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Mechanical Properties of four Lesser - Known Ghanaian Timber Species

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Abstract: The exploitation of timber in Ghana and many parts of tropical Africa is limited to very few of the over 800 known species whose mechanical properties for structural use are unknown. The global demand for these few species with excellent properties in terms of their strength and quality of finishes has led to their over-exploitation and destruction of other less accepted species during logging operations. The structural use of timber is very limited in tropical Africa in spite of its abundance in the forests and its sustainability by cultivation. Considerable discussion has been held about the fuller utilization of tropical forests with particular reference to lesser-known species (LKS), but the problem has remained intractable and very little has been done. One main problem in promoting the LKS is lack of information on their realistic mechanical properties based on structural size dimensions. This paper reports results of research on the mechanical properties of four lesser-known species using structural sizes to assess their suitability as structural members. The species are *Albizia ferruginea* (Awiemfosamina), *Sterculia rhinopetala* (Wawabima), *Blighia sapida* (Akye) and *Canarium schweinfurthii* (Bediwonua). The results of study showed that **Wawabima** was the strongest whilst **Bediwonua** was the weakest in terms of their bending strength, density and modulus of elasticity. **Wawabima** had outstanding bending strength properties. With reference to standard codes, **Wawabima** compares very well with strength class D40, followed by **Akye** and **Awiemfosamina** with strength class D30 – both classes belonging to hardwoods. On the other hand, **Bediwonua** falling within strength class C24 belongs to softwood. The results indicate that **Wawabima** and **Akye** possess very good bending strength properties that are suitable for consideration in the design of medium to heavy structures. **Awiemfosamina** possesses good compressive strength but low bending strength, and together with **Bediwonua** are suitable for light structural members.

Keywords: *Mechanical Properties, Lesser - Known, Timber Species, Structural Us*

I. INTRODUCTION

The exploitation of timber in Ghana and indeed in many parts of Africa is limited to very few of the over 800 known species. Some 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 global demand for these species with excellent properties in strength and quality of their finishes has led to a dangerous overexploitation and destruction of other less desired species during logging operations. Several abundant timber species are hardly utilized for construction because their material properties are unknown. Timber for structural construction is very limited in Ghana and Africa in spite of its abundance in the forests and the fact that it can also be sustained by cultivation. Ironically, structural construction in these countries is overly dependent on expensive, imported raw materials such as steel and cement.

Within the framework of timber as a construction material, a distinction is made between primary or commercially accepted species and lesser known or less accepted species. Freezaillah, 1990 [1] defines lesser-known species (LKS) as commercially less accepted species left in the forest after a logging operation. However, Hansom, 1983 [2] defines it as species that is not put to best advantage. There has been advocacy for fuller utilization of tropical forests with particular reference to LKS, but the problem has remained intractable and little has been done [1]. Eddowes, 1980 [3] identified inadequate data on physical and mechanical properties as one of the main problems in promoting LKS. According to Oteng-Amoako, 2006 [4], the forest occurrence of LKS is variable, usually from frequent to sparse, and data on their technological properties are limited. The LKS are mostly lower-risk species which can be exploited under normal forest harvesting practice. According to Brazier, 1978 [5], commercial hardwood harvested for industrial use often represents only three to ten percent of the timber volume in any given area. This assertion is supported by Youngs, 1977 [6] that 90% of log trade in Nigeria has been in only six primary species. Ofori, 1985 [7] reports that only about 80 tree species out of approximately 600 species in West Africa, which reach sizes suitable for lumber and plywood production, are exploited. In an FAO, 1988 [8] inventory project classification of Ghana's high forest tree species, only about 60 species were exported from the country between 1973 and 1988. Large numbers of wood species growing in the natural tropical forests are excluded from the international timber market because they are deemed "undesirable" for a number of reasons including the chemical constituents of their extractives and lack of adequate data on their mechanical properties.

