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CHANGE IN FLEXURAL PROPERTIES OF RAW AND LAMINATED BAMBOO WOOD (*Bambusa vulgaris*. Schrad) TO ASSESS ITS POTENTIALS FOR APPROPRIATE APPLICATION

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Abstract:
Sourcing of choice timber species is becoming increasingly difficult in the forests of West Africa including Nigeria. There is a need to provide alternative species by investigating the technical qualities of species that are hitherto neglected, therefore, the need to evaluate wood properties of Bambusa vulgaris with a view to assessing its potentials for appropriate utilizations. B. vulgaris culms were processed into different laminate thickness of 4mm, 6mm, 8mm and 10mm and test samples were also obtained from raw (unprocessed) bamboo. The Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) of the two categories were then evaluated using Jinan Hensgrand Universal Electronic Testing Machine (Model WDW-50). Data were analysed using descriptive statistics and ANOVA at $\alpha_{0.05}$. *The mean MOE of raw B. vulgaris was 4556.21±98.42N/mm². While the mean MOE for laminated B. vulgaris was 9300.03±898.16N/mm². The mean values varied accordingly with the laminate thickness. MOE values increased from laminate thickness of 4mm to 10mm with 4944.75±250.57N/mm² for 4mm thick; 6302.96±3269.47N/mm² for 6mm thick; 11003.80±6322.20N/mm² for 8mm thick and for 10mm thick is 14948.55±5190.75N/mm². on the other hand the mean MOR of raw B. vulgaris was 51.88± 112.80N/mm² and laminated was 60.87±16.40N/mm². There was increase from laminate thickness of 4mm to 10mm and is as follows: 45.53±10.58N/mm², 56.96±8.81N/mm², 61.17±11.95N/mm² and 79.81±12.53N/mm² for 4mm, 6mm, 8mm and 10mm thick, respectively. Statistically, there was significant difference among the different laminate thickness and the raw bamboo for MOR but no significant difference for MOE. MOE and MOR increased with increase in laminate thickness. The flexural properties of both raw and laminated B. vulgaris compared favourably with some other conventional timber species.*

Key words: *Bambusa vulgaris; laminate thickness; MOE; MOR; raw.*

INTRODUCTION

The over-exploitation of the existing forest resources and the disappearance of economic hardwood species is a great concern to wood scientists, technologists and users. While some species are being overstressed, hundreds of other species that are relatively unknown are being left or destroyed during harvesting, thus the role of tropical forest is diminished (Ojo *et al*. 2018). Despite the fact that tropical forest is diverse and endowed with several wood species, some of them are in high demand while others are ignored.

Higher price of the raw material force the manufacturers to find other available resources for the manufacturing of wood products. On the other hands, end-users of wood-based products have realized the serious danger this may pose to the environment if certain natural forest stands are depleted (Ahmad 2000). According to Freezaillah, (1984), one of the crucial questions in tropical-forest management today is the future of lesser-known/lesser-used species in which bamboo is part of. Hundreds of potentially valuable trees are being left behind, often simply burnt in the forest clearing operations, or by agricultural conversions and dam building. Their possible end-uses or even their properties are less known at present (Ojo 2016). A suitable substitute for timber should have comparable properties and compatible with existing processing technology. A fast growing and abundant species is also preferable. Bamboo is such a material.

The fact that there is inadequate knowledge about the properties of Raw and laminated bamboo species (*Bambusa vulgaris or common bamboo)* hence, the uses potentials of *B. vulgaris* have not been adequately optimized.

Soltis (1984) reported that wood building structures that were constructed without adequate knowledge of the wood strength properties performed poorly when compared to the engineered structures.

Bamboo wood has a long history as an exceptionally versatile and widely used resource in the world, having high social, economic and environmental values. Nowadays, it is becoming so increasingly important in the world's forest economy, because it is a superior wood substitute, cheap and efficient to produce and use, environmentally friendly. Besides, the forest is diminishing and thus potential alternative wood species is needed. (Yigardu *et al*. 2016).

