PROPERTIES OF 10 GHANAIAN HIGH DENSITY LESSER-USED-SPECIES OF IMPORTANCE TO BRIDGE CONSTRUCTION – PART 2: MECHANICAL STRENGTH PROPERTIES

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ABSTRACT

Logs from 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. The logs from the trees were converted on a horizontal bandmill to 27 and 53 mm thick boards. One-half of the boards were used in the green state and the other half air dried. Mechanical strength test specimens were prepared and tested in accordance with the British Standard BS 373:1957. The range of mean strength values in N/mm^2 in the 'green' [and dry] conditions for the ten wood species were as follows: - Modulus of Rupture: 69-132 [104-188], Modulus of Elasticity: 7,970-13,740 [9,740-17,620], Compression parallel to grain: 31-63 [54-92], Shear parallel to grain: 8.8-22.1 [15.1-15.1], and Hardness in kN: 3.5-11.3 [5.1-17.0]. The 10 species in decreasing order of strength was as follows: ***Lophira alata*** *(Kaku) >* ***Cynometra ananta*** *(Ananta) >* ***Strombosia glaucescens*** *(Afina) >* ***Celtis mildbraedii*** *>* ***Nauclea diderrichii*** *(Kusia) ≥* ***Celtis zenkeri*** *≈* ***Piptadeniastrum africanum*** *(Dahoma) >* ***Nesogordonia papaverifera*** *(Danta) >* ***Combretodendron africanum*** *(Essia) >* ***Sterculia rhinopetala*** *(Wawabima). Mean ratios of dry to 'green' MOR and MOE were 1.44 and 1.28. There was a good correlation (84.4~98.2%) between the Density (X) and the various mechanical strength values (Y). Regression equations in the form: $Y = aX^b$ were derived with R^2 values of 0.72-0.93.*

Keywords: **High Density Species, Bridge Construction, Mechanical Strength Properties**

INTRODUCTION

To improve the economy and standard of living of people far away from the main highway routes, the construction and maintenance of transport infrastructure (such as culverts and bridges) on rural feeder roads which connect rural areas to the main highways in Ghana is considered vital. Based on the use of locally available materials and labour, the use of timber for bridges of up to 20 metres span has been identified as being economical (Allotey, 1992; Jayanetti *et al*, 1999).

Sustainable forest management that 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 timber species. The LUS occur in abundance in the forest (Ghartey 1989, Jayanetti *et al*, 1999, Upton and Attah 2003). For the Department of Feeder Roads and Ghana Highways Authority to use the LUS for the construction of timber bridges, it is important that the 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.

The physical properties have been studied and reported in a companion paper (Ofori *et al*, 2009a). Properties studied 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).

For a study on the mechanical properties of the wood of high density LUS, tests on actual structural-sized timber is ideal but are not often used because of cost and unavailability of equipment. Small clear straight-grained specimens are used for determining fundamental mechanical properties (Green *et al*, (1999). The method utilises small, clear, straight-grained test specimens which represent the maximum quality that can be obtained (BSI, 1957; ASTM, 1999). The method remains valid for characterising new timbers and for the strict academic comparison of wood from different trees or different species.

The mechanical strength properties measured depend on the specific uses to which the timber is to be put. Timber is probably stressed in bending more than in any other mode and there are very many examples of timber being used in bending. Examples are when used as floor and ceiling joists and roof trusses. Shear strength parallel to the grain is the most important property that comes into play in the structural use of timber in jointing. High strength in compression parallel to the grain is required of timber used as columns, posts, and as notched timbers. Hardness is an important property when the timber is used for paving blocks, floors decking and bearing blocks. Resistance to crushing (or compression perpendicular to the grain) is an important property in a few selected end uses such as bearing blocks, bolted and notched timbers.

Tests which are very relevant to bridge construction applications are normally conducted in a primary testing programme. These would be tests to determine the static bending strength - modulus of rupture (MOR) and modulus of elasticity (MOE), compression parallel to the grain (C//g), and shear strength parallel to the grain. Secondary tests which are designed to reflect the likely end-use of the wood species would include the Janka Indentation (or Hardness) test and/or compression perpendicular to the grain. These are characteristics more relevant to joinery applications. Compression perpendicular to grain strength is often not carried out but is computed from the side hardness of the timber since there is a very high correlation between the two properties (Lavers, 1983). For wood at 12 per cent moisture content the correlation coefficient is 0.902 and the corresponding equation is $y = 0.00147x + 1.103$, where x is the hardness. For green wood the figures are 0.907 and $y = 0.00137x – 0.207$. On the basis of the above equation the compression strength perpendicular to the grain, y, (in N/mm^2) is generally computed from the side hardness (in N) test results.

