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# Laminated Bamboo Board: A Sustainable Alternative to Timber Board for Building Construction

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## Abstract

*There is increased advocacy for low-carbon environment globally, necessitating the promotion of ecologically friendly building materials. The health and environmental hazards associated with conventional building material production, as well as the high cost on the economy for the importation of machinery for their production; the massive utilisation of wood resources for construction purposes, and its effect on climate change, necessitates the search for alternative construction materials. The purpose of this study is to examine the sustainability of a composite board made from Bambusa vulgaris for building construction. A 600 mm x 600 mm wall and floor-board comprising three sample units for different thicknesses; 10 mm, 20 mm and 40 mm were produced from each segment; top, middle, and bottom, of the bamboo culm with approximately 8-10 mm laminate. The results revealed average compressive strength values for the bottom, middle, and top bamboo segments of 31.39 N/mm$^2$, 29.38 N/mm$^2$, and 24.99 N/mm$^2$, respectively. The highest impact bending strength of 33.66 N/mm$^2$ and 27.94 N/mm$^2$ occurs at the middle and top segments of the bamboo species respectively. Modulus of Rupture decreases from the bottom to the top segment of the bamboo species with values of 76.43 N/mm$^2$, 62.33 N/mm$^2$, and 56.70 N/mm$^2$, respectively. Furthermore, thermal properties indicate that it is a good material for interior walls, floors, and ceiling finishes. These findings have far-reaching implications for practice and economic development; regarding reduction in the cost of materials, and hence affordability for low-income housing; overall safety of the environment; and employment opportunities for Nigerian youths along the construction value chain.*

**Keywords:** Bamboo, Building materials, Eco-friendly, Laminated board, Sustainable material

## Introduction

Building materials contribution to the overall cost of construction has been put at about 60% (Jagboro and Owoeye, 2004). Predominantly used conventional building materials include concrete, steel, and wood. Ameh *et al.* (2019), listed the shortcomings of conventional materials such as concrete and steel to include: high cost, a substantial amount of energy required for their production and transportation, huge foreign exchange required for importation of constituent materials and heavy machinery for their production, and artificial ventilation necessitated by poor indoor thermal comfort in buildings made from modern construction materials. Wood and wood products on the other hand are eco-friendly conventional materials; however, the demand for wood as a forest resource continues to increase in proportion to the human population. Ultimately, this may lead to their depletion, as the rate of deforestation would be higher than the rate of their replenishing, with attendant impact on sustainability and climate change. Thus, Upton and Attah (2003), Donkor, Vlosky, and Attah (2005), Tomaselli (2007) encouraged the adoption of lesser-used or plantation- grown species for arresting the disequilibrium in the supply of wood products. Ugokwuku and Chioma (2015) suggest the use of innovative and locally available materials for low- cost housing development. Furthermore, Prastyatama and Maurina (2007) advocated the study of (architectural) materials, aimed at evoking primordial human emotions to bridge the gap of disconnectedness with earthy material.

There have been concerted efforts by researchers in the search for an eco-friendly and local alternative to conventional building materials in order to reduce the cost of construction, particularly for low-income earners in developing countries. Bamboo is one of such locally available eco-friendly materials with considerable potential to offset drawbacks in the conventional materials. Bamboos are giant grasses belonging to the family of *Gramineae*, sub-family of *Bambusoideare* (Effah *et al.*, 2014). The available record shows that there are between 1200 – 1500 species of bamboo found in 70 genera worldwide, of which *Bambusa vulgaris* is the dominant species in Nigeria (Gyansah and Kwofie, 2001). Bamboo is among the oldest building materials used by mankind and an alternative source of raw materials for the wood industry due to its ability to grow in various soils. Large bamboo can reach their full height of 15-30 meters in a period of approximately two to four months (Liese, 1987). Mature bamboo stems are ready for harvest in 4-5 years as against tropical hardwood which requires 30 years or more to reach full maturity. Also, bamboo growth is vegetative reproduction, that is when it is cut down, it re-grows in place using the existing root structure, therefore, a very sustainable resource that does not need re-planting after harvest. Moreover, bamboo has the capacity of mitigating climate change as it restores degraded land, acts as carbon sequesters, and protects from soil erosion. Bamboo is found in tropical and sub-tropical areas in many countries. In Nigeria, bamboo according to Ogunwusi and Onwualu (2011) is found in abundance in all the states of Southern Nigeria except Lagos and Bayelsa where the distribution is relatively less.