According to Mahdavi *et al*. (2011), using bamboo in its natural cylindrical form poses several challenges. Most importantly, it is difficult to create reliable connections owing to geometry and the fact that bamboo is prone to splitting. Also, since bamboo is not perfectly straight and has a non uniform cross section, practical issues, such as squeaky joints and thermal bridges, are a problem. Further, the fact that it is cylindrical makes it inefficient spacewise, therefore the need for bamboo lamination.

Analysis of the mechanical properties is the investigation of the material's behavior when subjected to loads. Material reactions under loads are the stress and strain generated within the materials and usually results in deformation (Hearn 1997). A sufficient knowledge of the mechanical behavior of bamboo wood enables a safe design for the materials service life. Haygreen and Bowyer, (1996) indicated that mechanical properties are usually the most important characteristics of wood products to be used in structural applications.

According to Atanda (2015), Bamboo is widely distributed in Nigeria. However, RMRDC, (2004) indicates that bamboo is widely distributed in the south and middle belt regions of Nigeria. In the Ogun, Oyo, Osun, Ondo, Edo, Delta, Rivers, Akwa-Ibom, Cross-River, Abia, Ebonyi, Enugu, Anambra and Imo states, the bamboo is not less than 10% of their natural vegetation. In Ekiti, Bayelsa, Lagos, Kogi, Kwara, Benue, and Nassarawa is between 6.0–9.0% of their natural vegetation and some pocket of bamboo clumps could be found in Niger, Taraba, Plateau and Abuja. Less than 3% is found in Adamawa, Bauchi, Borno, GombeKano, Kaduna, Katsina, Kebbi, Sokoto, Jigawa, Yobe and Zamfara states.

The most commonly used bamboo species in construction are the Bambusa, Chusquea, Dendrocalamus, Gigantochloa and Guadua (Minke 2012). *Bambusa vulgaris* is commonly available bamboo species in Nigeria (Ojo *et al.* 2016).

Africa has a total of over 2.7 million hectares of bamboo forest. In Nigeria a total of 1.5 million hectares is covered by bamboo (Lobovikov *et al.* 2007).

Bamboo can grow over 30m (98ft) tall, and be as large as 25-30cm (9.8-11.8 in) in diameter. However, the size range for mature bamboo is species-dependent, with the smallest bamboos reaching only several inches high at maturity. A typical height range that would cover many of the common bamboos grown in Nigeria is 4.5-12m (15-39ft), depending on species.

The aim of this research is to evaluate the flexural properties of *Bambusa vulgaris* wood to ensure its appropriate end use.

Therefore, the mechanical properties being discussed in this paper is the flexural properties which comprise the Modulus of Rupture and the Modulus of Elasticity of laminated bamboo and raw bamboo.

MATERIALS AND METHODS

The bamboo culms used for this study were harvested from bamboo stand at Forestry Research Institute of Nigeria (FRIN), Ibadan. Defect free culms of above seven years old with diameter ranging between 7.98cm to 8.51cm were harvested from the stand. Forestry Research Institute of Nigeria, Ibadan is between latitude 7^oN and 7.2^oN and longitude 26^oE and 27^oE.

The species of bamboo used for this study is *Bambusa vulgaris* (Variety Wamin), a bamboo species endemic to Southern Nigeria. For the raw bamboo specimen, Sections at the base where optimum cellwall thickness could be obtained (two sections) in between the nodes replicated nine (9) times and no preservative treatment was applied to them and the test was carried at 12% moisture content.

To determine the flexural properties of raw bamboo, British Standard 373: 1957 with a little modification in sample size was followed and test sample size of 300mmx20mmxoriginal thickness of sample was used (between 19.5mm and 20mm thickness). Samples were oven-dried at 105°C to a constant weight.

