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DEVELOPMENT OF STRENGTH CLASSES FOR TWO SELECTED NIGERIAN TIMBER SPECIES BASED ON BS 5268:2002 AND NCP2:1973

A.A. Jimoh¹, A.S. Fatolu², R.O. Rahmon^{3*} and O.Y. Babatunde⁴

Department of Civil Engineering, Faculty of Engineering and Technology,
University of Ilorin, Nigeria

¹aajimoh4real@yahoo.com, ²fatoluadesoji@yahoo.com, ^{3*}rorahmon2222@gmail.com,

⁴babatundeyusuf990@gmail.com

ABSTRACT

Broad range of research works have been carried out over the past few years and these have resulted in comprehensive information on materials properties of various species of timber in Nigeria. There is still research gap to cover many useful but unpopular timber species, therefore this research work is meant at characterising two commonly used timber species in Nigeria; *Isobberlinia doka* (Babo/Doka) and *Anogeissus leiocarpus* (Ayin) for structural use as well as comparing their properties with other known timber species. The logs of wood used were obtained from Irewolede Sawmill, from where tests specimen were prepared in accordance with BS 373:1957. A total of 240 test specimens were prepared from the timber species and Laboratory tests were carried out on these specimens using 100 kN Universal Testing Machine (UTM) at the National Centre for Agricultural Mechanization (NCAM), Ajase Ipo Road, Ilorin, Kwara State, to determine some of the physical and mechanical properties of the timber species. The strength properties tested includes: bending strength (MOR), modulus of elasticity (MOE), tensile strength, shear strength, compression strength (both parallel and perpendicular to grain) and cleavage strength while the physical properties tested include moisture content, specific gravity, and density. The results obtained show that the timber species are hardwood of higher strength classes (between strength classes D30 – D70) when compared with BS 5268:2002 whereas, Ayin is stronger than Babo timber species according to NCP 2:1973.

Keywords : Ayin, Babo, Grading, Strength, Timber

1. BACKGROUND/INTRODUCTION

Timber refers to wood in the form that is suitable for construction of carpentry, joinery or for reconversion for manufacturing purposes (Rahmon, 2018). 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. For timber members to be designed intelligently, the knowledge of the strength of timber under loads of different nature is important (Aguwa, 2013). Nigeria is one of the countries that have timber in surplus quantity (Jimoh et al., 2017a). It is called the world's only renewable natural resource since a new one can be grown where one has been cut down. The world has just less than 4 billion hectares of forest which cover approximately 20% of the world's land area as reported by Obasi et al., (2015). Alamu, and Agbeja (2011) stated that forest reserves take possession of approximately 10 million hectares, standing for about 10% of a land area of approximately 96.2 million hectares in Nigeria. If this natural resource is properly utilized, it will be of immense benefit to the country in terms of reduction in the cost of construction (Aguwa, 2012; Rahmon, et al., 2017; Ibitolu and Jimoh, 2017). The strength of a timber depends on its species and the effects of certain growth characteristics (Jimoh et al., 2017b). Different wood species have different strength characteristics. And also within a species, these characteristics may vary. Therefore, in practice, a classification system of strength classes is used (Jamala, et al., 2013). The need for local content in the construction of engineering infrastructure is now a serious engineering

challenge in Nigeria. This is because vast quantities of local raw materials, which must be processed and used for cost-effective abound (Aguwa, 2016; Rahmon et al., 2017; Zziwa et al., 2016). Construction activities based on these locally available raw materials are major steps towards industrialization and economic independence for developing countries. This explains huge interest and considerable intellectual resources being invested in understanding the mechanical or structural properties of the Nigerian timber (Aguwa and Sadiku, 2011). The demand for timber is unlimited as it continues to increase rapidly in Nigeria. Although several research works have been done on the 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.

Anogeissus leiocarpus (Ayin) is a fodder tree occurring in most of the Savanna areas from the driest regions to the borders of forest zones (Ibrahim et al., 1997). It belongs to the family *combretaceae*, which comprises of approximately 600 species in 20 genera of trees, shrubs and lianas, distributed in tropical and subtropical countries very often in the savannas (Tan et al., 2002). They are usually tall trees from 15 to 18 m in Senegal, 22 m in Ghana, and up to nearly 30 m in Nigeria with straight tapering bole, branching from low down, common in places, often gregarious and killing out grasses (Ibrahim et al., 1997). The leaves are alternate, elliptic to ovate, pale green and distantly placed on the stems with barks being scaly, grey and resistant to insects, termites and fire. Flowers and fruits have glucose heads with reflexed calyx-lobes (Fatolu, 2017).

