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Research Paper

Compressive Strength Characteristics of Ara and Apado Nigerian Timber Species

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Abstract

The paper examined the reliability of the Nigerian grown Ara and Apado timber species as column materials. The work focuses on the compressive strength characteristics of Nigerian Ara (Pterocarpus erinaceus) and Apado (Berlinia spp) timber column of nominal lengths 200, 400, 600 and 800 mm and cross section of 50 by 50 mm. The steps involved include collection and conditioning of Apa and Apado timber species, preparation of test specimens, determination of physical and compressive strength properties and derivation of continuous column design equations. Twenty (20) test samples were used for all the tests carried out. Apa and Apado have an average density of 652.83 and 732.56 kg/m^3, respectively. Moisture content of both species is less than the maximum recommended value of 20 % and the average strength at yield of Apa and Apado were 38.81 and 29.61 N/mm^2. The derived continuous equations for design of Apa and Apado column are $\sigma = 47.882^{-0.009\lambda}$ and $\sigma = 17.211^{-0.007\lambda}$ respectively. Ara and Apado have the reliability index of 0.63 and 0.65 respectively for a service life of 50 years, assuming other serviceability conditions are met. The paper therefore recommends the adoption of these equations for the design of compression members from these timber species, in Nigeria.

Keywords: - *Apado, Ara, Compressive strength, Reliability, Slenderness ratio.*

1. Introduction

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. If this natural resource is properly utilized, it will be of immense benefit to the country in terms of reduction in the cost of construction (Aguwa et al., 2015). Timber does not have consistent, predictable, reproducible and uniform properties as the properties vary with species, age, site and environmental conditions (Kliger, 2006). The strength of a timber depends on its species and the effects of certain growth characteristics (Porteous and Kermani, 2007). 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 (Rahmon et al., 2017). This is because vast quantities of local raw materials, which must be processed and used for cost effective abound (Aguwa, 2011). 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).

Structural timber is the timber used in framing and load-bearing structures, where strength is the major factor in its selection and use. 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). The Raw Materials Research and Development Council of Nigeria, RMRDC (1998) opined that the roof structure and ceiling noggins of most buildings are constructed with timber because of its workability and durability. Timber is natural and renewable. It has a high strength to weight ratio and is easy to work with, making it especially useful even where only basic technology and procedures are available (Apu, 2003).

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 Nigerian 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).

The reliability, R(t) of an item is defined as the ability of an item to perform a required function under stated conditions without failure for a stated period of time (Adedeji, 2008; Ajamu, 2014). Reliability coefficients range from 0.00 to 1.00, with higher coefficients indicating higher levels of reliability. However, reliability specifically measures the consistency of an item. According to Leitch (1988), reliability index using constant failure rate (CFR) model is given in equation (1):

$$\mathrm{R(t)} = e^{-\lambda t} \tag{1}$$

Where: R(t) = reliability index; λ = constant rate of failure; t = variable time and the failure rate (λ) is express as in equation (2):

$$\lambda = \frac{1-d}{T} \tag{2}$$

Where: T is the time (years), expected life span of timber, and d: the average compressive strength rate.

Nowak (2004) defines structural reliability as the probability that a structural system will satisfy the purpose for which it was designed and efficiently serve the period for which it was designed to without attaining a given limit state. Structural reliability and probabilistic methods have gradually grown to be important in modern structural engineering practice, especially when it involves naturally occurring materials like timber. Structural reliability could currently be used in the formulation of new generation design codes, evaluation of existing structures and probability risk assessment. One of the objectives for structural design is to fulfill certain performance criteria related to safety and serviceability. One of such performance criteria is usually formulated as a limit state, that is, a mathematical description of the limit between performance and non-performance (Thelandersson, 2003). Parameters used to describe limit states are loads, strength and stiffness parameters, dimensions and geometrical imperfections; since the parameters are random variables, the outcome of a design in relation to limit state is associated with uncertainty (Aguwa, 2012). A significant element of uncertainty is also introduces through lack of information about the actual physical variability. The objectives of this study is to conduct experiments on the Nigerian Ara and Apado timber species with a view to establishing their physical and strength properties, to check the conformity of these properties with BS 5268 (2002) and NCP 2 (1973), to derive continuous column design equations for the Nigerian Ara and Apado timber species as column structural material, to estimate the reliability of the Nigerian Ara and Apado timber species.

