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MECHANICAL CHARACTERIZATION AND GRADING OF *Irvingia gabonensis* TIMBER SPECIE ACCORDING TO BRITISH AND NIGERIAN STANDRADS FROM KWARA STATE NIGERIA

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Abstract: This study was conducted to investigate the physical and mechanical properties of Bush mango (*Irvingia gabonensis*) timber specie using BS 5268 (2002) and NCP 2 (1973). Specimens used in the experiment were obtained from sawmills in Kwara State, North-central Nigeria in green condition. Samples were seasoned naturally for six months and prepared according to BS 373 (1957) Methods of Testing Small Clear Specimen of Timber. Mechanical properties (three point bending parallel, compression parallel and perpendicular, shear parallel, and tension parallel to grain) and physical properties (moisture content and density) were conducted. The properties determined were then adjusted to the values at 12% and 18% moisture content in conformity with BS 5268 (2002) and NCP 2 (1973) for application in the Northern part of Nigeria. Statistical analysis was carried out using the strength/structural properties obtained. Bush mango has an average moisture content of 13.95% and the mean air-dried density was 714.50kg/m^3. The result of grade bending stress, density and mean modulus of elasticity showed that, *Irvingia gabonensis* can be graded and assigned to strength class D70 and N1 according to BS 5268 and NCP 2 respectively. The timber is suitable for load bearing structures like bridge beams, columns and railway sleepers.

Keywords: characterization, grading, *Irvingia gabonensis*, moisture content, strength properties

1. INTRODUCTION

Construction activities using vast quantities of locally available raw materials are major steps towards industrialization and economic independence for developing countries that are emphasizing more interest in timber. Structural timber is the timber used in framing and load-bearing structures, where strength is the major factor in its selection and use (Aguwa, 2012). Timber is a complex building material owning to its heterogeneity and species diversity. Nigeria is one of the countries that have timber in surplus quantity (Jimoh and Aina, 2017). Timber refers to wood in the form that is suitable for construction of carpentry, joinery or for reconversion for manufacturing purposes (Aguwa, 2010). 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 resources is properly utilized, it will be of immense benefit to the country in terms of reduction in the cost of construction (Aguwa, 2012; Ibitolu and Jimoh, 2017). The strength of a timber depends on its species and the effects of certain growth characteristics (Yeomans, 2003). 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 construction of engineering infrastructure is now a serious engineering challenge in Nigeria (Aguwa, 2016). This is because vast quantities of local raw materials, which must be processed and used for cost effective abound (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 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.

Irvingia gabonensis (Bush mango) is a species of African trees in the genus Irvingia, sometimes known by the common names wild mango, African mango, bush mango, dika or ogbono. They bear edible mango-like fruits, and are especially valued for their fat-and protein-rich nuts. *Irvingia gabonensis* is indigenous to the humid forest zone from the northern tip of Angola, including Congo, DR Congo, Nigeria, Cote d'Ivoire and south-western

Uganda. It is planted in parts of this area, such as in southeastern and south-western Nigeria and southern Cameroon. It grows straight, up to a height of 40m and 1m in diameter. It has buttresses to a height of 3m. The wood is hard and therefore used for heavy construction work as making ships decks or railway ties. Dead branches are used as firewood (Ogunwusi, *et al.*, 2013).

There is need to determine the physical and mechanical properties of *Irvingia gabonensis* since it is locally grown and used as structural materials in construction. Some timber strength properties listed in British Standard or European code were based on timber obtained from trees in those areas and the laboratory tests were conducted there (Aguwa et al., 2015a). The determined properties like density, grade bending stress and mean modulus of elasticity were used for grading and assigning strength class according to international code (BS 5268 part 2, 2002). The aim of this study was to characterize and grade South Western Nigeria grown *Irvingia gabonensis* timber in accordance with BS 5268 (2002) and NCP 2 (1973). The specific objectives were to obtain, season, prepare samples of *Irvingia gabonensis*, determine its physical and mechanical properties according to BS 373 (1957) and to grade *Irvingia gabonensis* timber specie in accordance with BS 5268 (2002) and NCP 2 (1973).

2. MATERIALS AND METHODOLOGY

⧉ Materials

Timber materials used in this study were obtained from matured *Irvingia gabonensis* tree at green condition from Sawmills in Ilorin, Kwara State, Nigeria and sawn to size 100x150x3600mm. Five logs of timber free from visible defects were selected and they were reduced to 100x150x1800mm 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 testing.

⧉ 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). Forty (40) 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 and density according to BS 373 (1957) Methods of Testing Small clear Specimen of Timber.

