3 levels of factor A (Mixing ratio) and replicated three times for each treatment combination.
The experiment was designed to include the following production variables:

i. Mixing ratio (M.R) of cement to ash (C:A) at 1:0, 1:1 and 2:1
ii. Different fibre lengths (F.L) 25 and 50mm
iii. Board size of 350 × 350 × 8mm

Experimental model
$Y_{ij} = \mu + M_i + L_j + e_{ij}$
Where;
Y_{ij} = Individual Observation
μ = General Mean
M_i = Effect of mixing ratio
L_j = Effect of fibre length
e_{ij} = Experimental Error

Statistical analysis
Statistical Package for Social Sciences was used to analyse the data, the experimental layout was factorial experiment in completely randomized design with 2 factors. The first factor (Mixing Ratio) has 3 treatment levels i.e. cement to pozzolan ratio, while the second factor (Fibre length) has 2 treatment levels i.e. 25 mm and 50 mm a total of 6 treatment combinations. (i.e. 2 × 3 factorial experiment in CRD). Analysis of variance was conducted to evaluate the relative importance of various sources of variation on thickness swelling, water absorption, modulus of rupture and modulus of elasticity. The effect of M.R and F.L. on the thickness swelling, water absorption, linear expansion, modulus of rupture and modulus of elasticity were determined. The follow–up test (Duncan Multiple Range Test) was conducted at 0.05 level of significant to know the difference between the means and to choose the best treatment combination from the factors considered.

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RESULTS AND DISCUSSION

Physical Properties

The mean values, Analysis of Variance, Duncan Multiple Range Test for Density, Thickness Swelling (TS), Water Absorption (WA) and Linear Expansion of the board produced were presented below;

Water Absorption

The mean values for Water Absorption (WA) after 24 hours ranged between 10.59 and 48.81 % for M.R 1:0, 1:1 and 2:1 of OPC to ash and for F.L 25 mm and 50 mm. After 48 hours, it ranged between 12.85 and 49.41 % and after 72 hours, it ranged between 13.64 and 50.83 % (Table 1).The Analysis of Variance carried out at 95% probability level showed that M.R has significant effect on water absorption after 24, 48 and 72 hours, but the Analysis of Variance also showed that F.L has no significant effect on water absorption after 24, 48 and 72 hours (Table 2). The follow up analysis using Duncan Multiple Ranged Test (DMRT) presented in Table 3, ranked boards produced from M.R 1:0 with the least minimum value while there was no significant difference between M.R 1:1 and 2:1 but there was significant difference between 1:0 and the other two mixing ratio for water absorption after 24, 48 and 72 hrs.

Water Absorption is a physical property related to dimensional stability of the boards, they give an idea of how cement bonded boards behave when exposed to severe humidity conditions, it is especially important in boards for external purposes. Wood water relation is the most indicative feature of wood with a major influence on dimensional stability and board durability. Results shows that the board samples after immersion in water for 24, 48 and 72 hours increases in water absorbed for boards produced from pure cement to boards produced with more OPC with less pozzolan and to boards produced with equal quantity of OPC and pozzolan. This finding is in agreement with the research on the production of cement bonded boards using newsprint and kraft paper by Owoyemi and Ogunrinde (2013),which revealed that; "Water absorption decreased with increase M.R while board density increased with increase in M.R." This is so due to the fact that ash content present in bamboo is very low compared to ash content produced from rice husk and some other agricultural materials (Folorunso and Anyata 2007).

***Table 1.* Mean value for Water Absorption**

Fibre length	**Mixing Ratio**		**Water Absorption (%)**		
		Observed density	24hrs	48hrs	72hrs
25	1:0	476.3	10.59 ± 4.74	12.85 ± 5.37	13.64 ± 5.44
	1:1	378.74	41.36 ± 5.83	43.74 ± 4.51	45.20 ± 3.13
	2:1	346.67	30.85 ± 1.43	32.55 ± 2.02	39.60±11.36
50	1:0	453.62	16.56 ± 3.33	17.78 ± 3.47	18.91 ± 3.86
	1:1	353.73	48.81 ± 10.17	49.41±10.17	50.83±10.95
	2:1	376.58	37.74 ± 11.47	38.84± 11.47	33.78 ± 2.15

***Table 2.* Analysis of Variance for Water Absorption**

	Water Absorption (%)		
	24hrs	48hrs	72hrs
Fibre length	35.11^{ns}	24.73^{ns}	19.06^{ns}
Mixing ratio	3076.93*	3021.50*	3104.28*
F.L*M.R	172.98^{ns}	119.20^{ns}	120.89^{ns}
Error	1826.69	1801.15	1846.66
Total	5111.71	4966.58	5090.89

