

Evaluation of Some Wood Properties of Nigeria Timber Using Four – Point Bending Test

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ABSTRACT

This study presents a relationship between developed physical and mechanical properties of Nigerian grown Teak (*Tectona grandis*) and Ebony ((Kanyan) *Diospyros mespiliformi*) timber. This is in order to determine the full potential for their utilization. Lack of knowledge on mechanical properties of structural timber has lead to structural application of unnecessarily high safety margins in timber design through estimation of strength properties. This usually leads to over-designing or under-designing, resulting into too strong or too weak timber structures respectively. Wood specimen for the test was prepared and determined in accordance with EN 13183-1 (2002) and EN 408 (2003). The mechanical properties were determined using three point bending test in accordance with EN 408 (2003). The mean moisture content, oven dry density, bulk density, bending strength, and modulus of elasticity were found to be 25.58% (MC), 695.88 Kg/m³ (DD), 872.98Kg/m³ (BD), 70.31N/mm² (BS) and 10981.29N/mm² (MOE) respectively for Teak (*Tectona grandis*) and 30.58% (MC), 768.56 Kg/m³ (DD), 998.66Kg/m³ (BD), 75.71N/mm² (BS) and 10937.90 N/mm² (MOE) respectively for Ebony ((Kanyan) *Diospyros mespiliformi*). A relationship between the properties was determined using regression equation. The equation developed from the model for Teak (*Tectona grandis*), the coefficients of determination (R^2) for the regression model were ($R^2 = 0.954$) and ($R^2 = 0.903$) for MOE and BS for dry density relationship. ($R^2 = 0.848$) and ($R^2 = 0.941$) for MOE and BS for their bulk density relationships and BS and MOE ($R^2 = 0.951$). The best relationship was between DD and MOE ($R^2 = 0.954$). The equation developed from the model for Ebony ((Kanyan) *Diospyros mespiliformi*), the coefficients of determination (R^2) for the regression model were ($R^2 = 0.893$) and ($R^2 = 0.894$) for MOE and BS for dry density relationship. ($R^2 = 0.756$) and ($R^2 = 0.652$) for MOE and BS for their bulk density relationships and BS and MOE ($R^2 = 0.813$). The best relationship was between DD and MOE ($R^2 = 0.893$).

Keywords: Physical Properties, Mechanical Properties, Simple Linear Regression, Nigerian timber, Four Point Bending Test

Aims Research Journal Reference Format:

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1. INTRODUCTION

1.1 General

Timber structure declined in number from 50 years ago when large trees became scarce and concrete technology became more reliable. However the modern materials, concrete and steel, have not been without their own problem and since the middle 70's much research effort has been undertaken to utilize smaller wood sections to build large structures.

Wood as natural lingo – fibrous material produced by tree has been one of the earliest structural materials discovered by man it exhibits a lot of variations in properties in terms of durability, strength, density. Due to this diversity in nature and characteristics of wood, exploitation of trees for structural and construction purposes was selective and limited. Nolan, (1994) affirm that despite the abundance of wood resource, wood has been underutilized with a view that it is a material to be avoided due to its perceived unreliability, variability and unknown properties

Timber is lighter to transport, easy to handle and work with on site, and has a natural empathy with the landscape. Its advantages in bridges is recognized by quite a large number of emerging countries, such as the west African territories, notably Ghana (Freedman et al., 2002).

Teak (*Tectona grandis*) is a medium-weight timber, according to Louppe, (2005) Teak heartwood is rated as durable to very durable. The wood is often dull yellowish when freshly cut but it turns golden brown or sometimes dark greyish-brown after exposure, often streaked greyish or blackish (Louppe, 2005). Teak (*Tectona grandis*) is a tropical hardwood species highly prized by the wood industry due to its superior mechanical and physical properties, as well as its pleasing aesthetic appearance (Kjaer et al, 1999; Sanwo, 1987, 1990). It is commonly used for all sorts of house construction and structural works, high class furniture, railway sleepers, flooring veneers, decorative structural works, luxury cabinet-work, frames (doors and windows), and joinery with solid wood, parquet flooring, staircases, carpentry, garden furniture, bridges and other construction in contact with water or the ground, electricity and telephone poles, fence posts, railcars, barrels even corrosive ones, turnery and sculpturing (Louppe, 2005).

