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Effects of density on variations in the mechanical properties of plantation grown *Tectona grandis* wood

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ABSTRACT

The effects of density on variations in the mechanical properties of plantation grown Tectona grandis wood aged 15, 20 and 25-year were examined. Six trees were selected from each age class from the Edo State Forestry plantation sites located within the Forest Reserves. Wood samples were collected from innerwood, middlewood and outerwood at 10, 50 and 90% of the tree merchantable height. The mean density values on oven dry weight and volume basis were 480, 556 and 650 Kg m^{-3}, moduli of rupture were 76.86, 103.95 and 134.69 N mm^{-2}, moduli of elasticity were 6846.92, 9920.54 and 12845.57 N mm^{-2}, compressive strength parallel to grain were 43.74, 58.47 and 75.36 N mm^{-2} for age 15, 20 and 25-year old Tectona grandis wood. Wood density and mechanical properties increased with increase in age. Whereas wood density and mechanical properties increased from pith to bark, they however decreased from base to top at any particular height. The correlations between density and MOR, density and MOE, density and CS were significant ($p < 0.001$). Therefore wood density can be used in predicting the mechanical properties of Tectona grandis wood.

Keywords: *Tectona grandis*, wood density, mechanical properties, plantation, radial direction, longitudinal direction, sampling heights,

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INTRODUCTION

Teak (*Tectona grandis Linn F.*) is one of the most valuable timber tree species in the tropics. It world-wide demand is attributable to its high quality timber on account of the attractiveness and durability of the wood it produce [1,2]. *Tectona grandis* is an exotic hardwood tree species of the family verbenaceae. It has been successfully established as exotic in many countries of the world including Nigeria, where it is raised as one of the fastest growing timber species. The tree is deciduous and grows to a height about 30 meters. It has fluted bole and sometimes possess slight buttress [3].

Teak plantations were established in the country in order to provide raw materials for poles and sawn timber as well as reduce the pressure on tree species from the natural forest. Despite the establishment of these fast growing exotic Teak plantations, adequate information about its wood density and mechanical properties are necessary for appropriate utilization. Wood density is of practical importance in its utilization and a good indicator of strength properties [4]. Density controls the extent of dimensional changes in wood and thus determines to a large extent the place of timber as a construction material. It is the strongest predator for paper properties and the mechanical strength of sawn timber [5,6]. Axial and radial variations on the density of *Tectona grandis* wood have earlier been reported [7]. The variations in the strength properties of *Nauclea diderichii* wood have also been studied and reported [8]. The pattern of wood density variations seems to have impact on the variations of most strength properties [9].

It is necessary therefore to study the pattern of variations in wood density and its impact on mechanical properties such as modulus of rupture, modulus of elasticity and compressive strength parallel to grain within and between trees of *Tectona grandis* wood. The objective of this study was to investigate the effects of wood density on the variations in the mechanical properties of *Tectona grandis* wood in order to recommend it for appropriate wood utilization.

MATERIALS AND METHODS

Wood samples of *Tectona grandis* were collected from Edo State forestry plantation sites located within the state forest reserves. Six trees were randomly selected from each similar aged stand of *Tectona grandis* in accordance with the provision of ASTM D 143-48 [10]. Sample trees with very close diameter classes, relatively straight stems and clear wood were selected for the study. Billets measuring 750 mm long were cut from felled trees at 10, 50 and 90% of the merchantable length of each bole. The billets were then sawn through the pith into four equal parts. A board of 20 mm thick was sawn from each of the four parts through the pith to the bark using circular bench saw. Wood samples for the tests were systematically selected from the innerwood, middlewood and outerwood. The samples were conditioned to 12% moisture content in a controlled laboratory. The relative humidity and temperature of the laboratory were maintained at 65±2% and 30^0 C respectively. The experiment was conducted as a three factor factorial in a completely randomized design with three replication of wood samples in each radial position. Factor A was the age classes at three levels of 15, 20 and 25-year old *Tectona grandis* wood. Factor B was the longitudinal positions were the samples bolts were collected at three levels of 10, 50 and 90% of the tree merchantable length while Factor C was the radial position where the wood samples were collected at three levels of innerwood, middlewood and outerwood.

