

EFFECT OF LAMINA THICKNESS ON SELECTED PROPERTIES OF BAMBOO (*Bambusa vulgaris* Schrad.ex J.C. Wendl.) GLULAM BOARD

Ganiyat Funke ODEBUNMI

Scientific Officer - Bioresources Development Agency
Address: Bioresources Centre, Ogbomosho, Oyo State, Nigeria
E-mail: odebunmiganiyat@yahoo.com

Olukayode Yekin OGUNSANWO

Professor - University of Ibadan, Ibadan
Address: Department of Forest Production and Products, 200284, Nigeria
E-mail: ogunsanwokay@yahoo.com

Adewunmi Omobolaji ADENAIYA*

Ph.D Student - University of Ibadan, Ibadan
Address: Department of Forest Production and Products, 200284, Nigeria
E-mail: wumexrulz@yahoo.com

Nureni Adedapo ADEWOLE

Senior Lecturer - University of Ibadan, Ibadan
Address: Wood Products Engineering Unit, 200284, Nigeria
E-mail: nureniadedapoadewole@gmail.com

Julius Olusegun OYEDELE

Centre Director - Bioresources Development Agency
Address: Bioresources Centre, Ogbomosho, Oyo State, Nigeria
E-mail: joaoyedele@yahoo.com

Abstract:

Bamboo (*Bambusa vulgaris* Schrad.ex J.C. Wendl.) has been identified to be a good substitute for wood. However, its small dimension limits its utilization, hence, it is often used in a laminated form. Numerous factors affect the technical properties of bamboo Glulam as revealed by several studies but lack of information on the effect of lamina thickness on the technical properties of bamboo Glulam therefore motivates this study.

Three to five year old bamboos (*Bambusa vulgaris*) were obtained from Lalupon in Lagelu Local Government Area of Oyo State. The bamboo culms were crosscut into 1 meter samples which were splitted into strips and planed into four different lamina thicknesses, coded as: T_1 (8mm), T_2 (6mm), T_3 (4mm) and T_4 (2mm). Glulam boards were produced from each lamina thickness and processed into specimens of 20x20x60mm. Swelling, shrinkage, density, thermal conductivity, compressive strength parallel (MCS//) and perpendicular to grain (MCS $\perp$) were evaluated. ANOVA was employed in the statistical analysis of the data generated.

Results show that density decreased with decreasing lamina thickness from T_2 - T_4 (0.61 - 0.57%) while thermal conductivity increased with decreasing lamina thickness from T_1 - T_4 (0.15 - 0.35W/m $^{-1}$ K $^{-1}$). MCS $\perp$ increased with decreasing lamina thickness from T_1 - T_3 (230.44 - 347.59N/mm ^{2}) while MCS// had a similar trend as that of the density. Physical property values varied from a structure to another without being able to establish a general trend of increase or decrease based on lamina thickness.

Statistical analysis revealed that properties were not significantly affected by lamina thickness ($p \leq 0.05$), except for MCS $\perp$ and radial shrinkage. It is therefore concluded that lamina thickness of 6mm be utilized when applications require better dimensional stability of the product, while 4mm lamina thickness should be utilized when applications require higher Glulam strength.

Key words: Bamboo; lamella thickness; physical properties; mechanical properties; Glulam.

INTRODUCTION

Intensive and unregulated exploitation of economic timber species in Nigeria have led to their scarcity both in the natural forests and forest reserves (RMRDC 2003; 2004). Where they are in available supply,

* Corresponding author

their age, diameter and occurrence per hectare are significantly low, often limiting their utilization for a wide range of structural applications.

Decline in resource availability and continuous increase in resource demand in today's industrialized world calls for the need to explore opportunities for new, sustainable building materials (Meadows *et al.* 1992) such as bamboo which is already being used as wood substitute in different parts of the world. The Asian countries such as China and India have greatly been involved in the exploration of the economic potentials of bamboo; however, the situation is opposite in developing countries such as in Nigeria and Sub-Saharan Africa as a whole. This situation could be reversed if the maximum potentials of bamboo will be harnessed and as such, intensified researches need to be conducted on this species in this part of the world.

Bamboo utilization as an alternative to wood is however limited by its relatively small size in comparison to wood. In Asia and other parts of the world where bamboo utilization is advanced, development of many engineered product such as bamboo Glulam is on the increase and as such, the properties of such products need to be determined in order to expose their inherent properties, so as to know the structural applications they are best suited for. One of the reasons attributed to its suitability for Glulam production is because its chemical extractives, which is relatively different from that of wood, makes its gluability easier than wood (Li 2004). In addition, glue laminated boards have been observed to possess superior mechanical strength than some economic tropical timber species like *Khaya senegalensis*, *Milicia excelsa* and *Mansonia altissima* (Ogunsanwo and Tersiev 2010).

