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Variation in density and some strength properties of sapwood and heartwood of *Afzelia Africana* Sm. ex Pers. and *Daniella oliveri* (Rolfe) Hutch. and Dalz. in Makurdi, Nigeria

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Abstract

Structural timber species like A. africana and D. oliveri commonly in use require adequate information of the inherent strength properties and durability to guide end user on applications in design and construction purposes. This study therefore investigated the variation in density, compressive strength perpendicular to grain (CSPG) and compressive strength parallel to grain (CSLG) and Modulus of Rupture (MOR) between the heartwood and sapwood of A. africana and D. oliveri. The study was conducted in Federal University of Agriculture Makurdi. Wood samples were collected from Alaide, Gwer West Local Government Area (LGA) of Benue State. Experimental designs for this study were 2x2x4 factorials in Completely Randomized Designs (CRD) with 4 replicates. There were 2 wood species, 2 wood portions, and 4 replicates. Data was analyzed with Analysis of Variance (ANOVA) and mean was separated with Fisher's Least Significant Difference (LSD) at $p \leq 0.05$. The Densities of A. africana and D. oliveri wood species were significant. A. africana recorded higher density of 860Kg/m^3 while D. oliveri had density of 620Kg/m^3. CSPG was not significant but significant in the parallel direction with A. africana having higher compressive strength of 96.0N/mm^2. The heartwood and sapwood of A. africana recorded higher densities of 960Kg/m^3 and 750Kg/m^2 than D. oliveri whose densities were 670Kg/m^3 and 570Kg/m^3 respectively. The effect of wood type on CSPG and CSLG were significant. A. Africana heartwood and sapwood had higher compressive strength in the parallel direction with the values of 105.0N/mm^2 and 79.0N/mm^2 than D. oliveri whose compressive strength were 44.0N/mm^2 and 38.0N/mm^2. D. oliveri heartwood and sapwood recorded higher MOR of 127.0N/mm^{2}and 96.0N/mm^2 while A. africana had 99.0N/mm^2 and 96.0N/mm^2.Inconsistency of characteristics is midst the foremost drawbacks of wood as a natural material. Therefore, the base for best assortment and usage of wood for building and mechanical purposes.

Keywords: *A. africana,* compressive strength, density, *D. oliveri,* MOR.

Introduction

Wood is a fibrous and porous structural tissue; found in trees, containing of a mixture of air spaces and fiber walls. The air spaces exist mostly in the form of fiber cavities (lumens) and to some extent as voids within fiber walls[1]. Wood are produced by tree and has been utilized the foremost building materials by man. It exhibits a lot of variation in properties in terms of durability, strength, figure, density and grain[2]. Wood itself is one of the oldest materials being used mainly because of its relationship between weight/strength[3].

Piece of wood material in use faces a constant interaction with various forces where the most prominent is compressive forces. Akpan[4] reported that wood used as props and column need high strength in longitudinal compression that have high density and compression strength across the grain. Researches have shown that wood is weaker in compression perpendicular to the grain in comparison in the compression parallel to the grain[5]. Wood strength is excellently ideated by its density; when the density is high the density is the wood is stronger. The MOR is an accepted criterion for wood strength[6].

A. africana is one of the highly graded frequently used as wood species in tropics and is the most preferred commercial timber wood in Nigeria[7]. Findings have it that heartwood of *A. africana* is highly resistant to decay and termites attack while it sapwood having low decay resistant is subject to stain by fungi[8].

D. oliveri is one of the largest trees of wooded savannahs of Sudan–Guinea, usually harvested from the wild for its timber[9]. The wood is used for purposes such as boxes and crates, furniture, interior joinery, block boards and veneer. The heartwood is brown, sometimes with greenish brown veins not clearly demarcated from the sapwood. Heartwood is known to be the dead core of the tree that result from chemical transformation which arises to increase the strength of a tree as it grows in girth. Sapwood comprises living cells, reserve materials and its major role in wood to conduction, transport and storage food materials, water and minerals from the root to the rest parts of a tree. Apart from differences in colour, heartwood and sapwood vary in regards to wood resilience[10].

