



# **EXPERIMENTAL ANALYSIS OF ENGINEERING PROPERTIES OF SOME SELECTED AFRICAN TIMBER SPECIES FOR SUSTAINABLE BUILDING DEVELOPMENT**

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## **ABSTRACT**

*This research work aims at the experimental analysis of engineering properties of some selected African timber species for sustainable building development. A well-designed questionnaire distributed to the correspondents was used to select the test samples. using availability and demand of the identified species, Mitragyna ciliata (Abura), Khaya senegalensis (Mahogany) and Terminalia superba (White Afarara) respectively were discovered as the three dominant higher known species while Funtumia ebrihu (Ire), pterocarpus erinaceus (Madoobiya) and Albizia labbek (Ayinre) the three dominant lesser known timber species. Samples of these species were obtained from Rijia lemu timber market, Kano Nigeria. Several experimental tests were conducted to determine the engineering properties of the samples in line with EN13183-1, EN408 and ASTM D193, using three- and four-point bending strength test methods. The formulated properties were used to acquire the characteristic values of the engineering properties in corespondant with EN384. The remaining engineering properties were calculated from the empirical formular given in EN338. Mitragyna ciliate was classified to C20, Khaya senegalensis to D35, Terminalia superba C14, Funtumia ebrihu D24, pterocarpus erinaceus D50 and Albizia labbek to class D40. The software EasyFit was used to create Stochastic*

*probability distribution models on the reference properties of the timber species in which Kolmogorov Smirnov test was the supporting distribution, which indicates that most suitable distribution for bending strength, modulus of elasticity and density was weibull, gumbel and lognormal distributions respectively. However, the questionnaire analysis indicates specie popularity as the major factor for the increased demand pressure on the higher known species instead of engineering properties. Therefore, for sustainable building development the use of lesser known timber species with good engineering properties should be encourage so as to reduce the escalating demand pressure on the higher known species to prevent the species from going into extinction.*

**Keywords:** Sustainable building development, African timber species, engineering properties, higher Known timber species, lesser known timber species, strength classes, Easy Fit

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## 1. INTRODUCTION

Building materials are commonly selected through functional, technical and financial requirements (Anson *et al* 2002), however with sustainability as a key issue in the last decades, the building industry, directly or indirectly causing a considerable part of the annual environmental damage, can take up the responsibility of contributing to sustainable development by finding more environmentally friendly construction materials like timber which currently can be recycled and reused ( Zimring, 2005).

Dobbelsteen and Ehrlich, (2002) introduced their relationship of sustainability with the world population, average welfare rate and environmental impact of welfare commodities, demonstrating the need of achieving a factor 20 environmental improvement by the year 2040 and many organizations and institutions have adopted this target. Moreover, Sustainability can also be achieved if residual trees left after the first harvest exist at sufficient densities and grow at rates that are fast enough to provide a harvestable volume in the second cutting cycle that is similar to the amount of the first harvest, hence regeneration must also be secured to attain long-term sustainability. (Erhard *et al*, 2006). In most African countries, well-known and expensive timber species are misused for firewood, charcoal and furniture construction instead of cheaper timbers which could serve the same purpose (Brandon, 2006). If lesser known timber species were utilized, a larger volume of prime timbers would be available for quality utilization or export than is the case presently, (Kelechi and Uche, 2015).

According to Duku and Hagan, (2011) the consumption of wood fuel in Africa increased from 20,678,000 m<sup>3</sup> in 2004 to 35,363,400 m<sup>3</sup> in 2008, whilst the consumption of wood charcoal increased from 752,000 m<sup>3</sup> to 1,477,700 m<sup>3</sup> during the same period. Additionally, it was estimated by Mitchual *et al* (2014) that wood for use as firewood and for the production of charcoal will increase from an average value of 37,600,000 tonnes in 2008 to 58,700,000 tonnes by 2020. This calls for the great need to avoid wastage, over design, or misuse of the species with good engineering properties, which can be achieved by researching the properties of some lesser known species so as to reduce the demand pressure on the higher

known species which are most times misused (Kelechi and Uche, 2015). Therefore, there is need for diversify forest demand which can be met either by spatially segregating uses for particular goods and services, or by managing forest stands to meet multiple objectives from the same area which is widespread at the tropics (Nittler and Tschinkel, 2005; Zhang, 2005).

Research is the bed rock for sustainable development, which in return will help to increase the production output of manufacturing company, ignite the industrial revolutions, help to increase the economy of the nation (Yekini et al., 2018; Fayomi et al., 2019; Osekhoghene et al., 2019; okokpujie et al., 2019; Igbini et al., 2018; Ongbaji et al., 2018; Onawumi et al., 2018; Oyekunle et al., 2018; Azeta et al., 2016).

Recycling of the timber will help to strengthen the production of the other engineering material, and will give great assistance to researchers in other for them to overcome some many challenges face by researchers in other to achieved the sustainability development goal (Dunmade et al., 2018; Okokpujie et al., 2018; Fayomi et al., 2018; Ezugwu et al., 2016; Nwoke et al., 2017; Fayomi et al., 2018).

However, the aim of this research is to carry out an experimental analysis of engineering properties of some selected African timber species for sustainable building development. This research work will help to achieve sustainability in constructions of structures involving timber thereby preventing the extinction of some dominant species and reduce poor utilization of some overlooked species.

## 2. METHODOLOGY

The materials needed for this experimental analysis are explained in section 2.1 and 2.3.

### 2.1. Materials: Timber Samples

The following sample timber species were used as research specimens.

- a. *Mitragyna ciliata* (Abura)
- b. *Khaya senegalensis* (Mahogany)
- c. *Terminalia superba* (White Afara)
- d. *Funtumia ebrifu* (Ire)
- e. *Pterocarpus erinaceus* (madoobiya)
- f. *Albizia labbekk* (Ayinre)

### 2.2. Questionnaire

Oral Interviews were conducted on ten different dealers from the two sample timber markets used for the research so as to get the names of available and nonavailable timber species in the market. A total of 150 questionnaires were drafted and distributed to the target audience in other to get 112 and 4 recovered and invalid questionnaires were analyzed using mean index formular used by (Kelechi and Uche, 2015). As in equation (1)

$$\text{mean index} = \frac{\sum a_i x_i}{N} \quad (1)$$

Where,  $a_i$  is a constant expressing the weight to each response,  $x_i$  is the frequency of responses and N is the total no of responses.

