MECHANICAL PROPERTIES OF THREE SELECTED TIMBER SPECIES IN ABEOKUTA, OGUN STATE, NIGERIA

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ABSTRACT

This study was conducted to determine the physical and mechanical properties of some common Nigerian timber species in Abeokuta, southwest Nigeria.. The timber species considered are: Ayinre (Albizia coriaria), Aga (Musanga cecropioides) and Orin dudu (Anogeissus leiocarpus). The physical properties of the selected timber species including moisture content and density were determined in accordance with timber design codes {EN 13183-1 and EN 408}. Mechanical properties of the timber species were determined using both four and three point bending tests based on standards such as EN 408 and ASTM D193. Characteristic values of the material properties were determined in accordance with EN 384. Mechanical properties and density of the selected timber species were modified to the equivalent moisture content of 18% in accordance to the standard code for Timber design in Nigeria (NCP). The least values of the mechanical properties obtained from the two standards mentioned above were considered.

***Keywords*: Design Codes, Mechanical Properties, Structural Uses, Timber Species**

1. INTRODUCTION

Timber is one of man's oldest building materials. It is are newable, naturally occurring organic polymer, unique in a world of synthetic and composite building materials. Today, timber is derived from sustainably managed forests and is one of our most environmentally friendly building materials. The wide distribution of timber, its ready availability, variety of uses and relative ease of handling and conversion, have all contributed to its wide acceptance in the building industry. The small tubular cells that are the fundamental structural elements of solid wood give timber its good properties for sound, electrical and heat insulation, for engineering requirements, and strong aesthetic appeal. Because of its wide range of properties, it is essential that for a particular application, the most suitable timbers pecies is selected (National Association of Forest Industries [NAFI], 2004).An elementary understanding of wood science can develop an intuitive understanding of wood properties to maximise the performance of the timber and minimise the impact of limitations ("Characteristics of Timber", 2010, p. 2).Advantages of timber include that they are stronger than other construction materials inproportion of weight, they can be easily worked to any size and shape, they are lightweight, they are economical as wastage is minimum, they are durable and that they are non-conductors of heat and electricity (Mitra, 2011).Trada (2002) highlights various properties and uses of timber as well as its species. The properties of timbers as submitted by" Properties of Timber" (2014) are determined by the structure of the wood, i.e., the types of cells and the chemical composition of the cell walls and cell contents, and by the proportion of the various cell types present in the wood. The distribution and arrangement of these wood elements vary considerably in different species of trees ("Properties of Timber", 2014).There are thousands of species of tree from which timber can be obtained, each with differentrates of growth, structural properties and degrees of durability (Structural Timber Association [STA], 2014, p. 1).All commercial timbers can be categorized into two broad groups: softwoods and hardwoods (STA, 2014, p. 1; Fathi, 2010, p. 8; Rajakaruna, 2002). According to STA (2014), softwood is obtained from coniferous trees and hardwood comes from broad-leaved trees. Softwood and hardwood are botanical terms and do not necessarily refer to the density or hardness of the wood. For example Balsa, which is known to be soft and used for building lightweight models, is a hardwood whereas Douglas Fir is a softwood with good durability and high strength properties (p. 1).

Poku, Wu and Vlosky (1999) in their study conducted on Ghanaian species of hardwood concluded that no dominant patterns of variation of specific gravity, radial and tangential shrinkages, maximum crushing strength, and modulus of elasticity exist in the trees of *Petersianthus macrocarpus.* They further posited that *Petersianthus macrocarpus.* is a dense wood (average specific gravity of 0.69) with high shrinkage values (radial shrinkage of 4.0% and tangential shrinkage of 6.9%) with relatively high strength values (maximum crushing strength-60 MPa and Modulus of Elasticity (MOE)-11,100 MPa). These values compare very closely with*Chlorophora excelsa* (with average values: specific gravity-0.78, radial shrinkage-4.0% and tangential shrinkage-6.0%, maximum crushing strength-57 MPa and MOE-12,300 MPa) (Tree Talk 1997). *Chlorophora excelsa*also has similar aesthetic features to *Petersianthusmacrocarpus (*p. 289).The thrust of this study is to determine the physical and mechanical properties of some selected timber species in Abeokuta; Ogun State, Nigeria through experimental works.

