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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 dorminant higher known species while Funtumia ebrifu (Ire), pterocarpus erinaceus (Madoobiya) and Albizia labbek (Ayinre) the three dorminant 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 ebrifu 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 m³ in 2004 to 35,363,400 m³ in 2008, whilst the consumption of wood charcoal increased from 752,000 m³ to 1,477,700 m³ 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; Igbinigie 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)

$$mean\ index = \frac{\sum a_i x_i}{N} \tag{1}$$

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 where 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 ρ is the density (in kg/m³) 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:

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

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

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

Where $\rho_{k,12\%}$the density at 12% MC, $\rho_w$is the density at the measured MC (kg/m³), $f_{m,12\%}$ the bending strength at 12% MC, $f_{measured}$is the measured bending strength (N/mm²), the bending modulus of elasticity at 12% MC is $\mathrm{E}_{\mathrm{m,12\%}}$(N/mm²), $\mathrm{E}_{measured}$is the measured bending modulus of elasticity (N/mm²) and u and ω 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):

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

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

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

Where ρ_k the characteristic value of density, $\bar{\rho}$ is the mean density (kg/m²), 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, $\mathrm{E_i}$ is the i^{th} values of modulus of elasticity, n is the number of specimens used and $\bar{\mathrm{E}}$ is the mean value of modulus of elasticity in bending (N/mm²).

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)

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

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

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

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

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

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

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

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

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

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

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

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

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, ρ_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$f_{t,90,k}$, fractile5^{th}-percentile MOE parallel to grain is $E_{0.05}$, characteristic values of mean MOE perpendicular to grain is E_{90mean}, $E_{0,mean}$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:

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

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, 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.

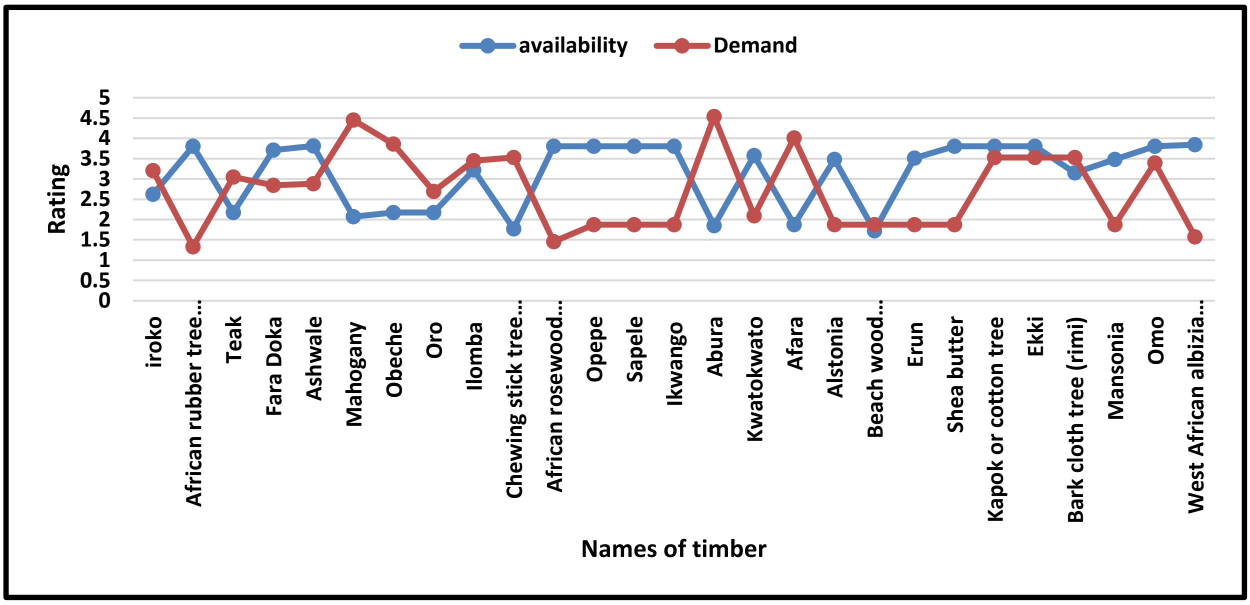

Figure 1 Rating of availability and demand of all timber species in African markets

