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Bending Strength Evaluation of Glulam Beams Made from Selected Nigerian Wood Species

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ABSTRACT

Bending strength, was assessed in glued laminated beams made from local wood species bonded with phenol resorcinol formaldehyde, polyurethane and urea-formaldehyde adhesives. The 3- point loading was used as the basis of bending strength assessment along the directions parallel and perpendicular to the glue line. The load orientation parallel to the glue line offered higher bending strength. Furthermore, the characteristic values of bending strength obtained were 35.16 N/mm^2, 40.79 N/mm^2, 47.34 N/mm^2, 60 N/mm^2, and 67 N/mm^2 for Afara, Akomu, Gmelina, Iroko, and Omocedar wood species. These values are similar to strength values given in EN 1194-1999 for glulam beams. Consequently, the findings of the study are beneficial to architects and structural engineers in exploring the dimensional, strength, and architectural flexibility glulam affords for both beam and column design and holds the potential for creating an industrial hub for enhancing the value chain around engineered wood and allied industries.

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1. INTRODUCTION

Support for sustainability in the built environment continues to grow as threats to the natural environment have been identified [1, 2]. A part of this support focuses on sustainable and renewable building and civil engineering materials [3, 4]. Construction materials that advance the course of sustainability are energy efficient, have low carbon emissions, and are eco-friendly [2]. Wood has been identified as a construction material with excellent environmental credentials to support sustainable development. According to Stokke et al. [5], wood is a porous and permeable cellular solid. It is a hard, fibrous tissue that makes up most of the trunks, branches, and roots of trees in the family of plants known as gymnosperms and dicotyledons.

Wood is a hard fibrous substance that essentially constitutes a tree's trunk and branches. It is defined as a naturaly occurring lignocellulosic polymer material that does not age significantly and is flexible for manufacturing high-quality innovative materials such as glued laminated timber (glulam) [6]. Glulam is an engineered wood product (EWP) composed of stress graded wood bonded horizontally with structural adhesives that can withstand torsion forces and applied service loads [7-9]. Glulam, therefore, has higher strength performance than sawn timber of equal dimension due to the permeability of the wood cellular structure to adhesives which creates a strong bond between selected defect-free laminates [9]. Glulam, a product of adhesive joining offers superior properties than sawn wood and wood joined by other mechanical methods. This is because adhesives ensure uniform stress distribution with lightness of the structure or a high strength - to -weight ratio within the structure and are as such a better and more prevalent jointing method with merits that outweigh other methods of joining wood composite structures [10, 11]. The world over, structural wood application is continuously being advanced as exemplified by low to medium-rise buildings built of

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wood. One of such examples is the Stellar cultural center, Skelleftea in Sweden almost totally built with wood [12]. The availability of wood in Nigeria is vast and should be explored in producing eco-friendly engineering wood products for the building industry. Therefore, this study was conducted to investigate the performance of glulam constituted of native wood. Previous studies have proven that engineering innovations such as EWPs, particularly glulam, improve the mechanical properties of wood beyond its natural limits [9, 13]. Numerous studies spanning decades have constantly established the engineering capability of wood as structural material [14, 15]. Glulam have on these accounts emerged in developed societies as a structural material for a wide range of construction and civil engineering applications [9, 15].

However, Nigeria's academia and building industry have not considered sufficiently the forestry sector as a viable supplier of structural fabrics for extensive structural application beyond ordinary roof and formwork. Therefore, many of the researchers in structural materials have paid little attention to the use of timber for structural purposes. Most of the studies in wood as a construction material have focused on sawn timber [16-19]. Only a few research works have investigated the use of indigenous wood species for glued laminated timber [20, 21].

However, the mechanical and physical properties of timber species such as; Southern pine (Pinus taeda L.), Douglas fir (Pseudotsuga menziesii) and Larch (Larix) wood species have been examined both in the sawn and glulam form [22-24]. Likewise, mechanical behaviour of some Nigerian wood species such as Strombosia pustulata, Macrocarpa bequaerti, Nauclea diderrichii and Entandrophragma cylindrica have similarly been studied [16-17]. However, these studies have either considered glulam elements of foreign timber species or sawn indigenous wood species. Thus, there is a rarity of indigenous research focused on developing Nigerian wood species into glulam beams.

Furthermore, for the few indigenous studies on glulam only non-structural adhesives such as polyvinyl acetate (PVAc) has been considered [20, 22]. PVAc is not suitable for structural wood bonding. The suitability of structural synthetic glues like phenol resorcinol formaldehyde (PRF), Urea-formaldehyde (UF) and Polyurethane (PU) on many Nigerian grown woods have not been extensively studied within the environmental conditions in Nigeria in line with literature [25].

