JASEM ISSN 1119-8362

Full-text Available Online at https://www.ajol.info/index/jasem and www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage. *Dec,* 2017
Vol. 21 (7) 1281-1285

Evaluation of Compressive Strength Characteristics of Structural-sized Apa (*Afzelia bipindensis*) and Opon (*Lannea schimperi*) Timber species columns found in Nigeria

JIMOH, AA; *RAHMON, RO; JOSEPH, SG

Department of Civil Engineering, University of Ilorin, Nigeria
**Email: rorahmon2222@gmail.com, Tel: +2347061276187; aajimoh4real@yahoo.com; josephsunday91@gmail.com*

ABSTRACT: The work centers on the compressive strength characteristics of Nigerian Apa (*Afzelia bipindensis*) and Opon (*Lannea schimperi*) timber species columns of nominal lengths 200, 400, 600 and 800mm and a nominal width and thickness of 50mm by 50mm. The data revealed that, Apa and Opon have an average density of 652.74 and 472.60kg/m^3 respectively. The mean moisture content (MC) of both species were less than the fibre saturation point (FSP) recommended value of 25-30% and the average strength at yield of Apa and Opon are 35.65 and 14.00N/mm^2. The derived continuous equations for design of Apa column and Opon column are $\boldsymbol{\sigma} = \mathbf{47.882^{-0.009\lambda}}$ and $\boldsymbol{\sigma} = \mathbf{17.211^{-0.007\lambda}}$ respectively. The results of the reliability analysis show that Apa and Opon timber species have reliability index of **0.64** and **0.65** respectively for a service life of **50** years, assuming other serviceability conditions are met. This design procedure is distinct and more effective than the usual procedure of classifying compression members as short, intermediate and long using their slenderness ratios. The paper therefore recommends the adoption of these equations for the design of compression members from these timber species in Nigeria.

DOI: https://dx.doi.org/10.4314/jasem.v21i7.10

Received 04 September 2017; received in revised form 30 October 2017; accepted 17 December 2017

Keywords: Apa, Compressive strength, Opon, Reliability, Structural-sized

Timber is one of the materials used in construction and is a sustainable resource (Porteous and Kermani, 2007). It is one of the few natural and renewable construction materials that exists but has its limitations in general use for construction, carpentry and upholstery (Apu, 2003). Also, timber is an organic material and thus is subject to deterioration with time (Robert, 2010). Structural timber is the timber used in framing and load-bearing structures, where strength is the major factor in its selection and use (Aguwa, 2010). Most woods used in the building construction are softwoods but in structures like bridges and railway sleepers, hardwoods are specially used (Karlsen and Slitskouhov, 1989). *Afzelia africana* is a timber specie locally known by its Yoruba name Apa and trade name Afzelia. Other common names for the specie are: Doussié (Cameroons), Apa (Nigeria), Mkola, Mbambakofi (Tanzania), Chanfuta, Mussacossa (Mozambique). Afzelia is a transition species found between the savannah forest of dry areas and the dense forests of humid regions. It occurs throughout West Africa, Uganda and parts of Tanzania. (Timber Research and Development Association, 1979). *Lannea schimperi* is locally known by its Yoruba name Opon and its vernacular name Rusty-leaved Lannea. The wood is whitish and light weighted (Oyen, 1987).

The main characteristic of these timbers under investigation is their buckling characteristics when subjected to compressive load. According to Robert (2006) buckling is a mode of failure that generally results from structurally unstable member due to compressive action on the said member and it depends on the geometric properties of the member. This study brings to focus current reasoning and the integration of advanced technologies to suit the available climatic, natural and human resources to solve the problem of transportation, by making cheaper, better and more reliable structural system in highways (Aguwa, 2011). The environment, the weather condition and the soil affect the growth of trees as well as their strength properties. Most of the timber strength properties recorded in British and European codes were based on timber obtained from trees on those areas and the laboratory tests were conducted there. Since all our timber structures are constructed of timber from Nigeria, there is the great need to determine their strength properties and subject them to structural reliability analysis in order to prove their degree of structural performances (Aguwa, 2010). A significant element of uncertainty is also introduced through lack of information about the actual physical variability. The aim of this study is to evaluate the compressive strength characteristics of structural-sized Nigerian grown Apa and Opon

**Corresponding author email: rorahmon2222@gmail.com*

timber species columns using constant failure rate reliability method.