This paper presents the study on the mechanical strength properties (static bending, shear, compression parallel to the grain and hardness) of the wood of 10 high density LUS.

MATERIALS AND METHODS

Materials

The wood samples for this study were obtained from the same logs that were used in the Part 1 of the companion study on the 'green moisture content, basic density and shrinkage characteristics' (Ofori *et al*, 2009a).

Conversion, Sampling and Air Drying

The logs were converted on a horizontal bandmill (‘Woodmizer’) to 27mm and 53mm thick boards. Some boards were cut for a previous study on Green Moisture Content, Basic Density, and Dimensional Shrinkage (Ofori *et al*, 2009a). Other boards were cut for this mechanical strength study and another study on woodworking (planning, boring, mortising, sanding, turning, etc). The 'green' test specimens (i.e. with the wood moisture content above fibre saturation point) for the mechanical strengths were cut to the sizes or dimensions and orientations required by the British Standard BS 373:1957 (BSI, 1957) and then kept in deep freezers pending the tests.

Boards for the 'dry' test samples for the mechanical testing and woodworking studies were dipped in an insecticide solution to prevent insect damage during drying. The boards were then stacked for air-drying under shed. After these boards were fully air-dried (to an equilibrium moisture content of between 14 and 17%), test specimens for the ‘dry’ test samples for the mechanical testing were dressed/prepared to the standard dimensions and orientations required by the British Standard BS 373:1957 and conditioned (at controlled temperature of 20 ± 3^{o}C and relative humidity of 65 ± 2 %) to about 12% moisture content.

RESULTS AND DISCUSSIONS

Physical

Moisture Content

Mechanical properties of wood are significantly affected by the moisture content of the specimen at the time of testing hence properties that are measured at different dry test moisture levels are adjusted to a standard moisture content base of 12% (Green *et al*, 1999).

The final mean moisture contents of the dry specimens after conditioning to the target ‘12%’ varied from 11.9% (*Celtis zenkeri)* to 13.5% *(*Kaku). These final mean moisture contents were used in adjusting the dry mechanical values of the specimens to the standard mechanical strength at 12% moisture content.

Density

The densities of the dry and green specimens are shown in Table 1. The density values given in the table represent only the specimens tested, and does not necessarily represent the estimated average clear wood density of the species. Density at '12%' moisture content varied from a mean low of 663 kg/m^3 (for Dahoma) to a mean high of 1047 kg/m^3 (for Kaku). Similarly, the green basic density varied from a mean low of 550~557 kg/m^3 (for Wawabima/Dahoma) to a mean high of 839 kg/m^3 (for Kaku).

Mechanical Properties

Variability in Strength Properties of Wood

The strength property of wood species is known to vary widely. Some indication of the spread of property values is therefore desirable (Green *et al*, (1999). The strength property is statistically normally distributed, with mean f_{mean} and standard deviation σ_{n-1} (Sunley, 1968; Ocloo, 1985; CEN, 2002). Ideally, the weakest strength value for a species should be used, but in practice a ‘characteristic strength’ is given. The European standard EN 12511 (CEN, 2002) for determining the characteristic value uses the 5% point of exclusion for the mean bending strength of the test specimens. For the mechanical strength property of small clear specimens, statistically, this reduced characteristic strength value at the 5% point of exclusion is:

$$P_{05} = f_{mean} - 1.96\sigma_{n-1},$$

where f_{mean} = Mean, and

σ_{n-1} = Standard Deviation.

Table 1: Density of test specimens

Wood Species	Dry Specimens				Green Specimens			
	Density at 12%, kg/m^3			Total No. of Specimens	Green Basic Density, kg/m^3			Total No. of Specimens
	Mean	Min.	Max.		Mean	Min.	Max.	
Kaku	1047	967	1243	335	839	752	905	323
Ananta	880	787	1026	327	717	662	818	173
Afina	840	637	1053	334	655	497	787	291
Celtis mildbraedii	781	578	1014	327	631	449	803	319
Celtis zenkeri	743	595	919	331	613	340	773	306
Essia	738	411	898	330	589	478	673	319
Danta	712	517	898	328	566	257	916	265
Kusia	684	583	794	317	596	474	709	301
Wawabima	685	419	905	321	550	435	661	246
Dahoma	663	501	905	327	557	272	690	297

Formulae for Calculating the Strength Values

The formulae used in calculating the strength values from the test data were those given in the British Standards BS 373: 1957 (BSI, 1957) which was followed in the test program of this study. The bending strength (modulus of rupture, MOR) and stiffness (Modulus of Elasticity, MOE) were computed using the three-point loading equations.

