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Density, compression and modulus of elasticity (MOE) of *Anogeissus leiocarpus* (DC.) Guill. and Perr. *Daniellia oliveri* (Rolfe) and *Gmelina arborea* (Roxb) wood species in Makurdi, Nigeria

Emmanuel Terzungwue Tembe, David Oriabure Ekhuemelo* and Terfa Kashimana Michael
Department of Forest Production and Products, Federal University of Agriculture Makurdi, PMB, 2373, Makurdi, Benue State, Nigeria
davidekhuemelo@gmail.com

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Abstract

The longevity of timber in service has been affected by lack of appropriate quality indices prior to end use application. This study determined density, compression parallelto grain (CSLG) and compression perpendicular to grain (CSPG) and the MOE of A. leiocarpus, D. oliveri, and G. arborea. The design was a factorial experimental of 3x3x4 consisting of 3 wood species, 3 wood positions and 4 test parameters in Completely Randomized Design (CRD). Results on variation among wood species revealed density in A. leocarpus, D. oliveri, and G. arborea as (925, 659 and 628)kg/m^3 individually. CSLG was (6.72, 5.53 and 4.37)N/mm^2 in G. arborea, D. oliveri and A. leocarpus respectively. CSPG was (9.07, 3.17 and 2.25)N/mm^2 in A. leocarpus, D. oliveri and G. arborea correspondingly. MOE was (2.25, 0.33 and 0.32)N/mm^2 in D. oliveri, A. leocarpus, and G. arborea separately. Interactions between wood species and positions of CSPG showed base, top and middle had 8.99N/mm^2, 9.08N/mm^2 and 9.15N/mm^2 respectively, in A. leocarpus. While in D. oliveri, (2.39, 2.73 and 4.39)N/mm^2) at the middle, top and base respectively. G. arborea had (2.44, 2.77 and 4.53)N/mm^2 at the middle, top and base respectively. Also, CSLG results were 4.9N/mm^2, 4.48N/mm^2 and 3.72N/mm^2 at the base, middle and top respectively. G. arborea trend showed an increase from the base of 5.46N/mm^2 to the middle of 6.08N/mm^2 and the highest at top 8.62N/mm^2. Density values were 955 kg/m^3, 915kg/m^3, 905kg/m^3 at the base, middle and top respectively, in A. leocarpus. In D. oliveri, it was 702kg/m^3, 92kg/m^{3}and 582kg/m^3 at the base, top and middle respectively. Whereas, in G. arborea it was 692kg/m^3, 552kg/m^{3}and 668kg/m^3 at the middle, top and base respectively. MOE indicates that A. leocarpus was peak (0.3575 N/mm^2) at the base and lowest (0.3150N/mm^2) at the middle. D. oliveri was highest (0.2790N/mm^2) at the base and lowest (0.2303N/mm^2) at the top. G. arborea was highest (0.3298N/mm^2) at the base and lowest (0.2968N/mm^2) at the top. Conclusively, A. leocarpus and D. oliveri and G. arborea wood species are recommended for carpentry, fuel wood production, building materials and carving for fine texture, durability, and good finishing.

Keywords: Density, compression, MOE, *A. leiocarpus, D. oliveri* and *G. arborea.*

Introduction

The ease of natural availability, the comfort of handling and processing as well as the outstanding relationship in weight and strength has made wood the foremost structural materials being used[1]. The mechanical and chemical characteristics of wood vary for the same species as regards to the position of their collection. Indicators like climate and soil environments influence the growth of the tree and reliably changes their features. The strength of wood can be seriously affected by the introduction of cracks during seasoning and arrangement of the fibers. According to Cali C. *et al.*[1] the strength characteristics of wood are reliant on the density, the ratio of juvenile wood and width of rings.

The strength of wood is also affected by the angle of the microfibrils, the content of extractives, moisture content the prevalence of attack by insects, the nature, position and number of nodes as well as other factors responsible for the difficulty of wood being used in structural projects[2].

The chemical, physical and structural properties of wood is associated with wood density. Wood density affects several wood-product making such as wood difficulty in cutting and machining, pulping process, and performance in the seasoning[3]. Disparities in wood density are similarly observed in trees along the longitudinal and radial directions within the annual growth rings. The differences in wood density among trees could be physiological and/or genetic reasons[4]. Furthermore, wood density intra-ring discrepancy in trees exist as a result of variations in dimension, arrangement, and structure of wood cells. These differences result from variations in tracheid development of latewood and earlywood in softwood species[5]. On the contrary, variation in hardwoods depends on proportion or the number of different cell types or spatial orientations. The size and the shape of the intra-ring wood density distinction is substantial to evaluating the extent of wood homogeneity[6]. For instance, the dearth of uniformity in l chemical and physical characteristics of wood is one of the main difficulties that the wood industry is facing[7].

