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STRENGTH CHARACTERIZATION AND GRADING OF LESS-USED NIGERIAN GROWN TIMBER SPECIES FOR STRUCTURAL APPLICATIONS

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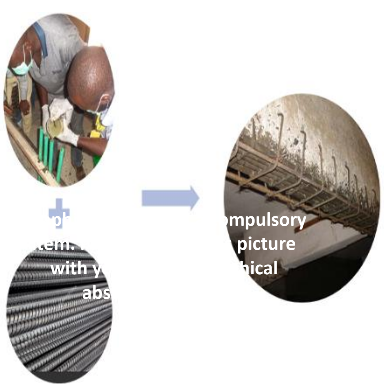
Graphical abstract



Abstract

The demand for timber is unlimited as it continues to increase rapidly in Nigeria. There is problem of undocumented properties of unpopular timber species used locally, especially in developing countries such as Nigeria. This research therefore aimed at characterizing and grading of three (3) less-used timber species in Nigeria for structural uses. Ayunre (Albizia zygia), Eku (Brachystegia eurycoma) and Ire (Funtunia elastica) timber species were obtained from different sawmills in Ilorin, Nigeria and preparation of various test specimens are in accordance with British Standards BS 373: 1957. A total of 300 specimens were used in determining the strength characteristics of the timber species a 300 kN capacity Testometric Universal Testing Machine (UTM) at Agricultural and Biosystems Engineering Laboratory, University of Ilorin. Twenty (20) specimens for each timber species were tested for structural/strength properties according to the British Standard. Results show that the timber species had average moisture contents of 12.47, 11.78 and 12.71% for Ayunre, Eku and Ire, respectively. For density classification, Ayunre and Eku were classified as heavy wood and Ire as light wood. The results obtained provided quantitative details of the strength properties of selected timber species which can be used in determining the application of these timber species for structural applications. The timber species were, therefore graded according to NCP 2 (1973), EN 338 (2009) and BS 5268 (2002).

Keywords: Ayunre, Eku, Grading, Ire, Strength Characterization

1.0 INTRODUCTION

Timber is a structural material used for the construction of different types of structures and the major mechanical property considered in its selection is the strength (Aguwa, 2016). For timber members to be designed intelligently, the knowledge of the strength of timber under loads of different nature is important (Aguwa et al., 2015). The strength characteristics of timber depend on the species, density, moisture content, presence and type of wood defects as well as on the dimension of the structure (Aguwa, 2016). Adeyemi (2016) and Jimoh et al. (2018) reported that timber as a structural material is different from steel and concrete because it is of biological origin whereas steel and concrete are of geological origin. The structural properties of timber are not easy to control because of their nature. Steel and concrete go through production process and some of their structural properties can be controlled. The demands for timber are increasing due to the need for local materials (Rahmon, 2018). Hardwoods are characterized with broad-leaves and examples are; Iroko (Milicia excelsa), Mahogany (Khaya senegalensis) Benin: Ogwango, Yoruba: Oganwo other names: Orere, Djave and Danta (Nesogordonia papaverifera, Benin: Urhuaro, Ibibio: Otalo, Yoruba: Otutu). Coniferous trees which are needle-like in leaves are known as softwood, some of these softwood are; Antiaris Africana (Benin: Ogiovu, Yoruba: Oro, other name: Ako), Alstonia boonei (Benin: Ukhu; Egbu, Yoruba - Ahun, other name: Otondo, Stoolwod) (Shasanya et al., 2015).

The quality of timber should be first priority in its selection, which must be free from any decay like rotten, warp, knot, fungi and mold or termite so that it would not give problem afterward. Before purchasing timber material for the construction, one must be well informed regarding timber types and forms to select as a single knot can bring down the show of whole wood work (Adebara et al., 2014). According to Obasi et al. (2015), 20% of the world's land area is cover with forest, which is about 4 billion hectares. Alamu and Agbeja (2011) stated that forest reserves take possession of approximately 10 million hectares, standing for about 10% of the land area of approximately 96.2 million hectares in Nigeria.