Strength Values

Tables 2 to 6 give summaries of the statistics of the Modulus of Rupture, Modulus of Elasticity, Compression parallel to grain, Shear parallel to grain, and Hardness values for the 10 LUS in the 'green' and 12% moisture conditions.

Mechanical Strength

The static bending strength values of the timbers when 'green' and at 12% moisture content are shown in Tables 2 and 3. The range of mean strength values in the 'green' [and dry] conditions for the ten species was as follows: - Modulus of Rupture: 69-132 N/mm^2 [104-188 N/mm^2] and Modulus of Elasticity: 7,970-13,740 N/mm^2 [9,740-17,620 N/mm^2]. The overall order of decreasing MOR of the 10 species was as follows: Kaku >> Afina ≈ Ananta > *Celtis mildbraedii* > Kusia ≥ *Celtis zenkeri* ≈ Dahoma > Danta > Essia ≈ Wawabima. The corresponding order of overall decreasing MOE of the 10 species was as follows: Kaku >> Ananta > Afina > Kusia ≈ *Celtis mildbraedii* > *Celtis zenkeri* ≈ Dahoma > Danta > Wawabima > Essia.

Bolza and Keating (1972) grouped Kaku and Ananta from Ghana in dry strength group S2 (i.e. MOR of 134 N/mm^2, while Kusia, Danta, Essia, and Wawabima are in group S3 (i.e. MOR of 114 N/mm^2), and Dahoma is in group S4 (i.e. MOR of 93.7 N/mm^2). This study indicates higher dry MOR values (in N/mm^2) for Kaku (188.4), Ananta (139.9), Danta (117.4), and Dahoma (109.6); and slightly lower dry MOR values (in N/mm^2) for Wawabima (110.8), Kusia (109.6) and Essia (103.7).

The compression and shear strengths parallel to the grain and hardness strength values are given in

Tables 4 to 6 respectively. The range of mean strength values in the 'green' [and dry] conditions were also as follows: Compression parallel to grain: 31-63 N/mm^2 [54-92 N/mm^2], Shear parallel to grain: 8.8-22.1 N/mm^2 [15.1-15.1 N/mm^2], and Hardness: 3.5-11.3 kN [5.1-17.0 kN]. The overall order of decreasing Compression and Shear strengths parallel to grain of the species was as follows: Kaku >> Ananta > Afina > *Celtis mildbraedii* > Kusia > Dahoma ≈ *Celtis zenkeri* > Danta > Essia > Wawabima. With respect to side Hardness, the timbers arranged in order of decreasing strength were as follows: Kaku > Ananta > Afina > *Celtis mildbraedii* > Kusia ≈ *Celtis zenkeri* > Dahoma > Danta > Essia > Wawabima.

Table 7 gives a summary of the density and mechanical strength values when 'Green' and at12% moisture content in one table. The overall, order of decreasing strength of the 10 species was as follows: Kaku >> Ananta > Afina > Celtis *mildbraedii* > Kusia ≥ Celtis *zenkeri* ≈ Dahoma > Danta > Essia > Wawabima. The order was similar to that of side Hardness.

Upton and Attah (2003) and TEDB (1994) have classified strength of species based on the MOE at 12% moisture content as follows: 'Very High' [19,000 N/mm^2 and more], 'High' [14,000-19,000 N/mm^2], 'Medium' [11000-14,000 N/mm^2], 'Low / Medium' [9,000-11,000 N/mm^2], and 'Low' [below 9,000 N/mm^2]. The above classification indicates the strength of the species studied to be 'High**'** in Kaku, Ananta, Afina and Wawabima; '*High/Medium***'** in Kusia, Dahoma and Essia; '*Medium***'** in *Celtis mildbraedii*, *Celtis zenkeri* and Danta.

The numeric values from Upton and Attah (2003) are based mainly on information in Bolza and Keating (1972) where the data had been grouped to enable gross differences in adequacy of sampling to be accommodated, thus avoiding the false impression of precision when absolute values for properties are published without the appropriate variability statistics (Bolza and Keating, 1972). This study, which results give the appropriate variability statistics, however, shows MOE at 12% moisture content to be '*High***'** in Kaku and Ananta; '*Medium***'** in Afina, *Celtis mildbraedii*, Kusia and *Celtis zenkeri*; and '*Low/Medium*' in Dahoma, Danta, Wawabima, and Essia.

