PROPERTIES OF 10 GHANAIAN HIGH DENSITY LESSER-USED-SPECIES OF IMPORTANCE TO BRIDGE CONSTRUCTION – PART 1: GREEN MOISTURE CONTENT, BASIC DENSITY AND SHRINKAGE CHARACTERISTICS

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ABSTRACT

Sixty trees of ten high density Lesser Used Species (LUS) of potential importance to bridge construction were extracted from four forest reserves - Bobiri, Pra-Anum, Nueng, and Subri River (in four different ecological zones). Logs from the trees were converted on a horizontal bandmill to 27 and 53 mm thick boards. Specimens were prepared from the green boards for the determination of the green moisture content, basic density, and dimensional shrinkage of each of the ten species: ***Celtis mildbraedii****,* ***Celtis zenkeri, Combretodendron africanum*** *(Essia),* ***Cynometra ananta*** *(Ananta),* ***Lophira alata*** *(Kaku),* ***Nauclea diderrichii*** *(Kusia),* ***Nesogordonia papaverifera*** *(Danta),* ***Piptadeniastrum africanum*** *(Dahoma),* ***Strombosia glaucescens*** *(Afina), and* ***Sterculia rhinopetala*** *(Wawabima). Mean green moisture content was lowest in Kaku (45%) and highest in* ***Celtis zenkeri*** *(93%). Mean basic density was highest in Kaku (840 kg/m^3) and lowest in* ***C. zenkeri*** *(560 kg/m^3). Mean green moisture content and mean basic density of the species negatively correlated with a correlation coefficient of -0.87. Mean total tangential shrinkage varied from a low of 6.2% for Dahoma to a high of 9.9% for Kaku. Based on the mean tangential shrinkage from green to 12% moisture content the dimensional shrinkage of the species were classified as 'small' for Dahoma, Kusia, Ananta and Danta; 'medium' for* ***Celtis mildbraedii****, Afina,* ***C. zenkeri****, Essia and Kaku; and 'large' for Wawabima. Tangential to radial shrinkage (T/R) ratio was 'very low' in Kaku, 'low' (or fairly close to 1.5) in Danta, Afina,* ***C. zenkeri*** *and* ***C. mildbraedii****, 'pronounced' (> 1.5) in Ananta and Dahoma; and 'very pronounced' (>> 1.5) in Kusia, Wawabima and Essia. The pronounced differential shrinkage (≥ 1.5) in these woods is likely to cause wide splits, checks and distortions if precautions are not taken during the kiln drying of these heavy wood species. Total longitudinal shrinkage was excessive and exceeded the normal figure of 0.2% in all ten species, and was higher than the rare figure of 0.4% in Kaku and Ananta.*

Keywords: **High Density Species, Bridge Construction, Green Moisture Content, Basic Density, Shrinkage**

INTRODUCTION

The construction and maintenance of transport infrastructure in developing countries is considered vital to improve the economy and standard of living of people far away from the main routes. In Ghana the routes which have been targeted are rural feeder roads which connect rural areas to the main highways. A major part of the work required to improve the road network is the construction of culverts and bridges. The use of timber for bridges of up to 20 metres span has been identified as being economical based on the use of locally available materials and labour (Allotey, 1992; Jayanetti *et al*, 1999).

Timber is unique amongst the major structural materials (concrete and steel), in that it is produced almost directly from a growing, organic resource. Potentially, this resource is completely renewable, and can be produced from sustainably managed forests to achieve both economic and environmental benefits, and eliminate the danger of deforestation. Sustainable forest management has been made a priority in Ghana, and the government is now actively pursuing the use of lesser-used-species (LUS) and plantation species to reduce the pressure on the more popular timbers.