### 2.3. Methods

The available timber market size of 50×300×3962mm (i.e. 2×12×156inches). Were sliced down to the require sizes and all experimental analysis done in accordance with the relevant

codes. The density and moisture content were determined in accordance with EN 408 (2010) and EN 13183-2 (2002) respectively, while bending strength and modulus of elasticity were determined by ASTM D193 (2000) stipulations. Also, the characteristic values were calculated and adjusted to 12% moisture content in accordance with EN 384 (2004) and EN 338 (2009) respectively. All laboratory experiments were conducted in the Concrete and Material Section of the Civil Engineering Laboratory, Bayero University Kano (BUK), Kano, Nigeria. The species moisture contents and density were determined in accordance with EN 13183-2 (2002) and EN 408 (2010) from equation (2) and (3) respectively:

$$MC = \frac{m_1 - m_2}{m_2} \times 100\% \quad (2)$$

$$\rho = \frac{m_1}{v} \quad (3)$$

Where,  $m_1$ ,  $m_2$  and MC are the initial mass (in grams), final mass (in grams) and Moisture content (in percentage) of test slice respectively. For density  $m_1$  is the mass (in kg) of the specimen,  $v$  is the volume (in cubic meter) of the specimen and  $\rho$  is the density (in  $\text{kg/m}^3$ ) of the specimen.

Experimentally determined engineering properties (Bending strength and MOE) were determined in accordance with ASTM D193 (2000). The characteristic values were determined in accordance with EN 384 (2004) and were further adjusted to recommended 12% MC in line with EN 338 (2009) using the equation as follows:

$$\rho_{k,12\%} = \rho_w \left( 1 - \frac{(1 - 0.5)(\omega - 12)}{100} \right) \quad (4)$$

$$f_{m,12\%} = \frac{f_{measured}}{1 + 0.0295(12 - u)} \quad (5)$$

$$E_{m,12\%} = \frac{E_{measured}}{1 + 0.0143(12 - u)} \quad (6)$$

Where  $\rho_{k,12\%}$  the density at 12% MC,  $\rho_w$  is the density at the measured MC ( $\text{kg/m}^3$ ),  $f_{m,12\%}$  the bending strength at 12% MC,  $f_{measured}$  is the measured bending strength ( $\text{N/mm}^2$ ), the bending modulus of elasticity at 12% MC is  $E_{m,12\%}$  ( $\text{N/mm}^2$ ),  $E_{measured}$  is the measured bending modulus of elasticity ( $\text{N/mm}^2$ ) and  $u$  and  $\omega$  is the measured MC (%).

The characteristic values of the reference material properties were determined in accordance with EN 384 (2004) and hence obtained with the following equations (7) - (9):

$$\rho_k = \rho_{05} = (\bar{\rho} - 1.65s) \quad (7)$$

$$f_k = 1.12f_{05} \quad (8)$$

$$\bar{E} = \left[ \frac{\sum E_i}{n} \right] 1.3 - 2690 \quad (9)$$

Where  $\rho_k$  the characteristic value of density,  $\bar{\rho}$  is the mean density ( $\text{kg/m}^3$ ),  $s$  is the standard deviation of densities of all specimens,  $f_k$  and  $f_{05}$  are the characteristic and 5th-percentile values of bending strength respectively,  $E_i$  is the  $i^{th}$  values of modulus of elasticity,  $n$  is the number of specimens used and  $\bar{E}$  is the mean value of modulus of elasticity in bending ( $\text{N/mm}^2$ ).

## 2.4. Computed Engineering Properties

Computed engineering properties includes Tensile strength parallel and perpendicular to the grain, Compressive Strength Parallel and Perpendicular to the Grain, Shear strength, 5 % modulus of elasticity parallel to grain, Mean modulus of elasticity perpendicular to grain and Shear Modulus. These were calculated using the empirical relationship provided in EN 338 (2009) shown in equations (10) - (21)

$$f_{c,0,k} = 5(f_{m,k})^{0.45} \quad (10)$$

$$f_{c,90,k} = 0.007\rho_k, \text{ for soft woods} \quad (11)$$

$$f_{c,90,k} = 0.015\rho_k, \text{ for hard woods} \quad (12)$$

$$f_{vk} = 0.2(f_{m,k})^{0.8} \quad \text{OR} \quad 4.0 \text{ for soft wood and } 5.0 \text{ for hardwood} \quad (13)$$

$$f_{t,0,k} = 0.6f_{m,k} \quad (14)$$

$$f_{t,90,k} = 0.4 \text{ for soft wood} \quad (15)$$

$$f_{t,90,k} = 0.6 \text{ for hard wood} \quad (16)$$

$$E_{0,05} = 0.67E_{0,mean}, \text{ for softwoods} \quad (17)$$

$$E_{0,05} = 0.84E_{0,mean}, \text{ for hardwoods} \quad (18)$$

$$E_{90,mean} = E_{0,mean}/30, \text{ for softwoods} \quad (19)$$

$$E_{90,mean} = E_{0,mean}/15, \text{ for hardwoods} \quad (20)$$

$$G_{mean} = \frac{E_{0,mean}}{16} \quad (21)$$

Were the characteristic values of compressive strength parallel to grain is  $f_{c,0,k}$ , characteristic values of compressive strength perpendicular to the grain is  $f_{c,90,k}$ ,  $f_{m,k}$  is characteristics bending strength,  $\rho_k$  is the characteristic density, characteristic values of Shear strength is minimum value of  $f_{v,k}$ , Characteristic value of tensile strength parallel to the grain is  $f_{t,0,k}$ , characteristic values of tensile strength perpendicular to the grain is  $f_{t,90,k}$ , fractile 5<sup>th</sup>-percentile MOE parallel to grain is  $E_{0,05}$ , characteristic values of mean MOE perpendicular to grain is  $E_{90,mean}$ ,  $E_{0,mean}$  is the mean MOE parallel to grain and mean shear modulus is  $G_{mean}$ .

