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I equally give thanks and appreciate our highly respectable reviewers and contributors for their invaluable contributions to the success of this journal.

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CONTENTS

GLUED-LAMINATED BEAMS: ASSESSMENT OF PHYSICO-MECHANICAL PROPERTIES OF LOCALLY SELECTED TIMBER SPECIES

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ABSTRACT

Timber application has a long history as a building material due primarily to his continued use for framing, cladding, flooring and flooring for major construction such as bridges, wharves, railways, sleepers etc. as well as domestic and industrial buildings. This paper assesses the suitability of three selected Nigerian timber species namely; *Guarea cedrata*, *Pterygota macrocarpa* and *Antiaris toxicaria* in production of Glued-laminated (glulam) beams. The glulam beams were produced with the use of polyvinyl acetate glue. (PVA). Physical properties of the timber species such as moisture content (MC) and densities were determined using BS EN 304:2001. The beams produced which are 1680mm by 150mm 120mm in dimension were later subjected to four point loading system to determine their flexural strengths and failure loads in accordance with ASTM D-198,(2003). The results produced showed that, the density of *Guarea cedrata* is 681.4:655.4 kg/m³, *Pterygota macrocarpa* is 648.00kg/m³:479.60 kg/m³ and *Antiaris toxicaria* is 471.79kg/m³:445.75 kg/m³ of solid to glulam respectively, while maximum load on each specie from flexural strength test indicated that, *Guarea cedrata* is 29.90kN:15.6kN, *Pterygota macrocarpa* was 29.7kN:14.43kN and, *Antiaris toxicaria* is 14.13kN:9.6kN for solid and glulam beams respectively. Compressive strength results showed that when loaded parallel to grain the mean result of the timber species are *Guarea cedrata* 23.60N/mm²;23.83N/mm², *Pterygota macrocarpa* 17.68N/mm²;15.83 N/mm² and *Antiaris toxicaria* 13.84 N/mm²;17.11 N/mm² meanwhile compressive strength when loaded perpendicular to the grain the mean result for the solid and glulam of each species are 8.67 N/mm²;8.71 N/mm² for *Guarea cedrata* 5.22 N/mm²;7.69 N/mm² for *Pterygota macrocarpa* and 7.21 N/mm²;6.63 N/mm² for *Antiaris toxicaria*. Solid beams have more flexural strength than the glulam beams and Glulam beams have high compressive strength than solid beams when loaded parallel and perpendicular to grain.

KEYWORDS: Timber, glued-laminated, flexural strength, compressive strength, modulus of elasticity and solid

INTRODUCTION

Glulam or glue-laminated timber, introduced in Europe in the late 19th century, consists of sawn lumber laminations bonded with an adhesive so that the grain of all laminations runs parallel with the long direction. One of the early uses of glulam in the United States was a glulam arch erected in 1934 at The United State Department of Agriculture (USDA) Forest Products Lab in Madison, Wisconsin. Glulam can be manufactured in a variety of shapes and sizes. Curved, tapered, circular, and spiral-shaped members have been manufactured. Straight beams can be designed and manufactured with horizontal laminations (load applied perpendicular to the wide face of laminations) or vertical laminations (load applied parallel to wide face of laminations). The applicability of structural timber to construction was made possible through its desirable qualities such as lightness, aesthetics and eco-friendliness. However, continuous use of timber for structural purposes is herculean task due to anisotropic nature of timber species. Advanced societies have developed and modified their sawn timber species through glue application in form of glue-laminated structural members such as beams, columns, joist etc. Nigeria timber species are yet to be fully explored along glued-laminated beams production.

Glulam is normally manufactured using lumber with the moisture content in the range 10–16%. It generally

comes with camber or upward deflection when manufactured with a moisture content of less than 12% and used under conditions where the moisture content is less than 12%, glulam is practically free from shrinkage and swelling. Dry condition is assumed when the moisture content during service does not exceed 16%. Wet use condition is assumed when the moisture content during service exceeds 16%. However, glulam is seldom used in wet condition; the strength characteristics of glulam are stronger in the longitudinal direction and weaker in the transverse direction. Manufacturers place high grade lumber near the surface (top and bottom), and use low grade lumber for the center (near the neutral plane). All joints (between lumber pieces in a lamination) must be of the scarf or at least of the finger type. Strength reducing joints and knots are staggered (Manja *et al.*, 2010). Laminating allows control over the location of material of different quality within the member cross-section. By placing the strongest material in the regions of greatest stresses (near the top and bottom in the case of a flexural member), member performance can be improved. Laminating also allows the dispersion of lumber defects throughout the length of the member. Glulam is commonly used as a replacement for sawn lumber when higher-sized lumber is unavailable. In practice, sawn lumber beams of nominal size greater than 6×18 (length over 25 ft.) are difficult to obtain. In these situations, glulam or

