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COMPARATIVE STUDIES OF EXTRACTED RESIN FROM PLANTAIN PEELS AS A POTENTIAL BINDER AND CO-BINDER WITH CEMENT IN PARTICLEBOARD PRODUCTION

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ABSTRACT

In this study, natural resin from dry, ground peels of unripe plantain were extracted with benzene/ethanol (2:1). This was employed as binder as well as co-binder with cement in the production of particleboards. Boards C (ratio 3:2:0 of sawdust:resin:cement by weight), A (ratio 3:1:1 of sawdust:resin: cement by weight) and B (ratio 3:0:2 of sawdust:resin:cement by weight) were all produced, while B serve as control. Board C exhibited least density (0.38 gcm^{-3}), while B had highest (1.05 gcm^{-3}). There appeared better physical properties for board A (water absorption - WA, thickness swelling - TS, linear expansion - LE and abrasion – ABS - values of 15.51%, 3.82%, 4.42% and 0.79% respectively) than B and C. However, the mechanical properties of board B appeared better than that of A as its modulus of rupture (MOR) and modulus of elasticity (MOE) were higher, though board A still had significant MOR and MOE values of 2.02 Nmm^{-2} and 2131.40 Nmm^{-2} respectively. The MOR and MOE tests on board C failed due to its lack of load-bearing capacity, though with least value of LE. The reduced density and improved physical qualities of board A exposed the extracted resin as a good potential binder if more research is geared towards developing its binding capacity. Infrared spectroscopy showed O-H and C=O bonds on the resin, while its chemical interaction with the cement reduced the functional group to C=O bond.

Keywords: Plantain, peels, particleboard, resin, cement.

INTRODUCTION

Over the years, plantain has been more importantly utilized as foods. The fruits are either eaten raw or processed as foods and raw material for industrial purposes. The peels are well known animal feeds due to their high moisture content, sources of fibres for the manufacture for paper, textile material and leather production (Morton, 1987). In some African countries like Kenya and Uganda, they serve as raw materials and source of binder for briquettes (a fuel resource made from any agro-industrial wastes that can be recycled for cooking or heating) as reported by Megan (2007) little is known about the exploitation and application of their natural resins present in peels. Resins from plants are known for their binding characteristics (Mantell, 1942; Harborne, 1984). Promising cement-bonded wood composites for structural purposes have evolved over many years. Its production is aimed at utilizing large quantity of sawdust at sawmills. Petroleum-based synthetic resins (e.g., phenolic and urea-formaldehyde), employed as binders have been well known to be efficient and as such became costly items in the processing of wood panel products (Frybort *et al.*, 2008). These costly products led to high cost of production of particleboards. Their ready availability is also a concern and crucial factor, especially in Nigeria where most of these products are imported; hence, the need for cheap and readily available binders that would be of equal or better qualities to these synthetic products has become imperative. Due to the high cost of thermosetting resin in board production in Nigeria, a great deal of interest is being developed on the use of cement as a binding agent, fortified with other mineralizing agents (Ajayi, 2000). Different mineral binders, including Portland cement, magnesia and gypsum, are used to fabricate boards with different properties (Simatupang and Geimer, 1990). However, the most expedient binder, concerning strength, durability and acoustic insulation properties is Portland cement (Frybort *et al.*, 2008) but their density has become a major concern as increased strength was always facilitated by more cement.

In the present study, natural resin, extracted from the peels of unripe plantain was employed as binder as well as in combination with cement for the production of particleboards, using cold-press method. The properties of the boards and the effects of mixing the extracted resin with cement on the properties of the board produced were investigated and compared with cement-bonded particleboards which have been well reported for their quality strength and other properties (Badejo, 1986; Fuwape, 1992; Frybort *et al.*, 2008).

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MATERIALS AND METHODS

Sample Collection and Preparation

The plantains (unripe) used for the study were bought along Okitipupa road, Ondo State, Nigeria. They were washed thoroughly with water, peeled, chopped into pieces with knife and sun-dried. The dried sample was pounded with mortar and pestle, blended and sieved to 300 µm with laboratory sieve at the department of Geology, Federal University of Technology, Akure, Nigeria.

Extraction of Resin from the Sample

The prepared sample was first defatted with N-hexane to remove all fat, after which resin was exhaustively extracted with benzene/ethanol (2:1) in a soxhlet extractor (TAPPI, 1998). Solvent was recovered from the extract by distillation. The resin was purified by evaporating off all the remaining solvent till there was no perceivable odour of the solvent in a fume cupboard.

