



## VARIATION IN DENSITY AND SHRINKAGE BETWEEN SAWMILL AND HAND PROCESSED *KHAYA SENEGALENSIS* WOOD IN SOKOTO, NORTH-WESTERN NIGERIA

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### ABSTRACT

*A research on shrinkage and density variation between sawmill and hand processed Khaya senegalensis timber was conducted to determine the effectiveness of the species in service. The wood samples obtained from Kara market Sokoto were cut into standard sizes for the determination of moisture content, density and shrinkage respectively. Analysis of variance was used to analyze the data. The study reveals that sawmill has an average moisture content of 15.43%, average density of 901.90kg/m<sup>3</sup> and volumetric shrinkage of 8.40%. While hand processed Khaya senegalensis has an average moisture content of 15.88%, average density of 812.07kg/m<sup>3</sup> and volumetric shrinkage 8.12%. However, density recorded in both sawmill and hand processed Khaya senegalensis wood belongs to high class, suggesting that even the hand processed can serve the low and middle income class satisfactorily and is thus recommended for economic consideration.*

**Keywords:** *Khaya senegalensis*, Sawmill, Wood, Density, Shrinkage, Moisture.

### Contribution/ Originality

This study is one of very few studies which have investigated the relationship between sawmill and hand processed wood in Nigeria. It contributes in the existing literature as well as in the wood preference among the small scale wood users (e.g. Local Carpenters) and large scale furniture factories in North-Western Nigeria.

### 1. INTRODUCTION

Wood is a hard fibrous structural tissue found in the stems, branches or roots of trees and other woody plants (Bonadea, 2014). It has been used for both fuel and as a constructional material. It is an organic material, a natural composite of cellulose fibers (which are strong in tension) embedded in a matrix of lignin (which resists compression). Wood is also defined as the

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secondary xylem in the stem of trees (Seahorseruler, 2014). In a living tree, it performs support function and also mediates the transfer of water and nutrients to the leaves and other growing tissues.

*Khayasenegalensis* belongs to the family *Meliaceae*; native to Africa, commonly known as African mahogany. It is a medium sized tree which can grow up to 15-30m in height and 1.0m in diameter (Anon, 2014). The bark is dark grey to grey-brown, while the heartwood is brown with a pink red pigment made up of coarse inter locking grains (Von Maydell, 1990). The species is characterized by leaves arranged in a spiral formation clustered at the end of branches.

The flowers are sweet scented, while the fruit changes from grey to black when ripening (Von Maydell, 1990). *K. senegalensis* is native to Senegal, Benin, Nigeria, and Central African Republic among others. However, despite range of uses identified, the wood is often used conventionally for carpentry, interior trim, furniture and building constructions (Richter, 2014). The wood is fairly easy to work with moderate blunting effect on cutting edges. It has good gluing properties hence it holds nails and screws, takes polishes and paints but peeling properties are poor due to relatively high density and inter locked grain (Prota, 2014). Similarly, wood movement can ruin a seemingly well constructed project. This can however be modified by determining the extent of shrinkage and density prior to construction.

### 1.1. Wood Moisture Content (MC)

The moisture content of wood is expressed in terms of its oven-dry mass, while in newly felled trees or freshly cut lumber it is often referred to as sap (Helmuth, 1990). At this stage the material is referred to as green, and is applicable where it is immersed in water e.g. in harbor pilling. While for other uses, the moisture content must be lowered in order to provide dimensional stability and reduce the risk of fungal attack, (Dinwoodie, 1989). Generally, a distinction is made between free water located in cell cavities, and bound water which is held within the cell walls. A fiber saturation point (FSP) is reached when free water evaporates from cell cavities, but bound water still saturates cell walls (Helmuth, 1990).

