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Full Length Research Paper

Correlation between density and other mechanical wood properties of *Ficus Exasperata* (Vahl) along axial plane

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Abstract

This study examined correlation between density and other mechanical wood properties of *Ficus exasperata* in Bunu Tai. Samples were collected along the axial direction: base, middle and top (sampling height). Wood samples for mechanical properties were prepared in accordance with British Standard Test 879 procedures. The experiment was laid in 2 x 3 factorial experiment in Completely Randomized Design (CRD), and data collected were subjected to one-way Analysis of Variance (ANOVA) at P<0.05 level of significance, while relationships and associations among mechanical properties were subjected to regression and correlation analyses. The results of ANOVA showed that the average mean values were 465.05±46.64kg/m^3, 3997.990±1488.19N/mm^2, 19.04±4.413m, and 3.7093±2.28N/mm^2 for density, modulus of elasticity (MOE), impact strength (IS) and modulus of rupture (MOR) respectively. Similarly, the results of regression analysis of density on IS, MOE and MOR showed that there was significant relationship (P<0.05: P-value=0.041384) between density and impact strength, and no significant relationship existed between density and MOE and MOR (P>0.05: P-value=0.15118) while their correlation coefficients (r) were 0.83, 0.91 and 0.14for IS, MOE and MOR respectively. The highest correlation coefficient was between density and MOE, followed by between density and IMS while the r-value between density and MOR was the lowest. Mechanical properties particularly IS had no correlation with density while MOR and MOE had positive correlations with density; an indication of possible associations and could therefore project *F. exasperata* wood as being recommended for usage for low construction and joinery purposes.

Keywords: Density, impact strength, modulus of elasticity.

INTRODUCTION

Wood is versatile in nature and has arrays of application; medical purpose, construction, furniture, making of domestic cooking utensils, ornamentals, manufactures of pulp and paper production. It has been used for hundreds of thousands of years for fuel and as construction material (Briffa, et. al., 2002, Fuwape, 2001). Variation in wood strength or mechanical properties, both between and within species, can be attributed to differences in wood density (Schniewind, 1989).

Brazier and Howell (1979) also expressed the opinion that density is one of the most important properties influencing the use of a timber. Cown (1992) reported that the density of wood is recognized as the key factor influencing wood strength (Cown, 1992).

Ficus exasperata commonly known as sand paper tree belongs to the family Moraceae, with 800 species occurring

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in the tropics, chiefly in Indomalaya and Polynesia (Odunbaku et al., 2008). In Nigeria, different species of Ficus such as *Ficus glomosa*, Ficus lecardi, Ficus goliath, *Ficus capensis, Ficus ingens* and F. elastic grow (Keay and Onochie, 1964).

In comparison with other materials, wood is unique. It is anisotropic, hydroscopic, porous and permeable with a sophisticated structure that is complicated by three major microscopic components – the vessel elements, the fibre and the parenchyma. The structure of the whole wood is that each of these major planes that is longitudinal (cross cutting direction) radial (quarter sawn direction) and tangential (flat sawn direction) possess distinctive features. Each plane has its own anatomical, physical and strength properties in relation to both the wood itself and to the wood machining process, which is affected by its distinct and complicate structure.

The structure of wood give interpretation to wood quality assessment which involves the consideration of large number of physical, mechanical and anatomical properties of wood are reported to be good indicator of timbers properties and uses (Anoop et. al., 2014). The features and characteristics of wood varied between species and within species. According to (Adeniyi et. al., 2013) the anatomical properties play an important role in selecting the proper wood for a particular usage because it affects strength properties, appearance, resistance to preservative treatment, and resistance to decay. Within a tree, there are differences in wood properties between the core wood of the tree and the outer wood, and variations from the bottom to the top of the tree according to Albert and Crampton (2004) showed a reliable knowledge of wood anatomical properties and behavior of wood under stress as essential for engineers, architects and carpenters in order to use timber more efficiently and to predict its suitability for structural application and other uses.

Utilization of wood for construction purpose without adequate knowledge of its strength and anatomical properties will perform poorly when compared with engineering materials (Ayinde, 2013).

This study examined the correlation between density and mechanical wood properties along the axial plane of *Ficus exasperata*.

MATERIALS AND METHODS

Study Area

Wood samples of *Ficus exasperate* were collected from Bunu Tai in Tai Local Government Area (TALGA) on latitude 4^{o}46'N and longitude 7^{o}13'E East of Port Harcourt and 15.4 miles (18.48km) away from Port Harcourt, Rivers State, Nigeria (David-Sarogoro & Emerhi, 2016).