Isobertinia doka (Babo/Doka): The wood of *Isobertinia doka*, called 'Abogo' or 'Sau' in trade, is used for joinery, furniture and cabinet work. Traditionally, it is also used for posts, poles, handicrafts and agricultural implements. It is suitable for light construction, flooring, panelling, moulding, ship building, railway sleepers, boxes, crates, veneer and pulpwood. As there are no physical differences between the heartwood and the very wide sapwood, the latter can be used just like the heartwood after treatment with preservatives (Fatolu, 2017). The wood is widely used for fuel or made into charcoal. Wood ash is used in soap making. The inside of the fruits is used to scour earthenware pots. Several parts of the tree have traditional medicinal uses. The bark is also used as vermifuge. In Mali a leaf decoction is used as a wash by women against infertility. A preparation from the roots and leaves is used against jaundice. *Isobertinia doka* is a host of wild silk worms, especially of the butterflies *Anaphe moloneyi* and *Gastrophylacaeis rufescens*, and its flowers are visited by honey bees. In northern Ghana the leaves are used as fixative when dyeing nails with henna. The heartwood is pinkish brown to reddish, mottled with irregular grey-purple veins; it is distinctly demarcated from the greyish to silvery or white sapwood, which is 3–7 cm wide and makes up about 40% of the bole volume. The grain is often distinctly interlocked and uneven, texture moderately coarse.

Generally, strength grading of timber offers a number of advantages both to the designer and the supplier of timber. The designer can undertake his design without the need to check on the availability and price of a large number of species and grades which he might use. Suppliers can supply any of the species/grade combinations that meet the strength class in a specification. The concept also allows new species to be introduced onto the market without affecting existing specifications for timber. The allocation of timber species to a strength class allows engineers to use the mechanical properties of the strength class in limit state design of timber structures. Material properties for grading include density, bending modulus of elasticity and bending strength that is obtained from laboratory experiments. In this research, the grading of timber species was in accordance with BS 5268: 2002 and NCP 2: 1973.

The determined properties such as density, grade bending stress and mean modulus of elasticity was used for grading and assigning strength class according to the national and international code of practice (NCP 2: 1973; BS 5268 part 2, 2002). The aim of this study was to characterize and grade Kwara State Nigeria grown *Anogeissus leiocarpus* (Ayin) and *Isobertinia doka* (Babo) timber species in accordance with BS 5268 (2002) and NCP 2 (1973). The specific objectives were to obtain, season, prepare samples of *Anogeissus leiocarpus* and *Isobertinia doka*, determine their physical and mechanical properties according to BS 373 (1957) and to grade *Anogeissus leiocarpus* and *Isobertinia doka* timber specie in accordance with BS 5268 (2002) and NCP 2 (1973).

2. METHODOLOGY

2.1 Materials

Timber materials used in this study were obtained from matured *Anogeissus leiocarpus* and *Isoberlinia doka* trees in green condition from Irewolede Sawmills, Ilorin and sawn to size 100 x 150 x 3600 mm. Five logs of timber free from visible defects were selected and they were reduced to 100 x 150 x 1800 mm for easy transportation to the Wood section of the Department of Civil Engineering Laboratory, Faculty of Engineering and Technology, University of Ilorin, Nigeria for seasoning, preparation, and physical testing.

2.1.1 Preparation of Test Specimens

Test specimens were seasoned for six months to attain equilibrium moisture condition (EMC) at Wood section of Department of Civil Engineering Laboratory, University of Ilorin, Nigeria. Natural seasoning method was adopted in line with Aguwa (2010). Twenty (20) samples were prepared for different laboratory tests which include three-point bending strength parallel to the grain, shear strength parallel to the grain, tension strength parallel to the grain, compressive strength parallel to the grain, compressive strength perpendicular to the grain, natural moisture content, specific gravity, and density according to BS 373 (1957) Methods of Testing Small clear Specimen of Timber.

2.1.2 Determination of Physical and Mechanical Properties

Physical and mechanical/strength properties for the various mechanical tests were determined using the prepared samples at the National Centre for Agricultural Mechanization (NCAM), Ajase Ipo Road, Ilorin Kwara State, using Universal Testing Machine (UTM), Testometric Model of 100 kN capacity with computer interface for data acquisition and analysis. Tests carried out to include three-point bending strength parallel to the grain, shear strength parallel to the grain, tension strength parallel to the grain, compressive strength parallel to the grain, compressive strength perpendicular to the grain, natural moisture content, specific gravity, and density according to BS 373 (1957). In each set of the tests, failure loads were recorded for computation of failure stresses, mean failure stress, standard deviation and coefficient of variation.