The bamboo culm has been made into a range of products for domestic and industrial applications. There have been several investigations on the suitability of bamboo for construction (Mbuge, 2000; Awalluddin *et al.*, 2017). Bamboo is adjudged nature's strongest botanical fiber, and often referred to as vegetable steel on account of its mechanical characteristics; like its' surface tensile strength in inter-nodal sections (Shao *et al.*,2010). Janssen (1981) opined that bamboo, depending on species and test protocols, can prove to be relatively stronger than concrete, steel, or timber.

Engineered bamboo is an innovative bamboo product like laminated bamboo and strand- woven bamboo or a combination of both, made from bamboo culms, with improved strength characteristics and durability (Sharma *et al.*, 2015). Engineered bamboo has successfully been used as structural columns and trusses in the Philippines (Richard *et al.*, 2017). Panels similar to Oriented Strand Board (OSB), Medium Density Fiber board (MDF), Particleboard, and Mat board among others are also made from bamboo fiber and bamboo chips; but panel made from strips (laminated) or strands (strand woven) are by far the most used in Europe. In Nigeria, however, Ameh *et al.* (2019) reported that current area of the major application of bamboo in the building industry is as temporary supports (i.e. formwork and scaffolding) while noting the average level of awareness and experience on the application of bamboo as structural members, particularly for traditional roofs and wall construction. In a study of professionals' perception of acceptability and use of innovative bamboo products for residential building construction, Ameh *et al.* (2019) further show likely disposition to use bamboo plywood, bamboo fiber board, laminated bamboo for general use as a substitute for wood, as well as bamboo board for wall partitions, and bamboo strips for both ceiling and flooring. Sharma *et al.* (2017) found that laminated bamboo possesses structural properties comparable to timber and timber-based products. Given these positive responses to the use and acceptability of bamboo for construction purposes, the purpose of the present study, therefore, is to examine the strength and thermal properties of laminate board made from dominant bamboo species (*Bambusa vulgaris)* in Nigeria.

The underpinning theory for this study is the theory of sustainable development based on the United Nations Sustainable Development Goals (UNSDG). The study focuses on achieving four of 2030 UNSDG, particularly; goal nine, which focus is to "build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation"; goal 11 "make cities and human settlements inclusive, safe, resilient, and sustainable"; goal 13 "take urgent action to combat climate change and its impact"; and goal 15 "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss."

## Materials and Methods

### Raw material (Bambusa vulgaris)

The species of bamboo used for this research is *Bambusa vulgaris*, predominant in the Southern part of Nigeria. The culms were harvested from a bamboo plantation on The Polytechnic, Ibadan Campus, Oyo State, Nigeria. The culms were of an average height of 22 meters; wall thickness, and outer diameter reducing from the bottom to the top as shown in Figure 1. Three different sections of the bamboo stem; bottom, middle, and the top was used for the study.

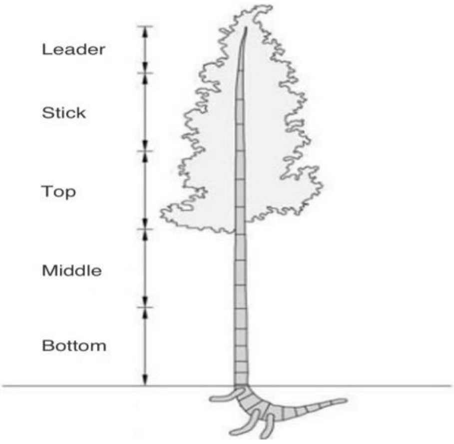

***Figure 1:*** Bamboo culm segments *(*Schröder, 2016*)*

*Preparation and treatment of the bamboo products*

Matured bamboo culms were collected from their natural habitat (Figure 2). The crosscut bamboo lengths were hand split with machete and knives (Figure 3). In general, the width of the splits varies from 25 mm to 50 mm depending on the size of culm samples. The splits were then allowed to dry in the air for four weeks to reduce their moisture content to around 30%. The inner and outer knots were removed from the splits by manual means with a sharp knife, after which the splints were removed and the surface of the splits was plained using a plaining machine, the type of machine used for plaining wood (Figure 4). Strips were further air-dried for 21 days to around 15% moisture content. The dried slivers were then immersed completely into a solution of Boric Acid for chemical treatment (Figure 5) for seven days. Boric Acid, also known as hydrogen borate, is the most popular bamboo preservation method (for indoor use) around the world because it is effective against wood pests, such as carpenter ants, termites, wood, and boring beetles and more environmentally friendly than other wood preservatives (Schröder, 2012). A mixture of 0.5 kg of Boric Acid was diluted with 150 litres of water.

