Strength Characterisation of Timbers for Building Construction in Uganda

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ABSTRACT
Lack of local Uganda timber standards formed the basis of the study. The specific objectives were to determine strength properties of selected timbers; develop a strength class system; and develop a non-destructive timber testing approach. Strength tests were conducted in bending, compression and shear parallel to grain following procedures of American Society for Testing and Materials (ASTM), ISO 8905 1988(E), AS/NZS 2878 (2000)and BS 373 (1957). The allowable Modulus of rupture (MOR) varied from 3.9 N/mm^2 to 20.3 N/mm^2; the mean Modulus of Elasticity (MOE) varied from 5,760 N/mm^2 to 13,440 N/mm^2; shear parallel to grain varied from 7.2 N/mm^2 to 13 N/mm^2; compression parallel to grain varied from 20 N/mm^2 to 59 N/mm^2 and density varied from 322 Kg/m^3 to 595 Kg/m^3. Four timber strength classes: SG4, SG8, SG12 and SG16 were developed. It was concluded that MOE and MOR of structural timber can be estimated from small clear MOE and MOR using reduction factors of 40% and 20% respectively. It was also concluded that a number of lesser-known timbers have strength properties comparable to those of well-known timbers. There is need to develop timber standards for Uganda.

Key words: building, construction, standards, strength class, timber

1.0 INTRODUCTION

Timber is a complex building material owing to its heterogeneity and species diversity. Timber does not have consistent, predictable, reproducible and uniform properties as the properties vary with species, age, site and environmental conditions (Kliger, 2000). The demand for quality timber for construction is on the rise in Uganda due to a boom in the building construction industry. With over-exploitation and scarcity of traditional timber species such as Mahogany and *Milicia excelsa* (Mvule), there is a diversity of previously unpopular species on the market. Zziwa *et al*., (2009) revealed that there are 48 timber species on market and despite the big number; consumers prefer only 20%. The durability, integrity and safety of structures from such species cannot be assured. Reliable structural use of timber has always been hampered by lack of appropriate design codes and well-established standards. In Uganda, timber classification is on the basis of species, colour and weight, or source whereas selection is based on nominal size, experience, visual appearance and species preference. Design of timber structures has been based on foreign standards such as BS 5268:1999 & 1998 on structural use of timber and BS 6399:1996 on loading; prescriptive procedures; and conservative assumptions (Zziwa *et al.,* 2006). This study was therefore conducted to determine strength properties of selected timbers; develop a strength class system; and develop a non-destructive timber strength testing approach.

2.0 METHODS

2.1 Determination of Strength Properties

The strength properties investigated were MOR, MOE, compressive stress, tensile strength, shear strength and cleavage strength. The species investigated were:- *Albizia coriaria(*Mugavu); *Albizia zygia* (White Nongo); *Blighia unijugata* (Nkuzanyana); *Celtis mildbraedii* (Lufugo); *Eucalyptus grandis* (Kalitunsi); *Lovoa brownii* (Nkoba); *Maesopsis eminii* (Musizi); *Uapaca guineensis* (Namagulu) *Pinus caribaea* (Pine); *Morus lactea* (Mukooge); *Khaya anthotheca* (Ugandan Mahogany); *Markhamia lutea* (Nsambya); *Piptadeniastrum africanum* (Mpewere); *Funtumia elastica* (Nkago); *Aningeria altissima* (Enkalati); *Albizia gummifera* (Red Nongo) and *Entandrophragma angolense* (Mukusu). Pair-wise ranking was used to prioritise the 20 timbers for investigation basing on availability and consumer preference. A structured matrix was used to compare two species a time to decide on the 20 timber species for investigation. A total of 30 respondents were involved and these were mainly timber dealers (n=15), saw millers (n=8) and contractors (n=7). Five boards of nominal dimensions 75 mm × 50 mm×2300mm were purposively sampled from timber yards in Kampala, the collection centre for timbers from various agro-ecological zones of Uganda. Fewer boards were used to get an estimate of the mean strength of clear wood, which is only a rough indication of the properties of structural lumber. Forty specimens were prepared per property test (AS/NZS 2878:2000). All specimens were air-dried to 12±3% moisture content prior to testing. Strength tests were carried out using a Universal Testing Machine (UTM) at Makerere University Faculty of Technology Structures Laboratory where the relative humidity was 65±3% and temperatures were 20±3ºC. Results from specimens with failure due to internally hidden defects were rejected. MOE and MOR were determined in a static bending test on SCS of 300 mm × 20 mm × 20 mm using a Testometric AX M500 – 25KN UTM at a loading rate of 6.6 mm per minute (Dinwoodie, 1981). The load at elastic limit (P_e) and the deflections (δ) were recorded and used for computation of MOE (E) in N/mm^2 using equation (1):