In a study conducted by Ogunsanwo *et al.* (2015), which investigated the chemical, physical, anatomical and mechanical properties of bamboo laminates produced from bamboo obtained from South-western Nigeria, they observed that shear forces may not only cause failure along the glue line of bamboo, but that failure may equally occur within the bamboo cell. This was explained by the fact that the shear forces may at times be greater than that of the bamboo cell than that of the glue line, thereby causing failure within the bamboo cell. On this basis, it was therefore conceptualized that the thickness of individual bamboo lamina may influence some technical properties of the Glulam boards. However, recent studies have also reported significant influence of lamina thickness on some glue laminated timber beams (Bourreau *et al.* 2013; Icimoto *et al.* 2016). With inadequate information on the influence of lamina thickness on the properties of bamboo Glulam, this study therefore aims to investigate how lamina thickness influences the technical properties of bamboo laminated structures and thus, identifying the best lamina thickness to be adopted for glue laminated products.

MATERIALS AND METHOD

Sourcing of Bamboo samples

Three to five (3-5) year old bamboo (*Bambusa vulgaris Schrad.ex J.C. Wendl.*) culms were obtained from Lalupon in Lagelu Local Government Area of Oyo State. The choice was made after a preliminary investigation of the stock maturity, species type and culm (stem) thickness. The bamboos were harvested freshly above the first node to avoid exposure to infestation. They were thereafter transported to the wood workshop, Department of Forest Production and Products, University of Ibadan, air-dried for two weeks before further processing.

Glue laminated boards (Glulam) production

The culms were cross-cut into 1 meter in length and splitted into strips. Due to the variation in thickness along the length of the bamboo culm, and in order to obtain the desired bamboo lamina thickness for the production of the boards, the cross-cut culms were initially sorted into four thickness classes of 1meter interval based on the thickness from base to top, such that the thicker ones obtained from the basal region were used in producing laminas of thicknesses 8mm and 6mm, while those obtained from the top of the culm were used in producing laminas of 2mm and 4mm thicknesses. Both the inner and outer surfaces of the bamboo strips were planed such that the cuticle of the outer surface was completely removed. During the planing process, the laminas were planed into 8mm, 6mm, 4mm, 2mm thicknesses using a digital vernier caliper for their measurement. The laminas were edged and soaked in dilute acid boric for two weeks to preserve them from insect attack. They were subsequently air-dried for 72 hours and four Glue laminated boards (Glulam) were produced for each lamina thickness using top bond adhesive (a polyvinyl acetate glue). All the experimental boards measured 1000mmx420mmx15mm in length, width and thickness, respectively. Each of these boards were codified as T₁, T₂, T₃ and T₄, representing boards produced from lamina thickness 8mm, 6mm, 4mm and 2mm, respectively. The boards were cold pressed using a clamp to ensure proper bonding of the laminas, and were allowed to cure for 14 days before further processing into.

Determination of physical properties of laminated boards

Swelling, shrinkage and density of the Glulam specimens were determined. For shrinkage, test specimens of 20mmx20mmx60mm were prepared and determined in accordance with ASTM D1037. The

samples were properly aligned and denoted as R, T and L respectively, in accordance with the anisotropic nature of wood (radial, tangential and longitudinal). The initial dimensions (D) were measured with the aid of digital vernier calliper, and oven-dried at $103\pm 2^{\circ}\text{C}$ until constant weight was achieved (D_o). Shrinkage (%) was determined as given below:

$$S = \frac{D - D_o}{D} \times 100 [\%] \quad (1)$$

where:

D = Initial dimension in mm

D_o = Final dimension (oven dry) in mm

Similar procedure was adopted for the preparation of specimens for the determination of the thickness swelling. However, the specimens, after the initial dimensions (D) were measured, were then soaked for 48 hours. The saturated dimensions (D_s) were measured and swelling (S_w) was determined as expressed below:

$$S_w = \frac{D_s - D_o}{D} \times 100 [\%] \quad (2)$$

where:

D_s = Final dimension (saturated condition) in mm

D = Initial dimension in mm

Density of the samples was determined using the formula below:

$$\text{Density} = \frac{\text{mass}}{\text{volume}} [\text{Kg/m}^3] \quad (3)$$

Determination of mechanical and thermal properties of laminated board

Compressive strengths parallel and perpendicular to the grain were determined in accordance with ASTM D143-52 (1997), while thermal conductivity was determined using the method described by Log and Gustafsson (1995).

Data Analysis

Descriptive statistics such as bar charts and tables were used to present the result. Analysis of variance (ANOVA) was used to test the significance of the variability in the properties examined at 5% probability level. Duncan Multiple Range Test was carried out at 0.05 level of significance as follow up test to separate means where significant differences were observed.

RESULTS AND DISCUSSION

Longitudinal swelling

Longitudinal swelling ranged from 0.19% – 0.52%, with the lowest value for T_2 and the highest for T_3 (Fig. 1.). A sinusoidal pattern of variation in longitudinal swelling was observed from T_1 – T_4 (0.44%, 0.19%, 0.52%, 0.37%). Longitudinal swelling is usually low when compared with radial and tangential swelling (Table 1 and Fig. 1.). Generally, earlywoods of bamboo has been reported to shrink more longitudinally than the latewood based on the assumption that fibre bundles are similar to latewood (having cells with low microfibril angle), while parenchyma cells functionally resembles earlywood which consists of cells with high microfibril angle (Yu *et al.* 2008). Since longitudinal swelling and shrinkage increases with the angle of microfibril inclination (Panshin and de Zeeuw 1980), this explains why the longitudinal swelling is more pronounced in culms obtained at the base than those at the top because they have fewer fibres and more parenchyma cells (Pliura *et al.* 2005, Yu *et al.* 2008). In relation to this study, it is expected that Glulam boards produced from laminas with thickness T_4 should swell less longitudinally as they contain more fibre cells by virtue of their position on the bamboo culm (top) than those produced from laminas with thickness T_1 which were obtained from the base. This anticipated result was observed in this study as longitudinal swelling was higher in T_1 than T_4 . Moreover, the highest value was obtained for the T_3 board (with lamina