Timber is one of the most promising building materials having good technical properties and low carbon footprint compared to other widely used building materials such as concrete or steel, but most of the properties of these timbers are not known, although several research works have been done on characterization of timbers, and have resulted in comprehensive information about their material properties, there is still research gap to cover many useful but unpopular timber species, most especially, those species in developing countries like Nigeria. This research work therefore aims at characterizing and grading of three (3) less-used timbers in Kwara state, Nigeria which are: Ayunre (Albizia zygia), Eku (Brachystegia eurycoma) and Ire (Funtunia elastica).

Albizia zygia (Ayunre) is a deciduous tree 9-30 m tall with a spreading crown and a graceful architectural form. It belongs to the family name Fabaceae. Bole, tall, clear and 240 cm in diameter. Bark grey and smooth. It has local names: Nyie avu (Igbo), Nongo (Swahili) and Ayunre (Yoruba). It is usually found in Cameroon, republic of Congo, Gabon, Ghana, Kenya, Nigeria, Sudan, Tanzana and Uganda (Rahmon, 2018). Brachystegia eurycoma (Eku) is an economic tree crop that grows in the tropical rainforest of West Africa. It belongs to the Caesalpiniaceae family, the spermatophyte phylum and of the order of Fabaceae. The tree is about 35 m tall, with bole of 2 m diameter. It is vaguely buttressed, has low branching, large, flat crown common on river banks of the forest zone in southern Nigeria and Cameroon. It is also a very popular plant in the eastern part of Nigeria (Jimoh and Rahmon 2018). Funtumia elastica (Ire) is a tree of height up to 30 m, with not quite straight, cylindrical, unbuttressed bole, 2.50 m in girth, of the deciduous forest from Guinea to West Cameroons and in the Congo basin, and along the Nile basin in Egypt, Sudan and Uganda. It belongs to the family Apocynaceae. The wood is white and soft, and undifferentiated between sap and heart (Rahmon, 2018).

According to Fuwape (2000), if adequate information on the magnitude of load, rate of loading and the duration of load are provided, the appropriate timber species may be selected from the different timber strength groups and natural durability classes. The lack of sufficient information on some timbers has been the basis for their misuse and failure as structural member. Information on the strength behaviour of these four Nigerian timber species will help validate the structural viability of the species. Data of this type will serve as guide for design and specification of these timbers for use as construction material. With adequate mechanical data on given specie of timber, loading information, rate of loading and duration of loading can be so managed such that design of such timber will be adequate and safe use of such timber will be guaranteed.

2.0 MATERIALS AND METHODOLOGY

Timber species used for this research were obtained from Albizia zygia, Brachystegia eurycoma and Funtunia elastica trees in green condition from Sawmills in Ilorin, the state capital of Kwara State, Nigeria. Ilorin is geographically located on coordinates 8029'47.90''N, 4032'31.70''E. six(6) major sawmill outlets which were used for material sourcing are as follows: Akalambi, Opo-Maalu, Sawmill Gararge, Irewolede, NNPC junction and Oluwa Bankole Sawmill. Material selection were done through inquiry and documentation using the following details: Local name of timber species, rate of patronage, source of timber species, marketable size of timber, and price per unit length of timber species. Selected Timber species were sawn to 100 x 150 x 3600 mm sizes. Logs of selected timber were moved to Timber Workshop of Civil Engineering department, University of Ilorin for seasoning, preparation, and physical testing.

2.1 Test Specimens Preparation and Properties (Physical and Strength) determination

Timber specimens were seasoned naturally for six months so as to reach equilibrium moisture condition (EMC) at Timber Workshop of Civil Engineering department, University of Ilorin, Ilorin, Nigeria. The natural method of seasoning was adopted in accordance with Aguwa (2010) method. The natural seasoning was done by stacking the timber so that enough air can circulate around each piece. This will increase the dimensional stability and make it stronger, durable and increase their weight. Twenty (20) specimens were tested for all strength and physical properties using BS 373: 1957 procedure. Determination of all mechanical/strength properties were examined using Testometric Universal Testing Machine model of capacity 300 kN with computer interface for data acquisition and analysis. Tensile, compression (parallel and perpendicular), modulus properties (elasticity and rupture), physical properties such as density and moisture content were determined. The data obtained were analyzed accordingly.