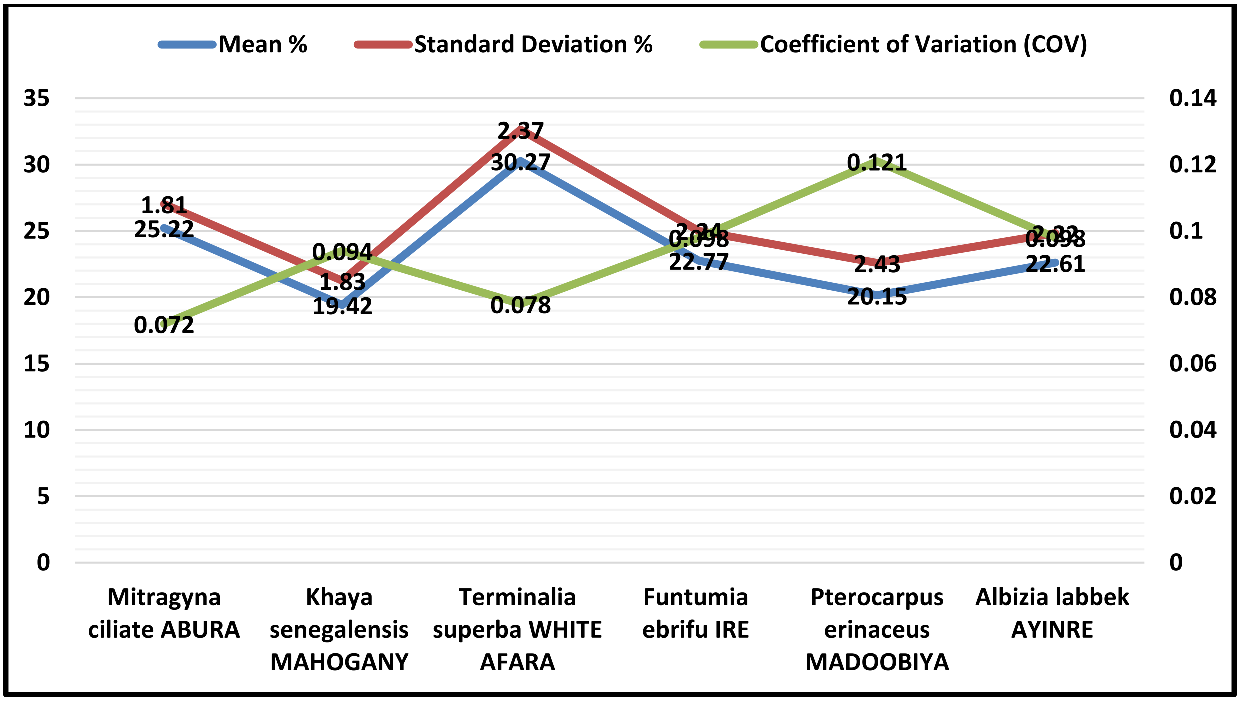

Figure 2 Results of Percentage Moisture Content

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.

