

# Strength Evaluation and Characterization of *Gmelina Arborea* Timber for Structural Applications



Y. Yau<sup>1\*</sup>, A. Ocholi<sup>1</sup>, J. M. Kaura<sup>1</sup>, A. Lawan<sup>1</sup>, T. A. Sulaiman<sup>1</sup>, H. Aliyu<sup>2</sup>

<sup>1</sup>Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria.

<sup>2</sup>Department of Civil Engineering, Nuhu Bamalli Polytechnic, Zaria, Nigeria.

**ABSTRACT:** The increasing demand for timber in Nigeria necessitates frequent investigation into less-known timber species to ensure a steady supply for construction. This study examined the strength evaluation and characterization of *Gmelina arborea* timber to investigate its suitability for structural applications. Clear specimens were prepared from *Gmelina Arborea* timber logs taken from the base, middle, and top sections of the tree trunk. The timber was characterised based on ASTM and BS EN standards to measure moisture content (MC), density, specific gravity and various strength and stiffness properties. Results showed a mean green moisture content of 141.28% and a density of 505.03 kg/m<sup>3</sup>. The mean shear strength is 7.65 N/mm<sup>2</sup>, tensile strength and modulus of elasticity (MOE) in tension are 63.74 N/mm<sup>2</sup> and 7741.1 N/mm<sup>2</sup>, compressive strength parallel and perpendicular to the grain are 35.83 N/mm<sup>2</sup> and 5.89 N/mm<sup>2</sup> with MOE of 6850 N/mm<sup>2</sup> and 450 N/mm<sup>2</sup> respectively. The bending strength and the corresponding MOE are 58.82 N/mm<sup>2</sup> and 11980 N/mm<sup>2</sup>. Statistical analysis revealed that Weibull distribution best fits the experimental data for density and bending strength, while the normal distribution fits the MOE in bending. Characteristic values were determined as 416.71 kg/m<sup>3</sup> for density, 33.24 N/mm<sup>2</sup> for bending strength, and 11980 N/mm<sup>2</sup> for the MOE in bending. Consequently, *Gmelina arborea* falls into C30 strength class according to BS EN 338, confirming its suitability for structural applications.

**KEYWORDS:** Characterization, Distribution functions, Characteristic values, Strength classification, Stiffness properties.

[Received Nov. 24, 2021; Revised May 15, 2022; Accepted May 26, 2022]

Print ISSN: 0189-9546 | Online ISSN: 2437-2110

## I. INTRODUCTION

Wood is mankind's oldest building material, after stone. It serves as an eco-friendly and economical building material suitable for various structural and decorative uses in both interior and exterior settings. It can be shaped and crafted into countless forms and dimensions using basic on-site construction techniques (Ekundayo, *et al.*, 2022). Wood offers significant environmental benefits. Trees absorb carbon dioxide (CO<sub>2</sub>) from the atmosphere, release O<sub>2</sub> into the atmosphere and store the carbon, hence making wood a natural carbon sink. Processing and transporting timber consume significantly less energy compared to producing steel and concrete (Adediji, *et al.*, 2023). In Nigeria, forests cover 31.3 million hectares out of the country's 92.4 million hectares of land, with about 100 of 490 tree species in use. Timber is unique among construction materials as it is renewable, largely recyclable, and does not contribute to greenhouse gas emissions (Wilson *et al.*, 2021). Its production also consumes significantly less energy than conventional materials like concrete and steel (Momohara *et al.*, 2021). Timber finds extensive use in various industries, especially construction, where it serves structural roles (e.g., roof trusses, engineered wood products) and non-structural roles (e.g., doors, window frames) (Ataguba *et al.*, 2015). Timber is abundant, lightweight, workable, and versatile, with high thermal

insulation, elasticity, strength, and aesthetic appeal, making it environmentally friendly and suitable for cost-effective building designs (Sholadoye *et al.*, 2016). Studies confirm that some Nigerian wood species are reliable for structural applications (Sotande and Riki, 2019; Lamidi *et al.*, 2022; Iwuoha *et al.*, 2021; Ekundayo *et al.*, 2022; Oyediran *et al.*, 2023). Physical and mechanical properties are key in determining wood's suitability for structural use. Physical properties such as density and moisture content impact wood's performance, while mechanical properties, including elasticity and strength, dictate its response to applied forces (Jamala *et al.*, 2013). Density, moisture content, and temperature significantly influence the mechanical properties of wood, which must be carefully considered in structural applications. Higher density enhances wood's strength, while increased moisture content reduces it, and vice versa. However, once moisture content exceeds the fibre saturation point (FSP), further increases have negligible effects on timber strength (Yau *et al.*, 2024a). Standardized tests, generally conducted at 12% moisture content, assess these mechanical properties (Harte, 2009).

*Gmelina arborea* belongs to hardwood timber which can grow up to 35 meters tall and over 3 meters in diameter in its natural habitats. Various plantations of this tree (*Gmelina arborea*) were established mostly in southern Nigeria about 53

\*Corresponding author: yyilyas@gmail.com

years ago, as possible pulp wood for paper industries and its material properties have never been properly investigated (Iwuoha, 2021). In Nigeria, Gmelina plantations already cover over 112,000 hectares of land. Despite its future potential as a valuable material, its current applications have largely been restricted to minor construction projects (Onyekwelu, 2003).

Research on Gmelina includes Ataguba *et al.* (2015), who compared the physical and mechanical properties of Gmelina arborea, Parkia biglobosa, and Prosopis africana timbers from North Central Nigeria. Oyediran *et al.* (2023) investigated the mechanical properties of Gmelina, Teak, Afara, Ayin, and Acacia to assess their suitability for long-span roof trusses, finding that Gmelina had a bending strength of 65.04 MPa, MOE of 3071.11 MPa, compressive strength of 28.6 MPa, tensile strength of 26.9 MPa, and shear strength of 2.4 MPa, with a density around 700 kg/m<sup>3</sup>. Ekundayo *et al.* (2022) analysed woods from Akure sawmills, including Gmelina and others aged 10 to 15 years, measuring density, bending strength, and dimensional stability. Gmelina was categorized as medium density (552.8 kg/m<sup>3</sup>) with low bending strength, and its shrinkage and swelling were 7.84% and 6.69%, respectively. Dvorak (2004) noted Gmelina's density increases from base to top and reported a high moisture content of 160% with an average density of 410 kg/m<sup>3</sup>, while Freddy and Moya (2008) found its moisture content ranges between 168 to 182%. Iwuoha *et al.* (2021) further investigated Gmelina's mechanical properties, reporting tensile strength between 36.89 to 98.72 MPa, compressive strength (parallel to grain) of 23.88 to 41.38 MPa, shear strength of 3.91 to 7.83 MPa, bending strength of 29.79 to 72.73 MPa, and density from 387 to 528 kg/m<sup>3</sup>. Limit state design codes, which enhance safety and cost efficiency, use characteristic values for timber strength and stiffness, calculated from sample lower 5-percentiles (for strength and density) and 50-percentiles, for MOE (Azmi *et al.*, 2022; Harte, 2009). Adjustments to these values consider sample size, variability, and deviations in testing conditions (BS EN 384: 2004). Graphical methods for fitting data to distributions include histograms, cumulative distribution functions, and P-P and Q-Q plots.