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**Figure 2:** Harvested bamboo culms cut into segments

**Figure 3**: Bamboo splits

**Figure 4:** Knot removal and planning

**Figure 5:** Treatment in Boric Acid solution

*Production of the bamboo products*

Seasoned and treated bamboo strips were laminated into two bamboo products: wall-board and floor-board (Figure 6). Three sample units for different thicknesses; 10 mm, 20 mm, and 40 mm were produced from each segment; top, middle and bottom, of the bamboo culm with approximately 8-10 mm laminate, for bamboo wall-board and floor-board respectively. Samples of the product were cut into a uniform size of 600 mm x 600 mm.

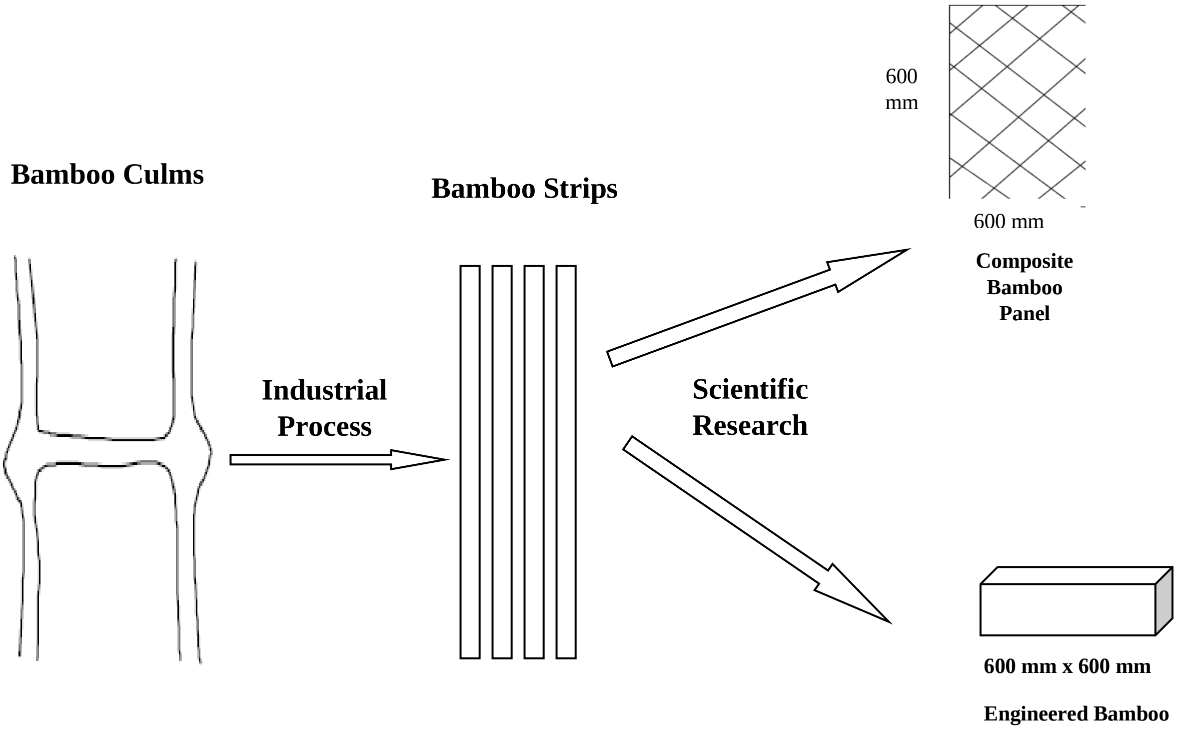


***Figure 6:*** *Production of engineered bamboo products*

### *Experimental design*

As a building material, bamboo products must pass some tests to ascertain conformity to standard functional requirements of building material for walls and floors regarding strength, durability, and thermal resistance. The information about these characteristics is an important requirement for the effective use of this bamboo species for different engineering applications. Therefore, the processing of a Composite Bamboo Board must be thorough to achieve all these requirements. The Composite Bamboo Board samples were machined and trimmed to standard sizes of 20 mm x 20 mm x300 mm for the determination of mechanical properties as described by Jamala *et al.*, (2013). The properties analysed here are compressive strength, bending strength (Modulus of Elasticity and Modulus of Rupture), impact bending strength, thermal effects (resistivity, conductivity, and transmittance), and nailing effect.

The compressive strength parallel to the grain properties of the composite wall-board and floor-boards was evaluated according to ASTM D143:2014. Specimens for the compressive strength test were tested on a 1,500 kNELE International compression testing machine.

The Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) were conducted using WDW-50 Computer Control Electronic Universal Testing Machine, 50 kN capacities. The value of MOR was calculated from the maximum loading force as shown in equation (1) (Baar *et al.* 2015).

$$\text{MOR} = \frac{3F_{\max}l}{2bh^2} \qquad (1)$$

Where: $F_{\max}$ is max. loading force; $l$ is span of support; $b$ is width of cross-section and $h$ is thickness of sample

Impact bending tests were conducted in accordance with ASTM D143: 2014. The tests were performed on bamboo samples with a uniform size of 20 mm x 20 mm x 300 mm, and were conducted at the Department of Forest Product Development and Utilization, Forestry Research Institute of Nigeria, Ibadan, using an Impact Bending Test Machine. The value of Impact Bending Strength was calculated as shown in equation (2) (Bucar and Merhar, 2015).

$$T = w_p\ x\ L\ (cosA_2 - cosA_1) \qquad (2)$$

Where: T is toughness (work on specimen), $w_p$ is weight of the pendulum, L is the distance from the centre of support to the pendulum's centre of gravity, $A_1$ is the Angle of entry (initial angle), and $A_2$ is the final angle when the pendulum travels across the break.

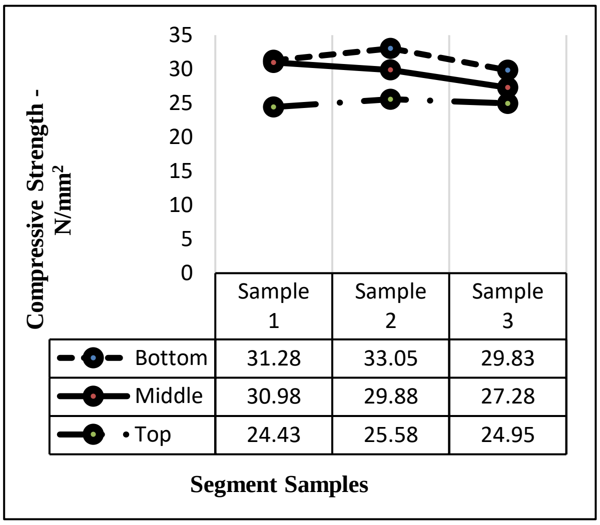
Samples for thermal properties were cut into a uniform size (600 mm x 600 mm) but of different thicknesses of 10 mm, 20 mm and 40 mm for top, middle, and bottom segments of the bamboo species. The samples were of two types - one was a composite laminated bamboo panel without any surface finish and the other one was a composite bamboo panel with Bam-Glue (Mixture of glue and powdered bamboo residue) surface finish; with the aim of comparing the thermal conductivity, resistivity, and transmittance of the bamboo boards with different thicknesses. The surface temperature was measured using the Infrared Thermometer.

## Results and Discussion

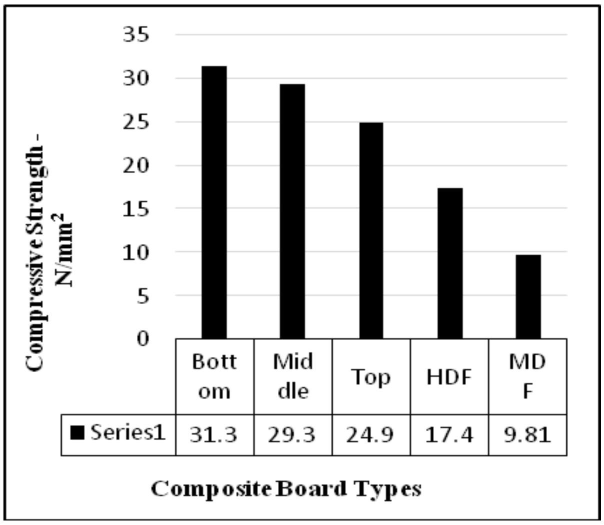
### Compressive strength

Figure 7 shows the compressive strength of samples of composite boards produced from the three segments of *Bambusa vulgaris* under study; while Figure 8 is a bar chart of comparison with imported Medium-Density Fiber board (MDF) and High-Density Fiber board (HDF);

which were made of Hard/Soft Wood chips/fibers with a resin binder. It can be observed from Figure 8 that compressive strength, on average, decreases from the bottom segment to the top segment of the bamboo species with values of 31.39 N/mm$^2$, 29.38 N/mm$^2$, and 24.99 N/mm$^2$, respectively. Figure 8 also revealed that the boards produced from the three bamboo-segment all have higher compressive strengths in comparison to the MDF and the HDF. This shows that the boards produced from the top, middle, and bottom segments of *Bambusa vulgaris* can all resist compressive stress better than the imported HDF and MDF which have compressive strength values of 17.41 N/mm$^2$ and 9.81 N/mm$^2$,respectively.It could be concluded that the compressive strength of *Bambusa vulgaris* species is fairly high when compared with hardwood like African Mahogany (khaya spp) with a compressive strength parallel to the grain of 25.7 N/mm$^2$ and 44.5 N/mm$^2$ at a green state and 12% moisture content, respectively (Green *et al.* 1999).



