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Characterization of Strength Properties of Nigerian Grown Timber Specie; Mansonia, Ilomba and Erun

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ABSTRACT
The need for local content in construction of building and engineering infrastructure is now a serious engineering challenge in Nigeria. Construction activities based on these locally available raw materials are major steps towards industrialization and economic independence for developing countries. The aim of this paper was to examine the Nigerian grown timber specie. The Mansonia, Ilomba and Erun specie are considered in the study. The specimens of structural sizes had been tested using three point bending loading test method as well as the oven dry method for the moisture content and density test in accordance with ASTM D 143 (2006). The study precisely assessed the static bending strengths, compression strengths and shear strengths parallel to the grain of the tested species. The strength properties of the tested timber species were generated and adjusted to 12% and 18% reference moisture contents to agree with the European and Nigerian reference moisture contents respectively. The characteristic strength of reference material properties of the tested species were estimated using 5 percentile values generated from EASYFIT statistical package. These 5 percentile values for the modulus of elasticity and bending strength properties enabled classification and grading of tested timber species into strength classes accordingly to EN 338 (2009). The Mansonia, Ilomba, and Erun were assigned to $_{D50}$, D_{35} and D60 respectively. The statistical test on the strength properties of the using Barlet's test at 5% level of significance shows no significant difference.

Keywords: Mansonia (Mansonia Altissima), Ilomba (Pycnanthus Angolensis), Erun (Erythrophleum ivorense), strength properties and strength classification.

I. INTRODUCTION

The need for local content in construction of building and engineering infrastructure is now a serious engineering challenge in Nigeria. This is because vast quantities of local raw materials, which must be processed and used for cost effective construction abound. 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. Structural timber is the timber used in framing and load-bearing structures, where strength is the major factor in its selection and use [1].

The strength and distribution of the material properties are linked with [2] recommendations. The modulus of elasticity and density are also of great importance for both ultimate and serviceability limit states for the design of timber structures. Modulus of elasticity is normally the most important parameter for strength grading of sawn timber [3]. The mean values of modulus of elasticity and the characteristic values of bending strength and density allow assigning timber species to a strength class of the International Strength Classification System [4] which is a European code of practice.

It is widely understood that employing this approach some risk of unacceptable structural performance must not be overruled [5] and [6]. The [7] which was developed using the CP 112 that was severally revised and replaced with BS 5268, that was also replaced by Eurocode 5 but NCP2 which is Nigerian Code of Practice for the timber structural design was never updated. Therefore, there is need for the review of NCP 2, to meet the current global best practices of limit state design as well as for the use of reliability approaches in structural timber design.

The objectives of the study to generate strength properties of Mansonia, Ilomba and Erun species, perform statistical test to ascertain if there is significant difference in the sources of the material using Barlet's test and assign the tested timber species into appropriate strength class in accordance with [4].

II. THEORETICAL CONSIDERATION

The bending strength of wood is usually presented as a modulus of rupture (**MOR**), which is the equivalent stress in the extreme fibres of the specimen at a point of failure assuming that the simple theory of bending applies. The **MOR** in three-point bending is calculated from Equation **1** where **MOR** is the modulus of rupture with units of N/mm^2, **P** is the load in N, **L** is the span in mm, **b** is the width in mm, and **d** is the depth in mm.

$$MOR = \frac{3PL}{2bd^2} \quad (1)$$

The modulus of elasticity in three point bending is calculated from Equation **2** where **MOE** is the modulus of elasticity in bending with units of N/mm^2, **P** is the load in N, at the limit of proportionality, **L** is the span in mm, Δ is the deflection in mm at the limit of proportionality, **b** is the width in mm, and **d** is the depth in mm.

$$MOE = \frac{PL^3}{4\Delta bd^3} \quad (2)$$

The compression parallel to the grain (**CPG**) and shear parallel to the grain (**SPG**) are calculated by Eqs **3** and **4** respectively where **A** is the cross-sectional area of the test piece.

$$CPG = \frac{P}{A} \quad (3)$$

$$SPG = \frac{P}{bd} \quad (4)$$

2.1 Density, bending, compression and shear strength at different moisture content

It is necessary to adjust strength values obtained at different moisture content levels to a constant moisture content level before any comparison of strength of wood species can be made. The strength property at moisture content **w** can be adjusted to strength at 12% moisture content using Equations 5 to 9.

1.1.1 Density of wood

The density can be adjusted to 12% moisture content (valid for moisture content of 12±3%) by the formula:

$$\rho_{12} = \rho_w \left[1 - \frac{0.5(w-12)}{100}\right] \quad (5)$$

where ρ_{18} is the density at 12% moisture content, ρ_w is the density at the moisture content w at the time of test [8].