Although significant research has provided detailed information on the properties of common timber species, a gap remains in characterizing many lesser known but potentially useful timber species in Nigeria (Jimoh and Aina, 2017). Research on classifying and grading timber for engineering use in Nigeria is limited, especially for underutilized species. Expanding the use of these lesser-known species could help reduce overexploitation of popular commercial woods like Mahogany, Obeche, Afara, and Teak (Ibitolu *et al.*, 2019; Wilson *et al.*, 2021; Jimoh and Jimoh and Ibitolu, 2018; Idris and Muhammad, 2013; Kaura *et al.*, 2015). For effective timber design, sufficient data on a species' properties is essential to meet performance standards. However, a major challenge is the lack of information on the physical variability and structural behaviour of these materials under load, which adds uncertainty to their use as structural elements. As timber demand in Nigeria rises with increasing housing and construction needs, regular research is needed to ensure a steady supply (Lamidi *et al.*, 2022). Utilizing lesser-known species with established properties could broaden the raw

material base, supporting construction demands while promoting economic independence and industrial growth in developing countries (Smith *et al.*, 2005; Jimoh and Aina, 2017). The International Wood Products Association (2015) also advocates for using lesser-known species to protect high-demand timber from overharvesting, aiding biodiversity conservation and ensuring future timber supply. Proper characterization is necessary to determine the suitability of these species for construction (Adediji *et al.*, 2023; ObinnaOsuji and Inerhunwa, 2017). The *Gmelina arborea* timber used in this research demonstrated volumetric shrinkage and swelling of 8.71% and 8.26%, respectively. Tangential shrinkage and swelling were 5.19% and 4.96%, radial shrinkage and swelling were 3.72% and 2.82%, and longitudinal shrinkage and swelling were 1.19% and 0.48%, respectively. The timber absorbed 94.7% water from the dry to fully saturated state over an average soaking period of 1272 hours (53 days) and lost 83.18% moisture during drying, reaching an equilibrium moisture content of approximately 12%. The material properties of Gmelina arborea timber identified in this study indicate strong potential for its use in the development of wood-based materials (Yau *et al.*, 2024b). This study aims to supply scientific basis as evidence for the material properties of *Gmelina arborea* timber and investigate its suitability for use in structural applications such as Engineered Wood Products (EWPs). Moreover, the study shall characterize, classify, and analyse the basic properties of Gmelina in line with the timber species whose material has been established and are currently being used in building and construction work.

## II. THEORITICAL ANALYSIS

Two different statistical analysis software, SPC for excel and Easy Fit were used to carryout statistical analysis on all the data obtained from the experiments in order to identify the distribution models related to the different experimental data. A P-P plot was utilized to evaluate the degree of fitting between the data obtained from experiment and the different distribution models (functions), with a significance level of 0.05. The results were reported as p-values and Akaike Information Criterion (AIC). In each case, the null hypothesis was that the experimental dataset conforms to the distribution model being tested.

## III. METHODOLOGY

### A. Materials

#### 1) Timber

The timber species used for this study was *Gmelina Arborea* (logs) in green condition sourced from a forest in Kachia LGA, southern part of Kaduna State, Nigeria (situated at Jaban Kogo, Sabon Sarki on latitude 9° 39' 21" N and longitude 8° 5' 11" E). A total of nine logs from three different randomly selected trees: three logs from each tree, with one log each gotten from the base, middle and top part of the tree trunk height, respectively. Table 1 displays the specific dimensions of the trees, along with the environmental conditions present during the process of harvesting.

**Table 1: Tree dimensions and environmental conditions during harvesting**

Tree Labels	Tree 1	Tree 2	Tree 3
Age of trees	20 yrs	20 yrs	20 yrs
Trees Height	13 m	12 m	15 m
Diameter at breast height	43.3 cm	41.7 cm	39.8 cm
Month	July		
Season	Rainy		

2) Equipment

Equipment used includes circular sawing machine, digital measuring instrument (weighing balance and callipers) and electric oven.

B. Methods

1) Acquisition of Material and Specimens preparation  
 The trees were cut down with a power saw and cut into 2.5-foot (70.6 cm) logs. The logs were segmented into three parts: the bottom, middle, and top, to ensure that the test results accurately reflect the tree's properties (Freddy and Moya, 2008 and Iwuoha et al, 2021). The green logs were transported to the Department of Civil Engineering, where they were seasoned and conditioned at 20°C (temperature) and 65% (relative humidity) for an approximate period of 14 weeks. Specimens for testing were cut at a moisture content of 15% to the reference sizes as given in Table 2, and then further condition to 12% moisture content (MC) before testing. Except for samples for the determination of MC and densities, green samples (unseasoned) were used.

**Table 2: Dimension and number of samples used for each test**

Property	Dimensions (mm)			No. of Specimen	Code (Specification)
	Width	Depth	Length		
Density and MC	50	50	50	135	ASTM D2395-17 and BS 373
Tensile Strength	6	20	300	45	BS 373
Compressive Strength Perpendicular	45	70	90	45	BS EN 408
Compressive Strength Parallel	30	30	180	50	BS EN 408
Shear Strength	50	50	63	40	ASTM D143-14
Bending strength	30	30	570	50	BS EN 408

2) Determination of Physical Properties

The densities and MCs of each sample were obtained by first measuring its initial mass ( $M_1$ ) and initial volume ( $V_1$ ) before drying using an electronic weighing balance and a digital calliper, respectively. The test specimens were then oven dried at  $103 \pm 2$  °C (temperature) to reach constant weight after two successive measurement. The final mass ( $M_2$ , oven dry mass) and the final volume ( $V_2$ , oven dry volume) were recorded of each sample. The MC was obtained using equation (1).

$$MC = \frac{M_1 - M_2}{M_2} \times 100 \tag{1}$$

The green, dry and basic densities as well as specific gravity for each sample were obtained using equation (2), (3), (4) and (5), respectively.

$$\rho_g = \frac{M_1}{V_1} \tag{2}$$

$$\rho_d = \frac{M_2}{V_2} \tag{3}$$

$$\rho_b = \frac{M_2}{V_1} \tag{4}$$

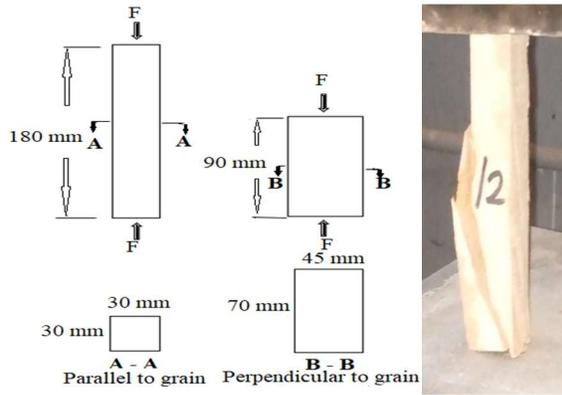
$$SG = K \frac{M_2}{V_1} \tag{5}$$

Where  $\rho_g$  is the green density,  $\rho_d$  is the dry density,  $\rho_b$  is the basic density, SG is the specific gravity, and K is constant determined by the units used to measure mass and volume ( $K=10^{-3} \text{ m}^3/\text{kg}$  when mass is in kg and volume is in  $\text{m}^3$ ).

