BENDING AND MODULUS OF ELASTICITY PROPERTIES OF TEN LESSER-USED TIMBER SPECIES IN GHANA USING STRUCTURAL DIMENSIONS

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ABSTRACT

For structural use, the properties of large size specimens are preferred to those of small clear specimens because of unavoidable defects such as knots and shakes found in wood. The objective of this study was to assess the bending strength, modulus of elasticity properties and failure behaviour of ten Lesser-used Species (LUS) by use of structural size dimensions (50mm x 120 mm x 2000 mm). The ten species were ***Albizia ferruginea****, (Gulland Perr) Beuth.,* ***Sterculia rhinopetala****,(K. Schum),* ***Blighia sapida****,(Koenig),* ***Canarium schweinfurthii*** *(Engl.),* ***Petersianthus macrocarpus****, (P. Beauv.) Liben,* ***Sterculia oblonga****, (Mast.)* ***Cola gigantea****, (A.Chev.)* ***Celtis zenkeri****, (Engl.)* ***Antiaris toxicaria*** *(Lesch.) and* ***Amphimas pterocarpoides*** *(Harms.). The moisture contents of the 10 timber species used ranged from 16.1% (****Antiaris toxicaria****) to 51.0% (****Albizia ferruginea****). It was observed during loading under flexure that the elastic stiffness and rate of increase in the strength capacity of the beams did not change after three cycles of loading and unloading. All the beams failed in a form of tension rupture. The breaks were usually splintering tension failure or brittle (brashness) tension failure or a combination of the two modes of failure.* ***Sterculia rhinopetala*** *exhibited the highest bending strength with a* 5^{th} *percentile bending strength of 56.8* N/mm^2 *and a mean local modulus of elasticity of 15,973* N/mm^2*.* ***Sterculia oblonga*** *was also found to be the* 2^{nd} *best in terms of material properties with a* 5^{th} *percentile bending strength of 52.1* N/mm^2 *and a mean local modulus of elasticity of 16,408* N/mm^2*.* ***Celtis zenkeri*** *which had the highest mean local modulus of elasticity, however, had the* 6^{th} *best* 5^{th} *percentile bending strength of 39.9* N/mm^2*. A good linear correlation (69.6-91.3%) was established between mechanical strength properties for average density, average bending strength, average local modulus of elasticity and average global modulus of elasticity.*

Keywords: Lesser-utilized species, bending strength, modulus of elasticity, density

INTRODUCTION

The exploitation of timber in Ghana and indeed in many parts of Africa is limited to a few of the over 300 known species (Oteng-Amoako, 2006). Some of the popular species are *Pterygota macrocarpa* (Koto), *Milicia excelsa* (Odum), *Khaya ivorensis* (Mahogany), *Triplochiton scleroxylon* (Wawa), *Terminalia ivorensis* (Emire), *Aningeria altissima* (Asanfina) and *Nesogordonia papaverifera*

(Danta). The demand for these species nationally and internationally with excellent properties in terms of their strength and the quality of their finishes have led to over-exploitation. Although there are many other timber species, their properties are less known. The available data on the mechanical properties of such species has generally been attained with tests on small clear specimens (either 2 x 2 x 30 inches or 1 x 1 x 16 inches as specified by ASTM D 143-52 (1994). For structural use, the properties of large size specimens which are generally quite different from those of small clear specimens because of the unavoidable defects such as knots and shakes, need to be determined. In Ghana, the bending strength, modulus of elasticity and failure behaviour of most Lesser-used Species (LUS) in structural size dimensions have not yet been determined.

Within the framework of timber as a construction material, a distinction is made between primary or commercially accepted species and lesser known or lesser-used species. For several reasons, the viability of timber in the context of construction is dependent on lesser known timber species rather than commercially accepted species. Freezaillah (1990) defines Lesser-known species (LKS) as a commercially less accepted species left in the forest after a logging operation. But, as stated by Hansom (1983), a better definition is that it is a species that is not being put to best advantage. The list of commercial species has lengthened to some extent because of advances in technology and promotion and because of a growing scarcity of the more desired species. There has been considerable discussion about the fuller utilization of tropical forests with particular reference to the LKS, but the problem has remained intractable and little has been done (Freezaillah, 1990). Eddowes (1980), in discussing the technical aspects of promoting the LKS in Papua New Guinea, identified inadequate data on physical and mechanical properties as one of the main problems in promoting the LKS. Lesser-known species are species yet to be exported, but are now being promoted or have the potential to be promoted in the local market.