other prefabricated members can be used. There are additional advantages that come with the use of glulam. Allowable strength properties of glulam are generally superior to those of sawn lumber. Glulam is a dimensionally stable material with average moisture content of 12%, compared with about 30% for sawn lumber (green). Adhesives used in glulam are not combustible and they do not lose strength under heat. Because of all these, glulam is commonly used as purlins, joists, headers, beams, and truss members. (Regina *et al.*, 2010).

Glulam is an engineered stress-rated product produced by face bonding individual lumber laminations. The thickness t of the laminations is 6.3–51.0mm. The most common application is for beams. Glulam is assembled by positioning laminae of various grades in the cross-section to create a member that can resist expected design stresses. Generally, the highest quality material is placed in the outer zones of the beam where the bending stresses are highest. For more detailed information, Lumber used for glulam is either visually graded for laminating grades or machine-stress-rated (E-rated) lumber grades. Allowable properties are derived from the principles set forth in ASTM D-3737, (1999). Allowable properties are targeted at 2.1 times the 5th percentile of the actual strength distribution from tests. Design follows the Timber Construction Manual (AITC, 1998) or the NDS (National Design Specification for Wood Construction) (AF&PA, 1997). The published work on FRP reinforced wood has been 'proof-of-concept' studies that have focused on short-term response of mostly reinforced rectangular glued-laminated beams (glulam). A basic understanding of FRP–wood bond issues, optimum FRP composition for compatibility with wood, optimum FRP–wood structural Members geometries and material properties, and modeling of long-term behavior are all fundamental science and engineering issues that still must be addressed. As in the development of reinforced and Pre-stressed concrete, basic engineering and material science research are needed to unlock the full potential of a wide variety of FRP (Fiber reinforced polymer) reinforced wood structural members, e.g., beams, columns, panels and connections. The versatility of timber finds wide application in the construction industry spanning from simple framing in housing projects to large scale public facilities. However, because sawn wood has restrictions to spans and cross-sectional dimensions due to size of tree as well as strength reducing features which occur at growth, its value as a structural material for extensive structural applications is limited.

Engineered wood products such as glue laminated timber (glulam) were therefore developed to improve the use of natural timber beyond its natural limitations. Structural glued laminated timber is an engineered structural timber glued up from suitably

selected and prepared pieces of stress graded lumber either in a straight or curved form with the grain of all pieces essentially parallel to the longitudinal axis of the member (APA, 1996),

According to the American plywood association (APA, 2013), glulam has remained the most resource-efficient approach to wood building products when it comes to optimizing products from a carefully managed timber resource. Glued laminated wood can be built out of defective wood without losing its strength properties. The application of glue laminated timber as a construction material would therefore make many species of timber previously regarded as non-merchantable useful for structural purpose. Clearly, this has the potential to revamp the forestry industry making it a massive employer of labor. Glulam can also be manufactured from small diameter fast growing tree, thereby bridging the supply deficit from slow growing trees (Evalina *et al.*, 2010).

According to the American institute of timber construction (AITC, 1993), structural glued laminated timber refers to an engineered, stress-rated timber product comprising assemblies of suitably selected and prepared wood laminations bonded together with adhesives. Glulam is used for beams, arches or columns consisting of several laminates of timber arranged parallel to the longitudinal axis of the member with the individual pieces assembled with their grains approximately parallel and glued together to form a member which functions as a single structural unit. This is often achieved by using different layers or fragments of timber glued or compressed in different directions, creating a new material. In order to obtain larger spans, finger-joints or other equivalent connections are used to bond different timber elements in the same horizontal layer (Abubakar and Nabade, 2013). In elements of this type, any strength reducing features, such as knots, that exist in the individual laminates are leveled out, unlike a solid timber element from the same piece. Furthermore, glulam offers the possibility of obtaining larger cross-sectional dimensions and longer lengths than solid timber (Manja *et al.*, 2010).

MATERIALS AND METHODS

The materials used for this research include three visually graded timber species locally sourced from Ado-Ekiti, Ekiti State, Nigeria according to BS 5268 (2002) namely (Obobo) *Guarea cedrata*, (*Oporoporo*) *Pterygota macrocarpa*, and (Oriro) *Antiaris toxicaria* polyvinyl acetate glue conforming both to B.S. EN 304 (2001) was used for the lamination. Wood processing machines and equipment including the flexural testing machine and compression testing machine were sourced and used for the research. These are all available at Wood workshop of Building Technology Department and Civil Engineering Department of Federal Polytechnic, Ado-Ekiti.