A. Recent research developments on strength properties of timber

Alik and Badorul, 2006 [9] investigated the strength characteristics of structural-size timber of six Malaysian species.

The species included *Dryobalanops beccarii*, *Dryobalanops fusca*, *Dryobalanops oblongifolia*, *Dryobalanops lanceolata*, *Dryobalanops rappa* and *Dryobalanops sumatrensis.* The Dryobalanops species which are all softwoods are lesser utilized and their properties needed to be established for standardization and commercial utilization. The authors established a correlation between small clear size and structural timber size as regards their modulus of rupture, direct tensile strength and modulus of elasticity. The results showed a weak correlation between small clear and structural size timber in terms of their modulus of rupture. They concluded that the strength values obtained from small clear wood specimens are inadequate to be used as the strength of full size structural timber. This is because the structural size members contain possible defects such as knots, checks and cracks which reduce their strength. Small clear samples tend to have higher strength values because of the lack of defects which is not the case in structural timber. It was calculated that the strength ratios of almost defect-free structural size to small clear specimens of the species were 0.75 and 0.77 at green and air-dried conditions of the wood respectively. Their findings were consistent with the study conducted by Alik and Nakai, 1997 [10], who used *Dipterocarp* species. Based on their density, the species could be classified under medium hardwood species. Alik and Nakai, 1997 [11] in another study showed that above fibre saturation point, the strength values appeared to be constant as the moisture content increased. In this case, within the green condition, there was no effect on the strength of the timber with an increase or loss of moisture content. De Vries et al., 2006 [12] investigated the modulus of elasticity and bending strength of locally grown larch (*Larix kaempferri*) round timber to assess the feasibility of using round timber in construction in The Netherlands. The authors indicated that the overall strength class for larch population grown in The Netherlands is C40. They also noted that the characteristic values of other strength properties (tension, compression, etc.) which are derived from the key values in EN 338:2003 [13] have to be revised for round timber. Chen et al., 2006 14] investigated the bending strength and modulus of elasticity of Douglas-fir and Hem-fir timber in Canada. Douglas-fir and Hem-fir species are softwoods which belong to the strength class of C16 for General Structural (GS) and C24 for Special Structural (SS) according to BS 5268:1997 [15]. The species were sampled in two sizes (105mm x 210mm and 105mm x 305mm in cross section) for both species. The specimens were also graded into Special Structural (SS) No.1 and No.2 grades according to the Canadian Lumber Grades Authority Standard grading rules. The research was conducted to obtain accurate material property information for the development of refined design procedures to benefit the construction industry in North America where timber is widely used for residential and light office, and industrial buildings. The characteristic mean modulus of elasticity and the characteristic bending strength were derived as a function of member size, species and grade.

Appiah-Kubi et al., 2012 [16] investigated the structural properties involving bending strength, deformation characteristics, density and modulus of elasticity of ten lesser-used structural timber size species in Ghana and their results are presented in Table 1. The authors found a good linear correlation (69.6–91.3 %) between mechanical strength for density, bending strength, local modulus of elasticity and global modulus o elasticity.

B. Significance of current research

Lack of adequate data on mechanical properties of lesser-utilized species in Ghana has led to over-exploitation of the few noble commercial species such as Odum, Mahogany, Iroko etc. whose properties are well known and established [17]. Prior to 1970, the characteristics of timber were assessed on the basis of the characteristics of small clear pieces of wood [18, 19]. However, Madsen, 1992 [20] showed that the strength of structural size timber is heavily influenced by the presence of natural features such as knots and pith. Alik and Nakai, 1997 [10] noted that using the results from full size structural timber was considered to be more reliable to allocate design stresses so as to eliminate the risk of stress assumptions. In addition, the values will reflect more on the actual strength of timber in use. There is lack of information on strength properties of full-size structural timber hence engineers, architects, designers and builders tend to use other materials such as concrete and steel for all buildings and structures in Ghana in spite of their extremely high costs. The proper and effective utilization of timber as a construction material very much depends on the experience and understanding of their technical data and also their structural behaviour with regard to each particular timber species.