2.2 Conditioning of the Timber Species

The species obtained were conditioned at a standard environmental temperature of (20 ± 2)0C and (60±5) relative humidity according to the British Code of Practice, BS 373:1957. Each of the sawn species were weighed successively at intervals of 24 hours and recorded until equilibrium moisture content (EMC) was attained.

2.3 Description of Testing Equipment

Strength properties for the various mechanical tests were performed using the Testometric Universal Testing Machine (UTM) at the Department of Agricultural and Biosystems Engineering Laboratory, Faculty of Engineering and Technology, University of Ilorin, Nigeria. Characteristics features of the machine are as follows: Machine Serial Number:35173, UTM Brand: Testometric, Model: DBBMTCL and Capacity of 300 kN with computer interface for data acquisition and analysis. The test type, orientation, name of the test, test speed and specimen dimensions and specimen weight were input to the computer to generate output curves and date for various tests conducted. Some of the straining rate for the mechanical property tests are as follows: static bending 0.26 in/min (6.6 mm/min), compression parallel and perpendicular 0.025 in/min (0.635 mm/min), shear parallel 0.025 in/min (0.625 mm/min), tension parallel 0.05 in/min (1.27 mm/min).

2.4 Conversion of Failure Stresses to Standards

Strength properties for the various mechanical tests were According to Aguwa (2016), there is no definite formula for adjusting for moisture content of timber specie. This is due to the vast number of species, with each having its own inherent variability. There have been two main schools of thought on the derivation of a suitable generalized formula for adjusting for moisture content; one being driven by the wood scientists while the other has been developed by the wood engineers. The Failure stresses for all strength properties obtained were all adjusted to standards of 12 % and 18 % as specified by BS 5268 (2002) and NCP 2 (1973). Equation (1) and (2) were employed accordingly.

$$F_{12} = F_w(1 + \alpha(W - 12)) \quad (1)$$

$$F_{18} = F_w(1 + \alpha(W - 18)) \quad (2)$$

where F12 = the ultimate strength at 12% moisture content, F18 = the ultimate strength at 18% moisture content, W = the moisture content at the time of testing, Fw = the ultimate strength at the moisture content at the time of testing, α = correction factor as used in Aguwa et al. (2015) and Rahmon (2018).

2.5 Static Bending

The Static Bending which was carried out using the method of central loading. The Static bending strength (flexural strength and Modulus of Rupture, MOR). The Modulus of Elasticity (MOE) using the bending strength as stated in Equation (3) in line with Aguwa et al. (2015).

$$E_{L3} = \frac{l^3}{4eh^3}\, k \quad (3)$$

where, EL3, the three-point bending modulus of elasticity, ℓ, the distance between the two supports (280 mm), e, the width of the beam (20 mm), h, the height of the beam (20 mm) and k is the slope of load-deformation graph that is. Minimum modulus of elasticity was determined by Equation (4) which shows the relationship between mean modulus of elasticity, Emean and the minimum modulus of elasticity, Emin.

$$E_{min} = E_{mean} - \frac{2.33\sigma}{\sqrt{N}} \quad (4)$$

where N is the number of specimens, is the standard deviation

2.6 Flexural Strength

Flexural testing is a mechanical method used to measure the mechanical behavior to unified bending loads. It is used to define the structural integrity of materials being tested. The test covered the determination of flexural properties of the timber species. Such properties are the modulus of rupture and the modulus of elasticity in flexure. The specimen shape and the test method for this experiment were carried out in accordance with BS 373:1957 (Method of Testing Small clear specimens of Timber). The test specimen dimension for static bending was 20 x 20 x 300 mm and the loading rate was 0.26 in/min (6.6 mm/min) as specified by the British Standard.

2.7 Compression Parallel And Perpendicular To Grain

The test was carried out on the 300 kN Universal testing Machine (UTM) using the specimen dimension of 20 x 20 x 60 mm and 50 x 50 x 50 mm for compression parallel and perpendicular to the grain. the ends of rectangular test piece are smooth and parallel and normal to the axis and testing machines were of such construction that the plates between which the test piece was placed were parallel to each other and remain so during the whole period of test so that the values obtained will be the true values. The loading rate for compression parallel and perpendicular were 0.025 in/min (0.635 mm/min).

