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Variations in Mechanical Properties among Trees of the Same and Different Age Classes of Teak (*Tectona Grandis L.F*) Wood.

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Abstract: The variations in mechanical properties such as modulus of rupture (MOR), modulus of elasticity (MOE) and compressive strength (CS) parallel to grain of *Tectona grandis* wood aged 15, 20 and 25 years old respectively were evaluated. Six trees from each even aged stand and similar class diameter were selected at the Edo State Forestry plantation sites. Wood samples were collected from outer wood, middle wood and inner wood at 10, 50 and 90 % of the tree merchantable height. The modulus of rupture, modulus of elasticity and compressive strength parallel to grain increased with increase in the age of the tree. The mean values of the modulus of rupture were 76.86, 103.95 and 134.69 N mm^{-2}, modulus of elasticity were 6846.92, 9919.54 and 12845.57 N mm^{-2} while the mean values for compressive strength parallel to grain were 43.74, 58.47 and 75.36 N mm^{-2} for 15, 20 and 25 years old *Tectona grandis* wood respectively. Modulus of rupture, modulus of elasticity and compressive strength parallel to grain increased from pith to bark but decrease from base to top. Analysis of variance conducted to test for significant differences in MOR, MOE and CS parallel to grain for the different age classes, longitudinal positions and radial positions were significant at 0.05 probability level.

Key words: *Tectona grandis*, Age classes, Modulus of Rupture, Modulus of Elasticity, Compressive Strength parallel to grain, Sampling Height, Radial positions etc

INTRODUCTION

Wood is a lignocellulosic material and a renewable natural resource. It is composed of cellulose, lignin, hemicelluloses and minor amount (5-10%) of extraneous materials contained in a cellular structure. It is a non-uniform heterogeneous material throughout the tree stem. Its structure, chemical components, physical and mechanical properties varies from pith to bark, from the tree base to the top, from the stem to the branches and root [15,11]. Wood varies systematically within one growth ring and at the cellular level. The chemistry, the micro fibril angle and mechanical properties change significantly from one cell wall layer to another [2]. The bulk of timber and other wood based forest products used in Nigeria are obtained from the forest reserve and free areas in high forest zones of the country. Over the years much exploitation of the forest has been done in order to meet the increasing demand of the teeming population [8]. This has resulted in progressive decline in the area of constituted forest and woodland in Nigeria [1]. From the forest industry perspective, this situation is disheartening as Nigeria grossly falls short of the internationally recommended forest cover per unit area of land. The supply of quality timber from the natural forests in Nigeria to wood based industries which took place up to the 1970s is no more available in the quantities that can sustain the usual large diameter class log required by these industries. The natural forest has shrunken considerably to less than 5% of Nigeria total land area of 913,000 km^2 [13]. The annual consumption of wood according to [13] has exceeded the allowable cut by about 3 million m^3 for industrial wood and about 10 million m^3 for fuel wood. The demand for wood and wood product will continue to increase due to Nigeria increasing population and rising standard of living of the people. In order to meet the demand for wood on sustainable yield basis, the wood supplied from the natural forest need to be supplemented with wood raised in plantation. To this end certain tropical and indigenous hard wood tree species such as *Tectona grandis, Nauclea diderichii, Terminalia superba, Terminalia ivorensis, Triplochiton scleroxylon* and *Mansonia altiss*ima are raised in plantation to supplement wood supplied from the natural forest [8]. Despite the establishment of these indigenous and tropical hard wood species in plantation, wood users

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will not be encourage to put them into maximum utilization except adequate information on their wood quality is available. The availability of scientific knowledge on the properties and behaviour of wood will make it possible to develop more efficient methods of using wood as a structural and construction material.

The main objective of this study therefore was to investigate the variations in mechanical properties among trees of the same and different age classes of *Tectona grandis* wood in Edo State. This information when available will provide relevant knowledge necessary for the efficient utilization of Teak wood for various industrial and construction purposes. Such information will also help to reduce the pressure on the utilization of trees from the natural forest.

The specific objectives of the study was to determine the variations in modulus of rupture, modulus of elasticity and compressive strength parallel to grain within and between trees of the same and different age classes of *Tectona grandis* in both longitudinal and radial positions.