Wood density determination was carried out using sample sizes of 20 x 20 x 60 mm according to BS 373 [11]. The test samples were oven-dried to a constant weight at 103 ± 2^0 C. Mechanical properties tests were also determined in accordance to BS 373 [11]. Modulus of rupture and modulus of elasticity of the wood samples were tested on a Hounsfield Tensiometer, using wood samples measuring 20 x 20 x 300 mm. The MOR was calculated from the maximum load at which each wood sample failed. The MOE was calculated using the load to deflection curve plotted on the graph by the machine. Compressive strength parallel to grain was determined by subjecting 20 x 20 x 60 mm wood samples to test on a Universal static bending machine and a compressiometer.

Analysis of variance was carried out to determine the level of significance among the various treatment means at 0.05% probability level. Means separation was done using Duncan New Multiple Range Test. Correlation and regression analysis were conducted to determine the relationship between density and mechanical properties of *Tectona grandis* wood.

RESULTS AND DISCUSSION

Wood Density

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 (Table 1). Therefore wood density increased with increase in age. Generally, there was a decrease in wood density from base to top and an increase from innerwood to outerwood (Table 1). These findings are in accordance with the report of Akachuku [12], for wood density of Nigerian Grown *Gmelinea arborea*. Fuwape and Fabiyi [8] also reported similar observation for wood density of plantation grown *Nauclea diderichii* wood. The observed decrease in wood density from base to top agrees with the auxin gradient theory [13]. According to the theory, the endogenous auxin arising in the apical region of growing shoots stimulates cambial division and xylem differentiation. Therefore high production of early wood near the crown contributes significantly to low wood density at the top. The increase in density from innerwood to outerwood may be due to the increasing age of the cambium. Analysis of variance carried out at 0.05% probability level showed that age, sample trees, longitudinal and radial positions contributed significantly to variations in wood density.

Table 1: Mean Density (kg m^{-3}) of Teak (*Tectona grandis*) wood in Relation to Age, Height and Positions

		Sampling	Height (%)		
Age (Years)	Radial Position	Base (10%) Mean ± SD	Middle (50%) Mean ± SD	Top (90%) Mean ± SD	Pooled Mean Mean ± SD
15	Outerwood	558 ± 4.75^{a}	520 ± 5.31^{b}	481 ± 5.45^{c}	520 ± 38.5
	Middlewood	512 ± 4.86^{d}	473 ± 5.92^{ce}	443 ± 5.66^{f}	476 ± 34.6
	Innerwood	473 ± 5.17^{ce}	447 ± 6.34^{fg}	403 ± 6.13^{h}	442 ± 35.4
	Pooled Mean	514 ± 42.5	480 ± 37.0	442 ± 39.0	480 ± 36.0
20	Outerwood	637 ± 4.29^{a}	590 ± 4.60^{b}	550 ± 4.81^{c}	592 ± 43.5
	Middlewood	602 ± 5.47^{d}	548 ± 3.66^{e}	508 ± 4.64^{f}	553 ± 47.2
	Innerwood	565 ± 5.26^{g}	520 ± 4.77^{h}	479 ± 5.26^{i}	522 ± 43.0
	Pooled Mean	601 ± 36.0	553 ±35.2	512 ± 35.7	556 ± 44.5
25	Outerwood	732 ± 6.42^{a}	701 ± 4.70^{b}	652 ± 5.60^{c}	695 ± 40.3
	Middlewood	687 ± 4.77^{d}	644 ± 5.51^{e}	602 ± 5.96^{f}	645 ± 42.5
	Innerwood	648 ± 5.35^{eg}	612 ± 4.69^{h}	561 ± 5.26^{i}	607 ± 43.7
	Pooled Mean	689 ± 42.0	652 ± 45.1	605 ± 45.6	650 ± 42.1

Each value is the mean and standard deviation of 6 replicates sampled trees of Teak.
Means of the same age with different superscript are significantly different ($p < 0.05$)

Modulus of Rupture

The mean MOR values obtained in this study were 76.86, 103.95 and 134.69 N mm^{-2} for age 15, 20 and 25-year old *Tectona grandis* woods respectively (Table 2). MOR values increased with age, a situation which may be due to increment of annual rings, addition of more mature wood and cambial age. MOR generally decreased from base to top and increased from innerwood to outerwood at any particular height (Table 2). The decreased in MOR from base to top appears to agree with the report of Fuwape and Fabiyi [8] on *Nauclea diderichii* wood. The increased trend in MOR from innerwood to outerwood was associated to the variations in some morphological features such as fibre length, fibre diameter, lumen width and fibre wall thickness [14]. Analysis of variance for MOR showed that age, sample trees, longitudinal and radial positions were significant at 0.05% probability level.

