International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:7, No:5, 2013

Development of EN338 (2009) Strength Classes for Some Common Nigerian Timber Species Using Three Point Bending Test

Abubakar Idris and Nabade Abdullahi Muhammad

Abstract**—**The work presents a development of EN338 strength classes for *Strombosia pustulata, Pterygotama crocarpa, Nauclea diderrichii* and *Entandrophragma cyclindricum* Nigerian timber species. The specimens for experimental measurements were obtained from the timber-shed at the famous Panteka market in Kaduna in the northern part of Nigeria. Laboratory experiments were conducted to determine the physical and mechanical properties of the selected timber species in accordance with EN 13183-1 and ASTM D193. The mechanical properties were determined using three point bending test. The generated properties were used to obtain the characteristic values of the material properties in accordance with EN384. The selected timber species were then classified according to EN 338. *Strombosia pustulata, Pterygotama crocarpa, Nauclea diderrichii* and *Entandrophragma cyclindricum* were assigned to strength classes D40, C14, D40 and D24 respectively. Other properties such as tensile and compressive strengths parallel and perpendicular to grains, shear strength as well as shear modulus were obtained in accordance with EN 338.

Keywords**—**Mechanical properties, Nigerian timber, strength classes, three-point bending test.

I. Introduction

TIMBERhas a long and distinguished history as a building material having been used for centuries for framing, cladding, flooring and roofing, in both domestic and industrial construction as well as bridges, wharves, railway sleepers and so on [1] and [2].

From the manufacturing view point, the environmental impact of timber structures is much smaller than for structures built using other building materials due to the low energy use and the low level of pollution associated with its manufacture [3]. Whilst most of the structural materials in use are processed from finite resources requiring large amounts of energy and producing significant green-house emissions, timber is grown using natural solar energy.

There are many timber species available in Nigeria. Timber production usually predominate in the Southern and Eastern parts of the country and almost all the species were classified based on the Nigerian Code of Practice (NCP) [4], ranging from weakest grade N1 to the highest grade N7. The code has referred largely with the permissible stress design code [5]. Presently, the permissible stress design approach has become outdated as it has been globally replaced by the limit state design approach.

Recently, Eurocode 5 (EC5) [5] has replaced [6] and is adopted in many countries around the world. It requires the timber strength grading to be in accordance with the international strength classification system. In the grading process, the mean Modulus of Elasticity (MOE), the characteristic values of bending strength and density are required [7] and [8]. These are known as the reference material properties, which are determined in the laboratory, and the other characteristic strength and stiffness properties, such as bending and compressive strength parallel and perpendicular to grain are calculated from those basic ones [9].

The work presents the development of EN338 [10] strength classification for the four (4) selected Nigerian timber species based on the results obtained from experimental measurements using three point bending test..

II. Materials and Methods

A. Materials

The materials used in this study are specimens obtained from the following timber species:

i. Strombosia pustulata
ii. Pterygotama crocarpa
iii. Nauclea diderrichii and
iv. Entandrophragma cyclindricum

1. Preparation of Test Specimens

For bending strength and MOE tests, a total number of 80 timber beams of 50mm×75mm×1500mm each, that is, 20 pieces from each of the selected timber species were prepared with the aid of sawing and milling machines. Slices of full cross sections of 50mm×75mm×50mm each, for MC and density determination were also prepared. A total of number of 60 slices, that is, 15 pieces from each of the selected timber species were prepared at the carpentry workshop of the Department of Civil Engineering, Ahmadu Bello University (ABU), Zaria, Nigeria.

B. Methods

1. Physical Properties of Timber

Physical properties are the quantitative characteristics of wood and its behaviour to external influences other than

I. Abubakar is with the Department of Civil Engineering, Ahmadu Bello University Zaria, Nigeria (phone: +2348028337767; e-mail: idrcivil1@ yahoo.com).

A.M. Nabade is with the Department of Civil Engineering, WaziriUmaru Federal Polytechnic BirninKebbi, Nigeria, (e-mail: amnabade@gmail.com).

applied forces. This includes MC and density [11].

2. Moisture Content of Timber

Because most timber properties are dependent on the amount of water present in the wood, determination of MCs in respect of all the four selected timber species is then necessary. The species MCs were determined in accordance with [12] and [13]. 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 ± 2^0C 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 specie was considered to be the mean values of 15 slices.

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[13].