Bunu Tai is a village in Tai Local Government Area Tai (TALGA) in Ogoni Land in Rivers State with handful of flora and fauna in degraded tropical rain forests. Prevailing tropical monsoon climate with lengthy and heavy rainfall seasons and dry seasons. Only the month of December and January truly qualifies as dry season month in the city. The harmattan, which climatically influences many cities in West Africa, is pronounced in Bunu Tai. Its heaviest precipitation occurs during September with an average of 370 mm of rain. December on average is the driest month of the year; with an average rainfall of 20 mm. the temperatures throughout the year in the city is relatively constant, showing little variation throughout the course of the year. Average temperatures are typically between 25^{o}C – 28^{o}C in the city.

The study was carried out at the Department of Forest Products Development and Utilization (FPD&U) Wood Anatomy and Timber Quality Laboratory, Forestry Research Institute of Nigeria, Ibadan (FRIN).

Specimens Extraction

Three merchantable trees of *Ficus exasperata* were randomly selected and felled for this study and cut into boles with the use of power chain saw. Three sections were marked out at 10% (base), 50% (middle), and 90% (top) along the axial direction of the log. The bole or discs obtained from three sections were replicated three times which made a total of nine (9) samples.

Mechanical Properties were studied using different standards

The impart or bending strength test was carried out in accordance with the method presented in the British Standard (BSI, 1989; Poku *et. al*., 2001) method of testing. Wood samples of 20 by 20 by 300m dimension were used. The test samples were supported over a span of 240mm on a supporting radius 15mm, spring restricted yokes were filled in order to arrest rebounded. This was then subjected to a repeated blow from a weight 1.5kg at increasing height and the value was recorded in meter as height of maximum hammers drops. The wood sample was placed in such a way that rings are parallel to the direction of hammers drops.

The modulus of rupture was carried out in accordance with British Standard method (BS 373). This involves the use of standard test specimens (20mm x 20mm x 300mm) in an ultimate testing machine (load was at the rate of 0.1mm/s). The bending strength of wood usually expressed as (MOR) which is the equivalent fibre stress in the extreme fibres of the specimen at the point of failure, then calculating using the formula:

$$MOR = \frac{3PL}{2bd^2}$$

Equation 1

Where P = maximum load at failure (N)
L = span of the materials between the support (mm)
b = width of the materials
d = thickness of the materials (mm)
The units of MOR is N/mm^2

The modulus of elasticity was calculated from the value obtained at the point failure recorded during test for MOR. However, while the MOR test is being carried out, a load deflection graph was plotted on the testing machine simultaneously. This provided for calculation of delta in addition to MOR parameters being defined. The MOE was calculated using the formula

$$MOE = \frac{PL^3}{\Delta 4bd^3}$$

Equation 2

Where P = maximum load at failure (N)
L = span of the materials (mm)
b = width of the materials (mm)

d = depth
= Deflection of beam Centre at proportional load

Delta which is the deflection of beam centre at proportional limit was calculated using the Pythagoras theorem: $C^2 = a^2 + b^2$ on the deflection curve as the distance from the start of the experiment to the perpendicular line drawn from the proportional limit to the absica of the graph drawn MOR test.

Experimental Design and Data Analysis

The experimental design was 2 x 3 Factorial Experiment arranged in Completely Randomized Design (CRD) with three replications, and the data collected were subjected to one-way analyses of variance (ANOVA) using the SPSS version 20.

RESULTS

Density of *Ficus exasperate*

The mean value for the density of *Ficus exasperata* is 465.06±46.64kg/m^3 as shown in Table 1. The pattern of variation of this species in this study is the decreasing order from the base to the top: 485.583±52.749,463.166±39.471 and 446.416±40.883 kg/m^3) respectively. This follows the general pattern of wood density, decreasing from the base to the top. According to Bada (1990), the possible factors responsible for the different values for individual trees is likely to be ecological, genetical factors and environmental attributes.
The analysis of variance showed that there is significant difference (P<0.05) along the sampling height (base, middle and top) while there is no significant difference (P>0.05) within trees.
Means in each column with the same alphabet are not significantly different (P>0.05) within trees using DMRT

Impact Test of *F. exasperate*

There was significant difference (P<0.05) between impact strength along the sampling height (base, middle and top): The pattern of variation decreases from top to the base: 51.947±16.469m, 21.513±3.554m and 15.358±4.573m top, middle and base respectively (Figure 1). The average maximum hammer drop (impact bending) for *Ficus exasperata* was 19.040± 4.413m.

The result of the regression analysis showed that significant difference (P<0.05: *P-value*=0.041384) between density and impact test while the correlation coefficient (r^2=0.831769) implies a direct relationship between them with 83%: density increased as impact strength.