Modulus of Elasticity

The mean values for MOE of 15, 20 and 25-year old *Tectona grandis* wood were 6846.92, 9920.54 and 12845.57 N mm^{-2} respectively (Table 2). This observation showed that MOE increases with age, which may be attributed to increments of growth rings, and the addition of more mature wood and cambial age. Generally the trend of variations in MOE showed a decrease from base to top and an increase from innerwood to outerwood at any particular height (Table 2). Similar trend of decrease in MOE from base to top have been reported in Slash pine [15]. Also Fuwape and Fabiyi [8] reported similar observations in MOE for plantation grown *Nauclea diderichii* wood. The effects of the different age, sample trees, longitudinal and radial positions on MOE were significant at 0.05% probability level.

Compressive Strength parallel to grain

The mean values of CS of *Tectona grandis* wood were 43.74, 58. 47 and 75.36 N mm^{-2} for age 15, 20 and 25-year old trees respectively (Table 2). This showed that CS increases with age. The observed trend in CS was a decrease from base to top and an increase from innerwood to outerwood at any particular height. The effects of the different age; sample trees, longitudinal and radial positions on variations in CS were significant at 0.05 % probability level.

Relationship between wood density and mechanical properties

The results obtained from the correlation analysis carried out to examine the linear relationship between wood density and mechanical properties were 0.970, 0.966 and 0.971% for Modulus of Rupture (MOR), Modulus of Elasticity (MOE) and Compressive Strength (CS) parallel to grain (Table 3). This relationship was highly significant at 0.001% probability level. Regression analysis was used to develop mathematical model using mean density values to predict the effects of density on the variations in Modulus of Rupture, Modulus of Elasticity and Compressive Strength parallel to grain. The following equation was developed from the model, MOR = 0.319x - 73.64, MOE = 32.15X - 8153 and CS = 0.184x - 44.09 (Table 4.43). The coefficients of determination (R^2) for the regression model were 0.941, 0.933 and 0.943% for Modulus of Rupture, Modulus of Elasticity and Compressive Strength parallel to grain (Table 4.). Graphical representation showing the relationship existing between density and Modulus of Rupture, density and Modulus of Elasticity, density and Compressive Strength parallel to grain are presented as scattered diagram (Fig. 1 - 3)

Table 2: Mean Values of Mechanical Properties of Plantation Grown Teak (*Tectona grandis*) in Relation to Age, Height and Positions