The yield was calculated thus:

$$\%\text{yield} = \frac{\text{weight of dry resin}}{\text{weight of sample}} \times 100$$

Infra-Red Spectroscopy of the Resin

The infrared spectroscopic analyses contained in this work were carried out using model 500 Infra-red Spectrophotometer, Buck Scientific Inc., Norwalk, CT, USA using KBr.

Particleboard Production

Production of the particleboards was carried out at the Department of Forest Products Development and Utilization (FPDU), Forestry Research Institute of Nigeria (FRIN), Jericho, Ibadan, Nigeria. The sawdusts used were mixture of hardwood species. They were pre-treated with hot water in an aluminum pot at 80^{o}C for about one hour to remove the water-soluble, all extractives like resin acids, terpenes, inorganic salts, fats, certain carbohydrates, tannins which might be present in the wood and capable of inhibiting the setting of the binders (Eero, 1981). They were later washed in cold water for 10 minutes; the leachate was separately removed and exposed to atmospheric air to dry and then transferred to controlled laboratory environment at moisture content of approximately 12%.

Calculation of the Weight of Materials Required

The quantities of materials required for the production of 350mm x 350mm x 6mm were calculated and measured out according to the level of combination in the experiment. Such variables were hardwood specie sawdust, the natural resin, cement and additive. Hardwood specie sawdust and binder (resin) were calculated based on the mixing ratio of the two components comprising the mass of the board. Benzene/ethanol solvent system was used as the liquid medium for the resin, while water was used for that of cement-bonded particleboards. The experimental combinations were as follows:

Board A - 3:1:1 (sawdust:resin:cement by weight ratio)
Board B - 3:0:2 (sawdust:resin:cement by weight ratio)
Boards C - 3:2:0 (sawdust:resin:cement by weight ratio)

Blending of Production Variable

The additive ($CaCl_2$) for the production of cement bonded board was first dissolved completely in water and added to the sawdust before mixing with the cement. The required quantity of water derived based on the relationship developed by Simatupang (1979) and also adopted by Erakhrumen *et al.* (2008) was added and thoroughly mixed afterwards in an aluminum bowl until a homogenous mixture was formed and the cement paste completely hydrated.

Required water (litres) = 0.35C + (0.30 - M)W
Where C = Cement weight (kg), M = Moisture content of the sawdust (oven-dry basis) and W = oven-dry weight of the sawdust.

All materials (the natural resin and sawdust) for the resin bonded particleboard produced were measured in kilogram based on the working ratio into an aluminum bowls and hand-mixed thoroughly until well blended, lump-free finishes were obtained.

Mat Formation and Processing

The furnish was hand formed into a uniform mat inside a wooden box of 350 mm x 350 *mm* that was placed on a caul plate made of iron. The mat formed was pre-pressed using wooden caul plate. Prepress was done in order to reduce the thickness of the mat formed, for free loading unto the cold press. The steel caul plate was covered with polythene sheet before board formation to prevent the sticking of the board to the plate. After board formation, the wooden plate was removed; another polythene sheet was placed on the mat before placing the metal caul plate. The board was loaded into the hydraulic press and pressure was applied at 1.23 Nmm^{-2} for 24 hours, before de-moulding.

Curing

After pressing, the mat still under compression was cured in the oven at 105 ^{o}C for about 4 hours. The boards were removed, allowed to cool, wrapped with polythene sheet and kept in the laboratory environment for 28 days to enhance further curing of the resin, while those experimental boards with only cement binders were air-dried after release from the hydraulic press, wrapped with polythene sheet and kept in the laboratory environment for 28 days to enhance further curing of the cement. Possible loss of water from the boards was prevented through proper wrapping of the sheet so as to maintain constant ambient condition. Boards were trimmed to avoid edge effect on test specimens, thereafter the board was stack for 21 days inside a controlled laboratory environment at relative humidity of 65±2% and temperature of 20 °C. All the other boards were produced through the production process as stated above.