Compression strength perpendicular to grain is a significant property in structural design since it regulates the bearing strength. Bearing strength, a wood relies on loading states and wood type. Compression strength perpendicular to grain characteristics rest on the orientation of annual rings in relation to the orientation of stress. Wood in service is continually networking with so numerous forces, where compressive forces are the utmost prominent. According to Akpan[8], timbers used for chair legs, columns and props require high strength in longitudinal compression. Consequently, assessing this property, is important to confirm that the wood sample does not buckle during loading hence exposing it to bending instead of compressive stress[9]. Contrarily, unlike other materials, timber is suggestively stronger in longitudinal compression in comparison to longitudinal tension with strength as low as one quarter[10]. Resistance to crushing is significant characteristics in few selected ends uses of wood such as rollers, railway sleepers, bearing blocks, wedges, and bolted timbers. High compression strength across the grain is high in timbers which are high in density[8]. Studies have shown that wood has less strength in compression perpendicular to the grain compared to compression parallel to the grain[10,11].

The employment of wood for construction has always been influenced by lack of firm standards where woods are just selected at random and used for various purposes without considering elementary and significant evidence that required to be considered. For example, the density, elastic limit of wood, and compressive strength of diverse species of woods which has led to failure in service and loss of property are imperative considerations for wood use. The aim of this study, therefore, was to determine the density*,* assess Modulus of Elasticity and compressive strength parallel and perpendicular to grain and Modulus of Elasticity along the axis of *A. leiocarpus, D. oliveri, and G. arborea.*

Materials and methods

Study area: This study was carried out at the Federal University of Agriculture Makurdi (FUAM) Benue State. Makurdi is the Headquarter of Makurdi Local Government Area (LGA) and also pairs as the state. The town is located within the Benue valley on latitude 6°22' and 7°56'N and longitude 7°37" and 9°05"E. It has a total area of 820km². The population of the inhabitants is about 300,377 people comprising 154,138 males and 146,239 females respectively[12].

Wood samples: Wood samples of and *G. arborea, D. oliveri* and *A. leocarpus* were collected from Timber Shades in Makurdi, Makurdi LGA, Benue state and prepared into standard measurement in the Forestry and Engineering Laboratory in FUAM.

Experimental design: The design used was a factorial experimental of 3x3x4 consisting of 3 wood species (*A. leiocarpus, D. oliveri, and G. arborea*), 3 wood portions (base, middle and top) and 4 tests parameters (density, compressive strength parallel to grain, perpendicular to grain and modulus of elasticity) in Completely Randomized Design (CRD).

Data collection: Data were collected from experiments carried out which includes density, CSPG, CSLG, and MOE. The wood for density determination was dried to obtain the proper dry weight after 3 days. For the CSPG and CSLG, each wood sample which measured 20×20×30cm was placed perpendicular on the testing machine to determine the crushing strength after an applied force.

Density determination: To determine the density, each of the selected specimen which measures 4×2×2cm was placed on a digital weighing balance and readings was taken subsequently. This process was repeated for each of the pieces of wood to obtain the dry weight of the species. To calculate for the wood density: calculate the volume of each sample using the formula:

V= Length x breadth x Height (1)

The Density was determined using the formula:

$$P = \frac{M^0}{V^0} \text{ g/cm}^3 \quad (2)$$

Where: P=Density, M=weight or mass of the specimen, V=Volume of the specimen.

Determination of MOE: MOR estimates stiffness of wood or quantifies the ability of the wood to bend easily and recover usual shape and size after the expiration of force action. The MOE was carried out using Inston 3336 model Universal Testing Machine (UTM. This involves the use of standard test specimens (20mm×20mm×20mm). Load at failure was recorded and the corresponding PC monitored values were taken directly from the machine static Modulus of elasticity (MOE) was tested using UTM Instron 3339 with two points loading and calculated with the following formula

MOE=Stress/Strain = PL/Ae (3)

Where: MOE=Modulus of elasticity, P=load, L=length of wood, A=cross sectional area of wood, e=extension.

Determination of compressive strength: To compressive strength was calculated using the formula:

S=p/A (4)

Where: S=Compressive strength, P=Maximum load applied to the specimen and A=Area.

Statistical analysis: Data collected for density, MOE, CSLG, and CSPG of the tree species were processed and subjected to analysis of variance (ANOVA) using GenStat discovery Edition Release 7.2DE. The mean values of tested samples were subjected to the LSD.

