PHYSICAL AND MECHANICAL PROPERTIES OF BAMBOO (*Bambusa vulgaris* Schrad. ex Wenld) BASED CEMENT-BONDED COMPOSITES AS INFLUENCED BY PRODUCTION VARIABLES

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Abstract

Cement Bonded Composites were produced from the mixture of *Bambusa vulgaris* (Bamboo) particles and inorganic binder. The effects of three levels of Board Density (BD) (1000 kg/m^3, 1100 kg/m^3 and 1200kg/m^3), three levels of cement/particle Mixing Ratio (MR) (1.5:1, 2.5:1 and 3.5:1) and three levels of Curing Reagent Concentrations CRC (1.5 %, 2.5 % and 3.5 %) were assessed. The experimental design was a 3 x 3 x 3 factorial experiment in a Completely Randomized Design (CRD) which gave 27 treatment combinations of experimental boards. Properties assessed include Water Absorption (WA), Thickness Swelling (TS), Modulus of Rupture (MOR), Modulus of Elasticity (MOE), and Energy at Break (EB). The Cost-Benefit Analysis (CBA) of the boards was also determined. Data obtained were subjected to Analysis of Variance and Correlation analyses. The WA and TS properties decreased as the Board Density (BD), Mixing Ratio (MR) and Curing Reagent Concentrations (CRC) increased. The WA values ranged from 3.40 % to 17.84 %, while the TS values ranged from 0.11 % to 0.73 % after 24hr immersion. The MOR, MOE and Energy at Break increased as the BD, MR and CRC increased. The MOR ranged from 2.29 N/mm^2 to 9.04 N/mm^2 while MOE ranged from 747 N/mm^2 to 4573 N/mm^2 and Energy at break ranged from 0.065 Nm to 0.261 Nm. The study shows increase in BD, MR and CRC caused a decrease in dimensional movement and increased the strength of boards. The strongest, stiffest and most dimensionally stable boards were produced at the highest BD (1200kg/m3), MR (3.5:1) and CRC (3.5 %). Cost-Benefit ratio gave a value greater than unit 1, which connotes that the project is economically viable, socially acceptable and profitable. The study thus confirms that the hot water pre-treated bamboo particles were suitable for the manufacturing of Cement Bonded Composites. This study should encourage research into the suitability of other non-wood lignocellulosic materials in the production of composite boards.

Keywords: Bamboo; Composites; Strength Properties; Production Variables
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Introduction

The continuing increase in population, urbanization and demand for other forms of land use, indiscriminate logging, overgrazing and overexploitation of wood resources has put the forests under pressure. These occurrences have significant impact on the operations of the forest industries, leading to a decline in the contribution of the industries to national and industrial development. Although forests regenerate naturally, the natural process of restocking exploited forests is rather slow and cannot match the rapid rate at which forests are being exploited. A contributing factor is the introduction of Taungya farming system where striplings and fencing post of economic species were heavily exploited and used as yam stakes- a predominant farm crop that was cultivated annually (Ajayi, 2000). The demand for wood raw material by forest industries in recent times has outstripped the production capacity of the forest. The poor log conversion efficiency of the sawmills is partly responsible for the high pressure on the forest resources and the destruction of forest cover. These constraints, brought about by dwindling timber resources from forests which led to increase and high demand for panels and composites as alternatives to wood products motivates the interest of wood scientists and technologists to conduct research that will bring about solutions to the rapidly depleting wood resources in the forests. In addition, wood composite industries demand more wood raw materials everyday despite the fact that the forest resources are diminishing. This has consequently prompted the research into sourcing for alternative raw materials (such as non-conventional materials) for production of panels and composites. These non-conventional materials include; rice by-products (rice straw, husks), coconut husks, maize stalk and cobs, groundnut shells, banana fibers, water melon peels and oil palm by-products as well as bamboo.

