VARIATION IN ANISOTROPIC SHRINKAGE OF PLANTATION-GROWN *Tectona grandis* (Linn) WOOD

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ABSTRACT

This study investigated anisotropic shrinkage of 15-year-old Tectona grandis wood to assess axial and radial variation. Four trees with clear bole and similar diameter were purposefully selected and felled from the plantation of Federal University of Agriculture, Abeokuta, Nigeria and used for this study. Wood samples were systematically collected from the outer, middle and inner wood sections of the radial direction and axially at base (25%), middle (50%) and top (75%) of the merchantable height. The mean value of wood weight was 29.77% while the mean values for longitudinal shrinkage, radial shrinkage, tangential shrinkage and volumetric shrinkage were 3.56%, 3.25%, 3.01% and 9.82% respectively. Variations in both axial and radial directions were statistically significant ($p \leq 0.05$) for all the properties evaluated except tangential shrinkage. This study showed that within tree and within species variation existed in the shrinkage properties of 15-year-old Tectona grandis. The variations have implications on dimensional stability of the species and therefore on the utilisation potentials.

Keywords: *Tectona grandis* wood, Axial and radial directions, Radial shrinkage, tangential shrinkage, volumetric shrinkage

INTRODUCTION

Wood is a natural, non-homogeneous material which reacts to changes in the surrounding humidity by varying its volume (Richter, 2014). It is an anisotropic (i.e exhibiting different properties along different axes) material (Amtzen and Charles, 1994). The magnitude of shrinkage and swelling depends on the amount of moisture either gained or lost by wood during fluctuation of moisture content. Wood properties vary along three mutually perpendicular axes i.e longitudinal, radial, and tangential because of the orientation of the wood fibres and the manner in which a tree increased in diameter as it grows (Amtzen and Charles, 1994). These changes in wood, generally take place from 0-30% moisture content, based on its oven dry weight (Helmuth, 1990). Higher rates of changes in moisture content amounts to shrinkage and swelling of wood, which causes not only dimensional changes, but also splitting, cracking or gluing separation in wood products. Variation exists both within a tree and from one tree to the other and also from sample to sample. This is arising from the fact that wood has different distribution patterns in its micro structure, arrangement, size and dimension of component cells (Rigatto, 2014). Generally, wood is characterized with special peculiarities which must be understood and considered for optimum application. Shrinkage is the change in volume of timber from green condition to its condition when dried to a specific moisture content of usually 12% (Steve, 2014). As timber dries, water is lost from cell walls thereby resulting in shrinkage. Drying wood products to the moisture content best suited for intended use will eliminate most problems and also ensure retention of its dimensional stability (Steve, 2014). Also proper drying of wood reduces drying defects, increases strength, minimizes dimensional changes and also provides a better base for paints, finishes, preservatives and adhesives (Helmuth, 1990). There is an increasing demand of *Tectona grandis* and understanding its pattern of variation in anisotropic shrinkage towards enhancing its effective and maximum utilisation and promoting value recovery of our plantations is apt. Therefore, a study of the variations in shrinkage characteristics of plantation grown *Tectona grandis* will be of help to provide relevant information on its wood quality and utilization potentials.

MATERIALS AND METHODS

Study Area

The Federal University of Agriculture, Abeokuta is located next to Ogun-Osun River Basin Development Authority (OORBDA), along Osiele-Abeokuta road, off Abeokuta-Ibadan road in the north Eastern end of the city at Alabata and is from the city center of Abeokuta which lies approximately on latitude $7^0$30' N and longitude $3^0$54' E. It lies within the humid lowland rain forest region with two distinctive seasons. The wet season extends from March to October while the dry season extends from November to February. The mean annual rainfall is 1113.1 mm. The rainfall has a characteristic bimodal distribution with peaks in July and September and breaks in August. The mean monthly temperature varies from 22.9^0C in August to 36.32^0C in March. The relative humidity is high ranging from 75.52^0C in February to 88.15^0C in July (Aiboni, 2001).

