Agriculture and Forestry Journal
Vol. 3, Issue 1, pp. 30-35, June, 2019
E-ISSN 2602-5795
Published by university of Tlemcen - ALGERIA

Available online at:
http://ojs.univ-tlemcen.dz/index.php/AFJ/

Open Access

Disparity in water absorption, radial shrinkage, tensile strength, and modulus of elasticity (MOE) between the heartwood and sapwood of *Afzelia africana* SM. and *Daniellia oliveri* (Rolfe) *in* Makurdi, Nigeria

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ARTICLE INFO

Article history:

Received: 12 December 2018
Accepted after corrections 11 March 2019

Keywords:

A. africana, D. oliveri, MOE, water absorption, radial shrinkage, tensile strength.

ABSTRACT

The study investigated the variation in the physical and mechanical properties of *A. africana* and *D. oliveri* wood. Factorial design of 2×2×4 in Completely Randomized Design (CRD) was used. Results showed that percentage water absorption of *A. africana* recorded 187.9% while *D. oliveri* had 160.1%. *D. oliveri* recorded a higher radial shrinkage of -72%. *A. africana* recorded a higher tensile strength of 2.61N/mm^2 while *D. oliveri* recorded 1.81N/mm^2. *D. oliveri* recorded significant difference with heartwood recording a higher value of 180.7% compared to the sapwood with 139.5%. The radial shrinkage of *D. oliveri* had higher shrinkage of -72% while heartwood was 0%. *A. africana* had 462N/mm^2 and 223N/mm^2 of MOE for heartwood and sapwood while *D. oliveri* recored 224N/mm^2 and 218N/mm^2 respectively. Heartwood of *A. africana* had a higher (462N/mm^2) value compared to the sapwood (231.7N/mm^2). The two-wood species exhibit high tensile strength and are therefore recommended for use in building purposes.

1. Introduction

Wood is a renewable, biological and biodegradable natural resource and has been used by humans for thousands of years. It is the most important and major forest product. It is recognized as one of the oldest known raw materials and from the pre-historic period man used it for fuel, tools, boat making and house construction Chao et al. (2016). Man depends on forest products especially wood and wood products for numerous purposes Zobel et al. (1998).

Wood is an environmentally sound and economical building material used either for indoors or outdoors for a wide variety of structural and decorative applications. Wood users often require high-quality wood products; however, the value of wood products is often limited by physical or biological damage. Wood and wood products need to be protected during manufacturing, storage, transportation, and when in service Uzunovic et al. (2008).

Wood is anisotropic in nature as a result; shrinkage and swelling of wood are not uniform in different directions of wood for the same change of moisture content. These dimensional changes are the least in the longitudinal direction (along with the tree trunk) and much greater in the transverse directions. The lower winding angle of the microfibrils in the S2 layer of cell wall causes wood to shrink or swell more in the transverse (radial and tangential) plane than in the longitudinal direction (Bowyer et al., 2003 and Hill, 2006). The longitudinal shrinkage or swelling in mature/outer wood is generally very small. However, in the case of juvenile wood and reaction wood of radiata pine, longitudinal shrinkage of up to 2.9 percent has been observed (Xu et al., 2009). In the transverse direction, shrinkage or swelling is more in the tangential than in the radial direction by a factor of 1.5-3. This is mainly due to the anatomical features of wood such as the presence of ray tissues, frequent pitting on radial walls, microfibrils arrangements and earlywood - latewood interaction (Bowyer et al., 2003; Pang and Haslett 2002).

D. oliveri belongs to the Family Caesalpiniaceae (Leguminosae - Caesalpinioideae). *D. oliveri* occurs from North east to North central and is one of the high grades commonly used wood species in tropical sub-Sahara Africa. The plant occurs in Senegal, East Africa and dense forest of humid regions in West Africa (Rowell, 2002). The heartwood is red-brown, grey or red with dark streaks and is moderately clearly demarcated from the up to 8 cm wide, whitish sapwood with a pink or brown tinge. The grain is interlocked, texture medium to coarse. The heartwood of *D. oliveri* is rated very decay resistant is reported to be resistant to termites. *D. oliveri* is preferred as a first-grade commercial timber in Nigeria. The wood, traded as 'West African gum copal' and

'Danielle', is used for light flooring, joinery, interior trim, furniture, boat building, toys, novelties, cattle-troughs, drums, bowls, rice-mortars, packing cases, draining boards, carvings, veneer, plywood, hardboard, and particle board (Rowell, 2002).