Ghana has considerable wealth in tropical hardwood timber resources. There are about 680 different species of trees in the forest reserves of Ghana. Approximately 420 of these tree species attain timber size and therefore, are of potential economic value. About 126 of them occur in sufficient volumes to be considered exploitable as a raw material base for the timber industry (Ghartey 1989). However, about 90% of the country's wood exports are covered by 10 species (Jayanetti *et al*, 1999), and only 4 species contribute roughly 60% of the total production (Upton & Attah 2003). The LUS occur in abundance in the forest, but increased harvesting must be on a sustainable basis to ensure continued harvesting potential.

For the Department of Feeder Roads and Ghana Highways Authority to use the LUS for the construction of timber bridges, it is important that suitable wood species are identified, and their physical and technological characteristics determined and assessed to find out which of them has the potential of being used for timber bridges. This would involve undertaking studies on the physical properties, mechanical strength, machinability (or woodworking) properties, and preservative treatability of the species. This paper is restricted to the study on the physical properties of the wood of 10 high density LUS.

Regardless of the source of a wood product, the user may be primarily concerned with the variability that may be encountered in the green moisture content and the basic density of wood. These are directly related to the weight of logs and green lumber. Information on green moisture content may be of concern to those who design harvesting and transport equipment, or must ship or transport green wood; and data on basic density is needed in estimating the variability in the strength of a wood product (Haygreen and Bowyer, 1996). Since denser woods shrink more than less dense woods, it is expected that variations in basic density might lead to some variation in shrinkage.

In characterizing wood species it is essential that the shrinkage of wood is known especially for applications or end-uses in bridge construction such as: bearing blocks, planking, decks, timber finished to size, beams, and joints (BS, 1957).

The physical properties studied and reported here were green moisture content; basic density based on the oven-dry weight and green volume; shrinkage from the green to 12% moisture content and oven-dried state (in the axial, tangential, and radial directions of the trees).

Indication of forest availability of the species (TEDB, 1994) is based on mean volumes (m^3) per km^2 in the production forests of Ghana (7,600 km^2) as: '*Abundant*' [over 1,000 m^3 per km^2], '*Plentiful*' [250 - 1,000 m^3 per km^2], '*Average*' [50 – 250 m^3 per km^2], and '*Below Average*' [below 50 m^3 per km^2]. Of the ten species selected for the study *Celtis mildbraedii*, *Celtis zenkeri*, *Piptadeniastrum africanum*, and *Nesogordonia* *papaverifera* were classified as '*Abundant*'; *Petersianthus macrocarpus*, and *Sterculia rhinopetala* as '*Plentiful*'; and *Strombosia glaucescens*, *Cynometra ananta*, *Lophira alata*, and *Nauclea diderrichii* as '*Average*'.

MATERIALS AND METHODS

Materials

Four forest reserves in four different forest ecological zones were identified. They were: Bobiri Forest Reserve (Moist Semi-Deciduous – North-East Type) – (6^o 39'N - 6^o 44'N and 1^o 15' W - 1^o 23' W), Pra-Anum Forest Reserve (Moist Semi-Deciduous – South-East Type) – (6^o 12' - 6^o 19' N and 1^o 9' - 1^o 17' W), Nueng Forest Reserve (Moist Evergreen) – (5^o 02' N - 5^o 14' N and 1^o 55' W - 2^o 07' W), and Subri River Forest Reserve (Wet Evergreen) – (5^o 05' N - 5^o 30' N and 1^o 35' W - 1^o 55' W).

Ten (10) LUS of potential importance to bridge construction were selected. For each species, six (6) trees were extracted from the forest reserves (see Table 1). In all, sixty (60) trees were obtained. They were made up of 24 trees from Bobiri Forest Reserve, 21 trees from Pra-Anum Forest Reserve, 6 trees from Nueng Forest Reserve, and 9 trees from Subri River Forest Reserve. The diameters of the trees at 1.3 metres above ground were at least 45cm, except the plantation grown Kusia trees that were about 30-45cm.

Clear boles between where the buttresses terminated and the branches began in each tree were obtained. Each clear bole was cut into 5 to 9 logs of 2.5m. The logs were immediately removed from the forest and conveyed to the laboratory.