Laboratory Tests on the Particleboards

Both the physical and mechanical properties of all the boards were determined in accordance with BS 373 (1979). Board specimen dimension of 152mm x152mm x 6mm was used to investigate the physical properties such as thickness swelling, water absorption and linear expansion, while 194mm x 50mm x 6mm was used to investigate the mechanical properties such as modulus of rupture and modulus of elasticity on tensiometre at Department of Forest Products Development and Utilization (FPDU), Forestry Research Institute of Nigeria (FRIN), Jericho, Ibadan, Nigeria.

Physical Properties

Water Absorption

This is a measure meant to test the dimensional stability of board, to have this test done; each test specimens was soak in water (at room temperature) for moisture uptake for 24 hours. The new weight was measured using highly sensitive weighing balance before and after soaked. Water absorption was expressed as the percentage increase in weight of the board over the original or initial weight.

$$\text{WA} = \frac{W_2 - W_1}{W_1} \times 100$$

Where: WA = water absorption (%), W_1 = initial weight, W_2 = final weight.

Thickness Swelling

The same procedure was used to determine the thickness swelling, using the same specimens at the same period of time for soaking. The thickness of the boards was measured using electronic veneer caliper before and after soaking for 24 hours at room temperature. The thickness swelling was expressed as the percentage of increase in thickness of the board over the original thickness. Thickness swelling was expressed as

$$\text{TS} = \left(\frac{T_2 - T_1}{T_1}\right) \times 100$$

Where: TS = thickness swelling (%); T_2 = final thickness; T_1 = initial thickness

Linear Expansion

This was also carried out by taking measurement of the initial length (L_1) with the aid of a veneer caliper at two different points along the length of the test specimen. The sample was soaked in water for 24 hours at room temperature and the measurement of the final length (L_2) was carried out at the designated two different points. The linear expansion (%) was estimated using:

$$\text{LE (\%)} = \left(\frac{L_2 - L_1}{L_1}\right) \times 100$$

Where: LE = Linear Expansion (%); L_2 = Final length (mm); L_1 = Initial length (mm)

Abrasion Test

The surface of the board was brushed 20 times with iron brush and the weight was determined before and after brushing the surface with the tool. Abrasion (%) was estimated using the formula below:

$$\text{ABS (\%)} = \left(\frac{A_2 - A_1}{A_1}\right) \times 100$$

Where: ABS =Abrasion (%); A_2 = Final weight (g); A_1 = Initial weight (g)

Mechanical Properties

Bending Strength

The test specimens of 194mm × 50mm × 0.6mm were cut from the boards and subjected to a force or load on the tensiometer with the support span. The specimens were supported by two rollers at each ends and loaded at their centres. The forward movement of the machine leads to gradual increase of load at the middle span until failures of the test specimens occurred. At the point of failure, the force exerted on the specimen that caused the failure was recorded; the Modulus of Rupture (MOR) of the test specimens was calculated using the formula;

$$\text{MOR} = \frac{3\rho L}{2bd^2}$$

Where;

MOR= Modulus of Rupture; ρ= Failing load; L= Span between centers of support (mm);
b= Width of test specimen (mm); d= mean thickness of the specimen (mm).

The panel's stiffness, Modulus of Elasticity (MOE), was determined from the bending test performed on each specimen and MOE was calculated using the formula;

$$\text{MOE (N/mm}^2\text{)} = \frac{\rho L^3}{4bd^3 H}$$

Where;

MOE= Modulus of elasticity of panel stiffness; L= Span between centres of support (mm)
b= Mean thickness of the specimen (mm); H= Increment in deflection (mm).

RESULTS AND DISCUSSION

Extraction of the Resin

The yield was found to be 9.13%.

As shown in table 1, the density of the boards ranged between 0.38 *g/cm*^{3} and 1.05 *g/cm*^{3}. The density of the cement bonded particleboard was reduced by about 57% when half of equal weight of the cement was substituted with the resin (i.e., 1:1) with no significant variation in other physical properties. The higher the proportion of cement in the boards, the higher the density (boards A and B). This is in conformity with publication by Erakhrumen *et al.* (2008). This is an important development as high density boards are difficult to handle, cut, nail and transport (Zhou and Kamdem, 2002) coupled with the cost of implication associated with higher content of cement in production. Board C which had the extracted resin as the sole binder possessed the least density value but its exhibition of high values of other physical properties except for linear expansion called for more research on improving the glueing strength of the resin.