2. MATERIALS AND METHODS

2.1 Materials

The materials utilised in this study were timber specimens obtained from Abeokuta; Ogun State in the South-Western part of Nigeria namely: Ayinre (Albizia coriaria), Aga (Musanga cecropioides) and Orin dudu (Anogeissus leiocarpus). 72number beams of 50 mm×75 mm×1000 mm each, that is, 24pieces per specie was prepared with the aid of sawing and milling machines for bending strength and modulus of elasticity tests while 15number slices of 50 mm×150 mm×300 mm each was prepared at Soil Laboratory of the Department of Civil Engineering, Federal University of Agriculture Abeokuta (FUNAAB),Nigeria for moisture content (MC) and density determination.

2.2 Methods

The physical properties of the selected timber species was determined in sync with EN 13183-1 (2002) and EN 408 (2003). The mechanical properties were evaluated in accordance with EN 408 (2003) and ASTM D193 (2000). The characteristic values of material properties (i.e. mechanical properties and density) of the timber species were evaluated in accordance with EN 384 (2004). The minimum values were recommended from the results of the characteristic values of mechanical properties, based on the specification of EN 384 (2004).

Moisture content (MC)

The moisture content of the selected timber species was first determined specifically by measuring the initial mass of specimen before drying using weighing balance. The specimen was subjected to oven drying at a temperature of 103±20C for 24 hours. The initial and oven dry mass of each specimen was recorded and the MC was then computed mathematically from the equation below:

Moisture Content (MC) = $\frac{M_{1-M_2}}{M_2} \times 100\%$ (1)

Where M_1 = initial mass of specimen andM_2= mass of oven dry specimen

Density

The density of wood is its mass per unit volume at a specified value of MC. The density of specimen was obtained in line with the standard; EN 408 (2003).The characteristic values of density of specimen will be determined using the equation below:

$\rho_{k= \rho_{05}} = [\overline{\rho} - 1.65s]$ (2)

Where ρ_k =The characteristic density, $\overline{\rho}$ = Mean of all densities of each specimen (kg/m^3) and S = standard deviation of each specimen (kg/m^3)

The 18% MC adjustment for characteristic value of density of timber specimenas required by NCP2 (1973) was computed using the equation;

$\rho_{k,18\%} = \rho_w \left(\frac{(1-0.5)(u-18)}{100}\right)$ (3)

Where $\rho_{k,18\%}$ = characteristic density at 18% MC,
ρ_w = characteristic density at the MC during the bending test, (kg/m^3) and
U = measured moisture content of each specimen (%)

Bending Strength

The four point and three point bending strength tests as specified by EN 408 (2003) and ASTM D193 (2000) was experimented on 5 specimens from each of the selected timber specie as shown in Plates 1 and 2. Each specimen was tested using universal testing machine (UTM) until failure occurred. The failure load in respect of the individual beam was obtained and recorded.

The four point bending strength test was computed from equation 4 (EN 408, 2003):

$f_m = \frac{aF_{max}}{2W}$ (4)

a = the distance between loading position and the nearest support (mm)

F_{max} = the maximum load (N), W = the section modulus (mm^3) and
f_m= the bending strength (N/mm^2).
The three point bending strength on the other hand was computed by the equation;

$$f_m = \frac{3F_{\max}l}{2bh^2} \qquad (5)$$

b = the width of cross-section in bending test (mm)
h = the depth of cross section in bending test (mm) and
l = is the length of test specimen between supports (mm)
The peak stress in the three point bending test is produced at the specimen mid-point with reduced stress elsewhere while four point bending test produces peak stresses along an extended region of the specimen and for both methods the shear was not taken into consideration as it is negligible when compared to bending.
The characteristic value of strength was now obtained from the equation;