MATERIALS AND METHOD

Material procurement **-** *Afzelia bipindensis* (Apa) and *Lannea schimperi* (Opon) timber species were bought from Tanke, Odo-Okun and Saboline sawmills in Ilorin, Kwara State, Nigeria. They were naturally seasoned for seven (7) months for the samples to attain equilibrium moisture content (EMC) environmentally. The natural seasoning was chosen over artificial seasoning which is faster because the proposed timber structure is column which is always completely exposed to natural atmospheric weather conditions. The timber samples were prepared and tested in accordance with the British Standard BS EN 408 (2003) Test for physical and mechanical properties of structural timbers at the Wood workshop of the Faculty of Engineering and Technology, University of Ilorin, Nigeria. Timber lengths of 50mm x 50mm section obtained from each sawmill was cut into lengths 200, 400, 600 and 800mm. A maximum height of 800mm was used due to the limited height of the testing machine. The physical property tests of the timber species was carried out at the structural laboratory of Civil Engineering Department, University of Ilorin, while the mechanical strength test was carried out using a Universal Testing Machine (UTM) of capacity 300kN at the Agricultural and Biosystems Engineering Laboratory of University of Ilorin, Kwara State, Nigeria.

Physical property tests: *Moisture Content* **-** In Accordance with BS 373 (1957) immediately after each mechanical test has been conducted, a small sample for determination of moisture content was cut from each test piece. The sample size was 50 x 50 x 50 mm and consists of a transverse section from near the point of fracture. The sample was weighed and then dried in an oven at a temperature of 103 ± 2 °C (217 ± 4 °F) until the weight is constant. The loss in weight expressed as a percentage of the final oven-dry weight is taken as the moisture content of the test piece. Percentage Moisture content, (m.c) is given as:

$$m.c.\% = \frac{W_a - W_0}{W_0} \, x \, 100\% \qquad (1)$$

Where: W_a = Air-dried weight of sample at test in grams, W_0 = Oven-dried weight of sample in grams.

Density - Density of a material is the ratio of the mass to the volume. In the 50mm x 50mm standard given by BS 373 (1957), all test pieces weight and dimensions were determined before test. The density is given as:

$$\rho = \frac{W_a}{V_a} = \qquad (2)$$

Where: ρ = density in kg/m^3, B = Breadth in cm, D = Depth in cm, H = height in cm, W_a = Air-dry weight of sample at test in grams (g), V_a = Air-dry volume of sample at test in cubic centimeters (cm^3).

Mechanical property test: Compressive Strength **-** Compressive strength test was carried out using a Testometric Universal Testing Machine. The following procedures were followed:

i. The timber was cut into various sizes (200, 400, 600 and 800mm); twenty samples for each of the sizes and then labeled.

ii. The machine height was now adjusted to the sizes of the specimen. Then the timber was fixed for loading.

iii. The speed of the test was calculated according to BS 373 (1957) standard as 13.020, 26.040, 39.060 and 52.075mm/min for the length 200, 400, 600 and 800mm respectively.
iv. The nominal length, the test speed, weight, breadth, width of the samples was inputted into the computer.
v. The machine was started and load deflection curve can be seen on the computer, the machine was stopped when the sample fails or when the curve starts to deflect downward.
vi. The buckling was measured, and the sample taken out of the machine.
vii. The steps were repeated for the remaining samples.
viii. From the load deflection curve obtained after the test, the stress and strain is calculated

$$\text{Stress, } \sigma\ (\text{N/mm}^2) = \frac{P}{A} \qquad (3)$$

$$\text{Strain, } \varepsilon\ (\%) = \frac{\Delta H}{H} \qquad (4)$$

Member slenderness was calculated as follows:

$$\text{Slenderness ratio, } \lambda = \frac{\text{Le}}{\text{r}} \qquad (5)$$

Where: Le = 1.0L, $r = \sqrt{\frac{I}{A}}$, $I = \frac{BD^3}{12}$, A = B*D and λ = Slenderness Ratio, Le = effective length, r = radius of gyration, I = moment of inertia, A = cross-sectional area, L = Length, B = Breadth, D = Depth.