Many of these differences between heartwood and sapwood are chemical in nature some cases, heartwood substances impregnate cell wall[11]. The amount of heartwood and sapwood in a tree changes in its genetics genera, species and provenances with indicators as silvi culture, growth conditions, site and tree age[12]. Strength is proportional to density hence; strength variation may occur between the heartwood and sapwood. This study intends to examine the variation in density, CSLG and perpendicular to the grain and MOR of the selected wood *A. africana* and *D. oliveri.*

Material and methods

The study area is Federal University of Agriculture, Makurdi (FUAM). FUAM is located in Agan council ward of Makurdi LGA. Makurdi is the capital of Benue State and is located on latitude 7°20' and 8°10 North and longitude 8°4' to 9°40' East. Rainfall and temperature range of 1500 to 1800 millimeter and 32°C to 35°C respectively. Makurdi LGA is bounded by Gwer-East LGA and Guma LGA.

Sample collection: Wood samples from sapwood and heartwood of *A. africana* and *D. oliveri* were randomly selected from matured trees of *A. Africana* and *D. oliveri* (Figure-1 and 2) in a sawmill in Alaide Gwer East LGA of Benue State.

After pre-cutting the samples were dried for 7 days and cut to the dimensions required to determine the density, CSLG and perpendicular to grain, MOR and Notch Impact strength.

Determination of Density: Density is the mass per unit volume of the wood material. The initial weight of the representative samples were measured using a digital weighing balance. The volume was determined by measuring the length, breadth and height. The values were used to compute the volume using the formula,

$$V = \text{Length } x \text{ Bbreadth } x \text{ Height.} \quad (1)$$

The Density was determined using the formula:

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

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

Determination of CSLG and perpendicular to the grain: The maximum CSLG and perpendicular to the grain was determined on Compressive Testing Machine (Figure-3). The dimensions of the sample used were 20mm×40mm×150mm. The loading velocity was fixed so that test was terminated within 90seconds and the loading of the test specimen was carried out such that position of the wood grain was perpendicular and parallel to the axis of the wood grain respectively.

The values were used to calculate compressive strength for the heartwood and sapwood, according to American Society for Testing and Materials[13] using the equation below:

$$\delta C = \frac{P}{bd^2} \text{ N/mm}^2 \quad (3)$$

Where: δC=Maximum compressive strength, b=width in mm, d=depth in mm, p=load in Newton.