Table 1: List of LUS extracted from Forest Reserves for the Timber Bridges Project

No	Species		Tree Numbers Extracted From Following Forest Reserves			
	Botanical Name	Common Name	Bobiri	Pra-Anum	Nueng	Subri
1	Piptadeniastrum africanum	Dahoma	1, 2, 3	4, 5, 6	-	-
2	Nesogordonia papaverifera	Danta	1, 2, 3	4, 5, 6	-	-
3	Strombosia glaucescens	Afina	1, 2, 3	4, 5, 6	-	-
4	Nauclea diderrichii	Kusia / Opepe	1, 2, 3	-	-	4, 5, 6 [P]*
5	Petersianthus macrocarpus	Essia	1, 2, 3	4, 5, 6	-	-
6	Celtis mildbraedii	Celtis / Esafufuo	1, 2, 3	4, 5, 6	-	-
7	Celtis zenkeri	Celtis / Esakokoo	1, 2, 3	4, 5, 6	-	-
8	Sterculia rhinopetala	Wawabima	1, 2, 3	4, 5, 6	-	-
9	Cynometra Ananta	Ananta	-	-	4,5,6	1, 2, 3
10	Lophira alata	Kaku / Ekki	-	-	4,5,6	1, 2, 3

* P = Plantation grown

Conversion and Sampling

The logs were converted on a horizontal bandmill (‘Woodmizer’) to 27 mm and 53 mm thick boards. Specimens were prepared from the green boards for the determination of the green moisture content, basic density, and dimensional shrinkage (from green to 12% moisture content and from green to oven-dry state) for all ten species. Some boards were cut and stored for subsequent mechanical strength (Ofori *et al*, 2009b) and woodworking studies.

Moisture Content Distribution

Two 2.5 cm strips were extracted and planed to 2 cm thickness. Each strip was then sawn to produce 2 cm by 2 cm square sections. The 2 cm by 2 cm square sections were then crosscut to 2 cm cubes. The green mass (W) of the specimen cubes was determined and then oven-dried at 101^{o}C - 105^{o}C until constant mass (D) was attained. The moisture content (MC) was then calculated according to the formula:

$$MC = ((W - D) / D) \times 100\ \%.$$

Basic Density

Two 2.5 cm strips were extracted and planed to 2 cm thickness. Each strip was then sawn to produce 2 cm x 2 cm square sections. The 2 cm x 2 cm square sections were then crosscut to 2 cm cubes. Each cube was soaked in water overnight or swollen by means of vacuum impregnation with water. The basic density on swollen volume and oven-dry mass basis was determined by the hydrostatic or immersion method. (The weight of a container and the water it contained were determined). The wood specimen was submerged in the water, and the mass of container plus water plus specimen was determined. [The increase in mass of water displaced by the specimen in grams is numerically equal to the volume of water displaced in cm^3]. The wood blocks were then oven-dried at 101^{o}C - 105^{o}C to constant mass and the oven dry mass determined). The basic density was calculated from the formula:

Basic density, kg/m^3 = [Oven-dry mass, kg] / [Mass of water displaced by swollen specimen (or volume of cube), m^3].

Shrinkage

Some 27 mm quarter-sawn boards earmarked for the shrinkage studies were sawn to include 2.5 cm wide strips from the pith to the bark. The strips were planed to 2-cm square sections to give the radial and tangential faces, and these were further cross-cut to 10 cm lengths.

The 2 cm x 2 cm x 10 cm specimens were prepared from each log of each tree. 50 specimens were selected from all five trees in each of the ten species. These were dried at room temperature in the laboratory over some few days, conditioned to 12% moisture content in a constant humidity atmosphere, and later on by oven drying.

During the air-drying, conditioning, and after the oven-drying, the specimens were weighed periodically and the dimensions of each specimen were measured using a digital micrometer screw gauge in the radial and tangential directions, and digital Vernier callipers in the longitudinal direction (Ofori and Obese-Jecty, 2001).