Ratio of Dry to Green 'Clear' Mechanical Strength Values

Many of the mechanical strength properties are affected by changes in moisture content below the fibre saturation point. Generally, most of the strength properties increase as wood is dried. Above the fibre saturation point, most of the mechanical properties are not affected by change in moisture content. Table 8 shows the ratios of the mechanical strength at 12% moisture content to that when 'green' for the species studied, and the comparative range ratios for USA hardwoods (ASTM, 1978). Ratios for the Ghanaian hardwoods were generally highest in Compression parallel to grain, followed by Shear parallel to grain, MOR, and Hardness; and least in MOE. Mean ratios of dry to 'green' MOR and MOE were 1.43 and 1.28. The ratios for the Ghanaian hardwoods were generally lower than the hardwoods of USA origin. It is apparent that the mechanical strength increases associated with drying small clear specimens from the green condition to 12 percent moisture content were generally greatest in Wawabima and Afina and least in Kusia.

Table 2: Modulus of rupture of 10 LUS when 'green' and at 12% moisture content

	Statistics of 'Green' Modulus of Rupture N/mm^2							Statistics of Modulus of Rupture at 12% MC N/mm^2					
Wood Species	Mean	P_{05}	Std. Dev.	Min.	Max.	Count	Mean Test MC	Mean	P_{05}	Std. Dev.	Min.	Max.	Count
Kaku	131.8	95.2	18.7	78.8	164.4	125	37.6	188.4	155.4	16.8	141.2	231.5	114
Ananta	99.2	65.3	17.3	62.1	142.6	56	46.1	139.9	99.2	20.8	95.0	183.7	110
Celtis mildbraedii	93.7	66.8	13.7	65.6	119.1	109	55.5	129.8	92.8	18.9	74.5	181.9	115
Afina	93.2	61.8	16.0	65.9	127.3	80	40.9	148.2	114.6	17.2	73.6	184.2	81
Kusia	91.3	72.5	9.6	69.8	118.0	98	66.4	109.6	76.0	17.1	67.4	145.2	115
Dahoma	85.8	67.8	9.2	64.8	108.4	96	62.8	109.6	83.1	13.5	73.1	139.0	113
Celtis zenkeri	85.1	59.9	12.8	60.8	128.4	105	69.3	124.7	92.3	16.6	94.2	162.4	109
Danta	78.8	59.0	10.1	58.3	98.8	80	56.1	117.4	92.5	12.7	88.6	165.7	118
Essia	74.1	53.0	10.8	52.6	99.1	116	67.8	103.7	80.9	11.6	78.6	132.9	103
Wawabima	69.0	55.4	6.9	56.9	83.9	100	75.5	110.8	84.5	13.4	87.1	149.8	102

Table 3: Modulus of elasticity of 10 LUS when 'green' and at 12% moisture content

	Statistics of 'Green' Modulus of Elasticity N/mm^2							Statistics of Modulus of Elasticity at 12% MC N/mm^2					
Wood Species	Mean	P_{05}	Std. Dev.	Min.	Max.	Count	Mean Test MC	Mean	P_{05}	Std. Dev.	Min.	Max.	Count
Kaku	13,736	9,800	2,008	9,150	18,430	125	37.6	17,622	13,484	2,111	12,834	22,369	114
Ananta	10,810	7,014	1,937	7,002	13,980	56	46.1	14,439	10,570	1,974	9,774	18,509	110
Kusia	10,389	7,712	1,366	7,620	14,180	98	55.5	11,708	8,876	1,445	8,671	16,640	115
Afina	9,634	6,953	1,368	6,275	12,806	80	40.9	13,355	10,470	1,472	9,807	16,889	81
Celtis mildbraedii	9,467	6,254	1,639	5,706	12,590	109	66.4	12,545	9,241	1,685	8,193	16,530	115
Dahoma	9,399	7,532	953	7,264	12,010	96	62.8	10,897	8,817	1,061	9,068	13,465	113
Celtis zenkeri	8,543	5,985	1,305	5,537	11,262	105	69.3	11,916	9,025	1,475	8,044	14,990	109
Danta	8,316	6,400	977	5,896	10,560	80	56.1	10,363	7,992	1,209	7,608	13,706	118
Wawabima	8,088	6,175	976	5,601	10,550	100	67.8	10,394	8,723	853	8,492	13,016	102
Essia	7,973	5,539	1,242	4,649	10,917	116	75.5	9,739	7,253	1,268	6,286	13,937	103

Table 4: Compression parallel to grain of 10 LUS when 'green' and at 12% moisture content

