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Bending Strength Classification of Some Common Nigerian Timber Species

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ABSTRACT

This paper was aimed at the EN338 (2009) strength classification of some common Nigerian timber species, namely; *Strombosia pustulata, Macrocarpa bequaertii, Nauclea diderrichii and Entandrophragma cyclindricum*. Twelve (12) timber planks from the selected species were supplied from Ekiti state in the southern part of Nigeria. The specimens for experimental measurements were prepared from the obtained timber planks. Laboratory experiments were conducted to determine the physical and mechanical properties of the selected timber species in accordance with EN408 (2003). The mechanical properties were determined using four point bending test. The generated properties were used to obtain the characteristic values of the material properties in accordance with EN384 (2004). The selected timber species were then graded in accordance with EN 338 (2009). *Strombosia pustulata, Macrocarpa bequaertii, Nauclea diderrichii* and *Entandrophragma cyclindricum* were assigned to strength classes D35, C14, D30 and D18, respectively. Other properties such as tensile and compressive strengths parallel and perpendicular to grains, shear strength as well as shear modulus were computed from the empirical relationships given in EN 338.

KEYWORDS: EN338, Characteristic values, Four point bending, EN 408, EN 384.

INTRODUCTION

Timber is an efficient building material not only with regards to its mechanical properties but because it is a highly sustainable material (Kohler and Branco, 2010). It is a unique structural material that is fully renewable and potentially very efficient with many environmental attributes (Afolayan, 2004). Timber, like other building materials, has inherent advantages that make it attractive in specific applications (Afolayan and Adeyeye, 1998; Aguwa and Sadiku, 2011).

For structural purpose, solid timbers are classified either as softwoods or hardwoods. Generally, trees that carry naked seeds are softwoods, while those with seeds inside a fruit are hardwoods.

Most woods used in building construction are softwoods, but in structures like bridges and railway sleepers, hardwoods are specially used (Karlsen and Slitskouhov, 1989; Aguwa and Sadiku, 2011).

Solid timbers for structural uses are strength graded according to standards such as EN338 which assign timber species to specific strength classes. The grading process usually focuses on the most important physical and mechanical properties: density, bending strength and modulus of elasticity (MOE) parallel to the grain. To reflect the variation of mechanical properties, the classification is based on characteristic values, which are 5^{th}-percentile or mean values, respectively. In Europe, the classification of structural timber is carried

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out according to a set of three linked standards (Steiger et al., 2010):

i. Determination of mechanical properties as well as dimensions, moisture content (MC) and wood density of test pieces as specified in EN408.
ii. Determination of characteristic values of mechanical properties and density derived from the test data according to EN384.
iii. Strength classification according to EN338. This standard defined twelve (12) strength classes for softwoods (C class) and eight (8) classes for hardwoods (D class).

A specific sample can be assigned to a certain strength class, if the characteristic values of density and bending strength (both of them are 5^{th}-percentiles) as well as MOE (mean value, usually derived from bending tests) match or exceed the values of the desired class. Additional mechanical properties needed for the design of timber structures are derived from these basic values by empirical relationships.

The current Nigerian code of practice for timber design, NCP2 (1973), which is a permissible stress design code, is largely based on BS 5268. Today, the replacement of BS 5268 (2002) with Eurocode 5 (EC5) has been the major problem in design with NCP2 (1973). EC5, on the other hand, is based on limit state format (Blass et al., 1995). The withdrawal of the former British code in 2009 and the complete adoption of EC5 in 2010 by the European countries have represented a full migration from the old to the new methodology approach (TRADA, 2010).

This paper was intended at the development of EN338 (2009) strength classification of the four (4) selected Nigerian timber species based on the results obtained from experimental measurements using four point bending test. Thus, this gives the leeway to adopt the EC5 design procedure in the Nigerian case study. The results of the experimental measurements can also be used to revise the Nigerian timber design code in order to meet up with the international standards.

MATERIALS, METHODS, RESULTS AND DISCUSSION

Materials

The materials used in this study are specimens obtained from the following timber species: *Strombosia pustulata; Macrocarpa bequaertii; Nauclea diderrichii* and *Entandrophragma cyclindricum.*

Preparation of Test Specimens

For bending strength and MOE tests, 80 No. beams of 50 mm×75 mm×1500 mm each, that is, 20 pieces from each species were prepared with the aid of sawing and milling machines. For MC and density, slices of full cross sections of 50 mm×75 mm×50 mm each, 60 No. slices, that is, 15 pieces from each specie were prepared at the carpentry workshop of the Department of Civil Engineering, Ahmadu Bello University (ABU), Zaria, Nigeria.