			Sampling	Height (%)		
Age (Years)	Wood Properties	Radial Position	Base (10 %) Mean ± SD	Middle (50 %) Mean ± SD	Top (90 %) Mean ± SD	Pooled Mean Mean ± SD
15	Modulus of Rupture (N/mm^2)	Outerwood	95.46±4.30^{a}	87.21± 7.36^{b}	76.38±5.72^{c}	86.35± 9.57
		Middlewood	89.25±5.67^{bd}	78.32± 5.62^{ce}	63.54±4.53^{f}	77.04±12.90
		Innerwood	80.23±5.73^{g}	65.40± 6.85^{fh}	55.94±3.73^{i}	67.19±12.24
		PooledMean	88.31±7.66	76.98±10.97	65.29±10.33	76.86± 9.58
20		Outerwood	127.87±6.38^{a}	112.48±4.35^{b}	98.31±4.57^{c}	112.89±14.78
		Middlewood	115.80±5.85^{d}	102.39±3.89^{e}	90.65±4.83^{f}	102.95±12.58
		Innerwood	108.71±5.10^{g}	96.79±4.53^{eh}	82.50±4.36^{i}	96.00±13.12
		PooledMean	117.46±9.69	103.89±7.95	90.49±7.91	103.95± 8.49
25		Outerwood	156.53±3.87^{a}	143.76±5.94^{b}	132.47± 4.87^{c}	144.25±12.04
		Middlewood	148.32±4.73^{bd}	135.29±7.63^{ce}	120.24± 6.73^{f}	134.62±14.05
		Innerwood	140.54±4.85^{eg}	124.38±7.40^{fh}	110.68± 6.54^{i}	125.20±14.95
		PooledMean	148.46±8.00	134.48±9.72	121.13±10.92	134.69± 9.53
15	Modulus of Elasticity (N/mm^2)	Outerwood	8752.60±407.56^{a}	7642.30±617.56^{b}	6491.68±657.15^{c}	7628.86±1130.52
		Middlewood	7947.91±476.91^{bd}	6846.05±596.42^{ce}	5587.35±354.07^{f}	6794.44±1182.13
		Innerwood	6863.34±796.65^{eg}	6253.68±483.32^{h}	5235.38±332.32^{fi}	6117.47±822.48
		PooledMean	7864.62±948.08	6914.01±696.80	5771.47±648.07	6846.92±757.06
20		Outerwood	11871.64±601.34^{a}	10734.82±607.58^{b}	9567.59±462.25^{c}	10724.68±1152.06
		Middlewood	10943.60±360.12^{bd}	9843.42±597.82^{ce}	8752.30±350.52^{f}	9846.44±1095.65
		Innerwood	10236.75±428.18^{eg}	9062.49±712.33^{h}	8263.26±233.58^{fi}	9187.50± 992.67
		PooledMean	11017.33±819.94	9880.24±836.77	8861.05±658.93	9920.54± 771.19
25		Outerwood	15254.53±359.56^{a}	13736.88±545.72^{b}	12238.42±443.18^{c}	13743.28±1508.07
		Middlewood	14352.13±351.23^{d}	12754.47±642.92^{ce}	11252.90±533.32^{f}	12786.50±1549.86
		Innerwood	13542.28±487.38^{bg}	11848.15±674.42^{ch}	10630.39±584.13^{i}	12006.94±1462.42
		PooledMean	14382.98±856.54	12779.83±944.62	11373.90±810.82	12845.57.44±869.68
15	Compressive Strength (N/mm^2)	Outerwood	57.34±4.22^{a}	48.72±3.28^{b}	41.83±3.54^{c}	49.30±7.78
		Middlewood	50.38±3.34^{bd}	45.37±3.34^{be}	36.59±3.38^{f}	44.11±6.98
		Innerwood	43.56±4.15^{g}	37.42±3.25^{h}	32.48±3.80^{i}	37.82±5.55
		PooledMean	50.42±6.89	43.84±5.80	36.98±4.69	43.74±5.75
20		Outerwood	72.54±3.70^{a}	64.57±2.88^{b}	55.79±4.21^{c}	64.30±8.38
		Middlewood	65.78±3.48^{bd}	58.26±3.04^{ce}	50.30±2.97^{f}	58.13±7.71
		Innerwood	60.51±3.04^{eg}	52.27±2.51^{h}	46.17±3.06^{i}	52.98±7.20
		PooledMean	66.28±6.03	58.36±6.15	50.77±4.82	58.47±5.67
25		Outerwood	95.48±2.40^{a}	81.76±3.74^{b}	72.35±3.69^{ce}	83.20±11.63
		Middlewood	83.21±3.05^{bd}	75.47±3.26^{eg}	65.47±2.45^{f}	74.72± 8.89
		Innerwood	78.24±3.50^{g}	67.34±4.35^{h}	58.87±4.10^{i}	68.15± 9.71
		PooledMean	86.68±8.86	74.86±7.23	65.56±6.74	75.36± 7.55

Each value is the mean and standard deviation of 6 replicates sampled trees of Teak.
Means of the same age with different superscript are significantly different ($p < 0.05$)

The correlation coefficient between wood density and mechanical properties was highly significant ($p < 0.001$). When the pooled mean values along the tree height levels were used, the correlation coefficient between density and mechanical properties were MOR and density ($r = 0.97$), MOE and density ($r = 0.96$) and CS and density ($r = 0.97$). The regression of the mean values of wood density in the longitudinal position with corresponding MOR showed that 94% of the variations in MOR was explained by density (Table 4). The linear equation gave the best fit for the relationship between MOR and density (Fig. 1). The regression of the mean values of density in the longitudinal position with corresponding MOE and CS showed that 93 and 94% of the variations in MOE and CS was explained by density (Table 4). The linear equations gave the best fit for the relationship between MOE, CS and density (Fig. 1- 3). This is an indication that wood density can be used to predict the strength properties of *Tectona grandis* wood

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 [16]. The authors reported that, the linear equations best fitted the relationship between strength properties and density. Fuwape and Fabiyi [8] made similar observation, when they investigated the relationship between density and mechanical properties of plantation grown *Nauclea diderichii* wood.

