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Dimensional Stability of Cement Bonded Boards Produced from *Thaumatococus danielli* Stalk

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Authors' contributions

This work was carried out in collaboration among all authors. Author EAA designed the study, wrote the protocol and wrote the first draft of the manuscript. Author SAA performed the statistical analysis, while author FTA managed the literature searches and the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Cement bonded boards 6 mm thick were produced using *Thaumatococcus daniellii* stalk. *Thaumatococcus daniellii* and cement were mixed together at two different mixing ratios and three board densities of 2.5:1 and 3:1 and 500, 600 and 700 g/cm^3, respectively. After 24 h of cold-water immersion, the mean water absorption of the cement bonded board ranged from 22.9 to 48.5% for (cement/stalk) mixing ratio of 3:1 and 2.5:1 with board density 700 and 500 g/m^3 respectively. Cement bonded board produced from the highest levels of cement: stalk ratio (3:1) and board density (700 g/cm^3) were dimensional more stable as they had the lowest value for water absorption. The least dimensionally stable boards were produced from the mixing ratio cement: stalk ratio (2.5:1) and board density (500 g/m^3). The mean values obtained for thickness swelling (TS) after 24 hours of cold-water immersion ranged from 0.19 to 0.74%. Result shows that the

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higher the increase in mixing ratio of cements to fibre (3:1) and board density (700 g/cm^3) caused decrease in thickness swelling and water absorption. From this study, *Thaumatococcus daniellii* stalk proved to be suitable for the production of cement–bonded board.

Keywords: Thaumatococcus daniellii stalk; cement bonded board; water absorption; thickness swelling.

1. INTRODUCTION

Cement bonded particleboard (CBPB) is viewed as a composite material or mixture comprising two phases: cement paste and wood chips. Cement-bonded board is an engineered particle composite product made from wood or other ligno-cellulosic raw materials bonded with inorganic binders such as cement, chemical additives and water and pressed under regulated pressure. The increasing interests and prospects of CBPBs in the building construction industries have been explained by the low costs and availability of the raw materials for production [1]. Raw materials for its range from agricultural residues [2] to forest biomass, bamboo, wood wastes (sawmill wastes, logging wastes), construction wastes and recycled wood materials [3]. The addition of wood particles/flour to cement improves fracture toughness by blocking crack propagation which permits the composite to carry load to a higher strain limit [4]. Adefisan [5] and [6] mentioned in previous studies carried out that incorporation of particles to cement led to greater flexural properties in wood-cement composites, poor interfacial bonding occurrence between fibre particles and cement which often results in low strength properties and thus affects composite durability.

A natural fibre–cement composite has been used extensively in construction materials and processes such as insulating, cladding, noise barriers, and house building [7]. The use of agricultural residues is preferable to virgin natural fibres due to environmental concerns. Most agricultural wastes are low-cost, lightweight, biodegradable, and environmentally friendly, and are obtained from renewable sources [8].

Particleboard products also has homogenous structure and can be manufactured in different sizes, thickness, densities and grades for numerous uses, making it a desirable material to work with [9]. The indiscriminate exploitation of the commercial timber species in protected areas, lack of effective utilization of wood resources due to huge wastes incurred in wood processing industries, the neglect of agricultural waste as a close substitute for wood are few of the problems that must be adequately considered and addressed. [10] hinted that agricultural wastes are unique reinforcing material as they are non-hazardous, renewable, and readily available at no cost. To date only a small percentage of these residues are turned into useful products and the rest is either left to rot or worse still, burnt, which pollutes the environment.

Ajayi and Olufemi [11] opined that plant fibres are of biological and lignocellulosic origin which are composed of chemical constituents (lignin, tannins resins, salts, silica, waxes, and ash) and polysaccharides (soluble sugar, starches, cellulose, and hemicelluloses), some of which impair the reaction between the woody element and inorganic cement binder as well as affect cement curing and setting time. Also, the inherent susceptibility of cellulosic fibres to moisture expansion is one of the obstacles of a natural fibre reinforced composite. The presence of high amounts of hydroxyl-groups, mainly in the amorphous regions of hemicelluloses in the cell wall of the natural fibre will lead to relatively high moisture sorption, dimensional instability, and rotting. As a consequence, composite properties incorporating natural fibres are affected negatively [12].

The rapidly changing economic and environmental needs of society are putting ever-increasing pressure on the forest industry to do more with less. This makes the use of alternative fibre sourced from agricultural residues or non-timber forest products more attractive and feasible. Nigeria is blessed with huge amount of bio-resources such as non-woody plants like straws, hemp, jute, kenaf, flax, bamboo, reeds, etc. Commercial production of these products can be facilitated and harnessed into national productivity for sustainable development [13].

Today, there has been increased demand for wood residues by the wood- based and paper industry and the rapidly growing composites industry, in addition to rising timber prices and diminishing resource quality. As a result, focus is moving towards exploring alternatives to solid wood. Utilizing this agricultural waste will also go a long way to salvage the environment from the problem of environmental pollution constituted by this agricultural waste disposal and the gases emitted when burnt. This therefore suggests the reason to explore the viable economic use to which these agricultural wastes can be put to aside from being dumped away and burnt off.

