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Determination of Strength Classes of Selected Nigerian Timbers in Accordance with EN338 (2009)

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Abstract- Wood has several unique, independent properties. The physical and mechanical properties of wood do vary from species to species and even within species due to environmental conditions during growth. In Nigeria, timber is been grade based on permissible stress (NCP) an upgrade to the limit state is required. A laboratory test was carried out to develop the physical and mechanical properties (four-point bending test) of the timber species in accordance with EN 13153-1, ASTM D143 and EN 408. The strength classification of selected timber was performed according to EN 338 using characteristic value of the material properties in accordance with EN384 from the generated physical and mechanical properties, after being adjusted to 12% (Eurocodes reference moisture content). The timber species considered were *Tectona grandis and Gmelina arborea.* The result showed *Tectona grandis* had a higher property than *Gmelina arborea* and the species were assigned to strength classes of D50 and D35 (hardwoods) respectively. The study shows that the selected timber species are suitable for structural purposes.

Keywords- Strength classes, Nigerian timber, Four-point bending test, *Tectona grandis, Gmelina arborea*

1 Introduction

Nigeria's tropical lowland rain forests contain around 560 kind of trees which serves as resources for the wood - based industry in Nigeria (Oyagade and Fasulu, 2005). Structural lumber (processed wood) can be produced from different kind of wood species; nevertheless, the different kinds used in an area depend on the economy, regional availability, and required strength properties. According to Mohammed (2014) "every country needs to develop its design codes because of diversity in geographical and environmental conditions". Many nations (Singapore and South Africa) have either developed or are in the process of developing their own codes of practice, based on the most recent available database (limit state). In most of the Common Wealth countries, including Nigeria (Onundi *et al.*, 2009; Auta and Mastenikov, 2006), the design or investigation of physical structures and facilities are in accordance with the requirements of the British Standard code of practice.

Nigeria Code of Practice (NCP 2, 1973) is the design code for timber structure in Nigeria based on permissible stress ranging from ranging from N_1 – N_7 and *Tectona grandis* and *Gmelina arborea* timber species were graded N_5 and N_3 respectively. The code NCP was developed with reference to CP112 (1971) of Great Britain, which was based on permissible stress design approach. CP 112 was revised and replaced with BS 5268; also, a permissible design code, this was further replaced with the Eurocode 5 which is based on limit state design philosophy. Therefore, there is need for revision/ upgrade of the NCP 2 for Nigerian timber from the permissible to the limit state design method which was never done since inception. Strength classes are sets of material properties that can be assigned to specific combinations of timber species and strength graded (Mohammed, 2014).

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Eurocodes 5 require that solid timbers should be graded in accordance to EN 338 (2009) which will help the designer not to under or over design and also the design using limit state design. It will also help the suppliers in class supply resulting in better utilization of timber. Therefore, the study is therefore aimed at finding the physical and mechanical properties of *Tectona grandis* and *Gmelina arborea* timber species in order to class them into different strength class.

2 Materials and Methods

2.1 Materials and Preparation of Test Specimens

The timber used are common types of timber available from the local saw-mill of Sabo Gari timber shed in Zaria Kaduna State and were taken to the concrete laboratory of Ahmadu Bello University Zaria. All samples of *Tectona grandis* and *Gmelina arborea* tested possessed structural sizes that are used in real timber construction which were selected on one occasion in order to obtain a test material without too high a variation in strength which could arise from different growth conditions.

The timber beams of average size of 50mm×75mm×1200mm were obtained for each timber specie. Slices of 20 pieces cross sections of 20mm × 20mm×20mm were prepared for the Moisture Content (MC) and density determination for each specie. A total number of 40 specimens were prepared for the bending strength and MOE tests, for each of the selected timber species.

2.2 Methodology

2.2.1 Physical Properties of Timber

Density of timber is defined as a timber's mass per unit volume measured at particular moisture content (Mitchell, 2018). Density serves as a measure for the mechanical properties. In the absence of any other data on the properties of a particular species, wood density is used as a guide to its utilization (Ofori *et al.*, 2009).

The species MC and densities were determined in accordance with EN 13153-1(2002) and EN 408 (2003).

Each slice was first measured to obtain its initial mass before drying using weighing balance. The test slices were then oven dried at a temperature of 103 ± 2^{0}C until constant weight, i.e., less 0.1% change in weight for twenty-four (24) hours after the last measurement. The samples were cooled and weighed. The initial and final mass of each slice were recorded and the MC (%), Dry density (ρ_d) using equation and bulk density (ρ_b) was calculated using equation (1), (2) and (3) respectively.

$$MC = \frac{m_i - m_o}{m_o} x100 \quad (1)$$

$$\rho_d = \frac{m_o}{v} \quad (2)$$

$$\rho_b = \frac{m_i}{v} \quad (3)$$

Where; m_i is the initial mass (Kg), m_o is final mass and (Kg), v is the volume of the specimen (m^3). All was considered to be the mean values of 20 slices.