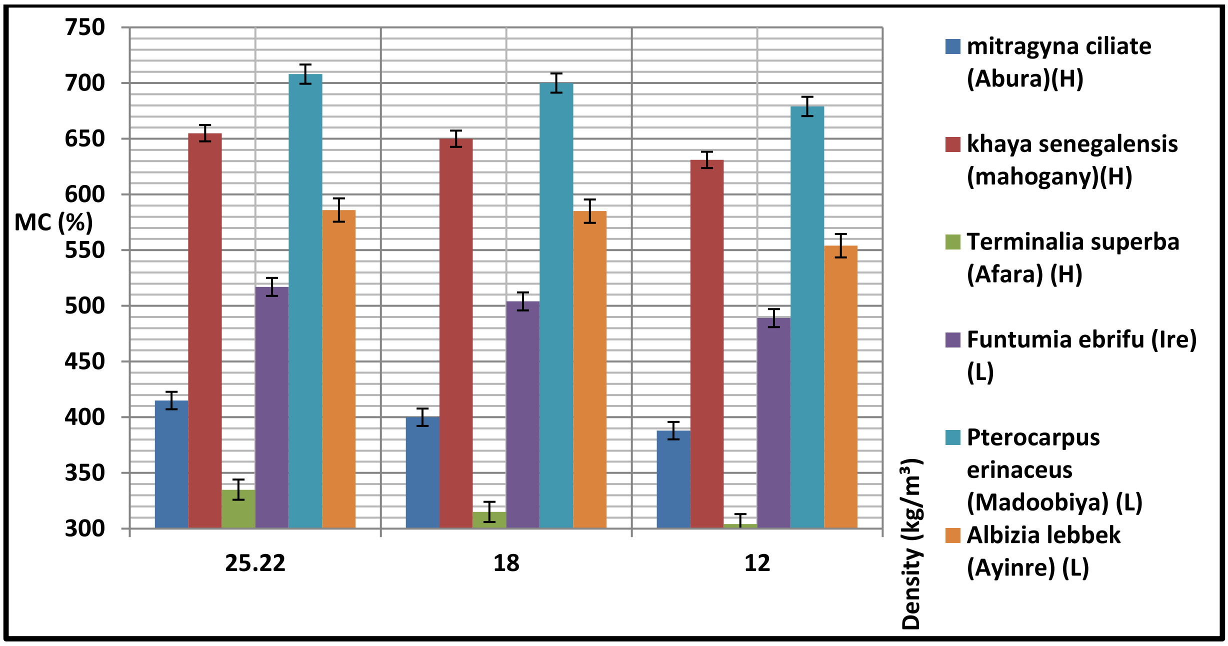

Figure 3 Results of Characteristic Values of Density at specific MCs

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

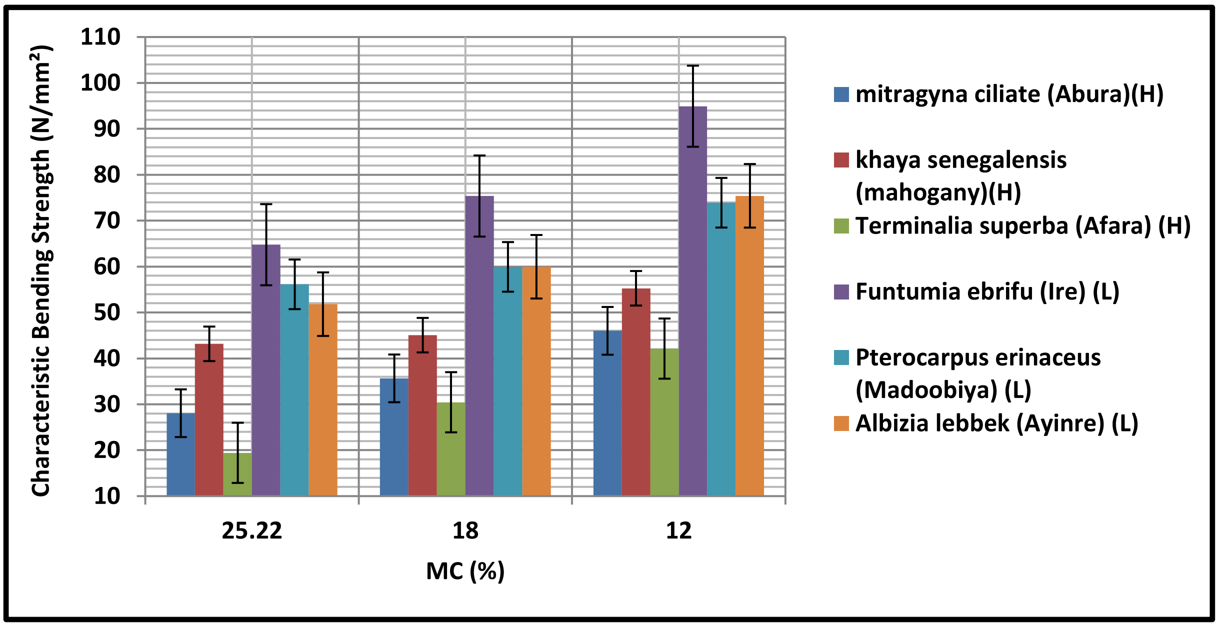

Figure 4 Characteristic Bending Strength Result

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/mm² but decreased to 75.36N/mm² at 18% MC and futher decreased to 64.76N/mm² at measured MC of 22.77%. This is the reasone why timber gets stronger as it dries.