Experimental Design

Wood samples of *Tectona grandis* were collected from the Forestry Plantation site of Federal University of Agriculture, Abeokuta. Four trees with very close diameter classes, straight stem devoid of crookedness were purposefully selected. Samples were collected from both axial and radial positions. Axially, 10cm disks were cut on site at different stem heights of 25%, 50% and 75% from the ground. Blocks of 20 ×20 × 20 mm were cut from each sample for the determination of the shrinkage. Radial demarcation into outerwood, middlewood and innerwood was carried out based on distance away from the pith. The test samples were completely immersed in water for 48 hours to attain an initial moisture content level. At this moisture content level, the initial swelling dimension (longitudinal, radial and tangential) were taken with the aid of a digital calliper. The test samples were then weighed and air dried for 48 hours. The samples were re-weighed with an electronic weighing balance until the weights of the samples remained constant. The moisture content of the test samples were computed using the formula;

$$M.C = \frac{\text{Initial weight of samples} - \text{oven dry weight of samples}}{\text{Oven dry weight of samples}} \times 100 \quad (1)$$

Determination of Wood Shrinkage

Samples were soaked in water for 24 hours and dimensions were taken at maximum moisture content (M.M.C). in the longitudinal, radial and tangential surfaces. The samples were then air dried for 48 hours until the weights of the samples remained constant. The dimensions of the oven-dried samples were again taken at the same spots as when they were taken at M.M.C. Shrinkage was calculated for the longitudinal, radial and tangential surfaces based on measured dimensions at soaked and oven-dry conditions. The dimensional shrinkage in longitudinal, radial and tangential directions were obtained through the formulae as shown below:

$$Tgs = \frac{Dt-dt}{dt} * \frac{100}{1} \quad (2)$$

$$Rgs = \frac{Dr-dr}{dr} * \frac{100}{1} \quad (3)$$

$$Lgs = \frac{Dl-dl}{dl} * \frac{100}{1} \quad (4)$$

Where,
Tgs = Tangential shrinkage
Rga = Radial shrinkage
Lgs = Longitudinal shrinkage
Dt= Tangential dimension (mm) at M.M.C.
Dl = Longitudinal dimension (mm) at M.M.C.
Dr – Radial dimension (mm) at M.M.C.
dt= Tangential dimension (mm) at oven dried M.C.
dl = Longitudinal dimension (mm) at oven dried M.C.
dr= Radial dimension (mm) at oven dried M.C.

The volumetric shrinkage (VS) of each sample wascomputed using the relationship below:

$$VS = 100 - \frac{(100-Lgs)(100-Rga)(100-Tgs)}{10^2}\% \quad (5)$$

Determination of Wood Weight

The weight of the initial and the oven dry condition was calculated using this formula

$$Weight = \frac{\text{initial weight} - \text{oven dry weight}}{\text{oven dry weihgt}} * \frac{100}{1} \quad (6)$$

RESULTS AND DISCUSSION

Mean Weight of *Tectona grandis*

The mean weight of *T.grandis* wood samples are shown in Table 1. The mean weight value obtained was 29.77%. Axially, the value ranged between 30.15 and 30.20 while radially, 27.53, 27.58 and 34.19 were recorded for innerwood, middlewood and outerwood respectively. The weight of wood is affected by the cell wall thickness, cell diameter, earlywood to latewood ratio and chemical content of the wood (Orwa *et al.*, 2009). An inconsistent pattern of variation was recorded from the base to the top while at the radial position weight decreased steadily from the outerwood to the innerwood with an indication of uniformity towards the bark. This observed pattern of variations can be attributed to changes in cell size and cell wall thickness that are associated with annual and periodic growth cycles and the increasing age of the cambium (Rigatto, 2014). Analysis of Variance of weight at both radial and axial positions showed that sampled trees and radial position showed a significant difference at 5% probability level. This is an indication that the sample trees and radial positions contributed to the variations in weight (Table 3).

Table 1: Axial and radial variation in weight of T*ectona grandis* wood.

Wood Property (%)		Sample height			Pooled Mean±S.D.
	Position	Base (25%)	Middle (50%)	Top (75%)	
% weight change	Outer wood	36.49 ±3.40	32.03±1.58	34.07±7.39	34.19±4.73
	Middle wood	30.44±7.16	23.24±11.65	29.06±10.67	27.58±9.63
	Inner wood	23.68±3.04	31.57±6.91	27.3326±11.00	27.53±7.74
Pooled Mean ±S.D.		**30.20±7.04**	**28.95±8.28**	**30.15±9.37**	**29.77±8.06**