⧉ Determination of Physical and Mechanical Properties

Physical and mechanical/strength properties for the various mechanical tests were determined using the prepared samples in the Department of Agricultural and Biosystems Engineering, University of Ilorin, Kwara State using Universal Testing Machine (UTM), Testometric Model DBBMTCL of 300kN capacity with computer interface for data acquisition and analysis. Tests carried out 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 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. The corresponding load deformation graphs were plotted automatically.

⧉ 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.

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

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

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).

⧉ 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., (2015b).

$$E_{L3} = \frac{l^3}{4eh^3}k \tag{3}$$

where E_{L3} is the three point bending modulus of elasticity, ℓ is the distance between the two supports (280mm), e is the width of the beam (20mm), h is the height of the beam (20mm) and k is the slope of load deformation graph that is $\frac{\Delta p}{\Delta f}$. Minimum modulus of elasticity was determined with Equation (4) which shows the relationship between mean modulus of elasticity, E_{mean} and the minimum modulus of elasticity, E_{min}.

$$E_{min} = E_{mean} - \frac{2.33\sigma}{\sqrt{N}} \tag{4}$$

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 were 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)&(6).

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

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

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 20x20x40mm 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 ± 2^0C for several hours until a stable mass was obtained. Equation (7) was used for the calculation of moisture content.

$$MC = \frac{m_1 - m_2}{m_2} x\,100\% \tag{7}$$

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

Determination of Density

Five samples of the timber with size 20x20x20mm were used for the determination of the density in accordance to BS 373 (1957). Density was calculated using Equation (8).

$$\rho = \frac{m}{v} \tag{8}$$

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 contents in accordance to BS 5268 (2002) and NCP 2 (1973). Equation (9) and (10) was used for the adjustment.

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

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

where is ρ_{12} = density at 12% moisture content in kg/m^3, ρ_{12} = density at 12% 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 (Ozelton and Baird, 1981).

$$f_b = \frac{f_m - k_p\sigma}{k_r} \tag{11}$$

where fb = 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., 2015b).

3. TEST SPECIMEN ARRANGEMENTS

Figures 1 - 4 below show the test specimen arrangement for various mechanical/strength tests carried on the timber specie using Testometric Universal Testing Machine (UTM) of capacity 300kN in Agricultural and Biosystems Engineering Laboratory, University of Ilorin, Nigeria.

Figure 1: Compression Test arrangement

Figure 2: Bending Test arrangement

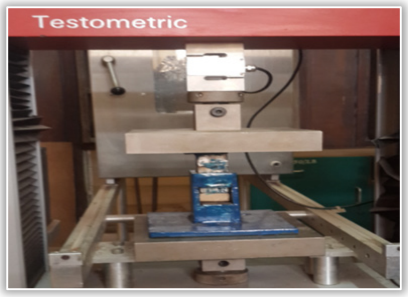

Figure 3: Tension Test arrangement

Figure 4: Tension Test arrangement

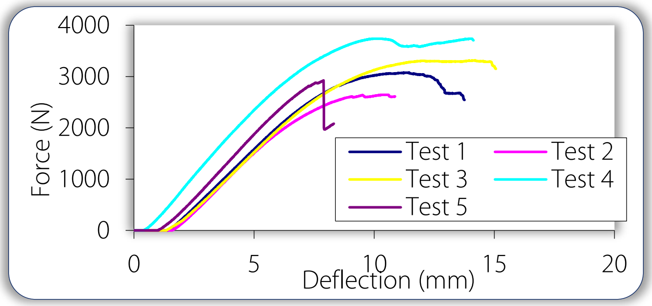

Figure 5: Force-deflection curve of Irvingia gabonensis under static bending load

4. RESULTS AND DISCUSSION

Table 1 presents the statistical results for *Irvingia gabonensis* such as the minimum, maximum, mean, standard deviation, coefficient of variation, 95% and 99% confidence limit of density at experimental moisture content are equally shown in the table. The mean value of the density was 714.50 kg/m^3 with standard deviation and coefficient of variation of 10.82kg/m^3 and 1.51% respectively. According to Findlay (1975), Bush mango was classified as medium wood. The density obtained fall between 570-1080 kg/m^3 belonging to strength class of D30-D70. The timber specie is hardwood according to BS 5268 (2002).

Table 2 and 3 present the statistical moisture content results of the following test: 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 on *Irvingia gabonensis* samples and the average moisture content of the experiments. The mean value of moisture content was 13.95% which fall below the fibre saturation point (FSP). The FSP is usually between 25-30% moisture content (Nabade, 2012) while the 95% and 99% confidence limits for the moisture content value of this timber specie was also found to be satisfactory, since the determined value from the test was within the confidence limits.