Shrinkage in drying at the various moisture contents and from the green to 12% moisture content and oven-dried state were calculated for the tangential, radial and longitudinal directions, and was expressed as a percentage using the formula:

$$\text{Shrinkage} = ((\text{change in dimension}) / (\text{green dimension})) \times 100\%$$

RESULTS AND DISCUSSION

Moisture Content Distribution

A typical summary of the basic statistics for the green moisture content of the ten wood species is represented by the data for the 6 trees of *C. mildbraedii* presented in Table 2. The green moisture content for all 100 specimens ranged from 49% to 96%. The overall average was 72% with standard deviation 12%. The within tree average green moisture content range was 56% - 86%. The analysis of variance indicates that differences between the average green moisture contents of the six trees were highly significant ($F_{(5,94)} = 45.200$, $P < 0.001$).

A summary of the analysis of variance (ANOVA) of the green moisture content of individual trees of each of the ten wood species is shown in Table 3. Apart from Afina ($F_{(3,36)} = 1.414$, $P = 0.254$), the differences between the average green moisture contents of the trees of each wood species were highly significant (P-value < 0.001).

A summary of the basic statistics for green moisture content of all the ten wood species is presented in Table 4. Mean green moisture content ranged from a low of 45% [in the range 40 – 55%] for Kaku to a high of 93% [in the range 72 – 147%] for *C. zenkeri*.

Basic Density

A typical summary of the basic statistics for the basic density of the ten wood species is represented by the data for the 6 trees of *C. mildbraedii* presented in Table 5. The basic density for all the 100 specimens of *C mildbraedii* ranged from 490 to 699 kg/m^3. The overall average was 619 kg/m^3 with standard deviation 40 kg/m^3. The within tree average basic density range was 593 to 636 kg/m^3. The analysis of variance indicates that differences between the average basic densities of the six trees were highly significant ($F_{(5,94)} = 19.23$, $P < 0.001$). These compare with the basic density of the wood obtained for a previous study from Bobiri Forest Reserve which ranged from 580 to 812 kg/m^3 and averaged 684 kg/m^3 (Ofori and Obese-Jecty, 2001).

Table 2: Summary of basic statistics of the green moisture content of *Celtis mildbraedii*

Statistic	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5	Tree 6	All Trees
Mean	62.6	64.7	56.1	85.8	70.1	81.1	71.9
Standard Deviation	8.3	2.2	6.1	9.0	2.6	9.0	12.4
Minimum	51.1	62.2	48.6	70.6	66.7	68.9	48.6
Maximum	72.8	70.4	68.2	96.1	76.7	92.8	96.1
Count	12	15	13	20	20	20	100
95% Confidence Level	5.3	1.2	3.7	4.2	1.2	4.2	2.5

Table 3: Summary of ANOVA of Mean Green Moisture Content of individual trees of the 10 wood species

Wood Species	Mean (± σ_{n-1})*	ANOVA between Individual Trees	
		Degrees of freedom	F
Afina	58.1± 6.4	$F_{(3,36)}$	1.414
Danta	74.4±17.6	$F_{(4,85)}$	221.320
Wawabima	78.1±16.2	$F_{(4,85)}$	66.149
Essia	80.7±11.2	$F_{(5,84)}$	16.342
Dahoma	88.2±27.2	$F_{(3,96)}$	59.457
Ananta	53.8± 5.4	$F_{(3,56)}$	22.053
Kaku	44.7± 3.2	$F_{(5,54)}$	9.694
Kusia	69.0±19.7	$F_{(4,95)}$	86.800
Celtis mildbraedii	71.9±12.4	$F_{(5,94)}$	45.200
Celtis zenkeri	92.5±18.4	$F_{(4,95)}$	44.597
All 10 Species		$F_{(9,820)}$	59.954