Longitudinal Shrinkage

The mean longitudinal shrinkage was 3.56%. The highest value (4.20%) was recorded in the middle followed by 3.58% at the base and 2.88% at the top while along the radial position longitudinal shrinkage increased consistently from the outerwood to the innerwood (Table 2). The pattern of variation showed that along the vertical axis longitudinal shrinkage was high at the base, it later decreased in the middle and rapidly decreased in the top giving an inconsistent pattern of variation. Radially, the pattern of variation shows that longitudinal shrinkage decreased gradually from the pith to the bark giving an indication of longitudinal uniformity towards the bark. Longitudinal shrinkage was observed to be a little higher than the radial shrinkage.The high longitudinal shrinkage in the corewood follows the same pattern reported by Donaldson (1992) and consistent with the high spiral grain angle observed by Cown *et al.,* (1991). Result of analysis of variance for longitudinal shrinkage showed that the trees, sampling heights and radial position have significant effect on the percentage longitudinal shrinkage at 5% probability level.

Radial Shrinkage

The mean radial shrinkage was 3.25%. The value increased from 3.88% in the middle to 3.13% in the top and 2.75% at the base. Radially, it decreased from 4.00% in the inner wood to 3.33% in the middle wood and 2.42% at the outer wood (Table 2). Axially, the radial shrinkage was highest at the middle and lowest at the base. This pattern could be attributed to some physiological activities in the wood cells. Also, the influence of the microfibril angle of S_2 layer plays a critical role in influencing shrinkage. Result of analysis of variance for radial shrinkage showed that the trees, sampling heights and radial position have significant effects at 5% probability level.

Tangential Shrinkage

The mean tangential shrinkage obtained was 3.01%. Along the bole the value ranged from 2.21% at the base to 3.25% at the top and 3.58% at the middle. Radially, the mean ranged from 3.54% in the inner wood to 3.00% in the outer wood and 2.50% in the middle wood (Table 2). The pattern of variation along the vertical axis indicates that tangential shrinkage was highest at the middle contrary to Okon (2014). Tangential shrinkage decreased from inner wood to outer wood (Table 2). The mean percentage shrinkage obtained in the tangential direction was equal or less than that obtained in the radial direction. The differences recorded could be attributed partly to the restricting effect of the rays on the radial plane, the difference in the degree of lignification between the radial and tangential walls, the difference in microfibrillar angle between the two walls and the increase in thickness of the lamella in the tangential direction in relation with that in the radial direction. Analysis of variance carried out showed that the variations among the trees, sampled height and radial positions were significant at 5% probability level (Table 3).

Volumetric Shrinkage

The volumetric shrinkage and swelling properties are affected by several wood factors, such as the heartwood to sapwood ratio of the fibrillary angle on the S2 layer. The mean volumetric shrinkage was 9.82%. The values ranged from 8.54% in the base to 9.25% at the top along the vertical axis. Radially, the value ranged from 10.65% in the inner wood to 12.13% at the outer wood (Table 2). Volumetric shrinkage exhibited an irregular pattern of variation along its bole. The irregular pattern of variation is contrary to Rigatto (2004). The inner wood of the study samples had the highest shrinkage. This may be due to the presence of greater amount of extractives in the inner wood which tend to inhibit normal shrinkage by bulking the amorphous regions in the cell wall substances Shrinkage differs in the three directions due to the influence of wood rays and different arrangements of fibrils on cell walls. Analysis of variance of volumetric shrinkage indicates that significant difference occurred among the trees, sampling heights and in the radial positions at 5% probability level (Table 3).

Table 2: Axial and radial variation in the Longitudinal, Radial, Tangential and Volumetric Shrinkages of *Tectona grandis* Wood