Lack of adequate information (mechanical properties) on the lesser-used species in Ghana has led to the over-exploitation of the few commercial species such as *Milicia. excelsa*, *Khaya. ivorensis*, *Milicia regia* whose properties are well known (Allotey, 1992). Prior to 1970, the characteristics of timber were assessed from tests carried out on small clear pieces of wood. However, following the extraordinary pioneering work by Madsen (1992), it was realized that this could be quite misleading. This is because the strength of structural size timber is much influenced by the presence of natural defects such as knots, pith flecks, etc. Alik and Nakai (1997a) noted in their work that using the results from full size structural timber was considered to be more reliable to allocate design strengths.

In this research work, ten lesser-used timber species were selected for the study. The species were *Albizia ferruginea*, *Sterculia rhinopetala*, *Blighia sapida*, *Canarium schweinfurthii* (Bediwonua), *Petersianthus macrocarpus* (Essia), *Sterculia oblonga* (Ohaa), *Cola gigantea* (Watapuo), *Celtis zenkeri* (Esa), *Antiaris toxicaria* (Kyenkyen) and *Amphimas pterocarpoides* (Lati). The objective of the study was to determine the bending strength, modulus of elasticity properties and failure behaviour of the selected lesser known species using structural size specimens.

MATERIALS AND METHODS

Materials

Two or three trees of each of the ten species were extracted from three forest regions in Ghana. The forests were located at Finaso Nkwanta (Moist Evergreen ecological zone), Kubease (Moist Semi-Deciduous – North-East Type) and Juaso (Moist Semi-Deciduous – South East type). The diameters of the trees at 1.3 m above ground were at least 45 cm with an average diameter of 60 cm. Clear boles of at least 25 m length were obtained and conveyed to Modern Wood Technology and Company Limited, Kumasi for processing. The logs were converted on a horizontal Band Mill to 55mm thick boards. The boards were then stacked for air-drying under a shed. Specimens were prepared from the boards for the determination of bending strength properties for each of the species. Test specimens were prepared according to the EN 408 (1995) standard for the determination of some physical and mechanical properties of structural timber.

Basic density and moisture content tests

Specimens were cut for the determination of basic density and 'green' moisture content. The standard for density determination was EN 408:1995 whilst that used for moisture content determination was EN 13183-1:2002.

Modulus of elasticity

Beam cross sectional dimensions of 50 x 120 mm with an effective span of 2500mm (Table 1) were used for both local and global modulus of elasticity tests. The European test method for the determination of the modulus of elasticity (MOE) in bending of structural timber, EN 408:1995 was used in this work.

The EN 408 specifies two methods or forms of determining modulus of elasticity; the local and global. The local modulus of elasticity is in principle based on pure bending deflection whilst the global modulus of elasticity is influenced by shear deflection (Solli, 1999). When measuring the global modulus of elasticity, the total deflection will be a combination of bending and shear deflection. The contributory effect of the shear deflection makes a fundamental difference between the global and local modulus of elasticity (Bostrom and Holmquist, 1999; Solli, 1999).

Table 1: Number of beams (50 x 120 x 2500 mm) tested for each of the 10 lesser-used species

Species			Number of Beams tested
Botanical Name	Local Name	Symbol	
Albizia ferruginea	Awiemfosamina	AF	7
Blighia sapida	Akye	BS	11
Canarium schweinfurthii	Bediwonua	CS	12
Celtis zenkeri	Esa	CZ	16
Petersianthus macrocarpus	Essia	PM	8
Sterculia oblonga	Ohaa	SO	10
Sterculia rhinopetala	Wawabima	SR	10
Cola gigantea	Watapuo	CG	10
Antiaris toxicaria	Kyenkyen	AT	11
Amphimas pterocarpoides	Lati	AP	12

The global modulus is not as sensitive to inaccurate measurements as the local modulus since the global deflection is about ten times the local. A measurement of the global modulus contains a higher number of possible sources of error. The temperature within which the tests were conducted ranged from 28 – 31^{0}C. The relative humidity was about 70%.