Preliminary tests to determine the physical properties (moisture content, MC and density) of wood were carried out using 3 (three) numbers of specimen dimensioned to be 50 mm x 50 mm x 50 mm per species in line with BS 386 2003. In order to allow natural drying process to take place, the species were subjected to natural seasoning after which the wood were dimensioned in line with ASTM D-198 as 1680mm x 150mm x 20mm for static bending test as shown in Figure 1 using circular saw machine. A total number of 15 specimens were prepared using polyvinyl acetate glue to make a 6-member lay-up (Figure 2). Moisture contents and densities of the glued laminated beams were determined by cutting a 120mm by 100mm by 50mm size close to region of failure from the failed beams. Compression test specimens were cut from samples of Flexural strength for two points loading was calculated using Equation 1

$$\text{Flexural strength } (f_m) = \frac{aP_{\max}}{2Z} \quad (1)$$

where ;

$P_{\max}$ is maximum applied load (N)

L is material span length between points in the test set up (mm)

b is width of the material specimen (mm)

d is average depth of the specimen (mm)

a is the distance from point of load application to bearing/support (mm)

In equation (1) above,

$$Z \text{ is the section modulus} = \frac{bd^2}{6} \quad (2)$$

b , h and l is the beam width, beam depth and beam span in mm respectively.

The two point and three point bending strength tests as specified by BS EN 408 (2003) and ASTM D-198 (2000) are used to carry out tests on the mechanical properties of glued laminated beams. Figure 1.3 further illustrates the typical setup for a four-point loading system used in this research.

Compressive strengths of the species were determined in compliance with ASTM-D198. The samples were loaded perpendicularly and parallel to grain of the timber. The compressive strength was calculated using Equation 3.

$$\sigma = \frac{P_{\max}}{\text{Surface Area}} \left(\frac{N}{\text{mm}^2} \right) \quad (3)$$

Modulus of Elasticity is described as a measure of resistance to bending deflection relative to stiffness, the procedure to determine Modulus of Elasticity for glulam products is fully described in ASTM D-198 (2003). Determination of elastic modulus was determined experimentally from the relationship between maximum deflection ($\Delta_{\max}$) at the center and maximum applied load ($P_{\max}$) from Table X2.1 of ASTM-D198 (2003), modulus of elasticity was defined as indicated in Equation 4.

$$E = \frac{P'a}{4bh^3\Delta} (3l^2 - 4a^2) \quad (4)$$

Where

P' is the load on beam at deflection, (N) below proportional limit

Δ is the deflection of beam at neutral axis between reaction and center of beam at the proportional limit, in. (mm)

a is the distance from point of load application to bearing/support (mm)

b is the width of beam in (mm)

RESULTS AND DISCUSSION

Moisture Contents

The results presented in table 1 below shows that the mean, standard deviation and coefficient of variation of moisture contents (MC) for (Obobo) *Guarea cedrata*, (Oporoporo) *Pterygota macrocarpa*, and (Oriro) *Antiaris toxicaria* timber species at purchase are given as 43.43%, 37.25% and 42.5% respectively with the corresponding coefficients of variation (COV) 0.072, 0.045 and 0.032. The standard deviations are also given in this order as 3.17, 1.66 and 1.35 respectively before seasoning of the timber species. The mean values of MC with respect of all the three species after seasoning are 17.71%, 17.19% and 16.49%. These values all lie within 12 to 18% as specified by the Nigerian code of practice (NPC, 2 1973), BS EN 1995-1-1 (2004), BS 5268 (2002) for glulam production. Table 3 shows that, *Antiaris toxicaria* contained most moisture before commencement of glulam production having lost 26.01% of moisture.

Density

The mean values of density (ρ) for the solid of the three species are respectively given by 500,380 and 300 kg/m³ with the corresponding values of standard deviations of 0.008, 0.0025 and 0.024 (Table 2). Likewise, coefficients of variation (COV) for densities of the species are respectively in the same order as 0.016, 0.0066 and 0.079. The result showed that *Guarea cedrata* is the hardest with density of 500kg/m³.