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

Mixing ratio	Water Absorption (%)		
	24hrs	48hrs	72hrs
1:0	13.58[b]	15.32[b]	16.28[b]
1:1	45.09[a]	46.57[a]	48.01[a]
2:1	34.29[a]	35.70[a]	36.69[a]

Thickness Swelling

The mean values for Thickness Swelling after24 hours water soak ranged between 0.58and 2.25 %, after 48 hours it ranged between 0.69 and 2.79 % and after 72 hours it ranged between 1.02and 2.60 %for M.R 1:0, 1:1 and 2:1 of OPC to ash and for F.L 25 mm and 50 mm (Table 4). The Analysis of Variance carried out at 95% probability level showed that M.R and F.L. has no significant effect on Thickness Swelling after 24, 48 and 72 hours water soak (Table 5).

Thickness swelling is a physical property for assessing the dimensional stability of the boards, it shows how cement bonded boards perform under severe humidity conditions; it is especially useful in boards for external purposes. Thickness swelling after 24, 48 and 72 hours increased for boards produced with only OPC to boards produced with equal quantity of OPC and pozzolan to boards produced with more OPC with less pozzolan, the least thickness swelling was recorded for the boards with highest OPC. This finding is in agreement with previous work on composites board by Owoyemi and Ogunrinde (2012) who stated in the result of their research on Flexural and Thickness Swelling properties of paper cement board made from waste paper that "Result for Thickness Swelling (TSW) for the boards produced showed that the least thickness swelling was recorded for the boards with the highest M.R 2:1 cement paper ratio". This observation as found in the research may be as a result of reduction in cement paste mixed with pozzolan and banana stalk, thereby allowing water to penetrate the uncoated space in the experimental boards.

Table 4. **Mean values for Thickness Swelling**

Fibre length	Mixing Ratio	Observed Density	Thickness Swelling (%)		
			24hrs	48hrs	72hrs
25 mm	**1:0**	476.30	0.58	0.69	1.69
	1:1	378.74	0.96	1.83	1.54
	2:1	346.67	1.63	1.38	1.96
50 mm	**1:0**	453.62	1.05	1.17	1.02
	1:1	353.73	1.23	2.79	1.97
	2:1	376.58	2.25	1.86	2.6

Table 5. **Analysis of Variance for Thickness swelling**

	Thickness Swelling (%)		
	24hrs	48hrs	72hrs
Fibre length (F.L)	0.01[ns]	0.44[ns]	0.08[ns]
Mixing ratio (M.R)	4.11[ns]	5.73[ns]	2.61[ns]
F.L*M.R	1.01[ns]	1.60[ns]	1.495[ns]
Error	26.91	30.67	27.5
Total	32.03	38.44	31.683

ns = no significant difference

Linear Expansion

The mean values for linear expansion after 24 hours ranged between 0.48 and0.94 %, after 48 hours, it ranged between 0.55 and 1.01 % and after 72 hours, it ranged from 0.58 % to 1.04 % for M.R of 1:0, 1:1 and 2:1 OPC to ash and for F.L 25 mm and 50 mm (Table 6). The Analysis of Variance carried out at 95% probability level

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showed that M.R and F.L has no significant effect on linear expansion after 24, 48 and 72 hours water soak (Table 7).

Linear expansion is one of the indices for determination of physical property related to dimensional stability of cement bonded boards. It is a function of performance of cement bonded boards when used in severe humidity prone environ, it is especially important in boards for external purposes. Relationship between wood and water is the most significant feature of wood with a major influence on dimensional stability. Linear Expansion increased for boards produced from pure cement to boards produced with more OPC with less pozzolan and to boards produced with equal quantity OPC and pozzolan following the same trend as in Water Absorption and Thickness Swelling.

Table 6. **Mean value table for Linear Expansion of the boards**

Fibre length	**Mixing ratio**	**Observed density**	**Linear Expansion**		
			24hrs	48hrs	72hrs
25 mm	1:00	476.30	0.48	0.55	0.58
	1:01	378.74	0.69	0.83	0.86
	2:01	346.67	0.49	0.64	0.79
50 mm	1:00	453.62	0.52	0.6	0.66
	1:01	353.73	0.94	1.01	1.04
	2:01	376.58	0.56	0.76	0.8

Table 7. **Analysis of Variance for Linear Expansion**

	Linear Expansion		
	24hrs	48hrs	72hrs
Fibre length	0.065^{ns}	0.03^{ns}	0.006^{ns}
Mixing ratio	0.134^{ns}	0.22^{ns}	0.100^{ns}
F.L*M.R	0.283^{ns}	0.19^{ns}	0.286^{ns}
Error	4.844	4.11	3.95
Total	5.325	4.56	4.34

ns = no significant difference

Mechanical Properties

The Results of Mean Values, Analysis of Variance and Duncan Multiple Range Test of Modulus of Rupture (MOR), Modulus of Elasticity (MOE)of the board produced were presented below;