| | Sample 1 | Sample 2 | Sample 3 |
|---|---|---|---|
| Bottom | 31.28 | 33.05 | 29.83 |
| Middle | 30.98 | 29.88 | 27.28 |
| • Top | 24.43 | 25.58 | 24.95 |



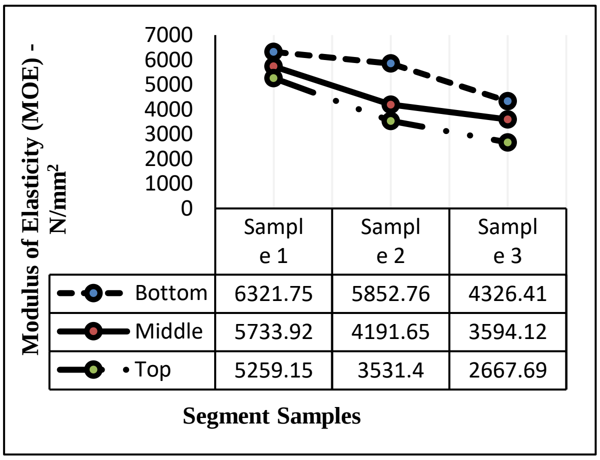
| | Bottom | Middle | Top | HDF | MDF |
|---|---|---|---|---|---|
| ■ Series1 | 31.3 | 29.3 | 24.9 | 17.4 | 9.81 |

***Figure 7:*** *Compressive strength of composite of Different bamboo boards*

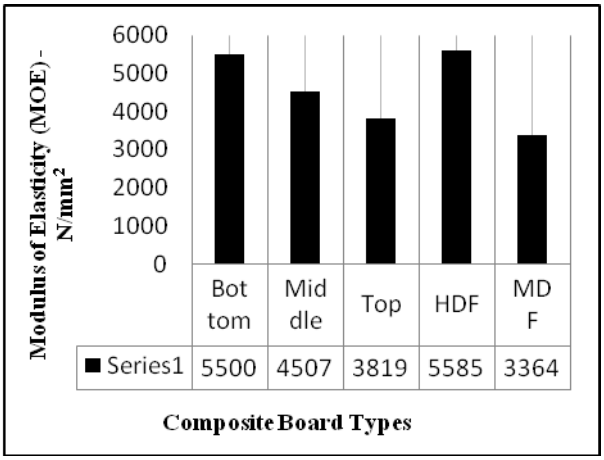
***Figure 8****: Average compressive strength composite boards*

### *Modulus of Elasticity (MOE)*

Figure 9 shows the MOE of samples of composite boards produced from the three segments of *Bambusa vulgaris* under study.



| | Sample 1 | Sample 2 | Sample 3 |
|---|---|---|---|
| Bottom | 6321.75 | 5852.76 | 4326.41 |
| Middle | 5733.92 | 4191.65 | 3594.12 |
| • Top | 5259.15 | 3531.4 | 2667.69 |



| | Bottom | Middle | Top | HDF | MDF |
|---|---|---|---|---|---|
| ■ Series1 | 5500 | 4507 | 3819 | 5585 | 3364 |

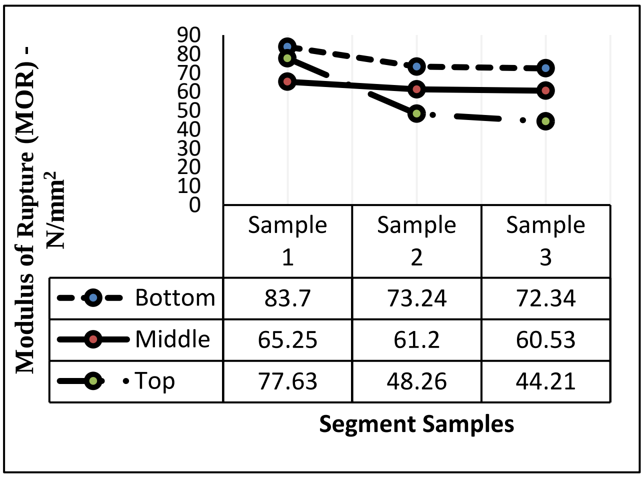
***Figure 9****: Modulus of Elasticity (MOE) of composite bamboo boards*