RESULTS AND DISCUSSIONS

The density of an air-dried timber has a direct relationship with the strength of the timber. Hence, the higher the density the higher the strength of the timber and vice versa. The average density of *Afzelia bipindensis* (Apa) and *Lannea schimperi* (Opon) are 652.74 and 472.60kg/m³ respectively.. This implies that Apa has a higher yield strength than Opon.

Table 1: Average density of timber species

Specie	Average density (kg/m^3)	
	Apa	Opon
Minimum	594.77	464.52
Maximum	710.70	480.67
Mean	652.74	472.60
Standard deviation	132.34	78.64
COV (%)	11.64	9.27
95% Confidence limit	594.74<x<710.74	438.14<x<507.07
99% Confidence limit	576.52<x<728.96	427.31<x<517.90

The average moisture content for Apa and Opon were 14.88 and 16.34% respectively as presented in Table 2. This result is satisfactory, since the mean values of moisture content of the two timber species are found to fall below the fibre saturation point (FSP). The FSP is usually between 25-30% MC (Nabade, 2012). At this moisture content the likelihood of decay of the timber is greatly reduced.

Table 2: Average moisture content of Apa and Opon

Specie	**Average moisture content (%)**	
	Apa	Opon
Minimum	12.68	15.09
Maximum	16.46	18.87
Mean	14.88	16.34
Standard deviation	3.89	5.68
COV (%)	6.98	5.68
95% Confidence limit	13.18<x<16.59	13.85<x<18.83
99% Confidence limit	12.64<x<17.12	13.07<x<19.61

Failure modes: A structural size timber column will normally fail by buckling, compression or a combination of both buckling and compression depending on the ratio of its height to its cross-sectional dimension. From the test carried out, it was observed that all 200 mm samples failed by crushing, while the 400, 600 and 800mm samples fail by buckling. The minimum and maximum shortening for Apa timber was 5mm for a height of 400mm and 21mm for a height of 800mm, while that of Opon timber was 7mm for 400mm height and 30mm for 800mm height. This re-affirms the previous deduction that Apa is stronger than Opon, since it experiences lesser lateral deflection. The compression failure of the 200mm samples was expected as it is the standard dimension for compression test.

Relationship between Mean Stress at yield, Young's Modulus and slenderness ratio ***:*** Slenderness is usually given as the ratio of the effective height to the radius of gyration of a compression member. The effect of geometry on strength is expressed in terms of the member's slenderness. For a compression member like column, as the member slenderness increases, the mean yield stress decreases. From the results presented in Table 3, it was observed that the average yield stress of both timber species decreases with increase in height. An exception is Opon timber with 400mm height having a lower average yield stress than the 600mm height. This may be due to defects in the timber sample

Table 3: Slenderness ratio, Stress @ Yield and Young's Modulus relationship for Apa and Opon

Mean Height (mm)	**Mean Slenderness ratio, λ**		**Mean Stress @ Yield, σ (N/mm^2)**		**Young's Modulus (N/mm^2)**	
	Apa	Opon	Apa	Opon	Apa	Opon
200.00	14.46	14.12	41.83	16.55	2175.91	921.88
400.33	28.94	28.85	39.17	12.86	1693.17	649.30
601.67	45.51	42.52	31.57	13.98	1183.76	560.62
801.33	57.80	57.16	30.03	12.60	1047.82	407.11
Average			**35.65**	**14.00**	**1525.17**	**634.73**

*Verification of design equations****:*** In other to derive a continuous column design equation for both Apa and Opon timber species, statistical regression analysis was performed on the stress at yield and slenderness ratio results for Apa and Opon timber column. The result of the regression analysis yields Equation 6 and 7 which is the desired column design equation for both Apa and Opon timbers respectively.

$$\boldsymbol{\sigma = 47.882^{-0.009\lambda}} \quad (6)$$

$$\boldsymbol{\sigma = 17.211^{-0.007\lambda}} \quad (7)$$

To examine how well the theoretical equation best fit the experimental results obtained, the values of stress at yield were obtained from the design equation with the experimental slenderness ratio as input alongside the experimental stress at yield. The ratio of the theoretical to the experimental yield stress was also calculated. It was observed that the ratio of the theoretical to experimental yield stress ranges between 77 and 121% for Apa timber, and between 67 and 149% for Opon timber, both having a mean value of unity. This implies that the theoretical result is in close agreement with the experimental results.