In this research work, four lesser-known timber species were selected for the study. The species are *Albizia ferruginea* (Awiemfosamina), *Steculia rhinopetala* (Wawabima), *Blighia sapida* (Akye) and *Canarium schweinfurthii* (Bediwonua). The overall aim of the study was to determine the mechanical properties of the selected lesser known species using structural size specimens. Mechanical properties including bending strength, modulus of elasticity, direct tensile strength parallel to the grain, compressive strength parallel to the grain, and density which are necessary for the design of timber structures are determined.

Table 1: Modulus of elasticity and bending strength of ten LKS [16]

	MOE (N/mm^2)				Bending Strength (N/mm^2)		
	Local		Global				5^{th}
Species	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**% tile**
AF	13847	**2544**	**11238**	**1819**	**49.9**	**9.1**	**31.7**
BS	**12686**	**3517**	**12078**	**1161**	**61.4**	**10.2**	**42.0**
CS	**10316**	**1281**	**9331**	**911**	**44.0**	**3.6**	**37.4**
CZ	**17422**	**2292**	**14273**	**1143**	**65.8**	**15.2**	**39.9**
PM	**12021**	**2223**	**10494**	**1504**	**60.9**	**9.6**	**41.7**
SO	**16408**	**3008**	**13004**	**1756**	**70.0**	**9.4**	**52.1**
SR	**15973**	**2839**	**13382**	**1356**	**81.7**	**13.1**	**56.8**
CG	**10219**	**2526**	**9679**	**1375**	**45.7**	**8.8**	**29.0**
AT	**9675**	**1105**	**8827**	**868**	**38.4**	**5.0**	**29.0**
AP	**15595**	**2397**	**14220**	**917**	**63.6**	**9.7**	**46.1**

AF= ***Albizia ferruginea;*** **BS=** ***Bligea sapida;*** **CS=** ***Canarium Schweinfurthli***
CZ = *Celtis zenkeri;* PM = *Petersianthus macrocarpus;* SO = *Sterculia oblonga*
SR = *Sterculia rhinopetala;* CG = *Cola Gigantean;* AT = *Antiaris toxicaria*
AP = *Amphimas pterocarpodes*

II. MATERIALS AND METHODS

A. Materials

Four lesser-known timber species: *Albizia ferruginea* (Awiemfosamina), *Sterculia rhinopetala* (Wawabima), *Blighia sapida* (Akye) and *Canarium schweinfurthii* (Bediwonua) were investigated. Two trees of each species were extracted from two ecological zone forests, namely, Moist Evergreen and Moist Semi-Deciduous. The diameters of the trees at 1.3 metres above ground were at least 45cm with an average diameter of 60cm. Clear boles of at least 25m lengths were obtained and conveyed to a sawmill close to the test laboratory for processing. The logs were converted on a horizontal Band Mill to 55mm and 110mm thick boards. Specimens were prepared from the boards for the determination of bending, compression, tensile, and density properties for each of the species. Test specimens were prepared according to the EN 408:1995 [21] standard for the determination of some physical and mechanical properties of structural timber. Specimens were also cut for the determination of density and green moisture content. The beam dimensions were 100 x 200 mm in cross section with an effective span of 3000mm (Table 2) in accordance with EN 408:1995 [21] specification. The tests were conducted at a temperature of approximately 29^{0}C and relative humidity of about 80%. Bending, tensile, compressive strengths and modulus of elasticity tests were carried according to the appropriate Eurocodes [21, 22, 23].