3. *Density*

The characteristic values of density of specie were determined in accordance with [14] from the equation:

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

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

The characteristic values of density were adjusted to the equivalent 12% MC in line with the requirements of [10] using the equation by [15] and [16]:

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

where $\rho_{k,12\%}$ 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 (%).

C. Methods

1. Mechanical Properties of Timber

Mechanical properties are the characteristics of a material in response to externally applied forces. They include elastic properties, which characterize resistance to deformation and distortion, and strength properties, which characterize resistance to applied loads [11].

2. Bending Strength

Four point bending strength tests as specified by [17] were carried out on 20 specimens from each of the selected timber specie in the concrete and materials laboratory of the Department of Civil Engineering, ABU Zaria. Each specimen was tested using Universal Testing Machine (UTM) until failure occurs. The failure load in respect of the individual beam was recorded. The bending strengths were then computed from the equation [17]:

$$f_m = \frac{3F_{\max} l}{2bh^2} \quad (4)$$

where f_m is the bending strength (N/mm^2), $F_{\max}$ is the maximum Load (in Newton), b is the width of cross-section in bending test (mm), h is the depth of cross section in bending test (mm) and l is the length of test specimen between supports (mm).

The characteristic values of strength properties based on the measured MC were computed from the equation [18]:

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

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

The characteristic values of bending strength were adjusted to the equivalent 12% MC in line with the requirements of EN 338 (2009) using the equation [15], [16]:

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

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).

3. Modulus of Elasticity

The global MOE was derived from four point bending test as specified by [17]. In determining the global MOE, load was applied at constant rate using UTM. The deflection of the beam corresponding to the load applied at constant rate was recorded. The global MOE of the individual beam was then computed from the following expression:

$$E_{m,g} = \frac{l^3(F_2 - F_1)}{48I(w_2 - w_1)} \quad (7)$$

where $E_{m,g}$ is the global MOE in bending, l is the length of the test specimen between the testing machine grips in bending test (mm), I is the second moment of area (mm^4),

$(F_2 - F_1)$ 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 [14]:

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

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

The characteristic values of MOE were also adjusted to the equivalent 12% MC in line with the requirements of EN 338 (2009) using the equation [15] and [16]:

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

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 (%).

III. Results and Discussions

Table I presents the average of the results for MC in respect of all the four selected timber species. The highest value of MC of 24.81% corresponds to *Pterygotama crocarpa* with SD of 2.21% and COV of 0.089, followed by *Strombosia pustulata*, followed by *Nauclea diderrichii* and the least MC value of 20.06% corresponds to *Entandrophragma cyclindricum* with SD of 2.15% and COV of 0.107. In general, MC values for all the species considered were slightly below fibre saturation point (FSP).

TABLE I
Average Results of Moisture Content

Timber Species	Mean (%)	St. D. (SD)	Coefficient of Variation (COV)
Strombosia pustulata	23.27	2.98	0.128
Pterygotama crocarpa	24.81	2.21	0.089
Nauclea diderrichii	23.22	2.86	0.123
Entandrophragma cyclindricum	20.06	2.15	0.107

Table II on the other hand, presents the average results of characteristic values of the mechanical properties and density of the selected timber species as adjusted to 12% MC in line with the requirements of EN 338.

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 the mentioned criteria, *Strombosia pustulata* was assigned to solid timber strength class D40 due to its minimum characteristic bending strength of 75.80N/mm^2, characteristic density of 557kg/m^3 and minimum mean MOE parallel to grain of 14.849KN/mm^2 as shown in Table II. The characteristic bending strength, density and mean MOE parallel to grain for strength class D40 from Table IV provided in the Appendix are 40N/mm^2, 550kg/m^3 and 13 KN/mm^2 respectively. Based on similar criteria, *Pterygotama crocarpa*, *Nauclea diderrichii* and *Entandrophragma cyclindricum* timber species were assigned to strength classes C14, D40 and D24 respectively.

TABLE II
Adjusted Characteristic Values of Material Properties to the Recommended 12% Moisture Content

Timber Species	Density (Kg/m^3)	3 Point. Bending strength(N/mm^2)	MOE from 3 point. bending (kN/mm^2)
Strombosia pustulata	557	75.80	14.849
Pterygotama crocarpa	301	41.36	8.179
Nauclea diderrichii	676	62.88	13.228
Entandrophragma cyclindricum	475	52.39	11.210

A. Other Material Properties

According to [14], for assigning grades and species to the strength classes in EN 338, only three characteristic values, i.e. bending strength, mean modulus of elasticity parallel to grain and density need to be determined, other properties may be taken from the Table IV. As such, other material properties such as tensile strengths parallel and perpendicular to grains, compressive strengths parallel and perpendicular shear modulus etc are taken from Table IV.