Methods

Physical Properties of Timber

i) Moisture Content of Timber

Because most timber properties are dependent on the amount of water present in the wood, determination of MCs is then necessary. The species MCs were determined in accordance with EN 408 (2003). The MC of each slice was determined by first measuring its initial mass before drying using weighing balance. The test slices were then oven dried at a temperature of 103 $\pm 2^0$C for 24 hours. The initial and final mass of each slice were recorded and the MC was then computed from the equation:

$$MC = \frac{m_1 - m_2}{m_2} \times 100\% \quad (1)$$

where m_1, m_2 and MC are the initial mass, final mass and MC of test slice.

The MC of the specie was considered to be the mean value of 15 slices.

ii) Density of Wood

The density of wood is its mass per unit volume at a specified value of MC. The density of slice was determined in accordance with EN 408 (2003).

The characteristic values of density of species were determined in accordance with EN 384 (2004) from the equation:

$$\rho_k = \rho_{05} = \left(\bar{\rho} - 1.65s\right) \quad (2)$$

where ρ_k is the characteristic density, $\bar{\rho}$ and s are the mean and the standard deviation of densities of all slices (in kg/m^3), respectively.

The 12% MC adjustment for density as required by EN 338 (2009) was made using the equation:

$$\rho_{k,12\%} = \rho_w\left(1 - \frac{(1-0.5)(\omega - 12)}{100}\right) \quad (3)$$

where ρ_w is the density at the MC during the bending test (also in kg/m^3) and ω is the measured MC (%).

Mechanical Properties of Wood

i) Bending Strength

Four point bending strength tests as specified by EN 408 (2003) were carried out on 20 specimens from each of the selected timber specie. Each specimen was tested to failure using Universal Testing Machine (UTM). The failure load for each beam was recorded. The bending strengths were then computed from the equation (EN 408, 2003):

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

where a is the distance between loading position and the nearest support (mm), $F_{\max}$ is the maximum load (N), W is the section modulus (mm^3) and f_m is the bending strength (N/mm^2).

The characteristic values of strength properties based on the measured MC were computed from the equation (Ranta-Maunus et al., 2001):

$$f_k = 1.12 f_{05} \quad (5)$$

where f_k and f_{05} are the characteristic and 5th-percentile values of bending strength, respectively.

The 12% MC adjustment for bending strength as required by EN 338 (2009) was made using the equation:

$$f_{m,12\%} = \frac{f_{measured}}{1 + 0.0295(12 - u)} \quad (6)$$

where $f_{m,12\%}$ is the bending strength at 12% MC, u is the measured MC (%) and $f_{measured}$ is the measured bending strength (*N/mm^2*).

ii) Modulus of Elasticity

The global MOE was derived from four point bending test as specified by EN 408 (2003). Load was applied at constant rate using UTM, and the deflection corresponding to the load was recorded. The global MOE was then computed from the following expression:

$$E_{m,g} = \frac{l^3(F_2 - F_1)}{bh^3(w_2 - w_1)}\left[\left(\frac{3a}{4l}\right) - \left(\frac{a}{l}\right)^3\right] \quad (7)$$

where $E_{m,g}$ is the global MOE in bending, a is the distance between inner point loads and supports (mm), l is the length of the test specimen between the testing machine grips in bending test (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 the increment of deformation (mm) corresponding to $(F_2 - F_1)$.

The characteristic values of MOE based on the measured MC were computed from the equation (EN 384 2004):

$$\bar{E} = \left[\frac{\sum E_i}{n}\right]1.3 - 2690 \quad (8)$$

where E_i is the ith value of MOE, n is the number of specimens and $\bar{E}$ is the mean value of MOE in bending.

The 12% MC adjustment for MOE as required by EN 338 (2009) was made using the equation:

$$E_{m,12\%} = \frac{E_{measured}}{1 + 0.0143(12 - u)} \quad (9)$$

where $E_{m,12\%}$ is the bending MOE at 12% MC, $E_{measured}$ is the measured bending MOE (N/mm^2) and u is the measured MC (%).

Results and Discussion

Table 1 shows the results for MC in respect of all the four selected timber species. The highest value of MC of 24.81% corresponds to *Macrocarpa bequaertii* with SD of 2.21% and COV of 0.089, followed by *Strombosia pustulata*, then followed by *Nauclea diderrichii* and the least MC value of 20.06% corresponds to *Entandrophragma cyclindricim* with SD of 2.15% and COV of 0.107. In general, MC values of all the species considered were slightly below fiber saturation point (FSP).