	Statistics of 'Green' Compression llg N/mm^2							Statistics of Compression llg at 12% MC N/mm^2					
Wood Species	Mean	P_{05}	Std. Dev.	Min.	Max.	Count	Mean Test MC	Mean	P_{05}	Std. Dev.	Min.	Max.	Count
Kaku	62.6	54.2	4.3	51.3	70.5	66	29.4	91.9	74.7	8.8	66.8	109.1	125
Ananta	48.7	33.6	7.7	31.8	69.6	57	43.9	74.1	61.8	6.3	59.2	86.3	79
Afina	41.4	29.4	6.1	29.8	55.6	104	52.5	68.9	53.9	7.7	52.6	84.1	119
Kusia	40.9	34.1	3.5	30.1	52.0	121	59.3	57.8	48.2	4.9	38.7	67.9	120
Dahoma	37.0	27.7	4.8	26.1	52.5	113	71.9	54.2	41.1	6.7	36.1	68.6	119
Celtis mildbraedii	36.0	23.1	6.6	22.7	50.2	114	61.4	62.1	45.4	8.5	46.0	81.5	107
Celtis zenkeri	35.8	24.3	5.8	24.0	51.2	105	65.0	59.4	48.3	5.7	46.9	69.7	119
Danta	34.1	24.8	4.7	24.5	46.1	59	65.2	57.5	48.7	4.5	48.3	74.5	106
Essia	31.5	25.1	3.3	24.9	38.0	104	74.5	53.3	41.7	5.9	41.4	66.7	114
Wawabima	30.6	23.9	3.4	21.7	35.5	46	67.1	53.5	41.1	6.3	41.4	67.0	112

Table 5: Shear parallel to grain of 10 LUS when 'green' and at 12% moisture content

	Statistics of 'Green' Shear llg N/mm^2							Statistics of Shear llg at 12% MC N/mm^2					
Wood Species	Mean	P_{05}	Std. Dev.	Min.	Max.	Count	Mean Test MC	Mean	P_{05}	Std. Dev.	Min.	Max.	Count
Kaku	22.1	18.9	1.6	19.2	25.7	64	31.2	32.5	28.6	2.0	28.7	35.9	72
Ananta	18.8	15.6	1.6	15.8	22.4	42	47.4	26.1	21.9	2.1	19.9	32.1	67
Afina	15.9	12.5	1.8	12.1	19.3	58	59.4	24.7	20.4	2.2	20.4	29.7	68
Kusia	15.1	12.6	1.3	11.9	17.3	57	50.9	22.2	19.1	1.6	18.7	25.0	66
Celtis mildbraedii	14.6	11.5	1.6	10.6	17.4	57	58.9	22.0	17.5	2.3	16.6	25.6	65
Dahoma	13.4	10.6	1.5	10.6	17.1	53	75.1	20.4	16.4	2.0	16.7	25.5	70
Celtis zenkeri	13.2	9.6	1.8	10.1	16.6	47	81.9	22.0	17.9	2.1	18.1	28.1	68
Danta	12.7	10.9	0.9	10.6	14.9	59	69.1	19.4	16.9	1.3	16.8	22.6	69
Essia	11.5	8.9	1.3	8.9	14.7	52	75.7	19.2	15.5	1.9	15.9	23.3	69
Wawabima	8.8	7.1	0.9	7.0	11.0	50	60.2	15.1	11.6	1.8	11.5	20.3	69

Table 6: Hardness of 10 LUS when 'green' and at 12% moisture content

	Statistics of 'Green' Hardness kN							Statistics of Hardness at 12% MC kN					
Wood Species	Mean	P_{05}	Std. Dev.	Min.	Max.	Count	Mean Test MC	Mean	P_{05}	Std. Dev.	Min.	Max.	Count
Kaku	11.26	8.38	1.47	7.75	15.31	114	29.5	17.00	13.87	1.60	12.17	21.66	120
Ananta	7.11	3.88	1.64	4.68	12.17	107	41.8	10.43	6.74	1.89	6.95	15.60	120
Afina	6.38	4.04	1.19	4.49	9.18	68	57.5	8.93	5.82	1.59	5.28	14.15	120
Celtis mildbraedii	6.37	4.40	1.01	4.55	9.13	96	70.2	7.60	3.44	2.12	3.93	14.08	120
Kusia	5.34	4.08	0.64	3.68	7.20	120	82.2	6.87	5.43	0.74	5.77	9.07	108
Celtis zenkeri	4.90	3.48	0.72	4.08	6.96	40	82.4	7.46	4.600	1.46	3.98	11.43	120
Danta	4.75	2.74	1.02	3.07	7.06	112	64.7	6.72	3.78	1.50	3.95	12.59	120
Essia	4.46	2.16	1.18	2.88	8.64	110	66.0	6.54	4.37	1.10	4.49	9.95	114
Wawabima	3.49	1.76	0.88	1.82	5.91	114	67.7	5.09	3.31	0.91	2.59	8.04	122