Compressive strength

Results of compressive strength of solid and glulam beam when loaded parallel to the grains indicates that glulam beam of *guarea cedrata* and *antiaris toxicaria* has the highest mean when loaded parallel to the grains of the species than the solid of the same beam while the solid of *pterygota macrocarpa* has the highest mean than the glulam of the same timber specie (Table 3). Furthermore, , results of compressive strength of solid and glulam beams when loaded perpendicular to the grains indicate that solid beams of *pterygota macrocarpa* and *antiaris toxicaria* has the highest mean when loaded perpendicular to the grains of the species than the glulam of the same beam, while the glulam of *guarea cedrata* has the highest mean than the solid of the same timber specie (Table 4).

Flexural Strength

There is a variation in the resistance of the woods to the external loads (Table 5). At rupture, the failure loads on the beams were found to be 29.90kN and 15.6kN; for *Guarea cedrata*, 14.13kN and 9.6kN for *Antiaris toxicaria* and 29.7kN and 14.43 for *Pterygota macrocarpa*. These results show that *Guarea cedrata* has the highest resistance to axial loads as a solid beam when *Antiaris toxicaria* has a low resistance as a glulam beam. While there is little variation in the loading resistance of *Antiaris toxicaria* with 14.13kN;

9.6kN, this shows that the glue ability of *Antiaris toxicaria* is higher than other beams. The results show that there was a decrease in the bending strength of both the solid and glulam beams simultaneously for two species out of the three species used for carrying out the experiment and the two species are *Guarea cedrata* and *pterygota macrocarpa* while the third specie which is *Antiaris toxicaria* has no increase or decrease in the bending strength while carrying out the experiment .The highest increase of bending strength in laboratory test occurred in *Guarea cedrata* with average bending strength of specimens of 5.12 N/mm² and 6.59 N/mm² (Table 6) of solid and glulam beam respectively.

Modulus of elasticity

The results showed that there was a decrease in the bending strength of glulam timber beams compared to solid timber beams. The highest increase of modulus of elasticity occurred in *Guarea cedrata* with average MOE of specimens of 65610 N/mm² and 56800 N/mm² (Table 7) of solid and glulam beam respectively. Glulam beams of *Pterygota macrocarpa* and *Antiaris toxicaria* both offer less stiffness compared to their solid components significantly while the difference in terms of MOE for *Guarea cedrata* is less significant.

CONCLUSION AND RECOMMENDATION

Physical investigation of the species carried out that *Guarea cedrata* is a hard wood considering the density while the remaining two species are soft as presented. To further show the characteristic strength, *Guarea cedrata* has the highest compressive strength when loaded both parallel and perpendicular to grain for both solid and glulam components. This is a clear indication that the wood has high load carrying capacity when subjected to axial loading. The results of flexural strength for the three species were very low when compared with standard, however could largely be as a result of local environmental condition and technical know-how in production process.

From the foregoing, the research has further showed the applicability and usage of local timbers for glulam productions. The species when subjected to more advanced production and technical processes will be suitable for structural components such as light-weight beams, columns etc.

Further research should be channeled to other local timber species to test their suitability for glulam production and other glue components should be investigated to determine the glue-ability of these species with other glue types.

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Figure 1: Two point static bending test setup