## 2.5. Goodness of Fit (GOF) of Data and Probabilistic Modeling of Engineering Property

The GOF test was done to show how well the selected distribution fit the generated data. The Kolmogorov Smirnov (K-S) test was performed on density, MOE and bending strength for each of the six species, in order to access if each data set comes from a population with a specified distribution. The K-S statistic (D) is based on the largest vertical difference between the theoretical and empirical cumulative distribution function:

$$D = \max_{1 \leq x \leq n} \left[ F(x_1) - \frac{i-1}{n} - F(x_i) \right] \quad (22)$$

Where D is the statistics of Kolmogorov-Smirnov test and  $F(x_i)$  is the cumulative distribution being tested (JCSS, 2006).

## 3. RESULTS AND DISCUSSIONS

From Figure 1, the highly demanded species are not readily available, it is obvious that *Mitragyna ciliata* (Abura) is the highest demanded specie with demand Likert rating of 4.54,

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followed by *Khaya senegalensis* (mahogany) 4.46 and *Terminalia superba* (Afara) 4.01 corresponding to least availabilities of 1.85, 2.07 and 1.87 respectively. Hence these three species are the three most highly demanded species used as the samples of the higherknown species. Likewise, *Funtumia ebrifu* Ire (African rubber tree) with the least demand rating of 1.33, then *pterocarpus erinaceus* madoobiya (African rosewood) 1.45 and *Albizia labbek* Ayinre, (West African albizia) 1.57, corresponding to high availabilities of 3.81, 3.81 and 3.84 respectively, these three specials are therefore the three most lesser known sample species.

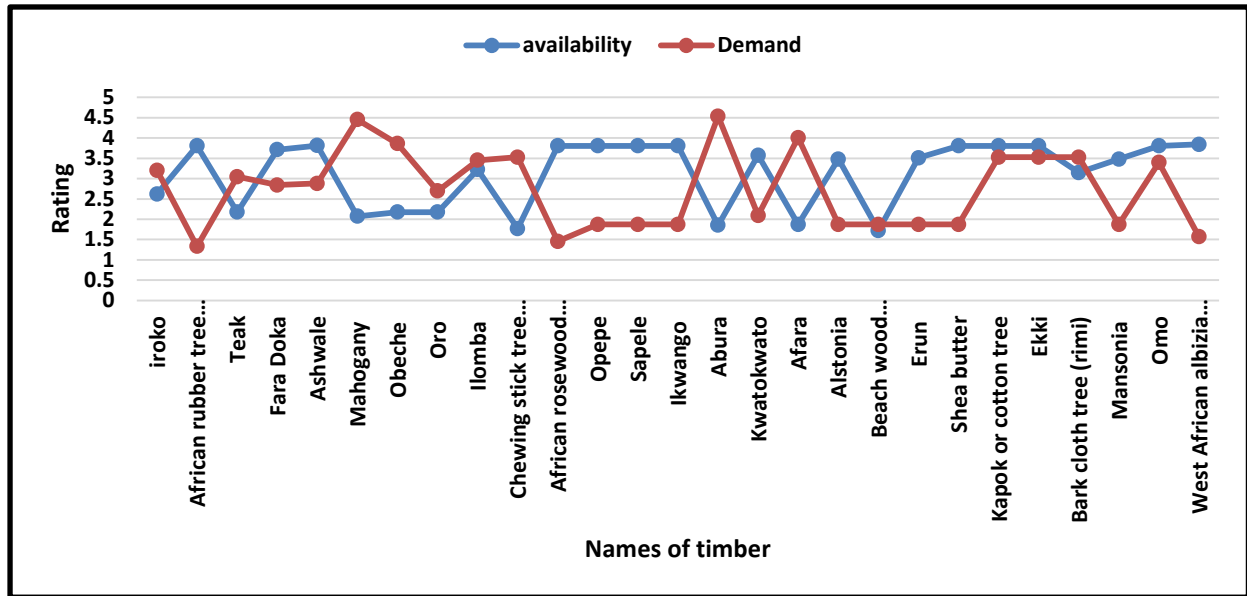


Figure 1 Rating of availability and demand of all timber species in African markets