The recent renewed interest in non-woody plants as particleboard fibres originated from a strong environmental motive. Many non-woody fibres used for particleboard production are available as by-products/waste of agriculture and thus can be potentially cheaper than wood plants of this type can be grown in areas that will not support trees, often with very limited water and low soil quality. Apart from the above, non-woody plants offer other several advantages including high annual yield per hectare, short growth cycle, moderate fertilization requirement, ease harvesting and transportation (Ververis et al. 2003).

T. daniellii is a plant species from Africa. It is a large, rhizomatous, flowering herb native to the rain forests of western Africa from Sierra Leone to Democratic Republic of Congo. It is known as Ewe eran leaves in Nigeria. It grows three to four meters in height, and has large papery leaves up to 46 centimetres long. In its native range, the plant has a number of uses besides flavoring. The sturdy leave petioles are used as tools and building materials (AFPD, 2008).

T daniellii stalks are erect cylindrical structures and grow from 3.0 to 3.5 meters tall, depending on the strain, climate and soil conditions. *T. daniellii* stock, were widely used for pulp and paper making since they are fibrous ligno-cellulosic materials like wood [14]. However, little attention has been given to its stalk for particles board production potentials. It is on this background that investigation was carried out to produce cement bonded board from *T. daniellii* stalks and determine its physical properties with a view of finding alternative material for wood in particle board production.

2. MATERIALS AND METHODS

2.1 Preparation of T. daniellii Stalks

T. daniellii stalks were procured from Oritamerin market, in Ibadan, Oyo state, Nigeria. Elephant brand of Ordinary Portland Cement (OPC) was used as a binder in this experiment. The stalks were dried and chopped manually into billet and shredded into flakes. Thereafter, the stalks flakes were pre-treated in a water bath with hot water at about 80°C for one hour, to remove water soluble sugar and other phytochemicals that can affect setting and curing of the cement binder. Next, the stalks were washed in cold water for 10 minutes, air dried to 12% moisture content and stored in polythene bags prior to use [15].

2.2 Board Formation

Mound of 350 x 350 mm made with wooden frame was placed on flat metal plate which was covered with polythene sheets to prevent the sticking of the formed boards on the plates. The mixed flakes of *T. danielli* stalks and cement hydrated with water was spread out on the plate, thereafter, a wooden plate press was used to press down the furnish within the mould to reduce the thickness of mat formed in order to enter the cold press freely and for good compaction. It was later covered with another polythene sheet, after which flat metal plate was placed on it and transferred to the press where it is cold pressed under a pressure of 1.23 N/mm^2 to a thickness of 6 mm for a period of 24 h. [15]. After this, the boards were removed from the mould and stored in a sealed polythene bags for 28days for further curing of the cement. After curing, the boards were cut to required test samples sizes and tested for sorption properties.

2.3 Testing

The dimensional stability of the boards was determined according to the procedures of ASTM, [16]. The test samples used for this test were cut to 50mm x 50mm dimensions which were required to determine the water absorption (WA) and thickness swelling (TS). The initial thickness and weight of the samples were measured and recorded before and after immersion in cold water for 24 hours. The percentage water absorption and thickness swelling for each test samples were calculated as:

$$\text{WA} = \left(\frac{W_2 - W_1}{W_1} \right) \times 100$$

Where: WA = Water absorption (%); W_2 = Final weight after soaking (g) W_1 = Initial weight before soaking (g).

Plate 1. *T. daniellii* plants

Plate 2. Collection OF *T. daniellii* stalk

Plate 3. Cutting of *T. daniellii* Stalks

Plate 4. CBB produced from *T. daniellii* Stalks

The thickness swelling is express as a percentage increase of the original thickness. It is express as follows:

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

Where: TS = Thickness swelling (%); T_2 = Final thickness after soaking (mm); T_1 = Initial thickness before soaking (mm).

2.4 Experimental Design and Statistical Analysis

The experiment was designed to be 2x3 factorial experiments in a Completely Randomized Design. The factors considered are: Two mixing ratio (2.5 and 3:1) (cement/stalk); and 3 board density (500, 600 and 700 g/m^3). Each of the board was replicated three times (n = 18). 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) according to Littell, et al. [17]

3. RESULTS AND DISCUSSIONS

3.1 Thickness Swelling

The mean values obtained for thickness swelling (TS) after 24 hours of cold- water immersion (Table 1) ranged from 0.19 to 0.74%. Result shows that increase in mixing ratio level and board density caused decrease in Thickness swelling properties. The lowest values were obtained from the boards produced at the higher level of mixing ratio 3:1 (cement: stalk) and board density (700 kg/m^3) which were dimensionally stable and showed reduction in thickness movement as they had the lowest value after 24 hours cold water immersion.