$$E = \alpha K \tag{1}$$

Where α is a specimen geometric parameter given by $\frac{L^3}{4bd^3} = 34.3$ for L = 280 mm, b = breadth (20 mm), d = depth (20 mm). K= the slope of the elastic portion of the Load -deflection graph.

The load (P_e) was recorded and used for computation of MOR (σ_b) in N/mm^2 using equation (2):

$$\sigma_b = \beta P_e \tag{2}$$

Where β is a specimen geometric parameter given by $\beta = \frac{3L}{2bd^2} = 0.0525$.

Tensile tests were futile; hence tensile stresses (σ_T) were derived from the MOR (σ_b) values using equation 3 according to Mettem (1986).

$$\sigma_T = 0.6\sigma_b \tag{3}$$

Compression parallel to grain tests on SCS of 60 mm x 20 mm x 20 mm were carried out using a UTM at a rate of 0.6 mm per minute (Dinwoodie, 1981). The maximum load (P_{max}) was recorded and the compressive stress parallel to the grain, (σ_c) in N/mm^2 was calculated using equation (4):

$$\sigma_c = \frac{P_{max}}{bd} \tag{4}$$

Ultimate shear strength parallel to grain involved measuring the maximum shear load (F_{max}) at a loading rate of 1.26 mm per minute and the shear stress,τ, was calculated using equation (5):

$$\tau = \frac{F\max}{tl} \tag{5}$$

Where t is the thickness = 50mm, and l is the length of the shearing plane = 40mm

2.2 Determination of Physical Properties

Basic density was obtained using green volume and oven-dry weight of 20 mm × 20 mm × 15 mm specimens. Specimens were soaked in distilled water till they sunk and attained green volume (V_g). The specimens were then oven-dried at a temperature of 103±2°C to constant weight (W_d), and the basic density (ρ) in kg/m^3 was calculated using equation (6):

$$\rho = \frac{Wd}{Vg} \times 1000 \tag{6}$$

Moisture content was determined in accordance with ISO 3133 (1975a); specimens were weighed immediately after testing to obtain their weight (W_t) and oven-dried at a temperature of 103±2 °C to constant weight to obtain the oven-dry weight (W_d). The moisture content was calculated using equation (7):

$$MC = \left(\frac{W_t - W_d}{W_d}\right) \times 100\ \% \tag{7}$$

All stresses were adjusted to $P_{12\%}$, their 12% MC equivalents, using equation (8):

$$P_{12\%} = P\ (1 + Z)^n \tag{8}$$

Where Z is the correction factor for moisture content (Adapted from Ishengoma and Nagoda, 1991), n = MC of specimen at the time of test -12, and P is the stress at time of test.

The minimum stresses were computed as the 5th-percentile minimum values from equation (9).

$$SCS_{0.05} = \overline{X} - t_{\alpha} S \tag{9}$$

Where t_α is the t-value at 95% confidence level dependent on sample size, $\overline{x}$ is the mean stress, $SCS_{0.05}$ is the 5th-percentile strength and S is standard deviation.

Allowable stresses (SCS_{basic}) were derived using equation (10)

$$SCS_{basic} = \frac{SCS_{0.05}}{F} \tag{10}$$

Where SCS_{basic} is the allowable bending stress and F is reduction factor =2.65 for tropical timbers; to allow for specimen size, rate of loading and safety considerations (Mettem, 1986).