Bamboo (*Bambusa vulgaris*) is a perennial, giant, woody grass belonging to the group angiosperms and the order monocotyledon. They are flowering perennial evergreen plants in the grass family Poaceae and subfamily of bambusoideae. More than 50 genera are divided into about 1,450 species (Zhang *et al*., 2002; Gratani *et al*., 2008). As a cheap and fast-grown resource with superior physical and mechanical properties compared to most wood species, bamboo offers great potential as an alternative to wood. It takes about 3-5 years for bamboo to reach full maturity, while indigenous hardwoods can take 20-120 years to mature. Despite the high utilization potentials of bamboo in the wood products sector, the forest industry in Nigeria has been on a gradual decline in terms of capacity utilization (Ogunwusi, 2011) as a result of dwindling timber resources. According to (Matoke *et al*., 2012), bamboo utilization is confined to domestic use due to lack of modern skills, inappropriate processing skills and technology. Matured Bamboo is stronger in tensile strength – superior to mild steel. In compression, it withstands up to 52,000 pounds per square inch-stronger than concrete.

Cement-bonded board is an engineered particle composite product made from wood or other lignocellulosic raw materials bonded with inorganic binders such as cement, chemical additives and water, and pressed under regulated pressure (Ajayi *et al*., 2008; Adedeji, 2011). It has better dimensional stability and it neither contains formaldehyde nor release poisons and toxic gases. Boards may be sawn, shaped, drilled, nailed and screwed with normal woodworking tools and machinery (Elten, 2004). The boards has high fire resistance, wet and dry rot resistance, freeze-thaw resistance, termite and vermin resistance, excellent workability, exceptional insulation and acoustic performance, and low cost and ease of manufacture (Adedeji, 2011). The use of locally sourced raw materials for the production of panel products as alternatives to sawn timber will increase the industrial and economic base for national development (Ajayi, 2003c). In view of the aforementioned, this research study focused on the investigation of the suitability of bamboo as reinforcing fiber for composite board.

Materials and Method

Particle Preparation

The bamboo culms (*Bambusa vulgaris*) used in this study was collected from the Department of Forestry and Wood Technology plantation at Obanla, Federal University of Technology, Akure, Ondo State. The cement was purchased from the local market, while the additive chemical ($CaCl_2$) was purchased from a standard scientific chemical laboratory, Akure, identified and confirmed in the Chemistry Laboratory of Federal University of Technology, Akure, Ondo State. The bamboo culms after harvesting, was de-limbed, cut into billets and the nodes removed to avoid interfering with the formation of the composite. The clean internodes were cut into strips using cutlass, and converted into chips and particles using the hammer mill. The pulverized particles was air dried to reduce the moisture content to 12 %, while unwanted particles and long fiber were eliminated using a sieve of 2.00 µm wire mesh. The particles were pre-treated with hot water at 100^0C temperature and constantly stirred for 30 minutes to remove inhibitory substances that may likely inhibit the setting and curing of the cement used as binder. The pre-treated particles were air dried for 14 days (Ajayi, 2000) to reduce the moisture content to 12 % and then stored in a polythene bag in the laboratory so as to maintain the moisture content prior to use.

Formation of the Board

The board formation was based on Mixing Ratios 1.5:1, 2.5:1 and 3.5:1 (Cement/ particles), board densities of 1000 kg/m^3, 1100 kg/m^3 and 1200 kg/m^3 by dry weight and curing reagent concentration of 1.5 %, 2.5 % and 3.5 % of the weight of cement. This formation procedure was based on the procedures of Ajayi and Olufemi, (2011) and Adefisan (2013).

The quantity of cement and bamboo particles were weighed and poured in a plastic bowl. Calcium chloride and water were weighed and mixed in a water jar and poured into the plastic bow containing the bamboo particles and cement. The mixture was thereafter thoroughly mixed together to prevent the formation of cement/particles lumps. The blended stock was then transferred, formed on the mould, reinforced with measured out quantity of fibers (to enhance board strength). Thereafter, the formed board was covered with polythene sheet to prevent sticking of the stock on the caul plate and overlaid with plywood at the top. The formed mat was pre-pressed to reduce the thickness before it was transferred to the cold press and pressed under pressure of 1.23 N/mm^2 to the required thickness for 24 hours. Thereafter, the formed mat was de-moulded and conditioned in a polyethylene bag for 28 days in a conditioning room to allow for further post-curing and setting of the cement. After this, the boards produced were trimmed and cut into test sample sizes for laboratory investigation.

