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Strength Properties of Bamboo-Fibre Cement Boards Used as Building Partitions

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Authors' contributions

This work was carried out in collaboration between the two authors. Author OPA initiated the study, while author COO designed it. Author OPA conducted literature review and the various tests, and wrote the first draft. Authors COO and OPA worked together on the initial manuscript sent for publication (reviewing results, inferences and conclusions). Both authors read and approved the final manuscript.

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ABSTRACT

This research studied the strength properties of Bamboo-fibre Cement Boards used as building partitions, and compares the results with those of a conventional partition board. Bamboo-fibre Cement Boards, with bamboo by volume of 0%, 10%, 20%, 30% and 40% (designated B0, B10, B20, B30 and B40, respectively) were subjected to strength tests, and the results compared with those obtained from carrying out similar tests on samples of Gypsum Board (a building partitioning material commonly in use, locally). The tests conducted include Flexural Strength, Impact-Endurance, Bulk Density and Compressive Strength tests. The results indicated that all mix ratios of Bamboo-fibre Cement Boards performed better than the Gypsum Board in flexural strength, except the B40 sample (which gave a 32.14 N/mm^2 reading); however, even this drop in flexural strength was not appreciable (as Gypsum Board gave a 32.88N/mm^2 result). Impact-endurance test results showed that of all mix ratios of Bamboo-fibre Cement Boards compared to Gypsum Board, Gypsum Board's impact-endurance value could only surpass that of B0. The next least performance in impact-endurance among the other mix ratios of Bamboo-fibre Cement Board (B10), recorded an energy loss per cross-sectional area of 1452.0 J/m^2 against gypsum board's 1219.7J/m^2. In terms of bulk density, Gypsum Board also recorded a lower bulk density than Bamboo-fibre Cement Board: 715.2 Kg/m^3 for Gypsum Board and 1468 Kg/m^3 for B40 - the least dense Bamboo-fibre Cement

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Board. The paper concludes that, if reducing dead weight is the primary target of employing partition boards in construction, then the Gypsum Board is a better alternative. However, in virtually all other performance parameters, the Bamboo-fibre Cement Board performed better (across most mix ratios) and is, therefore, more versatile.

Keywords: Bamboo; fibre-cement board; partitions; strength properties.

1. INTRODUCTION

One of the most promising types of cement boards is Bamboo-fibre Cement Board (because of the wide availability of the fibre material used, mostly in tropical countries). Non-availability of affordable and durable raw materials is an impediment to the attainment of the desired strength in materials used for building partitioning. This might result in direct compromise of quality for a cost advantage.

Functionally, materials used for building partitioning must be durable i.e. be resistant to adverse weather conditions; be impact-resistant, insect-resistant, easy to work with and adjustable to low densities (in areas of low bearing capacities), while maintaining desired strengths.

In Nigeria, there are two main varieties of bamboo: *bambusa vulgaris* and *oxystenanthera.* The former attains a height of 14-20 metres at maturity (with a girth of about 20 cm), and the latter could also reach a height of between 8 and 12 metres. Both varieties grow naturally in the forests below River Niger and in Taraba State [1].

Lima et al. [2] conducted a study on the durability of bamboo used as concrete reinforcement. The main motivation for the study was to evaluate the durability of bamboo when exposed to a high PH as there were claims of high alkalinity related to the presence of a cementitious matrix (caused when vegetal materials are used as concrete reinforcement). The experimental tests on the bamboo species *Dendrocalamus giganteus* showed that the bamboo tensile strength was comparable with the best wood used for construction, and even with steel. The study showed a linear tensile stress-strain curve for the bamboo species until failure. Bamboo tensile strength averaged 280 MPa in the specimens without nodes, and 100 MPa in the specimens with nodes.

Fibre-Reinforced Cement (FRC) board (or simply, fibre-cement board), is a widely-used building material developed by James Hardie in the early 1980s, while working on the use of alternative materials to avoid the continued use of asbestos for building products. His work was on the use of alternative materials to create building products with fibre as the reinforcing material. James Hardie and Co. Pty Ltd started manufacturing asbestos-cement products in Australia in 1917 [3].