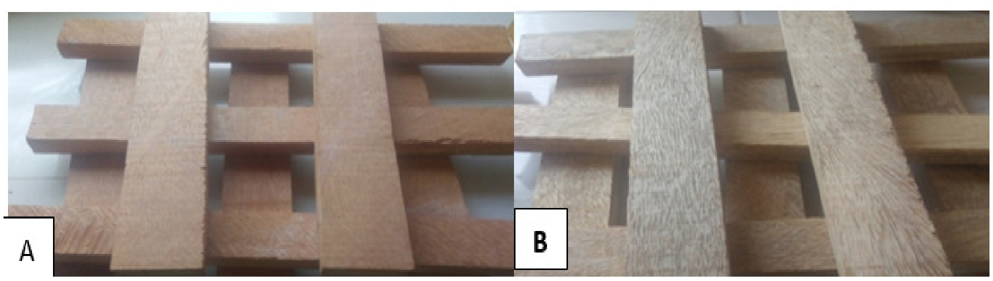

Figure-1: (A) Heart wood of *A. Africana* (B) Sapwood of *A. Africana.*

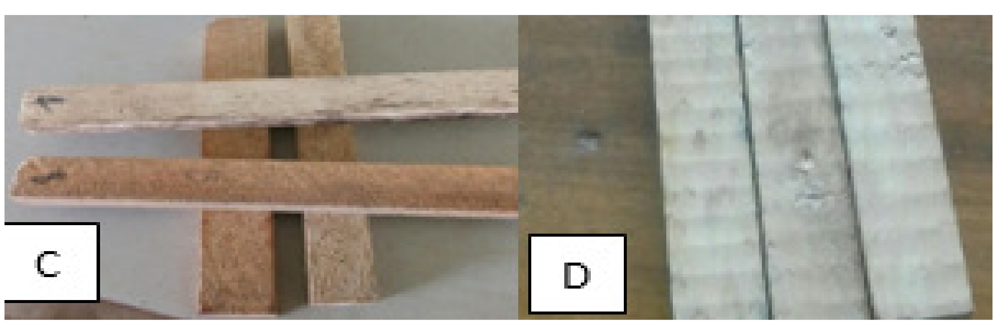

Figure-2: (C) Heart wood of *D. oliveri* (D) Sapwood of *D. oliveri.*

Figure-3: Compressive Testing Machine in Civil Engineering Laboratory, FUAM.

MOR: MOR test was carried out on test sample of 20mm×40mm×150mm was prepared and tested on instron 3369 model in a Universal Testing Machine (UTM) (Figure-4). The load was applied at the rate of 0.1mm/sec with the grain parallel to the direction of loading. The specimen was loaded on the radial face and the bending strength of the wood at point of failure was determined from the machine. Load at failure was recorded. The MOR was calculated using the following formula:

$$MOR = \frac{3 \times Pmax}{b \times h^2} \quad N/mm^2 \qquad (4)$$

Where: $Pmax$=Maximum load (N), b=width of the sample (mm) and h=Depth of the sample (mm).

Figure-4: UTM at Civil Engineering Laboratory, FUAM.

Data analysis: The data collected for sample test on Density, MOR, CSLG and perpendicular to the grain and Notch impact strength of the heartwood and sapwood of *D. oliveri* and *A. africana. The* Data were processed and subjected to ANOVA using GenStat Discovery Edition Release 7.2DE, based on a 2×2×4 factorial design in CRD. The significant differences between the mean values of the properties tested for were subjected to the Fisher's Least Significant Difference (LSD). The Results were presented in Tables for interpretation and discussion.

Results and discussion

Effect of Wood Species on Density, CSPG, CSLG, MOR, Notch Impact Strength: The ANOVA result in Table-1 shows that the effect of density on *A. africana* and *D. oliveri* wood species was significant. The density of *A. Africana* was significantly higher than that of *D. oliveri*. The density of *A. africana was* 860g/cm^3, while that of *D. oliveri* was 620g/cm^3. The effect of wood species on CSPG was not significant, but significant in CSLG.

MOR in between *A. africana* and *D. oliveri* were found to be significantly different. MOR of *D. oliveri* was higher than *A. africana* with the values of 115N/mm^2 and 98.0N/mm^2. ANOVA on the effect of wood species on Notch Impact Strength shown in Table-1 was not significant both *A. Africana* and *D. oliveri* had the same value of 72 J/mm^2.

The densities of *A. africana* and *D. oliveri* in this study were 860Kg/m^3 and 620Kg/m^3 respectively. *A. africana* had a higher density than *D. oliveri* and this may be due to the fact that the wood density and all its characteristics are limited to great variability[14,15]. Observed that variability in density is caused by differences in wood structures, notably the width of annual rings, proportion of late wood and the presence of juvenile woods. These results agree with Gerard and Louppe; Schmelzer, and Louppe[9,16]. Although the density of *A. Africana* in this study was higher than those obtained by Gerard and Louppe[9]. Variability in density may be attributed to differences in age of the tree used. *A. Africana* is regarded as highly graded timber in Nigeria[17] while *D. oliveri* is classified as medium grade timber.