2.3 Timber Strength Classes

The timber species were grouped into 4 species-independent classes characterized by unique strength properties and class names. The classification was based on the mean MOE and lower 5th-percentile bending stresses derived from small clear test data in accordance with the EN 338. The MOE and MOR were used in setting timber strength groups because the study revealed strong correlations between MOE and MOR. MOR is also a good measure of timber strength while MOE is a good predictor of strength (Divos and Tanaka, 2005). Arithmetic and geometrical progression were used to set the class boundaries. Allowable MOR values for the classes were set as multiples of 4.

2.4 Non-destructive Evaluation of MOE and MOR of Timber

The NDE approach was based on a prototype timber testing machine, which was fabricated and calibrated to give reliable values of MOE and MOR for timber using deflection as a predictor parameter. Fifty four specimens were tested using the NDE prototype to get the load required to cause a deflection of 5mm, P_{5mm} (predictor parameter). The specimens were then tested to destruction using the UTM to get the MOR and MOE according to BS 4978; ASTM D198-02 and ISO/FDIS 13910:2004(E).

3.0 RESULTS

3.1 Timber Strength Values

Table 1 shows means and standard deviations of basic density and strength properties of the investigated species. The figures in parentheses are the standard deviations. T-test checks showed significant differences (P<0.05) in strength properties and density of the investigated species.

Table 1: Mean strength (N/mm^2) and basic density (kg/m^3) for the timbers

Species name		MOR	MOE	Compression parallel to grain	Shear parallel to grain	Basic density
Scientific name	Local/Trade name					
Albizia coriaria	Mugavu	*45.8*	*5760*	35.11	9.82	567
		(13.4)	*(1403)*	(7.22)	(1.46)	(58)
Albizia zygia	White Nongo	*54.5*	*8124*	38.62	7.20	480
		(9.39)	*(1572)*	(7.50)	(2.35)	(67)
Blighia unijugata	Nkuzanyana	*48.5*	*9754*	35.43	11.79	536
		(8.86)	*(1528)*	(9.93)	(2.59)	(29)
Celtis mildbraedii	Lufugo	*77.1*	*13230*	41.55	13.02	569
		(11.18)	*(1219)*	(8.52)	(2.56)	(23)
Eucalyptus grandis	Kalitunsi	*33.9*	*8207*	29.69	8.18	526
		(14.36)	*(1567)*	(7.94)	(2.98)	(34)
Lovoa brownii	Nkoba	*46.2*	*9065*	36.36	12.06	514
		(12.78)	*(1821)*	(7.94)	(2.42)	(32)
Maesopsis eminii	Musizi	*27.9*	*8569*	26.94	7.79	407
		(7.83)	*(1110)*	(7.04)	(1.19)	(17)
Uapaca guineensis	Namagulu	*61.2*	*9320*	34.0	8.42	558
		(10.59)	*(1835)*	(7.90)	(1.13)	(43)
Pinus caribaea	Pine	*26.9*	*7810*	26.33	9.67	383
		(6.32)	*(1343)*	(5.53)	(1.14)	(15)
Morus lactea	Mukooge	*77.3*	*13,440*	58.45	9.445	595
		(11.49)	*(1516)*	(7.22)	(1.78)	(28)
Khaya anthotheca	Ugandan Mahogany	*50.3*	*9388*	35.57	7.37	481
		(9.04)	*(1733)*	(7.33)	(1.123)	(9)
Markhamia lutea	Nsambya	*43.9*	*7970*	31.74	7.534	427
		(5.36)	*(1276)*	(5.59)	(0.873)	(27)
Piptadeniastrum africanum	Mpewere	*48.7*	*10,702*	39.47		467
		(7.54)	*(715)*	(6.06)	**	(26)
Funtumia elastica	Nkago	*23.8*	*5612*	20.16	7.33	322
		(6.55)	*(1044)*	(4.797)	(2.444)	(23)
Aningeria altissima	Enkalati	*38.1*	*6161*	28.07	8.5	402
		(6.04)	*(1373)*	(9.65)	(1.78)	(20)
Albizia gummifera	Red Nongo	*43.7*	*9496*	40.11	8.27	410
		(11.47)	*(1291)*	(10.73)	(2.17)	(29)
Entandrophragma angolense	Mukusu	*34.6*	*7482*	25.90	8.814	475
		(5.9)	*(1093)*	(5.70)	(1.231)	(42)

All values quoted at 12% MC, the figures in parenthesis are standard deviations.
** Load capacity of UTM exceeded, so no data was captured.