2.8 Shear Parallel To Grain

The test specimens for the shear parallel to grain is L-shaped with length 35 mm and width 17.5 mm in accordance to the secondary method of BS 373:1957. The property determined is the measure of the resistance of the timber to shearing. The direction of shearing was parallel to the longitudinal direction of the grain. The loading rate for shear parallel to grain was 0.025 in/min (0.635 mm/min).

2.9 Tension parallel to grain

This test was used to predict how the material will react under force. It depicts the property ultimate tensile strength of a material. The tensile strength parallel to grain test was carried out in accordance to the secondary method of BS 373:1957. The test piece was so oriented that the direction of the annual rings at the cuboidal section is perpendicular to the greater cross-sectional dimensions. The load was applied to the 20 mm face of the ends of the test piece by special toothed plate grips which are forced into the wood before the test commenced. The loading rate for tension parallel to grain was 0.025 in/min (0.635 mm/min)

2.10 Moduli of Elasticity at 12 % and 18 % MC

Each of the (MOR) at experimental moisture content were all changed to 12 % and 18 % moisture content values in accordance with BS 5268 (2002) and NCP 2 (1973). The adjusted values were computed with Equation (5) and (6).

$$E_{m12} = \frac{E_{measured}}{1+0.0143(12-u)} \quad (5)$$

$$E_{m18} = \frac{E_{measured}}{1+0.0143(18-u)} \quad (6)$$

where Emeasured = modulus of elasticity at experimental moisture content, Em12 and Em18 = Modulus of elasticity at

12 % and 18 % moisture content respectively, and U = moisture content at the time of experiment.

2.11 Moisture Content

In determining the moisture content of the timber species, the twenty (20) samples of size 20 x 20 x 40 mm were obtained from the seasoned timber and the moisture content were obtained in accordance with the procedure stated in BS 373 (1957). The oven temperature was maintained constantly at 1050C for several hours until the weight is stable. Equation (7) was employed for the calculation of moisture content.

$$MC = \frac{m_1 - m_2}{m_2} \, x \, 100\% \qquad (7)$$

where MC = moisture content, m1 = weight of sample at test (g) and m2 = oven-dry weight of sample (g)

2.12 Density

Twenty samples of the timber species of size 20 x 20 x 20 mm were used for the determination of the density in accordance with BS 373 (1957). Density was calculated using direct measurement of length, width and thickness of the specimen using Vernier caliper using Equation (8).

$$\rho = \frac{m}{v} \qquad (8)$$

where, ρ = timber density, m = timber mass, and v = timber volume.

2.13 Conversion of Density to 12 % and 18 % Moisture Content

The computed densities were converted to 12% and 18% moisture content values in line with British Standard, BS 5268 (2002) and Nigerian Standard, NCP 2 (1973). Equation (9) and (10) were employed for the conversion.

$$\rho_{12} = \rho_w \left[1 - \frac{(1-0.5)(u-12)}{100}\right] \qquad (9)$$

$$\rho_{18} = \rho_w \left[1 - \frac{(1-0.5)(u-18)}{100}\right] \qquad (10)$$

where is ρ12 = density at 12% moisture content in kg/m3, ρ12 = density at 12% moisture content in kg/m3, ρw = density at experimental moisture content, U = experimental moisture content in %.

2.14 Basic and Grade Stresses

Basic stresses for all strength properties were calculated from the failure stresses as obtained from the UTM results using Equation (11) for the computation. Also, the grade stresses at 80, 63, 50 and 40 % values were equally computed in agreement with BS 5268 (2002).

$$f_b = \frac{f_m - k_p \sigma}{k_r} \qquad (11)$$

where fb = basic stress, σ = standard deviation of failure stress, kr = reduction factor and kp = modification factor = 2.33, Kr for bending and tension parallel to the grain = 2.25. Kr for compression parallel = 1.4 while Kr for compression perpendicular = 1.2 (Aguwa et al., 2015; Ozelton and Baird, 1981).