Properties Assessed

Water Absorption (WA) and Thickness Swelling (TS)

Water absorption and thickness swelling tests were conducted based on the procedures in ASTM, 2005. The test samples used were trimmed to 152mm x 50mm samples. The weight of the sample was measured, while a digital caliper was used to measure the thickness. The test samples were submerged in distilled water for 24 hours. Thereafter, they were removed and drained for 10 minutes to remove excess water. After this, the weight and thickness of the samples were measured. The percentage water absorption and thickness swelling for each test sample was calculated using the formula below:

Water Absorption (WA)

$$WA(t) = \frac{W(t) - Wo}{Wo} x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3.2)$$

Where WA (t) is the water absorption at time t, W_0 is the oven dried weight and W (t) is the weight of specimen at a given immersion time t.

Thickness Swelling (TS)

$$TS(t) = \frac{T(t) - To}{To} x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.3)$$

Where TS (t) is the thickness swelling at time t, T_0 is the initial thickness of specimens and T (t) is the thickness at time t.

Modulus of Rupture, Modulus of Elasticity and Energy at break

The flexural properties were determined by performing test in Universal Testing Machine model M500 and capacity 25 KN, which were carried out in accordance with the American standard of ASTM C1225-08. The tests were carried out by placing a flat sample of 194mm x 50mm x 6mm horizontally on a 3-point flexural testing machine. A perpendicular load was applied directly on the sample at the center cutting across the entire width of the board at a constant speed. At the point of break of the specimen, the flexural properties results were printed out automatically.

Cost Benefit Analysis

Cost-benefit analysis (CBA) was computed by calculating and comparing benefits and costs of the Cement Bonded Composite produced from the research study as shown in equation 3.4. The value obtained after the comparison of the total expected cost of material input against the total expected benefits in terms of sales was used to predict whether the benefits of the project or decision outweigh its costs, and if it is economically and socially acceptable and profitable for investment opportunity

$$\text{* Cost-benefit analysis (CBA)} = \frac{\text{total expected benefits}}{\text{total expected cost}} \ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

Experimental Design and Statistical Analysis

The experimental design for this study was 3 x 3 x 3 factorial experiment in a Completely Randomized Design (CRD), the combination of which gave 27 treatments combination. The factors consist of three Board Density (1000 kg/m^3, 1100 kg/m^3 and 1200 kg/m^3), three Mixing Ratio of cement to particles (1.5:1, 2.5:1 and 3.5:1) and three Curing Reagent Concentrations (1.5 %, 2.5 % and 3.5 %). The data collected were subjected to Analysis of Variance (ANOVA), while Mean Separation was carried out for significantly different parameters by using the Duncan's Multiple Range Test (DMRT).

Results

Effects of Production Variables on Water Absorption and Thickness Swelling of the Cement Bonded Composites

The Water Absorption ranged from 3.71 % to 17.84 %, while Thickness Swelling ranged from 0.11 % to 0.73 % as BD, MR and CRC increased from 1000 kg/m^3 to 1200 kg/m^3, 1.5:1 to 3.5:1 and 1.5 % to 3.5 % respectively after 24hrs immersion in water. This indicates that lower values of Water Absorption and Thickness swelling were obtained at higher mass per unit volume, cement/particle Mixing Ratio (3.5:1) and higher Curing Reagent Concentrations (3.5 %) as shown in Figure 1. In summary, the higher the Board Density, Mixing Ratio, and Curing Reagent Concentration, the lower the Water Absorption and Thickness Swelling of the board.

Effects of Production Variables on Modulus of Rupture, Modulus of Elasticity and Energy at Break

The values of the MOR, MOE and Energy at Break of the composite boards as determined on 3-point flexural loading point ranged between 2.294 N/mm^2 and 5.971 N/mm^2 for MOR, 747 N/mm^2 and 4573 N/mm^2 for MOE and 0.065 Nm and 0.261 Nm for Energy at Break. Increase in BD (1000 kg/m^3 to 1200 kg/m^3), MR (1.5:1 to 3.5:1), and CRC (1.5 % to 3.5 %) brought about increase in the values of MOR, MOE and Energy at Break as presented in Figures 2 and 3.