Table 1: Summary of the density result

Timber	Density (kg/m^3)						
	Min.	Max.	Mean	Std. Dev.	Coef. of Var.	Confidence Limit	
						95%	99%
Bush mango	686.74	734.23	714.50	10.82	1.51	710.26≤x≤718.74	708.93≤x≤720.07

Table 2: Natural moisture content of Irvingia gabonensis

Timber	Bending parallel	Tension parallel	Comp. parallel	Comp. perp.	Shear parallel	Mean Moisture Content (%)
Irvingia gabonensis (Bush mango)	12.47	13.38	15.69	14.42	15.87	13.95
	13.25	13.32	17.16	13.87	13.81	
	12.79	12.67	14.29	16.23	13.28	
	10.85	14.96	13.63	13.98	15.59	
	14.29	14.12	11.85	12.59	14.28	

Table 3: Summary of the moisture content results

Timber	Moisture content (%)						
	Min.	Max.	Mean	Std. Dev.	Coef. of Var.	Confidence Limit	
						95%	99%
Bush mango	10.85	17.16	13.95	1.43	10.28	13.39≤x≤14.51	13.21≤x≤14.69

Table 3 shows modulus of elasticity at experimental moisture content, sample 3 have the least modulus of elasticity 19275.96N/mm^2 while sample 4 have the highest value of modulus of elasticity 22915.23 N/mm^2. The mean value of the modulus of elasticity was 20574.88 N/mm^2.

Table 3: Modulus of Elasticity at Natural moisture content

Sample No	M.O.E (N/mm^2)	Sample No	M.O.E (N/mm^2)	Sample No	M.O.E (N/mm^2)	Sample No	M.O.E (N/mm^2)
1	19276.936	11	20546.783	21	19356.563	31	20539.561
2	19786.563	12	19856.356	22	20453.562	32	19878.673
3	19275.958	13	20003.569	23	20765.451	33	20879.568
4	22915.226	14	21005.673	24	19879.563	34	19764.563
5	20985.674	15	19767.647	25	20127.673	35	21999.563
6	19798.562	16	21267.662	26	20987.907	36	21987.674
7	21563.673	17	19978.637	27	20765.562	37	20997.563
8	20673.678	18	19652.672	28	22107.569	38	19753.127
9	19863.562	19	21675.426	29	21598.452	39	21653.673
10	19898.783	20	20563.672	30	19708.894	40	21342.567
$E_{minimum}$	19275.958						
$E_{maximum}$	22915.226						
E_{mean}	20574.877						
Std. Dev.	1048.381						
Coef. Var.	5.096						

Figure 5 shows the relationship between the force and deflection of timber beams (*Irvingia gabonensis*) under static bending load. Loads were applied at a constants peed of 0.12mm/s until the materials failed. This relation confirms timber as an elastic structural material which does not undergo plastic stage of deformation (Aguwa, 2010). It was also observed that as the force on the beam increased the deformation also increases until elastic limits were attained.

Table 4: Modulus of elasticity and density of Irvingia gabonensis at natural moisture content

Modulus of Elasticity (N/mm^2)	Value
$E_{minimum}$ (N/mm^2)	19275.96
E_{mean} (N/mm^2)	20574.88
Density (kg/m^3)	714.50

Table 4 shows modulus of elasticity and density of *Irvingia gabonensis* timber at natural moisture content. *Irvingia gabonensis* properties are comparable with those timbers in strength class D70 because it has density of 714.50kg/m^3, mean modulus of elasticity 20574.88N/mm^2 that is within the range of D70 in BS 5268 (2002). Based on this result, *Irvingia gabonensis* belongs to timber strength class D70.

Table 5: Basic stresses of Irvingia gabonensis at 12% moisture content

Type of stress	Value (N/mm^2)
Bending Parallel to the grain	190.40
Tension Parallel to the grain	62.39
Compression Parallel to the grain	71.97
Compression Perpendicular to the grain	50.16
Shear Parallel to the grain	4.48

Table 5 shows basic stresses of *Irvingia gabonensis* at 12% moisture content calculated from mean failure stresses and standard deviation of failure stresses. Basic stresses calculated were basic bending stress parallel to the grain, basic tensile stress parallel to the grain, basic compressive stress parallel to the grain, basic shear stress parallel to the grain and basic compressive stress perpendicular to the grain.

Table 6 shows basic stresses parallel and perpendicular to the grain as well as grade stresses at 12% moisture content. *Irvingia gabonensis* has grade bending stress of 49.39N/mm^2 which is comparable to range of grade bending stress of strength class D70 listed in Table 8 of BS 5268 (2002).