Stresses at 12% and 18% Moisture Content: Failure stresses for bending parallel to the grain, tension parallel to the grain, compression parallel to the grain, compression perpendicular to the grain and shear parallel to the grain were adjusted to values at 12% and 18% moisture content in accordance with BS 5268 (2002) and NCP 2 (1973). Equation (1) and (2) was used for the adjustment.

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

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

where F_{12} = failure stress at 12% moisture content, F_{18} = failure stress at 18% moisture content w = experimental moisture content in (%), F_w = experimental failure stress, α = correction factor (Bending = 0.04, compression = 0.05, shear = 0.03, tension = 0.05 and MOE = 0.02) (Rahmon, 2018).

Modulus of Elasticity: Based on three points bending test, Equation (3) from the strength of materials applied to straight beams was used, in conformity with Aguwa et al., (2015).

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

where E_{L3} is the three-point bending modulus of elasticity, ℓ is the distance between the two supports (280 mm), e is the width of the beam (20 mm), h is 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, E_{mean} and the minimum modulus of elasticity, E_{min} .

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

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

Modulus of Elasticity at 12% and 18% Moisture Content : Moduli of elasticity at experimental moisture content was adjusted to values at 12% and 18% moisture content in conformity 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 E measured = the modulus of elasticity at experimental moisture content, E_{m12} = Modulus of elasticity at 12% moisture content, E_{m18} = Modulus of elasticity at 18% moisture content and U = experimental moisture content.

Determination of Moisture Content: Samples of size 20 x 20 x 40 mm were cut from the seasoned timber and used for the determination of the moisture content in accordance with BS 373 (1957). The oven temperature was maintained constantly at $103 \pm 2^\circ\text{C}$ for several hours until a stable mass was obtained. Equation (7) was used for the calculation of moisture content.

$$MC = \frac{m_1 - m_2}{m_2} \times 100\% \quad (7)$$

Where MC = moisture content, m_1 = Initial mass of timber before oven dried, m_2 = final mass of timber after oven drying.

Determination of Density: Five samples of the timber with 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 Equation (8).

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

Where, ρ = density of the timber specimen, m = the mass of the timber specimen, and v = volume of the timber specimen.

Density at 12% and 18% Moisture Content : The densities computed from test results in kg/m^3 were adjusted to values at 12% and 18% moisture content in accordance with BS 5268 (2002) and NCP 2 (1973). Equation (9) and (10) was used for the adjustment.

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

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

Where is ρ_{12} = density at 12% moisture content in kg/m^3 , ρ_{18} = density at 18% moisture content in kg/m^3 , ρ_w = density at experimental moisture content, U = experimental moisture content in %.

Basic and Grade Stresses : Basic stresses for bending, tensile, compressive, shear parallel to the grain, compressive stress perpendicular to the grain, were calculated from failure stresses. Equation (11) was used for the computation. Various grade stresses at 80%, 63%, 50% and 40% values respectively were calculated according to BS 5268 (2002).

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

Where f_b = basic stress, mean failure stress at 12% moisture content, σ = standard deviation of failure stress, k_r = reduction factor and k_p = modification factor = 2.33, K_r for bending, tension and shear parallel to the grain = 2.25. K_r for compression parallel to the grain = 1.4 while K_r for compression perpendicular to the grain = 1.2 (Aguwa et al., 2015; Ozelton and Baird, 1981).

2.2 Test specimen arrangements

Figure 1-4 below show the test specimen arrangement for various mechanical/strength tests carried on the timber species using Testometric Universal Testing Machine (UTM) of capacity 100 kN at the National Centre for Agricultural Mechanization (NCAM), Ajase Ipo Road, Ilorin Kwara State, Nigeria.



Figure 1: Compression Test arrangement



Figure 2: Bending Test arrangement



Figure 3: Tension Test arrangement



Figure 4: Tension Test arrangement

3. RESULTS AND DISCUSSION

Tables 1 shows the results obtained from the laboratory experiments carried out for the Physical of the timber species under consideration. The Physical and mechanical properties of the timber species tested are presented in Table 1. It was revealed that the density obtained for Ayin and Babo ranges from 950 to 1150 kg/m^3 which implies that the timber species investigated are hardwoods since the values obtained are greater than 640 kg/m^3 (Ohagwu and Ugwuishiwu, 2011). Also, moisture content results show that the values obtained which are 8.73 and 15.89 for Ayin and Babo, respectively are below Fibre Saturation Point (FSP) i.e. below 25 % as stated by Nabade, 2012.