On the other hand, Laminates thickness of 4mm, 6mm, 8mm and 10mm were produced using the planning machine. They were stacked in an open air kiln system available in the Department of Forest Products Development and Utilization, Forestry Research Institute of Nigeria for 7days. Further, the laminates were dried in the oven at 105^oC to attain 12% moisture content prior to application of adhesive and carried out the laminated structures. The adhesive 'top-bond' a PVA (Polyvinyl acetate) adhesive was applied by brushing method to the planed surfaces of the bamboo laminates. The glued laminates were pre-pressed for 5 minutes in order to allow proper penetration of the adhesives before the introduction of pressure with clamps. Four laminate structure of 4mm, 6mm, 8mm and 10mm thick were used The samples were prepared in accordance with ASTM D 5456 (2009) and converted into standard test dimensional sizes of 20mmx20mmx300mm for Modulus of rupture and Modulus of Elasticity (Flexural property) test in accordance with British Standard 373: 1957. The laminate structures and the raw bamboo while replicated made a total of 46 test samples.

Modulus of Rupture

The bending strength of wood usually expressed as (MOR) which is the equivalent fibre stress in the extreme fibres of the specimen at the point of failure was determined using Jinan Hensgrand Universal Electronic Testing Machine (Model WDW-50). Modulus of Rupture was evaluated using the formula

$$MOR = \frac{3PL}{2bd^2} \qquad (1)$$

where: P = load in Newton (N),
L = span (mm),
b = width (mm),
d = depth (mm).

Modulus of Elasticity (MOE)

The modulus of elasticity was calculated from the values obtained at the point of failure recorded during tests for MOR.

$$MOE = \frac{PL^3}{\Delta bd^3} \qquad (2)$$

where:
P = Maximum load at failure (N);
L = Span in (mm);
B = Width in (mm);
d = Depth in (mm);
Δ = the deflection at beam centre at proportional load.

The experimental design adopted for the study was a Completely Randomized Design and the data obtained was subjected to analysis of variance at 0.05 level of probability with Statisca (data analysis software system) version 7.0 (2004).

RESULTS AND DISCUSSION

Modulus of Elasticity (MOE)

The mean MOE of raw *B. vulgaris* was 4556.21±98.42N/mm². While the mean MOE for laminated *B. vulgaris* was 9300.03±898.16N/mm². The mean values varied accordingly with the laminate thickness. MOE values increased from laminate thickness of 4mm to 10mm.with 4944.75±250.57N/mm² for 4mm thick; 6302.96±3269.47N/mm² for 6mm thick; 11003.80±6322.20N/mm² for 8mm thick and for 10mm thick is 14948.55±5190.75N/mm² (Fig 1).

It was observed that MOE increases with increase in laminate thickness with 10mm having the highest. This means that boards produced from the laminate thickness of 10mm were the strongest of all the other boards produced from the laminate thickness of 8mm, 6mm and 4mm therefore most suitable for construction purposes.

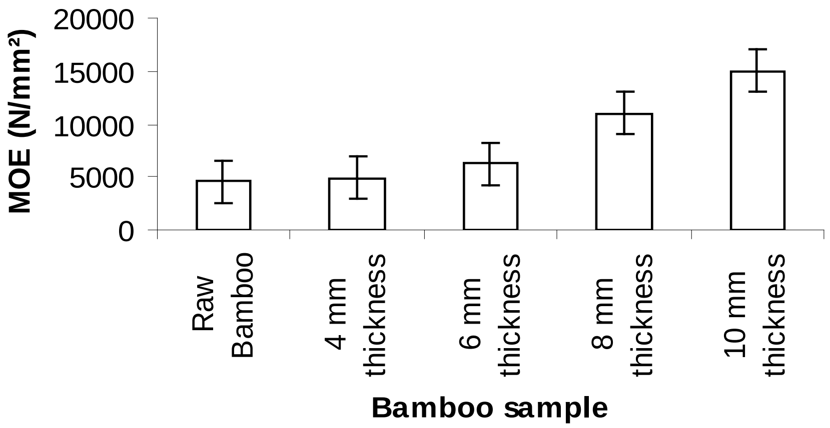

Fig. 1.
Modulus of Elasticity in respect with Bamboo sample.