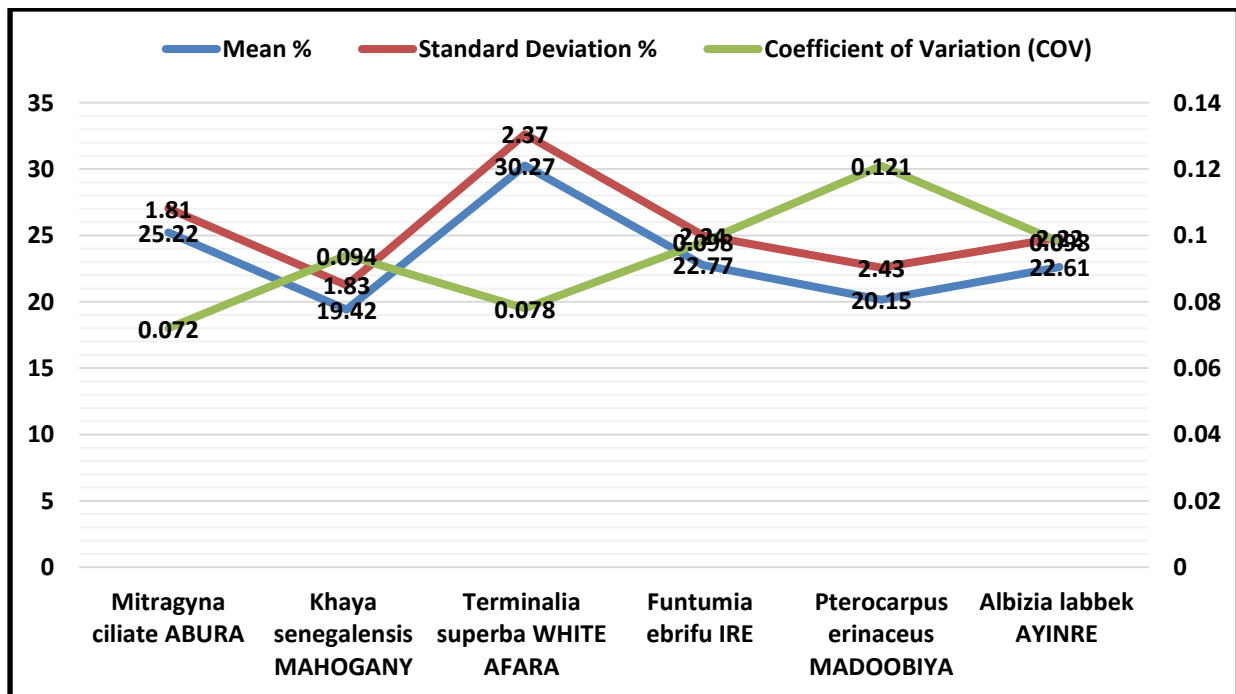
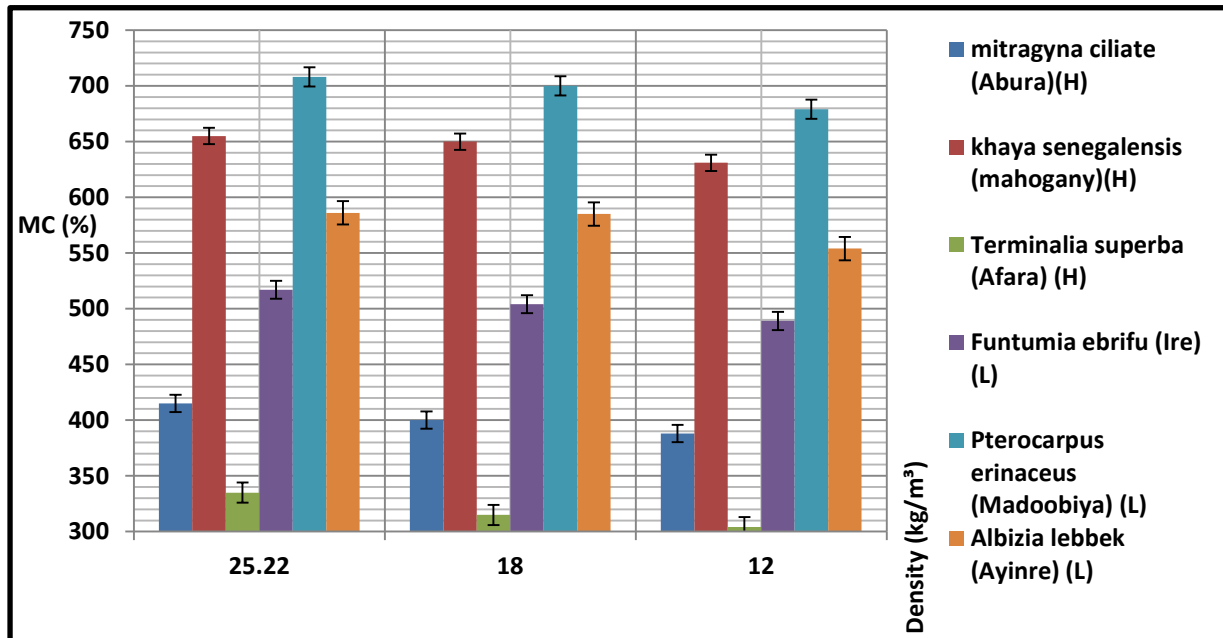


Figure 2 Results of Percentage Moisture Content

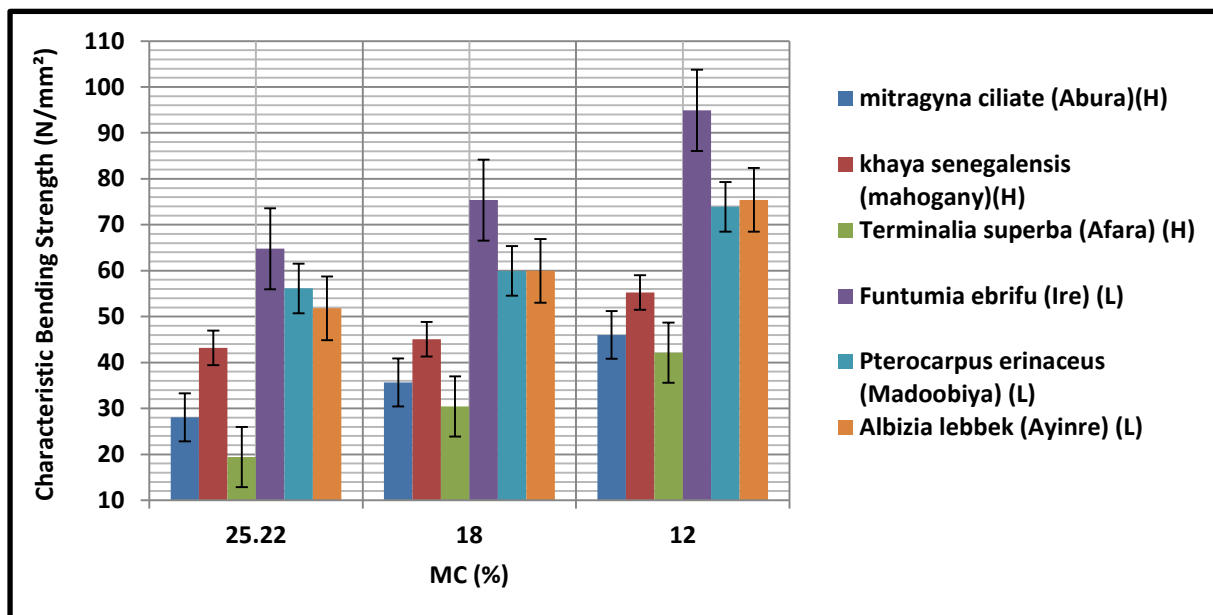
Figure 2, shows the percentage moisture content of *Mitragyna ciliate*, *Khaya senegalensis*, *Terminalia superba*, *Funtumia ebrifu*, *pterocarpus erinaceus*, *Albizia labbek*

timber species are 25.22%, 19.42%, 30.27%, 22.77%, 20.15% and 22.61% respectively with the standard deviation of 1.81%, 1.83%, 2.37%, 2.24%, 2.43%, and 2.22% and coefficient of variance of 0.072, 0.094, 0.078, 0.098, 0.121 and 0.098 respectively signifying there are no much deviation from the values of the mean.