Table 1: Results of physical properties of the timber species

Timber Species	Observed values	Moisture content (%)	Density(kg/m^3)	Specific gravity
Babo	Min.	11.73	817	0.84
	Max.	19.49	830	0.87
	Mean	14.48	820	0.85
	SD	3.02	0.01	0.01
Ayin	Min.	6.01	840	0.84
	Max.	12.39	1160	1.16
	Mean	8.73	950	0.95
	SD	2.83	0.15	0.15

Mechanical property: Tension parallel to grain: The mean values for Tension parallel to grain strength of the species at 12% moisture content are given in Table 2. It was observed that Ayin, recorded highest mean Tension parallel to grain which was 102.63 N/mm² (that is, it has higher resistance to failure in Tension parallel to grain than Babo at the same moisture content.) while Babo gave the lower Tension parallel to grain strength value which was 25.79 N/mm². When compared Tension results to some known species, Neem has 5.69 N/mm², *Xylopia aethiopica* 90.85 N/mm², *Terminalia ivorensis* 26.74 N/mm², *Vitellaria Paradoxa* 101.00 N/mm², *Hexalobus crispiflorus* 77.02 N/mm².

Table 2: Result of tension parallel to grain strength of the species

	Ayin	Babo
Mean failure stress (N/mm ²)	122.692	22.943
Standard deviation	25.177	15.06
Moisture content (%)	8.73	14.48
Strength @ 12% MC	102.63	25.79
Strength @ 18% MC	153.95	38.68
Basic stress (N/mm ²)	42.35	1.60
80% Grade stress (N/mm ²)	33.88	1.28

Compression perpendicular to grain: The mean values for Compression perpendicular to grain for the species at 12% moisture content are given in Table 3. It was observed that Ayin, recorded higher mean compression perpendicular to grain which was 25.66 N/mm² while Babo gave the lower compression perpendicular to grain strength value which was 7.32 N/mm², meaning that the resistance of Ayin to failure in compression perpendicular to grain was higher than the other specie at the same moisture content. When compared compression results to some known species, *Neem* has 20.23 N/mm², *Xylopia aethiopica* 17.98 N/mm², *Terminalia ivorensis* 7.75 N/mm², *Vitellaria paradoxa* 18.73 N/mm², and *Hexalobus crispiflorus* 8.44 N/mm².

Table 3. Result of Compressive Strength Perpendicular to Grain of the Species

	Ayin	Babo
Mean failure stress (N/mm ²)	30.67	6.513
Standard deviation	3.651	0.755
Moisture content (%)	8.73	14.48
strength @ 12% MC	25.66	7.32
strength @ 18% MC	38.48	10.98
Basic stress (N/mm ²)	26.11	7.92
80 % Grade stress (N/mm ²)	20.88	6.33

Compression Parallel to Grain : The mean Compression parallel to grain strength values for the three species at 12% moisture content are given in Table 4. It was observed that Ayin recorded higher mean compression parallel to grain which was 54.27 N/mm² while Babo gave the lower compression parallel to grain strength value which was 34.46 N/mm², that is, the resistance of Ayin to failure in compression parallel to grain was higher than that of Babo species at the same moisture content. When compared compression results to some known species, *Neem* has compression parallel to grain strength of 19.95N/mm², *Xylopia aethiopica* has 66.10 N/mm², *Terminalia ivorensis* 44.51 N/mm², *Vitellaria paradoxa* 45.70 N/mm², *Hexalobus crispiflorus* 30.86 N/mm².

Table 4: Result of compression parallel to grain strength of the species

	Ayin	Babo
Mean failure stress (N/mm ²)	64.879	30.66
Standard deviation	6.622	5.08
Moisture content (%)	8.73	14.48
strength @ 12% MC	54.27	34.46
strength @ 18% MC	81.41	51.69
Basic stress (N/mm ²)	47.13	28.47
80% Grade stress (N/mm ²)	37.70	22.78

Shear parallel to grain test

The shear parallel to grain strength values of the species at 12% moisture content are shown in Table 5. It was observed that, Ayin recorded highest mean shear parallel to grain which was 9.73 N/mm² while Babo gave a mean value of 6.55N/mm². It is observed from the results that, the resistance of Ayin to failure in shear parallel to grain was higher than that of the other specie at the same moisture content. When compared the shear results to the some known species, Neem has 7.40N/mm², Xylopia aethiopica 14.04N/mm², Terminalia ivorensis 6.45N/mm², Hexalobus crispiflorus 5.16 N/mm² and Vitellaria paradoxa 11.71 N/mm².