An Implication of the few research efforts in glue lamination of local wood species is the insufficient information on the mechanical capabilities of glulam from Nigeria grown timber species. Hence, this prevents the understanding necessary for setting domesticated performance requirements for glulam structural elements within the local environmental conditions which can influence the mechanical properties of glued structural elements. As the problem of property variance is common to all wood species, it will be inappropriate to directly apply to native wood species performance criteria for exotic species and wood commonly used for glulam most of which are not native to Nigeria. Therefore, it is only proper to study native wood species extensively for their behavior as adhesively bonded structural elements.

Consequently, this study, taking into cognisance the variability of wood (both within and between species as a result of differences in growth conditions due to variation in climatic conditions and silvicultural practices) aims to establish by standard procedures the undocumented characteristic bending strength values of glulam beams produced from Nigerian grown Afara (Terminalia superba) , Akomu (Pycnanthus angolensis), Gmelina (Gmelina aborea), Iroko (Milicia excelsa) and Omocedar (Stereospermum accuminatissimum) using phenol resourcinol , urea formaldehyde and polyurethane structural wood adhesives. Furthermore, this work reports for the first time the effectiveness of these structural adhesives on the Nigerian grown selected wood species. Hence, the glulam beams from these species can offer higher mechanical strength, higher dimension and design flexibility than wood in the traditional form. Therefore, the result of the study is useful for structural design of glulam beams produced from the wood species considered.

2. MATERIALS AND METHODS

The materials used in this research were five freshly cut wood samples of *Terminalia superba* (Afara), *Pycnanthus angolensis* (Akomu), *Gmelina arborea* (Gmelina), *Milicia excelsa* (Iroko) and *Steroespermum acuminatissimum* (Omocedar) with average age of 10 – 15 years obtained from one of the sawmills in Akure. Wood samples of 20mm x 20mm x 60mm and 20mm x 20mm x 300mm were prepared for determination of density and bending strength. Likewise, three (3) structural adhesives; Phenol resorcinol formaldehyde with the hardener component, Polyurethane and Urea Formaldehyde were used as binder. The moisture content of the wood samples was controlled in an electric oven regulated within a temperature range of 103±30 C to attain an average moisture content of 13%. Measurement for density was determined using an electronic weighing balance with precision to 0.1 decimal place. Bending strength test was conducted for determination of bending strength otherwise known as modulus of rupture (MOR) on a 20kN universal testing machine equipped with a computerized data acquisition system at the Department of Forestry and Wood Technology, Federal University of Technology Akure. Planks for the production of glulam specimens made up of three laminates were sized to 6mm x 50mm x 650mm laminates as shown in plate 1 and glued up horizontally on a clamping device for pressure application for 24 hours as shown in plate 2. After setting, laminated samples were resized to a final dimension of 20mm x 20 mm x 300mm as shown in plate 3 for bending strength evaluation.

2. 1. Moisture Content Moisture content was determined by oven drying at a temperature of 105 0C for 24 hours and was then determined as extracted from literature [26] using Equation (1):

$$MC = \frac{W_g - W_d}{W_d} \times 100 \quad (1)$$

where W_g is the green weight and W_d is the oven dry weight.

2. 2. Density Determination Density (ρ) was determined according to ASTM [27] after oven-drying for 24 hours using Equation (2):

$$\rho = \frac{M}{V} \quad (2)$$

Plate 1. Wood laminates for glue lamination

Plate 2. Improvised clamping system for pressure application

Plate 3. Finished glued laminated beam ready for testing

2. 3. Static Bending Test Bending strength (σ) was determined on a total of 50 solid wood beam specimens (control sample) and 300 glulam wood beam specimens using 3-point loading applied at a distance of 130mm away from each support as shown in Figure 1.

The modulus of rupture was then calculated using Equation (3):

$$\sigma = \frac{3 \times P_{max} \times L}{2 \times b \times h^2} \quad (3)$$

where P_{max} is the maximum load applied to point of failure (N), L is span of the specimen (mm), b is breadth of the specimen (mm) and h is depth of specimen (mm).

2. 4. Modulus of Elasticity (MOE) This was determined using Equation (4):

$$MOE = \frac{PL^3}{4 \times \Delta \times b \times h^3} \quad (4)$$

where P is load at the limit of proportionality (N), L is the loading span of the test specimen (260 mm), b and h are breadth and depth of the test specimen (mm) and Δ is deflection at the limit of proportionality (mm).