The mean values of WA ranged from 15.51 to 87.90%. The values obtained are similar to those reported by Erakhrumen *et al.* (2008). Experimental board C had the highest values, while board A had the least value; hence, the combination of the extracted resin and cement in ratio 1:1 produced board with more water resistance quality. This could be due to the encapsulation of the fibre of the board by the resin.

TS is an important attribute concerning dimensional stability of wood panel products. The compiled mean TS values for the experimental boards ranged from 3.82 to 22.67% (Table 1). These range values compared favourably to figures reported by Erakhrumen *et al.* (2008). The combination of both resin and cement again produced experimental board (A) of mono-dimensional stability when compared with the other boards.

The mean values for LE ranged from 2.42 to 4.80%. Experimental boards B had the highest value (4.80%), while the lowest was interestingly found in the board C. Boards A and B had values that competed favourably with each other. The trend of all the results showed that application of the extracted resin as sole binder lowers the linear expansion – a factor in measurement of dimensional stability of panel products. This could be attributed to non-hydrophilic nature of the resin. There was significant difference in the LE value obtained for board C and that of other boards at 5% level of probability (Table 1).

The mean values of ABS ranged from 0.79 to 55.44%. The lowest value was recorded for board A (Table 1). Board C had exceptionally high value (55.44%). The results were clear indication that there was an improved surface quality of the board produced with mixture of resin and cement (1:1). However, using the natural resin alone as binder resulted in poor abrasion. This could be

Physical Properties of the Boards Produced

Table 1. Mean Physical Properties of the Particleboards produced.

Board	Density (g/cm^3)	WA (%)	TS (%)	LE (%)	ABS (%)
A	0.45^a	15.51±1.01^a	3.82±2.78^a	4.42±0.29^b	0.79±0.68^a
B	1.05^b	16.97±2.96^a	4.47±1.84^a	4.80±0.32^b	1.17±0.43^a
C	0.38^a	87.90±24.20^b	22.66±4.64^b	2.42±0.57^a	55.44±19.68^b

All data represent the mean of three replicates. Values followed by the same superscripts in each column are not significantly different at ($p < 0.05$)

Table 2. Mean Mechanical Properties of the Particleboards produced.

Board	MOR (N/mm^2)	MOE (N/mm^2)
A	2.02^a±0.16	2,131^a.40±548.98
B	6.13^c±0.24	8,903^c.48±3,079.92
C	0.00	0.00

All data represent the mean of three replicates. Values followed by the same superscripts in each column are not significantly different at ($p < 0.05$)
MOR – modulus of rupture; MOE – modulus of elasticity

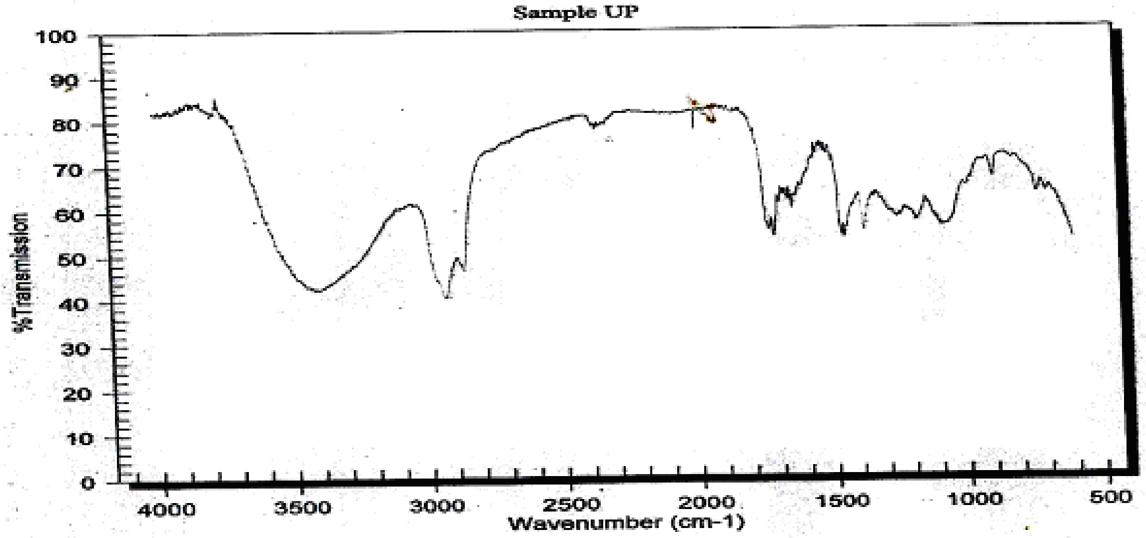

Fig. 1. Infrared Spectroscopy of the Extracted Resin from Plantain Peels.