Results and discussion

Effects of wood species on density, CSLG, and CSPG, MOE is indicated in Table-1. The analysis of variance effectively showed that the wood species on density was significant. *A. leocarpus* had the highest density of 925kg/m^3, while *G. arborea had* the lowest density of 628kg/m^3. CSLG was also significant among the different species of. *A. leocarpus* had 4.37N/mm^2. CSLG in D. *oliveri* reflected 5.53N/mm^2 and while G. *arborea* 6.72N/mm^2 respectively. CSPG was also significant among the different wood types. The values ranged from 9.07N/mm^2, in *A. leocarpus* to 3.17N/mm^2 *D. oliveri*, and 2.25N/mm^2 *G. arborea* (Table-1). MOE was significant with its values ranging from 0.33N/mm^2 in *A. leocarpus* to 2.25 mm^2 in *D. oliveri* and 0.32N/mm^2 in *G. arborea* respectively (Table-1).

Table-1: Effects of wood species on density, CSLG, CSPG and MOE.

Wood Species	Density (kg/m^3)	CSLG (N/mm^2)	CSPG (N/mm^2)	MOE (N/mm^2)
A. leocarpus	925	4.37	9.07	0.33
D. oliveri	659	5.53	3.17	2.25
G. arborea	628	6.72	2.25	0.32
LSD	53.5	0.811	0.51	0.019

The interaction between wood type and wood position in CSPG is revealed in Table-2. The interactions in *A. leocarpus* were not significant. The compressive strength result showed that the base had the lowest value of 8.99N/mm^2 followed by the top with 9.08N/mm^2 with the highest result in the middle with 9.15N/mm^2. *D. oliveri* had the lowest value of 2.39N/mm^2 at the middle followed by a top position with 2.73N/mm^2 with the highest (4.39N/mm^2) value at the base. *G. arborea* had the lowest value of 2.44N/mm^2 at the middle, followed by the top with 2.77N/mm^2 with the highest value at the base was 4.53N/mm^2.

Table-2: Effects of interaction between wood type and CSPG.

Wood position	Compressive strength perpendicular to grain (N/mm^2)		
	Wood Type		
	A. leocarpus	*D. oliveri*	*G. arborea*
Base	8.99	4.39	4.53
Middle	9.15	2.39	2.44
Top	9.08	2.73	2.77
LSD	NS	0.886	0.886

The result of CSLG interaction between the wood type and wood position is shown in Table-3. *A. leocarpus* showed no significant difference, the trend showed a decrease from the base 4.92N/mm^2, to the middle 4.48N/mm^2 and then the lowest value at the base 3.72N/mm^2. *D. oliveri* and *Gmelina arborea* showed significant differences. Whereas, the highest (4.55N/mm^2) value was recorded at top, middle and base values were 3.19N/mm^2 and 2.86N/mm^2 respectively in *D. oliveri*. The trend in *G arborea* showed variations with the lowest value (5.46N/mm^2) at the base followed by middle (6.08N/mm^2) and the highest values at the top 8.62N/mm^2.

Table-3: Effects of interaction between the Wood Type and Wood Position in CSLG.

Wood position	Compression Parallel to Grain (N/mm^2)		
	Wood Type		
	A. leocarpus	*D. oliveri*	*G. arborea*
Base	4.92	2.86	5.46
Middle	4.48	3.19	6.08
Top	3.72	4.55	8.62
LSD	NS	1.405	1.405

Effects of interactions between wood species and wood position on density is shown in Table-4. The result indicates that density was at the highest at the base as 955kg/m^3 at the middle 915kg/m^3 and the lowest at the top as 905kg/m^3 for *A. leocarpus*, though the ANOVA showed no significant difference along the bole. *D. oliveri* had the highest density values at the base as 702kg/m^3, at the top 692kg/m^3 and the lowest at the middle as 582kg/m^3. *G. arborea* had the highest density at the middle as 692kg/m^3, lowest at the top 552kg/m^3 and at the base as 668kg/m^3.

Table-4: Effects of interactions between wood species and wood position on density.

Wood position	Density (kg/m^3)		
	Wood Type		
	A. leocarpus	*D. oliveri*	*G. arborea*
Base	955	702	668
Middle	915	582	692
Top	905	692	552
LSD	NS	92.6	92.6

Effects of interactions between the wood type and wood position on the MOE is presented in Table-5. The result of the analysis shows that *A. leocarpus* had no significant difference. Its highest value was at the base with 0.3575N/mm^2 and the lowest was at the middle with 0.3150N/mm^2. *D. oliveri* showed its highest significant of value at the base with 0.2790N/mm^2 and the lowest at the top with 0.2303N/mm^2. *G. arborea* showed its highest significant value at the base with 0.3298N/mm^2 and lowest with 0.2968N/mm^2 at the top.

Table-5: Effects of interactions between the wood type and wood position on the MOE.