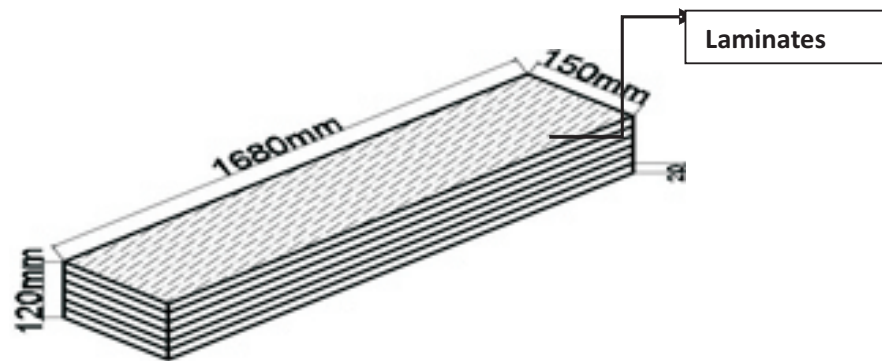


Figure 2: Illustration of member lay-up

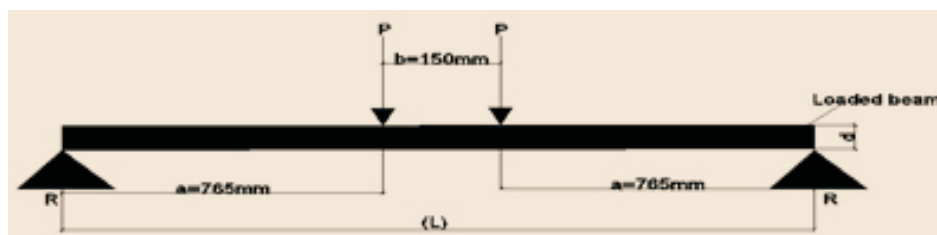


Figure 3: Illustration of Two points symmetrical loading system

Table 1: Summary of moisture content for before and after

MOISTURE CONTENT (%)					
Timber species		Mean	S. D	Variance	COV
<i>Guarea cedrata</i>	Before seasoning	43.43	3.17	10.08	0.072
	After seasoning	17.71	0.61	0.37	0.034
<i>Pterygota macrocarpa</i>	Before seasoning	37.25	1.66	2.74	0.045
	After seasoning	17.19	17.22	296.5	1.002
<i>Antiaris toxicaria</i>	Before seasoning	42.5	1.35	1.83	0.032
	After seasoning	16.49	15.55	241.76	0.943

Table.2 Summary of Density of Timber Species of study

Timber Species	Mean (g/cm ³)	S.D	Variance	COV
<i>Guarea cedrata</i>	0.50	0.008	0.000064	0.016
<i>Pterygota macrocarpa</i>	0.38	0.0025	0.000006	0.0066
<i>Antiaris toxicaria</i>	0.30	0.024	0.000576	0.079

Table 3 Summary of compressive strength result when loaded

COMPRESSIVE STRENGTH TEST RESULT (N/mm ²)					
Timber species		mean	S. D	COV	Variance
<i>Guarea cedrata</i>	Solid	23.60	23.92	1.01	572.0
	Glulam	23.83	24.30	1.02	590.6
<i>Pterygota macrocarpa</i>	Solid	17.68	17.69	1.0	312.9
	Glulam	15.83	15.84	1.0	250.8
<i>Antiaris toxicaria</i>	Solid	13.84	13.92	1.0	193.7
	Glulam	17.11	17.24	1.0	297.3

Table 4 Summary of compressive strength result when loaded

COMPRESSIVE STRENGTH TEST RESULT					
Timber species		Mean (N/mm ²)	S. D	COV	Variance
<i>Guarea cedrata</i>	SOLID	8.67	8.67	1.0	75.25
	GLULAM	8.71	8.71	1.0	75.89
<i>Pterygota macrocarpa</i>	SOLID	7.69	7.69	1.0	59.20
	GLULAM	5.22	5.22	1.0	27.28
<i>Antiaris toxicaria</i>	SOLID	7.21	7.22	1.0	52.15
	GLULAM	6.63	6.63	1.0	43.97

Table 5: Flexural test result of the timber beam perpendicular to

TIMBER SPECIES		Weight (kg)	Density (kg/m ³)	Max. Load (kN)	Deflection (mm)
<i>Guarea cedrata</i> {Obobo}	SOLID	15.7	681.4	29.90	34.77
	GLULAM	15.1	655.4	15.6	74.43
<i>Antiaris toxicaria</i> {Oriro}	SOLID	10.87	471.79	14.13	27.67
	GLULAM	10.27	445.75	9.6	74.33
<i>Pterygota macrocarpa</i> {Oporoporo}	SOLID	14.93	648.00	29.7	41.00
	GLULAM	11.05	479.60	14.43	72.00

Table 6: Summary of flexural strength result of solid and glulam beam of the selected timber species

Species		Mean (N/mm ²)	S.D	COV	Variance
<i>Guarea cedrata</i>	Solid	5.12	7.87	1.54	61.88
	Glulam	6.59	9.33	1.42	87.12
<i>Pterygota macrocarpa</i>	Solid	6.19	8.75	1.41	76.64
	Glulam	3.0	4.40	1.47	19.39
<i>Antiaris toxicaria</i>	Solid	2.94	4.23	1.44	17.89
	Glulam	2.94	2.88	0.98	8.29

Table 7: Summary of Modulus of elasticity result of solid and glulam beam of the selected timber species

Species		Mean (×10 ³) (N/mm ²)	S.D	COV	Variance
<i>Guarea cedrata</i>	Solid	65.61	98.62	1.50	9726.71
	Glulam	56.80	80.65	1.42	6504.94
<i>Pterygota macrocarpa</i>	Solid	67.18	87.48	1.30	7652.02
	Glulam	22.53	32.57	1.45	1060.67
<i>Antiaris toxicaria</i>	Solid	40.75	58.58	1.44	3431.93
	Glulam	16.52	24.17	1.46	584.24

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