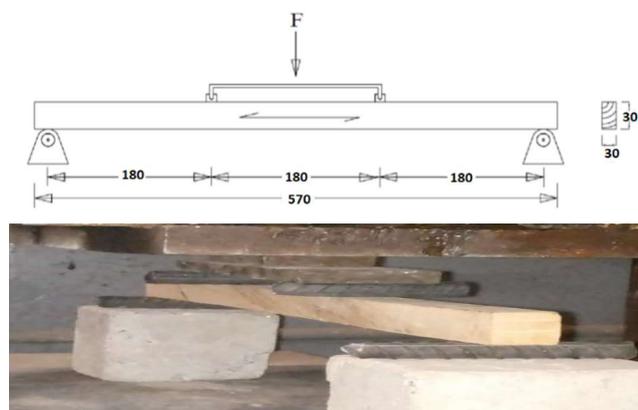
3) Determination of Mechanical Properties

Bending, shear, and compressive strength tests were conducted using a 250-tonne capacity universal testing machine and a sensitive dial gauge for measuring displacements with a precision of 0.001 mm. While the tensile strength test was performed using a 100 kN capacity electronic universal testing machine. The compressive strength test was conducted on specimens with dimensions as shown in Figure 1. The test piece for compression parallel to the grain was prepared with a full dimension, with a length that is six times the smaller cross-

sectional dimension, conforming to EN 408. To determine the bending strength of the timber, the test piece was loaded symmetrically at two points across span of 18 times its depth, as illustrated in Figure 2, following the guidelines of EN 408.

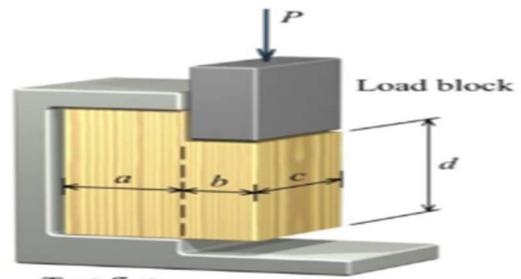


**Figure 1: Test configuration and set-up for specimen under compression**



**Figure 2: Test configuration (mm) and set up for bending strength**

For the tensile strength parallel to grain tests, the specimens were installed into the grips of the testing machine without any initial stress. This allowed the application of tensile force without introducing any bending stresses. To determine the shear strength parallel to the grain, tests were conducted on solid Gmelina arborea wood in accordance with ASTM D143-14. The shear tests involved applying compressive force using a shearing tool, following the guidelines of BS EN 392, as illustrated in Figure 3.



**Figure 3: Configuration of the test specimen for shear strength in solid wood**

The tensile ( $f_{t,0}$ ), shear ( $f_v$ ), and compressive ( $f_{c,0}$  and  $f_{c,90}$ ) strengths were determined using equation (6), while bending strength was determined using (7). The modulus of elasticity (MOE) in compression ( $E_{c,0}$  and  $E_{c,90}$ ), MOE in tension ( $E_{t,0}$ ) and MOE in bending ( $E_m$ ) were obtained using Equations (8), (9) and (10). However, the shear modulus ( $G_{mean}$ ) was computed using equation (13) in accordance with BS EN 338 and as adopted by Iwuoha *et al.* (2021).

$$f_{t,0} f_{c,90} f_{c,0} f_v = \frac{F_{max}}{A} \tag{6}$$

$$f_m = \frac{3F_{max} a}{bh^2} \tag{7}$$

$$E_m = \frac{al^2 (F_2 - F_1)}{16(W_2 - W_1)} \tag{8}$$

$$E_{c,0}, E_{t,0} = \frac{l_1 (F_2 - F_1)}{A(W_2 - W_1)} \tag{9}$$

$$E_{c,90} = \frac{h_o (F_{40} - F_{10})}{bl(W_{40} - W_{10})} \tag{10}$$

Where  $F_{max}$  is the maximum load at failure, A is the cross-sectional area of tested specimen in tension, shear and compression, b and h are the width and depth of tested specimens in bending, a is the distance between the point of loading and the nearest support in bending specimens, l is the span,  $F_2$  and  $F_1$  are the loads at point 2 and 1 on the regression line of load-deformation curve in bending,  $W_2$  and  $W_1$  are the displacement corresponding to  $F_2$  and  $F_1$ ,  $h_o$  is 0.6 h,  $F_{40}$  and  $F_{10}$  are 40% and 10% of  $F_{c,90,max}$ , and  $W_{40}$  and  $W_{10}$  is the increment of deformation corresponding to  $F_{40}$  and  $F_{10}$ .

To determine the MOE in bending, compression (parallel and perpendicular to the grain), and tension parallel to grain, load-deformation graphs from each tested specimen were analysed according to BS EN 408. The longest linear portion within the elastic range, with a correlation coefficient of 0.99, was used to calculate the load ( $F_2 - F_1$ ) and deformation ( $W_2 - W_1$ ) increments, as well as  $F_{40} - F_{10}$  and  $W_{40} - W_{10}$  values. Equations 8, 9, and 10 were applied to compute the MOEs for bending, compression

parallel to grain, compression perpendicular to the grain, and tension parallel to grain.

4) Statistical Analyses

a) Determination of distribution models for density, strength and stiffness properties

To establish a reliable foundation for engineering design, statistical analyses were conducted on the experimental data. Two different software tools, SPC for Excel and EasyFit, were utilized to determine the distribution functions corresponding to the various experimental datasets. A cumulative distribution function plot superimposed on the histogram data and a P-P plot were used to assess the fit between the experimental data and the various distribution functions, with a significance level of 0.05. The results were expressed as p-values. In all cases, the null hypothesis was that the experimental dataset conforms to the distribution function being tested. The p-values (highest), alongside Akaike Information Criterion (AIC) values (lowest) were used to determine the best distribution function that fit each experimental data.

b) Determination of characteristic values for density, strength and stiffness properties

Characteristic values of the material properties, such as mean values, 5<sup>th</sup> percentile, standard deviation, and coefficient of variation were obtained in accordance with BS EN 384. These values were determined as weighted means of the sample's lower 5-percentiles for strength properties and density, while the weighted mean of the sample averages (50<sup>th</sup>-percentiles or mean) was used to

calculate the MOE. For each sample, the 5<sup>th</sup>-percentile strength value was identified by ranking all test results in ascending order and determining the value below which 5% of the results fall. The equations provided in Annex A based on EN 338 standard methods were employed to calculate the characteristic values for properties not assessed in this study experimentally, including tension perpendicular to the grain ( $f_{t,90,k}$ ), MOE perpendicular to the grain ( $E_{90,mean}$ ), and shear modulus ( $G_{mean}$ ).

c) Allocation of EN 338 strength class

The allocation of a strength class to the Gmelina arborea timber species was carried out in accordance with BS EN 338. A timber population is assigned to a strength class if the characteristic values for bending strength and density are equal to or greater than the corresponding values specified in Table 1 based on BS EN 338 standard. Additionally, the characteristic mean modulus of elasticity in bending must meet or exceed 95% of the value required for the strength class as outlined in Table 1 based on BS EN 338 standard.

IV. RESULTS AND DISCUSSION

A. Physical and Hygroscopic Properties

1) Moisture content and Density

The results for the green moisture content of Gmelina trees are presented in Table 3 and summarised in Table 4. The moisture content (MC) for tree 1, tree 2 and tree 3 ranges from 121.6% to 164.57%, 119.76% to 170.06%, and 123.39% to 171.82%, respectively.