Table 5: Result of shear parallel to grain strength of the species

	Ayin	Babo
Mean failure stress (N/mm ²)	10.78317	6.095
Standard deviation	3.46314	2.259
Moisture content (%)	8.73	14.48
Strength @ 12% MC	9.73	6.55
Strength @ 18% MC	14.59	9.82
Basic stress (N/mm ²)	2.90	2.03
80% Grade stress (N/mm ²)	2.32	1.62

Modulus of elasticity (MOE): Modulus of Elasticity (MOE) is a measure of resistance to bending and is calculated by formula $PL^3/4bd^3$ (method A) BS 373: 1957. This is the amount of deflection of timber in response to a load. The Modulus of elasticity strength values of the two species at 12% moisture content are shown in Table 6. Ayin 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: Ayin > Babo .When compared to known species, Xylopia aethiopica has 11951 N/mm², Terminalia ivorensis 4686 N/mm², Neem 4338 N/mm², Vitellaria paradoxa 11136 N/mm², and Hexalobus crispiflorus 4564 N/mm².

Table 6: Result of modulus of elasticity of the species

	Ayin	Babo
Mean failure stress (N/mm ²)	13804.56	6264.73
Standard deviation	1358.232	1875.298
Moisture content (%)	8.73	14.48
Strength @ 12% MC	11998.93	6886.19
Strength @ 18% MC	17998.39	10329.29
Basic stress (N/mm ²)	17084.83	8545.47
80% Grade stress (N/mm ²)	13667.86	6836.37

Modulus of Rupture (MOR): From Table 7, at 12% moisture content, the average modulus of rupture of Ayin was 75.09N/mm² while Babo has the lower value of 53.75N/mm². It is therefore obtained from the result that the resistance of Ayin to static bending (MOR) was higher than that of the other specie at the same moisture content. When compared to some species, MOR in Aningeria altissima had 93.00 -130.00

N/mm², *Terminaria ivorensis* had 83.00 N/mm² and *Antiaris toxicaria* had 59.00 N/mm². Ataguba *et al.* (2015) recorded 12.5, 15.8 and 22.8 (N/mm²) for *Gmelina arborea*, *Parkia biglobosa* and *Prosopis africana*, respectively.

Table 7: Result of modulus of rupture of the species

	Ayin	Babo
Mean failure stress (N/mm ²)	86.3843	48.895
Standard deviation	19.1363	27.152
Moisture content (%)	8.73	14.48
Strength @ 12% MC	75.09	53.75
Strength @ 18% MC	112.63	80.62
Basic stress (N/mm ²)	30.24	7.71
80% Grade stress (N/mm ²)	24.19	6.17

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 (Barnett and Jeronimidis 2003; 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. Also from the Table, Ayin has highest modulus of rupture, modulus of elasticity and compression perpendicular to grain strength.

Table 8: Principal mechanical properties of the timber species at 12% moisture content

Mechanical properties	Ayin	Babo
MOE [N/mm ²]	11998.93	6886.19
MOR [N/mm ²]	75.09	53.75
Compression // to grain [N/mm ²]	54.27	34.46
Compression ⊥ to grain [N/mm ²]	25.66	7.32
Tensile strength [N/mm ²]	102.63	25.79
Shear parallel to grain [N/mm ²]	9.73	6.55

Strength Classification: The 80% Grade stresses of the three Nigerian timber species are given in Table 9, using the Bending parallel to grain strength values. Comparing these values with Table 10 of NCP 2:1973 Dry Grade stresses of Timbers, the following strength groups were obtained. This shows that Ayin is stronger than Babo timber species.

Table 9: Strength classification of the timber species

Mechanical properties	Ayin	Babo
Bending parallel to grain (N/mm ²)	24.19	6.17
Strength Group	N2	N7

4. CONCLUSION

The study involves determination of physical and mechanical properties of Nigerian timber species grown in Ilorin Kwara State according to the BS 373 (1957) and determination of their basic and 80% grade stresses. The two timber species were successfully characterized and graded. From the findings it was seen that significant difference exist between most of these properties and among the species, the variations can be attributed to the densities of the species. The results also compare favourably with other commonly used species. The results of this work will help Structural Engineers to design and construct timber structures using locally available timber instead of foreign ones. More research should be carried out on ways in which timber can be improved for construction purposes, development of software tools for timber building professionals.

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