From the foregoing, it is observed that the laminated bamboo has higher value compare to the raw bamboo, this can be attributed to the synergy and the bonding effects of the adhesive with which the strips were glued together. This shows that the adhesive used has great effects on the general properties of the materials produced from the use. Mohammedsherif (2018) found that the mean modulus of elasticity of air dried raw bamboo is 760N/mm² while the mean modulus of elasticity of Laminated Bamboo produced with parallel non-uniform thickness of lamellas orientation was 6250N/mm². The Modulus of Elasticity (MOE) and (MOR) of different Bamboo species as compare with *B. vulgaris* are listed in Table 1 below.

Table 1

MOE and MOR of different Bamboo species

Species	MOE (N/mm^2)	MOR (N/mm^2)
Phyllostachys bambusoides	10686.87	102.69
Bambusa arundinacea (Thorny bamboo)	12134.77	95.38
Melocanna beccifera	12686.35	56.35
Thyrsostachys oliverii	11858.98	88.04
Bambusa blumeana	4136.85	110.92
Bambusa vulgaris from Malaysia and Indonesia	6963.70	60.90
Gigantochloa scortechinii	4964.22	59.43
Phyllostachys pubescens	7928.97	97.34
Bambusa balcooa	7308.44	63.68
Bambusa nutans	12134.77	85.01
Bambusa tulda	12617.40	120.23
Bambusa tuldoides	15857.94	151.33
Guadua angustifolia	17236.89	141.65
Bambusa burmanica	17443.73	102.71
Bambusa pallida	12617.40	53.99
Cephalostachyum pergracile	18822.68	69.75
Dendrocalamus hamiltomii	2413.165	39.13
Oxytenanthera abyssinica	14616.88	81.78
Bambusa arundinacea	17443.73	90.98
Bambusa longispiculata	10066.34	49.50
Dendrocalamus giganteus	11721.08	50.67
Bambusa blumeana	8825.28	28.39
Gigantochloa levis	10411.08	19.60
***Bambusa vulgaris* (Raw)	4556.21	51.88
***Bambusa vulgaris* (Laminated)	9300.03	60.89

Sources; Ahmad (2000). ** Current research

Modulus of Elasticity is the ability of a material to retain its original shape and size after being stressed (Panshin and de Zeeuw 1980). Desch, (1988), stated that the ability of a wood member to bend freely and regain normal shape is called flexibility, and the ability to resist bending is called stiffness.

The modulus of elasticity (MOE) is a property of importance in determining the deflection of a beam under load. This is usually considered in conjunction with bending strength. The strength of a long timber column or strut is a critical property determined by the stiffness (MOE) of the material (Timings 1991). Shrivastava (1997) also added that MOE is the measure of stiffness; the higher the MOE, the less is the deflection or the greater the stiffness. It was also observed that the MOE measures the relation between stress and strain within the limit of proportionality. The MOE of raw and laminated bamboo can be said to be low and low/medium because Upton and Attah (2003) classified strength of wood based on the MOE at 12% moisture content as follows: 'Very High'(19,000N/mm^2 and more), 'High' (14,000-19,000N/mm^2), 'Medium' (11000-14,000N/mm^2), 'Low/ Medium' (9,000-11,000N/mm^2), and 'Low'(below 9,000N/mm^2). The MOE for both raw and laminated *B. vulgaris* compared favourably with some other bamboo species (Table 1).

However, the result of analysis of variance carried out shows that there is no significant difference, among the treatment, that is, among the solid bamboo and the different laminate structure (Table 2).

Table 2

Analysis of variance for Modulus of Elasticity (MOE)

Source of variation	df	SS	MS	F-value	P-value
Bamboo structure	4	44974141	11243535	1.40415	0.249637
Error	41	328302052	8007367		
Total	45	373276193			

Modulus of Rupture (MOR)

The mean MOR for laminated *B. vulgaris* was 60.89±21.09N/mm². The mean values varied accordingly with the laminate thickness. MOR values increased from laminate thickness of 4mm to 10mm with 45.53±10.58N/mm²; 56.96±8.81N/mm²; 61.17±11.95N/mm² and 79.81±12.53N/mm² for 4mm, 6mm, 8mm and 10mm thick, respectively (Fig. 2). As it was observed that MOR increases with increase in laminate thickness with 10mm having the highest. This means that boards produced from the laminate thickness of 10mm were the strongest of all the other boards produced from the laminate thickness of 8mm, 6mm and 4mm therefore most suitable for construction purposes.