**Table 3: Average MC (%) for three different parts of Gmelina Arborea trees**

Position	T1	T2	T3
Top	132.82 ± 3.15	129.97 ± 2.75	133.76 ± 3.00
Middle	148.10 ± 2.78	151.29 ± 3.23	154.89 ± 2.94
Base	140.33 ± 2.49	140.34 ± 2.31	140.01 ± 0.73
Mean	140.42 ± 1.85	140.53 ± 2.05	142.88 ± 1.93

The mean MC for trees 1, 2, and 3 are obtained as 140.42%, 140.53% and 142.88%, respectively, as can be seen in Table 3. Therefore, Gmelina is having an average green MC of 141.28%. It can be observed that for all the three trees, the MC gradually increases from the top to the middle section, and then slightly decreases down to the base. This is due to the fact that early woods are found in the middle section and they are usually formed of thinner cell walls with large cell lumens or cavities which accommodate large amounts of moisture. The results for basic and dry densities of Gmelina are shown in

Figure 4 and summarised in Table 4. The basic density of Gmelina trees tested on 135 specimens ranged from 406.93 kg/m<sup>3</sup> to 569.64 kg/m<sup>3</sup>, 427.36 kg/m<sup>3</sup> to 558.47 kg/m<sup>3</sup>, and 395.96 kg/m<sup>3</sup> to 558.03 kg/m<sup>3</sup> for trees 1, 2 and 3, respectively. Their mean values for the basic densities were found to be 509.61 kg/m<sup>3</sup>, 506.94 kg/m<sup>3</sup> and 498.54 kg/m<sup>3</sup>, respectively. These findings compared favourably with findings reported by other studies (Iwuoha et al., 2021; Dvorak, 2004; Karlinsari et al., 2008).

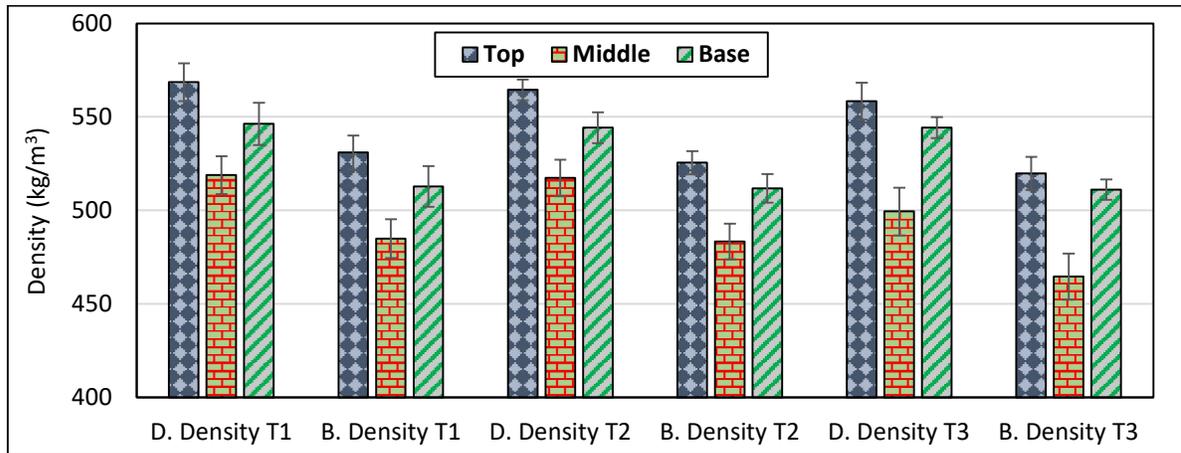


Figure 4: Variation of densities at different position along the height of the three trees

Furthermore, the density variation along the height of the trees was presented using a bar chart, as can be seen in Figure 4. High density from the base, decreasing gradually for some distance to the middle and then increasing towards the top. This can be attributed to the presence of tension wood at the top and bottom of the trees and also due to the high MC at the middle section, which has a negative correlation with density.

Analysis of variance (ANOVA) was performed to evaluate the differences in mean MC and density values among the three trees, as well as along the height of each tree. The result showed that the mean MC and density along the height of all the trees were significantly different ( $P\text{-value} < 0.05$ ). The ANOVA result for MC and density within the three different trees also showed significant differences.

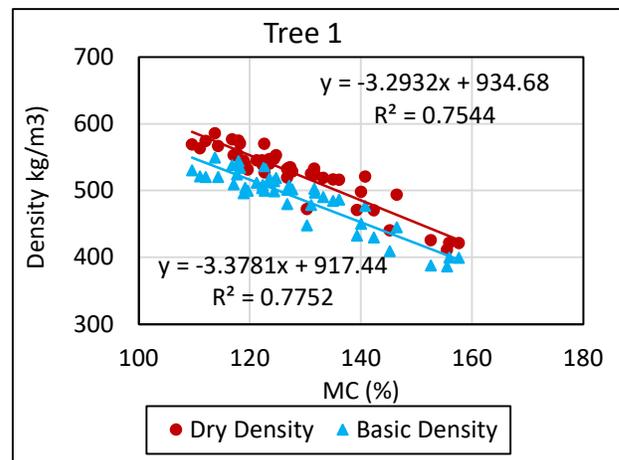
Table 4: Mean values for moisture content and densities of *Gmelina Arborea* tree parts

Property	MC (%)	Db (kg/m <sup>3</sup> )	Do (kg/m <sup>3</sup> )	Dg (kg/m <sup>3</sup> )	D12% (kg/m <sup>3</sup> )
MEAN	141.28	505.03	540.28	1213.88	565.17
SD	12.98	40.36	42.19	52.98	35.77
COV	9.19	7.99	7.81	4.36	6.33

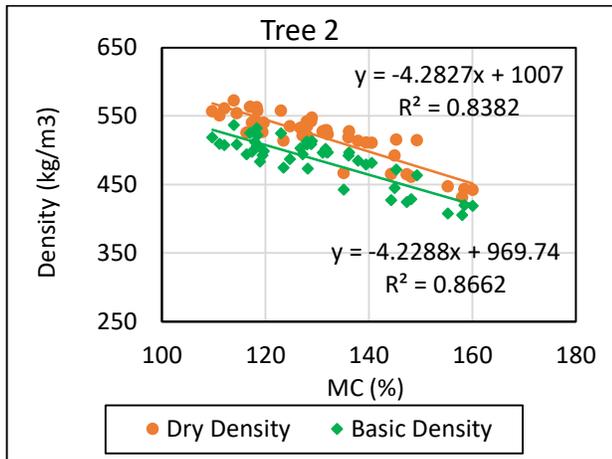
Db = Dry density, Do = Oven-dry density, Dg = Green density, D12% = Density at 12% MC

Table 4 presents the mean, standard deviation (SD), and coefficient of variation (COV) for various density measures and moisture content of samples from three different trees. The mean MC of the *Gmelina* is quite moderate at 141.28%, indicating a significant amount of water within the material. The SD of 12.98 and COV of 9.19% suggest a relatively consistent MC across samples, with moderate variability. The mean basic density (Db) is 505.03 kg/m<sup>3</sup>, representing the density of the wood when completely dried of moisture. The mean dry density (Do) is slightly higher than the basic density at 540.28 kg/m<sup>3</sup>, likely due to a reduction in the volume of the specimen during the drying process. The mean green density (Dg) is substantially higher at 1213.88 kg/m<sup>3</sup>, reflecting the density of the wood in its natural, wet state. The mean density at 12% MC (D12%) is 565.17 kg/m<sup>3</sup>, which is a common reference point for wood density measurements. *Gmelina* shows high moisture content with relatively consistent density measurements. The densities at different moisture levels (Db, Do, D12%) indicate how the wood density changes with moisture content, providing insights into the material's behaviour in different environmental conditions. The consistency in density measures (as indicated by low COV values) suggests reliable performance and uniformity in the wood samples, making them suitable for various applications