With the recent advancements in science and technology, manufacturing industries have in recent times started using raw materials from agricultural biomass as replacement for solid wood and non-biodegradable materials, to improve manufacturing productivity and availability [4].

Owing to their water-resistant and durable nature, fibre-cement boards are commonly used for kitchen countertops and bathroom slabs. Since fibre-cement boards adhere well to both wood and tiles, they make an excellent choice for an underlay. According to Lewitin [5], the primary benefit of cement board is that it does not break down, expand or warp, when wet.

Noura et al. [6] worked on the mechanical and physical properties of natural-fibre cement board for building partitions. The study included the preparation of fibre-cement panels made from the husks of rice and old newspapers (which were used in prefabricating the building panels), and the inclusion of two types of polymers (Poly-vinyl Acetate (PVA) and Poly Ol (PO) with rate (3:1), respectively), as additional materials in their manufacture. The flexural strength reached 6.99 MP (compared with imported panels of 3.5 MP). This was found to be 70% higher than that of the comparison material - a cement board made without the addition of natural fibres.

Generally, fibre-cement composites show improved toughness, ductility, flexural capacity and crack-resistance, compared to non-fibre-reinforced cement-based materials [7]. According to Liu and Pan [8], the flexural strength of natural-fibre cement board is 80% higher than that of typical building materials–with the exclusion of rice-husk cement board. Many cement boards have been used as building partitions for over a century.

The growth-rate of bamboo trees varies from species to species. Taller, running types (like *phyllostachys*) usually grow 3-5 feet in height, over a year. Older, more established plants – usually at least 3 years on the ground– will grow faster than the newly-planted ones. This makes them readily available for use in most parts of the country; hence the choice of bamboo-fibre for this research, is expected to lead to an increase in the use of the products developed from the findings of this research, in the near future.

The lightweight nature of bamboo (and its widely-acknowledged strength properties) can be used in complementing the strength properties of fibre cement boards. Costs can greatly be influenced while achieving strength targets. Presently, different forms of lightweight materials used for building partitioning exist (such as Paper-Gypsum Board, Magnesium Oxide Board and Calcium Silicate Board (Silica Sand). Each has a peculiar advantage over one or more of the others. Meanwhile, as these major raw materials are mineral and non-renewable raw materials, they are costlier and not readily available locally– unlike naturally-sourced fibre-based boards.

Some widely acknowledged disadvantages of bamboo in its natural state (such as low modulus of elasticity, high water-absorption and low durability) have set limits to a wider application of Bamboo in Civil Engineering and as concrete reinforcement [2].

Identifying alternatives that possess similar or higher structural properties would go a long way in providing availability of more choices of durable and affordable materials for building partitions. Another alternative, silica-sand fibrocement board has been criticized as being too expensive.

With the abundance of bamboo in the Tropics, this research contributes to identifying relatively low-cost and environmentally-sustainable materials for building partitioning, without compromising the strength requirements of the partition-boards produced.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Bamboo

Locally-sourced samples of bamboo were collected and cut into chips of about 40mm in length. The chips were then soaked in distilled water for 72 hours to remove the extractives (to prevent them from slowing down hydration). The fibres were removed from the distilled water and sun-dried for 24 hours.

Bamboo-fibre Cement Board matrices were prepared, using varying ratios of bamboo fibre by volume, to Ordinary Portland Cement (OPC) and silica sand. Only bamboo fibres passing through sieve size 4.750 mm and retained in BS sieve size 0.075mm, were used for the experiment– in order not to allow excessive voids in the final test-specimen, on the one hand, and prevent low strength (due to dusty particles), on the other.

2.1.2 Portland cement

Locally-sourced Portland Cement of grade 42.5R was used as the binder for the fibre-cement matrix.

Fig. 1. Samples of bamboo fibres used

2.1.3 Water

Only distilled water was used throughout the experiment with no exposure to contaminants or any chemical substance that could lead to experimental errors.

2.1.4 Silica sand

Fine Silica Sand with 100% of the sand samples passing through BS sieve size 4.750 mm and only 1.72% passing through BS sieve size 0.075 mm was used. The test was conducted to ensure particles were not larger than 4.750 mm, as only fine aggregates were allowed (as shown in Table 1).