Ebony (*Diospyros* spp.) is species of tropical hardwood trees favored for their hard and beautiful wood. Only the black or brown heartwood is used commercially. There are more than 300 species of African Ebony. Ebony is used for heavy flooring, interior trim, ship building, vehicle bodies, furniture, cabinet making, musical instruments, precision equipment, turnery, carvings, knife-handles, furniture; inlay work, wall paneling, golf club heads, and brush backs (Obeng, 2010 a; Hatchards, 1991). The need for local content in construction of engineering infrastructure is now a major 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 (Aguwa and Sadiku, 2011). Therefore, to determine the full potentials of the timber species for utilization structurally, this study investigates the relationship among the properties (physical and mechanical properties).

2. MATERIALS AND METHODS

2.1 Materials

Samples possessed structural sizes that are used in real timber construction. They are common types of timber available from the local saw-mill of Sabo Gari timber shed in Zaria Kaduna State and were taking to the concrete laboratory of Ahmadu Bello University Zaria.

2.1.1 Preparation of Test Specimens

The specimens were conditioned in a conditioning room of the laboratory at a temperature of $(20 \pm 2)^{\circ}\text{C}$ and a relative humidity of $65 \pm 5\%$ for 48 hours (EN 13183-1(2002) and EN 408 (2003). The specimen for determination of physical properties was prepared in accordance with EN13183-1 (2002) and EN 408, 2003 (E). Slices of cross sections of $50\text{mm} \times 75\text{mm} \times 100\text{mm}$ each cut from failed timber beam were prepared for the moisture content (MC) and density determination. A total of number of 20 slices of the selected timber species were prepared for the MC and the density determination.

The specimen for determination of Mechanical Properties was prepared in accordance with EN 408, 2003. For static Bending Strength (BS) and Modulus Elasticity (MOE) tests, a total number of 40 specimens for the selected timber specie were prepared with the aid of sawing and milling machines. The timber beams of average size of 50mm×75mm×1200mm. Small steel plate was inserted between the specimen and point of machine grip as well as the supports before loading in order to minimize the local indentation.

2.2 Methods

2.2.1 Physical Properties of Timber

2.2.1.1 Moisture Content

The green moisture contents were determined in accordance with EN 13183-1(2002) and EN 408 (2003). The moisture content 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 $103 \pm 2^{\circ}\text{C}$ until constant weight, i.e., less 0.1% change in weight for twenty four (24) hours after the last measurement. The samples were cooled and weighed. The initial and final mass of each slice were recorded and the moisture content was calculated using Equation 1.

$$MC = \frac{m_i - m_o}{m_o} \times 100 \quad (1)$$

Where; m_i is the initial mass, m_o is the final mass and MC is the Moisture Content of test slice. The MC of specie was considered to be the mean values of 20 slices.

2.2.1.2 Density

Density of timber is defined as a timber's mass per unit volume measured at particular moisture content. The density of the slices was determined in accordance with (EN 408, 2003). The volume of the sample was obtained by measuring the dimensions; the dry density calculated using Equation 2 and bulk density using Equation 3.

$$\text{dry density } \rho = \frac{\text{oven dry Mass}}{\text{Volume at test}} = \frac{m_o}{V} \dots \quad (2)$$

$$\text{Bulk density } \rho_b = \frac{\text{Initial Mass}}{\text{Volume at test}} = \frac{m_i}{V} \quad (3)$$

2.2.2 Mechanical Properties of Timber

Test was carried out under temperatures of $(20 \pm 2)^{\circ}\text{C}$ and relative humidity of $(65 \pm 5) \%$ as specified in EN 13183-1(2002) and EN 408 (2003). The bending strength tests as specified by EN 408 (2003) were carried out on 40 specimens from each of the selected timber specie. Each specimen was tested on the Avery Denison Universal Testing Machine. The central deflection of each test piece was measured relative to the end supports by means of a dial gauge graduated at 0.01mm. The moduli of elasticity were obtained from the least square lines of the load-deflection plots developed for each specimen. Deflection was measured using a dial gauge and failure load recorded. This was used to calculate the bending strength and the Modulus of Elasticity MOE.