B. Bending Strength (MOR) and Modulus of Elasticity (MOE) Tests

The test beam was simply supported and symmetrically loaded in bending at two points over an effective span of 3000mm as shown in Figure 1a. Small steel plates of length not greater than one-half of the depth of the test piece were inserted between the specimen and the loading heads to minimize local indentations. Lateral restraints were provided at the supports to prevent buckling. The restraints were provided such that they permitted 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 ($\pm$120) s. The load was increased at multiples of 4kN up to 16 kN (about 0.5 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 limited cycles of loading. The beam deflections were recorded by means of dial gauges for each load increment/decrement. The mode of fracture and growth characteristics at the fracture section of each test specimen were recorded.

Table 2: Number of Beams Tested and their dimensions for the 4 species

Species		Number of Beams tested	Test Dimension (mm)
Botanical Name	Local Name		
Albizia ferruginea (AF)	Awiemfosamina	7	100 x 200 x 3000
Blighia sapida (BS)	Akye	11	100 x 200 x 3000
Canarium schweinfurthii (CS)	Bediwonua	12	100 x 200 x 3000
Sterculia rhinopetala (SR)	Wawabima	10	100 x 200 x 3000

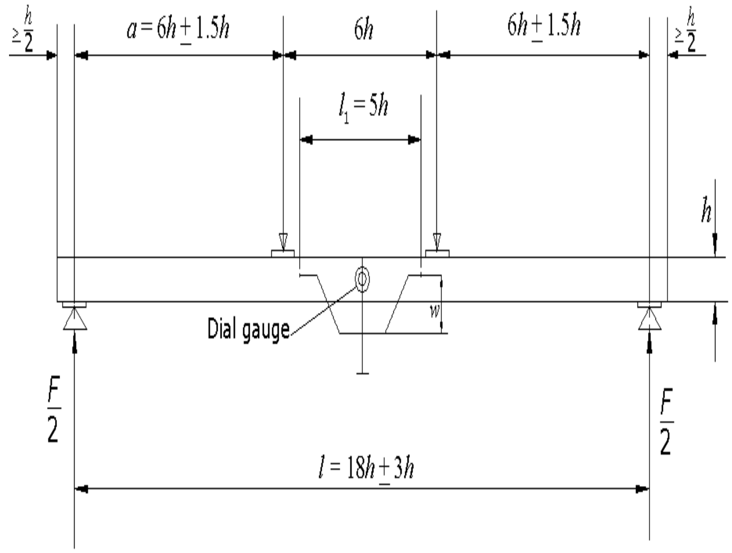

Figure 1a Schematic test arrangement for measuring local MOE

Figure 1b Typical experimental set-up with instrumentation

C. Compressive Strength Test

Specimens of dimensions 50 x 50 x 300mm were used for the test according to EN 408:1995 [21] which specifies that the test piece should have a length of six times the smaller cross-sectional dimension. The two end surfaces of the test pieces were prepared to ensure that they were plane and parallel to one another, and perpendicular to the axis of the piece. A universal strength testing machine was used. Forty (40) samples each of all the species were tested.

Care was taken to ensure that the specimen was placed at the central axis of the point of application of the compressive load. The failure load was recorded.

D. Tensile Strength Test

Tensile strength test was conducted in accordance with DIN 52186:1978 [23] to determine the ultimate tensile stress parallel to grain. Four (4) samples of each species of dimension 25 x 25 x 500 mm were used for the test. Upon load application, the piston of the tensile machine pulled the specimen apart at both ends until failure.

III. THEORETICAL CALCULATIONS

A. Bending strength (MOR)

The bending strength f_m was calculated using the equation;

$$f_m = aF_{max}/2Z \qquad (1)$$

where a is the distance between a loading position and the nearest support in the bending test, F_{max} is the maximum load applied in Newton and Z is the section modulus in cubic millimetres