thickness 4mm), which was produced from laminas obtained from the top of the bamboo culm and should have a lower swelling coefficient. This exceptionally high swelling in the T_3 boards may be due to anatomical variations within the T_3 laminas. Analysis of variance showed that lamina thickness insignificantly affected longitudinal swelling ($p>0.05$) in the produced laminated boards (Table 1).

Tangential swelling

Tangential swelling ranged between 5.56% – 8.34% (Fig. 1). A decrease in tangential swelling was observed from T_1 to T_2 , followed by an increase from T_3 to T_4 . T_4 , which has the thinnest lamina (2mm thickness) had the highest tangential swelling, and this may probably be due to the higher number of laminas glued together to obtain the same board thickness in comparison with the 6mm and 8mm laminas, thus, making them swell more tangentially because of their higher fibre content. On the other hand, the T_4 laminas, which were obtained from the upper part of the culm, have higher density compared to the T_1 to T_2 , implying that more cell wall materials were present in the laminated boards produced from the T_4 lamina thickness, and consequently inducing higher tangential swelling as a result. From Table 1, Analysis of variance shows that there is no significant difference in tangential swelling ($p>0.05$) among the various Glulam board thickness. This infers that lamina thickness has no considerable effect while choosing any of the four types thickness based on tangential swelling for potential utilization.

Radial Swelling

Radial swelling ranged from 1.52% – 3.88% (Fig. 1.). Radial swelling decreased from T_1 to T_2 (2.36% - 1.52%), and subsequently increased from T_3 – T_4 (3.63% - 3.88%). Similar to the tangential swelling result, radial swelling in the Glulam boards produced with lamina thickness T_4 may be as a result of the higher cell wall material in the T_4 laminas, as they were obtained from the upper culms of the bamboo (Kelemwork 2008), or perhaps, due to the increased number of lamina members in the Glulam boards due to its smaller thickness. From the result, radial swelling was approximately one-third the tangential swelling observed in the Glulam boards.

Statistical analysis shows that there is no significant difference in radial swelling ($p>0.05$) among the various Glulam boards. Thus, lamina thickness should be given less consideration in the production of laminated boards when considering radial swelling.

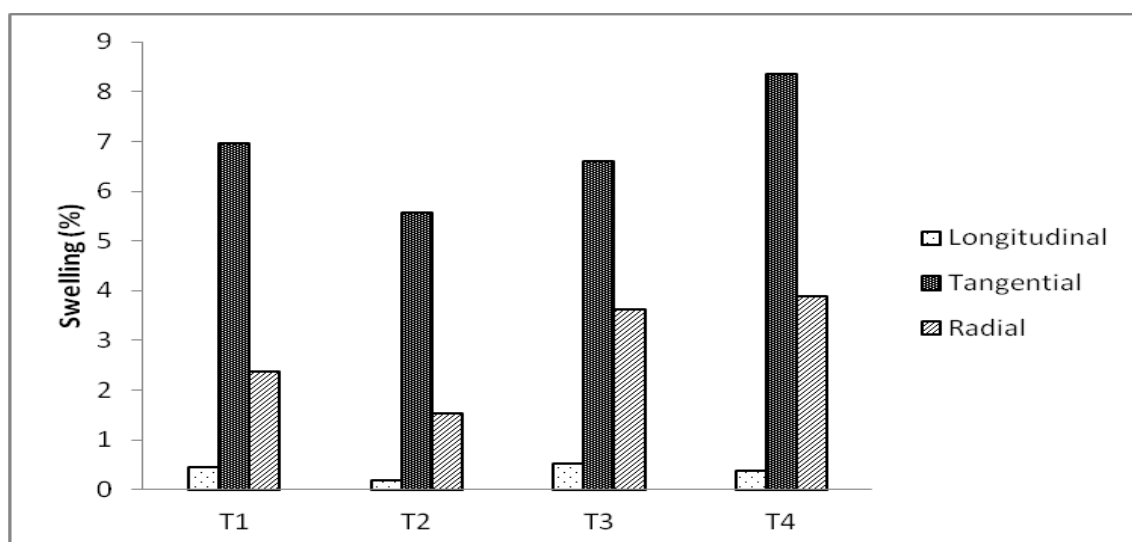


Fig. 1.
Mean Longitudinal, Tangential and Radial swelling of the bamboo Glulam samples produced from varying lamina thickness.