Bending strength test

The test beam was symmetrically loaded in bending at two points over an effective span of 2500mm as shown in Figure 1a. The test piece was set up simply supported with typical instrumentation as shown in Figure 1b. Small steel plates of length not greater than one-half of the depth of the test piece were inserted between the piece and the loading heads to minimize local indentations. Lateral restraints were provided at the supports to prevent buckling. The restraints are provided such that they permit the piece to deflect without significant frictional resistance. The load was applied by means of a hydraulic pump and was applied at constant loading-head movement so adjusted that maximum load was reached within 300 (±120) s. The load was increased at multiples of 2 kN up to 6 or 8 kN (about 40% of maximum expected failure load) and then reduced back to zero. This was repeated and the beam was loaded to failure at the third time of loading. The dial gauge readings were recorded for each load increment/decrement. The mode of fracture and the growth characteristics at the fracture section of each test piece was recorded.

The bending strength f_m was calculated using the equation:

$$f_m = a\,F_{max} / (2W) \qquad (1)$$

where W is the section modulus, F_{max} is the failure load and a is the distance between a loading position and the nearest support in a bending test.

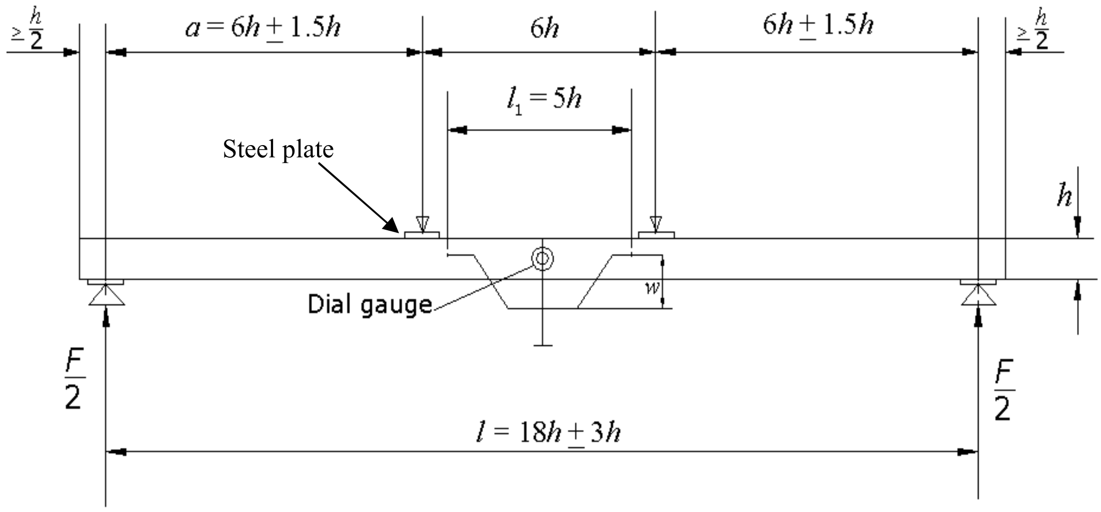

Figure 1a: Schematic test arrangement for measuring local modulus of elasticity in bending