Table 2, on the other hand, presents the results of characteristic values of the mechanical properties and density of the selected timbers as adjusted to 12% MC in line with the requirements of EN 338 (2009).

Table 1. Summary of MC Results

Timber Specie	MC (%)		Coeff. of Variation (COV)
	Mean	Std. Dev. (SD)	
Strombosia pustulata	23.27	2.98	0.128
Macrocarpa bequertii	24.81	2.21	0.089
Nauclea diderrichii	23.22	2.86	0.123
Entandrophragma cyclindricum	20.06	2.15	0.107

Table 2. Adjusted Characteristic Values of Material Properties to 12% MC

Timber Specie	Density (kg/m^3)	4 Pt. Bending Strength (N/mm^2)	MOE in Bending (kN/mm^2)
Strombosia pustulata	557	65.75	12.045
Macrocarpa bequaertii	301	30.57	8.169
Nauclea diderrichii	676	54.45	11.054
Entandrophragma cyclindricum	475	40.81	9.606

According to EN 338 (2009), a solid timber may be assigned a strength class if its characteristic values of bending strength and density are equal to or exceed the values for that strength class given in Table 1 of EN 338 (2009), and its characteristic mean MOE in bending equals or exceeds 95% of the value given for that strength class. Based on this mentioned criteria, *Strombosia pustulata* was assigned to solid timber strength class D35 due to its minimum characteristic bending strength of 65.75 N/mm^2, characteristic density of 557 kg/m^3 and minimum mean MOE parallel to grain of 12.045 kN/mm^2 as shown in Table 2. The characteristic bending strength, density and mean MOE parallel to grain for strength class D35 from the Table provided in EN 338 (2009) are 35 N/mm^2, 540 kg/m^3 and 12 kN/mm^2, respectively. Based on similar criteria, *Macrocarpa bequaertii*, *Nauclea diderrichii* and *Entandrophragma cyclindricim* timber species were assigned to strength classes C14, D30 and D18, respectively.

Other Material Properties

Other material properties such as tensile strengths parallel and perpendicular to grains, shear modulus, etc... as adjusted to equivalent 12% MC were calculated

The characteristic values of tensile strength parallel to grain, $f_{t,o,k}$ and compressive strength parallel to grain, $f_{c,o,k}$ were calculated from the following equations:

$$f_{t,0,k} = 0.6 f_{m,k} \quad (10)$$

$$f_{c,o,k} = 5(f_{m,k})^{0.45} \quad (11)$$

The characteristic values of tensile strength perpendicular to grain, $f_{t,9o,k}$ and compressive strength perpendicular to grain, $f_{c,9o,k}$ were calculated as follows::

$$f_{t,90,k} = 0.4 \text{, for softwoods} \quad (12)$$

$$f_{t,90,k} = 0.6 \text{, for hardwoods} \quad (13)$$

$$f_{c,90,k} = 0.007\rho_k \text{, for softwoods} \quad (14)$$

$$f_{c,90,k} = 0.015\rho_k \text{, for hardwoods} \quad (15)$$

The fractile 5th percentile MOE parallel to grain, $E_{0,0.05}$ was calculated from:

$$E_{0,0.05} = 0.67 E_{0,\ mean} \text{, for softwoods} \quad (16)$$

$$E_{0,0.05} = 0.84 E_{0,\ mean} \text{, for hardwoods} \quad (17)$$

The characteristic values of mean MOE perpendicular to grain, $E_{90,mean}$ were calculated from the equations:

$$E_{90,mean} = E_{0,mean}/30, \text{ for softwoods} \quad (18)$$

$$E_{90,mean} = E_{0,mean}/30, \text{ for hardwoods} \quad (19)$$

The characteristic values of mean shear modulus were calculated from the equation:

$$G_{mean} = \frac{E_{0,mean}}{16} \quad (20)$$

The characteristic mean density ρ_{mean} was computed from the equation:

$$\rho_{mean} = 1.2\rho_k. \quad (21)$$

In equations (10) to (21), $f_{m,k}$ is the characteristic bending strength, ρ_k is the characteristic density, $E_{0,mean}$ is the mean MOE parallel to grain, $E_{90,mean}$ is the mean MOE perpendicular to grain, $E_{0,0.05mean}$ is the fractile 5th percentile mean MOE parallel to grain and G_{mean} is the mean shear modulus.

Shear strength, $f_{v,k}$ was taken from Table 1 of EN 338 (2009) as specified by the code.