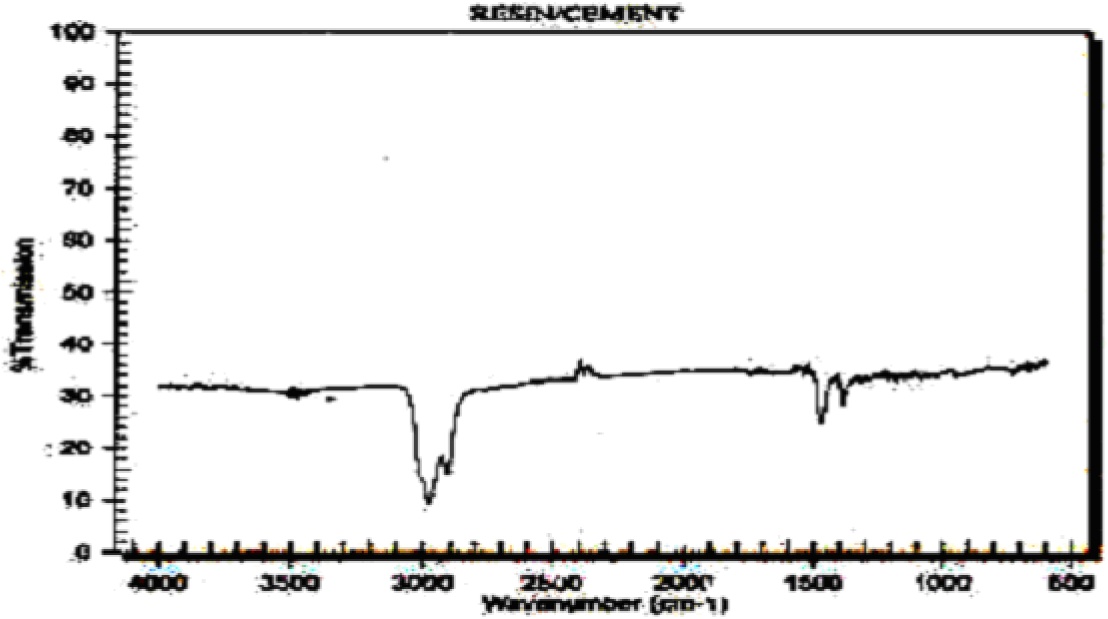

Fig. 2. Infrared Spectroscopy of the Mixture of the Extracted Resin with Cement (1:1).

due to lack of strong chemical bond between the resin and the lignocellulosic part of the board fibres.

The MOE reveals the ability of the boards to withstand stress, while the MOR reveals the bending strength of the boards. The mean values of Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) of the three experimental boards are summarized in table 2. Board B had the highest MOR and MOE values – 6.13 N/mm^2 and 8,903.48 N/mm^2 respectively, significant of best load strength. Nevertheless, the MOR and MOE values of 2.02 N/mm^2 and 2,131.40 N/mm^2 respectively, obtained for board A, still compete favourably with publications by Kwon and Geimer (1998), Ajayi (2002) and Zheng *et al.* (2007). However, the bending and tensile strength of board C could not be determined due to lack of mechanical strength to withstand the testing load; hence, the MOR and MOE tests failed (i.e., no MOR and MOE values) despite the fact that the board appeared to be physically strong and stable. The trend of influence of the resin proportion on MOR and MOE of the panels at each of the boards showed better strength with cement.

Infrared spectroscopic absorptions at 3500 cm^{-1}, 2850 cm^{-1} and 1750 cm^{-1} show presence of the O-H, methylene and C=O groups respectively in the extracted resin (Fig.

1). In figure 2, the absence of absorption at 3500 cm^{-1} showed that there was a chemical interaction between the extracted resin and the added cement. This could be explained by the probable ionic bond formed between the calcium atom of the cement and hydroxyl group on the resin

CONCLUSION

The extracted resin from plantain peels (unripe) had some binding characteristics that could serve some industrial purposes as applied in the production of the particleboards. Combination of the extracted resin and cement (1:1 by weight) as a binder for production of particleboard resulted in board with better physical properties and acceptable mechanical properties.

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