$$f_m = 1.12f_{05} \qquad (6)$$

(Ranta-Maunus, Forselius, Kurkela & Toratti, 2001).
f_{05} = 5th percentile values of bending strength

$$f_{m,18\%} = \frac{3F_{measured}}{1+0.0295(18-u)} \qquad (7)$$

Modulus of Elasticity (MOE)
Load was applied at constant rate using Universal Testing Machine (UTM). The deflection of the beam corresponding to the load applied at constant rate was carefully observed and recorded.
The MOE of the individual beam specimen derived from four point bending test was then computed from equation below (EN 408, 2003):

$$E_{m,g} = \frac{l^3\,(F_2-F_1)}{bh^3\,(W_2-W_1)}\left[\left(\frac{3a}{4l}\right)-\left(\frac{a}{l}\right)^3\right] \qquad (8)$$

Where$E_{m,g}$ = the global MOE in bending,
a = distance between inner point loads and supports (mm),
l = the length of the test specimen between the testing machine grips in bending test (mm),
(F_2-F_1) = the increment load (in Newton) on the regression line with a correlation coefficient of 0.99,
(W_2-W_1) = increment of deformation (mm) corresponding to (F_2-F_1).
Three point bending test was computed from equation below; (ASTM D193, 2000)

$$E_{m,g} = \frac{l^3\,(F_2-F_1)}{48I\,(W_2-W_1)} \qquad (9)$$

I = second moment of area (mm^4)
The characteristic values of MOE based on the measured MC was obtained from equation;

$$\overline{E_i} = \left[\frac{\sum E_i}{n}\right]1.3 - 2690 \qquad (10)$$

Where E_i = the *i*th value of MOE, n is the number of specimens ($E_{m,k} = \overline{E_i}$)
$\overline{E_i} =$ The mean value of MOE in bending.
The adjustment for characteristic MOE of timber specimen from the measured MC to 18% according to NCP2(1973) was evaluated using the equation below:

$$E_{m,18\%} = \frac{E}{1+0.0143(18-u)} \qquad (11)$$

Where,$E_{m,18\%}$ = characteristic bending MOE at 18% MC,
E = characteristic MOE at the measured MC (N/mm^2) and u = measured MC (%)

Other Material Properties
These were obtained from Timber code for design(EN 338) based on the characteristic value of the obtained results. Equations needed were provided in the code.

3. RESULTS AND DISCUSSION
The timber properties considered include MC, density, bending strength and MOE.

Moisture Content (MC)
The mean MC results for the three selected timber species are represented in Table 1.
The results of Table 1 show that the mean, standard deviation and coefficient of variation of MC for Aga (Musanga cecropioides), Ayinre (Albizia coriaria) and Orin dudu (Anogeissus leiocarpus)timber species are given by 24.50%, 20.12% and 25.23% respectively with the corresponding coefficients of standard deviations given in this order as 2.26, 2.17 and 2.94% and variation (COV) of 0.092, 0.114 and 0.132respectively. The mean values of MC with respect of all the four species were found to fall below the fibre saturation point (FSP). The FSP is usually between 25-30% MC (Nabade, 2012).

Table 1: Moisture Content Results

Timber Specie	Moisture Content (%)		Coefficient of Variance
	Mean Deviation	Standard	
Ayinre (Albizia Coriairia)	24.50	2.26	0.092
Orin dudu (Anogeissus Leiocarpus)	20.12	2.17	0.114
Aga (Musanga Cecropioides)	25.23	2.94	0.132

Density
The mean values, standard deviation, and coefficient of variation for the selected timber species are also represented in the Table 2.The mean values of density (ρ) for the three species are respectively given by 205.45kg/m^3, 304.56kg/m^3, and 178.84kg/m^3withCOV's of 0.033, 0.047 and 0.065 and the corresponding values of standard deviations of 16.55kg/m^3, 20.07kg/$m^3$and 23.24kg/m^3.The two measures of dispersions show a slight variation from the mean values with respect to all species. Table 3 shows the results of the characteristic densities which

are the 5-percentile. Since the current Nigerian timber design code is based on 18% MC, the values were adjusted to the recommended MC in order to suit the Nigerian environmental condition. The results given in Table 3 show that characteristic density decreases for all timber species as a result of the adjustment of MC from the measured value to 18% MC as computed using equation 2.3 as initially stated.

