THREE - POINT BENDING TEST EVALUATION OF SOME WOOD PROPERTIES OF EBONY (*Diospyros mespiliformis*) IN NIGERIA GROWN TIMBER

***, I. O. SHOLADOYE [1], I. ABUBAKAR [2] and S. T. IJIMDIYA [3]**

Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria

[kemtalsi@yahoo.com, 08036162960]

ABSTRACT

This study presents a relationship between developed physical and mechanical properties of Nigerian grown Ebony ((Kanyan) Diospyros mespiliformi) timber. This is in order to determine the full potential for its utilization. Wood specimens for the test were 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 ASTM D193 (2000). The mean moisture content, oven dry density, bulk density, bending strength, and modulus of elasticity were found to be 30.52% (MC), 768.56 Kg/m^3 (DD), 1060.89 Kg/m^3 (BD), 72.55 N/mm^2 (BS) and 11722.78 N/mm^2 (MOE) respectively. A relationship between the properties was determined using regression equation. The best relationship was between DD and MOE (R^2 =0.893) 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 relationship observed was between BD and BS (R^2 =0.652).

Keywords: Physical Properties, Mechanical Properties, Simple Linear Regression Nigerian Timber, Three-point bending test, Ebony (Diospyros mespiliformis).

1.0 INTRODUCTION

Ebony (*Diospyros* spp., family Ebenaceae) is species of tropical hardwood trees favored for their hard and beautiful wood. Only the black or brown heartwood is used commercially. The best commercial Ebony comes from India, Madagascar, Nigeria, Zaire, and the Celebes Islands (Hatchard, 1999). The wood of the Ebony is so dense, rapidly dulls tools used for working, sawing, or turning it. Even termites will bypass a fallen Ebony log. This density contributes to ebony's commercial appeal, as it results in a finish that takes a high polish, which adds to its beauty. The properties, attributed to ebony through both fact and myth, have been recognized for many generations. Today, Ebony is used for many purposes, including tool and knife handles, furniture, inlay work, wall paneling, golf club heads, and musical instruments (Hatchard, 1999). Although there are many species of ebony, only a few are of commercial-grade while its demand far exceeds the supply. Ebony (*Diospyros mespiliformis*) is more widespread and abundant than other Ebonies, but the heartwood is more brownish than blackish in colour, thus limiting its appeal (Hatchards, 1991).

According to Leonardo, (2008), timber is the oldest known building material capable of transferring both tension and compression forces - making it naturally suited as a beam element. It has a very high strength to weight ratio, it is relatively easy to fabricate and join, and it often out-performs alternative materials in hazardous environments and extremes of temperature (including fire).

Furthermore Leonardo, (2008), noted that timber does not corrode, while many species, if detailed correctly, can be very durable. The unique properties of timber have made it a cornerstone contributor to the advance of civilization and development of society as it known today.

Timber production in Nigeria is not proportional to its potential. Though, it's under-utilization is partly as a result of the lack of information about the wood properties of Nigerian grown and the great number of timber species. The determination of important wood properties allows construction activities using vast quantities of locally available raw materials which are towards major steps in industrialization and economic independence for developing countries that are emphasizing more interest in timber.

Structural timber is the timber used in framing and load-bearing structures, where strength is the major factor for its selection and use. To use timber in structures one need to grade the timber (that is, beams from a timber species that fulfils some predefined visual or machine measured characteristics are assigned to appropriate strength class for use in practice). The provisions of data on the mechanical and physical properties of these species are of great significance for their incorporation and use.

The importance of the relationship between the properties to utilization of a species cannot be overemphasized. Therefore, in order to determine the full potentials of Ebony (Kanyan) (*Diospyros mespiliformis*) for structural application, this study investigates the relationship among the properties.

2.0 MATERIALS AND METHODS

2.1 Materials

Ebony (Kanyan) (*Diospyros mespiliformis*) are processed into structural sizes that are used in real timber construction. The timber materials used were selected in order to obtain test samples without too high a variation in strength which could arise from different growth conditions. They were obtained from a local saw-mill in Zaria Kaduna State and were taken to the concrete laboratory of Ahmadu Bello University Zaria for tests. The timber specimen were subjected to temperatures of (20+2) °C and relative humidity of (65 +5) % as specified in EN 408, 2003 (E) in the concrete and materials laboratory for three weeks in order to condition them to the laboratory environment. The specimens were then sawn into the regular test piece sizes as required by the relevant specification.