Table 7: Summary of mechanical strength values of 10 LUS when 'green' and at 12% moisture content

Wood Species	Basic Density kg/m^3	'Green' Mechanical Strength					Density at 12%, kg/m^3	Mechanical Strength at 12% Moisture Content				
		MOR N/mm^2	MOE N/mm^2	Comp.llg N/mm^2	Shear llg N/mm^2	'Green' Hardness, kN		MOR N/mm^2	MOE N/mm^2	Comp llg N/mm^2	Shear llg N/mm^2	Dry Hardness kN
Kaku	839	131.8	13,736	62.6	22.1	11.26	1047	188.4	17,622	91.9	32.5	17.00
Ananta	717	99.2	10,810	48.7	18.8	7.11	880	139.9	14,439	74.1	26.1	10.43
Celtis mildbraedii	631	93.7	9,467	36.0	14.6	6.37	781	129.8	12,545	62.1	22.0	7.60
Afina	655	93.2	9,634	41.4	15.9	6.38	840	148.2	13,355	68.9	24.7	8.93
Kusia	596	91.3	10,389	40.9	15.1	5.34	684	109.6	11,708	57.8	22.2	6.87
Dahoma	557	85.8	9,399	37.0	13.4	4.99	663	109.6	10,897	54.2	20.4	6.22
Celtis zenkeri	613	85.1	8,543	35.8	13.2	4.90	743	124.7	11,916	59.4	22.0	7.46
Danta	566	78.8	8,316	34.1	12.7	4.75	712	117.4	10,363	57.5	19.4	6.72
Essia	589	74.1	7,973	31.5	11.5	4.46	738	103.7	9,739	53.3	19.2	6.54
Wawabima	550	69.0	8,088	30.6	8.8	3.49	685	110.8	10,394	53.5	15.1	5.09

Table 8: Ratio of dry* to green mechanical strength values

Wood Species	MOR	MOE	C llg	Shear llg	Hardness
Wawabima	1.61	1.29	1.75	1.71	1.46
Afina	1.59	1.39	1.67	1.55	1.40
Danta	1.49	1.25	1.69	1.52	1.41
Celtis zenkeri	1.47	1.39	1.66	1.67	1.52
Kaku	1.43	1.28	1.47	1.47	1.51
Ananta	1.41	1.34	1.52	1.39	1.47
Essia	1.40	1.22	1.69	1.67	1.46
Celtis mildbraedii	1.38	1.33	1.72	1.51	1.19
Dahoma	1.28	1.16	1.46	1.52	1.25
Kusia	1.20	1.13	1.41	1.47	1.29
MEAN	1.43	1.28	1.60	1.55	1.40
Ghanaian hardwoods	1.20 -1.61	1.13 – 1.39	1.41 – 1.75	1.39 – 1.71	1.19 – 1.52
USA hardwoods**	1.32 -2.10	1.11 – 1.53	1.61 - 2.60	1.13 – 1.82	-

*: Dry means 12% moisture content ** Source: (ASTM, 1978)

Correlation Between Density and Mechanical Strength

Correlations between the densities and mechanical strengths have been shown in Tables 9a and 9b for the green and dry conditions respectively. There was a good correlation (84.4 ~ 98.2%) between the Density and the various mechanical strength values. Density (X) and mechanical strength (Y) were highly correlated at 91.1 ~ 97.3% for 'green' wood and 84.4 ~ 98.2% for wood dried to 12% moisture content. The ratios of the 'green' mechanical strength to basic density were highest in Kaku, and least in Wawabima and Essia.

Functional Relationships Between Mechanical Strength Properties and Density

The density of wood is a good index of its properties as long as the wood is clear, straight grained, and free from defects. However, density values are also affected by the presence of gums, resins, and extractives which add to their weight and contribute little to mechanical strength properties (Lavers, 1983; Green *et al*, 1999).

Approximate relationships between various mechanical strength properties and density for clear straight-grained wood of hardwoods and softwoods are in the form of power functions such as: $Y = aX^b$. These relationships are based on average values for many softwood and hardwood species, and the average data vary around the relationships, so that the relationships do not accurately predict individual average species values or an individual specimen value. In fact, mechanical strength properties within a species tend to be linearly, rather than curvilinearly related to density; where data are available for individual species, linear analysis is suggested (Green *et al*, 1999).