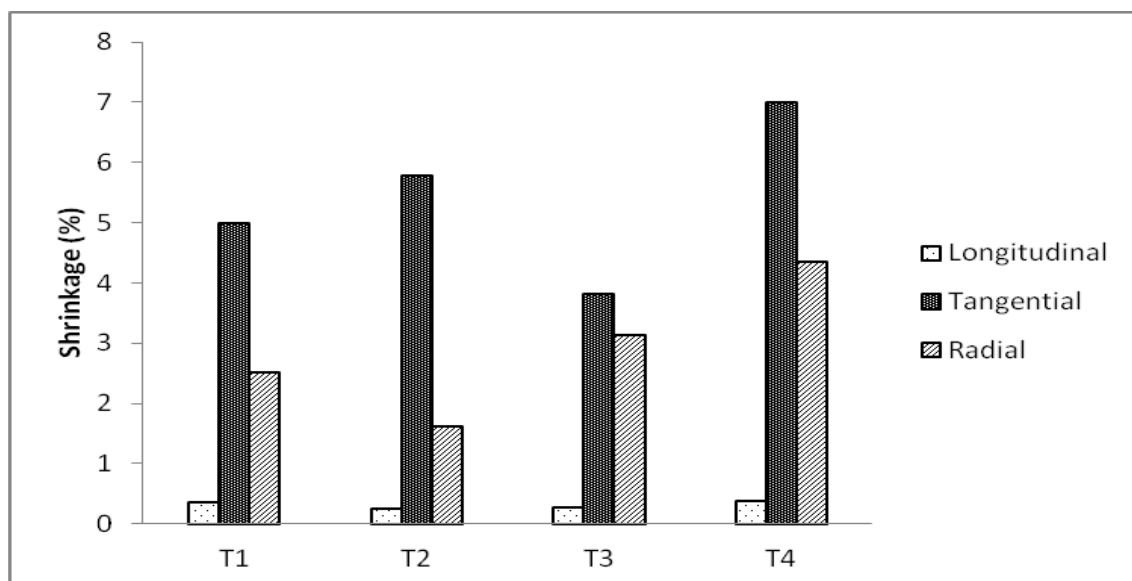


Fig. 2.

Mean Longitudinal, Tangential and Radial shrinkage of the bamboo Glulam samples produced from varying lamina thickness.

Longitudinal Shrinkage (%)

Longitudinal shrinkage ranged between 0.24% – 0.37% (Fig. 2.). Longitudinal shrinkage decreased from T₁ to T₂, after which an increase was observed from T₃ – T₄. This study showed an increasing trend in longitudinal shrinkage (0.24%, 0.27%, 0.37%) as lamina thickness decreased from T₂ – T₄, except in T₁ (0.35%) which deviated from this trend (Fig. 2.). This trend in longitudinal shrinkage is somewhat similar as expected to that of the longitudinal swelling observed in this study, except for the samples of the T₄ laminas which deviated from this trend. This deviation may be as a result of wide variation in the anatomical structures of the individual laminas of the T₄ samples.

However, statistical analysis shows that there is no significant difference in longitudinal shrinkage ($p > 0.05$) among the various Glulam board thickness.

Tangential Shrinkage

Tangential shrinkage ranged between 3.82% – 6.99%, with lamina T₃ having the least, while T₄ had the highest tangential shrinkage (Fig. 2.). A sinusoidal pattern of variation in tangential shrinkage was observed from T₁ – T₄.

Reports by Abd.Latif *et al.* (1993), Yu *et al.* (2008), Erakhrumen and Ogunsanwo (2009) showed a positive correlation between density and both radial and tangential shrinkage, suggesting that high wood density may lead to increasing transverse or lateral shrinkage, while several studies (Espiloy 1987, Santhoshkumar and Bhat 2014) also had shown that density increases with decreasing thickness i.e. from the base to the top. The trend here shows that tangential shrinkage increases from Glulam boards with thicker laminas to those with the thinner ones, except in T₃ which could be associated with wide variation in the anatomical structure of its laminas, as it plays an important role in the physical properties of bamboos. Analysis of variance shows that there is no significant difference in tangential shrinkage ($p > 0.05$) among the various lamina thickness (Table 1).

Radial Shrinkage

Radial shrinkage ranged between 1.61% – 4.35% (Fig. 2.). Radial shrinkage tended to increase from T₁ – T₄ (2.52%, 1.61%, 3.13% and 4.35%), except for T₂ where a sharp decline was observed. Bamboo lacks radially-oriented cells, hence, the radial and tangential shrinkage are usually similar as opposed to that of timber. As observed for tangential shrinkage, radial shrinkage tended to increase with decreasing lamina thickness. This may be associated with the increasing number of laminas in the Glulam boards with decreasing lamina thickness, consequently inducing a higher radial shrinkage due to more bamboo cells shrinking. Analysis of variance revealed significant differences in radial shrinkage ($p < 0.05$) among the various Glulam board thickness (Table 1). From utilization point of view, it is more appropriate to utilize lamina with thickness T₂ for Glulam manufacture based on the result of the follow-up test (Table 1), as they performed best by shrinking less radially than other lamina thicknesses and differed significantly from them.

The radial-tangential shrinkage ratio (R:T) is about 1:1.5, which is considerably lesser than the R:T swelling ratio.