- σ_{n-1} = Standard Deviation

Table 4: Descriptive Statistics of the Green Moisture Content of 10 Ghanaian LUS

Green MC Statistics	Kaku	Ananta	Afina	Kusia	*Celtis Mildbraedii*	Danta	Wawabima	Essia	Dahoma	*Celtis zenkeri*
Mean ,%	44.7	53.8	58.1	69.0	71.9	74.4	78.1	80.7	88.2	92.5
Std. Dev.	3.17	5.41	6.38	19.71	12.37	17.62	16.16	11.18	27.20	18.35
Minimum, %	40.0	43.5	38.3	33.5	48.6	44.3	43.0	55.9	50.5	71.9
Maximum, %	54.6	66.4	69.4	100.9	96.1	102.0	100.4	98.9	150.1	146.8
Count	60	60	40	100	100	90	90	90	100	100
95% C. L.	0.82	1.40	2.04	3.91	2.46	3.69	3.39	2.34	5.40	3.64

Std. Dev. = Standard Deviation 95% C.L. = 95% Confidence Level

A summary of the analysis of variance (ANOVA) of the basic density of individual trees of each of the ten wood species is indicated in Table 6. Apart from Afina ($F_{(3,36)}$ = 1.713, P = 0.1812), the differences between the average basic density of the trees of each wood species were highly significant (P-value < 0.001). A summary of the basic statistics for basic densities of all the ten wood species is presented in Table 7. Mean basic densities ranged from a high of 840 kg/m^3 (in the range 730 – 891 kg/m^3) for Kaku to a low of 560 kg/m^3 (in the range 413 – 683 kg/m^3) for *C. zenkeri*.

These basic density values indicate that the ten species could be classified as 'Medium-Heavy' (575-725 kg/m^3) to 'Heavy' (725-900 kg/m^3) according to ATIBT, 1990 and TEDB, 1994. The basic density values obtained in this study were high and show the potential of the wood species for heavy construction.

The correlation between the mean green moisture content (Table 4) and mean basic density (Table 7) of the species is negative with a coefficient of -0.8746.

Table 5: Summary of basic statistics of the basic density of *Celtis mildbraedii*

Statistic	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5	Tree 6	All Trees
Mean, kg/m^3	613	603	636	593	670	601	619
Standard Deviation	31	9	24	19	20	49	400
Minimum, kg/m^3	576	581	589	553	638	490	490
Maximum, kg/m^3	657	615	667	620	699	659	699
Count	12	15	13	20	20	20	100
95% Confidence Level	19.6	4.8	14.5	8.9	9.1	23.0	7.9

Table 6: Summary of ANOVA of mean Basic Density of individual trees of the 10 wood species [σ_{n-1} = Standard deviation]

Wood Species	Mean ($\pm \sigma_{n-1}$) kg/m^3	ANOVA between Individual Trees	
		Degrees of freedom	F
Afina	613 ± 39.6	$F_{(3,36)}$	1.713
Danta	572 ± 45.8	$F_{(4,85)}$	67.069
Wawabima	568 ± 61.1	$F_{(4,85)}$	80.634
Essia	586 ± 41.5	$F_{(5,84)}$	34.983
Dahoma	567 ± 58.2	$F_{(3,96)}$	51.283
Ananta	740 ± 37.1	$F_{(3,56)}$	13.583
Kaku	840 ± 32.6	$F_{(5,54)}$	14.272
Kusia	635 ± 68.0	$F_{(4,95)}$	33.782
Celtis mildbraedii	619 ± 40.0	$F_{(5,94)}$	19.225
Celtis zenkeri	560 ± 71.1	$F_{(4,95)}$	84.502
All 10 Species		$F_{(9,820)}$	195.259