Modulus of Elasticity *of F. exasperate*

Figure 2 shows the value for modulus of elasticity of *Ficus exasperata.* The mean value of modulus of elasticity (MOE) was 3997.990± 1488.19 N/mm^2. The modulus of elasticity decreased from base to top (Base 4557.842±1719.68, Middle 4036.371±1517.97 and Top 3399.757±1085.99)N/mm^2. There was no significant difference (P>0.05) along the axial height (base, middle and top) within the trees and interaction between the sampling height but differed (P<0.05) along each tree. Similarly, the result of regression density on MOE indicated no significant difference (P>0.05: P-value=0.15118) between them but there was a strong and direct relationship between density and MOE of *F. exasperata* (Correlation Coefficient (r=0.9091): at 90% which indicates a strong linearity (Table 2).

Modulus of Rupture (MOR) *of F. exasperate*

The result of modulus of rupture of *F.exasperata* showed that values ranged from 1.6067±0.62 to 5.5133±2.33N/mm^2 with a general mean of 3.7093N/mm^2.

Table 1. Mean value of density of *Ficus exasperate.*

	Height	Tree 1	Tree2	Tree3
	Base	523.250±70.165[a]	477.750±22.610[a]	455.750±36.631[a]
	Middle	476.750±42.496[b]	430.500±33.617[b]	482.250±22.29[b]
	Top	452.500±54.220[c]	452.000±39.554[c]	434.750±33.01[c]

Means in each column with the same alphabet are not significantly different (P>0.05) within trees using DMRT.

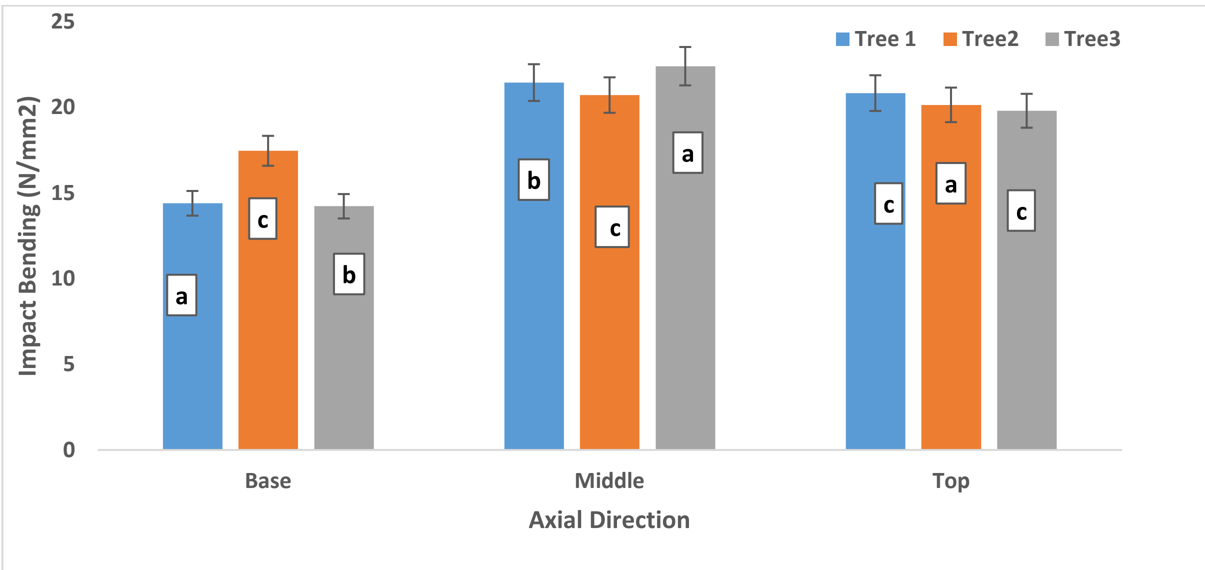

Figure 1. Mean value of Impact Strength of *Ficus exasperata* with the same alphabet are not significantly different (P>0.05) within trees.

The pattern of variation from base to top was inconsistent -Base 3.5978±2.11N/mm^2, middle 4.0356±2.31 N/mm^2 and Top 3.4944±2.63N/mm^2 (Figure 3) and no significant difference (P>0.05) in MOR along the sampling height (base, middle and top) of each tree but differed (P<0.05) within the trees and interaction between the sampling height and trees but differed (P<0.05) along each tree (Figure 3). The regression density on MOR result showed no significant difference (P>0.05: *P-value*=0.15118) between them and poor relationship or linearity (r^2=0.140047).