3. RESULTS AND DISCUSSION

3. 1. Density The result of the density of control specimen and glued laminated beams for each wood species laminated with PR, PU, and UF adhesives respectively is illstrated in Figure 2. The effect of adhesive type on the density of the glulam beams was assessed using ANOVA. It is observed across all the species laminated with PR, PU and UF adhesives that no significant change in density was recorded as a result of the different adhesives when the species type is held constant. Similarly, the difference in density between the treatment and control group was marginal and as a result insufficient to adduce to the gluing process. This is due to the fact that the glue lines of the laminated beams are thin and that the pressure application of the gluing process did not densify the laminated beams to give rise to significant density increase in the laminated wood beams over that of the raw material. This finding is similar to the reported data by Komariah et al. [28].

3. 2. Influence of Wood Species, Load direction and Adhesive on the Bending Strength of Glulam Beams The mean bending strength of glued

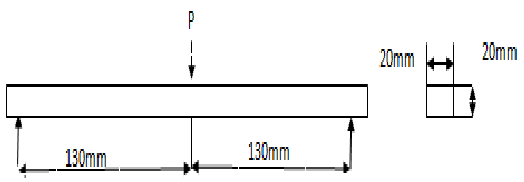


Figure 1. Static bending test setup

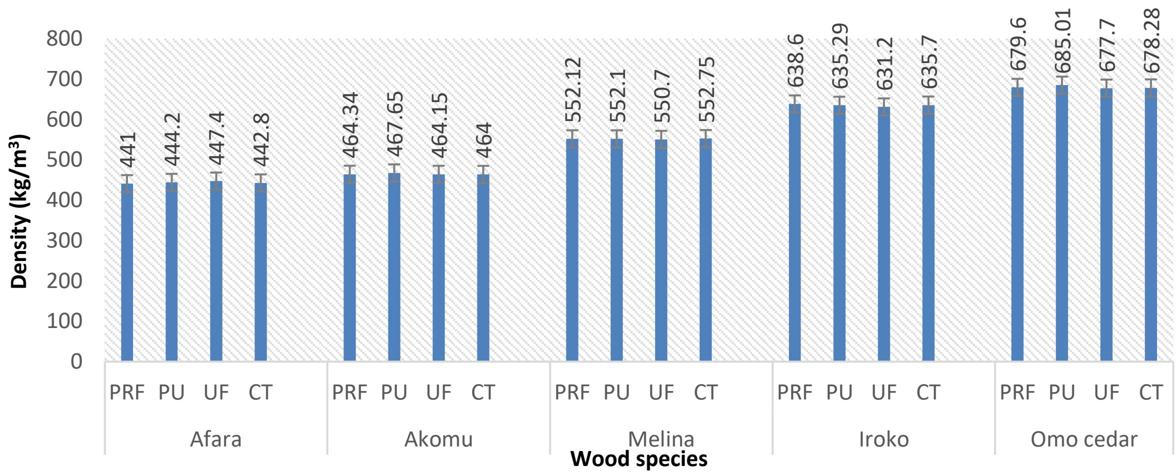


Figure 2. Density of glued laminated wood species at an average moisture content of 13%, CT is the Control specimen for each of the species

laminated beams of *Afara*, *Akomu*, *Gmelina*, *Iroko* and *Omocedar* species bonded with phenol resorcinol, polyurethane and urea-formaldehyde adhesive in Figure 3 showed that wood species and load direction had a significant effect ($p < 0.05$) on MOR values of the glued laminated beams. On the contrary, the effect of adhesive was not significant ($p > 0.05$) on the MOR values of glued laminated beams. Thus, the finding aligned with that reported in literature [29-31].

Similarly, the load direction had a statistically significant effect on the MOR values of the glued laminated beams. Load direction has a significant effect on the mean bending strength values of wood composites thus agreeing with some earlier studies [31-33]. Furthermore, the findings of this study also align with data reported by Burdurlu et al. [32] that mean bending strength values are higher in the edgewise direction than in the flatwise direction. The edgewise direction, which is the direction when the load application is parallel to the glue line is the stronger axis and the preferable axis for load application for non- bi-axially loaded beams [34].

The adhesive types in this study have no significant difference in the mean MOR values of the glulam beams. This is not because adhesive type do not affect mechanical properties in wood. However, for this study, the adhesive types considered are adhesives belonging to the same class type generally known as thermosetting adhesives; these are important adhesives in the class of wood adhesives used for structural gluing and standardized in EN 301 [35]. Therefore, the apparent lack of statistically significant difference in performance is due to class relationships and the consequent similarity in performance. This observation is similar to the findings reported by Bal and Bektaş [31].