2.1.1 Preparation of Test Specimens

2.1.1.1 Physical Properties

The specimens for determination of physical properties were prepared in accordance with EN13183-1 (2002) and EN 408, 2003 (E). Slices of cross sections of 50mm × 75mm × 50mm each cut from failed timber beam were prepared for the moisture content (MC) and density determination. A total number of 20 slices of the selected timber species were prepared.

2.1.1.2 Mechanical Properties

The specimens for determination of mechanical properties were prepared in accordance with in EN 408, 2003 (E). For static bending strength and modulus of elasticity (MOE) tests (Plate 1), 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 were obtained.

Plate 1: Laboratory Arrangement of the Three Point set up

2.2 Methods

2.2.1 Physical Properties of Timber

Physical properties are the quantitative characteristics of wood and its behaviour to external influences other than applied forces. This includes MC and density (Winandy, 1994). The specie moisture content was determined in accordance with EN 13183-1(2002) and EN 408, 2003 (E)

2.2.1.1 Moisture Content of Timber

The moisture content of each slice was determined by first measuring its initial mass before drying using electronic digital weighing balance. The test slices were then oven dried at a temperature of 103 ± 2^{0}C until constant weight, that is, less than 0.1% change in weight for twenty four (24) hours. The samples were cooled and weighed. The initial and final mass of each slice were recorded and the moisture content calculated with the following formula as given in Equation 1.

$$MC = \frac{m_i - m_0}{m_0} x100 \qquad (1)$$

where

m_i = the initial mass

m_o = final mass and

MC = Moisture content of test slice.

The MC of the specie was considered to be the mean values of 20 slices.

2.2.1.2 Density

Density is defined as a tree's mass per unit volume measured at particular moisture content. According to Elevitch, (2006), wood density is an important wood property for solid woods. EN 13183-1 (2002) indicated that density is a general indicator of cell size and is a good predictor of strength, stiffness, ease of drying.

2.2.1.2.1 Dry density:

The density of slice was determined in accordance with EN 408 (2003). All test specimens were weighed to obtain the green weight and the volume of the samples were calculated by first measuring the dimensions of the samples and the weight using an electronic balance before being placed in the furnace to oven dry at a temperature of 103+ 2^{0}C to constant weight so as to obtain the dry weight. This was achieved using Equations (2) and (3)

$$dry\ density = \frac{oven\ dry\ Mass}{Volume\ at\ test} \qquad (2)$$

$$\rho_d = \frac{m_o}{v} \qquad (3)$$

2.2.1.2.2 Bulk Density:

Bulk density was obtained using green volume and initial weight of each specimen before oven drying according to Equations (4) and (5).

$$Bulk\ density = \frac{Initial\ Mass}{Volume\ at\ test} \qquad (4)$$

$$\rho_b = \frac{m_i}{v} \qquad (5)$$

2.2.2 Mechanical Properties of Timber

The mechanical properties of wood are an expression of its behavior under applied forces. 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 (Quintanar, et al, 1997).

The Universal Testing Machine was used to determine deflection using a dial gauge while the failure load was recorded. This was used to calculate the bending strength and the Modulus of elasticity (MOE).

Longitudinal MOE, one of the basic properties of wood, is usually obtained through a standard three-point bending test, and calculated from the deformation of wood under low stress in the elastic region.

2.2.2.1 Bending Strength

This show the highest stresses in the outermost fibers of the wood when the beam breaks under a load. Three point bending strength tests as specified by ASTM D193 (2000) and BS373: (1957) were used on 40 specimens from the selected timber specie. Each specimen was tested using Universal Testing Machine (UTM) until failure occured. The failure load in respect of the individual beam was recorded. The bending strengths were then computed from Equation (6) according to ASTM D193 (2000).

$$f_m = \frac{3F_{max}\,l}{2bh^2} \qquad (6)$$

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).

2.2.2.2 Modulus of Elasticity

The modulus of elasticity was calculated from the values obtained at the point of failure recorded during the tests for the bending strength. This provided for the calculations of deflection which was used to estimate the MOE using Equation 7 (ASTM D193 (2000)).

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

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 $(F_2 - F_1)$.

2.2.3. Statistical /Data Analysis

The general statistical description such as mean value, standard deviations and the coefficient of variation for Ebony ((Kanyan) *Diospyros mespiliformi)* 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 given in Equation 8

$$Y_1 = b_o + b_i X_i + E_1 \qquad (8)$$

The coefficient of determination "R^2" 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 the variation in the independent variable (X).