DISCUSSION

Density of *F. exasperate*

The pattern of density variation decreasing from base to top follows the general pattern of wood density and possible factors responsible for the different values for individual trees is likely to be ecological, genetics factors and environmental attributes Bada (1990). This decrease from base to top agrees with Clark (2001) that reported a higher density at the stem base of young 6-year-old *A. melanoxylon* trees in Australia: an overall trend for reduction in density with tree height. One of the most important properties of lignocellulosic materials is density due to its effect on strength, performance and the general quality of final products (Zobel and van Buijtenen 2014; Anjos *et al.,* 2014; Priadi and Hiziroglu 2013). The mean value for density of *Ficus exasperata* is 465.0556±46.64kg/m^3 was lower than Blackwood (*Acacia melanoxylon*) with average 654 kg/m^{3}but similar to density variation between black wood trees in New Zealand i.e. 465–670 kg/m^3 in a group of 70 year-old trees, and considerable differences between seed lots (Jose *et al*., 2013). Arranged from 432 to 649 kgm^3 was reported in *A. melanoxylon* (Santos, *et al*., 2012). A longitudinal variation was highly

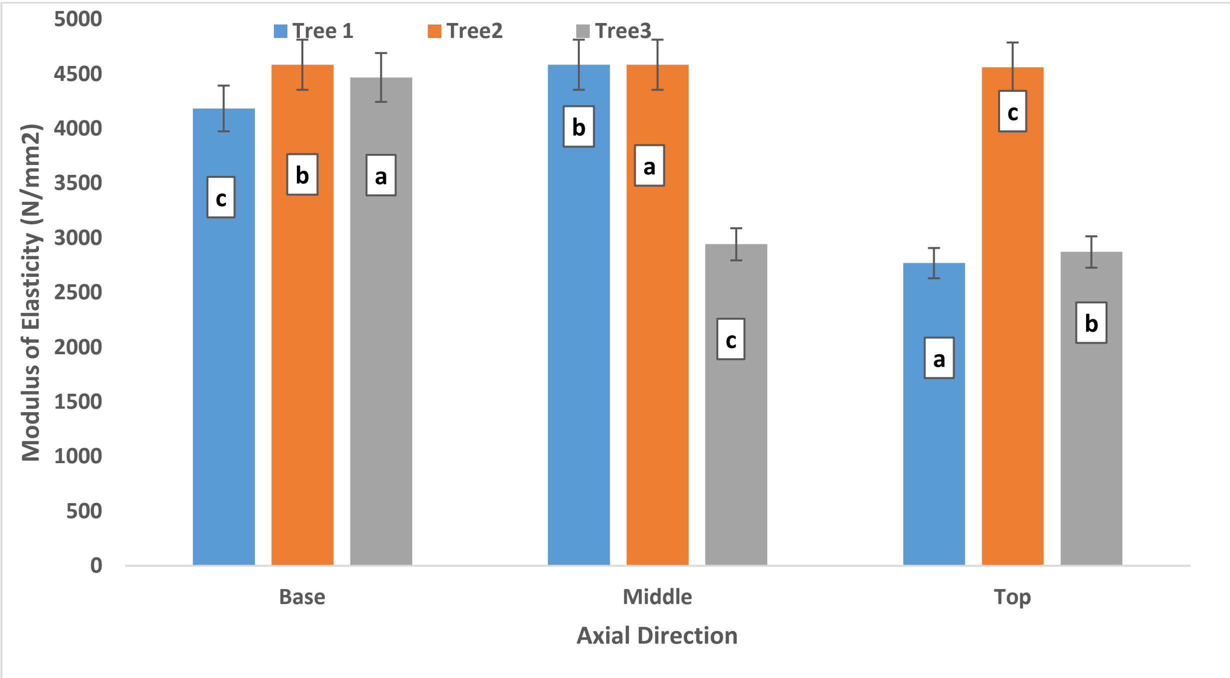

Figure 2. Modulus of Elasticity of *Ficus exasperata*: Bars with the same alphabet are not significantly different (P>0.05) within trees.

Table 2. Regression of Density on MOE.

	df	*SS*	*MS*	*F*	*P-value*	*Significance F*	r^2
Regression	1	158.6963	158.6963	0.162854	0.15118	0.755815	0.909151
Residual	1	974.4704	974.4704				
Total	2	1133.167					

significant but contributed little to the total variation (Jose *et al*., 2013).

Impact Test of *F. exasperate*

The impact strength decreasing from top to base showed that the wood has the highest ability to absorb shock that cause stress beyond the proportional limit (Somorin, 2005). Blackwood mechanical properties did not vary with tree height.