**Figure 3** Results of Characteristic Values of Density at specific MCs

Figure 3 indicates that density tends to increase with moisture content for all species, this is because timber tends to be lighter in weight as it gets dry.



**Figure 4** Characteristic Bending Strength Result

Figure 4 indicates that for all timber species characteristic strength decreases with increase moisture content. For example, the characteristic bending strength of *Funtumia ebrifu* (Ire) at 12% MC is 94.92N/mm<sup>2</sup> but decreased to 75.36N/mm<sup>2</sup> at 18% MC and further

decreased to 64.76N/mm<sup>2</sup> at measured MC of 22.77%. This is the reason why timber gets stronger as it dries.

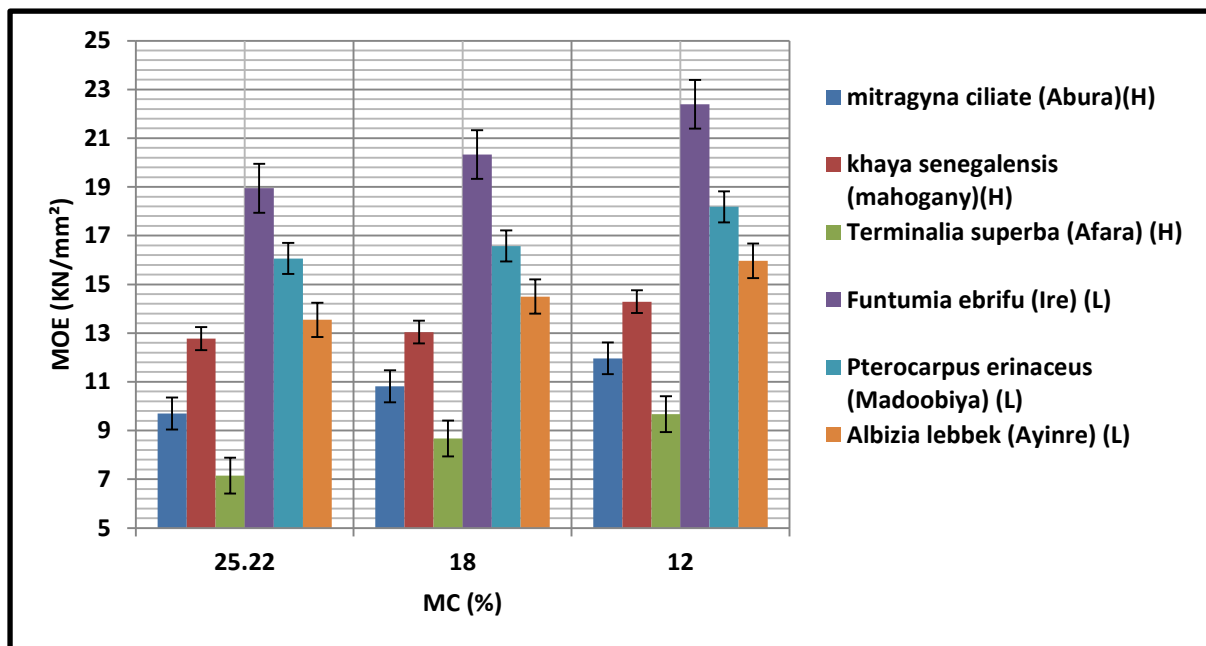


Figure 5 Characteristic MOE Results

The Figure 5 shows that Modulus of elasticity generally decreases with increased MC for all timber species. For instance, characteristics MOE of *Funtumia ebrifu* (Ire) at 12% MC is 22.39N/mm<sup>2</sup> but then decreased to 20.33N/mm<sup>2</sup> at 18% MC and decreased further to 18.94N/mm<sup>2</sup> at measured MC of 22.77. This implies that timber attains full stiffness when it is fully dry.

Table 1 Characteristic Values of Computed Engineering Properties

Computed Engineering Properties	Timber Species					
	Mitragyna ciliate Abura	Khaya senegalensis Mahogany	Terminalia superba Afara	Funtumia ebrifu Ire	Pterocarpus erinaceus Madoobiya	Albizia labbek Ayinre
Tension Parallel $f_{t,0,k}$ (N/mm <sup>2</sup> )	21.28	26.57	20.66	48.14	38.69	39.01
Tension Perpendicular $f_{t,90,k}$ (N/mm <sup>2</sup> )	0.4	0.6	0.4	0.6	0.6	0.6
Compression Parallel $f_{c,0,k}$ (N/mm <sup>2</sup> )	24.91	27.53	24.58	35.97	32.60	32.72
Compression Perpendicular $f_{c,90,k}$ (N/mm <sup>2</sup> )	2.7	9.5	2.2	7.83	10.2	8.8
Shear Strength $f_{vk}$ (N/mm <sup>2</sup> )	3.6	4.2	3.4	5.0	5.0	5.0



Computed Engineering Properties	Timber Species					
	Mitragyna ciliate Abura	Khaya senegalensis Mahogany	Terminalia superba Afara	Funtumia ebrifu Ire	Pterocarpus erinaceus Madoobiya	Albizia labbek Ayinre
5% MOE Parallel $E_{0,05}$ (KN/mm <sup>2</sup> )	6.6	9.7	6.0	13.9	11.8	11.2
Mean MOE Perpendicular $E_{mean}$ (KN/mm <sup>2</sup> )	0.33	0.77	0.30	1.49	1.21	1.06
Mean Shear Modulus $G_{mean}$ (KN/mm <sup>2</sup> )	0.62	0.75	0.56	1.04	0.88	0.83
Mean Density $\rho_{mean}$ (kg/mm <sup>2</sup> )	466	757	365	587	815	703