This condition exist at a moisture content of up to 30%, and moisture loss below the fiber saturation point causes shrinkage, because wood molecules draw closer together as water molecules leaves. Moisture content of wood below the fiber saturation point is a function of both the relative humidity and temperature of the surrounding air (Helmuth, 1990). At equilibrium moisture content (12%), wood neither gains nor loses water, because it has reached equilibrium with the vapor pressure of the surrounding atmosphere. Change in relative humidity and temperature of the surrounding air causes seasonal, daily, as well as long term changes in the moisture content of wood, thereby affecting strength of wood in service. However, once dried *Khaya senegalensis* is stable in service (Loupe, 2014).

### 1.2. Wood Shrinkage

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. Generally wood is characterized with special peculiarities which must be understood and considered for optimum application. One of these is hygroscopicity which causes dimensional changes due to the moisture absorption and desorption. Wood is a natural non-homogeneous material which reacts to changes in the surrounding humidity by varying its volume (Richter, 2014). 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. 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). However, *Khaya senegalensis* is a moderately heavy density species (Dinwoodie, 1989) with rates of shrinkage moderately from green to oven dry 4.0 – 5.9% (Radial) and 4.3-7.2% (tangential) respectively (Louppe, 2014).

### 1.3. Wood Density

Wood density is the amount of wood substance present per unit volume (Chave, 2006). It is of practical significance, because wood density is the best single criterion of strength (Dinwoodie and Desch, 1991). Wood strength refers to the ability of wood to resist external forces or loads tending to alter its size or shape (Steve, 2014). The presence of moisture influences significantly the density of wood, therefore mass and volume are determined at zero moisture content usually following a period of oven-drying at  $103 \pm 2^{\circ}\text{C}$ , thus density is quoted at 12% moisture content, because wood at this moisture content is in equilibrium state (Dinwoodie, 1989). The density of wood is also influenced by the presence of extractives, which are usually present in small amounts and the error involved in calculating density is very small, but in exceptional cases extractives can represent up to 10% of the mass of the wood (Dinwoodie, 1981). In this circumstance, in order to achieve a reliable estimate of density the extractives must first be removed by treatment with hot water or chemical solvents (Dinwoodie, 1981). The mechanical performance of wood is closely related to its density (Orwa, 2009). Variation in density is evident among various species as well as between samples of different species (Helmuth, 1990) such that the heaviest wood is found at the base of the tree, and there is a gradual decrease in density in samples from successively higher levels in the trunk (Dinwoodie and Desch, 1991). At any given height in the trunk there is usually a general increase in density outwards from the pith, but slowing down considerably thereafter. This variation in density between species and between samples of the same species is attributed to the influence of growth rate, site condition as well as species genetic compositions (Dinwoodie

and Desch, 1991). However, *Khaya senegalensis* has an average density of 710-810kgm<sup>3</sup> at 12% moisture content (Prota, 2014).

## 2. MATERIALS AND METHODS

### 2.1. Study Area

Sokoto state is situated between latitudes 11°-13° 05'N and longitudes 04°- 05° 15'E. It falls within the Sudan Savanna zone characterized by two distinct seasons (wet and dry) of varying duration and intensity. The state has a total land mass of about 25, 973km<sup>3</sup> (Anon, 2014). It is bordered in the North by Niger Republic, Zamfara state to the east and Kebbi state to the south and east respectively. The rainy season is short often 3-4months (usually from May to September) with highest fall in August. The mean annual rainfall is 550 - 750mm with relatively high temperature, though it varies with the season. The mean annual temperature is 28 - 40°C (Anon, 2014).

The vegetation of the area is characterized by few scattered trees amongst dominating herbaceous layers which are threatened by the inhabitants as a result of over exploitation without replacement. Consequently, the rate of wood consumption for construction and furniture is very high, though the inhabitants depend largely on wood supply from the southern part of the country which makes the price of wood as well as wood products relatively higher in the area (Olufemi and Malami, 2011).