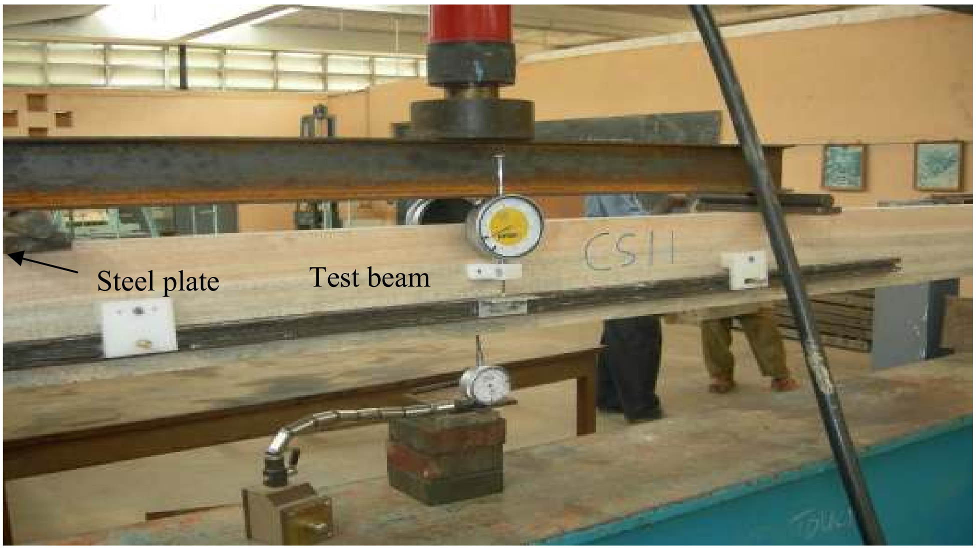

Figure 1b: Typical experimental set-up with instrumentation

RESULTS AND DISCUSSIONS

Moisture content and basic density

The moisture contents of the 10 timber species used, ranged from 16.1% (for *Antiaris toxicaria*) to 51.0% (for *Albizia ferruginea*) as shown in Table 2. The timber was only air-dried for about three months. For practical use, it is difficult to dry structural timber in Ghana to 12% moisture content by air-drying because of the very humid climate especially in the middle and coastal belts of the country. More so, if the recorded strengths could be derived at such high moisture contents, then higher strengths will be obtained when the timber species are in use.

The average density of the 10 timber species ranged from a minimum of 436 kg/m^3 for *Antiaris toxicaria* to a maximum of 1007 kg/m^{3}for *Sterculia rhinopetala*. These average density values indicate that the 10 species with the exception of *Antiaris toxicaria* and *Canarium schweinfurthii* 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. These high density values suggest that the timber species used in this study could be used for heavy construction (Ofori et al., 2009a). High density timber is expected to perform better in bending than low density timber (Tsuomis, 1991; Kollman and Cote, 1968; Davis, 1962). It is generally accepted that the density of wood is a good index of its properties as long as the wood is clear, straight grained, and free from defects. Density of wood is however affected by the presence of gums, resins and extractives which add to their weight and contribute little to mechanical properties (Lavers, 1983; Green *et al*, 1999; Ofori *et al*, 2009b).

Load-deflection and failure behavior

The load-deflection curves of all the species showed elastic load-deformation behaviour.

Table 2: Moisture content and density of the ten lesser-used species tested

Species	Moisture Content		Density	
	Mean (%)	Std. Dev.	Mean (kg/m^3)	Std. Dev.
Albizia ferruginea	51.0	10.63	740	75
Blighia sapida	28.5	9.70	899	55
Canarium schweinfurthii	30.4	5.80	488	30
Celtis zenkeri	29.0	7.90	829	31
Petersianthus macrocarpus	28.8	6.98	859	63
Sterculia oblonga	32.5	8.20	821	58
Sterculia rhinopetala	43.6	11.30	1007	86
Cola gigantea	19.4	5.40	671	74
Antiaris toxicaria	16.1	0.64	436	17
Amphimas pterocarpoides	16.4	1.12	772	29

However, the test beams did not return to their original positions after loading and unloading during the test. Permanent deformations were observed in the curves as presented in a typical curve (Figure 2). This means the species were not perfectly elastic. Cyclic loading, which is the repeated application of loads, was used in the test procedure. This is because many structures, such as bridges are usually subjected to repeated loading and unloading due to their usage. It has been found that structural components subjected to repeated loads may fail even though the associated stress levels are well below the yield strength (Bedford and Liechti, 2004). Basically, a small amount of damage is produced each time a load is applied. Although the amount of damage caused at each repetition, or cycle, is insufficient to cause failure, the damage can accumulate and eventually result in failure. It is observed that the elastic stiffness and rate of increase in the strength capacity of the beams did not change after the three cycles of loading (L1, L2 and L3) and two unloading (U1 and U2). This is indicative that the beam specimen did not undergo any stiffness deterioration or strength reduction for the limited cyclic loading.