Table 3: Correlation between Density and Mechanical properties of Teak (*Tectona grandis*) wood

	DENSITY	MOR	MOE	CS
DENSITY	1.000	0.970**	0.966**	0.971**
MOR	0.970**	1.000	0.983**	0.963**
MOE	0.966**	0.983**	1.000	0.956**
CS	0.971**	0.963**	0.956**	1.000

***significant (p < 0.001) probability level*

Table 4: Regression Equation between Density and Mechanical Properties of Teak (*Tectona grandis*) wood

Equation models	R	R^2
MOR = 0.319x-73.64	0.97	0.941%
MOE = 32.15x-8153	0.96	0.933%
CS = 0.184x-44.09	0.97	0.943%

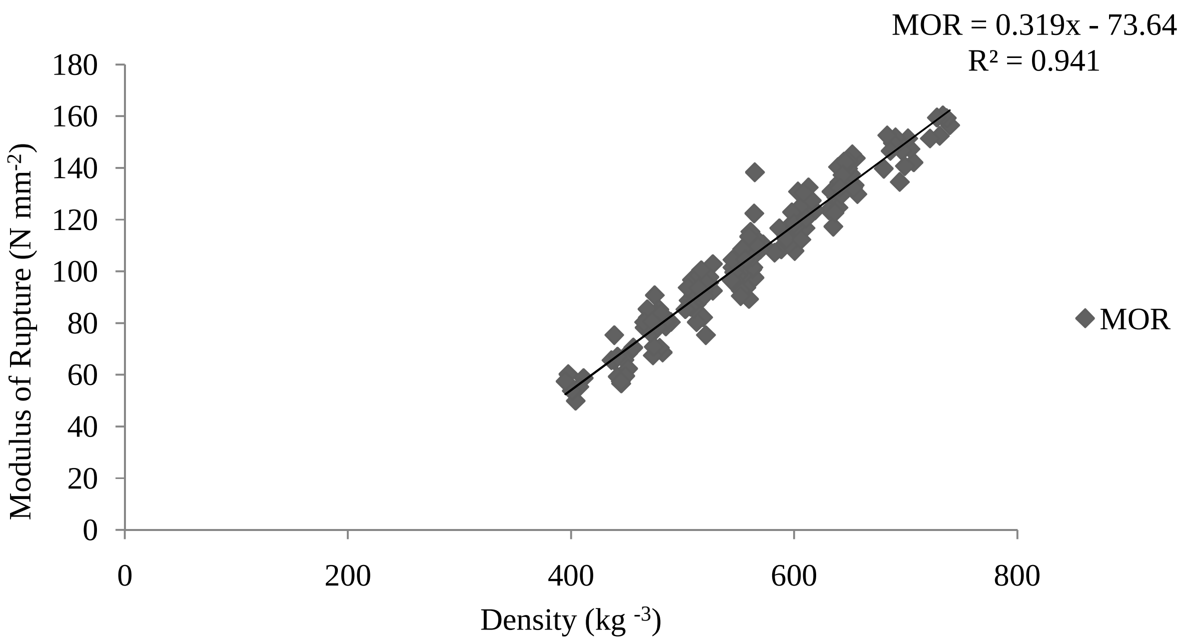

Fig.1: Relationship between Density and Modulus of Rupture of Teak (*Tectona grandis*) wood

