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EVALUATION OF THE UTILIZATION POTENTIAL OF AFRICAN BAMBOO (*Bambusa vulgaris* Schrad. ex J. C Wendl) GLUE-LAM THROUGH ITS STRENGHT PROPERTIES

*Ojo, A. R; Areghan, S. E and Ogutuga, S. O
Forestry Research Institute of Nigeria, Dept of Forest Products Development and Utilization-
*ojo.ar@frin.gov.ng

ABSTRACT

Historically, bamboo has been used in its natural form for light frame construction and furniture, and as a fiber feed stock for pulp and paper. Several researchers had studied bamboo as a raw material for particleboard, strand board and composite beams. None of these studies have addressed some of the factors in this study. This study was therefore conducted to assess the effect of adhesive, stem portion and laminate sizes on strength properties of *Bambusa vulgaris* with a view to assessing its potentials for appropriate utilizations. Variable factors such as stem portion (Top, Middle and Base) and laminate sizes (5mm and 10mm) were used for the production of bamboo-laminated boards. Strength properties such as the Modulus of rupture, Compression strength, Shear strength in perpendicular direction and shear strength in parallel direction were examined on the laminated board. The mean of the bamboo-laminated boards ranged from 35.28N/mm^2 to 536.96 N/mm^2 for Modulus of Rupture, 12.62N/mm^2 to 76.04N/mm^2 for Compression strength, 0.12 N/mm^2 to 0.56 N/mm^2 shear strength in parallel direction and 0.43 N/mm^2 to 1.26 N/mm^2 for shear strength in perpendicular direction. The result of ANOVA conducted shows that there are significant differences in the main factors considered for the production of bamboo laminated boards. Bamboo laminated boards produced from Top bond, at the base portion and laminated size of 10mm x 20mm had the best strength performance in this study. Based on the result obtained, there are potentials in utilizing bamboo for the production of building and structural materials.

Keywords: *Bambusa vulgaris*, strength, rupture and compression, shear

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INTRODUCTION

Over the years, much exploitation of the forest has been done in other to meet the increasing timber demand of the teeming population. This has resulted in serious depletion of the forest resource base to the extent that some favoured timber species have become scarce while others have become extinct in certain ecological zones (Fuwape 2000). Nigeria tropical forest is decreasing at an alarming rate today at about 3.5% annually (Popoola 2014). This is due to indiscriminate extraction of economic trees, over-exploitation of forest resources, fuel wood gathering, population pressure, decrease of forest for purposes like urbanization and industrialization. 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 the quest for choice species thus reduce the scope of tropical forest utilization.

Despite the fact that tropical forest is diverse and endowed with several species, some species are in high demand while some are less demanded. According to Freezaillah (1984), one of the crucial questions in tropical-forest management today is the future of lesser-known/lesser used species such as bamboo. Hundreds of potentially valuable trees are being left behind. - often simply burnt in forest clearing operations like logging, agricultural conversions and dam building. Little is known at present about their possible sustainable end-uses. The fact that there is inadequate knowledge about the properties of Bamboo laminated board have resulted into the misuse of the species, hence, the utilization potential of bamboo species have not been adequately optimized, hence, the reason for this research.

Bamboo as one of the most important non-wood forest products has long been recognized as a versatile plant. Bamboo can be used as an alternative source of raw materials for the wood industry due to its fast growing ability, which needs only between 3 and 4 years to mature before they are ready for harvesting (Razak *et al.*, 2010).

It is believed that effective utilization of bamboo and its conversion to other valuable products will contribute positively to the economy of the nation. It will also reduce the over exploitation of existing forest resources and the disappearances of economic hardwood species and reduce deforestation. Furthermore, producing laminate boards from bamboo will add more value to it thus, generating more income as well as creating diverse job opportunities. However, there is need for an effective research programme into the manufacturing of laminated bamboo boards for various grades of materials for future needs in construction works, household office furniture and paneling.

Bamboo based panels are products made from raw bamboo through a series of mechanical and chemical procedures, such as spraying glue, laying up, and hot pressing. The bamboo-based panels have advantages of large size, high strength, stabilization in shape and size, and its parallel and perpendicular strength and property that can be adjusted according to different demands (Zhang *et al.*, 2002). Bamboo based panels are relatively ideal engineering materials.