2. Material and Methods

2.1. Material procurement

Pterocarpus erinaceus (Ara) and *Berlinia spp (Apado)* timber species were obtained from Tanke, Odo-Okun and Saboline sawmills in Ilorin, Nigeria. They were naturally seasoned for six months for the samples to attain moisture content equilibrium 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 section of the Civil Engineering Department, Faculty of Engineering and Technology, University of Ilorin, Nigeria. Timber lengths of 50 x 50 mm section obtained from each sawmill was cut into lengths 200, 400, 600 and 800 mm. A maximum height of 800 mm was used due to the limited height of the testing machine. A typical nomenclature is given in Figure 1.

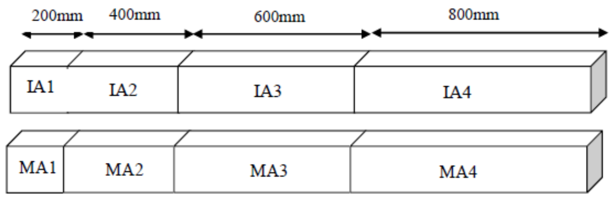

Figure 1: Lengths of Timber species

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 300 kN at the Agricultural and Biosystems Engineering Laboratory, Faculty of Engineering and Technology, University of Ilorin, Kwara State, Nigeria.

2.2. Physical property tests

2.2.1. Moisture content

In accordance with British Standard BS 373 (1957) Method of Testing small clear specimen of Timber, 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. Moisture content (m.c) in percentage is given as:

$$m.c.\% = \frac{W_a - W_0}{W_0} x\ 100\% \qquad (3)$$

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

2.2.2. Density

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

$$\rho = \frac{W_a}{V_a} = \frac{W_a}{BxDxH} \qquad (4)$$

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 (m^3).

2.3. Mechanical property tests

2.3.1. Compressive Strength

Compressive strength test was carried out using a Testometric Universal Testing Machine. The following procedures were carried out:

i. The timber was cut into various sizes (200, 400, 600 and 800 mm); 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) (Table 1).

Table 1: Test speed

Sample length (mm)	Test speed (mm/min)
200.00	13.020
400.00	26.040
600.00	39.060
800.00	52.075

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 (σ) and strain (ε) is calculated.

$$\sigma\ (\mathrm{N/mm^2}) = \frac{P}{A} \qquad (5)$$

$$\varepsilon\ (\%) = \frac{\Delta H}{H} \qquad (6)$$

Member slenderness was calculated as follows:

Slenderness ratio, $= \frac{Le}{r}$ (7) , where Le = 1.0L,

Radius of gyration, $r = \sqrt{\frac{I}{A}}$ (8), where $I = \frac{BD^3}{12}$, 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.

3. Results and Discussion

3.1. Density

The results of density are shown in Table 2. From the results, it was observed that the average density of *Pterocarpus erinaceus* (Ara) is 452.83 kg/m³ while that of *Berlinia spp* (Apado) is 732.56 kg/m³. This implies that Apado has higher yield strength than Ara.

Table 2: Average density of Ara and Apado

Specie	Average density (kg/m³)	
	Ara	**Apado**
Minimum	324.53	548.27
Maximum	587.23	742.67
Mean	452.83	732.56
Standard deviation	45.44	54.33
COV (%)	24.57	19.43
95% Confidence limit	424.67≤x≤480.99	698.89≤x≤766.23
99% Confidence limit	415.82≤x≤489.84	688.31≤x≤776.81

3.2. Moisture content

The minimum, maximum and average moisture content of Ara after compression test is 8.84, 18.06 and 13.87 % while that of Apado are 13.55, 19.76 and 15.71 %, respectively. This result is satisfactory, since it is less than the maximum recommended moisture content of 20 % for an air-dried sample. At this moisture content the likelihood of decay of the timber is greatly reduced.