A. africana is characterized by an excellent stability with little susceptibility to variations in humidity, small shrinkage rates during drying and a good natural durability. The wood is durable and treatment with preservatives is unnecessary, even for usage in permanent humid conditions or in localities where wood-attacking insects are abundant. This makes it an excellent wood for use in pleasure-crafts, especially for keels, stems, and panels, for bridges, as well as interior fittings. For such uses, it is sometimes as much in demand as teak. The wood is also valued for joinery and paneling both interior and exterior, parquet floors, doors, frames, stairs, furniture, and sporting goods. It has been used traditionally for canoes. It is commonly used for domestic articles such as boxes, bowls, spoons, mortars, and masks, and is locally popular for making drums (Gerard and Louppe, 2011).

The variations in water absorption (WA), radial shrinkage (RS), tensile strength (TS), and MOE between the heartwood and sapwood of A. africana and D. oliveri have not experienced much research and as such. This work tends to bring to the awareness of researchers, timber shade owners and the general public, the different variation in water absorption (WA), radial shrinkage (RS), tensile strength (TS), and MOE of *A. africana and D. oliveri*. Therefore, the aim of this study was to determine the variation in the water absorption, radial shrinkage, tensile strength and MOE between the heartwood and sapwood of *A. africana* and *D. oliveri.*

2. Materials and Methods

2.1. Study Area

The study area is the Federal University of Agriculture, Makurdi (FUAM). FUAM is located in Agan Council Ward of Makurdi LGA Benue State and lies between Latitude 7º and 44´ North and 8º and 33´ East in the middle belt region of Nigeria. The area is distinguished by two distinct seasons dry and wet in the southern guinea savannah. The climate of the place is tropical sub-humid climate with high temperatures; high humidity; average maximum and minimum daily temperature of 35° and 21°C in the wet season and 37°C and 16°C in dry season respectively. The mean annual rainfall value is 1200mm to 1500mm. The vegetation of the area has been described as Northern Guinea savannah (Tyowua et al., 2013).

2.2. Wood samples

Wood samples of *A. africana* and *D. oliveri* were collected from Timber Shades in Alaide, Gwer West LGA, Benue state and prepared for the various test (Fig. 1) in the Forestry Laboratory of the FUAM.

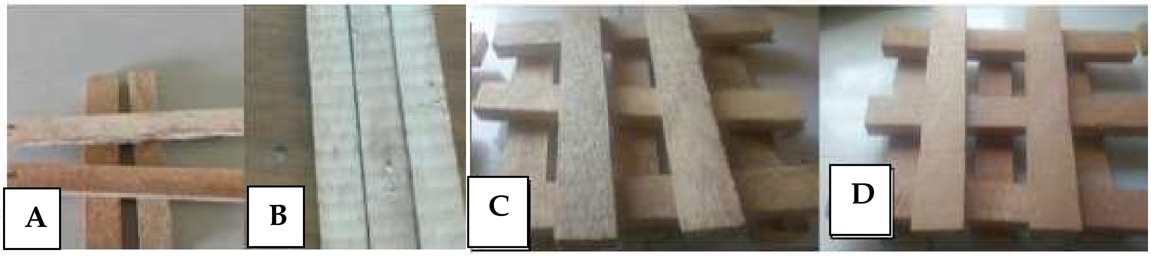

Figure 1. Wood samples of *A. africana* and *D. oliveri* (A. Heartwood of *D. oliveri;* B. Sapwood of *D. oliveri;* C. Heartwood *A. Africana;* D. Sapwood of *A. africana*)

2.3. Water Absorption

Water absorption for each condition was tested on strip samples, 4 replicates were prepared for each treatment on 2×2×4 wall thickness (mm) were tested for comparison according to Anokye *et al.*, (2014). Samples of wood were weighed and then immersed in water for 72hours, after which samples were removed and weighed again, the final weight was used in comparison to the initial weight to determine Water Absorption:

$$WA\ (\%) = W2\text{-}W1/W1x100 \qquad [1]$$

Where:
W2= wet weight of specimen after soaking in water; W1= Initial dry weight

2.4. Radial Shrinkage

Radial shrinkage is the reduction in dimensions of timber due to movement of moisture out of cell walls of the wood. The dimension of all samples was measured at green level. Then the samples were sun-dried until the sample's weights were constant. The final dimensions were used in comparison to the Initial dimensions. Calculations were made using the following relationships:

B= L1-L/L1 [2]

B (%) = L1-L2/ L1x100 [3]

Where:

B= Shrinkage (cm/cm or %); L1= Green or initial dimension (cm); L2= Dry or final dimension (cm).

2.5. Tensile Strength Test

2.5.1. Tensile strength perpendicular to grain test

This was carried out on test samples of 600 mm ×10 mm ×10 mm and was tested on Instron 3369 Model in a UTM. The load required for failure of sample perpendicular to grain was recorded. The load divided by the area gave the maximum tensile stress perpendicular to grain in the radial and tangential plane. The maximum load per area of stress gives an indication of splitting characteristic of the material in radial or tangential plane. The maximum tensile stress in perpendicular direction is also an indication of tensile strength of the wood in that direction.