***Figure 10****: Average Modulus of Elasticity (MOE) of different composite boards*

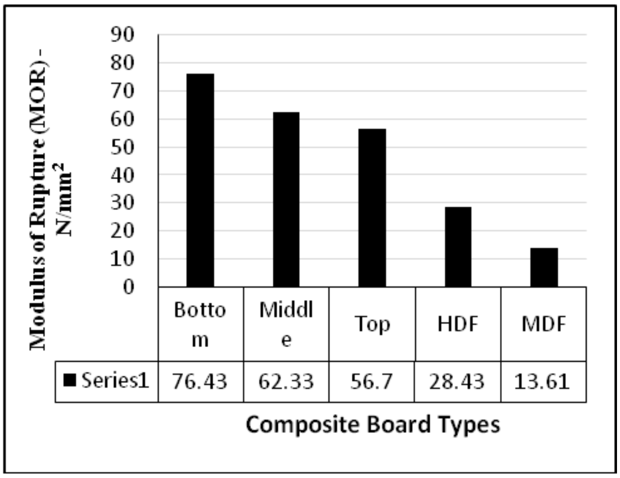
A bar chart representation of the comparison of the MOEs of composite board types in the market with the composite boards produced from the segments of *Bambusa vulgaris is presented in* Figure 10. It can be observed that MOE decreases from the bottom segment to the top segment of the bamboo species with average values of 5500.31 N/mm$^2$, 4506.56 N/mm$^2$, and 3819.41 N/mm$^2$, respectively. The Figure also revealed that boards produced from the three bamboo segments all have higher MOEs in comparison to the MDF while the modulus of elasticity of HDF is higher than those of the middle and top segments of *Bambusa vulgaris;* with almost the same value with the bottom segment. The MOE of African Mahogany is 7,900 N/mm$^2$ and 9,700 N/mm$^2$at a green state and 12% moisture content, respectively (Green *et al.*, 1999). This shows that the boards produced from the top, middle, and bottom segments of *Bambusa vulgaris* all can compete favourably with the imported HDF and MDF and some hardwoods regarding resistance to deflection.

## Modulus of rupture

Figure 11 shows the graphical representation of their MOR from the three segments of *Bambusa vulgaris* under investigation. Figure 12 shows a bar chart comparison of MOR of composite board types in the market with the composite boards produced from segments of *Bambusa vulgaris*. It can be observed from Figure 12 that MOR, on average, decreases from the bottom segment to the top segment of the bamboo species with values of 76.43 N/mm$^2$, 62.33 N/mm$^2$ and 56.70 N/mm$^2$, respectively. This follows the same trend as that of their MOEs. Figure 12 also revealed that boards produced from three bamboo segments all have higher MORs in comparison to the MDF and the HDF which is against the trend shown in MOE analysis where the HDF has a higher value than the three segments. The MOR of African Mahogany is 51 N/mm$^2$ and 73.8 N/mm$^2$ at a green state and 12% moisture content, respectively (Green *et al.*, 1999). This shows that the boards produced from the top, middle, and bottom segments of *Bambusa vulgaris is as good as* imported HDF and MDF regarding overall bending strength.



| | Sample 1 | Sample 2 | Sample 3 |
|---|---|---|---|
| Bottom | 83.7 | 73.24 | 72.34 |
| Middle | 65.25 | 61.2 | 60.53 |
| Top | 77.63 | 48.26 | 44.21 |



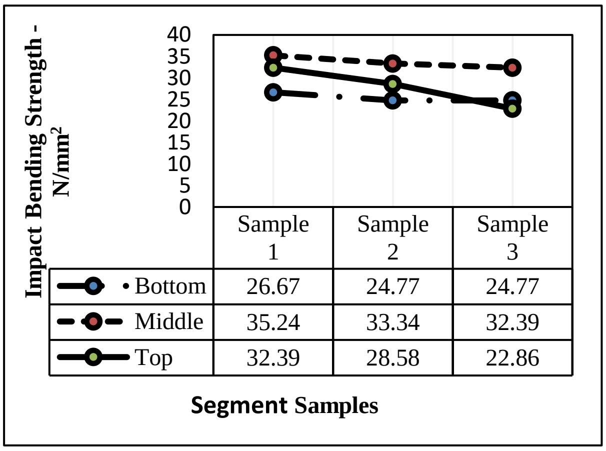
| | Bottom | Middle | Top | HDF | MDF |
|---|---|---|---|---|---|
| ■ Series1 | 76.43 | 62.33 | 56.7 | 28.43 | 13.61 |