The characteristic values of density and adjustment to equivalent of 12% MC in line with the requirements of EN338 (2009) using the equations (4), (5) (6) and (7) (Bostrom,1994); Heikkila and Herajarvi,2008).

$$\rho_{05} = (\bar{\rho} - 1.65s) \quad (4)$$

$$\rho_k = \frac{\sum \rho_{05},n_j}{\sum n_j} \quad (5)$$

$$\rho_{mean} = 1.2\rho_k \quad (6)$$

$$\rho_{k,12\%} = \rho_w(1 - \frac{(1-0.5)(u-12)}{100}) \quad (7)$$

Where, ρ and s are the mean and the standard deviation of densities of all slices (kg/m^3) respectively, ρ_k is the characteristic value of density, n_j is the number of specimens in sample j, $\rho_{05, j}$ is the 5-percentile value of density for sample j, $\rho_{k,12\%}$ is the density at 12 % MC, ρ_w is the density of the MC during the bending test (Kg/m^3) and u is the measured MC (%).

2.2.2 Mechanical Properties of Timber

The four - point bending flexural test provides values for the modulus of elasticity in bending, flexural stress , flexural strain and the flexural stress-strain response of the material. The test was performed on the Avery Denison Universal Testing Machine, with a specifically fabricated two-point central load transfer accessory. The sample was placed on two supporting pins a set distance apart and two loading pins placed at an equal distance around the center using the set up in Fig. 1 and Plate 1. These two loadings are lowered from above at a constant rate until sample failure. The bending test was in accordance with EN 408 (2003).

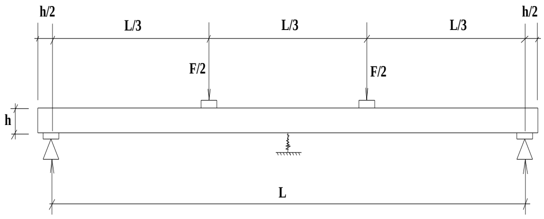

Fig.1: Four-point bending test set-up (EN 408, 2004)

Plate 1: Laboratory Arrangement of the Four Point Bending Test setup

Bending Strength (BS): This show the highest stresses in the outer most of the timber when the beam breaks under a load. The bending strengths were then computed from the Equation 8.

$$f_m = \frac{af_{max}}{2w} \quad (8)$$

Where, a is the distance between one load and the nearest support in mm, f_{max} is the maximum load at piece rupture in N, w is the section modulus of beam in mm^3.

The characteristic values of BS properties based on the measured MC and adjusted equivalent to 12% MC in line with the requirements of EN338 (2009) using equations (9) (Ranta-Maunus, *et al.*, 2001) and (10) (Bostrom, 1994; Heikkila and Herajarvi, 2008).

$$f_k = 1.12f_{0.5} \quad (9)$$

$$f_{m,12\%} = \frac{f_{measured}}{1+0.0295\,(12-u)} \quad (10)$$

Where, f_k, f_{05}, $f_{measured}$ and $f_{m,12\%}$ are the characteristic, 5th-percentile, measured and 12% MC values of bending strength (N/mm^2) respectively. u is the measured MC (%).

Modulus of Elasticity (MOE): The MOE was calculated from the values obtained at the point of failure recorded during tests for BS. This provided for the calculations of deflection which was used to estimate the MOE using the Equation (11) (EN 384, 2004).

$$E_m = \frac{l^3(F_2-F_1)}{4.7bh^3(w_2-w_1)} \quad (11)$$

l, b and h are the beam span, width and all in (mm), ($F_2 - F_1$) is the increment load (in Newton) on the regression line with a correlation coefficient of 0.99 and ($w_2 - w_1$) is corresponding the increment of deformation (mm).

The characteristic values of MOE based on the measured MC and adjusted value equivalent to 12 % MC (in line with EN 338 (2009)) were computed from the equation (12) and (13) (Bostrom, 1994; Heikkila and Herajarvi, 2008):

$$\bar{E} = \left[\frac{\sum E_i}{n}\right] 1.3 - 2690 \quad (12)$$

$$E_{m,12\%} = \frac{E_{measured}}{1+0.0143(12-u)} \quad (13)$$

Where $\bar{E}$, $E_{m,12\%}$ and $E_{measured}$ is the mean MOE value, 12% MC of MOE and the measured MOE in bending all in (N/mm²), E_i is the ith values of MOE, n is the number of specimens and u is the measured MC (%).

2.3 Percentile Values of Material Properties

The characteristic values of material properties reported in EN 338 (2009) are based on the 5 percentile values (EN 384, 2003) generated from EASYFIT statistical package.