MATERIALS AND METHODS

Wood samples of *Tectona grandis* were collected from Edo State Forestry plantation sites in Ologbo, Irrua and Ohrionmwon forest reserves. The total land area covered by *Tectona grandis* plantation in Edo State is 6,057 hectares with a volume of 1,856,848 m^3 [9]. The forest plantation lies between latitude 5^0 45' and 7^0 8' north and longitude 5^0 4' and 6^0 52' east. The climate of the area is tropical with distinct wet and dry season characterized by humid conditions in the south and sub-humid conditions in the north. The rain fall pattern is bimodal and varies from 2000 mm a year in the humid southern part to 1150 mm a year in the sub-humid northern parts. The mean monthly temperature is about 27^0c with a range of 22-35^0c while the relative humidity range is from 79-90% [10]. The topography of the area is generally flat with pocket of gentle undulation. Its soils are reported to be of very recent deposits and are derived from sand stones and shales. These soils are very susceptible to leaching, hence they lose their fertility very fast [7] Six trees were randomly selected from each even aged stand of *Tectona grandis* according to the provision of [3]. Sample trees with very close diameter classes, relatively straight stem and clear wood were selected. Billets measuring 750 mm were cut from felled trees at 10, 50 and 90% of the merchantable length of each stem. The billets were then sawn through the pith into four parts. A board of 20 mm thick was sawn from each of the four parts through the pith to the bark using a circular bench saw. Wood samples from the test were systematically collected from the innerwood (near the pith), and outerwood (close to the bark) while the middle wood was selected from the midpoint between the innerwood and the outerwood. The samples were conditioned to 12 % moisture content in a controlled laboratory at the time of the test. The experiment was carried out as a four factor factorial using a completely randomized design. Factor A was the age class, viz 15, 20 and 25 years. Factor B was the six trees selected from each even aged stand. Factor C was the longitudinal position of 10, 50 and 90 %. While factor D was the radial position viz, innerwood, middlewood and outerwood.

Mechanical properties determination was carried out in accordance with [6] specification. The static bending test from which the modulus of rupture (MOR) and modulus of elasticity (MOE) were evaluated was carried out using specimen size 20mm x 20mm x 300mm. The test was a centre-loading supported on a span of 280mm while the force was applied on the radial face at mid-span using a loading rate of 0.1mm/min on a Hounsfield Tensiometer machine. The MOR was calculated from the maximum load at which each wood sample failed. The MOE was calculated using load to deflection curve plotted on a graph by the machine. Compressive strength parallel to grain was determined by subjecting specimen size 20mm x 20mm x 60mm wood samples to test on a Universal static bending machine and a compressiometer in accordance with British Standard [5] specification

The values obtained were subjected to analysis of variance to evaluate the variance component and determine if there were significant differences in the mechanical properties of plantation grown *Tectona grandis* wood. The main effects considered were those due to differences between age classes, sample trees, longitudinal positions and radial positions. The interaction effects between the main components were also considered. Separations of means was carried out using Duncan Multiple Ranged Test (DMRT) at 0.05 % probability level.

RESULTS AND DISCUSSION

Modulus of Rupture: The MOR values obtained for *Tectona grandis* for the three age classes were 76.86, 103.95 and 134.69 N mm^{-2} for ages 15, 20 and 25 years old *Tectona grandis* wood (Table 1). The mean values of MOR in the longitudinal positions ranged from 65.29 to 88.31, 90.49 to 117.46 and 121.13 to 148.46 N mm^{-2} while in the radial positions the mean values obtained ranged from 67.19 to 86.35, 96.00 to 112.89 and 125.20 to 144.25 N mm^{-2} for ages 15, 20 and 25 years old *Tectona grandis* wood respectively (Table 1). The MOR values obtained in this study increase with the age of the tree from 15 years through 20 years to 25 years old *Tectona grandis* wood respectively. These observed increase in MOR values with the age of the tree may be due to increment of annual rings, addition of more mature wood and the increasing age of the cambium as the tree grow in girth. MOR values generally decreased from base to top and increase from inner wood to outer wood at any particular height level (Table 1). The observed decrease in MOR values from base to top and the increasing trend from pith to bark agrees with previous report on MOR values for *Nauclea diderichii.* [8].

The increased trend of MOR values from innerwood to outerwood may be associated to variations in some morphorlogical factors such as fibre length, wall thickness and fibre diameter as previously reported [8] on the increasing trend in MOR values from innerwood to outerwood of *Nauclea diderichii.* Roos *et al*, [14] observed such increase from pith to bark in quaking aspen while Ogunsanwo [12] reported same for *Triplochiton scleroxylon*. The differences in MOR values for the different age classes of *Tectona grandis* is in agreement with the report of Barret and Kellog [4] on the reduction in MOR values between young and older trees of Dauglas fir. Analysis of variance conducted at 0.05% probability level showed that variations in MOR for the different ages, sample trees, longitudinal positions and radial positions were significant (Table 4). This is an indication that age, sample trees, the longitudinal and radial positions from where the wood samples were collected contributed to variations in MOR.