Density

Density ranged between 0.57 – 0.61g/cm³ (Fig. 3). Density increased from T₁ to T₂, after which a consistent decrease was observed from T₂ – T₄. Several studies have reported that bamboo density increases from the bottom to the top of the culm (Espiloy 1987, Santhoshkumar and Bhat 2014), which has been attributed to the increase in fibre proportion and vascular bundles in the upper part of the culm (Liese 1998, Santhoshkumar and Bhat 2014). However, a contrasting observation was observed in this study as the trend of density variation tended to decrease with decreasing lamina thickness. (Fig. 3.). This may have been brought about by the interplay between the lamina porosity and varying number of laminas for each Glulam board. Firstly, T₁ and T₂ Glulam boards have are composed of laminas with low density by virtue of the position they were obtained from on the bamboo culm, and hence, have high porosity, which could have facilitated higher adhesive penetration into the laminas, thereby culminating in a higher density. The increase in density from T₁ and T₂ may be linked to the increasing number of laminas with decreasing lamina thickness, implying more adhesive absorption in T₂ than the T₁ boards. However, the reduction in density from T₃ to T₄ may be as a result of anatomical variations in their individual laminas, since it is believed that they are less porous, and would absorb a similar quantity of adhesive during the Glulam board production.

Statistical analysis revealed no considerable effect ($p>0.05$) of lamina thickness on Glulam board densities (Table 1).

Thermal conductivity

The relationship between thermal conductivity and thickness of laminas is shown in Fig. 4. The thermal conductivity of the Glulam boards ranged between 0.15W/mK and 0.35W/mK. There was an increasing trend in thermal conductivity with decreasing thickness, although, a plateau in thermal conductivity was observed between T₁ and T₂.

This increase in thermal conductivity with decreasing thickness can be attributed to the increased fibre proportion and vascular bundles in the thinner laminas. According to Shah *et al.* (2016), thermal conductivity increases with increase in cell wall material and decreases with increasing porosity. Since lamina thickness decreased with height of bamboo culm (as shown in the preparation of the samples) and density have been reported to increase with increasing height in bamboo (Santhoshkumar and Bhat 2014), this explains why the thinnest and densest lamina had higher thermal conductivity when compared to the other lamina thickness. From the study carried out by Adegoke *et al.* (2011) on thermo-physical and mechanical properties of some wood species, all the five species investigated had their thermal conductivity within the ranges of 0.2 - 0.26Wm⁻¹K⁻¹. This range of values is similar with the thermal conductivity range observed in this study (0.15 - 0.35Wm⁻¹K⁻¹), implying that bamboo Glulam can perfectly act as a substitute for timber when heat conductivity is a major factor being considered in material selection. Analysis of variance shows that there is no significant difference in thermal conductivity ($p>0.05$) among the various Glulam board thicknesses (Table 1).

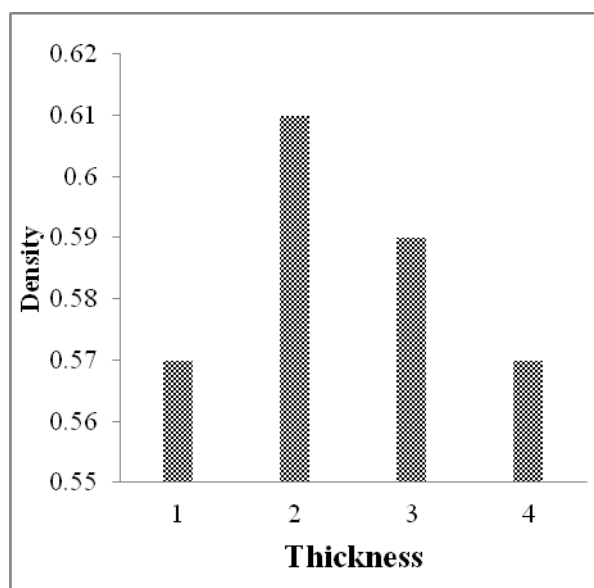


Fig. 3.

Mean Density and thermal conductivity of Glulam samples.

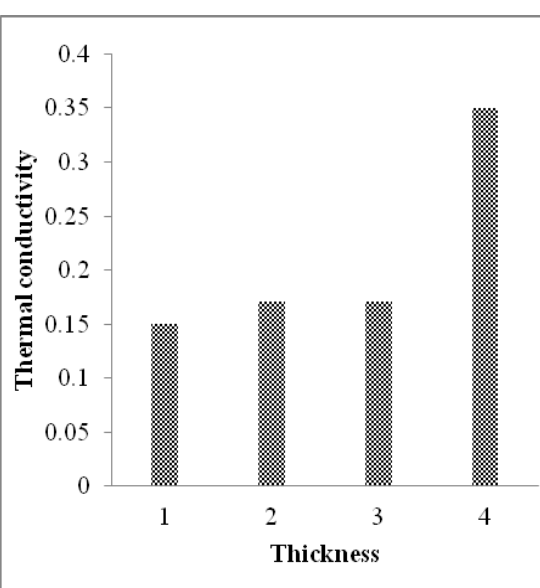


Fig. 4.