Table 1. Mean values obtained for water absorption and thickness swelling of cement-bonded board produced from *T. daniellii* stalk

Mixing ratio levels	Board density (kg/m^3)	WA(%) 24 hrs	TS(%) 24 hrs
2.5:1	500	48.5±4.71	0.74±0.10
	600	40.16±2.26	0.54±0.04
	700	34.17±0.46	0.43±0.04
3:1	500	43.97±2.12	0.43±0.15
	600	40.47±0.31	0.34±0.05
	700	22.93±6.76	0.19±0.15

Table 2. Analysis of variance of the thickness swelling and water absorption properties of the *T. daniellii* stalk cement-bonded boards

	SV	SS	DF	MS	F
	BD	0.23	2	0.11	11.35*
Thickness Swelling	MR	0.27	1	0.27	27.35*
	BD * MR	0.01	2	0.004	0.39^{ns}
	Error	0.12	12	0.01	
	Total	0.63	17		
Water Absorption	BD	972.32	2	486.16	37.49*
	MR	119.61	1	119.61	9.22*
	BD * MR	100.63	2	50.31	3.88*
	Error	155.61	12	12.97	
	Total	1348.18	17		

** = Significant at 5% probability level (P≤ 0.05): ns = Not significant; BD= (board density); MR= (mixing ratio)*

Resistance of the boards to water intake and thickness increased with the higher (3:1) mixing ratio. At these levels, the boards exhibited less spring back tendency. According to Ajayi [18] boards produced at the highest board density resist hydrostatic force against the bonds. This phenomenon is attributed to high compression ratio and compatibility, stronger bonds formation with little or no void spaces to accommodate water. The resistance to spring back forces was reduced at the lowest level of production variables thereby leading to the degradation of the bonds, weakness and fragility of boards which caused increase in TS.

Table 2 above shows the result of analysis of variance conducted on the thickness swelling after 24 hours of cold-water immersion. Mixing ratio levels and density were noted to have significant effect on the TS property of the boards produced, while the interaction between mixing ratio level and density does not have significant effect on the boards produced.

3.2 Water Absorption

The average values for percentage Water Absorption property is presented in Table 1 above. The values range from 22.93 to 48.5% following 24-hour cold-water immersion. The response of the boards to water intake shows that increase in cement/stalk ratio (2.5:1 to 3:1) caused a decrease in water absorption. The lowest value was obtained from the board with 3:1 (cement/stalk) mixing ratio, while the board that absorbed the highest volume of water was made at 2.5:1 (cement: stalk) mixing ratio. Generally, cement bonded board produced from the highest levels of cement: stalk ratio (3:1) and board density (700 g/m^3) were most dimensionally stable as they had the lowest value for water absorption. On the other hand, the least dimensionally stable boards were produced from the lower cement: Stalk ratio (2.5:1) and board density (500 g/m^3). All these observations are similar to the result obtained by Fuwape [19]; Badejo [20] and Ajayi, [21]. The boards with a mixing ratio 2.5:1 and density 500 g/m^3 was observed to be more porous and absorbed more water faster. This phenomenon was attributed to the inter particle void spaces which are easily stocked with the penetrating water thus increasing the board's weight after soaking. Ajayi, [18] reported that the observation of low water absorption at high cement: wood ratio might probably be due to the nonpenetrating of the void spaces and complete coating of particles with cement gel.

The analysis of variance conducted on the water absorption of the plastic composite produced from *T. daniellii* stalk is presented in Table 2. The effects of density mixing ratio level and the two factors interaction on water absorption after 24 hours cold water immersion was significantly different at 5% significance probability level.

4. CONCLUSIONS

Cement-bonded board were successfully produced from *Thaumatococcus daniellii* stalk in mixing ratio cement/ *Thaumatococcus daniellii* stalk (2.5:1 and 3:1) and with board density at 500, 600 and 700 g/mm^3. The board produced with 700 g/mm^3 and at mixing ratio of 3:1 had the lowest thickness swelling and water absorption after 24 hours cold-water immersion. Lower density and mixing ratio boards had poor performance in water resistance. The properties examined (water absorption and thickness swelling) improved as the mixing ratio and board density increased. The use of cement and *Thaumatococcus daniellii* stalk mixing ratio and board density at increasing levels between 2.5:1 and 3:1 and 500 and 700 g/mm^3 manifested in the production of stronger, stiffer and more dimensionally stable cement bonded composite boards.

Based on the result of this research, it can be concluded that a combination of *T daniellii* stalk and cement are suitable for the production of cement bonded composites. The dimensional properties of the boards at mixing ratio 3:1 and board density 700 g/cm^3 are absolute proof of its suitability for ceiling board production and proper indicators of the durability of the boards even under wet condition. This finding is capable of stimulating improved standardized cement-bonded particle boards production from *T. daniellii* stalk for industrial and economic development. Also, this research work is an eye opener to further investigation of efficient utilization of *T. daniellii* stalk that has been hitherto lying as waste in our environment. Thus, the result of this research provides information on the provision of affordable and sustainable housing materials through the use of *T. daniellii* stalk with cement.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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