Bamboo-based composite may also be the suitable alternative as the materials of prefabrication in terms of the various advantages they contain. However, the application of bamboo based panels utilization is still very limited. Bamboo is one of the most important non-wood forest products and has long been recognized as a multipurpose plant. The rapid development of wood industry has contributed to the scarcity of wood raw materials in the forest. With such high demand for wood, finding a substitute for wood is an urgent necessity hence the reason for this research work, this research therefore examines the influence of laminate thickness and culm portion along the sampling height of bamboo culm on selected strength properties of bamboo glue-lam board with a view to assessing its potentials for appropriate utilizations.

MATERIALS AND METHODS

The bamboo (*B. vulgaris*) used for this study were harvested from bamboo stand at Forestry Research Institute of Nigeria (FRIN). Defect free culms of above seven (7) years old were harvested from the stand. They were cross-cut into three sections along the axial direction (base, Middle and Top), each culm was split into strips at the carpentry workshop section of FRIN.

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Conversion into test specimen

Samples were further planed to 5mm and 10mm thickness for all the sampling potions using the planning machine. They were stacked in an open air kiln system available in the Department of Forest Products Development and Utilization for 7days. Processed and dried bamboo strips were later dried in the oven at 105^{o}C to attain 12% moisture content prior to application of the adhesive. The adhesive 'top-bond and Urea-formaldehyde were prepared by weighing certain quantity and applied through the process of spreading method to the planed surface of the bamboo. The glued laminates were pre-pressed for 5 minutes in order to allow proper penetration of the adhesives before the introduction of pressure with clamping machine. The samples were converted into standard dimensional sizes of 20mm x 20mm x 300mm for Modulus of rupture, 20mm x 20mm x 60mm for Compression strength test in accordance with British Standard 373.

Modulus of rupture

The Modulus of Rupture was carried out in accordance with British Standard Method BS 373. This involves the use of standard test specimens (20mm x 20mm x 300mm), in a Hounsfield Tensometer. The load was applied at the rate of 0.1 mm/sec. 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 then calculated using the formula

$$MOR = \frac{3PL}{2bd^2} \quad \ldots\ldots\ldots 1$$

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

Maximum compression strength parallel to grain (MCS//)

The maximum compressive strength parallel to grain was determined using a test sample of 20mm x 20mm x 60 mm in accordance with British Standard (BS 373). Load was applied at the rate of 0.01 mm/sec, and the corresponding force at the point of failure was taken directly on the scale and recorded. This was divided by the cross sectional area of the test specimen to obtain value for maximum compressive strength parallel to grain (MCS//) using the formula.

$$MCS = \frac{P_{\max}}{bd} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where Pmax =Maximum load (N), b = width (mm), d = depth (mm)

Shear strength parallel and perpendicular to grain

The Shear strength parallel and perpendicular to grain was determined using a test sample of 20mm x 20mm x 20mm cube in accordance with British Standard (BS 373). The cube was loaded through a ball seating, the relatively small movement of the long pivoted-arm giving approximately vertical shear, the load was applied at the rate of 0.0085mm/sec, and the corresponding force at the point of failure was taken directly on the scale and recorded and the shear strength was estimated using the formula below. The action was carried out on shear parallel and perpendicular to grain samples.

$$Shear = \frac{P}{bd} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

Where P = load (N), b = width (mm), d = depth (mm)

Experimental Design and Data analysis

The experimental design adopted for the study is a 2x3 factorial experiment in a Completely Randomised Design with six replication resulting into 36 population samples. Data were analysed using Analysis of Variance (ANOVA)

Factor A= laminate Thickness (5mm and 10mm)

Factor B= Sampling position (Top, Middle and base)

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RESULT AND DISCUSSION

Table 1: Mean values of strength properties assessed on laminated samples using different adhesives

Culm portion	Laminated size (mm)	MOR(N/mm^2)	Compressive strength(N/mm^2)	Shear strength //(N/mm^2)	Shear strength (┴) (N/mm^2)
Top	5	35.28 ± 4.34	44.92 ±12.21	0.23 ±0.06	0.95 ±0.08
	10	52.03 ±3.72	57.91 ±7.72	0.40 ±0.04	1.17 ±0.01
Middle	5	38.63 ±2.16	50.75 ±2.17	0.32 ±0.07	1.15 ±0.05
	10	65.74 ±4.89	61.82 ±1.59	0.48 ±0.01	1.20 ±0.01
	5	45.44 ±4.34	56.03 ±5.21	0.38 ±0.04	1.17 ±0.04
Base	10	69.81 ±3.86	76.04 ±5.46	0.56 ±0.05	1.26 ±0.02

Modulus of rupture (MOR)