## 3. EXPERIMENTATION

Sawmill and hand processed planks of *Khaya senegalensis* were purposively selected for the research. The total volume of each plank was first measured and then cut to 100.00 x 60.00 x 40.00mm for moisture content determination, 75.00x 45.00 x 20.00mm for density measurement as well as 100 x 20.00 x 20.00mm for shrinkage determination respectively (Pescarus and Cismaru, 1979). Analysis of variance (ANOVA) was used to analyze the data while mean separation was done using Duncan's multiple range test (DMRT).

### 3.1. Determination of Moisture Content (MC)

The weight of samples was measured using a weighing balance and then, oven dried at a temperature of 103°C ± 2°C for 24hours (A.O.A.C. (Association of Official Analytical Chemists), 1990). The moisture content (MC) was calculated using the equation below

$$MC = \frac{Wg - Wd}{Wd} \times 100$$

Where C = moisture content (%), Wg = Green wet (kg), Wd = Dry wet (kg)

### 3.2. Determination of Wood Density

Density simply means concentration of matter measured as mass per unit volume. In woodwork, an engineering interpretation of density is typically weight per unit volume

(Eckelman, 2014). The weight of the samples was measured using electronic weighing balance, while the volume was calculated using the formula:

$$V = l \times b \times h$$

Where  $V$  = volume ( $m^3$ ),  $l$  = Length (m),  $b$  = Breadth (m),  $h$  = height (m)

Density ( $P$ ) was calculated using:

$$P = \frac{W}{V}$$

Where  $P$  = Density ( $kg/m^3$ ),  $W$  = weight of dry wood sample (kg),  $V$  = Volume of oven dry wood sample ( $kg$ )

### 3.3. Determination of Shrinkage

The test samples were immersed in water for 30minutes and their moisture content (MC) was measured using a moisture meter at 15minutes interval until a fiber saturation point (30%) reached. This procedure agrees with ASTM (American Society for Testing Materials) (2006). The initial dimension across tangential, radial and longitudinal axis of the samples was measured, and then oven dried at a temperature of  $103^{\circ} \pm 2^{\circ}C$  for 30minutes. The final dimension of the three asymmetrical axis of the samples was measured using vernier calipers respectively. The coefficient of tangential, radial and longitudinal linear shrinkage of the samples was calculated using the equations below:

$$at = \frac{Dt - dt}{Dt} \times 100$$

$$ar = \frac{Dr - dr}{Dr} \times 100$$

$$al = \frac{Dl - dl}{Dl} \times 100$$

Where:  $at$ ,  $ar$ , and  $al$  are coefficients of Tangential, Radial and Longitudinal linear shrinkage (%) respectively.  $Dt$ ,  $Dr$  and  $Dl$  are initial dimensions (mm) of the green samples along Tangential, Radial and Longitudinal axis, while  $dt$ ,  $dr$  and  $dl$  are the final dimensions respectively. Also the coefficient of volumetric shrinkage ( $\alpha v$ ) of each sample was calculated using:

$$\alpha v = \frac{(100 - at)(100 - ar)(100 - al)}{10^4} \%$$

## 4. RESULTS AND DISCUSSIONS

### 4.1. Density

The wood samples were dried to a moisture content of 12-15% before density measurement. This is in line with the opinion of Dinwoodie (1989) that, density is frequently quoted at 12% moisture content, because wood at this state is in equilibrium with relative humidity of 65%. The results showed that, density variation range from  $861.28kg/m^3$  to  $947.37kg/m^3$  with mean value

of 901.90kg/m<sup>3</sup> for sawmill, and 749.82kg/m<sup>3</sup> to 856.30kg/m<sup>3</sup> with mean value of 812.07kg/m<sup>3</sup> for hand processed *Khaya senegalensis* respectively (Table 1).