Table 1 shows the computed characteristic values of the engineering properties of the sample species using the equations provided in EN 338 (2009). The computed engineering properties are The characteristic values of tension parallel to grain ( $f_{t,0,k}$ ) for *Mitragyna ciliate* (Abura), *Khaya senegalensis* (Mahogany), *Terminalia superba* (Afara), *Funtumia ebrifu* (Ire), *Pterocarpus erinaceus*(Madoobiya), and *Albizia labbek*(Ayinre) are 21.28, 26.57, 20.66, 48.14, 38.69 and 39.01N/mm<sup>2</sup> respectively. The corresponding characteristic tension perpendicular to grain ( $f_{t,90,k}$ ) are 0.4, 0.6, 0.4, 0.6, 0.6, 0.6N/mm<sup>2</sup> respectively. Likewise, the characteristic values of compression perpendicular to grain ( $f_{c,0,k}$ ) are in the same order as 24.91, 27.53, 24.58, 35.97, 32.60 and 32.72N/mm<sup>2</sup> respectively. The corresponding characteristic values of compression perpendicular to grain ( $f_{c,90,k}$ ) are 2.7, 9.5, 2.2, 7.3, 10.2 and 8.8N/mm<sup>2</sup> respectively. The corresponding characteristic shear strength ( $f_{v,k}$ ) are 3.6, 4.2, 3.4, 5.0, 5.0 and 5.0N/mm<sup>2</sup> respectively. Likewise, the characteristic values of 5% MOE parallel to grain ( $E_{0,05}$ ) are 6.6, 9.7, 6.0, 13.9, 11.8 and 11.2KN/mm<sup>2</sup> respectively. The corresponding mean MOE perpendicular to grain ( $f_{90,mean}$ ) are 0.33, 0.77, 0.30, 1.49, 1.21 and 1.06KN/mm<sup>2</sup> respectively. The corresponding mean shear modulus ( $G_{mean}$ ) are 0.62, 0.75, 0.56, 1.04, 0.88 and 0.83KN/mm<sup>2</sup> respectively. Also, the corresponding characteristic mean density ( $\rho_{mean}$ ) are 466, 757, 365, 587, 815 and 703kg/mm<sup>2</sup> respectively.

**Table 2** Classification of Engineering Properties for Selected Timber Species comparing with that Extracted from EN 338(2009)

Assigned Strength Classes	C20		D35		C14		D24		D50		D40	
	M. ciliata (Abura) (H)	Code	K. senegalensis (Mahogany) (H)	Code	T. superba (Afara) (H)	Code	F. ebrifu (Ire) (L)	Code	P.erinaceus (Madoobiya) (L)	Code	A. labbek (Ayinre) (L)	Code
Strength Properties (N/mm <sup>2</sup> )												
$f_{m,k}$	35.47	20.0	44.29	35.0	34.44	14.0	80.23	24.0	64.48	50.0	65.01	40.0

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Assigned Strength Classes	C20		D35		C14		D24		D50		D40	
	M. ciliata (Abura) (H)	Code	K. senegalensis (Mahogany) (H)	Code	T. superba (Afara) (H)	Code	F. ebrifu (Ire) (L)	Code	P.erinaceus (Madoobiy a) (L)	Code	A. lebbek (Ayinre) (L)	Code
$f_{t,0.05}$	21.28	12.0	26.57	21.0	20.66	8.0	48.14	14.0	38.69	30.0	39.01	24.0
$f_{t,90}$	0.4	0.4	0.6	0.6	0.4	0.4	0.6	0.6	0.6	0.6	0.6	0.6
$f_{c,0.05}$	24.91	19.0	27.53	25.0	24.58	16.0	35.97	21.0	32.60	29.0	32.72	26.0
$f_{c,90}$	2.7	2.3	9.5	8.1	2.2	2.0	7.83	7.8	10.2	9.3	8.8	8.3
$f_{v,k}$	3.6	3.6	4.2	4.0	3.4	3.0	5.0	4.0	5.0	4.0	5.0	4.0
Stiffness Properties (kN/mm <sup>2</sup> )												
$E_{0,m}$	9.846	9.5	11.577	12.0	8.945	7.0	16.607	10.0	14.000	14.0	13.320	13.0
$E_{0,0}$	6.6	6.4	9.7	10.1	6.0	4.7	13.9	8.5	11.8	11.8	11.2	10.9
$E_{90}$	0.33	0.32	0.77	0.8	0.30	0.23	1.49	0.67	1.21	0.93	1.06	0.86
$G_{me}$	0.62	0.59	0.75	0.75	0.56	0.44	1.04	0.62	0.88	0.88	0.83	0.81
Density (kg/m <sup>3</sup> )												
$\rho_k$	388	330	631	540	304	290	489	485	679	620	586	550
$\rho_{me}$	466	390	757	650	365	350	587	580	815	750	703	660

EN 338 (2009) quoted that a solid timber may be assigned to a strength class if its characteristic values of bending strength  $f_{m,k}$  and density  $\rho_k$  equal or exceed the values for that strength class given in Table 1 of the code and its characteristic mean MOE in bending  $E_{0,mean}$  equals or exceeds 95% of the value given for that strength class. Table 4.2 show the comparison of the code requirements with the experimentally determined and computed engineering properties in which shows that all the classification criteria were met hence *Mitragyna ciliata* (Abura) was assigned to strength class of C20 based on minimum characteristic bending strength  $f_{m,k}$  of 35.47N/mm<sup>2</sup>, characteristic density  $\rho_k$  of 388Kg/m<sup>3</sup> and minimum mean modulus of MOE parallel to grain  $E_{0,mean}$  of 9.846kN/mm<sup>2</sup>. The characteristic bending strength  $f_{m,k}$ , density  $\rho_k$  and mean MOE parallel to grain  $E_{0,mean}$  for strength class C20 from Table 1 of the code and Table 4.2 are 20N/mm<sup>2</sup>, 330kg/m<sup>3</sup> and 9.5kN/mm<sup>2</sup> respectively. *Khaya senegalensis* (Mahogany) was assigned to strength class D35, *Terminalia superba* (Afara) was assigned to strength class, *Funtumia ebrifu* (Ire) was

assigned to strength class, *Pterocarpus erinaceus* (Madoobiya) was assigned to strength class and *albizia labbekk* (Ayinre) was assigned to strength class D40.