The densities of *A. africana* heartwood and sapwood were 960kg/m^3, 750kg/m^3 while *D. oliveri* had the density of 670kg/m^3, 570kg/m^3 respectively. It was observed that the density of *A. africana* heartwood was higher than that of *D. oliveri* and also the sapwood of *A. africana* was higher than the sapwood of *D. oliveri*. *A. africana* heartwood had the higher density of 960Kg/m^3. This may be as a result of the fact that heartwood of most tree species has extractives deposited in them. These extractives have an effect on basic density of wood. Kayuma[18] found that heartwood with extractives content which contribute to the weight per unit area of wood has a higher density than the sapwood which makes difference in strength properties. The variation that occurs in heartwood and sapwood is probable because heartwood and sapwood components change among and within species and related to growth stand and individual tree biometric characteristics, site health and genetic control in accordance with Bamber and Fukazawa; Hillis; Taylor[19-21].

A. Africana is been used as a building component in construction. The more the extractive amount in wood the higher the quality. For pulp and paper making, the more the extractive features, the lower the potentials of the wood as raw materials for short fibre pulp making[22]. The values agree with Merela and Curfar[10] who stated that the density of the heartwood and sapwood of *Q. Robur, Q. petrea* and *Q. cerris* were within the range of 388-930kg/m^3 and 465-837kg/m^3 while the density of *A. Africana* heart wood in this study was higher.

Table-1: Effect of wood species density, CSPG, CSLG, MOR, Notch Impact Strength.

Wood Species	Density (kg/m^3)	CSPG (N/mm^2)	CSLG (N/mm^2)	MOR (N/mm^2)	Notch impact Strength (N/mm^2)
A. africana	860	46.0	92.0	98	72.0
Daniela oliveri	620	46.0	41.0	115	72.0
LSD	40.0	NS	0.7	0.25	NS

Effect of Wood Type on Density of *A. africana* and *D. oliveri*: Results from Analysis of Variance in Table-2 showed that the effect of wood type on Density of *A. africana* and *D. oliveri* was significant. The density of *A. afrcana* heartwood and sapwood were 960Kg/m^3 and 750kg/m^3 while that of *D. oliveri* heart and sapwood were 670kg/m^3 and 570kg/m^3 respectively.

Table-2: Effect of Wood Type on Density of *A. africana* and *D. oliveri.*

Wood Species	Wood Type	
	Heartwood (kg/m^3)	Sapwood (kg/m^3)
A. africana	960	750
D. oliveri	670	570
LSD	50.0	50.0

Effect of Wood Type on CSPG of *A. africana* and *D. oliveri.*: Results in Table-3 indicated that the effect of wood type on compression perpendicular to grain of *A. africana* and *D. oliveri* was significant. *A. Africana* Heartwood and Sapwood were 41.0N/mm^2 and 52.0N/mm^2 while that of *D. oliveri* were 70.0N/mm^2 and 22.0N/mm^2.

CSPG between *A. africana* and *D.* oliveri was not significant. Both *A. africana* and *D. oliveri* had the same value of 46.0N/mm^2. This may be as a result that wood is weaker in compression perpendicular to the grain than it is in compression parallel to the grain. The variation between the heartwood and sapwood varied significantly. *D. oliveri* heartwood had higher CSPG direction than *A. africana*. The sapwood *of A. africana* is higher than *D. oliveri*. The results contradict the conventional statement that *A. africana* heartwood are stronger than *D. oliveri* heartwood.

Effect of wood type on CSLG to grain of *A. africa* and *D. oliveri:* The result in Table-4 shows that the CSLG to grain for *A. africana* heartwood and Sapwood was 105.0N/mm^2 and 79.0N/mm^2 while *D. oliveri* was 41.0N/mm^2 and 38.0N/mm^2. The analysis of variance revealed significant differences between those two species. The variation in CSLG direction between *A. africana* and *D. oliveri* in this study were determined to be 98.0N/mm^2 and 41.0N/mm^2 respectively. *A. africana* compressive strength was higher than that of *D. oliveri*. This is in close range with the values obtained by Gerard and Louppe[9]. Although *A. africana* value obtained is lower.