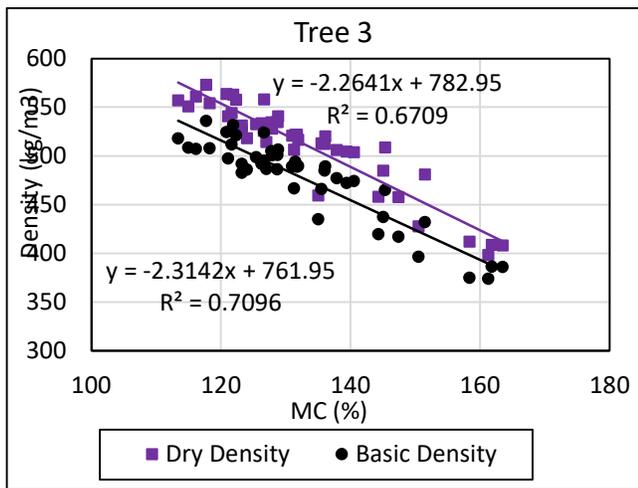
where predictability of material properties is crucial. In order to understand the relationship between density and MC, linear regression analysis was conducted between these two important physical properties, and the results are shown in Figure 5.



(a)



(b)



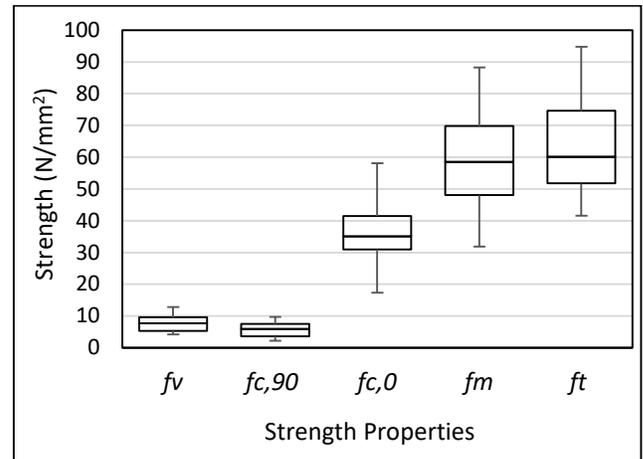
(c)

**Figure 5: Correlation between density and moisture content for the three trees**

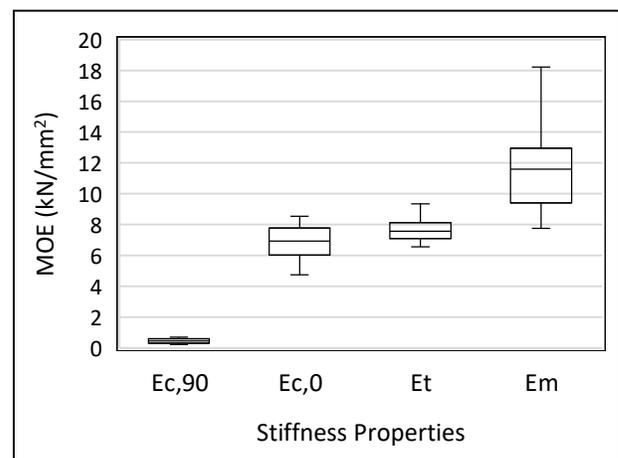
Figure 5 showed a strong negative correlation between densities (dry and basic) and MC for all three *Gmelina* trees considered, with  $R^2$  values of 0.7752, 0.8662 and 0.6709 for trees 1, 2 and 3, respectively. The discussions on the physical properties in this study are limited to the *Gmelina arborea* tree with dimensions and environmental conditions provided in Table 1.

**B. Strength and stiffness Properties**

The strength and stiffness properties of *Gmelina arborea* are summarized as box and whisker plot as shown in Figure 6a and 7b, respectively. Bending and tensile strength results are comparable, while the MOE in bending is higher than the MOE in tension. However, MOE in compression perpendicular showed the least stiffness value as can be observed in Figure 6. The general discussion on the strength and stiffness properties is limited to the *Gmelina arborea* trees with dimensions and environmental conditions provided in Table 1.



(a)



(b)

**Figure 6 (a, b): Strength and stiffness properties of *Gmelina arborea* timber specie**

1) Tensile strength ( $f_{t,0}$ ) and MOE parallel to grain ( $E_t$ )

Forty-five specimens with sample IDs TS1 to TS45 were tested in tension. The tensile strength of tested samples of *Gmelina* ranges from 41.6 N/mm<sup>2</sup> to 94.87 N/mm<sup>2</sup>. The elastic modulus in tension also ranges from 6567.57 N/mm<sup>2</sup> to 9843.28 N/mm<sup>2</sup>. A brittle failure was observed which occurred around the thinnest part of the test specimen without any prior notice. Five different stress-strain behaviours were noticed for all the specimens tested, and five specimens with sample ID. TS5, TS13, TS27, TS34, and TS40 were used to represent these behaviours as shown in Figure 7. While most of the specimens exhibited a linear behaviour up to the point of failure similar to that of specimen TS27.

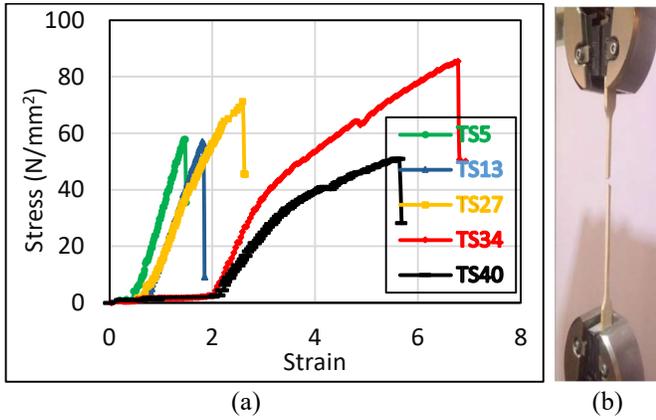
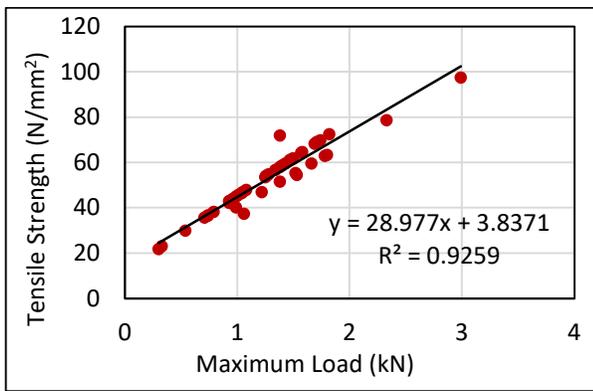
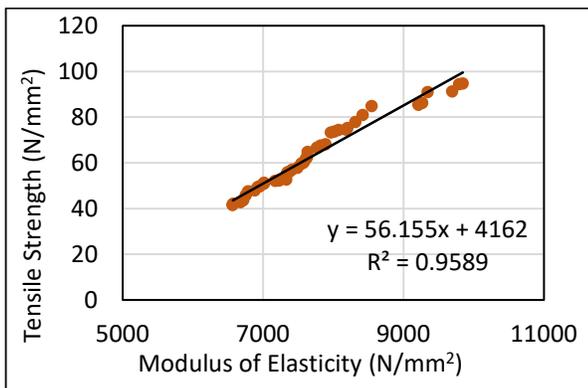


Figure 7: Stress-Strain curve and failure mode in tension

Linear regression analysis was conducted in order to establish relationship between the tensile strength of Gmelina with the MOE in tension and the maximum load at failure for all the tested specimen. Figure 8(a, b) shows the results of the linear regression, the results are showed a strong linear correlation between the tensile strength and both the MOE in tension and maximum load.