Modulus of Elasticity: The MOE values obtained for the three age classes of 15, 20 and 25 years old *Tectona grandis* wood were 6846.92, 9919.54 and 12845.57 N mm^{-2} respectively (Table 2). The mean values for MOE in the longitudinal positions ranged from 5771.47 to7864.62, 8861.05 to 11017.33 and 11373.90 to 14382.98 N mm^{-2} while in the radial positions the mean values obtained for MOE ranged from 6117.47 to 7628.86, 9187.50 to 10724.68 and 12006.94 to 13743.28 N mm^{-2} for ages 15, 20 and 25 years old *Tectona grandis* wood respectively (Table 2).

The observed increased in MOE values with increasing age of the tree may be attributed to the increment of growth rings and the addition of more mature wood as well as the increase age of the cambium as reported for *Nauclea diderichii* [8]. MOE increased from innerwood to outerwood at any particular height level along the tree bole (Table 2). Generally the trend of variations in MOE showed a decrease from base to top and an increase from pith to bark. Similar trend in MOE was reported in *Nauclea diderichii* [8]. The increase in MOE values from pith to bark was also observed in *Triplochiton sclroxylon* [12]. The observed increase in MOE may be attributed to the rapid growth in plantation trees at their early stages of development. Analysis of variance conducted at 0.05% probability level showed highly significant differences in MOE among ages, longitudinal positions and radial positions (Table 4). The interaction between age and height were significant at 0.05% probability level.

Compressive Strength Parallel to grain: The mean values obtained for CS were 43.74, 58.47 and 75.36 N mm^{-2} for ages 15, 20 and 25 years old *Tectona grandis* wood respectively (Table 3). The mean values for CS in the longitudinal positions ranged from 36.98 to 50.42, 50.77 to 66.28 and 65.56 to 86.68 N mm^{-2} while in the radial positions, the mean values ranged from37.82 to 49.30, 52.98 to 64.30 and 68.15 to 83.20 N mm^{-2} for ages 15, 20 and 25 years old *Tectona grandis* wood respectively (Table 3).

CS increased consistently with the age of the tree, from inner wood to outer wood at any particular height level but decreases from the tree base to the top (Table 3). The increased in CS from pith to bark have also been reported in *Nauclea diderichii*, *Triplochiton scleroxylon* and plantation grown Tamarach [8,12,5]. The increased in CS from innerwood to outerwood may be as a result of variations in some morphorlogical factors such as fibre length, wall thickness and fibre diameter. Analysis of variance conducted at 0.05 probability level to test the effects of the different ages, sampled trees, longitudinal positions and radial positions were significant (Table 4). The interaction between age and height, radial position and height were also significant at 0.05% probability level.

Conclusion: There was a general trend and pattern of variations in MOR, MOE and CS among the three age classes of 15, 20 and 25 years old plantation grown *Tectona grandis* wood. There were significant differences in mechanical properties within and between trees of the same and different age classes of *Tectona grandis*. Generally, mechanical properties decrease from the tree base to the top and increase from the pith outward to the bark. Differences in MOR, MOE and CS among the three age classes were also significant as mechanical properties increased with increase in age. Therefore the effect of age was the most important source of variation in MOR, MOE and CS of plantation grown *Tectona grandis*. This is an indication that, the choice of rotation age of trees can be used to control the mechanical properties of *Tectona grandis* wood.

Table 1: Mean Modulus of Rupture (N mm^{-2}) values of Teak (*Tectona grandis*) in Relation to Age, Heights and Positions

		Sampling	Height (%)		
Age (Years)	Radial Position	Base (10%) Mean±SD	Middle (50%) Mean±SD	Top (90%) Mean±SD	Mean Mean±SD
15	Outerwood	95.46±4.30a	87.21± 7.36b	76.38±5.72c	86.35± 9.57
	Middlewood	89.25±5.67bd	78.32± 5.62ce	63.54±4.53f	77.04±12.90
	Innerwood	80.23±5.73g	65.40± 6.85fh	55.94±3.73i	67.19±12.24
	Pooled mean	88.31±7.66	76.98±10.97	65.29±10.33	76.86± 9.58
20	Outerwood	127.87±6.38a	112.48±4.35b	98.31±4.57c	112.89±14.78
	Middlewood	115.80±5.85d	102.39±3.89e	90.65±4.83f	102.95±12.58
	Innerwood	108.71±5.10g	96.79±4.53eh	82.50±4.36i	96.00±13.12
	Pooled mean	117.46±9.69	103.89±7.95	90.49±7.91	103.95± 8.49
25	Outerwood	156.53±3.87a	143.76±5.94b	132.47± 4.87c	144.25±12.04
	Middlewood	148.32±4.73bd	135.29±7.63ce	120.24± 6.73f	134.62±14.05
	Innerwood	140.54±4.85eg	124.38±7.40fh	110.68± 6.54i	125.20±14.95
	Pooled mean	148.46±8.00	134.48±9.72	121.13±10.92	134.69± 9.53