Yield stress= Load/Area x 1000 [4]

A= Lx Wx H [5]

Where:

A = Area of rectangular surface; L = Length; H = Height.

R= L0-L1 /L0 x 100

Where:

R - Reduction in area at fracture; L0 - Original length; L1 - New length.

E= L2/L1 x 100 [6]

Where:

E : Elongation; L1: Actual length; L2: Gauge length.

2.5.2. Modulus of Elasticity

The MOE was carried out using Inston 3336 model UTM. This involves the use of standard test specimens (20 mm ×20 mm ×20 mm) from MOR test the corresponding MOE was recorded. Load at failure was recorded. Static MOE was calculated with the following formula:

MOE= Stress/ Strain = P L/ Ae [7]

Where:

p= load; L= Length of wood; A= Cross sectional area of wood; e= extension.

2.6. Statistical Analysis

Data were processed and subjected to ANOVA. The significance for samples were tested and determined using Fisher's Least Significance Difference (LSD) to determine the various variations between the sapwood and heartwood of *A. africana* and *D. oliveri.*

3. Results

The result of Analysis of Variance shows a significant difference on the effect of wood specie on Water Absorption between *A. africana* and *D. oliveri*. *A. africana* has a value of 187.9%, while *D. oliveri* was 160.1% (Table1). The result of Analysis of Variance shows that there was no significant difference on the effect of wood specie on Radial Shrinkage between *D. oliveri* and *A. africana* -36%, while D. oliveri was -72%, Analysis of Variance shows that there was no Significant difference. Effect of the wood specie on the tensile strength of *D. oliveri* was 2.61N/mm^2, while *D. oliveri* was 0.34N/mm^2. Analysis of variance shows a significant difference. Effect of wood specie on Modulus of Elasticity of *D. oliveri* was 342N/mm2, while *D. oliveri* was 221N/mm^2. Analysis of Variance shows that there was no significant difference.

The result of the Analysis of variance on Water Absorption revealed a significant difference between the heartwood and sapwood of *D. oliveri* while there is no significant difference between the heartwood and sapwood of *A. Africana*

Table 1. Effect of Wood Species on Water absorption, Radial shrinkage, Tensile strength, and MOE

Wood Specie	Water Absorption (%)	Radial Shrinkage (%)	Tensile Strength (N/mm2)	MOE (N/mm2)
A. africana	187.9	-36	2.61	347
D. oliveri	160.1	-72	1.81	221
LSD	13.31	NS	0.34	NS

Results on Table 2 shows that the Water Absorption for *A. africana* heartwood and sapwood was 138.6% and 137.2% while *D. oliveri* was 180.7% and 139.5%.

Table 2. Effect of Water Absorption in wood portions

Wood Portion	*A. africana* (%)	*D. oliveri (%)*
Heartwood	137.2	180.7
Sapwood	138.6	139.5
LSD	NS	18.82

The result of the Analysis of Variance revealed a significant difference between the heartwood and sapwood of *D. oliveri,* while there was no significant difference between the heartwood and sapwood of *A. africana.*

Results on Table3 shows that the Tensile strength for *A. africana* heartwood and sapwood was 2.83N/mm^2 and 2.01N/mm^2 while *D. oliveri* was 2.40N/mm^2 and 1.61N/mm^2**.**

Table 3. Effect of Tensile Strength in wood portions

	Tensile strength	
Wood Portion	***A. africana* (%)**	***D. oliveri(%)***
Heartwood	2.83	2.40
Sapwood	2.01	1.61
LSD	NS	0.48

The result of the Analysis of Variance revealed a significant difference between the heartwood and sapwood of *D. oliveri* while there is no significant difference between the heartwood and sapwood of *A. africana*.

Results on Table 4 shows that the Radial shrinkage for *A. africana* heartwood and sapwood was -73% and -72% while *D. oliveri* was 0% and -72%.

Table 4. Effect of Radial shrinkage in wood portion

	Radial shrinkage	
Wood Portion	***A. africana* (%)**	***D. oliveri (%)***
Heartwood	-72	0
Sapwood	-73	-72
LSD	NS	63.8

Result of the Analysis of Variance revealed a significant difference between the heartwood and sapwood of *A. africana while* there is no significant difference between the heartwood and sapwood of D. *oliveri*.

Results on Table5 shows that the Modulus of Elasticity for *A. africana* heartwood and sapwood was 462N/mm^2 and 223N/mm^2 while *D. oliveri* was 224N/mm^2 and 218N/mm^2.