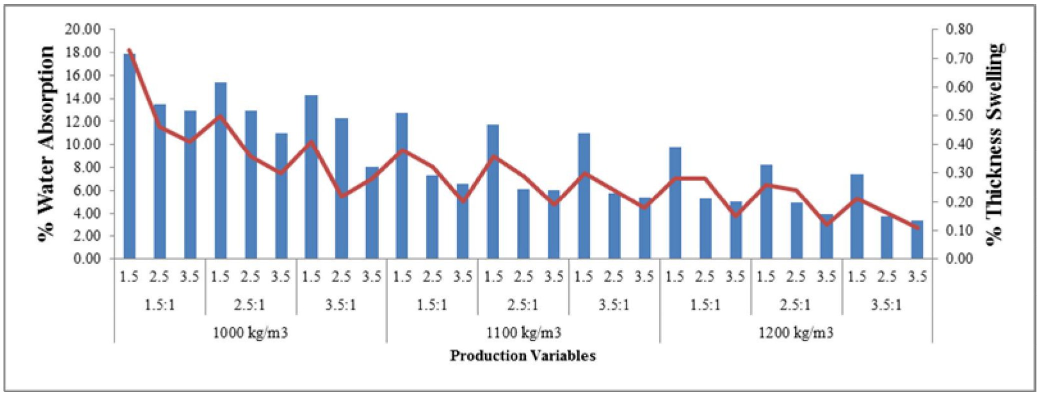

Figure 1: Effect of Production Variables on WA (%) and TS (%) of the CBC

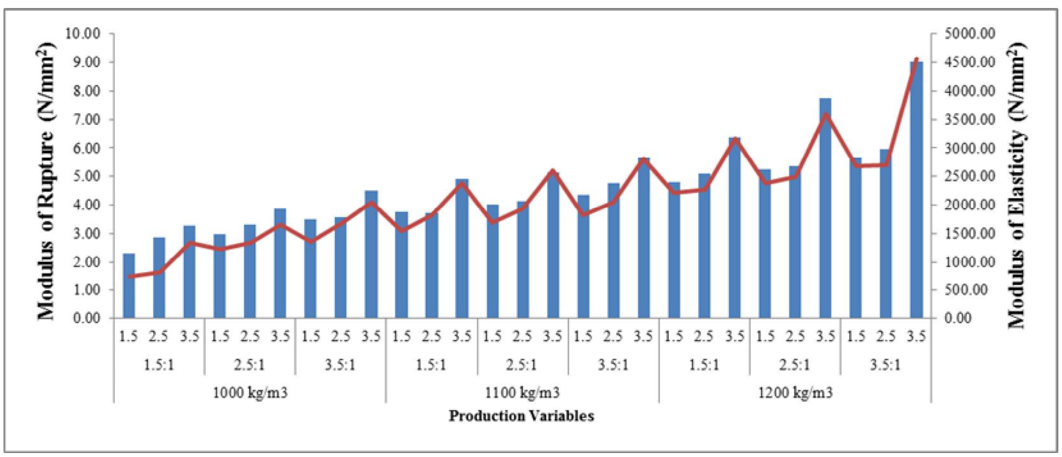

Figure 2: Effect of Production Variables on MOR and MOE of the CBC

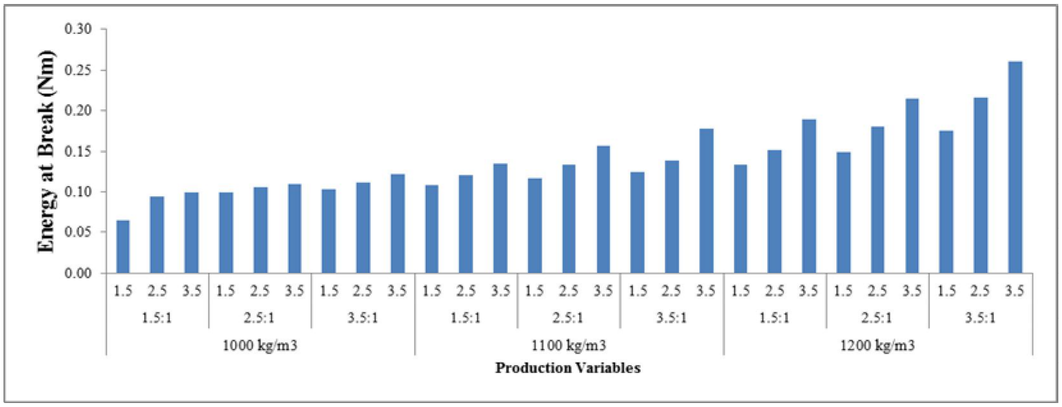

Figure 3: Effect of Production Variables on Energy at Break of the CBC

The Analysis of Variance (Table 3) revealed that the BD, MR and CRC had significant effects on WA, TS, MOR, MOE and EB respectively (Table 1) of the cement bonded composites (CBC) produced at 5 % probability level. The interaction of the BD*MR showed significant effects on TS, MOR, MOE, EB with the exception of WA, while interaction of BD*CRC had significant effects on all of the properties. Similarly, the interaction of MR*CRC had no significant effects on WA, MOR and EB but had significant effects on TS and MOE. The interaction of BD*MR*CRC on the other hand had no significant effects on the production variables.

The result of the Duncan Multiple Range Test (DMRT) revealed that significant differences exist in the WA and TS for BD of 1000 kg/m^3 and 1100 kg/m^3; 1000 kg/m^3 and 1200 kg/m^3; and 1100 kg/m^3 and 1200 kg/m^3 at 5 % probability level. Significant differences exist in the MOR, MOE and EB for BD of 1000 kg/m^3 and 1100 kg/m^3; 1000 kg/m^3 and 1200 kg/m^3; and 1100 kg/m^3 and 1200 kg/m^3 (Table 2). There are significant differences in the WA and TS for MR of 1.5:1 and 2.5:1; 1.5:1 and 3.5:1; and 2.5:1 and 3.5:1. In the same vein, significant differences