B. Local Modulus of Elasticity

The local modulus of elasticity, $E_{m,l}$, was calculated from the following expression:

$$E_{m,l} = \frac{al_1^2(F_2-F_1)}{16I\,(w_2 - w_1)} \qquad (2)$$

where

$F_2 – F_1$ is an increment of load in Newtons on the regression line
w_2 – w_1 is the increment of deformation in millimeters corresponding to $F_2 – F_1$ (Fig. 2)
a is the distance between a loading position and the nearest support in a bending test;
l_1 is the gauge length for the determination of modulus of elasticity
I is the second moment of area in millimeter to the fourth power

The deformation, w, is measured at the centre of the span. It is the average of measurements on both faces of the neutral axis and is measured at the centre of a central gauge length of five times the depth of the section. The data is used to plot a load - deformation graph. A section of the graph between $0.1F_{max}$ and $0.4F_{max}$ is used for a regression analysis.

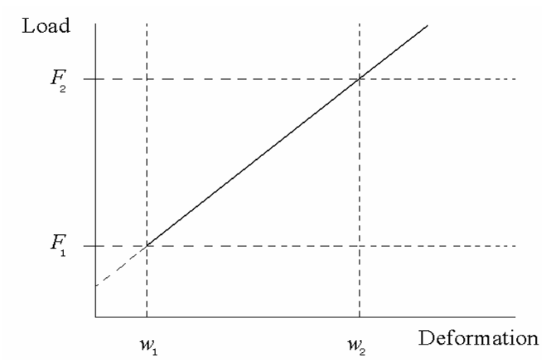

Figure 2: Load-deformation graph within the range of elastic deformation

C. Compressive and Tensile strengths

The compressive or tensile strength was determined using the failure load and the cross-sectional area of the specimen.

$$\sigma_{c,t} = F/A \qquad (3)$$

where, $\sigma_{c,t}$ is the compressive or tensile strength, F is the failure load and A is the cross sectional area of the specimen.

IV. RESULTS AND DISCUSSIONS

A. Typical load-deflection behaviour

The load-deflection curves of all the species showed elastic load-deformation behaviour. 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 illustrated in Figure 3 after three cycles of loading, indicating that the species were not perfectly linearly elastic. It is well known that structural components subjected to repeated loads may fail even though the associated stress levels are well below the yield strength [24]. Basically, a small amount of damage is produced each time a repeated load is applied. Although the amount of damage done in each repetition, or cycle, is insufficient to cause failure, 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. This is indicative of the fact that the beam specimen did not undergo any stiffness deterioration or strength degradation for the limited cyclic loading.

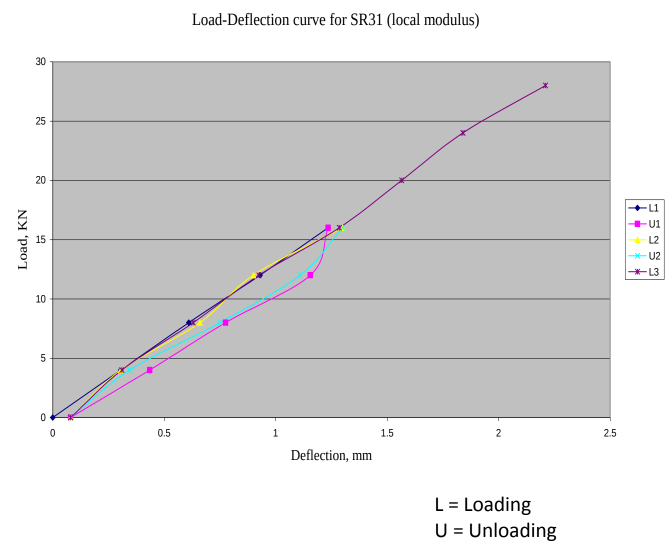

Figure.3: Typical load-deformation curve of the species

B. Failure modes of beams

All the AF timber beams failed in tension with a break in the centre of the beams. The failure was sudden and brittle. Failures in the AF beams occurred along existing cracks along the grains of the beams. Some failures occurred at or near areas of recognized weaknesses and defects such as knots, spots and holes. A typical cracking pattern of an AF beam is shown in Fig 4. Most of the BS timber beams failed in tension whilst a few beams failed in shear. The failures occurred around positions of knots in the shear regions. Generally, the failures occurred at points of weakness or defects. A couple of beams had their grains diagonally oriented and failure occurred along such grains. Some failed with a split in the tension zone associated with loud noise.