(a)



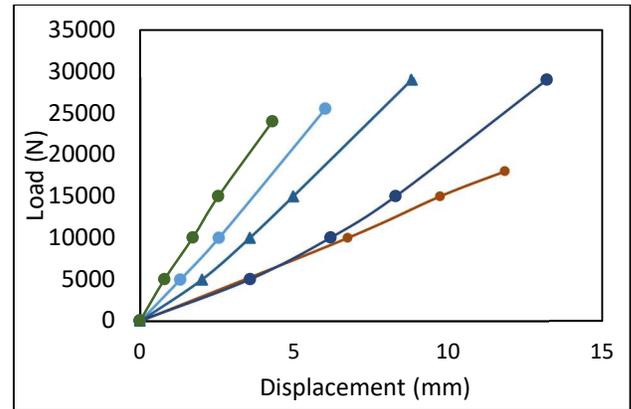
(b)

Figure 8: Correlation between tensile strength and MOE in tension/Max. Load

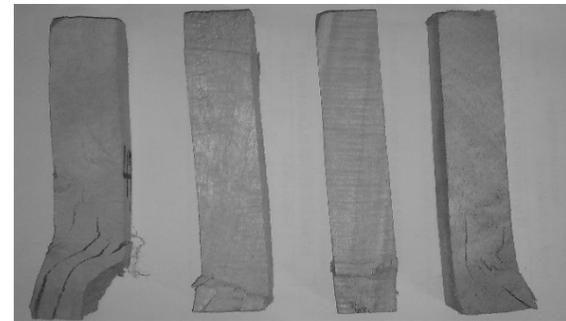
2) Compressive Strength ( $f_{c,0}$ ) and Modulus of Elasticity ( $E_{c,0}$ ) parallel to grain

Fifty specimens of Gmelina were tested to determine their compressive strength parallel to grain. The result obtained ranged from 17.34 N/mm<sup>2</sup> to 58.2 N/mm<sup>2</sup> with a mean value

of 35.82 N/mm<sup>2</sup>. The load-deformation behaviour of the specimens under compression was linear until the point of failure was reached, as shown in Figure 9. The MOE in compression parallel to grain ranged from 5330 to 8550 N/mm<sup>2</sup>, with a mean value of 6850 N/mm<sup>2</sup>. The effect of density and MC on the strength is shown in Figure 10, which indicated a strong positive correlation with the density and a negative correlation with the MC.

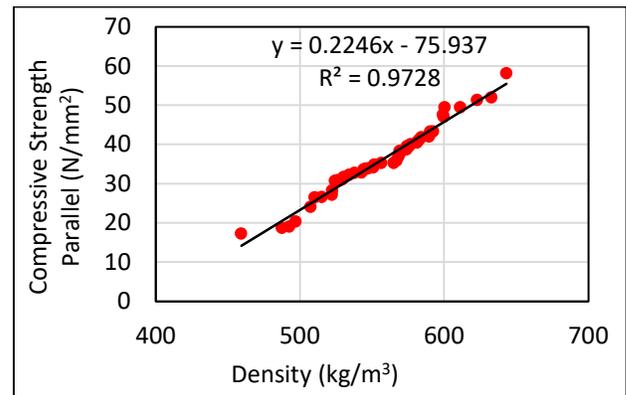


(a)

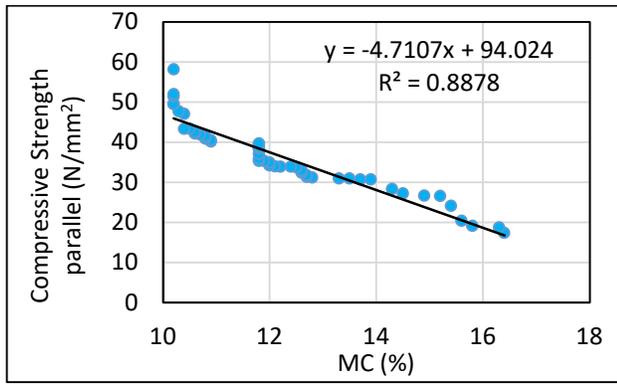


(b)

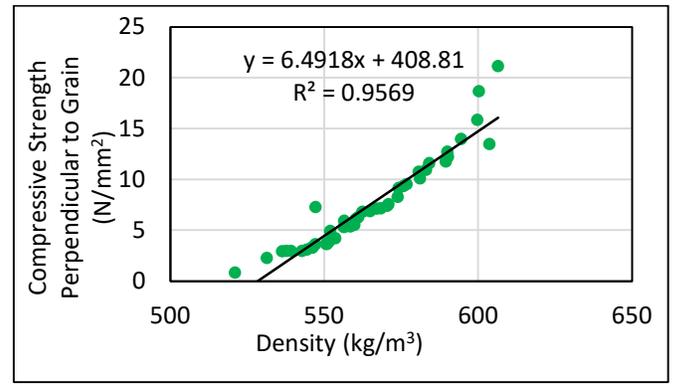
Figure 9: Load-deformation behaviour and mode of failure for the compression parallel to grain



(a)



(b)

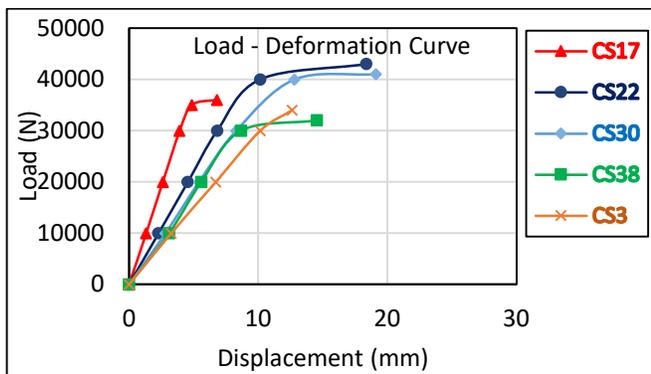


(a)

**Figure 10: Density and MC correlation with compressive strength parallel to grain**

3) Compressive strength ( $f_{c,90}$ ) and MOE ( $E_{c,0}$ ) perpendicular to grain

To determine the compressive strength perpendicular to grain, forty-five specimens of Gmelina were tested. The result obtained ranged from 0.81 N/mm<sup>2</sup> to 21.13 N/mm<sup>2</sup> with a mean value of 7.65 N/mm<sup>2</sup>. A slight reduction in length was observed, followed by some minor cracks on the tested specimens when compared to the untested specimens. Typical load-deformation curves of the samples under compression perpendicular to grain are shown in Figure 11 for samples with ID numbers CS17, CS22, CS30, CS38, and CS3. The MOE perpendicular to grain ranged from 225 N/mm<sup>2</sup> to 688 N/mm<sup>2</sup> having a mean of 450 N/mm<sup>2</sup>. The compressive result indicated a strong positive correlation with density and a negative correlation with MC, as observed in Figure 12, which shows the same pattern as that of compressive strength parallel to grain (Fig. 10).