Table 2: Density Results

Timber Specie	Density (kg/m^3) Mean	Standard Deviation	Coefficient of variance
Ayinre (Albizia Coriairia)	205.45	16.55	0.033
Orin dudu (Anogeissus Leiocarpus)	304.56	20.07	0.047
Aga (Musanga Cecropioides)	178.84	23.24	0.065

Table 3: Results of Characteristic Values of Density

Timber Specie		Ayinre	Orin dudu	Aga
Density	ρ_k	178.14	271.44	140.49
	$\rho_{18\%}$	172.35	268.56	135.41

Bending Strength

Table 4 shows the bending strength values based on the measured MC and 18% adjusted MC. The adjustment of bending strength values to the equivalent 18% MC was as a result of environmental condition in Nigeria (NCP, 1973).The results of characteristic bending strengths presented in Table 4.0 show that there was an increment in the characteristic bending strength as MCs were adjusted to 18% for all timber species and this can be likened to moisture migration. For instance, the bending strength for Orin dudu at the measured MC corresponding to four point bending test was 43.45N/mm^2. The adjusted values of bending strength to 18% MC increased to 47.80 N/mm^2. According to equation 2.6, characteristic bending strength increases for any value of MC above 18%. This is because the denominator of equation 2.7 is less than 1 when MC is greater than 18%. For all the species considered, MC's are greater than 18%. This also applies to other strength properties such as tensile and compression parallel and perpendicular to grains. Also it can be observed that the three point bending test results gave higher bending strengths than the corresponding four point test for all the species.

Table 4:Characteristic Values of Bending Strength

Timber Specie	Ayinre		Orin dudu		Aga	
	4pt	3pt	4pt	3pt	4pt	3pt
$f_{m,k}$(N/mm^2)	30.69	38.62	47.8043.45		24.78	30.06
$f_{18\%}$(N/mm^2)	37.97	47.78	46.35	50.98	31.50	38.21

Modulus of Elasticity (MOE)

Table 5 which shows the results of characteristic MOE in bending clearly depicts that characteristic MOE increased as the MC's were adjusted to 18% with respect to all the species considered. For both equation 2.7 and equation 2.11; the values of characteristic MOE increases when MC is greater than 18%. This also implies that timber attains its greatest stiffness when approaching dryness. This also applies to other stiffness properties such as mean MOE perpendicular, 5% MOE, shear modulus (Nabade, 2012).

Table 5:Characteristic Values of MOE for 3-point and 4-point test

Timber Specie	Ayinre		Orin dudu		Aga	
	4pt	3pt	4pt	3pt	4pt	3pt
$E_{m,k}$(KN/mm^2)	8.12	10.37	7.75	9.18	6.26	7.28
$E_{18\%}$(KN/mm^2)	8.95	11.43	7.99	9.47	6.98	8.12

Table 6: Characteristic Values of Material Properties To 18% MC

Timber property	Density (Kg/m^3)	MOE		Bending Strength	
		4pt	3pt	4pt	3pt
Ayinre	178.14	8.12	10.37	30.69	38.62
Orin dudu	271.44	7.75	9.18	43.45	47.80
Aga	140.49	6.26	7.28	24.78	30.06

MOE and Bending Strength in N/mm^2

Table 7:Adjusted Characteristic Values of Material Properties To 18% MC

Timber property	Density (Kg/m^3)	MOE (N/mm^2)		Bending Strength(N/mm^2)	
		4pt	3pt	4pt	3pt
Ayinre	172.35	8.95	11.43	37.97	47.78
Orin dudu	268.56	7.99	9.47	46.35	50.98
Aga	135.41	6.98	8.12	31.50	38.21