The mean values of modulus of rupture (MOR) assessed on laminated samples using bamboo culm is presented in Table 1. The mean ranged from 35.28N/mm^2 to 69.8N/mm^2, the values varied accordingly in the culm portion and dimension sizes of the laminated samples. In dimensional size of 5mm, the base portion of bamboo used has the highest tensile strength of 45.44N/mm^2 followed by 38.63N/mm^2 and the least tensile strength of 35.28N/mm^2 for middle and top, respectively. While in the dimensional size of 10mm, the base portion also recorded highest modulus of rupture with value of 69.81N/mm^2, followed by the middle portion with 65.74N/mm^2 and the least modulus of rupture of 52.03N/mm^2 for top portion of the bamboo culm, the result shows that the larger the dimensional size used for the laminated samples the higher the modulus of rupture. Sampling position along the vertical axial of the bamboo also played an important factor, the base portion of the stem recorded modulus of rupture higher than the other portion. Atanda, (2015) opined that bamboo strength varies along with culm height

The finding in the current study is contrary to the one reported by Hamdan *et al.*, (2009) in which case both middle and top values (135.0N/mm^2 to 92.9N/mm^2) and (129.2N/mm^2 to

97.6N/mm^2) respectively were higher than values recorded in the base(123.3N/mm^2 to 85.8N/mm^2) of bamboo culm. This may be attributed to the fact that the values of the current study shows that the modulus of rupture was best in laminated board, Ahmad, (2000) obtained 185.30 N/mm^2 for clear specimen of Calcutta bamboo. As observed by Ogutuga (2014) MOR ranged from 35.16N/mm^2 to 92.82N/mm^2. The laminate thickness of 4mm, 6mm, 8mm and 10mm had MOR values of 57.66N/mm^2, 64.69N/mm^2, 74.53N/mm^2 and 92.82N/mm^2, respectively. The laminate thickness of 4mm had the lowest MOR value in the untreated LBB while, the laminate thickness of 10mm had the highest MOR value.

Ojo (2016) obtained the mean MOR of *Borassus aethiopum* to be 94.61±23.49N/mm^2 ranging from 130.96±1.06N/mm^2 for the base, 102.98±1.30N/mm^{2}for the middle and 70.56±1.03N/mm^2 for the top. FPRL, (1966) recorded a mean value of 83.3N/mm^{2,} for *Milicia excelsa*, 76.3 N/mm^2 for *Mitragyna sp*, 95.5N/mm^2 for *Khaya senegalensis*, and 39.9N/mm^2 for *Antiaris africana*. Ayarkwa (1997) and Asafu-Adjaye *et al.*, (2013) obtained 104N/mm^2 and 65N/mm^2 respectively for *B. aethiopum* from Ghana. While Ojo *et al.*, (2012) obtained 59.20N/mm^2 for the same species in a derived savannah zone in Nigeria.

The analysis of variance result is presented in Table 2. All the factors assessed in the modulus of rupture which includes laminated size and stem portion were all significantly different at 0.05 level of probability.

Compressive strength parallel to grain

From table 1, the mean ranged from 44.92N/mm^2 to 76.04N/mm^2. In laminated size of 5mm, base portion of the bamboo stem has the highest compression strength parallel to grain of 56.03N/mm^2, followed by the middle portion with compression value of 50.75N/mm^2 and least compression strength parallel to grain with 44.92N/mm^2 at the top. In dimensional size of 10mm, the base portion of the bamboo laminated board has the highest compression strength parallel to grain of 76.04N/mm^2, followed by the middle portion with compression strength parallel to grain of 61.82N/mm^2 and the least compression value is from the top portion of the culm used in the production of the sample with 57.91N/mm^2. The compression strength parallel to grain value recorded in laminated samples with dimensional size of 10mm having the best compression strength than the 5mm.

The findings in the current study is contrary to the one reported by Hamdan *et al.*, (2009) in which case both base and top values (85.6N/mm^2 to 34.2N/mm^2) and (72.3N/mm^2 to 39.6N/mm^2) respectively were higher than the values recorded in the middle values (70.7N/mm^2 to 34.7N/mm^2) of bamboo culm. This may be attributed to the fact that the values of the current study which shows that the compression strength parallel to grain is best in laminated samples made with top bond glue. Bamboo strength varies along with culm height, the compressive strength increases with height while bending strength has opposite pattern (Atanda, 2015). Ogutuga, (2014), observed the MCS// of bamboo glue-lam to range from 41.44N/mm^2 to 50.00N/mm^2 with the highest laminate thickness having the highest MCS//