2.15 Arrangement of Test Specimen

Figure 1 - 4 show the test specimen arrangement for various mechanical/strength tests carried on the timber species using Testometric model of (UTM) of 300 kN capacity at the Agricultural and Biosystems Engineering Laboratory, University of Ilorin, Ilorin, Nigeria.

Figure 1 Compression Test arrangement

Figure 2 Bending Test arrangement

Figure 3 Tension Test arrangement

Figure 4 Tension Test arrangement

3.0 RESULTS AND DISCUSSION

3.1 Result of Physical Properties

The moisture content for each property are shown in Table 1 with respect to all the three timber species. It was observed that the moisture content values obtained were found to fall below the fibre saturation point (FSP) which is usually between 25 – 30 % as stated by Nabade (2012). According to Aguwa (2016), when timber neither gains nor losses moisture at a given constant humidity and temperature, an equilibrium moisture content (EMC) is attained. It was also observed that Ire has the highest value of moisture content (12.71 %), followed by Ayunre (12.47 %) and Eku (11.78 %). The 95 and 99 % confidence limits for the moisture content values of the three (3) timber species were also found to be satisfactory, since the determined values from tests are within the confident limits. The standard deviations of the moisture content for the timber species are given as follow: 1.73, 2.08 and 0.95 respectively with the corresponding coefficients of variation (COV) of 13.64, 16.65 and 8.05 % following the ranking order. These coefficients of variation indicate how large the standard deviation is in relation to the mean of the specie. The results show that timber species vary in moisture content and Ire has more variability in their moisture content values than other species while Eku has the least variability.

Table 1 Moisture Content of the Timber Species

Timber	Moisture content (%)						
	Min.	Max.	Mean	Std. Dev.	Coef. of Var.	Confidence Limit	
						95%	99%
Ayunre	8.96	16.48	12.47	2.08	16.65	11.66≤x≤13.29	11.40≤x≤13.54
Eku	9.64	13.87	11.78	0.95	8.05	11.41≤x≤12.15	11.29≤x≤12.27
Ire	9.67	16.23	12.71	1.73	13.64	12.03≤x≤13.39	11.82≤x≤13.60

Wood density is a measure of the amount of cell wall substance per unit volume of wood. It is an important index for estimating the strength and mechanical properties of wood to determine its suitability for various uses (Jimoh and Aina, 2017). Woods with more weight for a given volume have a higher density than woods with less weight. Both weight and volume of wood are affected by the amount of moisture it contains. Therefore, when specifying density it is important to also state moisture conditions (Novascotia Canada, 2015). Table 2 shows the mean values of the density for each of the tests carried out, the standard deviation and the coefficient of variation with respect to all the three species. The mean values of density (ρ) for the three species (Ayunre, Eku and Ire) are respectively given as 1108.97, 1148.25 and 389.13 kg/m3 with the corresponding values of standard deviation of 73.78, 62.29 and 25.96 kg/m3. Similarly, the coefficients of variation of the species are respectively given in the same order as 6.65, 1.51, 5.43 and 6.67 %. According to Findlay (1975), Ayunre and Eku were classified as heavy wood while Ire as light wood.

Table 2 Density of Timber Species

Timber species	Density (kg/m^3)						
	Min.	Max.	Mean	Std. Dev.	Coef. of Var.	Confidence Limit	
						95%	99%
Ayunre	978.57	1248.97	1108.97	73.78	6.65	1080.05≤x≤ 1137.89	1070.96≤x≤ 1146.98
Eku	1038.75	1252.34	1148.25	62.29	5.43	1123.83≤x≤ 1172.67	1116.16≤x≤ 1180.34
Ire	321.28	463.36	389.13	25.96	6.67	378.95≤x≤ 399.31	375.76≤x≤ 402.50