exist in the MOR, MOE and EB for MR of 1.5:1 and 2.5:1; 1.5:1 and 3.5:1; and 2.5:1 and 3.5:1 at 5 % probability level of significance (Table 3). Similarly, there are significant differences in the WA and TS for CRC of 1.5 % and 2.5 %; 1.5 % and 3.5 %; and 2.5 % and 3.5 %. Following the same trend, there are significant differences in the MOR, MOE and EB for CRC of 1.5 % and 2.5 %; 1.5 % and 3.5 %; and 2.5 % and 3.5 % (Table 4). The occurrence observed above suggests that BD, MR and CRC have significant effects on the WA, TS, MOR, MOE and EB of the Cement Bonded Composites.

Table 1: Analysis of Variance for Properties Assessed of the CBC

		Properties Assessed				
Source	**df**	**WA**	**TS**	**MOR**	**MOE**	**EB**
Board Density (BD)	2	0.001*	0.001*	0.001*	0.001*	0.001*
Mixing Ratio (MR)	2	0.001*	0.001*	0.001*	0.001*	0.001*
Curing Reagent Conc. (CRC)	2	0.001*	0.001*	0.001*	0.001*	0.001*
BD * MR	4	0.099ns	0.001*	0.039*	0.025*	0.001*
BD * CRC	4	0.001*	0.001*	0.001*	0.001*	0.001*
MR * CRC	4	0.177ns	0.029*	0.098ns	0.006*	0.207ns
BD * MR * CRC	8	0.345ns	0.406ns	0.271ns	0.003*	0.154ns
Error	55					
Total	81					

*significant ns: not significant ($p \leq 0.05$)

Table 2: Properties of the Cement Bonded Composites as affected by Board Density

Board Density	WA (%)	TS (%)	MOR (N/mm^2)	MOE (N/mm^2)	Energy @ Break (Nm)
1000 kg/m^3	13.12^a	0.41^a	3.352^c	1352^c	0.101^c
1100 kg/m^3	8.06^b	0.27^b	4.497^b	2075^b	0.135^b
1200 kg/m^3	5.74^c	0.20^c	6.144^a	2900^a	0.186^a
SE±	**0.18**	**0.01**	**0.057**	**47.67**	**0.002**