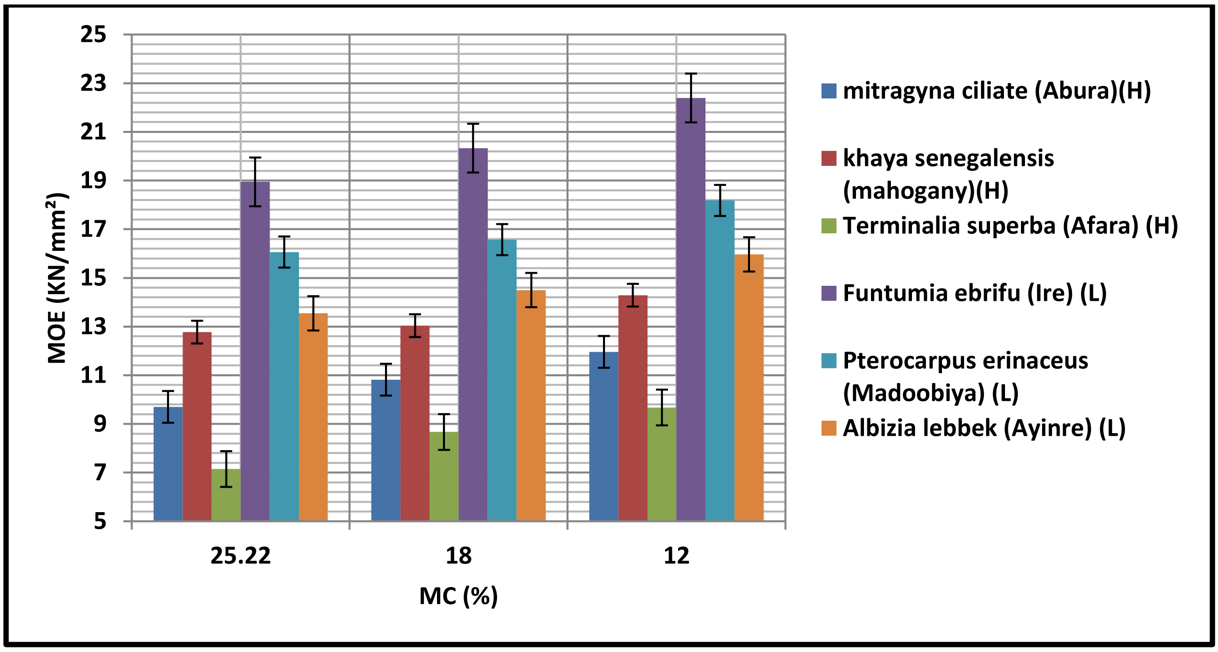

Figure 5 Characteristic MOE Results

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/mm² but then decreased to 20.33N/mm² at 18% MC and decreased further to 18.94N/mm² 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/mm²)**	21.28	26.57	20.66	48.14	38.69	39.01
Tension Perpendicular $f_{t,90,k}$**(N/mm²)**	0.4	0.6	0.4	0.6	0.6	0.6
Compression Parallel $f_{c,0,k}$**(N/mm²)**	24.91	27.53	24.58	35.97	32.60	32.72
Compression Perpendicular $f_{c,90,k}$**(N/mm²)**	2.7	9.5	2.2	7.83	10.2	8.8
Shear Strength f_{vk}**(N/mm²)**	3.6	4.2	3.4	5.0	5.0	5.0
5% MOE Parallel $E_{0,05}$**(KN/mm²)**	6.6	9.7	6.0	13.9	11.8	11.2

Computed Engineering Properties	**Timber Species**					
	Mitragyna ciliate Abura	**Khaya senegalensis Mahogany**	**Terminalia superba Afara**	**Funtumia ebrifu Ire**	**Pterocarpus erinaceus Madoobiya**	**Albizia labbek Ayinre**
Mean MOE Perpendicular E_{mean}(KN/mm²)	0.33	0.77	0.30	1.49	1.21	1.06
Mean Shear Modulus G_{mean}(KN/mm²)	0.62	0.75	0.56	1.04	0.88	0.83
Mean Density ρ_{mean}(kg/mm²)	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 engeneering properties are The characteristic values of tension parallel to grain ($f_{t,0,k}$) for *Mitragyna ciliate* (Abura), *Khaya senegalensis (*Mahogany), *Terminalia superb* (Afara), *Funtumia ebrifu* (Ire), *Pterocarpus erinaceus*(Madoobiya), and *Albizia lebbek*(Ayinre) are 21.28, 26.57, 20.66, 48.14, 38.69 and 39.01N/mm² 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/mm² 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/mm² 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/mm² respectively. The corresponding characteristic shear strength ($f_{v,k}$) are 3.6, 4.2, 3.4, 5.0, 5.0 and 5.0N/mm² 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/mm² 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/mm² respectively. The