2.4 Derived Material Properties

The Density, Modulus of elasticity and Bending Strength were obtained from the laboratory are known as the reference properties of timber. Other strength and stiffness properties are calculated from the reference properties in accordance with the recommendation of EN 384 (2004) EN 338 (2009) and Table 1 of the JCSS (2006).

3 Results and Discussions

3.1 Physical Properties of Species

The MC of *Tectona grandis and Gmelina arborea* as presented in Table 1, both of service class 3 and is slightly above its Fiber Saturated Point (FSP) of 24 % and 26 % as given in CIRAD (2012) and considered to be Stable and poorly stable respectively. A stable timber is naturally durable, weathers well, easy to work, resistant to corrosion of fasteners and acids (Halkett *et al*., 2011). The MC FSP strongly influences the mechanical properties. Nigeria Code of Practice (NCP2,1973) reported that below saturation point (MC between 27 - 30 %) all strength properties (except toughness) increase with decrease in MC and there is no noticeable effect of moisture changes above FSP. While according to Ali (2010), wood will not swell or shrink from changes in MC above FSP. However, it changes dimension as MC varies below FSP. These dimensional changes may result in splitting, checking, warping and shrinkage. Also, Antwi *et al*. (2014) explained that the mechanical properties of wood increase with a MC decreases below FSP. Noah *et al*. (2014) reported MC of *Gmelina arborea* to be 30.79% slightly lower than that of these findings.

The mean density (ϱ) values of *Tectona grandis* and *Gmelina arborea* result is presented in Table 1 with little variability in the density. The moisture adjustment to 12 % showed a density loss of 6.79 % and 7.32% respectively for the two species. This implies a decrease in MC of timber have a corresponding decrease in its density. From the findings Nellie (2013) reported air dry density of *Tectona grandis* (Teak) to be 650 Kg/mm³ which is a less than the one determined in this study. While Hossain and Abdul Awal (2012) and Junji and Yoshitomo (2011) quoted air dry density value of *Tectona grandis* as 665 Kg/m³ and 640 Kg/m³ respectively which is closer to this study's findings.

Noah *et al.* (2014) reported density of *Gmelina arborea* to be 475.56 Kg/m³ at MC of 30.79 % closer to this research. Vallejos *et al*., (2015) gave *Gmelina arborea* (Melina) density in humid and dry climate of over 500 Kg/m³. Roque and Filho (2009) gave density in humid and dry climate that ranged from 454 - 578 Kg/m³ and 483 - 686 Kg/m³ respectively. This is within the range of 560 Kg/m³ gotten in this research. Adam and Krampah (2005) reported *Gmelina arborea as a* moderately lightweight wood, with a density is 400 - 510 Kg/m³ at 12 % MC. Ajayi *et al*. (2008) Classified *Gmelina arborea* as a low-density wood of 480 Kg/mm². Adeniyi *et al.* (2013) (value obtained from NCP 2, 1973) gave a density of 512 Kg/mm² at a moisture content of 18 %. Therefore, the result of *Gmelina arborea* from this result is within past research range. Density of a timber is a constant property that changes notably with the amount of MC thereby given different density values at different MC from top to bottom of a tree. This variation may also be due to genetic, physiological or silvicultural treatments (Muller-Landau, 2004).

Table 1. Mean values of the moisture content, dry density and bulk density

Timber Species	*Tectona grandis*	*Gmelina arborea*
MC (%)	25.58	31.16
Std	3.34	3.51
COV	0.131	0.132
ρ_d (Kg/m³)	695.88	445.83
Std	42.84	36.94
COV	0.062	0.083
ρ_b (Kg/m³)	872.98	564.17
Std	49.56	43.89
COV	0.057	0.078
$\rho_{k,12\%}$ (Kg/m³)	813.70	522.86

3.2 Mechanical Properties

The mean, standard deviations and Coefficient of variation of the bending strength of the test results are tabulated in Table 2. The moisture adjustment of *Tectona grandis* and *Gmelina arborea* to 12 % showed a percentage increase in the bending strength of 66.86 % and 76.04 % respectively. This shows that the BS increase with decrease in moisture content. This means that, among all the reference material properties of timber, moisture variation has highest effect on the bending strength. Also, timber attains its greatest strength when it is fully dry.

Louppe (2005) gave at 12 % MC, the modulus of rupture is 81 - 196 N/mm². Adeniyi *et al*. (2013) (value obtained from (NCP 2, 1973) gave at a MC of 18 % a BS of 22.4 N/mm² for *Tectona grandis* which is close to this finding. CIRAD, (2012) gave static bending strength (12 % MC) to be 64 N/mm² for *Gmelina arborea*. Adeniyi *et al*. (2013) (value obtained from (NCP 2, 1973) gave at a moisture content of 18 % a BS of 14 N/mm². Adam and Krampah (2005) reported *Gmelina arborea* at 12 % MC, the modulus of rupture is 55 - 102 N/mm² also close to the finding in this research in Table 2.