Wood Property (%)	**Position**	**Base (25%)**	**Middle (50%)**	**Top (75%)**	**Pooled Mean±S.D.**
Longitudinal shrinkage	Outer wood	2.63±0.75	2.88±0.48	2.88±0.63	2.79±0.58
	Middle wood	3.38±2.10	4.25±1.85	2.75±1.50	3.46±1.78
	Inner wood	4.75±0.29	5.50±0.41	3.00±0.71	4.42±1.18
Pooled Mean±S.D.		**3.58±1.49**	**4.20±1.51**	**2.88±0.93**	**3.56±1.41**
Radial shrinkage	Outer wood	2.63±0.48	1.75±0.65	2.88±1.181	2.42±0.90
	Middle wood	3.00±0.41	4.13±1.18	2.88±0.85	3.33±0.98
	Inner wood	2.63±1.25	5.75±2.53	3.63±0.48	4.00±2.02
Pooled Mean±S.D.		**2.75±0.75**	**3.88±2.28**	**3.13±0.88**	**3.25±1.51**
Tangential shrinkage	Outer wood	2.38±0.85	3.13±2.93	3.50±0.71	3.00±1.71
	Middle wood	2.13±1.31	2.25±0.29	3.13±2.17	2.50±1.41
	Inner wood	2.13±0.63	5.38±3.66	3.13±0.63	3.54±2.43
Pooled Mean±S.D.		**2.21±0.89**	**3.58±2.81**	**3.25±1.25**	**3.01±1.89**
Volumetric shrinkage	Outer wood	7.63±0.85	7.75±3.20	9.25±1.71	8.21±2.09
	Middle wood	8.50±1.58	10.63±2.84	8.75±4.48	9.29±3.06
	Inner wood	9.50±1.87	16.63±6.50	9.75±1.50	11.96±5.00
Pooled Mean±S.D		**8.54±1.57**	**11.67±5.61**	**9.25±2.66**	**9.82±3.84**

Table 3: Analysis of Variance (ANOVA) of the weight and shrinkage characteristics of *Tectona grandis* wood.

Wood Property	Source of Variation	Sum of Squares	df	Mean Square	F
%Weight change	Radial Position (RP)	352.921	2	176.461	2.901*
	Sampling Height (SH)	12.155	2	6.078	.100[ns]
	Interaction (RP x SH)	268.995	4	67.249	1.106[ns]
	Error	1642.312	27	60.826	
	Total	2276.384	35		
Longitudinal shrinkage	Radial Position (RP)	16.014	2	8.007	6.005**
	Sampling Height (SH)	10.681	2	5.340	4.005*
	Interaction (RP x SH)	7.194	4	1.799	1.349 ns
	Error	36.000	27	1.333	
	Total	**69.889**	**35**		
Radial shrinkage	Radial Position (RP)	15.167	2	7.583	5.442**
	Sampling Height (SH)	7.875	2	3.937	2.826*
	Interaction (RP x SH)	19.083	4	4.771	3.424*
	Error	37.625	27	1.394	
	Total	**79.750**	**35**		
Tangential shrinkage	Radial Position (RP)	6.514	2	3.257	.960[ns]
	Sampling Height (SH)	12.347	2	6.174	1.820[ns]
	Interaction (RP x SH)	14.819	4	3.705	1.092[ns]
	Error	91.563	27	3.391	
	Total	**125.243**	**35**		
Volumetric shrinkage	Radial Position (RP)	89.389	2	44.694	4.348*
	Sampling Height (SH)	64.431	2	32.215	3.134*
	Interaction (RP x SH)	83.694	4	20.924	2.035[ns]
	Error	277.563	27	10.280	
	Total	**515.076**	**35**		

ns = Not significant at 5% (p<0.05) level
* = Significant at 5% (p<0.05) level
** = Significant at 1% (p<0.01) level

Table 4: Analysis on weight change, Percentage Shrinkage in the radial and axial position of *Tectona grandis* wood

Position	% weight change	Longitudinal shrinkage	Radial shrinkage	Tangential shrinkage	Volumetric shrinkage
Outer	34.19[a]	2.79[a]	2.42[a]	3.00[a]	8.21[a]
Middle	27.58[b]	3.46[ab]	3.33[ab]	2.50[a]	9.29[ab]
Inner	27.53[b]	4.42[b]	4.00[b]	3.54[a]	11.96[b]
Base (25%)	30.20[a]	3.58[ab]	2.75[a]	2.21[a]	8.54[a]
Middle (50%)	28.95[a]	4.21[a]	3.88[b]	3.58[a]	11.67[b]
Inner (75%)	30.15[a]	2.88[b]	3.13[ab]	3.25[a]	9.25[ab]

Mean with different superscripts along the same column are significantly different at 5% (p<0.05) level.

CONCLUSION

This work showed that variations existed in the shrinkage properties of 15 year old *Tectona grandis*. Both the within tree variation and within species variations were established. The weight change and shrinkage characteristics observed in this study were significant at different height levels as well as in the longitudinal, radial and tangential positions. The variations recorded clearly show that the species is susceptible to high distortion in timber drying and dimensional instability with multiplier effects on utilisation.

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