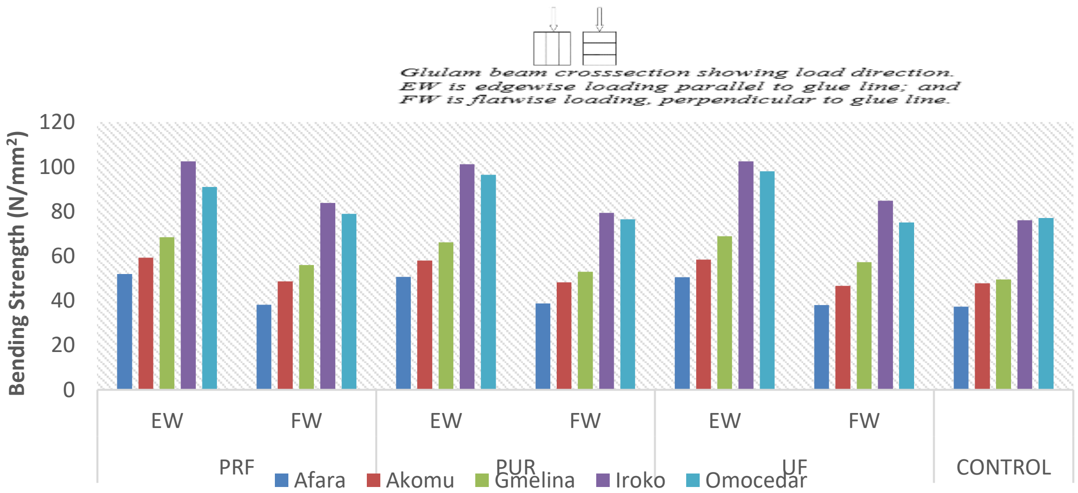
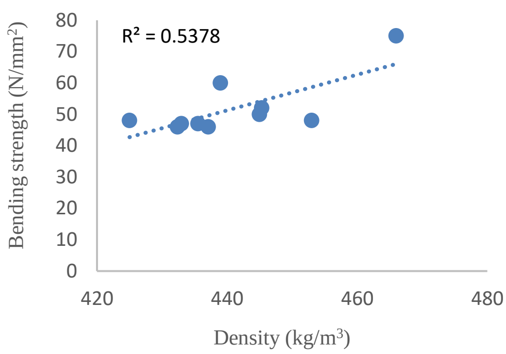


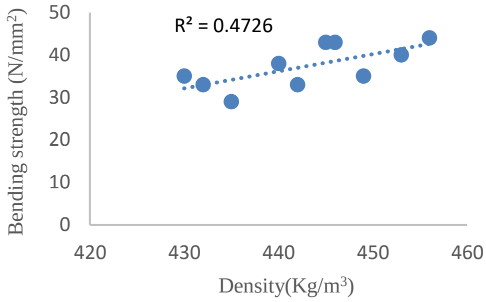
Figure 3. Effect of wood species, load direction, and adhesive on MOR of glulam beams

3. 3. Relationship between Density and Bending strength of Glulam Beams The influence of density on the mechanical property of structural elements is well established [36, 37]. This relationship in glued laminated beams was investigated. Bending strength - density plots were generated from the experiments conducted. The representative plot for the MOR – density relationship for the specimens is shown in Figures 4a and 4b. A good relationship was generally found between the density of glued laminated beams and the respective bending strength values. By a good relationship, it is meant that the positive correlation between MOR and wood density ranged from moderate to strong. Moderate positive correlation ranging from 0.3 to 0.7 while strong positive correlation ranges from 0.7 to 1.0 [38]. While control specimens showed similar relationship, the correlation values between bending strength and density were largely higher in glued laminated beams (0.54) in Figure 4a compared to the control specimen (0.47) in Figure 4b. This trend could be due to the fact that it is possible to select laminates of known density prior to gluing as against the natural constitution of solid wood beams which cannot be altered in the sawn state.

3. 4. Characterization of Reference Properties of Glulam Beams from the Selected Species The characteristic reference material properties such as density, MOE and MOR for the glulam beams were derived using Equation (5):



(a) Glulam beams



(b) Control beam

Figure 4. MOR - Density plot for *Afara* glulam beam and Control beam specimens

$$C_{bs} = \text{Xfb} - 2.33\text{S} \quad (5)$$

where C_{bs} is the chatacteristic material property , Xfb is the mean of the property considered and S is the standard deviation of the population.