Modulus of Rupture

The mean values for MOR ranged between 1.46 to 3.49 % (Table 8) for M.R of 1:0 (OPC), 1:1 and 2:1 of OPC to ash and for F.L 25 mm and 50 mm. The Analysis of Variance carried out at 95% probability level(Table 9) showed that M.R has significant effect on MOR of the boards produced and F.L has no significant effect on MOR. The follow up analysis using Duncan Multiple Ranged Test (DMRT) (Table 10) ranked boards produced from M.R 1:0 with the maximum value while there is no significant difference between M.R 1:1 and 2:1 but there is significant difference between 1:0 and the two other M.R (1:1 and 2:1).

Modulus of Elasticity

The mean values for MOE ranged from 473.21to 1306.91 % and for M.R 1:0, 1:1 and 2:1 of OPC to ash and for F.L 25 mm and 50 mm (Table 8). The Analysis of Variance carried out at 95% probability level showed that M.R has significant effect on MOE of the boards produced and F.L has no significant effect on MOR(Table 9).The follow up analysis using Duncan Multiple Ranged Test (DMRT) ranked boards produced from M.R 1:0 with the maximum value while there was no significant difference between M.R 1:1 and 2:1 but there was significant difference between 1:0 and the two other M.R(1:1 and 2:1) as showed in Table 10.

Modulus of Rupture and Modulus of Elasticity are mechanical properties related to strength, they give an idea of how cement bonded boards behave when subjected to tensile stress, they suggest the maximum load such boards can withstand before deformation. Boards produced from 25mm strand tends to be the strongest board due to the facts that they are well arranged and compacted and are much better aligned than boards produced from 50mm F.L. This assertion correlates with the opinion of Badejo *et al.*, (2011) research on cement bonded board. They opined that boards produced from short fibres length had better mechanical properties. Wood strand well oriented due to the shortness of the fibre, will accordingly increase bending strength, flexibility and the dimensional stability of the board produced (Oyagade 1988). (Owoyemi and Ogunrinde 2013) reported that increase in cement content improves the properties of the board produced. Oyagade (1988) reported that strand geometry is highly correlated with board key properties. In his study, he discovered that boards produced from strand are stronger and more dimensionally stable than boards produced from sawdust. Semple and Evans (2004) confirmed this assertion that using small strand, the structure will be more compacted, reduced void space and irregularities. Observation from the board produced showed that board produced from 25mm has the best surface finish.

***Table 8.* Mean values for Modulus of Elasticity and Modulus of Rupture**

Fibre length	**Mixing ratio**	**MOE**	**MOR**
25 mm	1:00	2728.8 ±431.40	3.49± 0.53
	1:01	489.36 ± 102.57	1.70± 0.31
	2:01	1222.58 ± 219.72	1.91± 0.62
50 mm	1:00	1306.91 ± 178.58	3.03± 0.37
	1:01	473.21 ± 209.11	1.46± 0.36
	2:01	663.83 ± 256.84	1.82± 0.19

***Table 9.* Analysis of Variance for board produced**

	MOR	**MOE**
Fibre length	0.01^{ns}	1929582.28^{ns}
Mixing ratio	9.48*	7066316.06*
F.L*M.R	0.65^{ns}	1963990.14*
Error	6.44	2318918.67
Total	16.58	0.000000133

***Table 10.* Duncan Multiple Range Test (DMRT) for mixing ratio**

Mixing ratio	**MOR**	**MOE**
1:0	3.26^{a}	2017.85^{a}
1:1	1.76^{b}	855.97^{b}
2:1	1.69^{b}	568.52^{b}

CONCLUSION

The use of bio-based fibres has become imperative as regards strength properties. Boards produced from banana stalk has demonstrated good strength properties because of its long fibres

This research has revealed that board produced from pure OPC i.e. M.R 1:0 and F.L 25mm exhibited the lowest physical property in terms of Water Absorption, Thickness Swelling and Linear Expansion and the highest mechanical strength property in terms of Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) which may be due to the thorough encapsulation of fibres by the binders and closure of the void spaces between the banana stalk. It was also observed that the Mechanical properties of each board produced increased with increase M.R and reduced with increase F.L.

From the above proven observation it can be deduce that the physical and mechanical properties of cement bonded board from banana stalk and pozzolan can be improved when a minimum fibre length of banana stalk is used with increased M.R of cement to pozzolan to achieve better physical and mechanical property. This research work is also a step further into the utilization of banana stalk that has been lying as waste in the farm and agriculture industries which in some cases constitute nuisance to the environment and at the same time lead to the release of toxic organic substances into the environment. Observation from this study shows that F.L 25mm boards produced with only OPC has the highest strength property.

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