Also a single factor Analysis of Variance (ANOVA) was performed on the theoretical and experimental stress at yield using the null hypothesis (H_0: $\mu 1 = \mu 2$) that the means are equal at 95% confidence interval. For both timber specie, it was observed that F < Fcrit and α (0.05) < P-value. Hence, we accept the null hypothesis H_0 that the means of both the theoretical and experimental values are equal at 0.05 level of significance. This means that the theoretical stress at yield derived from the design equation agrees with the experimental results. Therefore Equation 6 and 7 can be used for the rational design of Apa and Opon timbers respectively.

Reliability Analysis: The result of the reliability analysis shows that Apa and Opon timber species have reliability index of 0.64 and 0.65 respectively (which is greater than 0.5, the minimum index for a reliable structure according to Adedeji (2008), Ajamu (2014) and Abdulraheem (2017) for a service life of 50 years, assuming other serviceability conditions are met.

Table 4: Strength Analysis of Apa timber

Height (mm)	Average Strength (σ) (N/mm^2)	Cumulative Strength (Q_i) (N/mm^2)	Remaining Strength (R_i) (N/mm^2)	Strength Rate (d_i)
200	41.83	41.83	100.77	0.4151
400	39.17	81.00	61.60	0.3887
600	31.57	112.57	30.03	0.5125
800	30.03	142.60	0	1.0000

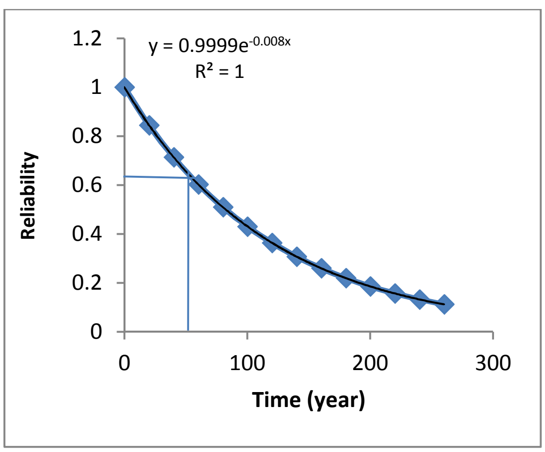

Fig 1: Reliability of Apa timber

Table 6: Strength Analysis of Opon timber

Height (mm)	Average Strength (σ) (N/mm^2)	Cumulative Strength (Q_i) (N/mm^2)	Remaining Strength (R_i) (N/mm^2)	Strength Rate (d_i)
200	16.55	16.55	39.44	0.4196
400	12.86	29.41	26.58	0.3245
600	13.98	43.39	12.60	0.5260
800	12.60	55.99	0	1.0000

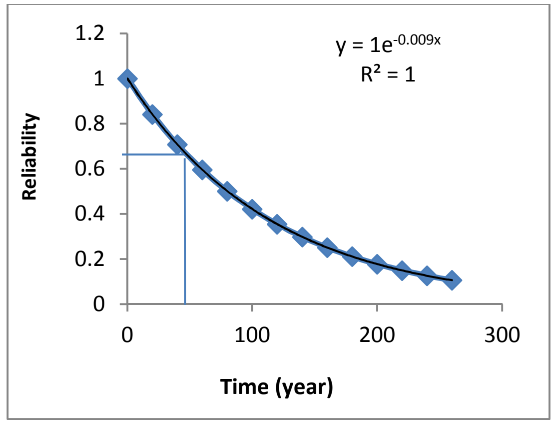

Fig 2: Reliability of Opon timber

*Conclusion***:** The overall conclusions emerging from this study indicates that Apa has higher yield strength than Opon and thus will be more suited for Structural use. Direct relationship exists between physical properties such as moisture and density, and mechanical properties such as yield strength and elastic modulus. The equations derived from the regression analysis on the experimental results can be used to obtain the stress at yield if the slenderness ratio of a structural size timber column from the specie is known. With the results obtained and the associated equations derived, the strength of both timber species can be accurately predicted, thereby encouraging the use of these natural and sustainable construction materials.