The characteristic values represents a lower limit value which 99% of the samples surpass [39, 40]. The characteristic values of bending strength which is the index property for glued laminated beam for strength classification were considered along the edgewise load direction as shown in Tables 1, 2 and 3. It is seen from this study that the values were 35.16N/mm2 for Afara beams, 40.79N/mm^2 for Akomu, a higher value of 47.34N/mm^2 was recorded for Gmelina beams, while 60N/mm^2 and 67N/mm^2 were obtained for Iroko and Omocedar beams respectively. The characteristic bending strength values obtained from this study compares with values of glued laminated timber beams used for structural application. BS EN 1194 [41] gives the characteristic bending strength class of glulam beams. This standard recognizes four strength classes; GL 24, GL 28, GL32 and GL 36. These strength classes mean glued laminated beams with characteristics bending strength of 24N/mm^2, 28 N/mm^2, 32N/mm^2, and 36N/mm^2. For example, GL 32 means glued laminated beam with characteristic bending strength of 32N/mm^2. Thus, the values obtained in this study for the selected species compares with the classification of BS EN 1194 [41] as shown in Table 3.

TABLE 1. Characteristic value of density of edgewise loaded glued laminated beams from the selected wood species

Species	Mean Density (kg/m³)	Standard deviation	Coefficient of Variation	Characteristic value of Density (kg/m³)
Afara	444.13	11.48	2.58	417
Akomu	462.50	20.62	4.46	414
Gmelina	552.73	9.76	1.76	530
Iroko	634.23	24.97	3.93	576
Omo cedar	681.53	33.18	4.86	604

TABLE 2. Characteristic MOE value of edgewise loaded glued laminated beams from the selected wood species

Species	Mean MOE (N/mm^2)	Standard deviation	Coefficient of variation	Characteristic value of MOE (N/mm^2)
Afara	5203 ± 344.4	922	17.72	3054
Akomu	6583 ± 314.27	841	12.78	4622
Gmelina	7316 ± 669.56	1793	24.51	3138
Iroko	10566 ± 1419.97	3802	35.99	1706
Omo cedar	10966 ± 863.18	2311	21.08	5580

TABLE 3. Characteristic MOR value of edgewise loaded glued laminated beams from the selected wood species

Species	Mean MOR (N/mm^2)	Standard deviation	Coefficient of Variation	Characteristic value of MOR (N/mm^2)
Afara	51	6.8	0.13	35.16
Akomu	58.5	7.6	0.13	40.79
Gmelina	67.8	8.78	0.13	47.34
Iroko	102.6	18.4	0.18	60
Omo cedar	97.08	12.92	0.13	67

3. 4. Adjustment of Three Point Edgewise Bending Strength to Four Point Values

It is established in literature that the value of MOR is dependent on the method of strength evaluation. Destructive strength evaluation of MOR using 3-point loading yields higher values of MOR than evaluation by 4-point loading as a result of the location of the maximum moment and maximum axial fiber stress [42]. Hence, to make the results of this study comparable to EN 408 standard and EN384 based on the 4-point method of bending strength evaluation, the values of MOR from this study were corrected to values equivalent to 4-point evaluation. The conversion was done using the regression equation between 3-point and 4-point MOR as proposed by Hein and Brancheriau [42]. The properties of the regression equation used for this conversion are; R^2 of 0.74, Standard error of estimation (SEE) of 7.87. Figure 5 shows the MOR values from the laboratory test using the 3-point evaluation and the adjustment to the corresponding 4-point values according to Hein and Brancheriau [42] using Equation (6):

$$MOR4p = 0.889 \times MOR3p + 5.14 \qquad (6)$$

The values of bending strength are presented in Figure 5 for all the glued laminated beams from the selected species evaluated by 3-point bending test and adjusted to 4-Point bending strength values using equation 6. It is shown from Figure 5 that there was strength reduction when the 3-point MOR values were adjusted to 4-point MOR values. The mean value of Afara which was 51N/mm^2 upon adjustment is seen to be 50.47N/mm^2. Similarly, Akomu glued laminated beams upon adjustment were reduced from a mean 3–point MOR of 58.53N/mm^2 to 4-point MOR of 57.16 N/mm^2. Likewise, Gmelina glulam beams with a mean bending strength of 67.76N/mm^2 from the 3-point evaluation are reduced to 65.38N/mm^2 equivalent 4-point MOR. Also, Iroko beams with 102.6N/mm^2 mean 3- point MOR were