Where $E_{m,g}$ is the global modulus of elasticity 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 $(F_2 - F_1)$. 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).

2.3 Data Analysis

The general statistical description such as mean value, standard deviations and the coefficient of variation for timber species were determined. A simple linear regression analysis was used to determine the extent of response of a variable Y to a change in variable X as in Equation 6.

$$Y_1 = b_0 + b_1 X_i + E_1 \quad (6)$$

The coefficient of determination “R²” was used to verify the suitability of the regression equations for each observation. This index measures the proportion of the variation in the dependent variable (Y) which is explained by variation in the independent variable (X).

3. RESULTS AND DISCUSSION

3.1 Experimental Results of Properties of Timber Species

3.1.1 Moisture Content

The mean values of the moisture content, dry density, bulk density, bending strength and modulus of elasticity results for three point and four point test for the timber species are presented in Table 1.

Table 1:

Properties	Timber Species	Mean	Std (s)	COV
Moisture Content (%)	<i>Tectona grandis</i>	25.58	3.34	0.131
	<i>Diospyros Mespiliformis</i>	30.58	0.92	0.030
Dry Density (kg/m ³)	<i>Tectona grandis</i>	695.88	42.84	0.062
	<i>Diospyros Mespiliformis</i>	768.56	91.20	0.119
Bulk Density	<i>Tectona grandis</i>	872.98	49.56	0.057
	<i>Diospyros Mespiliformis</i>	998.66	90.03	0.090
Bending Strengths (N/mm ²)	<i>Tectona grandis</i>	70.31	11.20	0.159
	<i>Diospyros Mespiliformis</i>	75.71	6.72	0.089
Modulus of Elasticity (N/mm ²)	<i>Tectona grandis</i>	10981.29	1493.60	0.136
	<i>Diospyros Mespiliformis</i>	10937.90	1741.30	0.159

Mean Value of the Timber Properties

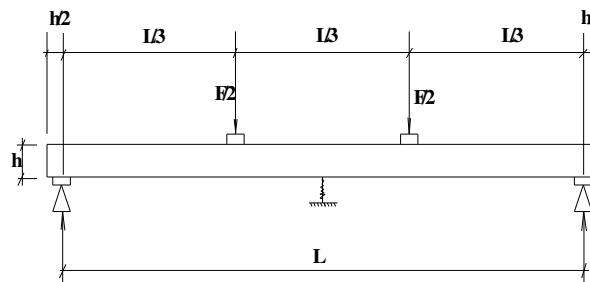


Figure 1: Dimensional Arrangement of the Four point Bending Test (EN 408, 2003)

2.2.2. 1 Bending Strength

This show the highest stresses in the outer most fibres of the wood when the beam breaks under a load. The bending strengths were then computed from the Equation 4 for the four point bending test.

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

Where a, is the distance between one load and the nearest support in mm, b is the width of specimens, h is depth of specimens, W is the section modulus of beam in mm³.

2.2.2. 2 Modulus of Elasticity

The modulus of elasticity was calculated from the values obtained at the point of failure recorded during tests for Bending Strength. This provided for the calculations of deflection which was used to estimate the Modulus of elasticity MOE using the Equation 5 for the four point bending test.

$$E_m = \frac{L^3(E_2 - E_1)}{4.7bh^3(W_2 - W_1)} \dots \quad (5)$$

The mean moisture contents values of the four point sample for the Teak (*Tectona grandis*) and Ebony (*Diospyros Mespiliformsis*) are 25.58%, and 30.58% respectively, with the corresponding standard deviation and coefficients of variation (COV) (measure of dispersion) of 3.34 and 0.92 and 0.131 and 0.030 respectively. The highest moisture content was found in Kanya (*Diospyros Mespiliformsis*) which is 30.58%. The result shows little variability in Kanya (*Diospyros Mespiliformsis*) compare to other species.