Table 5. Effect of Modulus of Elasticity in wood portion

	Modulus of Elasticity	
Wood Portion	***A. africana* (%)**	***D. oliveri (%)***
Heartwood	462	224
Sapwood	223	218
LSD	237.7	NS

4. Discussion

In this study*, D. oliveri* showed higher water absorption capabilities than *A. africana* in both their heartwood and sapwood, this result agrees with Green and Evans (2008) in their research work which shows that the effect of mechanical properties of wood is widely dependent on the response to the various temperature of the environment they are found. Temperature influences the percentage of water molecules which could overcome the energy barrier of desorption. This effect was noticed and quantified on diffusion rate measurements. Kollmann (1959) indicate a 1.3% decrease per 10˚C increase between 20˚C and 80˚C. Skaar (1988) reported a 1.2% decrease per 10˚C between 20˚ and 100˚C. Tensile strength for *A. africana* heartwood and sapwood was 2.83N/mm^2 and 2.01N/mm^2 while *D. oliveri* was 2.4N/mm^2 and 1.61N/mm^2. The analysis of variance revealed a significant difference between the heartwood and sapwood of D. oliveri, while there is no significant difference between the heartwood and sapwood of *A. africana* , Pavlina, (2008) in his work express that the strength of a given object in terms of each of forces can predict how the object will respond to different situations and loads, and it is very essential to understand the limitations of a material when using it to build structures or to perform another function that will put it under stress.

In the course of the study the radial shrinkage for *A. africana* heartwood and sapwood was -72% and -73% while *D. oliveri* was 0% and -72%. The analysis of variance revealed a significant difference between the heartwood and sapwood of *A. africana* while there is no significant difference between the heartwood and sapwood of D. oliveri. For wood, the lumen and the pores are very little or not at all affected by the shrinkage process. The answer for this characteristic pattern of wood shrinkage lies within the anatomical structure of the cell wall.

The structural positioning of cellulose chains inside the largest layer of the cell wall (S2) causes most of the shrinkage to happen along a direction perpendicular to the tree stem and just a small amount along its length (~0.3%). The fibrils making up the primary part of the cell wall tend to be oriented spirally, almost at right angles to the fiber length, fitting tightly around a water-swollen fiber. Any gain or loss in moisture content will be restrained by these fibril wrappings. During a desorption process, at high moisture contents the restraining action is very efficient but further drying determines the non-crystalline region of these fibrils to begin to shrink. The restraining is proportional with the microfibril angle (Abe and Yamamoto, 2006). It is a fortunate feature because it limits the amount of swelling and shrinkage but in the same time creates stresses at cell wall level (Seborg, 1953).

MOE for *A. africana* heartwood and sapwood was 462 N/mm^2 and 223 N/mm^2 while *D. olive*ri was 224N/mm^2 and 218N/mm^2. The analysis of variance revealed a significant difference between the heartwood and sapwood of *A. africana* while there is no significant difference between the heartwood and sapwood of *D. oliveri.*

5. Conclusion

The study shows that water absorption and radial shrinkage of wood samples in this study were higher in than *D. oliveri* than in *A. africana*. Conversely, tensile strength of *A. africana* was higher than *D. oliveri* and was a significant. In the same vein, MOE was higher in *A. africana* than *D. oliveri* and was not significant. Comparing heartwood and sapwood of wood species, there was significant difference in water absorption between heartwood and sapwood of *D. oliveri*, while, there is no significant difference between the heartwood and sapwood of *A. african*. In radial shrinkage, there was significant difference between the heartwood and sapwood of *D. oliveri* while, there was no significant difference between the heartwood and sapwood of *A. africana.* For tensile strength, there was significant difference between the heartwood and sapwood of D. *oliveri*, while, there was no significant difference between the heartwood and sapwood of *A. africana.* Variation in Modulus of Elasticity revealed a significant difference between the heartwood and sapwood of *A. africana* while, there was no significant difference between the heartwood and sapwood of D. *oliveri*. The wood species exhibit high tensile strength and flexibility and are therefore recommended for use in engineering construction, timber utilization, and building industries.

Acknowledgements

Authors wish to acknowledge the contributions of Technical staff of Department of Civil Engineering, Federal University of Agriculture Makurdi, Nigeria for their technical assistance during laboratory work.

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Please cite this Article as:

TEMBE E.T., EKHUEMELO D.O. & SAMUEL B.E., 2019. Disparity in water absorption, radial shrinkage, tensile strength, and modulus of elasticity (MOE) between the heartwood and sapwood of *Afzelia africana* SM. and *Daniellia oliveri* (Rolfe) *in* Makurdi, Nigeria. *Agric. For. J.,* 3(1): 30-35.
DOI: https://doi.org/10.5281/zenodo.3239263