The SR timber beams failed in flexural compression. There was excessive deflection of the beams at failure. Some of the beams had bearing failure at the supports. The moisture content was high so the sap from the wood was seen dripping from some of the beams at failure. The CS timber beams generally buckled laterally during loading before breaking in the flexural tension zone. A few of the CS beams did not break in flexural tension but rather deflected laterally undergoing excessive buckling. In this case, the beams became unstable and could not be loaded any further. The geometric dimensions of the cross-sections coupled with the provision made at the supports against buckling made it difficult to explain this failure mode which was not expected for the CS beams.

Figure 4 Typical cracking of an AF beam

C. Local versus Global MOE

Solli, 1999 [25] investigated the differences between the local and global modulus of elasticity (MOE) in bending of structural timber. The European test method for the determination of the MOE in bending of structural timber, EN 408:1995 [21], was used in his work. There have been several discussions whether the local or the global value is the most representative value of the bending stiffness. The local MOE which is the current system and works well is well known in the European strength class system [13]. The limits of deflection given in the European building regulations are based on design by local MOE. The local value as described in EN 408:1995 [21] is based on the critical section and therefore cannot be representative for a whole span. The test procedure of global MOE is easier and timesaving compared with the corresponding local MOE test procedure. The 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. Measurement of the global MOE contains a higher number of possible sources of error such as the initial twisting of test pieces during testing.

D. Mechanical properties of timber species

The bending strength, compressive strength, tensile strength, modulus of elasticity, moisture content and density of timber species are shown in Table 3. It is noted that the modulus of elasticity and bending strength increase with increased density.

The order of decreasing characteristic (5^{th} percentile) bending strength (MOR) of the four species was as follows: *Sterculia rhinopetala* (SR), *Blighia sapida* (BS), *Albizia ferruginea* (AF) and *Canarium schweinfurthii* (CS). The corresponding order of overall decreasing modulus of elasticity (MOE) of the four species was as follows: *Sterculia rhinopetala* (SR), *Blighia sapida* (BS), *Albizia ferruginea* (AF) and *Canarium schweinfurthii* (CS). The study therefore indicates that *Sterculia rhinopetala* (Wawabima) possesses the overall best bending strength properties suitable for consideration in the design of structural members. *Sterculia rhinopetala* (Wawabima) has a 5^{th} percentile bending strength of 47.6 N/mm^2 and a local modulus of elasticity of 15,562 N/mm^2. *Blighia sapida* (Akye) was found to be the 2^{nd} best in terms of material properties. It has a 5^{th} percentile bending strength of 19.5 N/mm^2 and a local modulus of elasticity of 13,274 N/mm^2. It can also be used for structural purposes. *Albizia ferruginea* (Awiemfosamina) had good 5^{th} percentile compressive strength of 25.2 N/mm^2. However, it could not be recommended for construction as a heavy or medium structural material because it has low 5^{th} percentile bending strength of 14 N/mm^2 from the results. The order of decreasing compressive strength is: *Blighia sapida* (BS), *Sterculia rhinopetala* (SR), *Albizia ferruginea* (AF) and *Canarium schweinfurthii* (CS). *Canarium schweinfurthii* (Bediwonua) is the species with relatively lowest structural properties. It had a 5^{th} percentile MOR of 11.5 N/mm^2 and an MOE of 9209 N/mm^2.