2.2 Experimental Method

2.2.1 Mix ratio

The mix ratio of Ordinary Portland Cement, to silica sand was 1:1 by volume, while the water-to-cement ratio was 0.6, by mass. The amount of bamboo fibre that was used varied from 10% by volume of the mix to 20%, 30% and up to 40%.0% bamboo fibre was also mixed, for test-control purposes.

2.2.2 Sample sizes

For each of the mix ratios, materials were provided for six (6) samples for flexural test (of 250 × 350 × 20 mm size); two (2) samples for impact-endurance test (of size 300 × 300 × 10 mm), nine (9) samples for the compressive test (of size 150 × 150 × 150 mm), and three (3) samples (of size 100 × 100 × 10 mm) for the bulk specific gravity test.

Table 1. Sieve analysis of sand

Sieve size (mm)	% passing
4.750	100.00
2.360	86.0
0.600	74.0
0.425	51.0
0.212	34.0
0.150	22.9
0.075	16.5
Pan	0.00

Table 2. Sieve analysis of bamboo fibre

Sieve size (mm)	% passing
4.750	100.00
2.360	97.70
0.600	72.80
0.425	55.04
0.212	16.80
0.150	6.28
0.075	1.72
Pan	0.00

2.2.3 Casting and testing of specimens

The flexural and compressive strength tests were conducted in accordance with BS EN 12390 [9], while the impact-endurance test was conducted according to BS EN 14019 [10]. The compressive strength and bulk density tests were carried out at the Materials Testing Laboratory of the Department of Civil Engineering, University of Ibadan. The flexural strength test was carried out at the Department of Agricultural Engineering of the University of Ibadan, while the impact-endurance test was carried out at the Forestry Research Institute of Nigeria (FRIN), Ibadan.

3. RESULTS AND DISCUSSION

The results obtained for the flexural, impact-endurance, and compressive strength tests are as follow:

3.1 Flexural Strength Test Results

The flexural strength tests carried out showed an increase in mean flexural strength, from B0 through to B20, while a slight reduction was noted for B30 and B40. B0 had a flexural strength of 33.19 N/mm²; B10 had 33.89 N/mm², and B20, 34.63 N/mm². B30 had a flexural strength of 34.24 N/mm², while for B40, it was 32.24 N/mm². Even though higher flexural strengths are desirable, it must be noted that the differences obtained in flexural strengths were very negligible. Gypsum Board had a mean flexural strength of 32.88 N/mm².

Fig. 2. Flexural testing of partition board specimen

Table 3. Flexural strength of bamboo fibre-cement board compared to that of Gypsum Board

Partition board specimen	Flexural strength (N/mm²)
B0	33.19
B10	33.89
B20	34.63
B30	34.24
B40	32.14
Gypsum board	32.88

3.2 Impact-endurance Test

The results showed a progressive increment in the impact-endurance values (i.e. energy-loss per cross-sectional area) as the percentage of bamboo fibre increased, with B0 having an impact-endurance value of 285.8 J/m², B10 with a value of 1,452 J/m², B20 with a value of 1,669.2 J/m², B30 with a value of 2,109.4J/m² and B40 with an impact-endurance value of 2,178J/m².The comparison material (Gypsum Board) had an impact-endurance value of 1,219.7 J//m².This shows that Gypsum Board only surpassed B0 in terms of impact-endurance.

During the conduct of the test, there was total collapse of B0 (with pronounced cracks preceding the shattering into pieces of the sample). On the other hand, samples containing bamboo fibre showed various levels of toughness (as reflected in the higher energy-loss by the impact-testing machine). B40 was the best performer – registering just a hole (which took the shape of the 3.5 kg drop-hammer used); the other samples depicted varying levels of cracks over the surface of the test specimens (inversely proportional to the quantum of bamboo contained), and generally also attesting to lower energy loss per cross-sectional area than B40.

The comparison material (Gypsum Board) had an impact-endurance value of 1,219.7 J/m² - implying that Gypsum Board could only perform better than B0, in terms of impact endurance.

Fig. 3. Impact-endurance testing

Gypsum Board also showed no cracks but its performance was averagely lower when compared to Bamboo-fibre Cement Board. Impact-endurance was measured as: Energy loss Per Cross Sectional Area.