Compressive strength parallel to grain

Compressive strength parallel to grain ranged from 55.27N/mm^2 – 61.44N/mm^2 (Fig. 5). Compressive strength parallel to grain followed the same trend as the density, increasing from T_1 - T_2 , after which a consistent reduction was observed from T_2 – T_4 . The highest strength was observed in T_2 , while T_1 had the lowest strength. This study overall showed that compressive strength parallel to grain decreased with decreasing lamina thickness, with exception of T_1 . According to Ogunsanwo *et al.* (2015), effective bamboo lamination requires a proper bonding among the laminated members such that forces acting to disengage the members can be resisted. Malanit *et al.* (2009) asserted that denser wood species are more difficult for adhesives to penetrate due to the small size of their fibre lumens, their thick cell walls, and their narrow pit openings between fibres; all of which restrict adhesive penetration thereby creating poor bonding and weak products. Similar to woody species, bamboo also exhibits anatomical variations which may influence the penetration of adhesives during Glulam production. The decreasing compressive strength parallel to grain from T_2 to T_4 , therefore, can be attributed to the decreasing porosity of lamina members from T_2 - T_4 which caused a decrease in adhesive penetration into the lamina members from T_2 - T_4 . The lamina members for the T_4 were obtained from the top of the bamboo culm which is denser and less porous, while T_2 was obtained further down the culm, which is more porous. However, the lower compressive strength value for T_1 may be as a result of the fillers used in the bamboo Glulam, as some areas of the Glulam boards needed the application of fillers and samples obtained for the examination of this property might have been derived from such regions, which may have led to its low strength. From Table 1, analysis of variance showed that there is no significant difference in the strength parallel to grain ($p>0.05$) among the various Glulam board thickness. Thus, lamina thickness has no marked effect on the compressive strength of the produced Glulams.

Compressive strength perpendicular to grain

Compressive strength perpendicular to grain ranged from 230.44N/mm^2 - 347.59N/mm^2 (Fig. 6). There was an increasing trend in Compressive strength perpendicular to grain from T_1 - T_3 (230.44 - 347.59N/mm^2), after which a tremendous reduction was observed from T_3 – T_4 (347.59 - 184.97N/mm^2). T_3 (347.59N/mm^2) had the highest compressive strength perpendicular to grain while T_4 (184.97N/mm^2) had the lowest. Thus, it can be said that compressive strength perpendicular to grain overall increased with decreasing lamina thickness. This may be as a result of the differences in densities of the lamina members. The increasing compressive strength perpendicular to grain indicates that the denser laminas (i.e. those obtained at the top) resisted compression forces tending to collapse the bamboo fibres by compression more than the lighter laminas, which are mainly composed of tubular cells such as vessels and parenchyma cells that collapse easily under compression forces (Fig. 7). The low compressive strength perpendicular to grain reported for Glulams produced from lamina T_4 may be as a result the weak joints produced from the use of fillers around some localized parts on the Glulam boards, as samples prepared for this strength test may have been obtained from this region of the board.

Analysis of variance revealed significant differences in the strength perpendicular to grain ($p<0.05$) among the various Glulam board thickness (Table 1). The Follow-up test revealed that Glulam boards produced from T_3 had significantly higher compressive strength perpendicular to grain (Table 1).

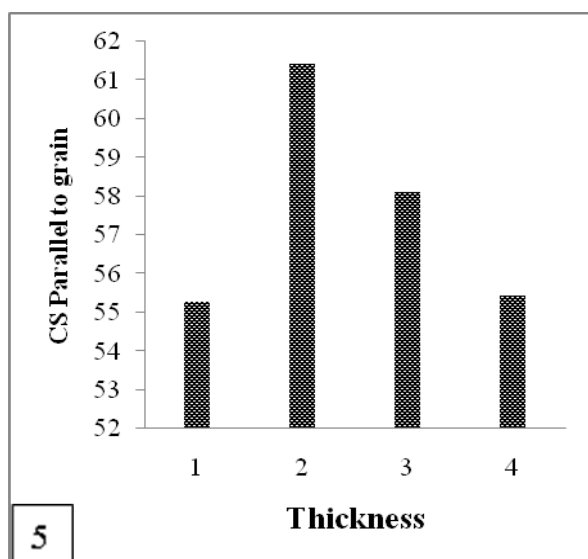


Fig. 5.

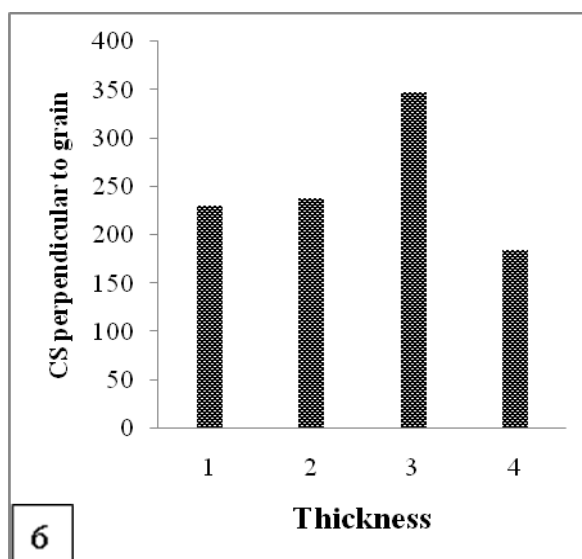


Fig. 6.

Mean Compressive strength parallel and perpendicular to grain of Glulam samples.