Figures 1a and 1b show the functional relationships between the mechanical strength properties and the density of the ten Ghanaian hardwood species. Regression equations (Table 10) in the form: $Y = aX^b$ were derived with R^2 values of between 0.72 and 0.93.

Table 9a: Correlation between basic density and the green mechanical strength values

CORRELATION	Basic Density	Green MOR	Green MOE	Green Comp. llg	Green Shear llg	Green Hardness
Basic Density	1					
Green MOR	0.918	1				
Green MOE	0.942	0.972	1			
Green Comp. llg	0.957	0.956	0.972	1		
Green Shear llg	0.911	0.940	0.925	0.959	1	
Green Hardness	0.932	0.973	0.940	0.958	0.944	1

Table 9b: Correlation between density and mechanical strength at 12% moisture content

CORRELATION	Density at 12% MC	MOR at 12% MC	MOE at 12% MC	Comp. llg at 12% MC	Shear llg at 12% MC	Hardness at 12% MC
Density at 12% MC	1					
MOR at 12% MC	0.844	1				
MOE at 12% MC	0.921	0.958	1			
Comp. llg at 12% MC	0.937	0.974	0.982	1		
Shear llg at 12% MC	0.889	0.904	0.950	0.944	1	
Hardness at 12% MC	0.936	0.951	0.954	0.981	0.947	1

Table 10: Functions relating mechanical properties to density* (basic and at 12% mc) of clear, straight-grained wood

Mechanical Strength Property	'Green' wood		Wood at 12% mc	
	Density (X) Strength (Y) Relationship	R^2	Density (X) Strength (Y) Relationship	R^2
Modulus of Rupture, MOR (N/mm^2)	$Y = 0.0430\ X^{1.19}$	0.78	$Y = 0.0445\ X^{1.19}$	0.90
Modulus of Elasticity, MOE (N/mm^2) x 100	$Y = 0.0581\ X^{1.15}$	0.85	$Y = 0.0575\ X^{1.15}$	0.84
Compression parallel to grain (N/mm^2)	$Y = 0.0023\ X^{1.52}$	0.88	$Y = 0.0556\ X^{1.05}$	0.89
Shear parallel to grain (N/mm^2)	$Y = 0.0004\ X^{1.62}$	0.72	$Y = 0.0062\ X^{1.22}$	0.73
Hardness, kN	$Y = 6E\text{-}06\ X^{2.15}$	0.81	$Y = 2E\text{-}06\ X^{2.27}$	*0.93*

* *For 'green' wood, basic density is based on green volume and ovendry weight; For dry wood, density is based on volume at 12% moisture content and ovendry weight*