***Figure 11:*** *Modulus of Rupture (MOR) of composite bamboo boards.*

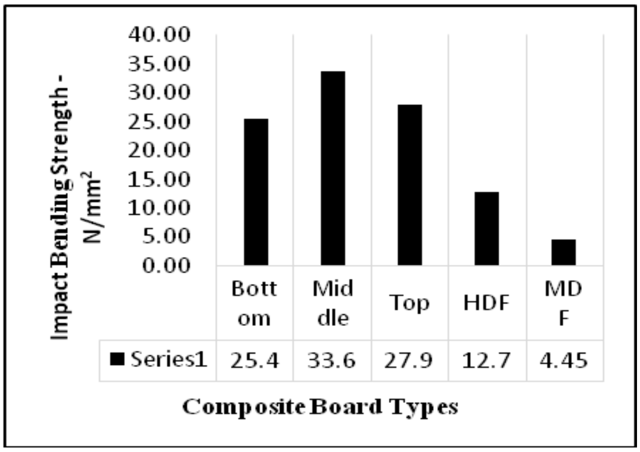
***Figure 12****: Average Modulus of Rupture (MOR) of different composite boards.*

*Impact bending strength*

Figure 13 shows the impact bending strength of samples of composite boards produced from the three segments of *Bambusa vulgaris* under investigation; while Figure 14, shows the bar chart presentation of the comparison of the impact bending strength of composite board types in the market with the composite boards produced from *Bambusa vulgaris*. The result as observed from Figure 14 shows that the middle segment is the toughest (the highest impact bending strength) of all the samples of composite boards with an average value of 33.66 N/mm$^2$; followed by the top segment with an average impact bending strength of 27.94 N/mm$^2$; while the bottom segment recorded an average toughness of 25.40 N/mm$^2$. Figure 14 further revealed that boards produced from the three bamboo segments all have clear higher impact bending strengths in comparison to the MDF and the HDF available in the market. This shows that the boards produced from the top, middle, and bottom segments of *Bambusa vulgaris* are much tougher than the imported HDF and MDF.



| | Sample 1 | Sample 2 | Sample 3 |
|---|---|---|---|
| Bottom | 26.67 | 24.77 | 24.77 |
| Middle | 35.24 | 33.34 | 32.39 |
| Top | 32.39 | 28.58 | 22.86 |



| | Bottom | Middle | Top | HDF | MDF |
|---|---|---|---|---|---|
| ■ Series1 | 25.4 | 33.6 | 27.9 | 12.7 | 4.45 |

***Figure 13:*** *Impact bending strength different of Composite Bamboo Boards.*

***Figure 14****: Average impact bending strength of of Composite Boards.*

*Thermal properties*

Tables 1 and 2 reveals the thermal properties (conductivity, resistivity, and transmittance) of different segments of Composite Bamboo Board for different thicknesses (10, 20 and 40 mm) at different heating distances of 100, 150, 200 and 300 mm for different surface finishes. The results show that thermal resistivity and conductivity increases from the top segment to the bottom segment but no significant changes for different thicknesses (10 mm, 20 mm, and 40 mm). The thermal transmittance as shown in Tables 1 and 2 decreases from the top segment to the bottom segment which was expected since thermal transmittance is the inverse of thermal resistivity. These observations are applicable to the two different surface finishes and it is an indication that the Composite Bamboo Panel is a bad conductor of heat with an appreciable U-Value which makes it a good material for interior surfaces-walls, ceilings, and flooring.

*Nail Effects*

Table 3, shows the nail effects on different segments of the Composite Bamboo Board regarding Open Space and Length. Nailing is important to connect different components of wood in building construction. The proper connection among components of a building speaks volumes of the strength and stability of such a building. Nail-ability of wood material is the ability of a wood material like bamboo to be nail friendly without deterring it or have a negative effect on the material. The results (Figure 15) revealed that 76.2 and 63.5 mm nails had significant open space effect on all Composite Bamboos Board of the top (maximum of 1.75 and 1.0 mm, respectively), middle (maximum of 2 and 1.3 mm, respectively) and bottom (2.5 and 1.5 mm, respectively) segments; while the 38.1 mm nail had little or no