**Table 3** Kolmogorov Smirnov (K-S) Test Results

Timber Property		Density				MOE				Bending Strength			
Timber Species	Distribution Type	Normal	Lognormal	Gumbel	Weibull	Normal	Lognormal	Gumbel	Weibull	Normal	Lognormal	Gumbel	Weibull
Mitragyna ciliate	D	0.252	0.252	0.280	0.262	0.255	0.283	0.224	0.248	0.253	0.259	0.267	0.248
	$\alpha_{0.05}$	0.338	0.338	0.338	0.338	0.294	0.294	0.294	0.294	0.294	0.294	0.294	0.294
	Rank	2	1	4	3	3	4	1	2	3	2	4	1
Khaya senegalensis	D	0.252	0.250	0.280	0.261	0.267	0.289	0.241	0.252	0.253	0.251	0.267	0.248
	$\alpha_{0.05}$	0.338	0.338	0.338	0.338	0.294	0.294	0.294	0.294	0.294	0.294	0.294	0.294
	Rank	2	1	4	3	2	4	1	3	3	2	4	1
Terminalia superba	D	0.252	0.253	0.280	0.262	0.244	0.279	0.223	0.243	0.253	0.251	0.267	0.248
	$\alpha_{0.05}$	0.338	0.338	0.338	0.338	0.294	0.294	0.294	0.294	0.294	0.294	0.294	0.294
	Rank	1	2	4	3	3	4	1	2	3	2	4	1
Funtumia ebrifu	D	0.337	0.329	0.274	0.238	0.274	0.292	0.251	0.256	0.238	0.236	0.232	0.231
	$\alpha_{0.05}$	0.338	0.338	0.338	0.338	0.294	0.294	0.294	0.294	0.294	0.294	0.294	0.294
	Rank	4	3	2	1	3	4	1	2	4	3	2	1
Pterocarpus erinaceus	D	0.252	0.250	0.280	0.260	0.274	0.292	0.250	0.255	0.253	0.252	0.267	0.248
	$\alpha_{0.05}$	0.338	0.338	0.338	0.338	0.294	0.294	0.294	0.294	0.294	0.294	0.294	0.294
	Rank	2	1	4	3	3	4	1	2	3	2	4	1
Albizia Labbekk	D	0.224	0.222	0.237	0.236	0.273	0.291	0.249	0.256	0.238	0.236	0.232	0.230
	$\alpha_{0.05}$	0.338	0.338	0.338	0.338	0.294	0.294	0.294	0.294	0.294	0.294	0.294	0.294
	Rank	2	1	4	3	3	4	1	2	4	3	2	1

Table 3 shows the Kolmogorov Smirnov test result of the experimentally determined engineering properties. The hypothesis regarding the distribution form is rejected if the test statistics, D, is greater than the critical value at 0.05 confidence level. Therefore, from Table 3 the probability density and cumulative probability density function of *albizea lebbek* and lognormal distribution with the lowest Kolmogorov Smirnov statistics (D) of 0.222 has the best fitting model of density for all the six species. Likewise, considering the ranking of the four distribution models for bending strength, Weibull distribution corresponds with the least K-S statistics of 0.231. In the same way, for MOE considering the ranking of the four distribution models, gumbel distribution was found to be the most fitted distribution model for modulus of elasticity of solid timber with the least K-S statistics value of 0.224

#### 4. CONCLUSIONS

In this research work carried out experimental analysis of engineering properties of some selected African timber species for sustainable building development and has the following conclusions from the research work

1. Generally, there are about 27 available timber species in African timber market

2. Popularity of the timber species is the major factor contributing to the high demand pressure on the higher known species.
3. The three dominantly higher known timber species available are *Mitragyna ciliate* (Abura), *Khaya senegalensis* (Mahogany) and *Terminalia superb* (Afara) respectively while *Funtumia ebrifu* (Ire), *pterocarpus erinaceus* (Madoobiya) and *Albizia labbek*(Ayinre) are the dominant lesser known species respectively.
4. All the lesser known sample species with only one higher known sample specie belongs to the hard wood class D while other remaining two higher known species belong to the softwood class.
5. Variation in the moisture content of timber is the major factor that influences dynamic properties of timber.
6. From the research results, the hard wood sample species *Khaya senegalensis* (Mahogany), *Funtumia ebrifu* (Ire), *Pterocarpus erinaceus* (Madoobiya), and *Albizia lebbek* (Ayinre) are applicable for use in high load-bearing timber structural elements.
7. The two soft wood species, *Mitragyna ciliate* (Abura) is best utilized in medium load-bearing while *Terminalia superba* (Afara) is the weakest specie and as such not applicable for use in high load-bearing.
8. With the use of EasyFit software, the engineering properties of all the sample species are suitable to be modelled with Kolmogorov Smirnov test with stiffness, strength properties and density best modeled with Gumbel, Weibul and Lognormal distributions respectively.

## 5. RECOMMENDATIONS

The following measures are recommended from the research

1. For sustainable building development the use of lesser known timber species with good engineering properties should be encourage so as to reduce the exalating demand pressure on the higher known species to make harvesting more feasible and prevent the species from going into extinction.
2. Diversified usage of various timber species should be encouraged by utilizing species with unsuitable engineering properties were very low load-bearing is required. so as not to highten the price of the popular species due to misuseage.

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## REFERENCES

- [1] ASTM D193 “Standard method of testing small clear specimens of timber,” American Society for Testing and Materials, 2000, USA.
- [2] Azeta J, Okokpujie KO, Okokpujie IP, Osemwegie O, Chibuzor A. A Plan for Igniting Nigeria’s Industrial Revolution. International Journal of Scientific & Engineering Research. 2016;7(11):489.
- [3] Brandon, D., Suitability of Salvage Timber in Structural Design. B.eng Thesis Submitted to Department of Civil and Environmental Engineering. Massachusetts Institute of Technology 2006.