This result however, opposes the findings of Reilly and Robertson (2013), who recorded 637kg/m<sup>3</sup> as an average density of *Khaya senegalensis* wood sample obtained from a merchantable log. On the other hand, agreed with the findings of Dinwoodie (1989) who stated that, variation in density of some common hardwoods at 12% moisture content ranges between 176kg/m<sup>3</sup> to 1230kg/m<sup>3</sup>. The values though, are subject to considerable fluctuation on account of systematic variations within a single tree as well as genetic and environmental variation between trees of the same species. Moreover, mean density of 812.07kg/m<sup>3</sup> recorded from hand processed samples at 12-15% moisture content agreed with the work of Brennan and Radomiljak (2014) who recorded 680kg/m<sup>3</sup> as mean dry density of wood sample obtained from 8years *K. senegalensis* at 7% moisture content. In the same vein, the findings of this research opposes the work of W.D.B. (2014), whereby 640kg/m<sup>3</sup> was recorded as mean density of *K. senegalensis* at 12% moisture content. According to Robertson and Reilly (2012), *K. senegalensis* is a moderately heavy density species with density value of about 750kg/m<sup>3</sup> at 12% moisture content. This agrees with findings of this research, in which 749.82kg/m<sup>3</sup> to 856.30kg/m<sup>3</sup> were obtained as density variations in hand processed samples of *K. senegalensis*. Also the finding of this research agrees with the findings of Prota (2014) that, *K. senegalensis* has density of 710-900kg/m<sup>3</sup> at 12% moisture content.

#### 4.1. Shrinkage

The coefficients of linear shrinkage along longitudinal axis ( $\alpha_l$ ) range from 0 - 2.91% in sawmill and 0.99 - 3.88% in hand processed with mean values of 1.44% and 2.05% respectively. While the coefficient of linear shrinkage along the radial axis ( $\alpha_r$ ) ranges from 0-14.29% in sawmill and 5-14.29% in hand processed with mean values of 7.67% and 9.52%. Similarly along tangential axis, the coefficient of linear shrinkage ( $\alpha_t$ ) ranges from 0-19.05% in sawmills and 0-14.29% in hand processed with mean value of 7.68% and 8.54% respectively. However, the coefficient of volumetric shrinkage ( $\alpha_v$ ) of samples in sawmill varied from 7.56% to 9.52% with mean value of 8.40% while in hand processed, it varied from 7.12% to 9.22% with mean value of 8.12%. (Table 1). The values 0.99-3.88% recorded as coefficient of linear shrinkage along longitudinal axis in hand processed samples of *K. senegalensis*, agreed with the finding of Helmuth (1990) that, shrinkage is minimal (between 0.1 and 0.2) longitudinally along the grain. The findings of this research opposed the work of Louppe (2014) who state that, *K. senegalensis* has moderate rates of shrinkage, from green to oven dry 4.0-5.9% (radial) and 4.3-7.2% (tangential), on the other hand, the research results agreed with the finding of Steve (2014) who state that, *K. senegalensis* has a volumetric shrinkage of 10%.

Moreover, the results obtained in this research tally with the opinion of Dinwoodie and Desch (1991) that, when wood dries from above fiber saturation point to the oven dry state, the change in longitudinal dimension is very small while in the radial or tangential axis appreciable

shrinkage occurs up to 5% and 10% (average) respectively, though few timbers are characterized with low shrinkage values e.g. Afzelia, Teak etc. The result also tally with the work of Albert (2014) that, shrinkage along the grain is negligible, ranging from 2 - 8%, such that *K. senegalensis* has an average shrinkage of 3.0% (Radial) and 4.1% (Tangential) respectively. Generally, the variation in shrinkage between the three asymmetrical axes observed in this research, confirm the anisotropic property of wood as pointed out by Dinwoodie (1981). In the same vein, it agrees with Helmuth (1990) who stated that, shrinkage differs not only for different wood species, but also between and within trees of the same species.