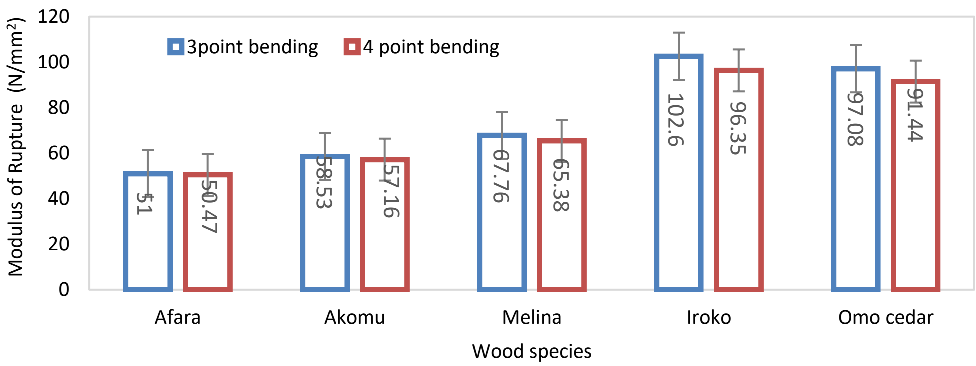


Figure 5. 3- point MOR adjusted to 4- Point MOR values

adjusted to a 4 –point MOR reduced mean value of 96.35N/mm^2. Lastly, Omo cedar glulam with mean 3-point MOR of 97.08 N/mm^2 were also adjusted to 91.44N/mm^2.

3. 5. Adjustment of Four Point Edgewise Bending Strength to Reference Depth of 150mm

The values of the bending strength were adjusted to the reference depth of 150 mm using Equation (7). This equation is applied because the depth of the test piece deviates from the specimen specification of EN 408 [43]. This adjustment is permissible only for bending strength and tensile strength according to clause 5.3.4.3 of EN 384 [44]. The adjustment of bending strength to reference depth is achieved by multiply the bending strength of the test specimen by a factor obtained using Equation (7):

$$k_h = \left(\frac{150}{h}\right)^{0.2} \tag{7}$$

where k_h is the depth adjustment factor as specified by EN 408 [43] and h is the depth of the specimen which is 20 mm The results of applying this value is shown in Figure 6. From Equation (7) the mean 4-point bending strength of the glued laminated beam in Figure 5 are scaled up to reference depth of 150 mm such that for any given glued laminated beam with bending strength β N/mm^2 at the depth h = 20 mm for the test specimen, the adjusted bending strength to reference depth would be $\beta \times k_h$:

where k_h is $\left(\frac{150}{20}\right)^{0.2}$ = $(7.5)^{0.2}$ = 1.149

Therefore, the adjusted bending strength to reference depth of 150mm = β N/mm^2 × 1.149.

The result in Figure 6 termed 4p MOR adjusted to 150mm ref. depth was obtained by multiplying results of the corresponding 4p MOR by a factor of 1.149 so as to reflect MOR values to the reference depth of 150 mm. Shown in Figure 6 are values of glued laminated beams from the selected wood species. The results were converted to 4-point MOR values using Equation (6). These results were further scaled up to reference depth of 150mm in line with EN 408 [43]. It is shown in the same figure that the bending strength of *Afara* with mean 4-point MOR of 50.47 N/mm^2 was scaled up to a 75.5N/mm^2 .Similarly, *Akomu* glulam beams were scaled up to a mean MOR of 85.52 N/mm^2. Also, *Gmelina* show a mean MOR of 97.81 N/mm^2 at the reference depth of 150 mm. Likewise, the mean MOR of *Iroko* and *Omocedar* increased to 144.14 N/mm^2 and 136.8 N/mm^2 respectively. Furthermore, the values of stiffness (MOE) for the edgewise and flatwise tested glued laminated beams from the selected species are presented in Figure 7.

3. 6. Fracture Mechanism in Glulam Beams

The fracture of the glulam beams investigated in this research was characterized by different forms of tension failure at the ultimate stress limit which developed at the bottom fiber of the beams under the applied load towards the compression region at the top as shown in plate 4. The fracture is seen as cracks which developed due to tension parallel to grain splitting the bottom laminates of the wood. Where wood grains are oriented parallel to the longitudinal axis, simple tension failure mechanism develops as the major fracture pattern [45].