Table 6 gives the average values of material properties of the selected timber species as adjusted to 18% MC. The results presented in Table 6 showed that Orin dudu (Anogeissus Leiocarpus) was found to have the highest density value of 268.56 Kg/m^3 followed by Ayinre (Albizia Coriairia) with 172.35Kg/m^3 and the least value of 135.41 Kg/m^3 corresponding to Aga (Musanga Cecropioides).The results also show that for the four selected timber species, decrease in the value of strength and stiffness properties was in this order: Orin dudu (Anogeissus Leiocarpus), Ayinre (Albizia Coriairia), Aga (Musanga Cecropioides).

Other Properties based on 18% MC

The results of other material properties of the timber species computed from the empirical relationships given in EN 338 (2009) are as presented in Table 8. In the determination of these material properties, only the minimum values of strength and stiffness properties were considered in the computations (EN 384, 2004). However, for the all cases, the minimum values correspond to those obtained from the four point bending test. Also, the material properties given in Table 8 were adjusted to the 18% MC in order to suit the Nigerian environmental condition.

Table 9 presents the summary of the results of both the physical and mechanical properties of the four timber species as recommended by EN 384 (2004). The characteristic values of the reference and other properties as computed based on the measured MCs and as adjusted to 18% MC were presented.

Table 8: Characteristics of Other Properties Based On 18% MC

Other Timber properties	Ayinre	Orin dudu	Aga
Tension Parallel $□_{□,0,□}$(N/mm^2)	22.78	27.81	18.9
Tension Perpendicular $□_{□,90,,□}$(N/mm^2)	0.6	0.6	0.4
Compression Parallel $□_{□,0,□}$(N/mm^2)	25.67	28.10	23.62
Compression Perpendicular $□_{□,90,□}$(N/mm^2)	1.25	4.07	0.98
Shear Strength $□_{□,□}$(N/mm^2)	4.0	4.0	4.0
5% MOE Parallel $□_{0,05}$(KN/mm^2)	5.44	6.51	4.19
Mean MOE Perpendicular$□_{90,□□□□}$(KN/mm^2)	0.18	0.43	0.21
Mean Shear Modulus $□_{□□□□}$(KN/mm^2)	0.34	0.41	0.26
Mean Density $□_{□□□□}$ (Kg/m^3)	213.77	325.73	168.59

Table 9: Summary of Results of Physical and Mechanical Properties of Selected Timbers

Other Timber Properties	Ayinre	Orin dudu	Aga
No. of Specimen for Bending & MOE/MC	24/15	24/15	24/15
Measured MC (%)	24,50	20.12	25.23
Characteristic Density at measured MC	178.14	271.44	140.49
Adjusted Char. Density to 18%	172.33	268.56	135.41
3point Characteristic Bending strength	38.62	47.80	30.06
4point Characteristic Bending strength	30.69	43.45	24.78
Adj. 3point Char. Bending strength to 18%	47.78	50.98	38.21
Adj. 4point Char. Bending strength to 18%	37.97	46.35	31.50
3point Characteristic MOE	10.37	9.18	7.28
4point Characteristic MOE	8.12	7.75	6.26
Adj. 3point Char. MOE to 18%	11.43	9.47	8.12
Adj. 4point Char. MOE to 18%	8.95	7.99	6.98
Tension Parallel	22.78	27.81	18.9
Tension Perpendicular	0.4	0.6	0.4
Compression Parallel	25.67	28.10	23.62
Compression Perpendicular	1.25	4.07	0.98
Shear Strength	4.0	4.0	4.0
5% MOE Parallel	5.44	6.51	4.19
Mean MOE Perpendicular	0.18	0.43	0.21
Mean Shear Modulus	0.34	0.41	0.26
Measured Mean Density	213.77	325.73	168.59

4. CONCLUSION AND RECOMMENDATIONS

In Abeokuta, South West Nigeria, Orin dudu (*Anogeissus leiocarpus)* has been shown by experimental works to have the highest values of mechanical properties followed by Ayinre (*Albizia coriaria*) and Aga (*Musanga cecropioides*) respectively. Hence it is suitable for various structural applications. Orin dudu is readily available in sawmills in Abeokuta and it has more durability as compared to Ayinre and Aga. Timber to be used in construction should be properly seasoned and coated from bacterial and fungi attack to ensure durability. Construction using timber material completely in interior works likes staircase, partition walls etc. should be encouraged to promote the structural uses of timber in the country.