Table III presents the values for other material properties of the selected timber species as extracted from Table IV.

Wood is an orthotropic and anisotropic material. Because of the orientation of the wood fibres and the manner in which a tree increases in diameter as it grows, properties vary along three mutually perpendicular axes: longitudinal, radial, and tangential. The longitudinal axis is parallel to the fibre (grain) direction, the radial axis is perpendicular to the grain direction and normal to the growth rings, and the tangential axis is perpendicular to the grain direction and tangent to the growth rings.

TABLE III
CHARACTERISTIC VALUES OF OTHER MATERIAL PROPERTIES BASED ON 12% MC

Other Material Properties	Timber Species			
	Strombosia pustulata (D40)	*Pterygotama crocarpa* (C14)	*Nauclea diderrichii* (D40)	*Entandrophragma cyclindricum* (D24)
Tension Parallel $f_{t,0,k}$ ((N/mm^2)	24	8.0	24	14
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)	26	16	26	21
Compression Perpendicular $f_{,c,90,k}$ ((N/mm^2)	8.3	2.0	8.3	7.8
Shear Strength $f_{v,k}$ ((N/mm^2)	4.0	3.0	4.0	4.0
5% MOE Parallel $E_{0,05}$ ((KN/mm^2)	10.9	4.7	10.9	8.5
Mean MOE Perpendicular $E_{90,mean}$ ((KN/mm^2)	0.86	0.23	0.86	0.67
Mean Shear Modulus G_{mean} (K(N/mm^2)	0.81	0.44	.81	0.62
Mean Density ρ_{mean} (kg / m^3)	660	350	660	580

APPENDIX

TABLE IV
STRENGTH CLASSES – CHARACTERISTIC VALUES

	Strength Properties (N/mm^2)						Stiffness Properties (kN/mm^2)				Density(Kg/m^3)	
	Bending	Tension parallel	Tension perpendicular	Compression parallel	Compression perpendicular	Shear	Mean modulus of elasticity parallel	5% modulus of elasticity parallel	Mean modulus of elasticity Perpendicular	Mean shear modulus	Density	Mean density
	Hardwood specie											
D70	70	42	0.6	34	13.5	5.0	20	16.8	1.33	1.25	900	1080
D60	60	36	0.6	32	10.5	4.5	17	14.3	1.13	1.06	700	840
D50	50	30	0.6	29	9.3	4.0	14	11.8	0.93	0.88	620	750
D40	40	24	0.6	26	8.3	4.0	13	10.9	0.86	0.81	550	660
D35	35	21	0.6	25	8.1	4.0	12	10.1	0.80	0.75	540	650
D30	30	18	0.6	23	8.0	4.0	11	9.2	0.73	0.69	530	640
D24	24	14	0.6	21	7.8	4.0	10	8.5	0.67	0.62	485	580
D18	18	11	0.6	18	7.5	3.4	9.5	8	0.63	0.59	475	570
	Softwood specie											
C50	50	30	0.4	29	3.2	4.0	16	10.7	0.53	1.00	460	550
C45	45	27	0.4	27	3.1	4.0	15	10.0	0.50	0.94	440	520
C40	40	24	0.4	26	2.9	4.0	14	9.4	0.47	0.88	420	500
C35	35	21	0.4	25	2.8	4.0	13	8.7	0.43	0.81	400	480
C30	30	18	0.4	23	2.7	4.0	12	8.0	0.40	0.75	380	460
C27	27	16	0.4	22	2.6	4.0	11.5	7.7	0.38	0.72	370	450
C24	24	14	0.4	21	2.5	4.0	11	7.4	0.37	0.69	350	420
C22	22	13	0.4	20	2.4	3.8	10	6.7	0.33	0.63	340	410
C20	20	12	0.4	19	2.3	3.6	9.5	6.4	0.32	0.59	330	390
C18	18	11	0.4	18	2.2	3.4	9	6.0	0.30	0.56	320	380
C16	16	10	0.4	17	2.2	3.2	8	5.4	0.27	0.5	310	370
C14	14	8	0.4	16	2.0	3.0	7	4.7	0.23	0.44	290	350

Source: EN338 [10]

NOTE 1 Values given above for tension strength, compression strength, shear strength, 5% modulus of elasticity, mean modulus of elasticity perpendicular to grain and mean shear modulus, have been calculated using the equations given in annex A.