REFERENCES

Abdulraheem, KK (2016). Reliability Index Assessment of Solid and laminated teak Wooden Deep I-Beam for residential Building. M. Eng. Thesis report submitted to the Department of Civil Engineering, Faculty of Engineering and Technology, University of Ilorin, Nigeria.

Adedeji AA (2008). Reliability-Based Probability Analysis for Predicting Failure of Earth Brick Wall in Compression. Nigerian Journal of Construction Technology and Management, 9(1), 25 – 34.

Aguwa, JI (2010). Reliability Studies on the Nigerian Timber as an Orthotropic, Elastic Structural Material. Ph.D. Thesis submitted to Post Graduate School, Federal University of Technology, Minna, Nigeria.

Aguwa JI (2011). Structural Reliability analysis of the Nigerian Ekki timber bridge beam subjected to deflection under the ultimate limit state of loading; presented and published in the Book of

Proceedings, 2nd Biennial Engineering Conference, Titled Energy, Global Environmental Change, Food Security and Engineering Infrastructure, organized by School of Engineering and Engineering Technology, Federal University of Technology, Minna, Nigeria, 16th – 18th November, 2011, pp311 - 318.

Ajamu, SO (2014). Optimal design of cement-lime plastered straw bale mansory under vertical load and thermal insulation for a residential building. Ph. D Thesis report submitted to the Department of Civil Engineering, faculty of Engineering and Technology, University of Ilorin, Nigeria.

Apu, SS (2003). Wood Structure and Construction Method for Low-cost Housing. International Seminar/Workshop on Building materials for Low-cost Housing, Indonesia. p:7-28.

BS 373 (1957). Methods of Testing Small clear Specimens of Timber, British Standards Institution, 2 Park Street, London WIA 2BS.

British Standard European Standard EN 408, (2003) – Timber Structures – Structural Timber and Glue-laminated Timber – Determination of some Physical and Mechanical Properties. London: British Standard Institution,. pp. 1 – 33.

BS 5268; (2002). The Structural Use of Timber part 2; for Permissible Stresses, Materials and Workmanship, 5th Edition British Standards Institution, 2 Park Street, London WIA 2BS, pp 176.

Karlsen, G; Slitskouhov YU (1989). 1st Edition Wooden and Plastic Structures Mir Publishers Moscow, USSR, pp 400.

Nabade, AM (2012). Determination of Strength classes for Itako (*Strombosia pustulata*), Oporoporo (*Macrocarpa bequaertii*), Opepe (*Nauclea diderrichii*) and Ijebu (*Entandrophragma cyclindricum*) Nigeria timber species based on EN 338 (2009). M. Sc. Thesis submitted to the Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria.

NCP 2; (1973). Nigerian Standard Code of Practice; The use of Timber for Construction, Nigerian Standards Organisation, Federal Ministries of Industries, Lagos, Nigeria, pp 71.

Oyen, LPA (1987). Lannea schimperi (Hochst. ex A.Rich.) Engl. [Internet] Record from PROTA4U. Brink, M. & Achigan-Dako, E.G. (Editors). PROTA (Plant Resources of Tropical Africa/ Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands. <http://www.prota4u.org/search.asp >. Accessed 1 February 2017.

Porteous, J; Kermani, A (2007). Structural Timber Design to Eurocodes. Blackwell Publishing, USA.

Robert, HF (2010). Wood as a Sustainable Building Materials. Wood as an Engineering material, Wood Handbook.

Robert, JM (2006). Buckling of Bars, Plates and Shells. Bull Ridge publishing, Blacksburg, pp. 1-30.

Timber Research and Development Association, TRDA. (1979). "Timbers of the World", Longman, New York, pp. 8-9.