Table 7: Descriptive Statistics of the Basic Density [kg/m^3] of 10 Ghanaian LUS

Basic Density Statistics	Kaku	Ananta	Kusia	*Celtis mildbraedii*	Afina	Essia	Danta	Wawabima	Dahoma	*Celtis zenkeri*
Mean, kg/m^3	840	740	635	619	613	586	572	568	567	560
Std. Dev.	33	37	68	40	40	42	46	61	58	71
Min., kg/m^3	730	659	501	490	562	487	470	427	448	413
Max., kg/m^3	891	882	833	699	783	687	676	695	659	683
Count	60	60	100	100	40	90	90	90	100	100
95% C.L.	8.4	9.6	13.5	7.9	12.7	8.7	9.6	12.8	11.5	14.1

Min. = Minimum Max. = Maximum Std. Dev. = Standard Deviation 95% C.L. = 95% Confidence Level

Shrinkage

Table 8a and 8b summarizes the shrinkage measurements for all the specimens of the 10 species studied. Mean total tangential shrinkage (from green to oven-dry) varied from a low of 6.2% for Dahoma to a high of 9.9% for Kaku. According to the shrinkage classification provided by TEDB (1994) and Upton & Attah (2003), the mean tangential shrinkage values obtained indicate that shrinkage from green to 12% moisture content is ‘small’ [2.5-4.0%] in Dahoma, Kusia, Ananta and Danta; ‘medium’ [4.0-5.5%] in *C. mildbraedii*, Afina, *C. zenkeri*, Essia and Kaku; and ‘large’ [over 5.5%] in Wawabima. However, the corresponding radial shrinkage values obtained indicate that shrinkage is ‘small’ [1.0-2.0%] in Dahoma and Kusia; ‘medium’ [2.0-3.0%] in Essia, Ananta, Wawabima, *C. mildbraedii*, Danta, *C. zenkeri*, and Afina; and ‘large’ in Kaku [over 3.0%].

The values for *C. mildbraedii* compare well with the total shrinkage in the tangential, radial and longitudinal directions (from green to oven-dry) of 9.1, 6.7, and 0.21%, and from green to 12% moisture content of 4.1, 3.4, and 0.16% respectively obtained in a previous study of five trees from Bobiri Forest Reserve (Ofori and Obese-Jecty, 2001).

The shrinkage values obtained in this study were high. It shows that in areas in heavy construction where shrinkage is important, dimensional detailing must be very critical. Typically, total longitudinal shrinkage is only 0.1-0.2% for most species and rarely exceeds 0.4% (Haygreen & Bowyer, 1996). The total longitudinal shrinkage exceeded the figure of 0.2% in all ten species. It was between 0.2 - 0.3% for Danta, Wawabima, *C. mildbraedii* and *C. zenkeri*, and between 0.3 - 0.4% for Kusia, Afina, Dahoma and Essia, and was higher than the rare figure of 0.4% in Kaku (0.41%) and Ananta (0.43%).

Thus most of these heavy density wood species would seem to exhibit excessive longitudinal shrinkage (maximum figures of above 0.39% and up to 1.01%). Attention should therefore be paid to structural design detailing in uses where longitudinal stability is important.

The ratio of tangential shrinkage to radial shrinkage (T/R) is used as an index of dimensional stability. Ratios higher than 1.5 are considered pronounced (Haygreen & Bowyer, 1996). Table 8b indicates that the T/R ratio was 'very low' [1.30-1.35] in Kaku, and 'low' (1.43 – 1.60) (which are fairly close to the 1.5) in Danta, Afina, *C. zenkeri* and *C. mildbraedii*. A 'high' ratio of 1.57-1.75 was obtained for Ananta and Dahoma. Rather 'very high' ratios of 1.85 – 2.37 were obtained in Kusia, Wawabima and Essia. The pronounced differential shrinkage in the woods of Ananta, Dahoma, Kusia, Wawabima and Essia is likely to cause wide splits, checks and distortions if the necessary precautions are not taken during the kiln drying of these Ghanaian heavy wood species

CONCLUSIONS

Moisture Content Distribution and Basic Density

Mean green moisture content ranged from a low of 45% for Kaku to a high of 93% for *Celtis zenkeri*. Mean basic densities ranged from a high of 840 kg/m^3 for Kaku to a low of 560 kg/m^3 for *Celtis zenkeri*. These basic density values indicate that the ten species are classified as 'Medium-Heavy' (575-725 kg/m^3) to 'Heavy' (725-900 kg/m^3) (ATIBT, 1990; TEDB, 1994).