The CSLG to the grain of the heartwood and sapwood of *A. africana* are 105.0N/mm^2, 79.0N/mm^2 while *D. oliveri* had 70.0N/mm^2, 40.N/mm^2 respectively.

Table-3: Effect of Wood Type on CSPG of *A. africana* and *D. oliveri.*

Wood Species	Wood Type	
	Heartwood (N/mm^2)	Sapwood (N/mm^2)
A. africana	41.0	52.0
D. oliveri	70.0	22.0
LSD	NS	0.08

The CSLG direction in A. *Africana* heartwood and sapwood were higher than *D. oliveri*. Ayobi *et al*[23] observed that difference in strength properties between the heartwood and sapwood were due to the chemical structure in heartwood and sapwood. The number of extractives in the heartwood is higher than sapwood. The formation of heartwood is the main cause of variation. Curtu *et al.;* Porter[24,25] also reported that for some selected end uses such as railway sleepers, rollers, wedges, bearing blocks and bolted timbers, resistance to crushing is an important property. This agrees with Ayobi *et al*[23] who studied the mechanical properties of heartwood and sapwood in white and red oaks to be used as railway sleepers and obtained values for heartwood and sapwood which ranges from 29.4 to 84.3N/mm^2 and 54.8 to 67N/mm^2, although *A. africana* heartwood had higher compressive strength in this study than as stated as stated in the literature reviewed.

Effect of Wood Type on MOR of *A. africana* and *D. oliveri:* According results shown in Table-5 on the effect of wood type on MOR of *A. africana* and *D. oliveri* was significant. *A. africana* heartwood and sapwood was 99.0N/mm^2 and 96.0N/mm^2 while *D. oliveri* was 127.0N/mm^2 and 102.0N/mm^2 respectively.

The effect of wood species on MOR for *A. africana* was 98.0N/mm^2 while *D. oliveri* was 115.0N/mm^2 and it was observed that *D. oliveri* was greater in MOR than *A. africana*.

This contradicts the conventional believe that *A. africana* are stronger in strength properties than *D. oliveri*. Also, the effect of wood type on MOR varied significantly *A. africana* heartwood and sapwood were 99.0N/mm^2, 96.0N/mm^2 while that of *D. oliveri* were 127.0N/mm^2 and 102.0N/mm^2. It was determined that the differences in MOR could be attributed to differences in anatomical structure namely cell types and genetic differences resulting into wood structure[26].

Table-4: Effect of wood type on CSLG to grain of *A. africana* and *D. oliveri.*

Wood Species	Wood Type	
	Heartwood (N/mm^2)	Sapwood (N/mm^2)
A. africana	105.0	79.0
D. oliveri	44.0	38.0
LSD	0.1	0.1

Table-5: Effect of wood type on MOR (N/mm^2) of *A. africana* and *D. oliveri.*

Wood species	Wood Type	
	Heartwood (N/mm^2)	Sapwood (N/mm^2)
A. africana	99.0	96.0
D. oliveri	127.0	102.0
LSD	0.35	0.35

Conclusion

In this study, wood density was significantly higher in A. *africana* compared to *D. oliveri*. It is also varied significantly between the heartwood and sapwood of *A. Africana* and *D. oliveri.* CSPG between *A. africana* and *D.oliveri* was not significant. *A. africana* and *D. oliveri* had the same value of CSPG but varied significantly between the heartwood and sapwood. The proportion of heartwood in *D. oliveri* was higher than *A. africana. A. africana* compressive strength was higher than that of *D. oliveri*. The CSLG direction in *A. africana* heartwood and sapwood were higher than *D.oliveri*. It was observed that *D. oliveri* had higher MOR than *A. africana* but, varied significantly in the heartwood and sapwood. The changes of all characteristics are among the major demerit of wood as raw materials. Consequently, this become the foundation for best selection and utilization of timber for buildings and structural purposes.

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