corresponding mean shear modulus (G_{mean}) are 0.62, 0.75, 0.56, 1.04, 0.88 and 0.83KN/mm² respectively. Also, the corresponding characteristic mean density (ρ_{mean}) are 466, 757, 365, 587, 815 and 703kg/mm² 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. lebbek (Ayinre) (L)**	**Code**
Strength Properties (N/mm²)												
$f_{m,k}$	35.47	20.0	44.29	35.0	34.44	14.0	80.23	24.0	64.48	50.0	65.01	40.0
$f_{t,o,k}$	21.28	12.0	26.57	21.0	20.66	8.0	48.14	14.0	38.69	30.0	39.01	24.0

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. lebbek (Ayinre) (L)**	**Code**
$f_{t,90,k}$	0.4	0.4	0.6	0.6	0.4	0.4	0.6	0.6	0.6	0.6	0.6	0.6
$f_{c,0,k}$	24.91	19.0	27.53	25.0	24.58	16.0	35.97	21.0	32.60	29.0	32.72	26.0
$f_{c,90,k}$	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/mm²)												
$E_{0,mean}$	9.846	9.5	11.577	12.0	8.945	7.0	16.607	10.0	14.000	14.0	13.320	13.0
$E_{0,05}$	6.6	6.4	9.7	10.1	6.0	4.7	13.9	8.5	11.8	11.8	11.2	10.9
$E_{90,mean}$	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_{mean}	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/m³)												
ρ_k	388	330	631	540	304	290	489	485	679	620	586	550
ρ_{mean}	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 ρ_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/mm², characteristic density ρ_k of 388Kg/m³ and minimum mean modulus of MOE parallel to grain$E_{0,mean}$ of 9.846kN/mm². 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/mm², 330kg/m³ and 9.5kN/mm² 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
Pterocarpu serinaceus	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 dorminantly 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 dorminant 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 excalating 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 misusage.

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