Table 2: Mean Modulus of Elasticity (N mm^{-2}) values of Teak (*Tectona grandis*) in Relation to Age, Heights and Positions

		Sampling	Height (%)		
Age (Years)	Radial Position	Base (10%) Mean±SD	Middle (50%) Mean±SD	Top (90%) Mean±SD	Mean Mean±SD
15	Outerwood	8752.60±407.56a	7642.30±617.56b	6491.68±657.15c	7628.86±1130.52
	Middlewood	7947.91±476.91bd	6846.05±596.42ce	5587.35±354.07f	6794.44±1182.13
	Innerwood	6863.34±796.65eg	6253.68±483.32h	5235.38±332.32fi	6117.47± 822.48
	Pooled mean	7864.62±948.08	6914.01±696.80	5771.47±648.07	6846.92± 757.06
20	Outerwood	11871.64±601.34a	10734.82±607.58b	9567.59±462.25c	10724.68±1152.06
	Middlewood	10943.60±360.12bd	9843.42±597.82ce	8752.30±350.52f	9846.44±1095.65
	Innerwood	10236.75±428.18eg	9062.49±712.33h	8263.26±233.58fi	9187.50± 992.67
	Pooled mean	11017.33±819.94	9880.24±836.77	8861.05±658.93	9919.54± 771.19
25	Outerwood	15254.53±359.56a	13736.88±545.72b	12238.42±443.18c	13743.28±1508.07
	Middlewood	14352.13±351.23d	12754.47±642.92ce	11252.90±533.32f	12786.50±1549.86
	Innerwood	13542.28±487.38bg	11848.15±674.42ch	10630.39±584.13i	12006.94±1462.42
	Pooled mean	14382.98±856.54	12779.83±944.62	11373.90±810.82	12845.57± 869.68

Table 3: Mean Compressive Strength (N mm^{-2}) values ofTeak (*Tectona grandis*) in Relation to Age, Heights and Positions

		Sampling	Height (%)		
Age (Years)	Radial Position	Base (10%) Mean±SD	Middle (50%) Mean±SD	Top (90%) Mean±SD	Mean (%) Mean±SD
15	Outerwood	57.34±4.22a	48.72±3.28b	41.83±3.54c	49.30±7.78
	Middlewood	50.38±3.34bd	45.37±3.34be	36.59±3.38f	44.11±6.98
	Innerwood	43.56±4.15g	37.42±3.25h	32.48±3.80i	37.82±5.55
	Pooled mean	50.42±6.89	43.84±5.80	36.98±4.69	43.74±5.75
20	Outerwood	72.54±3.70a	64.57±2.88b	55.79±4.21c	64.30±8.38
	Middlewood	65.78±3.48bd	58.26±3.04ce	50.30±2.97f	58.13±7.71
	Innerwood	60.51±3.04eg	52.27±2.51h	46.17±3.06i	52.98±7.20
	Pooled mean	66.28±6.03	58.36±6.15	50.77±4.82	58.47±5.67

Table 3: Continue

25	Outerwood	95.48±2.40a	81.76±3.74b	72.35±3.69ce	83.20±11.63
	Middlewood	83.21±3.05bd	75.47±3.26eg	65.47±2.45f	74.72± 8.89
	Innerwood	78.24±3.50g	67.34±4.35h	58.87±4.10i	68.15± 9.71
	Pooled mean	86.68±8.86	74.86±7.23	65.56±6.74	75.36± 7.55

Table 4: Analysis of Variance for Mechanical properties of Teak (*Tectona grandis*).

Source of variation	Degree of freedom	Modulus of Rupture	Modulus of Elasticity	Compressive Strength
Age	2	1479.72*	1761.36*	1167.07*
Height	2	293.27*	283.99*	314.10*
Radial Position	2	148.94*	127.05*	186.14*
Age*Height	4	0.86ns	4.41*	4.77*
Age*Radial Position	4	0.41 ns	0.21ns	2.00ns
Radial Position*Height	4	0.41ns	1.87ns	2.01*
Age*Radial Position*Height	8	0.74ns	0.19ns	0.38ns
Error	135			
Total	161			

*significant at 0.05 probability level
ns = not significant at 0.05 probability level

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