NOTE 2 The tabulated properties are compatible with timber at moisture content consistent with a temperature of 20^{0}C and a relative humidity of 65%.

NOTE 3 Timber conforming to classes C45 and C50 may not be readily available.

NOTE 4 Characteristic values for shear strength are given for timber without fissures, according to EN 408. The effect of fissures should be covered in design codes.

IV. CONCLUSION

The results have shown that, out of the four tested timber species, three belongs to the deciduous specie, D class (that is, the class of hardwoods) and one belongs to the coniferous specie, C class (that is, the class of softwoods). This strength classification according to [10] identified 12 classes of softwoods and 8 classes of hardwoods in order of increasing strength ranging from weakest grade of softwood (that is, C14) to the highest grade of hardwood (that is, D70).

Based on the experimental works carried out, the three hardwood species namely: *Strombosia pustulata, Nauclea diderrichii* and *Entandrophragma cyclindricum* are recommended for engineering applications such as in roof fabrications as well as in timber structures as structural elements. *Pterygotama crocarpa i*s the weakest species and as such not recommended for use for high load-bearing purposes.

ACKNOWLEDGMENT

The technical staffs of concrete and materials laboratory of the Department of Civil Engineering, ABU Zaria are acknowledged for their tremendous efforts in conducting the laboratory experiments.

REFERENCES

[1] I. Ferguson, B.La Fontaine, P.Vinden, L.Bren, R.Hateley and B.Hermesec"Environmental properties of timber," Research Paper commissioned by FWPRDC, 1996, Australia
[2] W. R. Lawson "Timber in building construction: Ecological implications," Research paper commissioned by the Timber Development Association (NSW) Limited and FWPRDC, 1996, Australia.
[3] J. Kohler "Reliability of timber structures," A dissertation submitted to the Swiss Federal Institute of Technology for the degree of doctor technical sciences, 2006
[4] NCP2 "The Use of Timber for Construction," Nigerian Standard Code of Practice, accredited by the Standard Organisation of Nigeria (SON), Federal Ministry of Industries, 1973, Lagos, Nigeria
[5] EN 1995 "Design of timber structures: Part 1-1: General – Common rules and rules for Buildings," European Committee for Standardisation, CEN, 2004, Brussels, Belgium.
[6] BS 5268 "Structural use of timber Part 2: Code of Practice for permissible stress design, materials and workmanship, British Standard Institute, BSI, 2002, London.
[7] P.Glos, "Strength gradingin timber Engineering STEP 1", 1995b, The Netherlands,pp A6/1-A6/8.
[8] JCSS "Probabilistic Model Code: Part 3: Resistance Models: Properties of Timber," Joint Committee on Structural Safety, 12th Draft, Internet version: 2006, http://www.jcss.ethz.ch
[9] P.Glos. "Solid Timber – Strength Classes. in Timber Engineering STEP 1",1995a, pp A7/1-A7/8. Centrum Hout, The Netherlands
[10] EN338 "Structural Timber: Strength Classes," European Committee for Standardisation, CEN, 2009, Brussels, Belgium.
[11] J. E.Winandy "Wood Properties,"WisconsinEncyclopaedia of Agricultural Science., 1994, Orlando, FL: Academic Press: Vol. 4, p.551-554
[12] EN 13183-1 "Moisture content of a piece of sawn timber: Determination by oven Dry Method," European Committee for Standardisation, CEN, 2002, Brussels, Belgium
[13] EN 408 "Timber structures – Structural timber and Glued-laminated timber: Determination of some physical and mechanical properties," European Committee for Standardisation, CEN, 2003, Brussels, Belgium
[14] EN 384 "Structural timber: Determination of characteristic values of mechanical properties and density," European Committee for Standardisation, CEN, 2004, Brussels, Belgium.
[15] L. Bostrom "Machine strength grading, Comparison of four different systems", Swedish National Testing and Research Institute, Building Technology SP.Report, 1994:49, 57p.
[16] K.Heikkila, and H. Herajarvi "Stiffness and strength of 45×95mm beams glued from Norway Spruce using 8 different structural models," Conference COST E53 29-30. Delft, 2008, the Netherlands.
[17] ASTM D193 "Standard method of testing small clear specimens of timber," American Society for Testing and Materials, 2000, USA.
[18] A. Ranta-Maurus, M. Forselius, J. Kurkela and T. Toratti"Reliability analysis of timber structures," Nordic Industrial Fund, 2001, Technical Research Centre of Finland.