3.0 RESULTS AND DISCUSSIONS

3.1 The Physical Properties

The physical properties of Ebony ((Kanyan) *Diospyros mespiliformi)* are presented in Table 1. The average moisture content (MC) is 30.52% with a standard deviation of 0.96 and a coefficient of variation (COV) of 0.032. The average dry density (DD) is 768.56 kg/mm^2 with a standard deviation of 91.20 and a coefficient of variation of 0.119. The average bulk density is 1060.89 kg/mm^2 with a standard deviation of 51.06 and a coefficient of variation of 0.048. Obeng, (2010) gave a density range of 900- 1010kg/mm^3 at 12% moisture content. Adeniyi et al., (2013), (value obtained from NCP 2, (1973) gave a density of 864Kkg/m^3 at a moisture content of 18%. The physical properties of common woods gave Ebony to be 0.978g/cc density. All these shows that, the Ebony ((Kanyan) *Diospyros mespiliformi)* is within the limit of other research

3.2 Mechanical properties

The mean, standard deviations and coefficient of variation of the bending strength (BS) of the test results are tabulated in Table 1, they are 72.55 N/mm^2, 6.56 and 0.118 respectively. The modulus of elasticity's (MOE) mean, standard deviation and coefficient of variation were obtained as 11722.78 N/mm^2, 1384.80 and 0.118 respectively. Obeng, (2010) gave at 12% moisture content modulus of rupture (MOR) range of 130 - 179 N/mm^2 and a range of 15,500- 18,900N/mm^2 for the MOE. Adeniyi et al 2013, (value obtained from NCP 2, (1973) gave at a moisture content of 18% a BS and MOE of 28 and 12,500. The Physical properties of common woods gave Ebony, Andaman marble-wood (India) the MOR 7.8kg/mm^2 and MOE to be 1270 kg/ mm^{2}and Ebony, Ebène marbre (Maritius, E. Africa) MOR 5.5kg/ mm^{2}and MOE to be 1007 kg/ mm^2. All these shows that, the Ebony ((Kanyan) *Diospyros mespiliformi)* is within the limit of past research

TABLE 1: STATISTICAL EXPRESSIONS OF TEST RESULTS

	Sample size	Mean Value	Standard Deviation	Coefficient of Variation
Moisture Content	20	30.52	0.96	0.032
Dry density	20	768.56	91.20	0.119
Bulk density	20	1060.89	51.06	0.048
Bending Strength	40	72.55	6.56	0.090
Modulus of Elasticity	40	10937.90	1741.30	0.159

3.3 Relationship between Wood Density and Mechanical Properties

The equation developed from the model is shown on Table 2. 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 as earlier noted by (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).

The 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 (in Figure 1 -5)

Earlier studies examined the predictability of some wood mechanical properties from density on various hardwood species such as *Eucalyptus globulus*, *E. nitens* and *E. regnans* (Yang and Evans, (2003) and Izekor1, et al, (2010) on teak *Tectona grandis* wood). These studies reported density as a good estimator of mechanical properties. The correlation between strength properties and wood density based on oven-dry weight of three *Celtis spp* have been investigated and found to be very high (Ocloo and Laing (2003)). These authors reported that, the linear equations best fitted the relationship between strength properties and density. Fuwape and Fabiyi (2003) made similar observation, when they investigated the relationships between density and mechanical properties of plantation grown *Nauclea diderichii* wood.

TABLE 2: SIMPLE LINEAR REGRESSION BETWEEN THE PROPERTIES

	Equation Models	R	R^2
Dry Density and Mechanical Properties of	BS = 0.067x + 21.39	0.946	0.894%
Diospyros mespiliformi	MOE = 14.71x + 566.2	0.945	0.893%
Bulk Density and Mechanical Properties of	BS = 0.102x -35.50	0.807	0.652%
Diospyros mespiliformi	MOE = 24.17x + 13.769	0.869	0.756%
Bending Strength and Mechanical Properties of*Diospyros mespiliformi*	MOE = 190.3x - 2008	0.902	0.813%