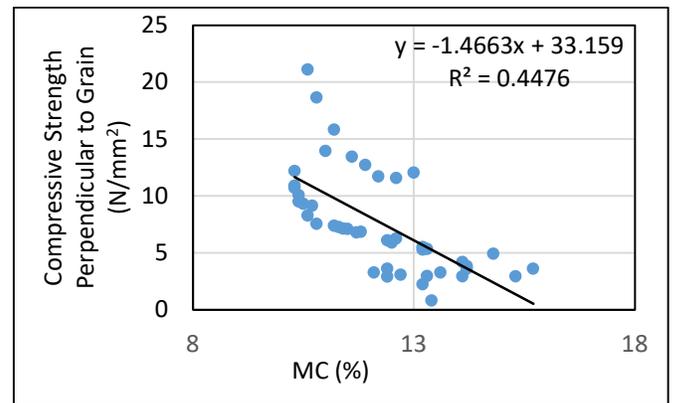


(a)



(b)

**Figure 11: Load-deformation curve and mode of failure for compression perpendicular**



(b)

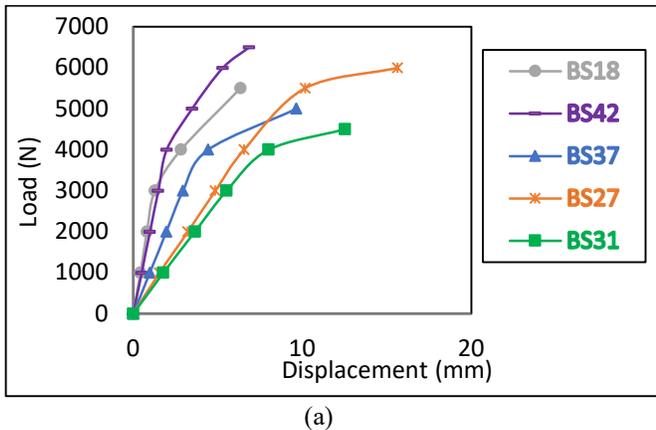
**Figure 12: Compressive strength perpendicular to grain with density and MC**

4) Shear Strength ( $f_v$ )

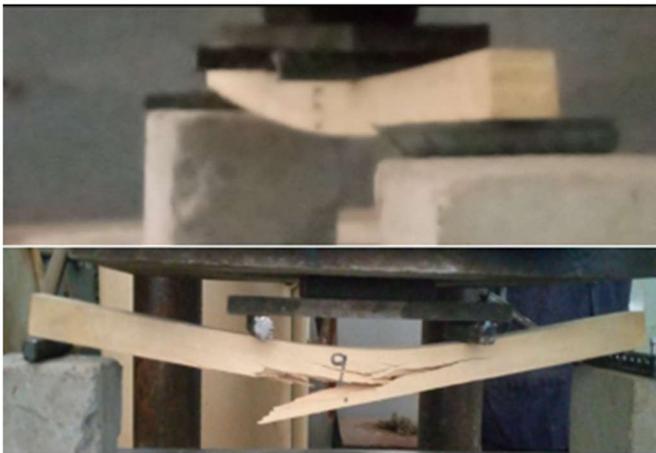
Forty specimens were tested for shear strength; the results obtained ranged from 4.28 N/mm<sup>2</sup> to 12.83N/mm<sup>2</sup>. The mean shear strength was obtained as 7.65 N/mm<sup>2</sup>. This result compares well with that of compressive strength perpendicular to grain, which can be seen clearly on the box plot in Figure 6, with the shear strength slightly higher.

5) Bending strength ( $f_m$ ) and MOE in bending ( $E_m$ )

The results of the bending strength for the 50 specimens tested ranged from 31.95 N/mm<sup>2</sup> to 88.27 N/mm<sup>2</sup> (adjusted result to reference size). Failure of 90% of the specimens starts at the bottom, where the tensile stress is maximum, with cracks propagating and approaching the ends of the samples, resulting in shear along the grain of the samples in the process. The specimens failed due to the combined effects of tensile stress and shear stress caused by the bending action. 10% of the specimens behave differently, and this is as a result of an internal defect observed after the test. The mode of failure and load-displacement curves of most of the specimens in bending are shown in Figure 13. Five specimens with sample IDs B18, BS42, BS37, BS27, and BS31 were used to display the load-deformation behaviour in bending. The MOE in bending was between 7510.6 N/mm<sup>2</sup> and 15548.98 N/mm<sup>2</sup>. Furthermore, the relationship between the bending strength and other related properties is shown in Figure 14.

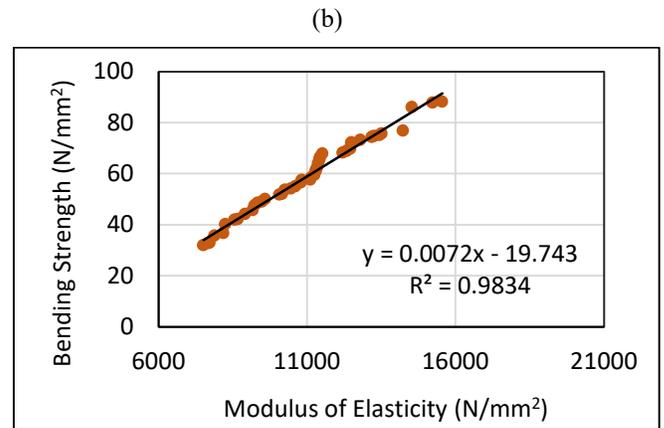


(a)



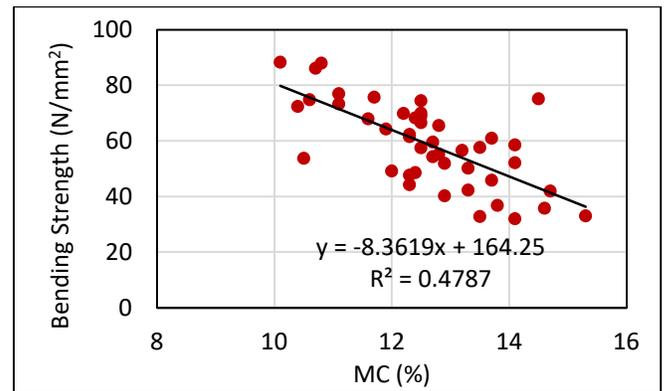
(b)

Figure 13(a, b): Bending strength Load-displacement curve and mode of failure



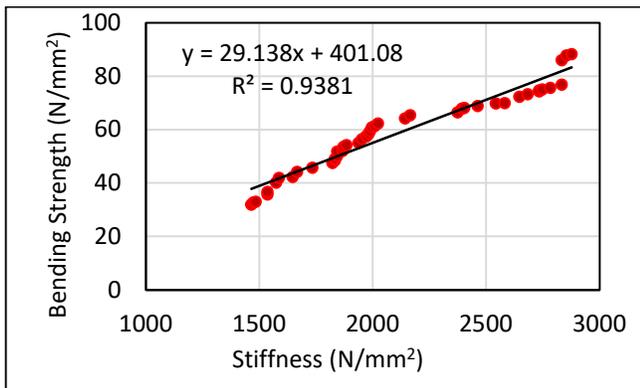
(b)