Table 3 presents the results of the other material properties of the selected timber species as computed from the empirical relationships given above. The results were found to be at least equal to those provided in Table 1 of EN338 (2009).

Table 3. Other Material Properties of Selected Timber Species

Other Material Properties	Timber Specie			
	Strombosia pustulata	***Macrocarpa bequertii***	***Nauclea diderrichii***	***Entandrophragma cyclindricum***
Tension, Parallel $f_{t,0,k}$ ((N/mm^2)	39.45	18.34	32.67	24.49
Tension, Perpendicular $f_{t,90,k}$ ((N/mm^2)	0.6	0.4	0.6	0.6
Compression, Parallel $f_{c,0,k}$ ((N/mm^2)	32.89	23.30	30.21	26.53
Compression, Perpendicular $f_{c,90,k}$ ((N/mm^2)	8.4	2.1	10.1	7.1
Shear Strength $f_{v,k}$ ((N/mm^2)	4.0	3.0	4.0	3.4
5% MOE, Parallel $E_{0,0.05}$ ((kN/mm^2)	10.1	5.5	9.3	8.1
Mean MOE, Perpendicular $E_{90,mean}$ ((kN/mm^2)	0.40	0.27	0.37	0.32
Mean Shear Modulus G_{mean} (kN/mm^2)	0.75	0.51	0.69	0.60
Mean Density ρ_{mean} (kg / m^3)	668	361	811	570

CONCLUSION

The results of characteristic values of the reference material properties as adjusted based on 12% MC in line with EN 338 (2009) requirements have shown that *Strombosia pustulata*, *Macrocarpa bequaertii*, *Nauclea diderrichii* and *Enyandrophragma cyclindricum* timber species were assigned to strength classes D35, C14, D30 and D18, respectively as their minimum values of the reference material properties were found to be least equal to the ones provided in Table 1 of EN 338 (2009).

Based on the results of experimental works, the following recommendations were made:

i) Adoption of EC5 design procedure in respect of the selected timber species is recommended.
ii) Revision of NCP2 (1973) in order to update to new timber design methodology approach is also recommended.

REFERENCES

Afolayan, J. O. (2004). "Cost Effective Vibration Criteria for Wooden Floors". Asian J. Civil Engrg. (Building and Housing), 5 (1-2), 57-67.

Afolayan, J. O., and Adeyeye, A. (1998). “Failure Analysis of a Glue-Jointed Roof Truss”. J. Engrg. & Applied Sciences, 17 (1), 51-63.

Aguwa, J. I., and Sadiku, S. (2011). “Reliability Studies on the Nigerian Ekki Timber as Bridge Beam in Bending under the Ultimate Limit State of Loading”. J. Civil Engrg. and Const. Tech., 2 (11), 253-259.

Blass, H. J., Aune, P., Choo, B. S., Goerlacher, R., Griffths, D. R., and Hilson, B. O. (1995). Timber Engineering Step 1, 1st Ed., Centrum Hout, the Netherlands.

BS 5268. (2002). “Structural Use of Timber, Part 2, Code of Practice for Permissible Stress Design, Materials and Workmanship”, BSI, London.

EN 408. (2003). “Timber Structures – Structural Timber and Glued-laminated Timber: Determination of Some Physical and Mechanical Properties”. CEN, Brussels, Belgium.

EN 384. (2004). “Structural Timber: Determination of Characteristic Values of Mechanical Properties and Density”. CEN, Brussels, Belgium.

EN 338. (2009). “Structural Timber: Strength Classes”. CEN, Brussels, Belgium.

Eurocode 5. (2004). “Design of Timber Structures”. Part 1-1, CEN, Brussels, Belgium.

Karlsen, G., and Slitskouhov, Y.U. (1989). “Wooden and Plastic Structures”. 1st Ed., Mir Publishers, Moscow, Russia.

Kohler, J., and Branco, J. M. (2010). “Modelling of the Performance of Timber Structures”. Swiss Federal Institute of Technology, Action COST E55.

NCP2. (1973). “The Use of Timber for Construction. Nigerian Code of Practice”. Fed. Ministry of Industries, Lagos, Nigeria.

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

Steiger, R., Arnold, M., and Jockwer**,** R**.** (2010). “Property Relationships Used in EN338 Strength Grades of Norway Spruce Timber". Proc. of 13th World Conf. on Timber Engrg., British Columbia, Canada, 1-3.

TRADA. (2010). “Embracing Eurocode 5”. Timber Research and Development Association, Version 2-Construction Briefings, UK.