Table-1. Distribution of Density and Shrinkage of the samples

| Sample         | Density kg/m <sup>3</sup> | Shrinkage (%)      |                    |                    |                    |
|----------------|---------------------------|--------------------|--------------------|--------------------|--------------------|
|                |                           | <i>AI</i>          | <i>ar</i>          | <i>at</i>          | <i>av</i>          |
| Sawmill        | 901.90 <sup>a</sup>       | 1.4 <sup>ns</sup>  | 7.67 <sup>ns</sup> | 7.68 <sup>ns</sup> | 8.40 <sup>ns</sup> |
| Hand processed | 812.07 <sup>b</sup>       | 1.97 <sup>ns</sup> | 9.52 <sup>ns</sup> | 8.54 <sup>ns</sup> | 8.12 <sup>ns</sup> |
| Standard error | 5.34                      | 0.167              | 0.744              | 0.841              | 7.55               |

Means followed by the same letters along the Colum are not statistically different ( $p>0.05$ ).

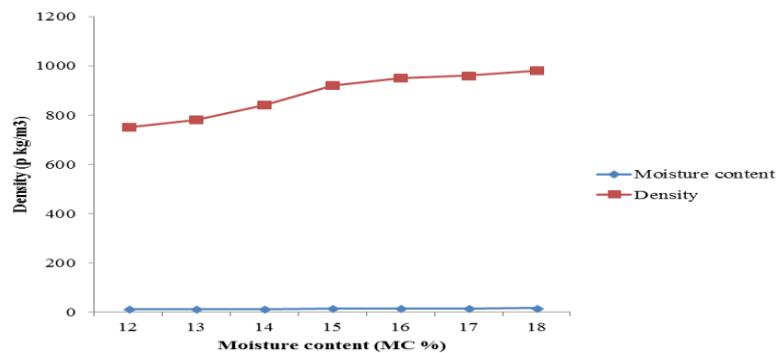


Figure-1. Graphical Relationship of Density & Moisture content of *K. senegalensis* Wood.

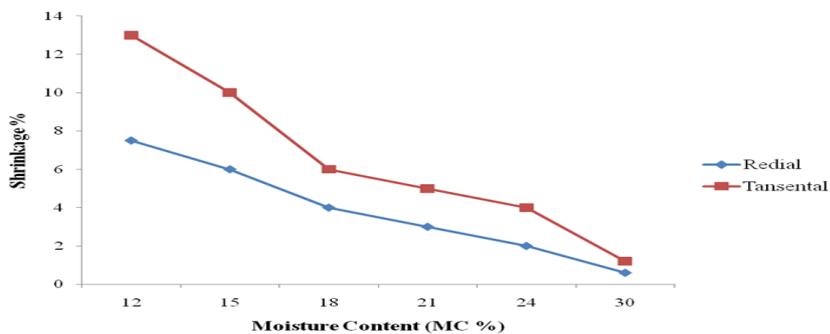


Figure-2. Graphical Relationship between Shrinkage and Moisture Content of *K. senegalensis* wood.

## 5. CONCLUSION

The mechanical performance of wood is closely related to its density. Similarly, the dimensional changes in wood are unequal in different directions. In view of this, the knowledge of

density and shrinkage is not only important but necessary. This paper highlighted the variation in density and shrinkage between Sawmill and Hand processed *Khaya senegalensis* timber in Sokoto State Nigeria, with a view to enable the users maximize the effectiveness of wood in service. However, analysis of variance indicated no significant difference between sawmill and hand processed *Khaya senegalensis* timber at 0.5% level. (Table 1)

## 6. RECOMMENDATIONS

In view of the findings of this research, the following recommendations were made:

1. Considering the long dry season in Sokoto state, *K. senegalensis* should be dried to a moisture content of 15-20% before it is subjected to service.
2. Dried wood should be coated with preservatives to avoid termite attack.
3. In view of the physical limitations or irregularities in size and shape, sawmill processed *K. senegalensis* is recommended.
4. *K. senegalensis* plantations should be encouraged in Sokoto state as mature stand are seldom identified due to exploitation without replacement.
5. For further research, care should be taken in the selection of wood sample due to variation in moisture content between heart wood and sap wood, which thus influence density and shrinkage.

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