5. CLASSIFICATION/GRADING OF BUSH MANGO TIMBER SPECIE

Table 7 shows the summary results of the experiment for classification/grading of the *Irvingia gabonensis* in accordance with BS 5268 (2002). According to BS 5268 (2002), strength class may be assigned to a specie, if its characteristic value of grade bending stress and mean density equal or exceed the value for that class giving in Table 8 of BS 5268-2 (2002) and its mean modulus of elasticity in bending equal or exceed 95% of the value given in that strength class. Based on these criteria, *Irvingia gabonensis* was assigned to strength class D70 due to its grade bending stress parallel to the grain of 49.39N/mm^2, mean density of 714.50kg/m^3 and mean modulus of elasticity of 20574.88 N/mm^2. This is in agreement with strength class D70 listed in BS 5268-2 (2002) of grade bending stress of 23N/mm^2 and above, mean density of 900kg/m^3 and above and mean modulus of elasticity 21000 N/mm^2.and above.

Comparing the basic stress in Table 8 in this research with the Dry Basic Stress in Table 7 of NCP 2, Bush mango timber specie fall into N1 strength group based on the experimental, 80% Grade stress as well as the density of the timber specie.

Table 6: Various Stresses for *Irvingia gabonensis* at 12% Moisture Content

Type of Stress	Value (N/mm^2)	Type of Stress	Value (N/mm^2)
Mean failures bending stress parallel to the grain	176.62	Grade compressive Stress (63%) parallel to the grain	23.56
Basic bending Stress parallel to the grain	61.74	Grade compressive Stress (50%) parallel to the grain	18.70
Standard deviation of failure bending stress par. to grain	16.18	Grade compressive Stress (40%) parallel to the grain	14.96
Grade bending Stress (80%) parallel to the grain	49.39	Mean failures comp. stress perpendicular to the grain	45.70
Grade bending Stress (63%) parallel to the grain	38.90	Basic compressive Stress perpendicular to the grain	16.69
Grade bending Stress (50%) parallel to the grain	30.87	Standard deviation of failure comp. stress perp. to grain	13.10
Grade bending Stress (40%) parallel to the grain	24.70	Grade compressive Stress (80%) perp. to the grain	13.35
Mean failures tensile stress parallel to the grain	56.85	Grade compressive Stress (63%) perp. to the grain	10.52
Basic tensile Stress parallel to the grain	18.16	Grade compressive Stress (50%) perp. to the grain	8.35
Standard deviation of failure tensile stress par. to grain	6.86	Grade compressive Stress (40%) perp. to the grain	6.68
Grade tensile Stress (80%) parallel to the grain	14.53	Mean failures shear stress parallel to the grain	4.23
Grade tensile Stress (63%) parallel to the grain	11.44	Basic shear Stress parallel to the grain	0.68
Grade tensile Stress (50%) parallel to the grain	9.08	Standard deviation of failure shear stress par. to grain	1.16
Grade tensile Stress (40%) parallel to the grain	7.26	Grade shear Stress (80%) parallel to the grain	0.54
Mean failures comp. stress parallel to the grain	65.58	Grade shear Stress (63%) parallel to the grain	0.43
Basic compressive Stress parallel to the grain	37.39	Grade shear Stress (50%) parallel to the grain	0.34
Standard deviation of failure comp. stress par. to grain	5.68	Grade shear Stress (40%) parallel to the grain	0.27
Grade compressive Stress (80%) parallel to the grain	29.91		

6. CONCLUSIONS

The authors concludes that *Irvingia gabonensis* is a hardwood (D Class) of D70 strength class and N1 strength group according to BS 5268 (2002) and NCP 2 (1973) with good Engineering properties and can be used as beams, columns, rafters, railway sleepers and timber bridge materials. Having successfully characterized and classified/graded this specie, *Irvingia gabonensis* timber can be compared with other species on international basis, hence this timber is recommended to engineers for use in design of load bearing structures such as bridge beams, columns and railway sleepers.

Table 7: Strength class for *Irvingia gabonensis* according to Table 8 BS 5268-2 (2002)

Grade Stress (80%) (N/mm^2)	49.39
Density (kg/m^3)	714.50
Mean Modulus of Elasticity (N/mm^2)	20574.88
Strength Class	D70

Table 8: Strength class allocation based on NCP 2 (1973)

Experimental Stress (N/mm^2)	176.62
NCP 2 80% Grade Stress (N/mm^2)	49.39
Density (kg/m^3)	714.50
Strength Class	N1

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