Table 3: Average moisture content of Ara and Apado

Specie	Average moisture content (%)	
	Ara	**Apado**
Minimum	8.84	13.55
Maximum	18.06	19.76
Mean	13.87	15.71
Standard deviation	7.53	9.84
COV (%)	35.43	42.68
95% Confidence limit	9.20≤x≤18.54	9.61≤x≤21.81
99% Confidence limit	7.74≤x≤20.00	7.70≤x≤23.73

3.3. Stress-strain relationship of Ara and Apado timber

The continuous column design equations of stress-strain relationship of Ara and Apado timber species was obtained from the regression analysis as given in equation (9) and (10), respectively. The continuous equations are as follows:

$$\sigma = 47.882^{-0.009\lambda} \quad (9)$$

$$\sigma = 17.211^{-0.007\lambda} \quad (10)$$

Table 4 presents the relationship that exist between the timber species stress, strain, slenderness ratio and Young's Modulus. The stress at which a column buckles decreases as slenderness ratio increases and the mean length increases as well.

Table 4: Slenderness ratio, Stress @ Yield and Young's Modulus relationship for Ara and Apado

Mean Height (mm)	Mean Slenderness ratio, λ		Mean Stress @ Yield, σ (N/mm²)		Young's Modulus (N/mm²)	
	Ara	**Apado**	**Ara**	**Apado**	**Ara**	**Apado**
200.67	13.91	14.21	37.32	37.10	1726.16	2020.66
402.67	27.82	28.63	41.89	30.04	1373.71	1594.56
600.67	41.44	42.52	37.25	22.79	1142.17	1036.18
802.67	54.93	58.27	38.79	28.49	1000.17	764.32
Average			38.81	29.61	1310.55	1353.93

3.4. Verification of design equations

The relationship between experimental stress at yield and the theoretical stress using equation at yield for Pterocarpus erinaceus (Ara) and Berlinia spp (Apado) were both subjected to an Analysis of Variance (ANOVA) test. The results of One-way Analysis of Variance (ANOVA) on experimental stress at yield and the theoretical value at 0.05 significance level is given in Table 5 and 6 for Ara and Apado respectively. The P-values that is 0.008087 and 0.008455 are both less than 0.05 which implies that there is significant differences between the experimental and theoretical values obtained.

Table 5: ANOVA Analysis for Ara

ANOVA: SINGLE FACTOR SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	12	379.28	31.60667	18.20186		
Column 2	12	383.4997	31.95831	6.52446		
ANOVA						
Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.741911	1	0.741911	0.06001	0.008087	4.30095
Within Groups	271.9895	22	12.36316			
Total	272.7314	23				

Table 6: ANOVA Analysis for Apado

ANOVA: SINGLE FACTOR SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	12	347.08	28.92333	15.53202		
Column 2	12	350.6691	29.22242	12.08924		
ANOVA						
Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.536723	1	0.536723	0.038863	0.008455	4.30095
Within Groups	303.8339	22	13.81063			
Total	304.3706	23				

3.5. Reliability Analysis

Tables 7, 8, 9 and 10 show the reliability analysis of Ara and Apado timber species using Constant Failure Rate model. The result of the reliability analysis as obtained from Figure 2 and 3 shows that the timber species have reliability index of 0.64 and 0.63 (which is greater than 0.5, the minimum index for a reliable structure according to Abdulraheem (2016), Adedeji (2008) and Ajamu (2014)) for a service life of 50 years, assuming other serviceability conditions are met.

Table 7: Strength Analysis of Ara 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	37.32	37.32	117.93	0.3164
400	41.89	79.21	76.04	0.3552
600	37.25	116.46	38.79	0.4898
800	38.79	155.25	0	1.0000

Average Strength rate, $d = \frac{0.3164+0.3552+0.4898+1.0000}{4} = 0.5404$

Failure rate, $\lambda = \frac{1-d}{t}$, assuming a service life of 50 years and that other serviceability conditions are met, the reliability of the Ara timber column is evaluated as shown below using Constant Failure Rate (CFR).

$$\lambda = \frac{1 - 0.5404}{50} = 0.009192/year$$

Table 8: Reliability using CFR

Time (years)	λt	$e^{-\lambda t}$	Time (years)	λt	$e^{-\lambda t}$
0	0	1	140	1.287	0.2761
20	0.184	0.8319	160	1.471	0.2297
40	0.368	0.6921	180	1.655	0.1911
60	0.552	0.5758	200	1.838	0.1591
80	0.735	0.4795	220	2.022	0.1324
100	0.919	0.3989	240	2.206	0.1101
120	1.103	0.3319	260	2.389	0.0917