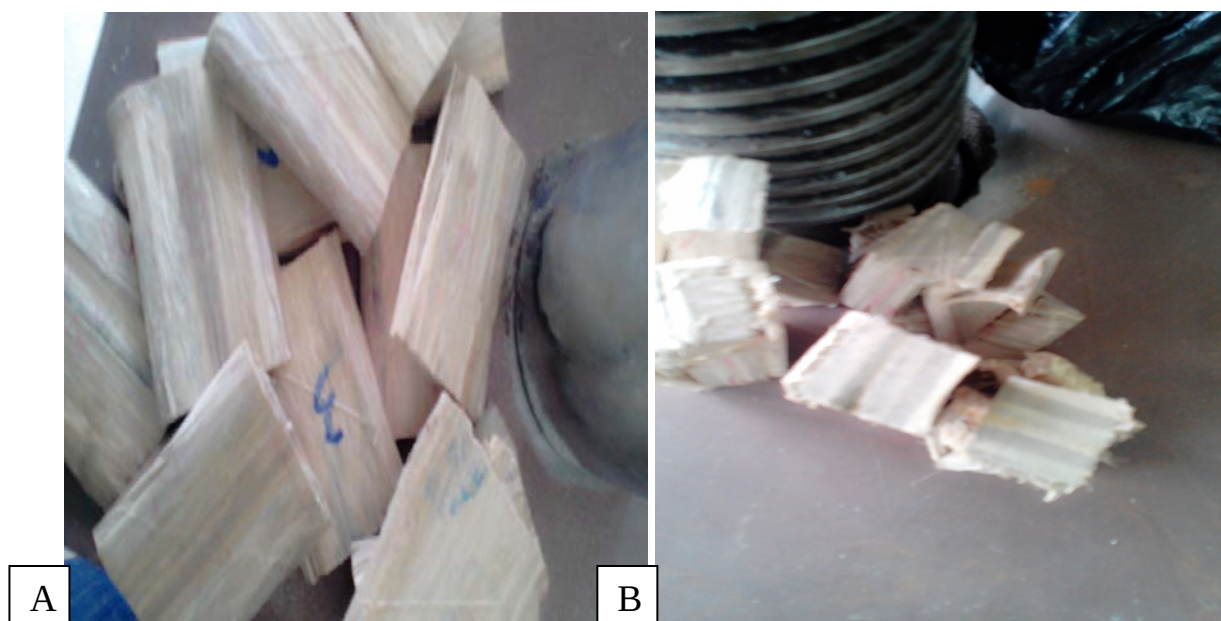


Fig. 7.

Failed Glulam samples after: A - compression force perpendicular to grain; B - compression force parallel to grain.

Table 1

Effects of Lamina thickness on selected properties of *Bambusa vulgaris*

Laminate Properties	Laminate thickness			
	T ₁	T ₂	T ₃	T ₄
Longitudinal swelling (%)	0.44 ^a	0.19 ^a	0.52 ^a	0.37 ^a
Tangential swelling (%)	6.97 ^a	5.56 ^a	6.59 ^a	8.34 ^a
Radial swelling (%)	2.36 ^a	1.52 ^a	3.63 ^a	3.88 ^a
Volumetric swelling (%)	9.33	7.08	10.22	12.22
Longitudinal shrinkage (%)	0.35 ^a	0.24 ^a	0.27 ^a	0.37 ^a
Tangential shrinkage (%)	4.98 ^a	5.79 ^a	3.82 ^a	6.99 ^a
Radial shrinkage (%)	2.52 ^{bc}	1.61 ^c	3.13 ^{ab}	4.35 ^a
Volumetric shrinkage (%)	7.50	7.40	6.95	11.34
Density (g/cm ³)	0.57 ^a	0.61 ^a	0.59 ^a	0.57 ^a
Thermal conductivity (W/mK)	0.15 ^a	0.17 ^a	0.17 ^a	0.35 ^a
MCS (N/mm ²)	55.27 ^a	61.44 ^a	58.13 ^a	55.44 ^a
MCS _⊥ (N/mm ²)	230.44 ^a	238.53 ^a	347.59 ^b	184.97 ^a

N.B: Means with the same superscript on the same row are not significantly different ($p \leq 0.05$) using Duncan Multiple Range Test

CONCLUSION

Based on the results of this study, it is difficult to precisely conclude on the effect of lamina thickness on the investigated properties of the experimental Glulam boards. However, anatomical variations in the properties of the lamina members, by virtue of their positions on the bamboo culm, as well as the different sources of the bamboo may have influenced the board properties. Factors such as density, porosity and adhesive quantity came into play in the Glulam samples which gave rise to the observed properties. To even out the effect of these external factors in order to establish the effect of lamina thickness on the technical properties of bamboo Glulam, all laminas should be obtained from the same part of bamboo culms growing on the same site, as well as applying a uniform glue quantity in the production of the Glulam. Nonetheless, most of the properties varied insignificantly with increasing thickness, with only radial shrinkage and compressive strength perpendicular to grain being significant at varying lamina thickness. In most cases, there were sharp deviations in the trends of the properties observed for some of the Glulam samples, which indicates that bamboo may vary widely between culms, as the Glulam boards were produced from lamina members from different bamboo culms, though belonging to the same axial positions. From this study however, lamina thickness of 6mm should be utilized when dimensional stability is the major characteristic being considered during application while lamina thickness 4mm should be considered for applications where compression stresses are applied.