3.1.2 Wood Density

These are expressed in terms of oven dry and bulk densities. The mean oven dry density (ρ_d) values for Teak (*Tectona grandis*) and Ebony (*Diospyros Mespiliformsis*) are 695.88kg/m³, and 768.56kg/m³ respectively. Also, Standard deviations(s) were 42.84 and 91.20 with the corresponding coefficients of variation (COV) of 0.062 and 0.119 respectively. This also shows that Teak has little variability in their densities. From the test result it is evidence that Ebony (*Diospyros Mespiliformsis*) has the highest density value of 812.81kg/m³. Nellie, (2013) reported air dry density of Teak to be 650kg/m³ which is a little less than the one determined in this study. Hossain and Abdul Awal (2012) and Junji and Yoshitomo (2011) quoted a air dry density value of Teak (*Tectona grandis*) as 665kg/m³ and 0.64g/cm³. The mean density values, based on oven-dry weight and volume were 480, 556 and 650 kg m⁻³ for 15, 20 and 25-year old *Tectona grandis* wood respectively from the findings of Izekor, 2010. Though this findings is not subject to age it also show that the test result for *Tectona grandis* is within the range of past findings.

3.1.3 Bulk density Test

The mean bulk density (ρ_b) values for Teak (*Tectona grandis*), and Ebony (*Diospyros Mespiliformsis*) are 872.98kg/m³ and 998.66kg/m³ respectively. Also, the Standard deviations(s) of 49.56 and 90.03 with the corresponding coefficients of variation (COV) were 0.057 and 0.09. Valero et al., 2005 reported wood density for 20-year-old teak in plantations in western Venezuela to vary from 0.54 to 0.67.

3.1.4 Bending Strength and Modulus of Elasticity Result

The respective values of bending strength for Teak (*Tectona grandis*) and Ebony (*Diospyros Mespiliformsis*) are 70.31N/mm² and 75.71N/mm². The Standard deviations (s) and the corresponding coefficients of variation are shown on the Table 1. The computed values of the Moduli of Elasticity are 10981.29 N/mm² and 10937.90 N/mm² obtained for the four point bending test for Teak (*Tectona grandis*) and Ebony (*Diospyros Mespiliformsis*) respectively. The standard deviation (s) and coefficient of variation shown on Table 1