1.1.2 Modulus of elasticity in static bending

$$E_{12} = \frac{E_w}{1+0.0143*(12-u)} \quad (6)$$

where E_{18} is the modulus of elasticity at 12% moisture content, and E_w is the modulus of elasticity at moisture content w at the time of test [8].

1.1.3 Bending strength

The ultimate strength in static bending (modulus of rupture) at moisture content w, can be adjusted to strength at 12% moisture content according to the formula:

$$f_{12} = f_{bw}(1 + \alpha(w - 12)) \quad (7)$$

where f_{12} is the strength at 12% moisture content, f_{bw} is the strength at moisture content w, and **α** is the correction factor for moisture content whose value shall be obtained from national standards. If the value of **α** is not available a factor of 0.04 can be used for rough estimation [9].

1.1.4 Ultimate stress in compression parallel to the grain

For compression parallel to the grain, the Equation for strength at 12% moisture content is given by:

$$\sigma_{12} = \sigma_w(1 + \alpha(w - 12)) \quad (8)$$

where σ_{12} is the compression strength at 12% moisture content, and σ_w is the strength at moisture content w. The moisture content correction factor for ultimate stress in compression parallel to the grain is denoted by α. The value of α is obtained from national standards; if its correct value is unknown, a value of 0.05 is then assumed for rough estimations [9].

1.1.5 Shear stress parallel to the grain

The equation used to estimate shear strength at 12% moisture content is given by:

$$\tau_{12} = \tau_w(1 + \alpha(w - 12)) \quad (9)$$

where τ_{12} is the shear strength at 12% moisture content, τ_w is the shear strength at moisture content w, and α is a correction factor equal to 0.03 for rough estimations [9].

III. MATERIALS AND METHODS

1.2 Wood sample collection

The Nigerian grown Mansonia, Ilomba and Erun species which are hardwood [7] were tested. Experimental procedure employed is accordance with [4] and [10] which provided methodical basis for the testing. The samples of timber species were obtained from Sabon Garin Zaria timber sheds. The tests were carried out in the laboratory of the Department of Civil

Engineering, Ahmadu Bello University. The set-up of the three bending test is shown in Figure 1 in accordance with [10].

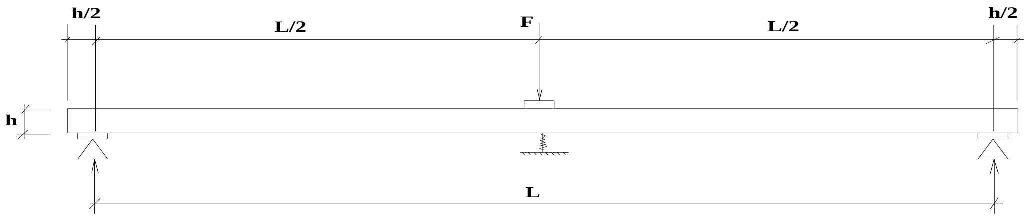

Figure 1: Three-point Bending Test Set-up (ASTM D 143, 2006)

1.3 **Preparation of test specimen**

The samples were naturally seasoned for three (3) months for them to attain equilibrium moisture content. The conditioning requirement is that prior to testing, specimens must be conditioned to (20±2)^{0}C and (65±5)% relative humidity. The mass of the specimen changes by less than 0.1% within at least 24 hour, when it undergoes conditioning and it is considered that the moisture content is at equilibrium with the ambient condition. The experimental tests were conducted in the strength of material laboratory of the department of civil engineering, Ahmadu Bello University, Zaria. The samples and dimensions of test specimen as well as the strength properties determined are shown in Table 1.

Table 1: Number of samples and dimensions of test specimens

Test	**Mansonia**	**Mansonia,**	**Erun**	**Sample Dimensions**		
	No. of Specimens	No. of Specimens	No. of Specimens	Width (mm)	Depth (mm)	Length (mm)
Bending	40	40	40	20	20	300
Compression	40	40	40	20	20	60
Shear	40	40	40	20	20	20
Total	120	120	120	-	-	-

1.4 **Determination of strength properties of the wood samples**

Immediately after preparation of test specimens, all strength properties were determined on a Universal (Multiple) 50 ton Avery Machine. The straining rate for Modulus of Elasticity (**MOE**) and Bending Strength (**MOR**) was 0.26 in/min while shear and compression were each strained at the rate of 0.025 in/min. After loading of each sample test, the load that caused each wood sample to fail was recorded and the sample was immediately placed in a polythene bag to prevent moisture content changes.

The moisture content of each wood sample was immediately determined after the strength test. Small portions of wood samples (2 cm×2 cm×2 cm) near the portion of rupture (of test pieces for **MOR**) were used to determine the moisture content. However, the whole test piece for compression and shear strengths parallel to the grain was used for moisture content (**MC**) determination. The moisture content of each specimen of a particular test conducted was recorded with the results of the particular test to which it refers. The formulae for the various strength properties can be determined using Equation 1 to 9.