3.2 Result of Mechanical Properties

3.2.1 Tensile Strength Parallel To Grain

Mean values for the Tensile Strength parallel to grain of all the timber species are presented in Table 3. It was observed that Ayunre recorded highest mean Tension parallel to grain which was 64.81 N/mm2 (that is, it has higher resistance to failure in Tension parallel to grain than other species at the same moisture content) while Ire gave the lowest Tension parallel to grain strength value which was 59.20 N/mm2. When compared to some known species, Emi-gbegi, 45.37 N/mm2 (Ibitolu, 2017), Prosopis Africana, 13.6 N/mm2 (Ataguba et al., 2015), Adeyemi, (2016) recorded 77.69 N/mm2 for Ara and Adefemi, (2015) recorded 69.61 N/mm2 for Apa. The strength at 12 % moisture content value obtained for Ayunre, Eku and Ire timber species were found to be higher than that of Emi-gbegi, Prosopis Africana but lower than that of Ara and Apa. The 95 and 99 % confidence limits for the mean modulus of rupture of these Nigerian timbers are also shown in the table and they are satisfactory, since most of the determined values from test are within the ranges.

Table 3 Result of Tensile Strength of the Timber Species

	Ayunre	Eku	Ire
Mean failure stress (N/mm^2)	63.32	64.27	57.17
Standard deviation	5.90	5.04	6.25
Moisture content (%)	12.47	11.78	12.71
Strength @ 12% MC	64.81	63.50	59.20
Strength @ 18% MC	45.81	44.22	42.05
Basic stress (N/mm^2)	22.03	23.35	18.94
80% Grade stress (N/mm^2)	17.63	18.68	15.15

3.2.2 Compressive Strength Perpendicular To Grain

Results of Compressive Strength perpendicular to the grain for the timber species are reported in Table 4. It was observed that Ire recorded the highest mean compression perpendicular to grain which was 37.11 while Eku has the lowest value of 25.11 N/mm2. By comparing the observed values with the known values such as Neem: 30.35 N/mm2 (Aina, 2016), Adere: 8.6 N/mm2 (Ibitolu, 2017), Eriri: 10.6 N/mm2 (Ibitolu, 2017), Emi-gbegi: 12.2 N/mm2 (Ibitolu and Jimoh, 2017), Iponhon: 21.61 N/mm2 (Adeyemi, 2016). Ayunre, Eku and Ire values were higher than that of Adere, Eriri, Emi-gbegi and Iponhon, while Eku value is less than that of Neem. The 95 and 99 % confidence limits for the mean modulus of rupture of this Nigerian timber are also shown in the table and they are satisfactory, since most of the determined values from test are within the ranges.

Table 4 Compressive Strength Perpendicular to Grain of the Timber Species

	Ayunre	Eku	Ire
Mean failure stress (N/mm^2)	34.82	25.41	35.84
Standard deviation	8.73	1.48	8.42
Moisture content (%)	12.47	11.78	12.71
strength @ 12% MC	35.64	25.11	37.11
strength @ 18% MC	25.19	17.48	26.36
Basic stress (N/mm^2)	14.76	18.76	16.11
80 % Grade stress (N/mm^2)	11.81	15.01	12.89

3.2.3 Compressive Strength Parallel to Grain

Compressive Strength parallel to grain results are presented in Table 5. It was observed that Ayunre recorded the highest mean compressive strength parallel to grain of 36.84 N/mm2 while Ire has the lowest value of 20.01 N/mm2, that is, the resistance of Ayunre to failure in compression parallel to grain was higher than that of Eku and Ire species at the same moisture content. When compared with some already established results such as Apa: 28.599 N/mm2 (Adefemi, 2015) and Khaya senegalensis, 54N/mm2 (CIRAD, 2009). Ayunre and Eku value are higher than that of Apa but all the three species less than the Khaya ivorensis in compression parallel to grain. The 95 and 99 % confidence limits for the mean modulus of rupture of this Nigerian timber are also shown in the table and they are satisfactory, since most of the determined values from test are within the ranges.