Means in the same column having different superscripts are significantly different ($p \leq 0.05$)

Table 3: Properties of the Cement Bonded Composites as affected by Mixing Ratio

Mixing Ratio	WA (%)	TS (%)	MOR (N/mm^2)	MOE (N/mm^2)	Energy @ Break (Nm)
1.5:1	10.10^a	0.36^a	4.119^c	1812^c	0.122^c
2.5:1	8.91^b	0.29^b	4.647^b	2104^b	0.141^b
3.5:1	7.92^c	0.24^c	5.227^a	2411a	0.159^a
SE±	**0.18**	**0.01**	**0.057**	**47.67**	**0.002**

Means in the same column having different superscripts are significantly different ($p \leq 0.05$)

Table 4: Properties of the Cement Bonded Composites as affected by Curing Reagent Concentration

CRC	WA (%)	TS (%)	MOR (N/mm^2)	MOE (N/mm^2)	Energy @ Break (Nm)
1.5 %	12.04[a]	0.38[a]	4.072[c]	1763[c]	0.120[c]
2.5 %	7.80[b]	0.29[b]	4.307[b]	1876[b]	0.139[b]
3.5 %	7.08[c]	0.21[c]	5.614[a]	2687[a]	0.163[a]
SE±	**0.18**	**0.01**	**0.057**	**47.67**	**0.002**

Means in the same column having different superscripts are significantly different ($p \leq 0.05$)

Cost Benefit Analysis

The CBA was calculated by comparing the total expected cost of each option against the total expected benefits, to see whether the benefits outweigh the costs, and by how much (Table 5). Benefit-cost ratio, as calculated was greater than unity, i.e.1, thus the project is economically viable, socially acceptable and profitable and consequently, it can generate its cost input as well as profit. Current Market survey as at January/February 2015 revealed that commonly used conventional ceilings board varies in prices and are comparatively low to the market price of cement bonded board. For instance, Gypsum Ceiling board and Gypsum Mineral Fiber boards of sizes 600mm x 600mm wide and 5/8 inches are sold at six hundred and twenty naira (₦ 620), while PVC (laminated) Gypsum board of the same size cost five thousand naira (₦5000) per bundle containing 10 pieces of the board. In the same vein, Asbestos ceiling board of 2 inches by 2 inches is sold at a price of two hundred and fifty naira (N250) per board. Comparing these prices with that of the Cement Bonded Composites produced which after benefit cost ratio gave an individual cost of two hundred and fifty naira (₦ 250), it is observed that the cost/price of the experimental board is lower compared to conventional boards of comparative sizes. Although, this price is the same as the price of Asbestos ceiling board, the use of asbestos ceiling board on the other hand in this millennium is discouraged and even banned in some countries due to associated critical health issues (such as cancer of the lungs), while alternative raw materials for ceiling boards are been advocated.

Table 5: Benefit Cost Analysis for Cement Bonded Composite

S/N	Total Costs	Cost (prod. of 90 boards) ₦	Unit Cost (₦)	
1	Fabrication of Machine	46000	3600.00	**Depreciated cost*
2	Construction of Moulds (350mm x 350mm x 6mm) 30 boards	32000	355.56	
3	Bamboo Particle (Cutting and pulverizing)	10000	111.11	
4	Concrete slab as basement for machine	5000	5800.00	**Depreciated cost*
5	Polythene (Nylon) (60)	1000	11.11	
6	Cement (Dangote) 1 bag	2050	22.78	
7	Potash Alum	600	6.67	
8	Additive (CaCl3) 2 bottles	6000	66.67	
9	Hydraulic Jack	12000	2000.00	**Depreciated cost*
10	Reinforcement fibers	1500	16.67	
11	Miscellaneous	5000	55.56	
	Total Expenses	**121150**	**12046.11**	
12	Benefit			
13	Cost of Board		250	
14	Number of boards produced		90	
	Total cost of boards		**22500**	
	Benefit Cost Ratio (B/C)	**Total cost / Total expenses**	**1.87**	