The average failure loads for each of the 10 LUS timber species is shown in Table 3. The highest average experimental failure load of 22.8 kN was measured for *Sterculia rhinopetala* beams whilst the lowest of 10.7 kN was measured for *Antiaris toxicaria* beams. *Sterculia rhinopetala* had the highest density of 1007 kg/m^3 whilst Antiaris toxicaria had the lowest density of 422 kg/m^3. Even though the failure load of *Sterculia rhinopetala* (22.8 kN) was slightly higher than that of *Sterculia oblonga* (20.2 kN), the ultimate deflection of *Sterculia oblonga* (2.5 mm) was higher than that of *Sterculia rhinopetala* (1.57 mm). This could be explained by the fact that the density of *Sterculia rhinopetala* (1007 kg/m^3) was higher than that of *Sterculia oblonga* (821 kg/m^3) as shown in Table 3. There was no particular trend in the value of the ultimate loads so far as the predominant failure loads were concerned other than the effect of density. The highest average ultimate deflection of 3.9 mm was measured for *Cola gigantea* with an average ultimate load of 12.6 kN. All the average ultimate deflections were lower than both the theoretical deflections and the BS 5268 permissible design deflection (0.003 x span). A maximum theoretical deflection of 5.8 mm was expected for *Sterculia rhinopetala* beams which actually recorded 1.57 mm.

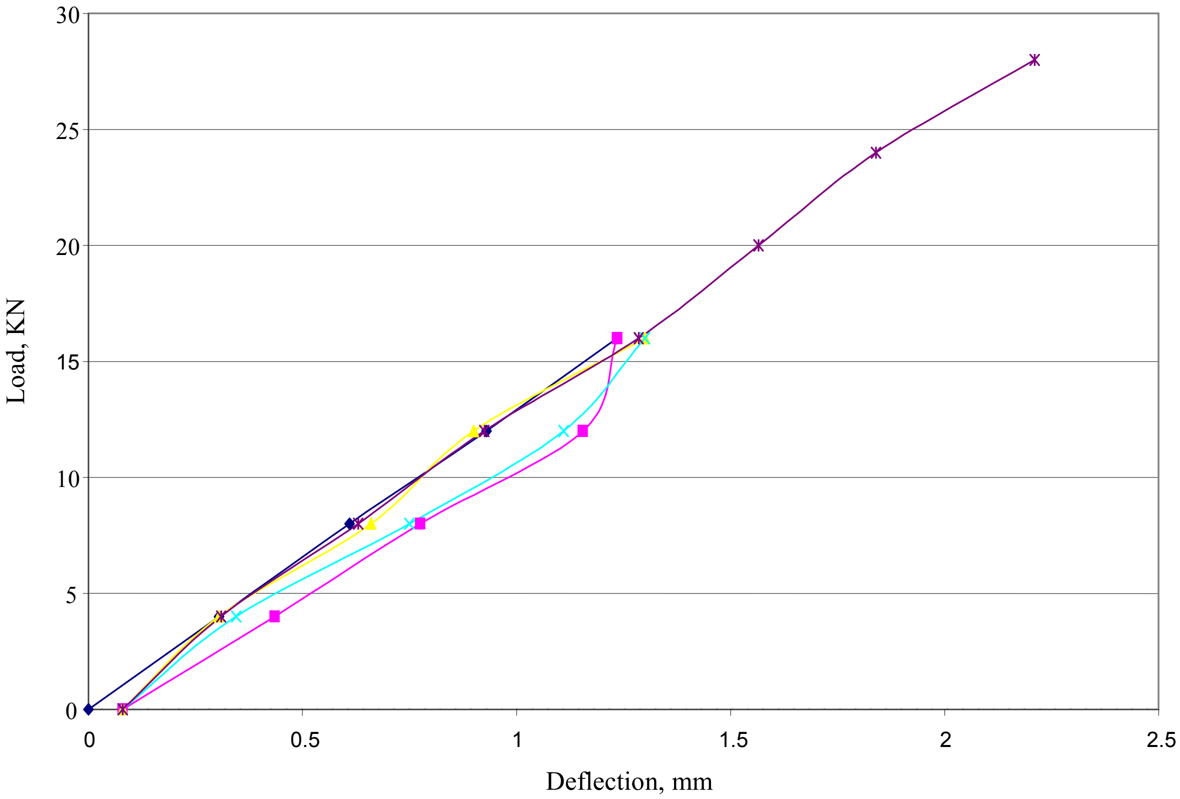

Figure 2: Typical load-deformation curve (SR31local modulus) of the species (L1 = First cycle loading; UI = First cycle unloading; L2 = Second cycle loading; U2 = Second cycle unloading; L3 = Loading to failure)

This is indicative of the fact that *Sterculia rhinopetala* beams exhibited the least deflection per unit load for all the LUS timber species studied.