Akira (1978), reported 16N/mm^2 for *B. aethiopum* sampled in Ghana, Guinea, Sudan and Kenya while, Ayarkwa (1997) reported 58N/mm^2 and Asafu-Adjaye (2013), reported 35.10N/mm^2 for *B. aethiopum* from Ghana. The difference could have been caused by ages of trees sampled for the studies and sampling position. Lausberg *et al.*, (1995), were of the opinion that genetic factors and growing conditions could cause such variation. FPRL (1966), recorded 16.94N/mm^2 for *Hildegardia barteri*, 30.45N/mm^2 for *Afzelia Africana* and 34.44N/mm^2 for *Daniellia oliveri*. This indicates that value obtained from the present study is in the same range with those from primary species that are already popular in structural applications. The result of analysis of variance is presented in table 2 below. The major factors such as stem portion and laminated sizes are significantly different at 0.05 level of probability.

Shear strength in parallel direction to grain.

The mean value of shear strength in parallel direction accessed on the laminated samples produced from bamboo culm presented in table 1, in the laminated samples, shear strength ranged from 0.23N/mm^2 to 0.56N/mm^2. In laminated size of 5mm, base portion of the bamboo stem has the highest shear strength in parallel direction of 0.38N/mm^2, followed by the middle portion with value of 0.32N/mm^2 and least shear strength in parallel with 0.23N/mm^2 at the top.

In dimensional size of 10mm, the base portion of the bamboo laminated board has the highest shear strength in parallel direction of 0.56N/mm^2, followed by the middle portion with shear strength in parallel direction of 0.48N/mm^2 and the least shear strength value in parallel direction is from the top portion with 0.40N/mm^2. The shear strength value in parallel direction recorded in laminated samples with dimensional size of 10mm having the best shear resistance than the 5mm. The finding in the current study is contrary to the one reported by Sulastiningsih *et al*., (2009). In which case the mean value for the shear parallel to grain is 3.76N/mm^2 which is higher than the mean value of the current study which is 0.31N/mm^2. The result of analysis of variance is presented in table 2 below. The major factors such as the stem portion and laminated sizes are significantly different at 0.05 level of probability

Shear strength in perpendicular direction

The mean value of shear strength in perpendicular direction assessed on the laminated samples produced from bamboo stem is presented in Table 1. The mean shear strength ranging from 0.95N/mm^2 to 1.26N/mm^2. In laminated size of 5mm, base portion of the bamboo stem has the highest shear strength in perpendicular direction of 1.17N/mm^2, followed by the middle portion with shear strength($\perp$) value of 1.15N/mm^2 and least shear strength in perpendicular with 0.95N/mm^2. In dimensional size of 10mm, the base portion of the bamboo laminated board has the highest shear strength in perpendicular direction of 1.26N/mm^2, followed by the middle portion with shear strength in perpendicular direction of 1.20N/mm^2 and the least shear strength value in perpendicular direction is from the top portion of the culm with 1.17N/mm^2. The shear strength value in perpendicular direction recorded in samples with dimensional size of 10mm having the best shear resistance than the 5mm. The result of analysis of variance is presented in table 2 below. The major factors such as the stem portion and laminated sizes are significantly different at 0.05 level of probability, This implies that the effect of laminate size and, stem portion are significant on shear strength in perpendicular direction to the glued point on bamboo samples produced.

Table 2: ANOVA table showing the F-value of the Parameters assessed

		F-cal				
SV	df	MOR	MCS//	Shear//	Shear(┴)	F-tab
Culm portion	2	94.59*	13.63*	27.64*	33.99*	3.40
Laminate sizes	1	225.49*	102.74*	87.64*	143.76*	4.26
Culm portion x Laminate sizes	2	39.11*	0.49ns	0.44ns	1.52ns	3.40
Error	30					
Total	35					

*represent significant different while ns represent not significant at 0.05 level of probability

CONCLUSION

The information on the effect of culm portion and laminate sizes of bamboo-laminated boards was successfully investigated. Stem portion of bamboo used are Top, middle and base and the last variables are from the laminated size of 5mm and 10mm. Based on the result obtained better strength performances were recorded in the base portion of the bamboo culm than the middle and top portion of the bamboo culm and laminate size 10mm performed better than size 5mm. This shows that the higher the laminate sizes the better the laminated board

Based on the result obtained in this study, there are greater opportunities for the utilization of bamboo as a constructional material, and can be suitable in internal building application. Laminated bamboo board provides an alternative wood for furniture, interior design and building materials. Developing laminated bamboo board industry can reduce the rate of logging as well as reduce wood shortage and contribute to the sustainable development of the prefabrication industry and the protection of environment. Producing laminated bamboo board, with a longer service life can reduce logging activity and at the same time support the natural resource conservation

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