- [4] Dauber E, Fredericksen TS, Pena M. Sustainability of timber harvesting in Bolivian tropical forests. *Forest Ecology and Management*. 2005 Aug 3;214(1-3):294-304.
- [5] Duku MH, Gu S, Hagan EB. A comprehensive review of biomass resources and biofuels potential in Ghana. *Renewable and sustainable energy reviews*. 2011 Jan 1;15(1):404-15.
- [6] Dunmade I, Udo M, Akintayo T, Oyedepo S, Okokpujie IP. Lifecycle Impact Assessment of an Engineering Project Management Process—a SLCA Approach. In IOP Conference Series: Materials Science and Engineering 2018 Sep (Vol. 413, No. 1, p. 012061). IOP Publishing.
- [7] EN 13183-2: “European Standard: Moisture content of a piece of sawn timber Part 2” Estimation by electrical resistance method English version 2002.
- [8] EN 338 “Structural Timber Strength Classes”, European Committee for Standardisation, CEN, Brussels, Belgium 2009.
- [9] EN 384 “Structural Timber: Determination of Characteristic values of Mechanical properties and Density”, European Committee for Standardisation, CEN, Brussels, Belgium 2004.
- [10] EN 408 Timber structures – Structural timber and Glued-laminated Timber: Determination of some physical and mechanical properties”, European Committee for Standardization, CEN, Brussels, Belgium 2010.
- [11] Ezugwu CA, Okonkwo UC, Sinebe JE, Okokpujie IP. Stability Analysis of Model Regenerative Chatter of Milling Process Using First Order Least Square Full Discretization Method. *International Journal of Mechanics and Applications*. 2016 Jun 18;6(3):49-62.
- [12] Fayomi OS, Okokpujie IP, Fayom GU, Okolie ST. The Challenge of Nigeria Researcher in Meeting up with Sustainable Development Goal in 21st Century. *Energy Procedia*. 2019 Jan 1; 157:393-404.
- [13] Fayomi OS, Okokpujie IP, Kilanko O. Challenges of Research in Contemporary Africa World. In IOP Conference Series: Materials Science and Engineering 2018 Sep (Vol. 413, No. 1, p. 012078). IOP Publishing.
- [14] Fayomi OS, Okokpujie IP, Udo M. The Role of Research in Attaining Sustainable Development Goals. In IOP Conference Series: Materials Science and Engineering 2018 Sep (Vol. 413, No. 1, p. 012002). IOP Publishing.
- [15] Gaith FH, Khalim AR, Ismail A. Application and efficacy of information technology in construction industry. *Scientific Research and Essays*. 2012 Sep 27;7(38):3223-42.
- [16] Igbini O, Okokpujie IP, Dirisu JO, Igbiniwahia DI, Okokpujie KO. DEVELOPMENT AND PERFORMANCE ANALYSIS OF HORIZONTAL WASTE PAPER BALING MACHINE. *International Journal of Mechanical Engineering and Technology (IJMET)*. 2018 Oct 31;9(10):84-101.
- [17] Kelechi-Asumba S.E, O.A.U Uche. Characterization of timber species in Kano. Paper presented at the 1st annual international conference of faculty of science, northwest university, Kano, Nigeria. 2015. ISBN-978-978-53550-5-5.
- [18] Kelechi-Asumba SE, Uche OA. An Investigation on the Engineering Properties of Higher and Lesser Known Timber Species in Kano Market. In Proceedings of the Annual Conference on Building Local Capabilities in the Nigerian Metals Industries Nigeria Metallurgical Society (NMS) 2015 (pp. 71-75).
- [19] Mitchal SJ, Frimpong-Mensah K, Darkwa NA. Evaluation of Fuel Properties of Six Tropical Hardwood Timber Species for Briquettes. *World Academy of Science, Engineering and Technology, International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering*. 2015 Aug 1;8(7):531-7.
- [20] Nittler J, Tschinkel H. Community forest management in the Maya Biosphere Reserve of Guatemala: Protection through profits. *US Agency for International Development*

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- (USAID) and Sustainable Agriculture and Natural Resource Management (SANREM), University of Georgia, USA. 2005 Jan 10.
- [21] Nwoke ON, Okokpujie IP, Ekenyem SC. Investigation of Creep Responses of Selected Engineering Materials. *Journal of Science, Engineering Development, Environment and Technology (JOSEDET)*. 2017;7(1):1-5.
- [22] Okokpujie IP, Fayomi OS, Leramo RO. The Role of Research in Economic Development. *InIOP Conference Series: Materials Science and Engineering 2018 Sep (Vol. 413, No. 1, p. 012060)*. IOP Publishing.
- [23] Okokpujie IP, Fayomi OS, Ogbonnaya SK, Fayomi GU. The Wide Margin Between the Academic and Researcher in a New Age University for Sustainable Development. *Energy Procedia*. 2019 Jan 1; 157:862-70.
- [24] Onawumi A, Udo M, Awoyemi E, Okokpujie IP. Alternate Maintainability Evaluation Technique for Steering System of Used Automobiles. *InIOP Conference Series: Materials Science and Engineering 2018 Sep (Vol. 413, No. 1, p. 012062)*. IOP Publishing.
- [25] Ongbali SO, Igboanugo AC, Afolalu SA, Udo MO, Okokpujie IP. Model Selection Process in Time Series Analysis of Production System with Random Output. *InIOP Conference Series: Materials Science and Engineering 2018 Sep (Vol. 413, No. 1, p. 012057)*. IOP Publishing.
- [26] Osekhoghene DJ, Olayinka OS, Isaac FO, Princess OI. IGNITION TIME OF SELECTED CEILING MATERIALS AND ESCAPE TEMPERATURE TIME PREDICTION OF FIRE FIGHTER RESCUE MISSION. *Journal of Chemical Technology & Metallurgy*. 2019 Jan 1;54(1).
- [27] Oyekunle JA, Dirisu JO, Okokpujie IP, Asere AA. Determination of Heat Transfer Properties of Various PVC and Non-PVC Ceiling Materials Available in Nigerian Markets. *International Journal of Mechanical Engineering and Technology (IJMET)*. 2018 Aug 31;9(8):963-73.
- [28] Van den Dobbelsteen AA, Van der Linden AC, Klaase D. -Sustainability needs more than just smart technology. *InAdvances in Building Technology 2002 (pp. 1501-1508)*.
- [29] Yekini SE, Okokpujie IP, Afolalu SA, Ajayi OO, Azeta J. Investigation of production output for improvement. *International Journal of Mechanical and Production Engineering Research and Development*. 2018;8(1):915-22.
- [30] Zhang Y. Multiple-use forestry vs. forestland-use specialization revisited. *Forest Policy and Economics*. 2005 Feb 1;7(2):143-56.
- [31] Zimring CA. *Cash for your trash: Scrap recycling in America*. Rutgers University Press; 2009.