3.3 Compressive Strength

The compressive strength test results below show a decreasing level at 28 days compressive strength, in the different mix proportions of Bamboo-fibre Cement boards. While samples B0 and B10 have very close average compressive strength values of 14.84 N/mm² and 14.37 N/mm², respectively, and samples B20 and B30 also have very close 28- day compressive strength values (8.44 N/mm² and 7.68 N/mm², respectively), it must be noted that B40, with the least density (as discussed above) also has a very low compressive strength value of 2.55 N/mm². This can be attributed to the decreasing level of compressive properties of the specimen as the percentage of bamboo fibre by volume increases. The decreasing compressive strength of the Bamboo-fibre Cement mixes as Bamboo fibre percentage increases has been attributed to the inhibitive properties of the lignin present in the Fibre-cement Composite, inhibiting hydration of cement with inhibition directly proportional to the percentage of Bamboo-fibre by volume of the mix.

Table 4. Impact-endurance of bamboo fibre-cement board compared to that of gypsum board

Partition board specimen	Energy loss per cross-sectional area (J/m²)
B0	285.8
B10	1452.0
B20	1669.2
B30	2109.4
B40	2178.0
Gypsum Board	1219.7

Fig. 4. Specimen showing failure of B40 after impact-endurance test

3.4 Bulk Density

The results showed a progressive reduction in the density of Bamboo-fibre Cement Board samples, as the percentage of bamboo fibre

Table 5. Compressive strength of bamboo fibre-cement board

Curing period	Compressive strength (N/mm²)				
	B0	**B10**	**B20**	**B30**	**B40**
7 days	13.63	11.94	6.73	6.46	1.94
14 days	16.19	12.60	8.42	7.61	1.97
28 days	14.84	14.37	8.44	7.68	2.55

increased. Mean values show B0 (i.e. 0% bamboo fibre by volume) had the highest density with 2,108 kg/m³, followed by B10 (with 10% bamboo fibre), having 2,017 kg/m³; B20 (with 20% bamboo fibre) having 1,821 kg/m³; B30 (i.e. with 30% bamboo fibre) having 1,629kg/m³ and B40(i.e. 40% bamboo fibre) having 1,468 kg/m³. However, it must be noted that Gypsum Board has 715.2 kg/m³ bulk density (which is about half the least bulk density of Bamboo-fibre Cement Board obtained).

Table 6. Bulk densities of bamboo-fibre cement board compared to that of Gypsum board

Partition board specimen	Bulk densities (Kg/m³)
B0	2108
B10	2017
B20	1821
B30	1629
B40	1468
Gypsum Board	715.2

4. CONCLUSION

The following conclusions can be drawn from the results of this experiment:

1. Flexural strength increased up to B20, but declined for B30 and B40. Flexural strength for Gypsum Board only exceeded that of B40, of all the specimens used, but by negligible decimal points.
2. Of all the types of partition-board specimens used for impact-endurance test, the Gypsum Board was the worst performer, after B0; B0 had an impact-endurance test result of 285.8 J/m², followed by Gypsum Board at 1219.7 J/m²; the lowest result from other specimens was 1452J/m² for B10, while the best performer was B40, with 2178J/m².
3. The bulk density of Gypsum Board is considerably lower than that of the five (5) mix proportions of Bamboo-fibre Cement Boards tested for comparison. The lightest of the bamboo varieties (i.e. B40), had a bulk density of 1,468 Kg/m³ while Gypsum Board had just 715.2 Kg/m³.
4. Where reducing dead weight is the primary purpose of using partition boards, Gypsum Board will be a better performer, compared to Bamboo-fibre Cement Board, as the bulk density of Gypsum Board has proved to be lower.
5. Bamboo-Fibre Cement Board can be used for erecting partitioning in locations with higher risks of impact failure, compared to Gypsum board.
6. B40 is an excellent performer in impact-endurance, when compared to Gypsum Board, but in other desirable strength characteristics (like bulk density),Gypsum Board showed better performance (although the bulk density of B40 is still allowable, relative to other performance characteristics).
7. With respect to flexural tests, Gypsum Board showed better performance than B40 (by very negligible values); hence, in absolute terms, even B40 is not a poor performer in flexural strength and, therefore, the Bamboo-fibre Cement Board can readily be used in place of Gypsum board.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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