Table 8a: Summary of some Descriptive Statistics of Shrinkage of 10 Ghanaian LUS (Mean ± Std. Dev., Range in squared brackets)

Wood Species	Green Moisture Content %	Total Shrinkage [Green to Oven Dried] %			Shrinkage from Green to 12% M.C. %		
		Tangential T	Radial R	Longitudinal L	Tangential T_{12}	Radial R_{12}	Longitudinal L_{12}
Kaku	45 ± 3.9	9.9 ± 1.10	7.6 ± 0.67	0.41 ± 0.08	5.3 ± 0.80	3.9 ± 0.46	0.21 ± 0.04
	[40-55]	[6.7-11.5]	[6.2-8.7]	[0.28-0.65]	[3.3-6.6]	[3.1-4.8]	[0.13-0.31]
Wawabima	78 ± 12.7	9.5 ± 1.09	4.6 ± 0.96	0.26 ± 0.08	5.6 ± 1.14	2.5 ± 0.69	0.16 ± 0.07
	[43-100]	[7.9-11.9]	[3.5-6.3]	[0.14-0.41]	[2.4-7.2]	[1.2-3.9]	[0.06-0.33]
Essia	81 ± 8.5	9.0 ± 1.13	4.4 ± 0.76	0.37 ± 0.10	5.0 ± 0.82	2.1 ± 0.38	0.24 ± 0.07
	[56-99]	[5.6-11.1]	[3.5-7.1]	[0.22-0.61]	[3.7-7.4]	[1.3-2.9]	[0.13-0.46]
Afina	58 ± 14.0	8.3 ± 1.26	5.7 ± 1.20	0.35 ± 0.11	4.4 ± 0.85	2.8 ± 0.87	0.17 ± 0.07
	[38-85]	[5.2-10.6]	[4.2-9.0]	[0.08-0.65]	[2.4-6.1]	[1.9-6.4]	[0.03-0.36]
Celtis	93 ± 11.7	8.0 ± 1.72	5.4 ± 1.30	0.29 ± 0.09	4.4 ± 1.39	2.8 ± 0.98	0.15 ± 0.07
zenkeri	[72-147]	[3.4-11.4]	[3.5-8.9]	[0.13-0.57]	[1.7-7.1]	[1.5-5.7]	[0.01-0.32]
Ananta	54 ± 4.7	7.8 ± 0.80	5.0 ± 0.52	0.43 ± 0.21	3.7 ± 0.37	2.2 ± 0.28	0.20 ± 0.09
	[40-66]	[5.8-9.2]	[3.9-6.5]	[0.17-1.01]	[2.9-4.5]	[1.7-2.9]	[0.05-0.44]
Celtis	72 ± 9.8	7.7 ± 1.26	5.2 ± 0.66	0.27 ± 0.11	4.1 ± 0.99	2.5 ± 0.58	0.13 ± 0.05
mildbraedii	[49-96]	[4.5-11.1]	[4.2-7.6]	[0.14-0.89]	[2.2-6.7]	[1.5-4.3]	[0.05-0.28]
Kusia	69 ± 13.5	7.3 ± 0.54	4.3 ± 0.71	0.35 ± 0.09	3.5 ± 0.57	1.9 ± 0.37	0.18 ± 0.06
	[39-101]	[5.6-8.3]	[3.3-7.0]	[0.19-0.65]	[1.6-5.8]	[1.4-3.4]	[0.08-0.34]
Danta	74 ± 10.0	6.9 ± 0.83	4.8 ± 0.72	0.23 ± 0.07	4.0 ± 0.71	2.7 ± 0.53	0.11 ± 0.04
	[44-102]	[5.3-8.2]	[3.9-6.0]	[0.14-0.39]	[2.5-5.2]	[2.0-3.6]	[0.06-.022]
Dahoma	88± 19.7	6.2 ± 0.99	3.9 ± 0.79	0.35± 0.11	3.0 ± 0.58	1.7 ± 0.39	0.23 ± 0.12