3.2 Timber Strength Classes

Four strength groups namely SG4, SG8, SG12 and SG16 were derived (Table 2) in view of the anticipated loading categories in building construction. For each strength class (SG), the number refers to allowable bending stress. For instance, SG8 refers to a strength group with an allowable bending stress of 8 MPa.

Table 2: Timber strength Classes and Properties

Strength Class	Allowable MOR (N/mm^2)	5^{th} Percentile MOR (N/mm^2)	Mean MOE (N/mm^2)
SG4	4	10.60	5710
SG8	8	21.20	8148
SG12	12	31.80	9710
SG16	16	42.40	11898

SG4 includes: *Funtumia elastica, Pinus caribaea, Maesopsis eminii,b Albizia gummifera*, *Lovoa brownii* and *Albizia coriaria*; SG8 includes *Entandrophragma angolense, Eucalyptus grandis, Khaya anthotheca, Blighia unijugata* and *Aningeria altisima*; SG12 includes *Markhamia lutea, Piptadeniastrum africanum, Albizia zygia* and *Uapaca guineensis* and SG16 includes *Celtis mildbraedii* and *Morus lacteal.* Conservative approaches were used

3.3 Non-destructive Timber Strength Testing

The coefficient of determination relating P_{5mm} and MOR is 0.425; that is P_{5mm} explains 43% of the variation in MOR whereas the coefficient of determination relating P_{5mm} and MOE is 0.588; that is P_{5mm} explains 59% of the variation in MOE. Coefficients of determination could improve by testing more samples. Figure 2 shows the use of P_{5mm} as a single predictor of MOE and MOR of structural size timber. The dotted lines show the lower 5^{th} percentile MOE and MOR values. In the figure, simple linear regression analysis was used.

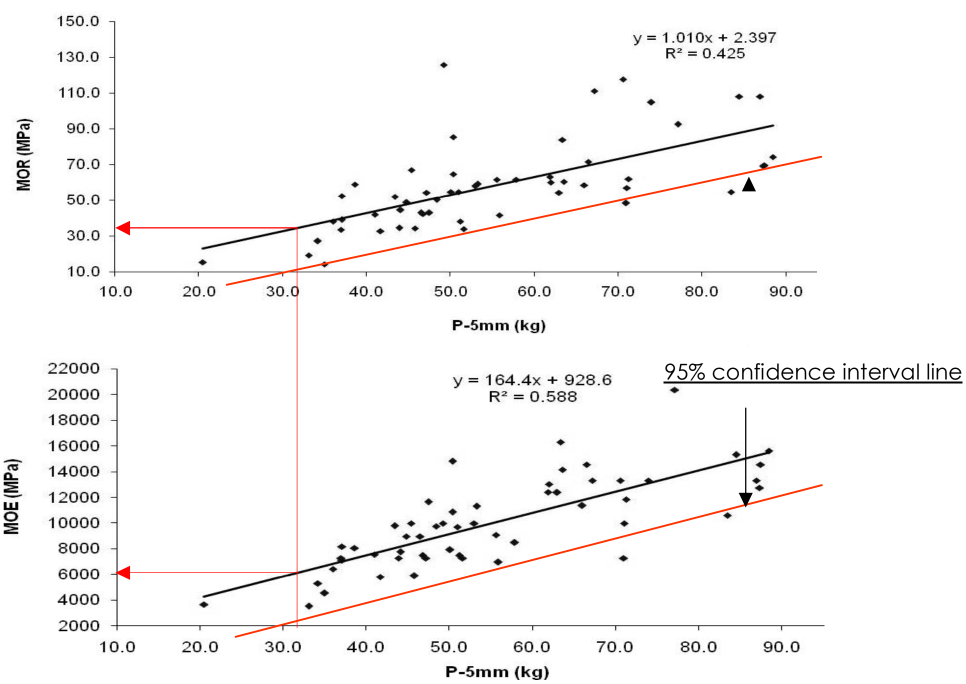
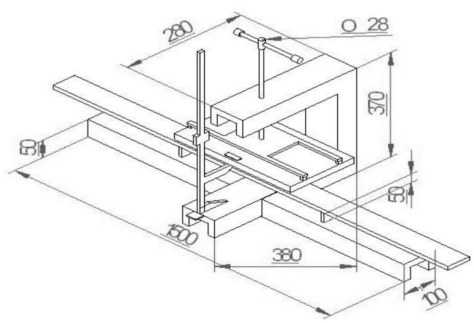