1.5 **Characteristic strength classification**

Characteristic strength value, f_k which is defined as the 5% fractile value of the strength property is being used for strength classification of solid timber [2]. The percentile values were generated using EASYFIT statistical package. The characteristic strength value, f_k is determined using the formula;

$$f_k = 1.12f_{0.05} \qquad (10)$$

The values derived by the equation (10) were then compared with the standard ones from EN [4] and a corresponding strength class was given to a certain timber piece. The [4] strength classification defines the minimum characteristic bending strength, modulus of elasticity and density for each class. The classification of the species into various hardwood strength classes was made using the characteristic bending strength. The limiting values of the characteristic bending strength from [4] are presented in Table 2.

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Table 2: Limiting Values of Characteristic Bending Strength (EN 338)

Strength Class	**D18**	**D24**	**D30**	**D35**	**D40**	**D45**	**D50**	**D60**	**D70**
Bending Strength (N/mm^2)	≤18	>18.0 and ≤24.0	>24.0 and ≤30.0	> 30.0 and ≤ 35.0	> 35.0 and ≤ 40.0	> 40.0 and ≤ 45.0	> 45.0 and ≤ 50.0	> 50.0 and ≤ 60.0	> 60.0

1.6 **Analysis of Variance of Timber Properties**

Analysis of variance was used with confidence in this study, to investigate whether any significant difference exist in the material properties between and within timber species. In this thesis, the analysis of variance was employed using Barlet's test. It is required that, the variance of material property of the considered samples are equal. The equality of this variance can be checked using Bartlet's test. In this test, a null hypothesis was tested on the equality of variance of material property of the considered samples. The hypotheses employed were as follows:

H0: The variance is identical

Ha: At least one of the variance is different from another.

IV. RESULTS AND DISCUSSION

1.7 **Mean strength properties of the timber species**

The mean values of the density for the Mansonia, Ilomba and Erun were found to be 742.95kg/m^3, 526.35kg/m^3 and 937.45kg/m^3 respectively with corresponding coefficient of 0.05, 0.07 and 0.06 as presented in Table 3. The COV show that there is less variability in the values of density within the specimens of each species. The values of density agree with general range of timber density as published in [11] and [12] who recorded variation in density between 160 kg/m^3 to 1250 kg/m^3 among timber species.

The mean values of Modulus of elasticity for the Mansonia, Ilomba and Erun were found to be 10215.60N/mm^2, 8185.50 N/mm^2 and 14752.50N/mm^2 respectively with their corresponding coefficients of variations of 0.07, 0.11 and 0.15 as presented Table 2. The high values of modulus of elasticity for all the species indicate high elasticity of the species. This implies that deformation produced is completely reasonable [13].

The computed values of bending for the Mansonia, Ilomba and Erun were found to be 52.10N/mm^2, 37.90N/mm^2 and 72.60N/mm^2 respectively, with their corresponding coefficients of variation of 0.17, 0.20 and 0.21 as presented in Table 2. The high values of bending strength indicate high load carrying capacity of the species in bending and are the maximum moment borne by the specimens [1].

The values of compression parallel to grain for the Mansonia, Ilomba and Erun were found to be 31.45N/mm^2, 25.35N/mm^2 and 34.50N/mm^2 respectively, with their corresponding coefficients of variation of 0.14, 0.16 and 0.20 as presented in Table 2. These values of shear parallel to grain agree with the range of 3N/mm^2 to 15N/mm^2 [14].

The values of shear parallel to grain for the Mansonia, Ilomba and Erun were found to be 5.25N/mm^2, 3.60N/mm^2 and 6.20N/mm^2 respectively, with their corresponding coefficients of variation of 0.15, 0.18 and 0.20 as presented in Table 2. These values of shear parallel to grain agree with the range of 3N/mm^2 to 15N/mm^2 [14].

Table 3: Mean Strength properties of the timber species at (w) moisture content

Species	**Density (kg/m^3)**	**Modulus of elasticity (N/mm^2)**	**Bending strength (N/mm^2)**	**Compression Parallel to grain (N/mm^2)**	**Shear Parallel to grain (N/mm^2)**	**Moisture content, w (%)**
Mansonia	742.95 (0.05)	10215.60 (0.07)	52.10 (0.17)	31.45 (0.14)	5.25 (0.15)	21.15
Ilomba	526.35 (0.07)	8185.50 (0.11)	37.90 (0.20)	25.35 (0.16)	3.60 (0.18)	17.12

Erun	937.45 (0.06)	14752.50 (0.15)	72.60 (0.21)	34.50 (0.20)	6.20 (0.20)	19.34

Note: values in brackets are coefficient of variation

1.8 Adjusted strength properties of the timber species

The strength properties of the timber species were adjusted to 12% reference moisture content Equations (5 to 9). These values were also adjusted to 18% moisture content based on [7] using interpolation. The adjusted values of the strength properties of the timber species are presented in Table 4.