A summary of the predominant failure mode of the 10 LUS timber species tested in the laboratory is given in Table 4. All the beams failed in a form of tension rupture. The breaks were usually splintering tension failure or brittle (brashness) tension failure or in some instances a combination of both modes of failure. *Albizia ferruginea*, *Celtis zenkeri*, *Antiaris toxicaria* and *Amphimas pterocarpoides* timber species failed in splintering tension mode. Four (4) other species; *Petersianthus macrocarpus*, *Sterculia oblonga*, *Sterculia rhinopetala* and *Cola gigantea* timber species failed in brittle (brashness) tension failure whilst the remaining two (2) species (*Blighia sapida* and *Canarium schweinfurthii*) failed in a combined splintering and brittle tension failure modes. The failure modes of the timber beams were observed to be related to the grain texture of the wood.

The species which failed in splintering tension were mostly medium to fine textured with straight grains as reported in other publications (Ayarkwa *et al.*, 2012; Anon, 2000; TEDB, 1994). On the other hand, brittle tension failure was observed in wood with coarse grains (Farmer, 1972). Some of the *Sterculia rhinopetala* beams had bearing failure in addition to flexural tension failure. Even though all the beams were within the dimensional limits to avoid lateral buckling, the *Canarium schweinfurthii* beams had the tendency to undergo lateral buckling before failure. It was observed that some of the timber beams (*Sterculia oblonga* species) underwent excessive deflections before failure.

Figure 3: Typical splintering tension failure of an *Albizia ferruginea* beam

Table 3: Average failure loads and deflections of the 10 lesser-used species tested

Species	Experimental Failure loads (kN)	Deflections (mm)		
		Experimental	Theoretical	BS 5268 limits (0.003 x span)
Albizia ferruginea	14.7	1.44	3.7	7.5
Blighia sapida	17.6	1.69	4.0	7.5
Canarium schweinfurthii	17.2	1.47	2.6	7.5
Celtis zenkeri	18.6	1.02	4.6	7.5
Petersianthus macrocarpus	17.0	2.65	5.2	7.5
Sterculia oblonga	20.2	2.50	4.7	7.5
Sterculia rhinopetala	22.8	1.57	5.8	7.5
Cola gigantea	12.6	3.90	4.5	7.5
Antiaris toxicaria	10.7	1.43	3.3	7.5
Amphimas pterocarpoides	17.0	1.30	3.9	7.5

Table 4: Predominant failure modes of structural size timber of the ten lesser-used species

Species	Predominant failure mode
Albizia ferruginea	Splintering tension failure
Blighia sapida	Combined splintering tension failure and brittle tension failure
Canarium schweinfurthii	Combined splintering tension failure, brittle tension failure and buckling of beams
Celtis zenkeri	Splintering tension failure
Petersianthus macrocarpus	Brittle tension failure
Sterculia oblonga	Brittle tension failure with excessive deflection in some beams
Sterculia rhinopetala	Brittle tension failure and bearing failure in some beams
Cola gigantea	Brittle tension failure
Antiaris toxicaria	Splintering tension failure
Amphimas pterocarpoides	Splintering tension failure

Modulus of elasticity and bending strength

The bending strength and modulus of elasticity are shown in Table 5 for the 10 timber species. The higher the density of a species, the higher the modulus of elasticity and the higher the bending strength. The order of decreasing characteristic (5th percentile) bending strength (MOR) of the ten (10) species was as follows: *Sterculia rhinopetala*, *Sterculia oblonga*, *Amphimas pterocarpoides*, *Blighia sapida*, *Petersianthus macrocarpus*, *Celtis zenkeri*, *Canarium schweinfurthii*, *Albizia ferruginea*, *Cola gigantean* and *Antiaris toxicaria*. The corresponding order of overall decreasing mean local modulus of elasticity (MOE) of the ten species was as follows: *Celtis zenkeri, Sterculia oblonga, Sterculia rhinopetala*, *Amphimas pterocarpoides, Albizia ferruginea, Blighia sapida*, *Cola gigantea, Petersianthus macrocarpus, Canarium schweinfurthii* and *Antiaris toxicaria*. *Sterculia rhinopetala* (Wawabima) has a 5th percentile bending strength of 56.8 N/mm^2 and a mean local modulus of elasticity of 15,973 N/mm^2. *Sterculia oblonga* was also found to be the 2nd best in terms of material properties. It had a 5th percentile bending strength of 52.1N/mm^2 and a mean local modulus of elasticity of 16,408 N/mm^2. *Celtis zenkeri* which had the highest mean local MOE, had the 6th best 5th percentile bending strength of 39.9 N/mm^2. Global MOE values were mostly lower than the local MOE values for each species.