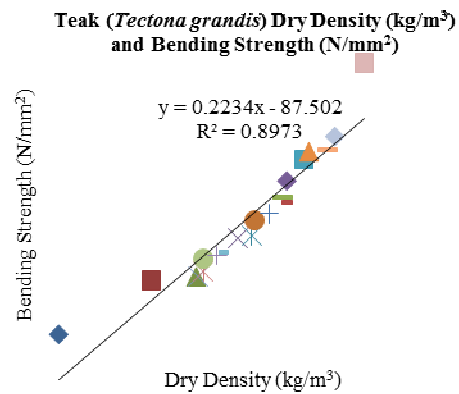


Figure 3: Relationship between the Dry Density and the Bending Strength

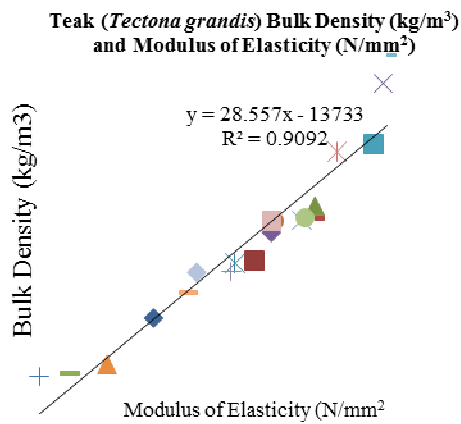


Figure 4: Relationship between the Bulk Density and the Modulus of Elasticity

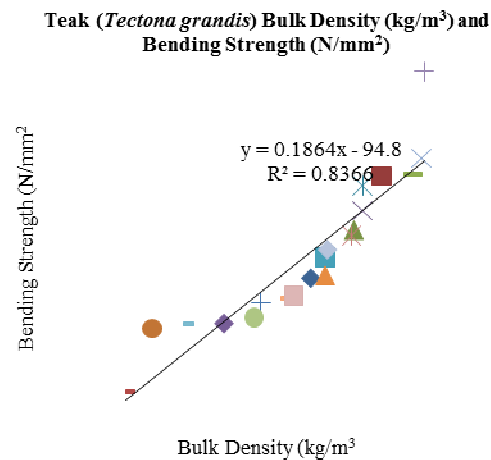


Figure 5: Relationship between the Bulk Density and the Bending Strength

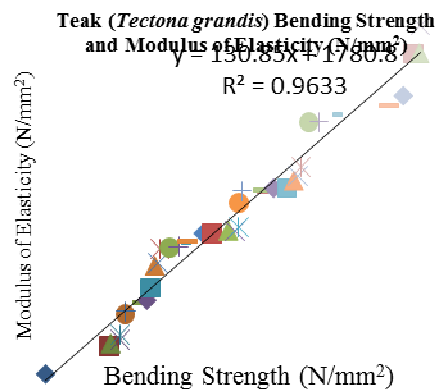


Figure 6: Relationship between the Bending Strength and the Modulus of Elasticity

The equation developed from the model for Ebony ((Kanyan) *Diospyros mespiliformi*) is shown on Table 3. The coefficients of determination (R^2) for the regression model were ($R^2 = 0.893$) and ($R^2 = 0.894$) for MOE and BS for dry density relationship, ($R^2 = 0.756$) and ($R^2 = 0.652$) for MOE and BS for their bulk density relationships and BS and MOE ($R^2 = 0.813$). The best relationship was between DD and MOE ($R^2 = 0.893$). Both density and knots are correlated to strength and stiffness, but while density demonstrates a stronger correlation to stiffness than strength, knot parameters are more correlated to strength (Kliger et al. 1995). This is also indicated by the fact that density is significantly more important in predicting MOE and DD and BS ($R^2 = 0.894$) followed by BS and MOE ($R^2 = 0.813$) then BD and MOE ($R^2 = 0.756$) while the least was between BD and BS ($R^2 = 0.652$).

Graphical representation showing the relationship existing between Dry density (DD) and Modulus of elasticity (MOE), Dry density (DD) and Bending Strength (BS), Bending Strength (BS) and Modulus of elasticity (MOE), Bulk density (BD) and Modulus of elasticity (MOE) and Bulk density (BD) and Bending Strength (BS) are presented as scattered diagram (Fig. 6-11)

Table 3: Simple Linear Regression between the Properties of Ebony ((Kanyan) *Diospyros mespiliformi*)

Properties	Equation Models	R	R ²
Dry Density and Mechanical Properties	BS = 0.067x + 21.39	0.946	0.894%
	MOE = 14.71x + 66.2	0.945	0.893%
Bulk Density and Mechanical Properties	BS = 0.102x -35.50	0.807	0.652%
	MOE = 24.17x + 13.769	0.869	0.756%
BS and MOE	MOE = 190.3x - 2008	0.902	0.813%