The results revealed that there is significant drop in density with decrease in moisture content for all the species and this implies that moisture content has significant effect in the density of timber as it affects the strength properties of timber [15] and [16].

The results revealed that the values of modulus of elasticity decrease with increment in moisture content for all the species. This implied that moisture content has much influence in the modulus of elasticity of timber, which also predetermines the end-use timber material, especially the structural timber [17].

There is very significant reduction in bending strength values as the moisture content increases for all the species. It is clear from this result, that among the reference material properties of timber, that is density, modulus of elasticity and bending strength, moisture variation has more effect on bending strength.

Table 4: Mean adjusted strength properties of the timber species to (w_i) moisture content

Adjusted parameters	Mansonia		Ilomba		Erun	
Moisture content (w_i)	12%	18%	12%	18%	12%	18%
Density (kg/m^3)	708.96	731.25	512.88	528.67	903.05	931.17
Modulus of elasticity (N/mm^2)	11753.48	10697.47	8832.16	8083.774	16482.54	15040.71
Bending strength (N/mm^2)	71.1686	58.66	45.66	36.57	93.92	76.49
Compression Parallel to grain (N/mm^2)	45.84	36.40	31.84	24.23	47.16	36.81
Shear Parallel to grain (N/mm^2)	6.69	5.75	4.15	3.50	7.57	6.45

1.9 Mean Strength Characteristics Strength and Classification

The characteristic modulus of elasticity and bending strength defined as the 5% fractile, for the tested timber species under investigation were analysed and results presented in Table 5. The percentile values were generated using EASYFIT statistical package. The computed characteristic values of density, modulus of elasticity or bending strength is being used in assigning the tested timber species into the appropriate strength class as stipulated in [4].

Table 5: Characteristic strength values for reference properties of the species

Timber species	Density (kg/m^3)		Modulus of elasticity (N/mm^2)		Bending strength (N/mm^2)	
	$\rho_{0.05}$	ρ_k	$E_{0.05}$	E_k	$f_{0.05}$	f_k
Mansonia	668.93	749.20	9884.30	11070.42	46.76	52.37
Ilomba	427.07	478.32	7246.70	8116.30	31.62	35.41

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Erun	701.36	785.52	12759.00	14290.08	58.67	65.71

The strength classification of the species into various hardwood strength classes was made using the characteristic bending strength and this governed by the lowest strength class applicable to one of these properties. The tested timber specie; Mansonia, Ilomba, and Erun were assigned to D50, D35 and D60 as presented in Table 6.

Table 6: Proposed allocation of tested species to EN 338

Timber Species	**Group strength NCP2 (1973)**	**Characteristic Bending Strength(N/mm^2)**	**EN 338 Strength Class**
Mansonia	N_3	52.37	D50
Ilomba	-	35.41	D35
Erun	N_2	65.71	D60

1.10 **Analysis of Variance of Timber Properties**

The Bartlet's test results for the strength properties of the species are presented in Table 7. It could be observed that the computed p-values for all the tested species are greater than the significance level α=0.05, hence the null hypothesis H_0 could not be rejected. The risk of rejecting the null hypothesis H_0 while it is true is high for all the tested species. For example, Erun specie under density-values has the highest risk value of 98.6% to reject the null hypothesis. This implies that there is high equality of variance of Erun species for density test results. However, the samples of each species considered for test were not affected by the difference in the sources of the material. Hence, the data can be used for the classification of the tested timber species in to appropriate strength class in accordance with [4].

Table 7: Bartlet's test results for strength properties of the species at α=0.05

	P-Values			
Timber Species	Density	MOE	Bending strength	Decision
Mansonia	0.207	0.606	0.500	Accept
Ilomba	0.962	0.524	0.405	Accept
Erun	0.986	0.785	0.670	Accept

V. CONCLUSION

i. The strength properties i.e. density, modulus of elastity, bending strength, shear and compresion parallel to the grain of the three-selected Nigerian timber species were generated experimentally and the species were assigned to different strength classes in accordance with EN 338 (2009).

ii. The samples of each species considered for statistical test (Bartlet's Test**)** were not affected by the difference in the sources of the material. Hence, the data were used for the classification of the timber species in to appropriate strength class in accordance with EN 338 (2009).

iii. The classification of the tested species into various strength classes was made using the generated characteristic strength properties based on the European solid timber strength classification (EN 338, 2009). The species; Mansonia, Ilomba, and Erun are assigned to D50, D35 and D60.

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