Solli (1999) investigated the differences between the local and global modulus of elasticity (MOE) in bending of structural timber. There have been several discussions whether the local or the global value is the most representative value of the bending stiffness. Some researchers believe that since the local MOE is the current system being used and works well, there is no need to welcome a new system of global MOE, whose possible consequences are unknown. The local MOE is well known in the European strength class system (EN 338:2003), so with new system of values, design engineers might be confused. It is worthy of note that the limits of deflection given in the European building regulations are based on design by local MOE. It is also argued that the local MOE is not the correct parameter for the calculation of the deflection of timber floors. The argument is that the local value as described in EN 408:1995 is based on the critical section and therefore cannot be representative for a whole span. In addition, the test procedure of global MOE is easier and timesaving compared with the corresponding local MOE test procedure.

Solli also concluded that global MOE is not as sensitive to inaccurate measurements as local MOE since the global deflection is about ten times the local. The local MOE is in principle based on pure bending deflection whilst global MOE is also influenced by shear deflection. A measurement of the global MOE contains a higher number of possible sources of error such as the initial twisting of test pieces during testing. If the intended use of MOE is to estimate the corresponding bending strength of a piece of timber then the local MOE is the unrivalled alternative of the two methods.

Table 5: Modulus of elasticity and bending strength of the ten lesser-used species

Species	Modulus of elasticity (N/mm^2)				Bending Strength (N/mm^2)		
	local		global				
	Average	Std. Dev.	Average	Std. Dev	Average	Std. Dev	5th Percentile
Albizia ferruginea	13847	2544	11238	1819	49.9	9.1	31.7
Blighia sapida	12686	3517	12078	1161	61.4	10.2	42
Canarium schweinfurthii	10316	1281	9331	911	44	3.6	37.4
Celtis zenkeri	17422	2292	14273	1143	65.8	15.2	39.9
Petersianthus macrocarpus	12021	2223	10494	1504	60.9	9.6	41.7
Sterculia oblonga	16408	3008	13004	1756	70	9.4	52.1
Sterculia rhinopetala	15973	2839	13382	1356	81.7	13.1	56.8
Cola gigantea	10219	2526	9679	1375	45.7	8.8	29
Antiaris toxicaria	9675	1105	8827	868	38.4	5	29
Amphimas pterocarpoides	15595	2397	14220	917	63.6	9.7	46.1

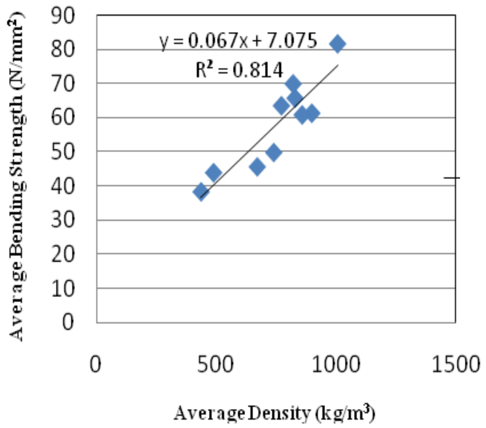

Figure 4a: Relationship between average density and average bending strength of the ten lesser-used species

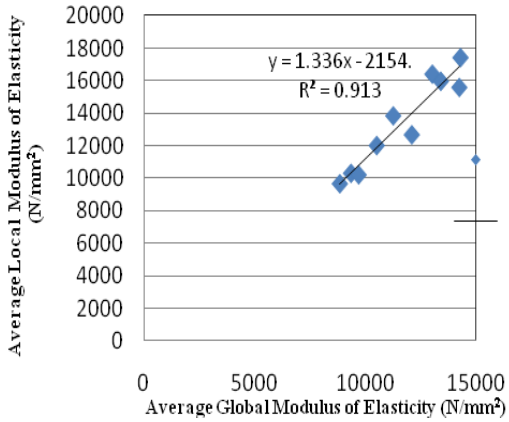

Figure 4b: Relationship between average global MOE and average local MOE of the ten lesser-used species