Discussion

Water Absorption and Thickness Swelling

As observed in this study, the value for WA and TS compared with other values obtained from related studies are considerable low. According to Ebay (2014), this occurrence can be attributed to the fact that bamboo particle does not hold more moisture as compared to other forms of raw materials/particles used in the manufacture of cement bonded board. The effect of dimensionally stable, stiffer and stronger composites can be attributed to high cement content which is responsible for reduction in absorption of water and decrease in thickness. In comparison, the result obtained is at variance with some studies that have identified coconut husk as a material with high lignin content with low affinity for moisture which thus, act as a barrier for cellulose microfibril. It is also consistent with the outcome of work carried out by Rahman and Khan (2007) who identified coconut husks fibres as being hydrophilic due to the presence of hydroxyl groups from cellulose and lignin components. Assertions mentioned above collaborates with the findings of this research study on low water absorption and thickness swelling due to low affinity for water as it has been reported that the lignin content of bamboo is higher (about 20-30 % w/w) than the 29.79 % lignin contents of coconut husk (Pilanee *et al*., 2011), sorghum 17.2 %, bagasse 27.7 % and rice straw 20.9 % (Martin *et al.*, 2007; Ashori *et al*., 2011). Based on European standards, cement bonded board should have a maximum thickness swelling value of 8 % for 2-h immersion. In addition, the maximum thickness swelling for 24-h requirement EN 317 (European Standardization Committee, 1993b) is 15 %. The values of water absorption and thickness swelling (0.11 % to 1.25 %) obtained for the Cement Bonded Composites in this study were within the acceptable range of values of the EN standard

The values as obtained in this study were considerably lower than the range of values as reported by Ergun and Halil (2009) in which the values of TS and WA vary from 0.32 to 5.62 % and 14.69 to 27.80 % respectively; Badejo *et al.*, (2011) in which WA values ranged from 24.66 to 46.37 % while values for TS ranged from 0.98 to 3.62 %. The values for TS and WA ranged from 2.15 % to 6.69 % and 27.33 % to 32.14 % for *Gmelina aborea*- based board; 1.80 % to 7.25 % and 27.71 % to 32.55 % for *Leucenea leucocephala*- based board (Ajayi, 2000) and 2.25 % to 2.94 % and 30.13 % to 36.51 % for maize stalk – based board (Ajayi, 2006).

The observed decrease in WA and TS with increase in BD, MR and CRC according to Ajayi, (2000) and (2003b) is probably due to high compression ratio, better particle bonding, less visible void spaces and smoother board surfaces which perhaps have hindered absorption of water and increase the board's level of resistance to water absorption. Generally, the removal of the boards from the press, and the immersion in water caused a spring-back, weakened, break down and deformation of bonds, fragility and expansion of initial void spaces (Ajayi 2010). Furthermore, the stone-like nature, hardness, stable and strong bonds formation in the boards were attributed to the increase in the CRC which accelerated the earliest curing and setting of cement-fibers bonds, retarded the negative effect of the remnant extractives, in order to prevent reduction in hydration temperature and exothermic reaction capable of concretizing the network of bonds within the boards. The high values of WA and TS at low curing reagent concentration may be due to inadequate chemical additive to retard the effect of remnant inhibitory substances, thereby slowing down the setting and curing and crystallization of cement with the particles at lowest level of Board Density. This may have been responsible for the inadequate bonds formation in boards (Ajayi 2003c; Ajayi *et al*., 2009). This implies that physical properties of boards can be modified positively by increasing the Board Density, cement/particle Mixing Ratio and curing reagent concentration in boards in order to produce stable and highly densified boards.

Mechanical Strength Properties

European norms (EN) standard (EN 312-3, 1996), minimum requirement for the MOE of particleboards for general uses and furniture manufacturing is 1600 N/mm², while ISO 8335 (International Organization for Standardization, 1987) requirements for MOR and MOE, specifies 9 N/mm² and 3000 N/mm². The maximum range of values of mechanical properties obtained in this study is more than the acceptable standards as stated above.