From the topmost beam which is *Afara* to *Akomu* the second beam, splintering tension failure was observed with ragged breaks occurring in the wood fiber. The glue lines are shown to be avoided along the path of the crack progression. This indicates the integrity of the glue lines. Furthermore, from the middle third beam which is *Gmelina*, to *Iroko* and *Omo cedar*, the fracture is characterized by a combination of simple tension failure and some cross-grain tension failure occurring from the bottom fibers towards the compression region. Furthermore, plate 5 shows the case of severe cross- grain tension failure in *Afara*, *Gmelina* and *Omo cedar* glulam beams. Cross-grained tension is characterized by a diagonal crack from the bottom and splitting through to

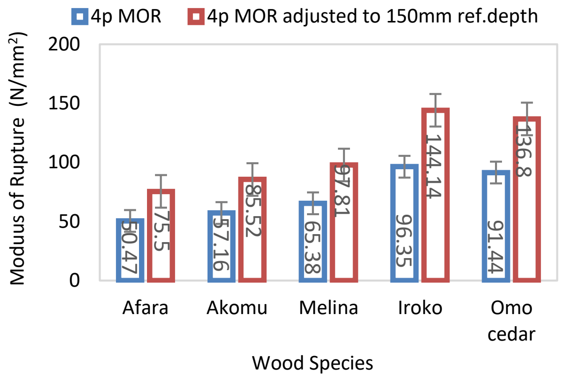


Figure 6. 4- point MOR values adjusted to reference depth of 150mm

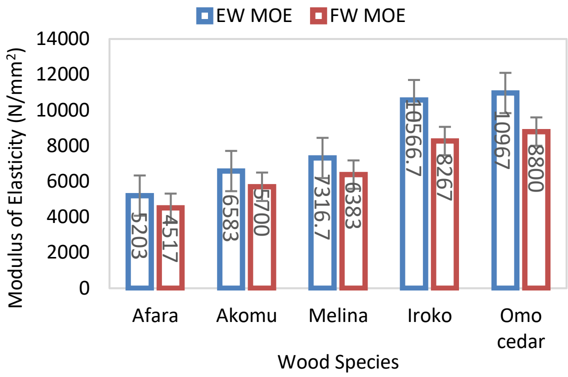


Figure 7. Stiffnes values in the edgewise (EW) and flatwise (FW) load direction

Plate 4. Fracture form of glulam beams from up to down: Afara, Akomu, Gmelina, Iroko and Omo cedar wood species

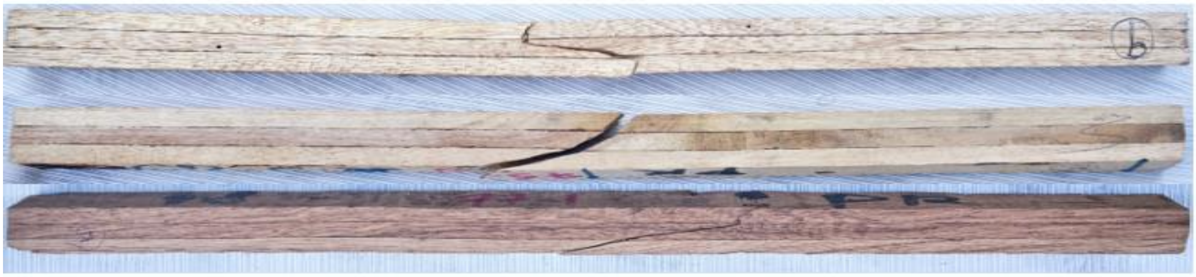


Plate 5. Cross grain tension failure in glulam beams

the top of the wood. Cross grain results when the grain of the wood deviates from being parallel to the longitudinal axis. Consequently, tensile stress resulting from flexural load acts in a manner sloping to the grains to produce oblique cracks as shown in plate 5. The tensile capacity of wood is severely low across the grain than parallel to the grain [45]. As a result, cross-grained wood resulting from wrong sawing method or natural defect is not suitable for glulam elements designed as flexural members as such members relying on tensile strength perpendicular to grain (which is reportedly 10% that parallel to the grain) suffer severe tension failure [45, 46]. For the topmost and bottom member in *Afara* and *Omo cedar*, the cross-grain failure was relatively ductile as the beam was not completely severed. However, for *Gmelina*, the cross-grain tension failure was brittle as seen by the complete severing of the beam into two from bottom to top. Thus, the study corroborates findings in literature that tension failure is severe in cross grain wood under flexural stress [45-46].