Table 5 Result of Compressive Strength Parallel to Grain

	Ayunre	Eku	Ire
Mean failure stress (N/mm^2)	35.99	29.72	19.32
Standard deviation	2.47	2.30	1.82
Moisture content (%)	12.47	11.78	12.71
strength @ 12% MC	36.84	29.36	20.01
strength @ 18% MC	26.04	20.45	14.21
Basic stress (N/mm^2)	21.60	17.40	10.77
80% Grade stress (N/mm^2)	17.28	13.92	8.62

3.2.4 Bending Strength of Timber Species

The bending strength is a measure of resistance to bending and is calculated by formula PL3/4bd3 (method A) of BS 373: 1957. This is the amount of deflection of timber in response to a load. The bending strength values of all the timber species are shown in Table 6. Ayunre timber showed higher strength values than resistance to bending than the other species. The overall order of decreasing MOE of the species was as follows: Ayunre > Eku > Ire. When compared to known species such as The 12% moisture content of Eku timber specie was found to be higher than 5500 N/mm2 for Obeche, (Aina, 2016), Adeyemi, (2016) obtained at 12 % moisture content a value of 5525.28 N/mm2 for Omo, Khaya ivorensis (8192.54 N/mm2) by Jamala et al. (2013). The value for Khaya ivorensis is higher than that of Ire, whereas the value obtained for Obeche, Omo and Khaya ivorensis are all less than the value obtained for Ayunre and Eku. The 95 and 99 % confidence limits for the mean modulus of rupture of this Nigerian timber are also shown in the table and they are satisfactory, since most of the determined values from test are within the ranges.

Table 6 Result of Bending Strength of the Timber Species

	Ayunre	Eku	Ire
Mean failure stress (N/mm^2)	14092.18	11220.99	7430.90
Standard deviation	1492.26	911.55	1145.40
Moisture content (%)	12.47	11.78	12.71
Strength @ 12% MC	14224.65	11171.62	7536.42
Strength @ 18% MC	12533.59	9825.10	6644.71
Basic stress (N/mm^2)	4717.87	4043.15	2116.50
80% Grade stress (N/mm^2)	3774.30	3234.54	1693.20

3.2.5 Modulus of Rupture (MOR)

From Table 7, at 12% moisture content, the average modulus of rupture of Ayunre has the highest, follow by Ire and Eku accordingly, which are 93.23, 60.33 and 59.18 N/mm2. It is therefore obtained from the result that the resistance of Ayunre to static bending (MOR) was higher than that of the other species at the same moisture content. When compared with 50.13 N/mm2 recorded for Black Afara (Kaura et al., 2015) and 90.41 N/mm2 for Meliceae exclesa (Jamala et al., 2013), D. fusca, 65.14 N/mm2 and D. rappa, 61.32 N/mm2 (Duju and Hisham, 2015), Ahun, 39.36 N/mm2 (Mohammed, 2014). The 12 % moisture content strength of Ayunre, Eku and Ire were higher than Black Afara, D. rappa and Ahun and also higher than 20.62 N/mm2 obtained for Neem (Aina, 2016) but less than 120.54 N/mm2 reported for Negro Pepper (Jimoh and Aina, 2017). The 95 and 99 % confidence limits for the mean modulus of rupture of these Nigerian timbers are also shown in the table and they are satisfactory, since most of the determined values from test are within the ranges.

Table 7 Modulus of Rupture of the Timber Species

	Ayunre	Eku	Ire
Mean failure stress (N/mm^2)	91.51	59.75	58.66
Standard deviation	8.33	10.94	6.46
Moisture content (%)	12.47	11.78	12.71
Strength @ 12% MC	93.23	59.18	60.33
Strength @ 18% MC	71.27	44.84	46.25
Basic stress (N/mm^2)	32.05	15.23	19.38
80% Grade stress (N/mm^2)	25.64	12.18	15.51

Regarding wood mechanical properties, the arrangement and proportions of ground tissues (axial and ray parenchyma, fibres and vessels) in hardwood species are considered to play a key role (Bowyer et al., 2003). From Table 8, it can be concluded that at 12% moisture content, the mechanical properties of the species vary from one another, this can be associated with a considerable difference in density between the species.