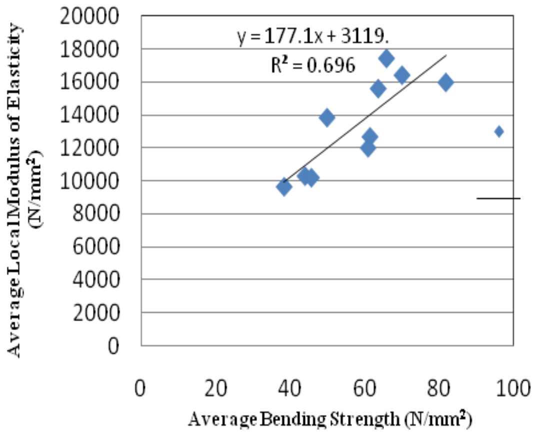

Figure 4c: Relationship between average bending strength and average local MOE of the 10 lesser-used species

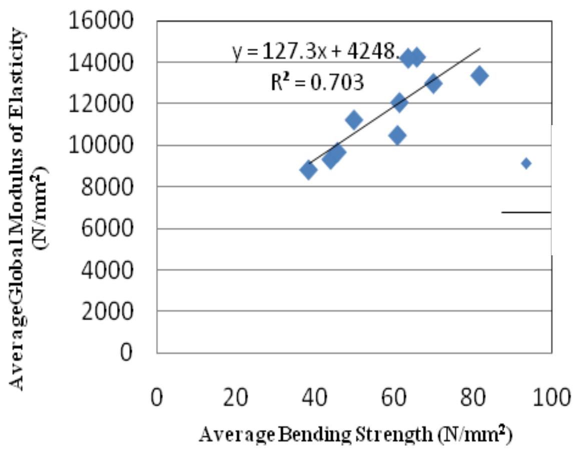

Figure 4d: Relationship between avearge bending strength and average global MOE of the 10 lesser-used species

Correlation between mechanical strength properties

Correlation between mechanical strength properties have been shown in Figure 4a-d for average density, average bending strength, average local MOE and average global MOE. All the properties were found to be linearly related to each other. There was a good correlation (81.4%) between average density values and average bending strength values (Figure 4a). Average local and global MOE values (Figure 4b) were highly correlated with a correlation coefficient of 91.3%. As shown in Figures 4c and 4d, average bending strength values were correlated at 69.6% and 70.3% for average local and global MOE values respectively.

CONCLUSION

In Ghana, the properties of structural size specimens, which are generally quite different from those of small clear specimens because of the unavoidable defects such as knots and shakes, have not yet been determined. In this study, the mechanical properties of ten Lesser Known Species (LKS) of timber were investigated to assess their suitability for structural use. The moisture contents of the 10 timber species used ranged from 16.1% to 51.0%. The average density of the species ranged from a minimum of 436 kg/m^3 for *Antiaris toxicaria* to a maximum of 1007 kg/m^3 for *Sterculia rhinopetala*. The mean density values indicate that the 10 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. It was observed during loading under flexure that the elastic stiffness and rate of increase in the strength capacity of the beams did not change after the three cycles of loading and unloading. This is indicative of the fact that the beam specimen did not undergo any stiffness deterioration or strength reduction for the two cycles of loading. All the beams failed in a form of tension rupture. The breaks were usually splintering tension failure or brittle (brashness) tension failure or in some instances a combination of both modes of failure.

Sterculia rhinopetala exhibited the highest bending strength with a 5th percentile bending strength of 56.8 N/mm^2 and a mean local modulus of elasticity of 15,973 N/mm^2. *Sterculia oblonga* was also found to be the 2nd best in terms of material properties with a 5th percentile bending strength of 52.1N/mm^2 and a mean local modulus of elasticity of 16,408 N/mm^2. *Celtis zenkeri* which had the highest mean local MOE, however, had the 6th best 5th percentile bending strength of 39.9 N/mm^2. A good linear correlation (69.6-91.3%) was found between mechanical strength properties for average density, average bending strength, average local MOE and average global MOE.

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