4. CONCLUSION

The selected Nigerian wood species are glueable using PR, PUR and UF hence the advantages of higher strength and dimension for extensive structural application can be derived from these wood species in the glulam form than wood in the traditional form. It is shown also that wood species with higher densities offer higher characteristic bending strength values as seen in Omo cedar with the highest values in density of 681.53 kg/m^3, MOE of 10966N/mm^2 and characteristic bending strength of 67N/mm^2 compared to Afara (with the lowest values in density of 444.13kg/m^3, MOE of 5203N/mm^2 and characteristic bending strength of 35.66N/mm^2. Hence, the choice of wood by the effect of the wood density must be considered in obtaining the desired engineeing properties. Furthermore, results of glulam beams in edgewise bending versus the control shown thus is: 51N/mm^2; 37.3N/mm^2, 58.5N/mm^2; 47.8N/mm^2, 67.8N/mm^2; 49.5N/mm^2, 102.1N/mm^2; 76.1N/mm^2 and 95.1N/mm2; 77.1N/mm^2 from Afara through Omocedar. The results thus shows that the glulam beams were significantly higher than the control (custom wood) especially in the edgewise direction. Hence these wood species can be engineered for higher bending strength. Similarly, the bending strength of glulam specimens in edgewise bending and flatwise bending were: 51N/mm^2; 38.3N/mm^2, 58.5N/mm^2; 47.8N/mm^2, 67.8N/mm^2; 55.3N/mm^2, 102.1N/mm^2; 82.6N/mm^2 and 95.1N/mm^2; 76.8N/mm^2 from Afara through Omocedar. It is seen from these values that glulam beams were significantly higher in bending strength along the edgewise direction than the flatwise direction and as such square sections should be loaded in the edgewise direction. Also, the axis of loading for higher bending strength in glulam beams should be parallel to the glue line as against perpendicular to glueline due to the combination of the anisotrophy of wood and higher shear capacity of the glueline in contributing to the bending strenght. The results further show that low and high density wood species can be mixed for glulam production by using low density wood species in the core of glulam beams where tension and compression is neutral while high density species used as the outtermost member where these forces are extreme so as to derive structral elements of higher mechanical strength. Based on the failure patterns observed, glue lines in glulam beams resist failure effectively by transferring forces to wood fibre. The failure modes also show that cross grain wood is not suitable for glulam production.

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Persian Abstract

چکیده

ترکیب خاک با استفاده از جاذب‌ها باعث بهبود ساختار خاک شده و مقاومت برشی خاک را نیز تقویت می‌کند. از سویی دیگر می‌توان اینگونه تفسیر کرد که ترکیب خاک با جاذب، به شرط رعایت طرح اختلاط و نسبت بهینه، قدرت جذبِ آبِ خاک را افزایش داده و احتمال نفوذ و نشت آب‌های زیر زمینی حاوی مواد خطرساز را کاهش می‌دهد و از این طریق، مولفه‌های مقاومتی خاک را تقویت می‌کند. در این مقاله، تاثیر فلزات سنگین و جاذب‌ها بر روی رفتار ژئوتکنیکی خاک‌های ماسه–رسی حاوی نیترات سرب و روی به عنوان فلزات سنگین و زئولیت و خاکستر سبوس پوسته برنج (پسماند کشاورزی) به عنوان جاذب، مورد مطالعه قرار گرفته است. نتایج نشان می‌دهد که جایگزین کردن خاکستر پوسته برنج و زئولیت در ترکیب دانه‌بندی خاک با ۲۰ درصد رس کائولینیتی به شکل قابل توجهی منجر به کاهش نیترات روی و سرب می‌شود. همچنین، سطح متخلخل خاکستر پوسته برنج به عنوان یک مزیت تاثیرگذار در افزایش جذب و تعدیل نشت آلودگی، می‌تواند در صورت جایگزینی با کائولینیت، قدرت جذب خاک را ارتقا دهد. جایگزین کردن ۱۵ درصد خاکستر پوسته برنج با کائولینیت قدرت جذب نیترات‌های سرب و روی را به ترتیب ۲۲۸.۸ و ۲۹۱.٦ درصد افزایش می‌دهد. شایان ذکر است که افزودن فلزات سنگین نیتراتی به کائولینیت حدود روانی و پلاستیک خاک را افزایش می‌دهد همچنین باعث تغییر پارامترهای تحکیم خاک می‌گردد بر اساس نتایج به دست آمده، با افزاش حضور فلزات سنگنین به مقدار ۵۰۰۰ ppm مقدار حد روانی از ٤۹.۸ به ۵۹.۱ می‌رسد در حالی که، حد پلاستیک از ۳۱ (در حالت عدم حضور فلز سنگین) به ۳٦.٤ (در حضور ۵۰۰۰ ppm فلز سنگین) میل می‌کند.