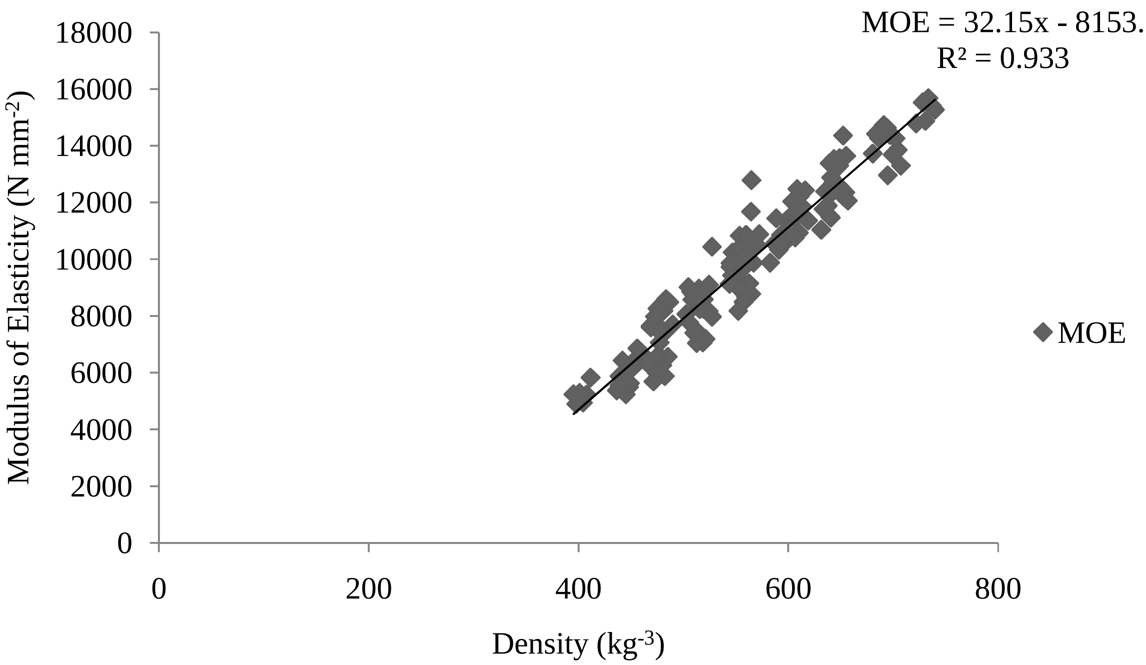

Fig.2: Relationship between Density and Modulus of Elasticity of Teak (*Tectona grandis*) wood

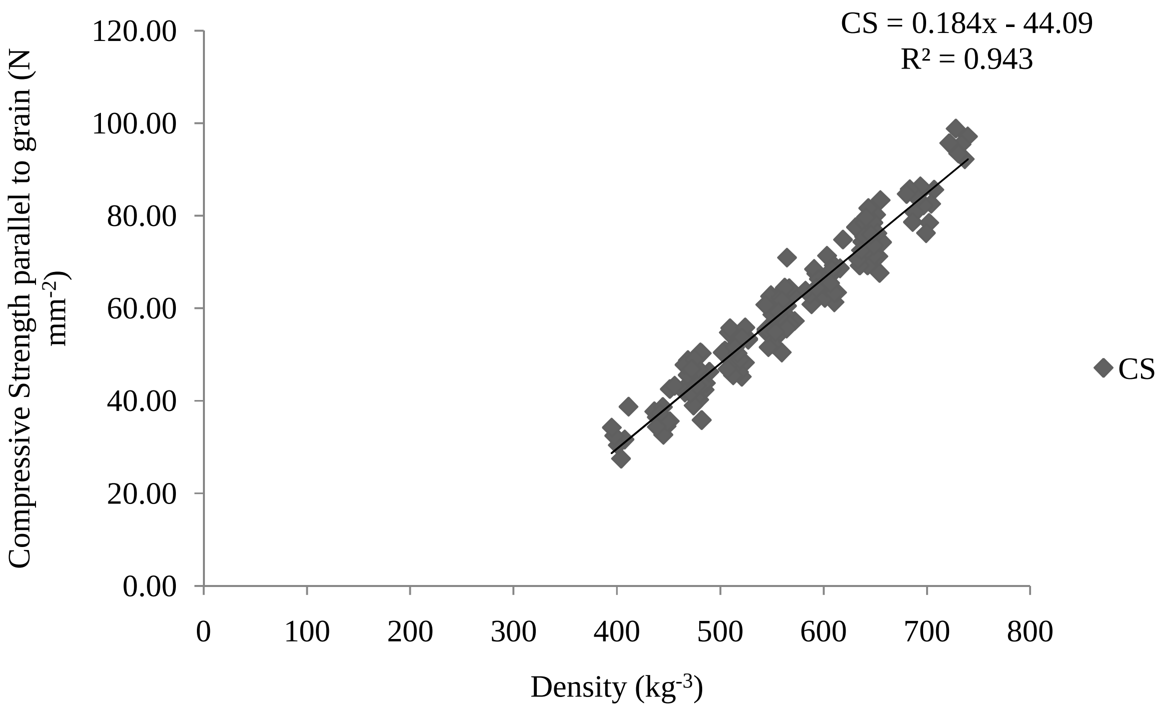

Fig 3: Relationship between Density and Compressive Strength parallel to grain of Teak (*Tectona grandis*) wood

CONCLUSION

The variations in wood density, MOR, MOE and CS within and between trees of the same and different age classes of 15, 20 and 25-year old *Tectona grandis* wood were significant. Wood density and mechanical properties studied increased with increase in age, hence age was the most important source of variations in wood density, MOR, MOE and CS parallel to grain of *Tectona grandis* wood. Therefore, the choice of rotation age of *Tectona grandis* wood can be used to control its strength properties. Generally, density and mechanical properties decreases from the tree base to the top whereas it increases from the innerwood to the outerwood at any particular height. Thus it can be inferred from the results of this study that density has a strong positive correlation with the mechanical properties of *Tectona grandis* wood and can therefore be use in predicting its strength properties.

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