Table 8 12 % MC results of Principal Strength Characteristics of the Timber Species

Mechanical properties (N/mm^2)	Ayunre	Eku	Ire
Bending Strength	14224.65	11171.62	7536.42
Modulus of Rupture	93.23	59.18	60.33
Compression parallel	36.84	29.36	20.01
Compression perpendicular	35.64	25.11	37.11
Tension Strength	64.81	63.50	59.20

3.2.6 Strength Classification

According to NCP 2:1973, the 80% Grade stresses of the two Nigerian timber species are given in Table 9, using the Bending parallel to grain strength values. Comparing these values with Table 7 of NCP 2:1973 Dry Grade stresses of Timbers, the following strength groups were obtained. This shows that Ayunre is stronger than Eku and Eku is also stronger than Ire timber species. The strength classes for Nigerian timber species in general ranges from the highest grade N1 to the weakest grade N7 strength classes. Grade stresses obtained for Ayunre, Eku and Ire timber species in modulus of rupture, had been allocated to strength class N3, N6 and N5 which implies that Ayunre and Eku are suitable for use in load bearing structures such whereas Ire species is suitable for use in furniture components, plywood and joineries.

Table 9 Strength class allocation (NCP 2:1973)

Timber species	**Experimental Stresses (N/mm^2)**	**NCP 2 80% Grade Stresses (N/mm^2)**	**Strength Classes**
Ayunre (*Albizia zygia*)	91.51	25.64	N3
Eku (*Brachystegia eurycoma*)	59.75	12.18	N6
Ire (*Funtumia elastica*)	58.66	15.51	N5

Based on BS 5268: 2002 criteria, Ayunre, Eku and Ire were assigned to strength class D50, D30 and C14, respectively due to their material properties as specified by the code. Table 10 shows the strength allocation according to BS 5268 (2002).

Table 10 Material properties for BS 5268 classification

Timber species	**Grade stress 80 (N/mm^2)**	**Mean Modulus of Elasticity (N/mm^2)**	**Density (kg/m^3)**	**Strength Classes**
Ayunre	25.64	14092.18	1108.97	D50
Eku	12.18	11220.99	1148.25	D30

Ire	15.51	7430.90	389.13	C14

Table 11 presents the EN 338 (2009) strength classification in which Ayunre and Eku were allocated to strength classes of D50 and D30, respectively using their characterized values of density, bending strength and modulus of elasticity, they both belong to hardwood class. Ire was allocated to strength class C14, which is softwood class.

Table 11 Summary of Strength Class for EN 338

Timber species	Density (kg/m^3)	MOR (N/mm^2)	Bending Strength (N/mm^2)	Strength Classes
Ayunre	1140	93	14188	D50
Eku	1184	60	11186	D30
Ire	399	60	7507	C14

4.0 CONCLUSIONS

Laboratory experiments were conducted to determine the physical and mechanical properties of three (3) less-used Nigerian timber species, namely: Ayunre (Albizia zygia) Eku (Brachystegia eurycoma) and Ire (Funtumia elastica), in accordance with BS 373: 1957. According to Findlay (1975), the density classification of the selected timber species is as follows: heavy wood for Ayunre and Eku and light wood for Ire. The mean values of MC with respect to all the three timber species were found to fall below the fibre saturation point (FSP) which is usually between 25 - 30 % MC according to Nabade (2012). The three (3) timber species were successfully characterized and graded according to NCP 2 (1973). Ayunre, Eku and Ire timber species were, therefore graded according to NCP 2 (1973) and assigned to their corresponding strength classes as N3, N6 and N7, respectively. In accordance to EN 338 (2009) Ayunre, Eku and Ire were assigned to strength classes of D50, D30 and C14, respectively. However in accordance to BS 5268 (2002), Ayunre, Eku and Ire were assigned to strength classes D50, D30, and C14, respectively. Hence, the three timber species were successfully characterized and graded.

5.0 RECOMMENDATIONS

i. Structural Engineers, carpenters, building technologists, and other timber users can use Ayunre and Eku for heavy duties, while Ire is applicable for non-structural use.

ii. Lack of adequate information (strength/mechanical properties) on the less-used timber species in Nigeria can lead to over-exploitation of the few commercial species such as Ayin, Ara, Mahogany, Obeche, Opepe and Teak whose properties are well known. Therefore, more research should be channel to classification and grading of less-used timber species.

iii. Reliability-based optimal design of the graded timber species should be investigated in order to ascertain their reliability with time.

iv. There is an urgent need for revision of NCP 2 (1973) in order to incorporate the newly graded timber species.

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