The significance difference along the axial height of *F. exasparata* disagrees with Aleru and David-Sarogoro (2016) that observed no significant difference (P>0.05) of the Impact Strength in their different moisture regimes (wet and dry basis), axial heights and interactions between mango (*Mangira indica*) woods while these no significant difference within the trees and interaction between the sampling height and trees.

Modulus of Elasticity

The decrease in MOE of *F. exasperata* from base to top 3997.990± 1488.19 N/mm^2 agrees with Aleru and David-Sarogoro (2016) that observed also decrease in *Mangira indica's* MOE from base to top from 7870.18 to 12393.83N/mm^2. This pattern of variation is in accordance with Ayinde, (2013) who reported that density at the top is lower than the density at the base. This finding is also in line with Wuraola (2012) on his work on evaluation of selected physical and mechanical properties of *Terminalia catappa*. According to Kwaku *et al,* (2014), MOE is a measure of resistance to bending: which implies that deformations produced by low stress are completely recoverable after loads are removed. In simplest term, according to Meier (2008) MOE measures the woods stiffness and is a good indicator of wood strength. The wood orientation of the microfibril angle (MFA) in the cell wall along the fibre

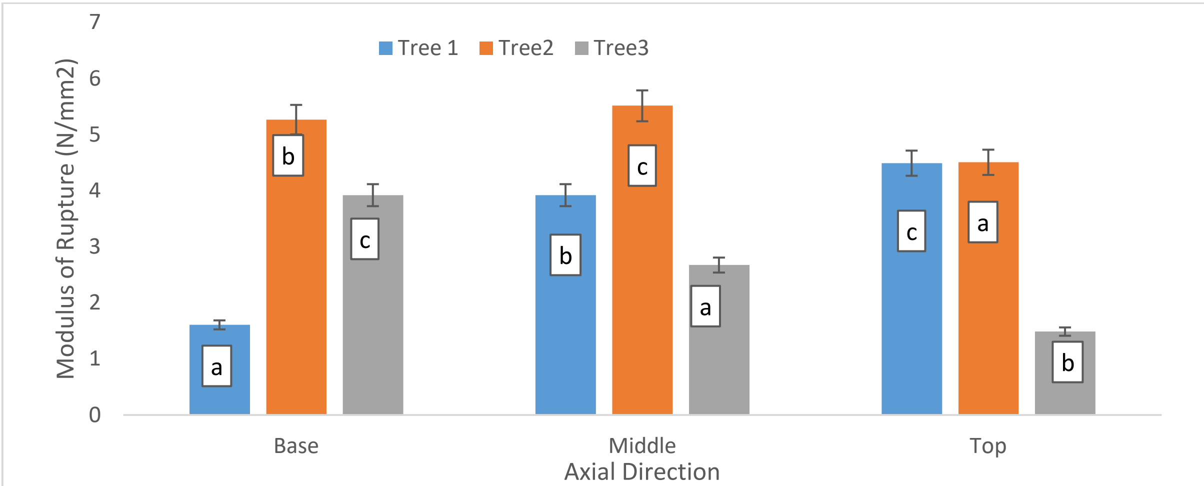

Figure 3. Modulus of rupture (MOR) *of F. exasperata:* Bars with different letters indicating significant difference within trees.

axis is presumed to have played a primal role on the MOE and/stiffness of the wood (Cave and Walker, 1994). The strong and direct relationship between density and MOE of *F. exasperata*: Correlation Coefficient of 90% indicates a strong linearity. This disagrees with Zhang (1997) that MOE is poorly and least linearly related to wood density.

Modulus of Rupture *of F. exasperate*

This result inconsistency in MOR from base to top was is in line with Akinde, (2012) who reported fluctuation in MOR of *Newbouldia leavis* but disagrees with Aleru and David-Sarogoro (2016) that high MOR in *Mangira indica* increased axially from 34.70 to 43.95 N/mm^2. From the foregoing, the species is softer than *Mangira indica* wood.

The poor relationship or linearity (R^2=0.140047) between density and MOR of *F. exasperata* agrees with Zhang (1997) that modulus of rupture and the maximum crushing strength in compression parallel to the grain are most closely and almost linearly related to wood density.

CONCLUSION

The findings have found that the species is a very soft species with outstanding mechanical properties- particularly IS had no correlation with density while MOR and MOE had positive correlations with density. With these mechanical properties which showed that the species can be used for low construction and joinery purposes. The microscopic of the secondary cell should be studied to elucidate more intrinsic qualities like micro fibril of the cell wall. The chemical properties should be considered to ascertain the percentage of the lignin and extractive contents present in the wood.

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