	[51-150]	[4.4-8.2]	[2.2-6.3]	[0.23-0.88]	[2.0-4.1]	[0.9-2.5]	[0.10-0.73]

Table 8b: Summary of some derived descriptive statistics of shrinkage of the 10 Ghanaian LUS

Shrinkage Parameter	Kaku	Wawabima	Essia	Afina	Celtis zenkeri	Ananta	Celtis mildbraedii	Kusia	Danta	Dahoma
Total Tangential, T, %	9.9	9.5	9.0	8.3	8.0	7.8	7.7	8.2	6.9	6.2
Total Radial, R, %	7.6	4.6	4.4	5.7	5.4	5.0	5.2	4.3	4.8	3.9
Total Longitudinal., L,%	0.41	0.26	0.39	0.35	0.29	0.43	0.27	0.35	0.23	0.35
Tangential to 12%,T_{12}, %	5.3	5.6	5.0	4.4	4.4	3.7	4.1	3.6	4.0	3.0
Radial to 12% MC, R_{12}, %	3.9	2.5	2.1	2.8	2.8	2.2	2.5	1.9	2.7	1.7
Long. to 12% MC,L_{12}, %	0.21	0.16	0.24	0.17	0.15	0.20	0.13	0.18	0.11	0.23
T/R Ratio	1.30	2.08	2.05	1.45	1.47	1.57	1.50	1.90	1.43	1.58
T_{12}/R_{12} Ratio	1.35	2.26	2.37	1.57	1.59	1.66	1.60	1.85	1.49	1.75

The correlation between the mean green moisture content and mean basic density of the individual ten species is negative with a correlation coefficient of -0.87.

Analysis of variance of the green moisture content (and of basic density) of individual trees of each of the ten wood species indicates that apart from Afina, the differences between the average green moisture contents (and of basic densities) of the trees of each wood species were highly significant.

Shrinkage

Mean total tangential shrinkage (from green to oven-dry) varied from a low of 6.2% for Dahoma to a high of 9.9% for Kaku; the mean tangential shrinkage values obtained indicate that shrinkage from green to 12% moisture content is small [2.5-4.0%] in Dahoma, Kusia, Ananta and Danta; medium [4.0-5.5%] in *C. mildbraedii*, Afina, *C. zenkeri*, Essia and Kaku; and large [over 5.5%] in Wawabima.

The corresponding radial shrinkage values obtained indicate that shrinkage is small [1.0-2.0%] in Dahoma and Kusia; medium [2.0-3.0%] in Essia, Ananta, Wawabima, *C. mildbraedii*, Danta, *C. zenkeri*, and Afina; and large in Kaku [over 3.0%].

The ratio of tangential shrinkage to radial shrinkage (T/R) was very low [1.30-1.35] in Kaku, and low (1.43 – 1.60) in Danta, Afina, *C. zenkeri* and *C. mildbraedii*. A high ratio of 1.57-1.75 was obtained for Ananta and Dahoma; and rather higher ratios of 1.90 – 2.37 were obtained in Kusia, Wawabima and Essia. The pronounced differential shrinkage (≥ 1.5) in the woods of Ananta, Dahoma, Kusia, Wawabima and Essia is likely to cause wide splits, checks and distortions if the necessary precautions are not taken during the kiln drying of these heavy wood species from Ghana.

The total longitudinal shrinkage exceeded the normal figure of 0.2% in all ten species; and was higher than the rare figure of 0.4% in Kaku (0.41%) and Ananta (0.43%). Most of these heavy density wood species seem to exhibit excessive longitudinal shrinkage; and attention should therefore be paid to structural design detailing in uses where longitudinal stability is important.

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