In comparison with other studies, the properties of boards manufactured here are satisfactory. Fuwape *et al*., (2007) used wastepaper and sawdust and obtained slightly higher MOR ranging from 4.85 N/mm² to 11.69 N/mm². Goroyias *et al*., (2004) also obtained moderately higher MOR of 11.9 N/mm² using sludge. Fiber of coir (*Cocus nucifera*) was used to produce cement-bonded boards by Ferraz *et al*., (2011) with lesser MOR of 3.78 N/mm². Fuwape *et al*., (2007) reported higher MOE values ranging from 2800 N/mm² to 5570N/mm². Ferraz *et al*., (2011) reported maximum MOE of 1150 N/mm² which is less than the maximum obtained in this study. However, values obtained in this study is more than the values obtained by Owoyemi, and Ogunrinde, (2013) and Owoyemi, *et al*., (2014) in their study on newsprint and kraft papers as materials for cement bonded ceiling board in which the MOR and MOE values ranged from 1.07 N/mm^2 to 2.35 N/mm^2 and 252.58 N/mm^2 to 674.42 N/mm^2 respectively. Papadopoulos *et al*. (2006) produced a cement-bonded OSB using oriented strand-type particles. For boards produced with cement/wood ratio of 1:1 they found MOR values of about 3.1 N/mm² and MOE values of about 467 N/mm², which are lower than those observed here. The increased strength and stiffness obtained for the boards at increasing MR and density conforms to similar findings on cement bonded particleboards as revealed by Badejo *et al.*, (2011) and Ajayi and Aina, (2012). This occurrence according to Fuwape *et al*., (2007), is due to the fact that, the flexural properties of cement boards are strongly correlated with Board Density.

Impact strength (Energy at break) is an important property that gives an indication of the resistance of a material to vibration or shock loading. It is also a measure of the work done in breaking a test piece (Dahunsi, 2000). Impact strength of fibre-reinforced polymer is governed by the matrix–fibre interfacial bonding, and the properties of matrix and fibre (Alomayria *et al*., 2014). When the composites undergo a sudden force, the impact energy is dissipated by the combination of fibre pullouts, fibre fracture and matrix deformation (Wambua *et al.*, 2003). Therefore, high flexural strength of treated fibre-reinforced composites is due to the better interfacial adhesions in the composite (Sreekumar *et al*., 2009).

In general , boards produced at highest level of BD (1200 kg/m^3), MR (3.5:1) and CRC (3.5 %) were structurally stronger and had highest resistance to bending force than boards produced at lowest levels of BD (1000 kg/m^3), MR (1.5:1) and CRC (1.5 %) as they contain more void spaces capable of facilitating initial break when load is applied.

Cost Benefit Analysis (CBA)

Cost-benefit analysis (CBA) is a tool employed to evaluate projects by providing with a set of values that are useful to determine its feasibility from an economic standpoint. Conceptually, it simply means that results are easy for decision makers to comprehend, and therefore enjoys a great deal of favour in project assessments. Brian and Rodrigue, (2013) in their opinion reported that the end product of the procedure is a benefit/cost ratio that compares the total expected benefits to the total predicted costs. The result of the benefit cost ratio analysis as revealed in this study work showed the figure to be 1.87 as stated in Table 34. This showed that the project if invested on will generate sufficient income to cover its cost and generate profit or returns. The project is thus economically feasible and financially viable as the benefits outweigh the cost input into the project in collaboration with the findings of Christopher, (2014) on project management.

Conclusion

The study revealed that *Bambusa vulgaris* is a suitable raw material for the production of Cement Bonded Composite after the treatment and in combination with the inorganic binder and the catalyst. Increase in BD, MR, CRC caused decrease in the WA and TS and increase in MOR, MOE and EB. This shows that the increase in the weight of boards, cement content in boards and curing reagent concentration responsible for the speed up of chemical reaction and bond formation enhances the production of stable, strong and stiff boards for better performance. Boards manufactured met the minimum physical and mechanical strength requirements for European Committee for Standardization (EN) and International Organization for Standardization (ISO). Potential and effective utilization of bamboo particle which was obtained from *Bambusa vulgaris* culms as raw material in cement bonded particle board could serve as an alternative to wood based products and sawn timbers for use in construction works and furniture. This will subsequently reduce pressure on forest and forest resources overtime. Based on the findings of this study, it can be stated that bamboo culms has potential as a supplement fibrous material for composites manufacturing.

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