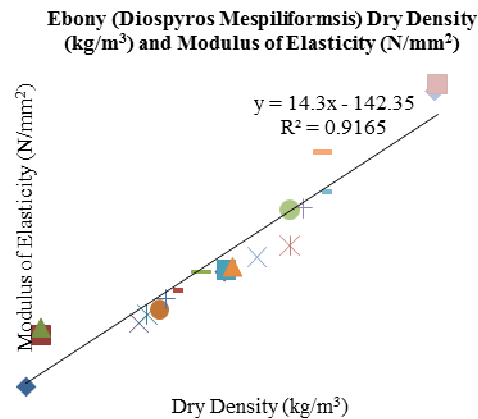


Figure 7: Relationship between the Dry Density and the Modulus of Elasticity

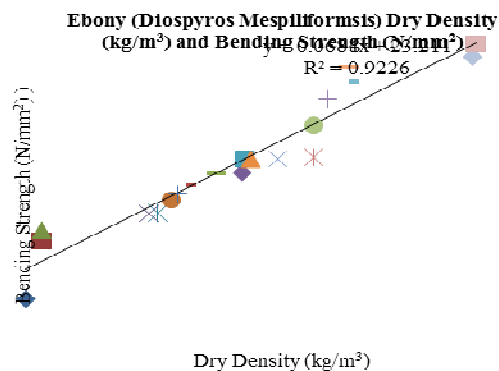


Figure 8: Relationship between the Dry Density and the Bending Strength

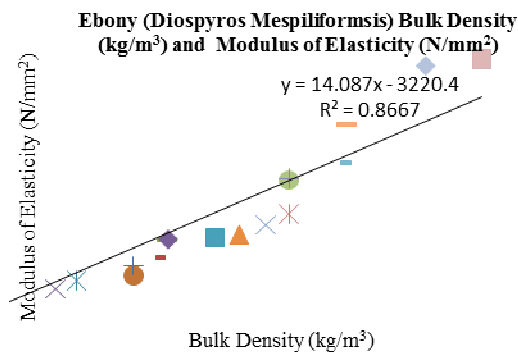


Figure 9: Relationship between the Bulk Density and the Modulus of Elasticity

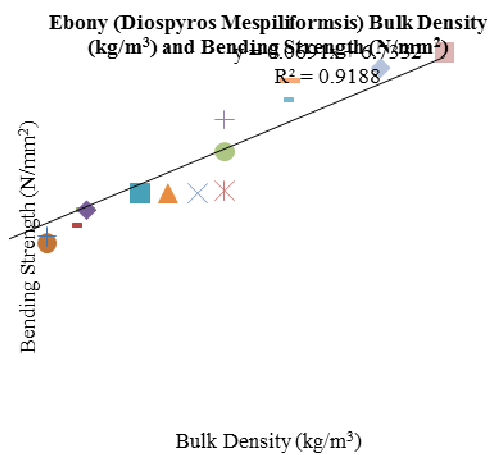


Figure 10: Relationship between the Bulk Density and the Bending Strength

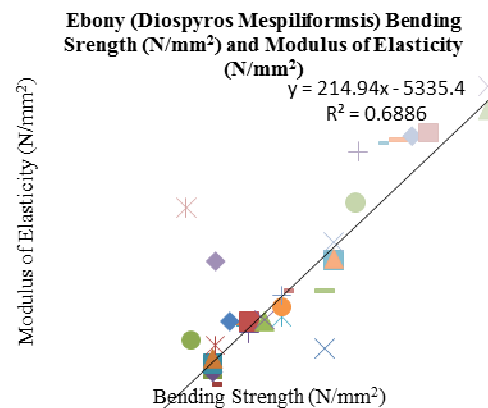


Figure 11: Relationship between the Bending Strength and the Modulus of Elasticity

4. CONCLUSIONS

Wood density and bending strength have a close affinity with a number of other properties which have great significance in successful timber utilization. This study presents a relationship between developed physical and mechanical properties of Nigerian grown Teak (*Tectona grandis*) and Ebony ((Kanyan) *Diospyros mespiliformi*) timber. The best relationship was between DD and MOE ($R^2 = 0.954$) for Teak (*Tectona grandis*). While for Ebony ((Kanyan) *Diospyros mespiliformi*) timber the best relationship was between DD and MOE ($R^2 = 0.893$). The result thus shows that density has a strong positive correlation with the mechanical properties of the timber species and can therefore be use in predicting its strength properties.

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