Tectona grandis is within the range of findings reported by past researchers. Louppe (2005) gave at 12 % MC, MOE 7600 - 17,500 N/mm². Adeniyi *et al.* (2013), (value obtained from NCP 2, 1973) gave at a MC of 18 % MOE of 10,600 N/mm². The Physical properties of common woods gave *Tectona grandis* MOE to be 11957 N/mm². Saravanan *et al.*, (2014) gave MOE of 11,906 N/mm² at 12 % MC.

These findings of Noah *et al.* (2014) is close to this study, who gave *Gmelina arborea (Melina)* MOE to be 11145.77 N/mm² at MC of 30.79%. Lower to this research is documentation in CIRAD (2012) on *Gmelina arborea* at 12 % MC of 9120 N/mm² MOE. Also, reports by Adam and Krampah (2005) at 12 % MC, MOE 5500 - 10,800 N/mm². Junji and Yoshitomo (2011) quoted MOE at 12.5 % to be 10,600 N/mm². These variations in strength is dependent on the tree growth to physical and chemical properties of the soil as well as environmental factors such as temperature, light, and water.

Table 2. Bending Strength and Modulus of Elasticity (N/mm²)

Timber Species	*Tectona grandis*	*Gmelina arborea*
Bending Strength (N/mm²)	70.31	40.28
Std	11.20	1.18
COV	0.159	0.09
Modulus of Elasticity (N/mm²)	9709.77	8495.12
Std	1493.60	1905.10
COV	0.154	0.224
$F_{m12\%}$ (N/mm²)	117.32	70.91
$E_{m12\%}$ (N/mm2)	12050.05	70.91

3.3 Other Material Properties

These properties may be taken from the Table 1 of the EN338 or calculated using the information in the Annex A of the EN338.

3.4 Allocation of Strength Classes

According to EN 338 a solid timber may be assigned a strength class if its characteristic values of bending strength and density equal or exceed the values for that strength class given in Table I of EN 338 given in the Appendix, and its characteristic mean MOE in bending equals or exceeds 95% of the value given for that strength class. Based on these criteria, *Tectona grandis* was assigned to solid timber strength class D50 due to its minimum characteristic bending strength of 51.25 N/mm², characteristic density of 791.21 kg/m³ and minimum mean MOE parallel to grain of 11,585,67 N/mm² as shown in Table 3. *Gmelina arborea* timber species were assigned to strength classesD35 due to its minimum characteristic bending strength of 35.22N/mm², characteristic density of 491.75kg/m³ and minimum mean MOE parallel to grain of 8,495.12N/mm² as shown in Table 3.

Table 3. Proposed Allocations of Strength Class for the Timber Species

Timber Specie		*Tectona grandis*	*Gmelina aborea*
		D50	D35
Strength Properties N/mm²			
Bending	f_{mk}	51.25	35.22
Tension parallel	$f_{t,0k}$	30.75	21.13
Tension perpendicular	$f_{t,90}$	0.60	0.60
Compression parallel	$f_{c,0k}$	30.78	26.00
Compression perpendicular	$f_{c,90k}$	9.30	8.10
Shear	f_{vk}	4.00	4.00
Stiffness Properties in kN/mm²			
Mean MOE //	$E_{0,\ mean}$	14.00	12.00
5 % MOE //	$E_{0.05,\ mean}$	11.76	10.08
Mean MOE ⊥	$E_{90,\ mean}$	0.93	0.80
Mean shear Modulus	$G_{,mean}$	0.875	0.750
Density	$\rho_{k,0.5}$	620.00	540.00
Mean Density	ρ_{mean}	750.00	650.00

4 Conclusion

Laboratory experiments were conducted to determine the physical and mechanical properties of timber species: *Tectona grandis* and *Gmelina arborea* in accordance with EN 13183-1 (2002), EN 408 (2003) and ASTM D143 (2006). The mechanical properties were determined using four - point bending tests. The characteristic values of the material properties were obtained in accordance with EN 384 (2004). *Tectona grandis and Gmelina arbore* were assigned to strength classes D50 and D35. Other properties such as tensile and compressive strengths parallel and perpendicular to grains, shear strength as well as shear modulus were also obtained in accordance with the EN338.

Therefore, from this study it shows that both are hardwood and can be use structurally in the construction industry. *Tectona grandis* can be recommended for engineering applications such as in timber structural elements. *Gmelina arborea is* therefore recommended for non-load-bearing purposes and can be further improved by proper seasoning.

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