REFERENCES

ASTM D193 (2000). *Standard Method of Testing Small Clear Specimens of Timber*, American Society for Testing and Materials, USA.

Characteristics of Timber – Relationship to Properties. (2010). Retrieved from http://www.boeingconsult.com/tafe/mat/Timber/Properties-short.pdf

EN 13183-1 (2002). *Moisture Content of a Piece of Sawn Timber, Determination by Oven Dry Method*. European Committee for Standardisation, CEN, Brussels, Belgium.

EN 338 (2009). *Structural Timber: Strength Classes.* European Committee for Standardisation, CEN, Brussels, Belgium.

EN 384 (2004).*Structural Timber: Determination of Characteristic Values of Mechanical Properties and Density*. European Committee for Standardisation, CEN, Brussels, Belgium.

EN 408 (2003). *Timber Structures – Structural Timber and Glued Laminated Timber: Determination of Some Physical and Mechanical Properties*. European Committee for Standardisation, CEN, Brussels, Belgium.

Fathi, M.S. (2010). *Introduction to Wood and Timber.*Civil Engineering Materials Lecture Note, Department of Civil Engineering, RAZAK School of Engineering and Advanced Technology, UTM International Campus. Retrieved from http://www.sab2112.files.wordpress.com/2010/09/nota-sab-2112-wood-timber-2page.pdf

Nabade, A. M. (2012). *Development of Strength Classes for Itako (Strombosia pustulata), Oporoporo (Macrocarpa bequaertii), Opepe (Nauclea diderrichii) and Ijebu (Entandrophragma cyclindricum) Nigerian Timber Species Based on EN 338 (2009).* M.Sc. Thesis, Department of Civil

Engineering, Ahmadu Bello University, Zaria, Nigeria.

Mitra, N. (2011). *Timber.* Retrieved from http://www.facweb.iitkgp.ernet.in/nilanjan/CE20100_Lecture_14.pdf

National Association of Forest Industries. (2004). *Timber Species and Properties*(Revised Ed.). Retrieved from http://www.woodsolutions.com.au/fwpa/article_downloads/Timberspeciesandproperties.pdf

NCP (1973). *The Use of Timber for Construction*. Nigerian Standard Code of Practice, Nigerian Standard Organisation, Federal Ministry of Industries, Lagos, Nigeria.

Poku, K., Wu, Q. & Vlosky, R. (2001). Wood Properties and their variations Within the Tree Stem of Lesser-Used Species of Tropical Hardwood from Ghana. *Wood and Fiber Science, 33 (2):284-291*. Retrieved from http://www.rnr.lsu.edu/people/Wu/PDFFiles/Kofuwood2001.pdf Properties of Timber. (2014). Retrieved from http://www.timbertech.wikispaces.com/file/view/Characteristics%2Bof%2BTimber.pdf

Rajakaruna, M. (2002). *Properties of Timber.*Timber Education Program, The University of Western Australia. Retrieved from http://www.picnicpt-h.schools.nsw.edu.au/documents/

Ranta-Maunus A., Forselius, M., Kurkela, J. & Toratti, T. (2001).*Reliability Analysis of Timber Structure*, Nordic Industrial Fund, Technical Research Centre of Finland.

Structural Timber Association. (2014). *Timber as a Structural Material – An Introduction.* Structural Timber Engineering Bulletin. Retrieved from http://www.cti-timber.org/sites/default/files/STA_Timber_as_a_structural_material.pdf

Trada. (2002). *Timbers – their Properties and Uses.* Retrieved from http://www.home-extension.co.uk/timber.pdf