REFERENCES

- Abd.Latif M, Ashaari A, Jamaludin K, Mohd J (1993) Effects of anatomical characteristics on the physical and mechanical properties of *Bambusa bluemeana*. *Journal Tropical Forest Science*, 6(2):159-170.
- Adegoke AJ, Adewole AN, Adelugba AE (2011) Thermo physical and mechanical properties of free wood species Grown on Abeokuta, Ogun state, Nigeria. Published by Forestry Association of Nigeria (FAN) Conference. 321-328pp.
- Bourreau D, Aimene Y, Beauchêne J, Thibaut B (2016) Feasibility of glued laminated timber beams with tropical hardwoods .Eur. J. Wood Prod. 71:653-662.
- Erakhrumen AA, Ogunsanwo OY (2009) Water absorption, anti-swell efficiency, and dimensional stability properties of neem seed oil treated wild grown *Bambusa vulgaris* Schrad. Ex J.C. Wendl. in Southwest Nigeria. *BioResources*, 4(4):1417-1429.
- Espiloy Z (1987) Physico-mechanical properties and anatomical relationships of some Philippine bamboos. In: (A.N.Rao, et al., eds.). Recent research on bamboo. Proceedings of the International Bamboo Workshop, Hangzhou, China, 6-14 October. Chinese Academy of Forestry, Beijing China; International Development Research Center, Ottawa, Canada. pp. 257-265.
- Icimoto FH, Neto CC, Ferro FS, de Macedo LB, Christoforo AL, Lahr FAR, Júnior CC (2016) Influence of Lamellar Thickness on Strength and Stiffness of Glued Laminated Timber Beams of *Pinus oocarpa*. *International Journal of Engineering*, 6(2):51-55.
- Kelemwork S (2008) Testing of two Ethiopian Bamboo species for value add products. Retrieved from <http://www.eabp.org.et/Publications/present/Testing of Two Ethiopian Bamboo.pdf>
- Li X (2004) Physical, chemical and mechanical properties of bamboo and its utilization potential for fibreboard manufacturing. M.Sc. Thesis, Louisiana State University, Baton Rouge, LA, USA. pp.68.
- Liese W (1980a) Anatomy and properties of bamboo. Retrieved August 12, 2016. <http://www.studymode.com/essays/Bamboo-1302838.html>
- Liese W (1998) The Anatomy of Bamboo Culms. BRILL. Retrieved from <http://books.google.com/books?hl=en&lr=&id=dIVAGsXNPSSC&pgis=1>
- Log T, Gustafsson SE (1995) Transient plane source (TPS) technique for measuring thermal transport properties of building materials. *Fire Mater.*, 19(1):43–49
- Malanit P, Barbu MC, Frühwald A (2009) The gluability and bonding quality of an Asian bamboo *Dendrocalamus asper* for the production of composite lumber. *J Trop Forest Sci.*, 21(4):361-368.
- Meadows DH, Meadows DL, Randers J (1992) Beyond the limits: Confronting global collapse, envisioning a sustainable future, Chelsea Green Publishing, White River Junction, VT.
- Ogunsanwo OY, Terziev N (2010) Mechanical Properties of Glue-Laminated Boards of Bamboo *Bambusa vulgaris* from Nigeria. J. Kidela and R. Lagana (Eds) Proceedings of 6th International Symposium on Wood Structure and Properties. Zvolen, Slovakia, September, 6 – 10, 2010. Pub. Arbora, Zvolen, Slovakia. ISBN 78-80-968868-5-2. Pp. 183-186.
- Ogunsanwo OY, Terziev N, Panov D, Daniel G (2015) Bamboo (*Bambusa vulgaris* Schrad.) from Moist Forest and Derived Savanna Locations in South West Nigeria-Properties and Gluability. '*Nigerian bamboo*,' *BioResources* 10(2):2823-2835.
- Panshin AJ, De zeeuw C (1980) Textbook of Wood Technology, 4th edition. McGraw-Hill, New York, USA, pp. 722.
- Pliura A, Yu Q, Zhang SY, Mackay J, Perinet P, Bousquet J (2005) Variation on wood density and shrinkage and their relationship to growth of selected young poplar hybrid crosses. *Forest Science*, 51(5):472-482.
- RMRDC (2003) Report of the Multidisciplinary Task Force on Wood and Wood Products. Raw Materials Research and Development Council Publication. 2004.
- RMRDC (2004) Bamboo Occurrence, Distribution and Utilization In Nigeria. Raw Materials Research and Development Council Publication.2004.
- Santhoshkumar R, Bhat KV (2014) Variation in density and its relation to anatomical properties in bamboo culms, *Bambusa bambos* (L.) Voss. *Journal of Plant Sciences*, 2(3):108-112.
- Shah DU, Bock MCD, Mulligan H. Ramage MH (2016) Thermal conductivity of engineered bamboo composites. *J Mater Sci.*, 51:2991–3002
- Yu HQ, Jiang ZH, Hse CY, Shupe T (2008) Selected physical and mechanical properties of Moso bamboo (*Phyllostachys pubescens*). *J Trop Forest Sci* 20(4): 58-263.