There are few facilities available in the country to dry timber, and so the timber was only air-dried for about three months in deviation from standard practices [26]. For practical use, structural timber in Ghana is never dried to 12% because of the very humid climate, which would quickly raise the moisture content again. Therefore, the moisture content of the four (4) timber species used ranged from 38.1 to 66.2% as shown in Table 3. Another valid argument is that 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 range of mean compressive strength parallel to grain values is 31.5 – 46.5 N/mm^2 while the range of values for the characteristic compressive strength parallel to the grain of the species is 24.9 – 38.8 N/mm^2 [16]. The overall order of decreasing compressive strengths parallel to grain of the species is *Blighia sapida* (Akye), *Sterculia rhinopetala* (Wawabima), *Canarium schweinfurthii* (Bediwonua) and *Albizia ferruginea* (Awiemfosamina).

Table 3: Mechanical properties of timber species

Species	MOR (N/mm^2)		MOE (N/mm^2)	C S (N/mm^2)		T S (N/mm^2)	Density (kg/m^3)	MC %
	Mean	5^{th} %	Mean	Mean	5^{th} %	5^{th} %	Mean	Mean
AF	29.2	14.0	12619	31.5	25.2	22	881	66.2
BS	39.6	19.5	13274	46.5	38.8	31	1006	38.1
SR	63.2	47.6	15562	39.4	30.6	27	1038	52.1
CS	25.2	11.5	9209	35.4	24.9	25	497	41.2

MOR = modulus of rupture (Bending strength; MOE = modulus of elasticity
CS = compressive strength; TS = tensile strength; MC = moisture content
% = percentile

E. Strength classification of four Lesser Known Timber Species

The selection of timber for structural purposes must be dependent on both the strength and durability characteristics. Bending, compression, tensile strength and MOE tests were conducted on all the four (4) selected species to determine their mechanical properties as shown in Table 3. Quartey et al., 2008 [27] conducted durability tests on the same species in a related research. From the results, Albizia *ferruginea* was found to be the most durable species. Both *Sterculia rhinopetala* and *Blighia sapida* were found to have good natural durability characteristics. *Canarium schweinfurthii* was found in the same study to have poor natural durability [27].

Results obtained were used to classify the various species into their proposed strength classes according to the EN 338: 2003 [13]. The results indicated that *Sterculia rhinopetala* (Wawabima) was the species with the overall best material properties and compares well with EN 338:2003 [13] class D40. It therefore belongs to strength class D40 and qualifies to be used as structural timber members such as in design and construction of bridges, farm structures, industrial and residential buildings. *Sterculia rhinopetala* (Wawabima) was found to be the species with the overall best material properties suitable for consideration in the design of structural members. *Blighia sapida* (Akye) was also found to be the second best in terms of material properties and compares well with strength class D30. It can also be used as a structural member for construction. *Canarium schweinfurthii* (Bediwonua) compares with C24 even though strength class C24 belongs to softwoods. *Albizia ferruginea* (Awiemfosamina) produced some good results such as very good compressive stress and is classified as class D30. However, it should be recommended for construction as a light structural member because it had a low characteristic bending strength from the results. *Sterculia rhinopetala* (Wawabima) and *Blighia sapida* (Akye) are therefore recommended for use in medium to heavy structural timber applications.

CONCLUSIONS

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 four lesser known timber species were investigated to assess their suitability for structural use. These species abound in the forests of Ghana and West Africa. According to EN 338: 2003 [13], *Blighia sapida* (Akye) compares very well with strength class D30, Sterculia *rhinopetala* (Wawabima) compares well with strength class D40, *Canarium schweinfurthii* (Bediwonua) compares with C24 even though strength class C24 belongs to softwoods. *Albizia ferruginea* (Awiemfosamina) is in the class of D30 with respect to the strength values obtained. The results indicate that *Wawabima* and *Akye* possess very good bending strength properties that are suitable for consideration in the design of medium to heavy structures. *Awiemfosamina* possesses good compressive strength but low bending strength, and together with *Bediwonua* is suitable as light structural members such as in residential buildings, light commercial buildings and pedestrian bridges.

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