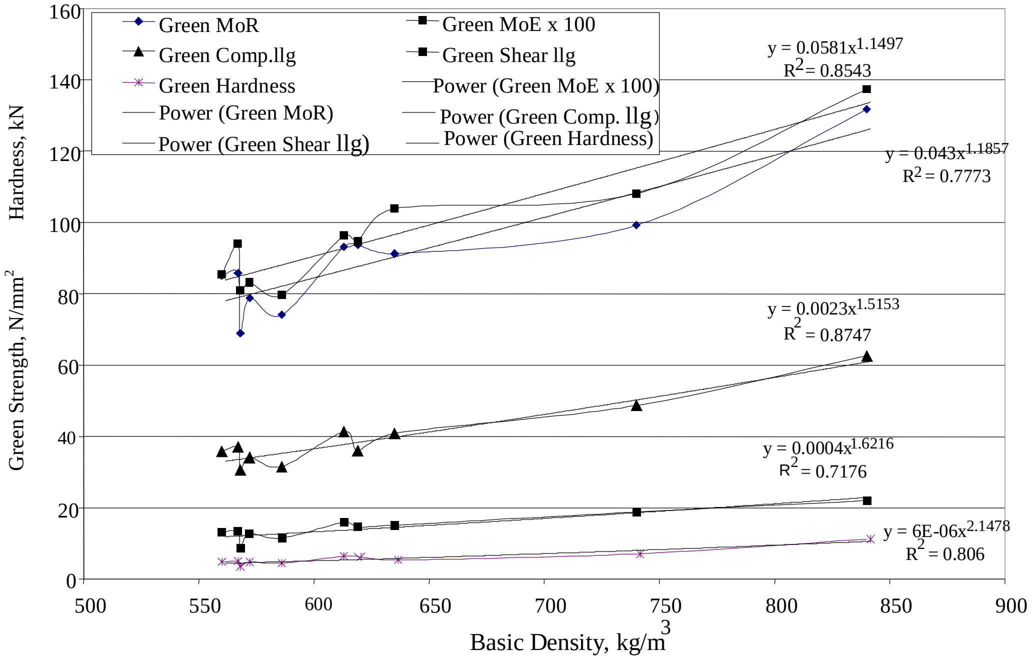

Figure 1a: Relationship between basic density and green strength

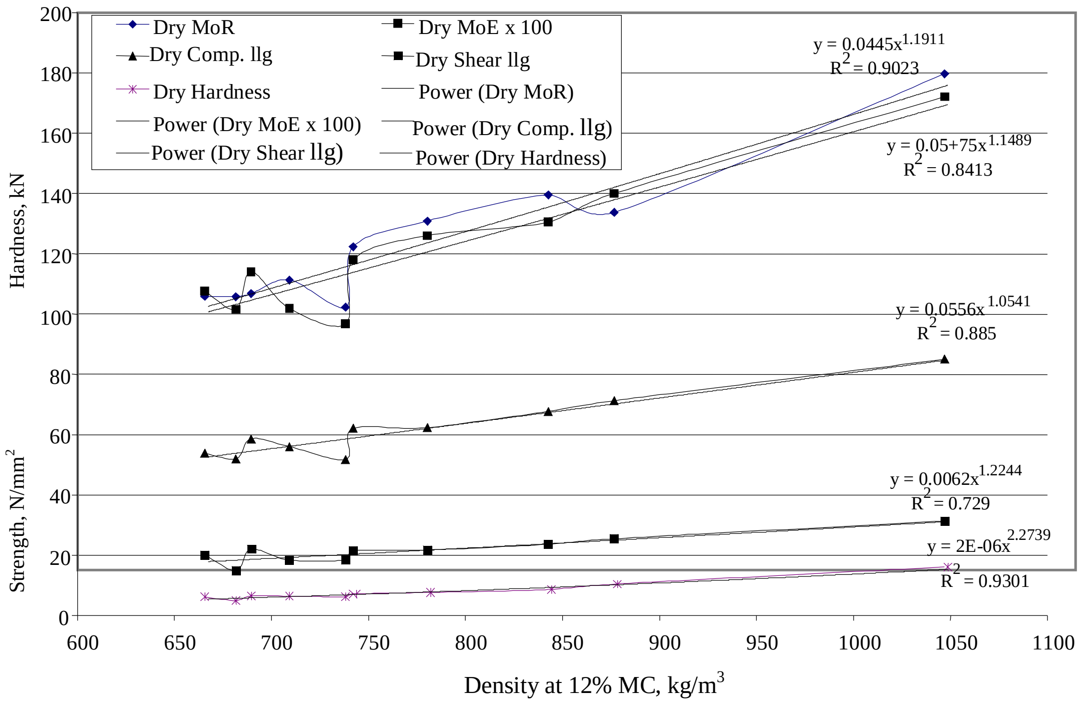

Figure 1b: Relationship between density at 12% MC and strength

CONCLUSIONS

The range of mean strength values in the 'green' [and dry] conditions for the ten species were as follows: - Modulus of Rupture: 69-132 [104-188] N/mm^2, Modulus of Elasticity: 7,970-13,740 [9,740-17,620] N/mm^2, Compression parallel to grain: 31-63 [54-92] N/mm^2, Shear parallel to grain: 8.8-22.1 [15.1-15.1] N/mm^2, and Hardness: 3.5-11.3 [5.1-17.0] kN.

The overall order of decreasing strength of the 10 species was as follows: Kaku > Ananta > Afina > *Celtis mildbraedii* > Kusia ≥ *Celtis zenkeri* ≈ Dahoma > Danta > Essia > Wawabima. Mean ratios of dry to 'green' MOR and MOE were 1.44 and 1.28.

According to the Upton & Attah (2003) and the TEDB (1994) classification, strength is 'High' in Kaku and Ananta; 'Medium' in Afina, *Celtis mildbraedii*, Kusia and *Celtis zenkeri*; and 'Low/Medium' in Dahoma, Danta, Wawabima and Essia.

The ratio of strength increases associated with drying small clear specimens from the 'green' condition to 12 percent moisture content were generally greatest in Wawabima [1.29-1.75] and Afina [1.39-1.67] and least in Kusia [1.13-1.49].

Density (X) and mechanical strength (Y) were highly correlated at 91.1 ~ 97.3% for 'green' wood and 84.4 ~ 98.2% for wood dried to 12% moisture content. Regression equations in the form: $Y = aX^b$ were derived with R^2 values of 0.72 ~ 0.93.

Strength of Kaku seems to be highest relative to its basic density. Strength of Wawabima (and to a less extent that of Essia) is low relative to its basic density.

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