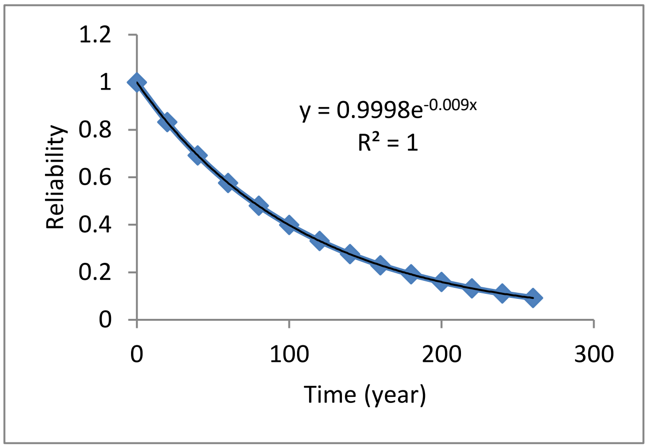

Figure 2: Reliability of the Ara timber

Table 9: Strength Analysis of Apado 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	37.10	37.10	81.32	0.4562
400	30.04	67.14	51.28	0.3694
600	22.79	89.93	28.49	0.4444
800	28.49	118.42	0	1.0000

Average Strength rate, $d = \frac{0.4562+0.3694+0.4444+1.0000}{4} = 0.5675$

Failure rate, $\lambda = \frac{1-d}{t}$, assuming a service life of 50 years and that other serviceability conditions are met, the reliability of the Apado timber column is evaluated as shown below using Constant Failure Rate (CFR).

$$\lambda = \frac{1 - 0.5675}{50}\ 0.008650/year$$

Table 10: Reliability using CFR

Time (years)	λt	$e^{-\lambda t}$	Time (years)	λt	$e^{-\lambda t}$
0	0	1	140	1.211	0.2979
20	0.173	0.8411	160	1.384	0.2506
40	0.346	0.7075	180	1.557	0.2108
60	0.519	0.5951	200	1.730	0.1773
80	0.692	0.5006	220	1.903	0.1491
100	0.865	0.4211	240	2.076	0.1254
120	1.038	0.3542	260	2.249	0.1055

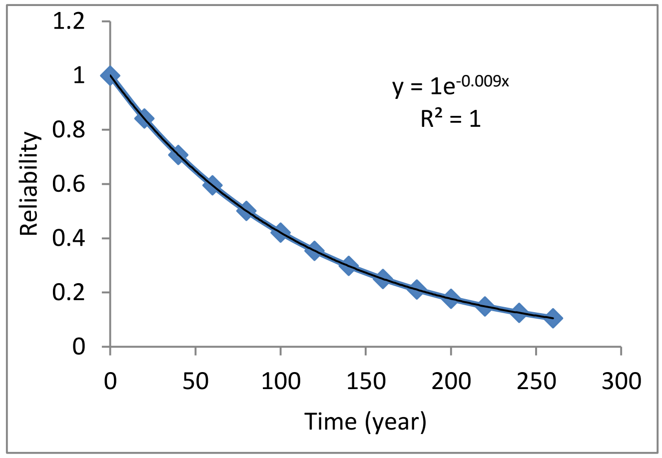

Figure 3: Reliability of the Apado timber

4. Conclusions

The overall conclusions emerging from this study are;

- The average density of Apado is higher than that of Ara.
- The moisture content in the timber species were both less than the saturated fibre moisture content which is 20 % which indicates that the timber was well seasoned before the test.
- It was found that the maximum stress of Ara timber is higher than that of Apado, since ultimate stress of the material depends on its strength; hence Ara timber is of higher strength compared to Apado timber.
- The continuous equation for Ara timber was $\sigma = 47.882^{-0.009\lambda}$ and that of Apado timber was $\sigma = 17.211^{-0.007\lambda}$.
- The result of the reliability analysis shows that Apa and Apado timber have reliability index of 0.63 and 0.65 respectively for a service life of 50 years, assuming the design load limit is not exceeded.

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