Figure 2: Predicting timber flexural strength by regression analysis

3.4 Discussion

The timber strength properties and the allowable bending stresses were comparable to those of strength classes C14 to C40 and TR 26 for softwoods and D30 to D70 for hardwoods (BS 5268: Part 2: 1996). For instance, the allowable bending stress of Pine was 5.3 N/mm^2 which puts it in strength class C16. The proposed system is in agreement with the Philippine Machine Stress Grading system and the BS 5268: Part 2: 1996. It should be noted that the proposed classes are much broader than the BS 5268 and more refined than the Philippine system. Results further showed that MOE values of the investigated tropical timbers were generally lower than those of temperate species listed in BS 5268: Part 2: 1996. The observed low values could be due to differences in rates of growth between tropical and temperate tree species. As noted by Dunham *et al.* (1999), fast-growing trees have lower 5th percentile strength which is only 55% of that for the slowest-growing trees. The system was based on small clear test data, which is not representative of structural size timber. In addition, the stresses were adjusted to their equivalents at 12% moisture content. Nevertheless, the system was based on proven methods and thus can provide a more systematic approach to structural application of diverse timbers in Uganda than is possible with the inconsistent subjective approaches.

The rationale for coming up with only four strength groups is that in Uganda, timber classes are basically for guiding timber selection and pricing unlike in countries such as United States of America and Canada where there are strict regulatory quality control mechanisms and market competition has a big influence on the final product value specification (Green *et al.*, 2006; Fernández-Golfín *et al.,* 2007). In addition, tropical timbers consist of hundreds of species that are difficult to identify, hence few classes are of benefit as a variety of species can serve similar applications in building construction. Strength classes SG8 and SG12 are recommended for building construction where stiffness is a controlling factor and where strength requirements are not so critical. It should be noted that the four groups were formulated to take care of strength requirements only. Results indicate that lesser-known timbers such as *M. lutea* and *U. guineensis* have strength properties comparable to those of well-known timber species.



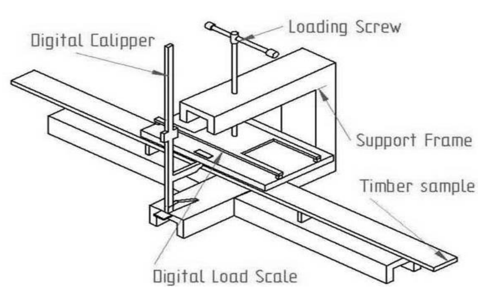


Figure 1: The non-destructive timber testing prototype machine

The positive correlation between P_{5mm} and MOE/MOR confirmed that P_{5mm} is a potential predictor of MOR and MOE. Galligan and McDonald (2000) noted that timber should be segregated by a characteristic that correlates with other timber properties. Thus the non-destructive approach can be used to estimate the MOR and MOE of timber using Figure 2. The NDE approach might as well enhance the market value of lesser-known timber species through quick comparison with traditional species.

4.0 CONCLUSIONS

1. Four timber strength classes: SG4, SG8, SG12 and SG16 were suggested.
2. The field-based NDE approach can be used to predict the MOE and MOR of timber.

5.0 RECOMMENDATIONS

1. Lesser-known timber species such as *M. lutea* and *U. guineensis* should be promoted to reduce pressure on well-known but currently scarce timber species.
2. There is need to allocate the various timber species on Uganda's market to the four timber classes, SG4, SG8, SG12 and SG16, for quality assurance in timber trade and utilisation.
3. There is need for collaborative research involving University academia, National Bureau of Standards, National Forestry Authority, Uganda Institution of Professional Engineers and other partners to develop local timber standards.

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