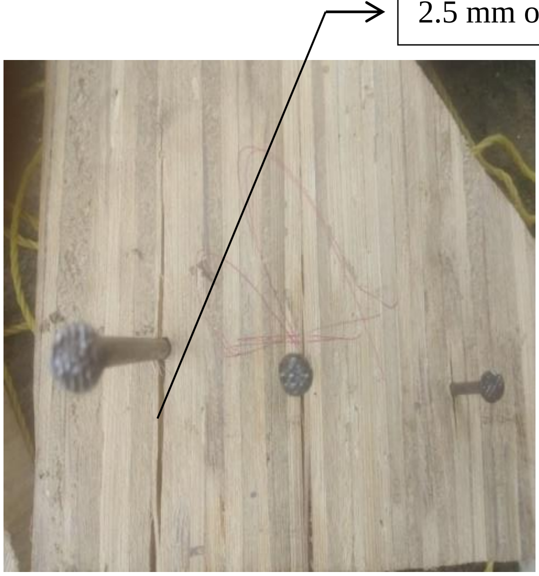
***Table 1: Thermal properties of composite bamboo board with no surface finish***

| ***Board Thickness*** | ***Thermal Conductivity W/mK*** | | | ***Thermal Resistivity*** $m^2K/W$ | | | ***Thermal Transmittance*** $W/m^2K$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | ***10 mm*** | ***20 mm*** | ***40 mm*** | ***10 mm*** | ***20 mm*** | ***40 mm*** | ***10 mm*** | ***20 mm*** | ***40 mm*** |
| Bottom | 0.14 | 0.13 | 0.14 | 0.17 | 0.19 | 0.20 | 7.17 | 6.40 | 6.83 |
| Middle | 0.13 | 0.13 | 0.12 | 0.18 | 0.22 | 0.21 | 6.43 | 6.33 | 5.96 |
| Top | 0.13 | 0.13 | 0.12 | 0.18 | 0.22 | 0.23 | 6.29 | 6.37 | 5.87 |

***Table 2: Thermal properties of composite bamboo board with bam-glue surface finish***

| **Board Thickness** | ***Thermal Conductivity W/mK*** | | | ***Thermal Resistivity*** $m^2K/W$ | | | ***Thermal Transmittance*** $W/m^2K$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | ***10 mm*** | ***20 mm*** | ***40 mm*** | ***10 mm*** | ***20 mm*** | ***40 mm*** | ***10 mm*** | ***20 mm*** | ***40 mm*** |
| Bottom | 0.14 | 0.13 | 0.14 | 0.17 | 0.19 | 0.20 | 7.17 | 6.40 | 6.83 |
| Middle | 0.13 | 0.13 | 0.12 | 0.18 | 0.22 | 0.21 | 6.43 | 6.33 | 5.96 |
| Top | 0.13 | 0.13 | 0.12 | 0.18 | 0.22 | 0.23 | 6.29 | 6.37 | 5.87 |

open space effect on the boards (maximum of 0.3, 0.5 and 0.5 mm respectively on top, middle and bottom segments of the boards). The observation of the length of effect followed the same trend as for the open space effect as shown in Table 3. Figure 16 shows the finished Composite Bamboo Board.A tongue and groove connection will limit any adverse effect of nails on the bamboo product finish.



2.5 mm open space at bottom at 106 mm long (76.2 mm Nail)

**Figure 15:** *Nail effect on the laminated panel*

**Figure 16:** *Laminate composite wall board 600 mm x 600 mm*

***Table 3: Nail effects on composite bamboo board***

| | *Maximum Open Space Mm* | | | *Length of Effect mm* | | |
|---|---|---|---|---|---|---|
| *Nail Size* | *38.1 mm* | *63.5 mm* | *76.2 mm* | *38.1 mm* | *63.5 mm* | *76.2 mm* |
| Bottom | 0.5 | 1.5 | 2.5 | 21 | 89 | 106 |
| Middle | 0.5 | 1.3 | 2.0 | 16 | 70 | 100 |
| Top | 0.3 | 1.0 | 1.75 | 10 | 45 | 78 |

## Conclusion

Conventional materials used for building construction are not only costly but have adverse environmental and health implications. Bamboo is a local, cheap and eco-friendly alternative to conventional building materials. This study set out to examine the strength and thermal properties of the composite board made from dominant bamboo species (*Bambusa vulgaris)* in Nigeria. The results of the strength and thermal properties of composite bamboo board produced from the three segments (Bottom, Middle, and Top) of *Bambusa vulgaris* are comparatively higher than those of High-Density Fiber board (HDF) and Medium Density Fiber board (MDF) common in Nigeria markets today. This suggests that innovative products for wall partitions, flooring, ceiling, among other uses in the building industry can be made from the bamboo culm. These findings have far-reaching implications for practice and economic development; regarding reduction in the cost of materials, and hence affordability for low-income housing; overall safety of the environment; and employment opportunity for Nigerian youths along the construction value chain.

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