Wood position	Modulus of Elasticity (N/mm^2)		
	Wood Type		
	A. leocarpus	*D. oliveri*	*G. arborea*
Base	0.3575	0.2790	0.3298
Middle	0.3150	0.2348	0.3273
Top	0.3162	0.2303	0.2968
LSD	NS	0.033	0.033

Discussion: From the study conducted, the results show that *A. leocarpus* had the highest density of 925kg/m^3, while *G. arborea had* the lowest density of 628kg/m^3. This could be due to reasons such as the light nature of *G. arborea*, the formation of late and early wood, heart, and sapwood formation. The density wood is somewhat greater at breast height than the upper portion of the tree. A parallel pattern was also observed between the wood samples. Mitchell *et al.*[13] attributed this pattern in density to the thicker tracheid walls located at breast height which is rather higher in the stem. This could result from variation might be owing to genetic, physiological as confirmed by density differences within a tree changes from bark to pith and with height in the stem. The density of wood differs from late-wood tissue to early-wood tissue consisting of cells comparatively small diameter with a small lumen and a thick wall, hence, has a greater density than a larger cell lumen with thin-walled early-wood cells[14]. Researchers have agreed that the main factor determining the density of wood is the width of the early-wood band within any one annual ring[15]. In softwood species, the basis of the density of the latewood zone is more than that of early-wood. Consequently, any increase in the amount of latewood unavoidable leads to an upsurge in whole ring elementary density[16]. Regularly, the relative densities of the latewood and earlywood within a tree are strongly correlated. Frequently, a tree with high-density early-wood will likewise possess high-density latewood.

For the compression perpendicular to the grain, the results show that the base of *A. leocarpus* has the lowest compressive strength compared to the top which has the highest compressive strength with 9.8N/mm^2. This implies that the bottom has a lower crushing strength compared to the top[17]. The results *for D. oliveri* show the middle having the lowest compressive strength perpendicular to grain compared to the top with the highest compressive strength. *G. arborea results* show that the middle has the lowest compressive strength perpendicular to grain compared to the base with the highest strength 4.33N/mm^2. For compression parallel to grain, the values being insignificant showed the lowest compressive strength at the top of *A. leocarpus* and the highest at the base with 4.92N/mm. *D. oliveri* has the lowest compressive strength at the base and the highest compressive strength at the top. *G. arborea* has its values as insignificant where the base possesses the lowest compressive strength at the base and the highest compressive strength at the top with 8.62N/mm^2. A similar research was carried out by Zalelem[17]. This could be as a result of the age of the tree, location of the tree.

For Modulus of Elasticity, *A. leocarpus* has its highest results at the base and lowest at the base with 0.3575N/mm^2 and 0.3312N/mm^2. MOE shows an increasing pattern from top to bottom. This means that the strength is high at the bottom of the tree[17]. *D. oliveri* shows the highest results at the base with 0.2790N/mm^2 and the lowest at the top with 0.2303N/mm^2 as MOE shows decreasing trends from bottom to top it implies that the strength is high at the bottom of the tree[17]. *G. arborea* shows the highest results at the base with 0.3298N/mm^2 and the lowest at the top with 0.2968N/mm^2. This also shows high strength at the bottom of the tree[17]. These results are comparable to that of Asafu-Ad jaye[18] that there is difference along and across the stem of tree species. MOE reveals decreasing pattern towards the top portion. The maximum values for stiffness were recorded at the bottom position of these tree species. The important factors controlling the stiffness of timber are its density and the microfibril angle. However, there are a number of other variables which may be anatomical in origin like fiber length, knots, and spiral grain. Another is environmental like moisture content and temperature[19].

Conclusion

The test of selected wood species shows that the strength of a timber depends on its species and hence different wood species have different strength characteristics. The results obtained in this study has provided quantitative information on the mechanical properties of selected wood species which can be used in determining the application of these wood for either heavy and for building, construction or for other purposes such as the manufacture of furniture. *A. leocarpus* had the highest density while *G. arborea* had the lowest density in compressing strength parallel to grain, perpendicular to grain and Modulus of Elasticity.

The result of the interaction between the wood species and wood position were not significant. The result on the interaction between the wood type and position in compression parallel *A. leocarpus* showed no significant difference, while *Gmelina* *arborea* showed a significant difference. The interaction between wood species and the position on density showed that *D. oliveri* had the highest density value at the base, *G. arborea* had its highest at the middle while *A. leocarpus* had no significant difference. The interaction between the wood type and the position on the Modulus of Elasticity, the result showed that *A. leocarpus* had no significant difference, *D. oliveri* showed highest significant of value at the base, while *Gmelina arborea* should its highest at the base.

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