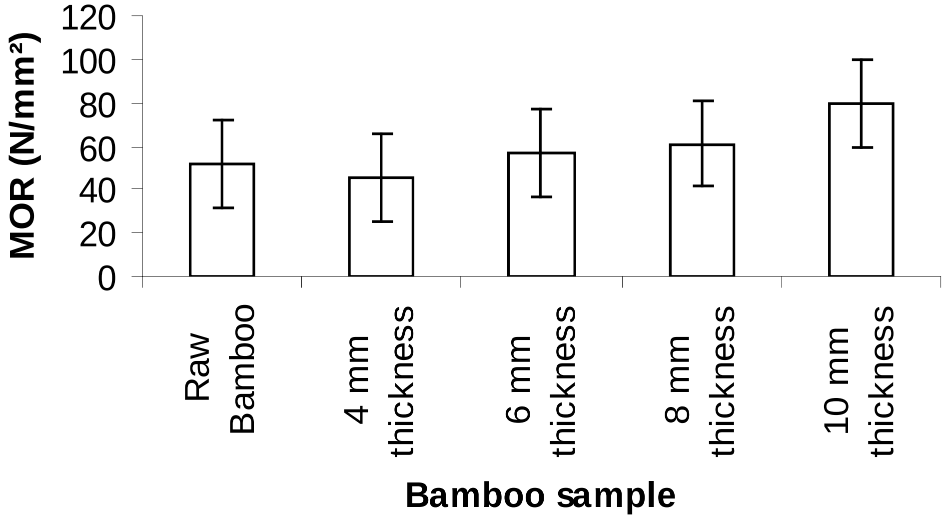

Fig. 2.
Modulus of Rupture in respect with Bamboo sample.

The mean modulus of rupture of air dried raw bamboo was 15.40MPa while the mean modulus of rupture of LBL produced with parallel strip lamination orientation was 65.06MPa (Mohammedsherif 2018). Ojo *et al*. (2018) also observed variation in the MOR of laminated bamboo with two laminate thickness of 5mm and 10mm thick at different portion along the bamboo culm (base, middle and top) to be 35.28N/mm^2, 38.63N/mm^2 and 45.44 ±4.34N/mm^2, respectively for 5mm thickness and 52.03 ±3.72N/mm^2, 65.74 ±4.89N/mm^2 and 69.81 ±3.86N/mm^2, respectively for 10mm thickness.

The modulus of rupture is important in members subjected to transverse loading as in the loading of roof trusses (Timings 1991).

Meanwhile, the result of analysis of variance carried out shows that there is significant difference among the bamboo structure, that is, among the raw bamboo and the different bamboo laminates (Table 3). The MOR for both raw and laminated *B. vulgaris* obtained in this study compares well with some of bamboo species (Table 1).

Table 3

Analysis of variance for Modulus of Rupture (MOR)

Source of variation	df	SS	MS	F-value	P-value
Bamboo structure	4	4489.24	1122.31	19.1960	0.000000
Error	41	2397.10	58.47		
Total	45	6886.34			

CONCLUSION AND RECOMMENDATIONS

The flexural properties of raw bamboo and laminated bamboo with different laminate thickness have been analyzed and can be said to be elastoplastic, that is, it has both elastic and plastic behaviour. MOE was determined not to significantly vary among the bamboo structure but MOR changes as a result of different laminate thickness.

The flexural properties of laminated bamboo varies consistently among the different laminate thickness from 4mm to 10mm thickness, this gives an indication of the tendency of obtaining material of better quality with high laminate thickness because the flexural properties increases as the bamboo laminate increases. Both raw and laminated *Bambusa vulgaris* can be regarded as a low and low/medium flexural wood, from the foregoing, *B. vulgaris* is suitable for structural application and structural composite and can serve as alternative for timber thereby reducing the pressure on the existing forest.

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