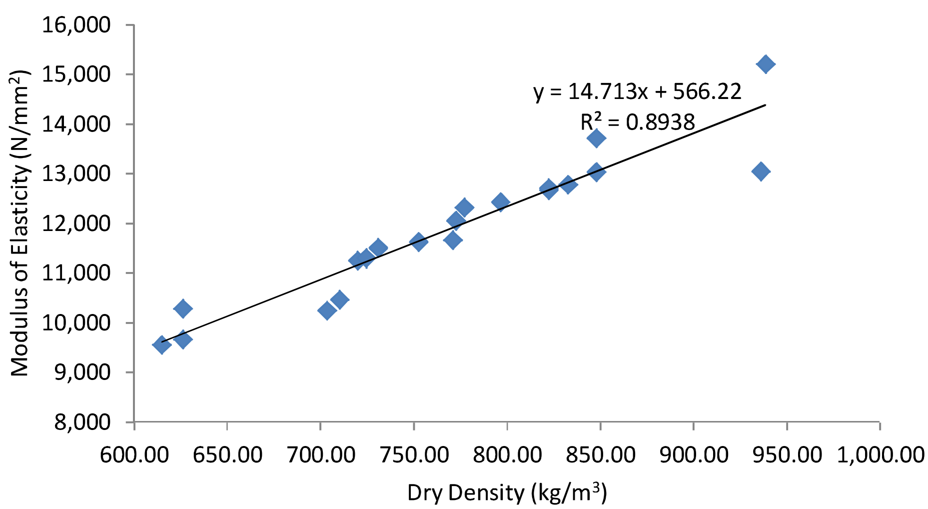

Figure 1: Relationship between Dry Density and Modulus of Elasticity

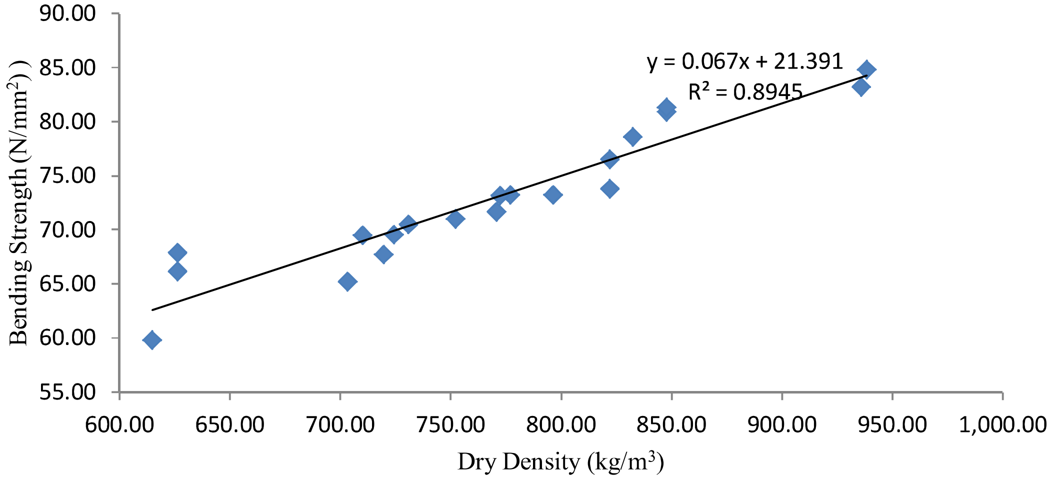

Figure 2: Relationship between Dry Density and Bending Strength

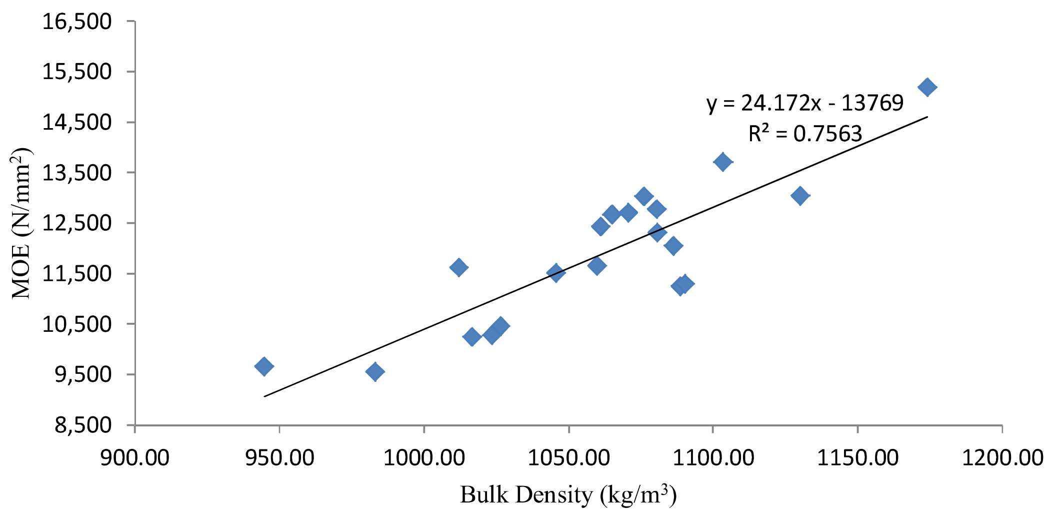

Figure 3: Relationship between Bulk Density and Modulus of Elasticity

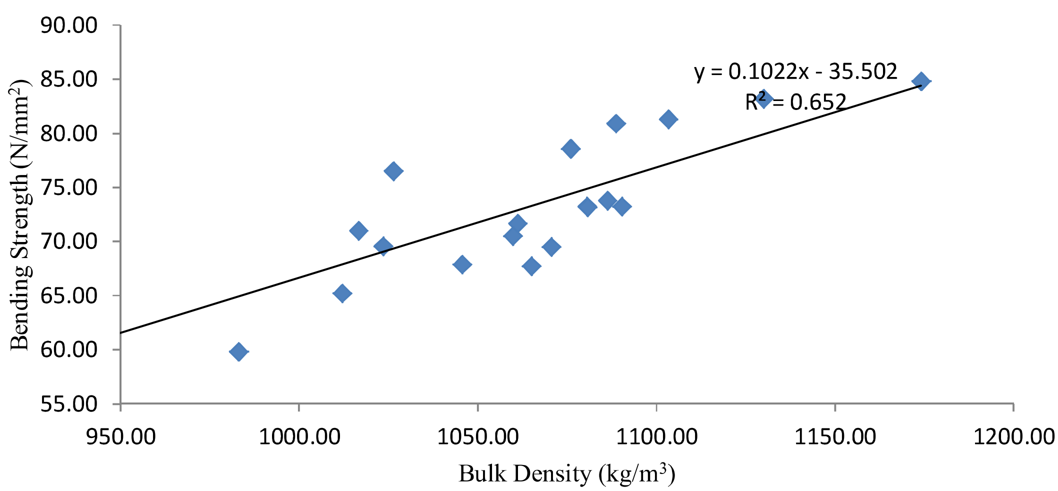

Figure 4: Relationship between Bulk Density and Bending Strength

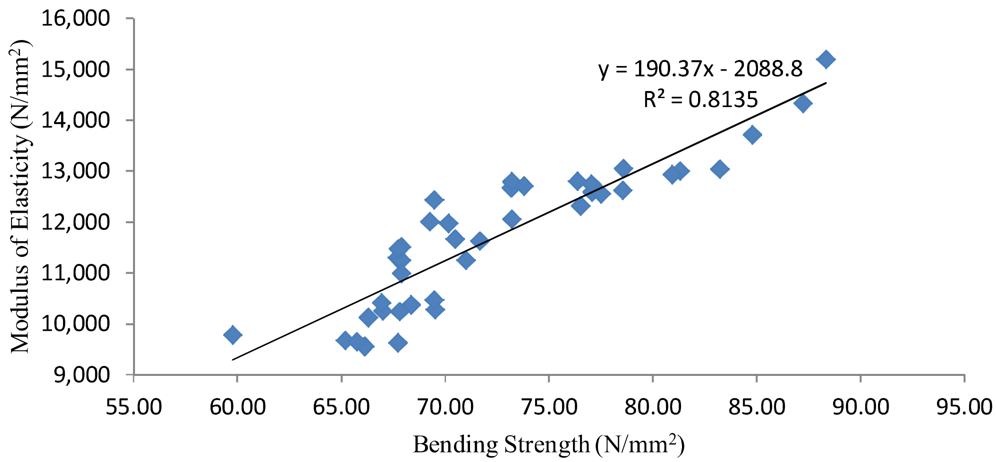

Figure 5: Relationship between Bending Strength and Modulus of Elasticity

4.0 CONCLUSION

This study shows that the best relationship was between DD and MOE ($R^2 = 0.893$) 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 relationship observed was between BD and BS ($R^2 = 0.652$). Thus, it can be inferred from the results of this study that density has a strong positive correlation with the mechanical properties of Ebony (Kanyan) (*Diospyros mespiliformis*) wood and can therefore be used in predicting its strength properties for the structural applications.

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