(c)

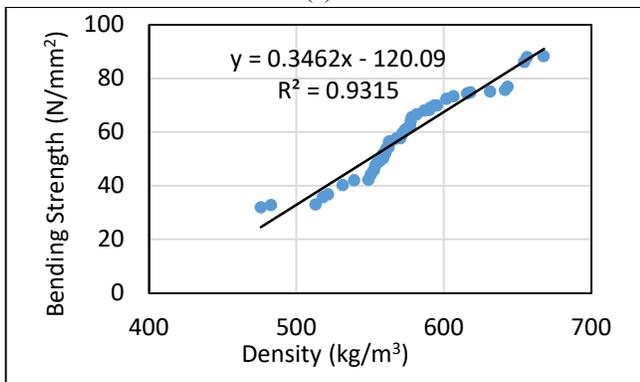


(d)

Figure 14: Bending strength correlation with (a) stiffness (b) Density (c) MOE (d) MC



(a)



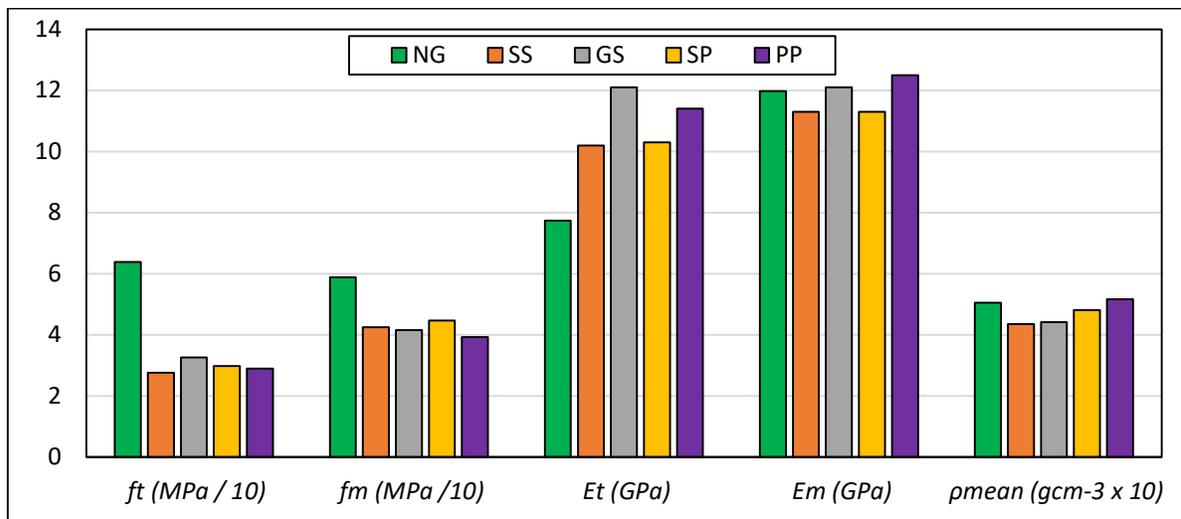
6) Comparison between the properties of *Gmelina arborea* and other timber species

Various studies have conducted experiments in order to characterise, classify and grade locally available timber for use in structural applications. Jimoh and Ibitolu (2018) classified three timber species: *Vitex donina*, *Ceiba pentandra*, and *Pseudocedrela kotschyi*. Ibitolu *et al.* (2019) and Lamidi *et al.* (2020) each characterized and graded two species: *Rhizophora racemosa* and *Syzygium guineense*, and *Funtumia elastica* (Ire) and *Newbouldia laevis* (Akoko), respectively. Lamidi *et al.* (2022) examined four lesser-used species: *Brachystegia eurycoma* (Ako), *Pterocarpus erinaceus* (Ara), *Guarea cedrata* (Obobo), and *Ricinodendron heudelotii* (Epuu). Adediji *et al.* (2023) focused on strength classification for three indigenous Northern Nigerian species: *Mangifera indica*, *Terminalia catappa*, and *Phoenix dactylifera*. In comparison to the findings in this study on *Gmelina arborea*, density value for *Gmelina* (505.5 kg/m<sup>3</sup>) is in a mid-range classification among the cited species, higher than *Rhizophora Racemosa* (433 kg/m<sup>3</sup>) and close to *Pterocarpus erinaceus* (515.27 kg/m<sup>3</sup>) but significantly lower than *Vitex donina* (706 kg/m<sup>3</sup>) and *Newbouldia laevis* (681.8 kg/m<sup>3</sup>). *Gmelina*'s density suggests moderate strength potential, aligning well with BS EN 338 strength class C30, which is similar to *Mangifera indica* (530 kg/m<sup>3</sup>) in Adediji *et al.* (2023). *Gmelina*'s bending strength (58.82 N/mm<sup>2</sup>) is higher than all species cited, except *Newbouldia laevis* (63.99 N/mm<sup>2</sup>). This indicates that *Gmelina* is particularly strong in

bending applications, making it suitable for structural purposes requiring high bending strength. Notably, the next highest bending strength found is *Syzygium guineense* at 36.394 N/mm<sup>2</sup>, which reinforces *Gmelina*'s superior bending capacity relative to most local timbers studied. The compressive strength parallel to grain (35.83 N/mm<sup>2</sup>) is comparable to that of *Funtumia elastica* (37.1 N/mm<sup>2</sup>) and significantly higher than *Mangifera indica* (26.95 N/mm<sup>2</sup>). It indicates a robust structural capacity that supports its C30 classification, aligning it with structurally stronger timbers suitable for load-bearing applications. However, it is lower than *Newbouldia laevis*, classified as D60, which exhibits a notably high compressive strength parallel to grain (63.99 N/mm<sup>2</sup>). *Gmelina*'s compressive strength perpendicular to grain (7.65 N/mm<sup>2</sup>) is significantly higher than other species such as *Mangifera indica* (3.83 N/mm<sup>2</sup>) and *Terminalia catappa* (3.12 N/mm<sup>2</sup>).

This property is crucial in structural contexts where lateral loads are applied, such as in CLT panel applications. *Newbouldia laevis* again stands out with an unusually high compressive strength perpendicular to grain (46.99 N/mm<sup>2</sup>), though it is the exception rather than the norm in the studies reviewed. In terms of strength class (BS EN 338), with a

classification of C30, *Gmelina* compares favourably to several local species but shows moderate classification relative to timber types like *Vitex donina* (D30) and *Newbouldia laevis* (D60). This classification supports *Gmelina*'s utility in structural applications, though it is generally lower than timbers with significantly higher density and strength characteristics (e.g., *Newbouldia laevis*). *Gmelina arborea* demonstrates an excellent balance between density, bending strength, and compressive strengths (parallel and perpendicular to grain) that aligns with the BS EN 338 C30 classification. In general, *Gmelina arborea* used in this study, presents a valuable option for structural applications, with properties that can meet medium-strength structural requirements effectively. Further research could expand on its environmental durability, especially under long-term exposure, to strengthen its profile as a viable material in broader construction applications. Figure 15 provides a comparison of key material properties of *Gmelina arborea* in this study with those of European softwoods commonly used in mass timber production.



NG: Nigerian *Gmelina* (used in this study), SS: Swedish Spruce, GS: German Spruce, SP: Swedish Pine, PP: Polish Pine (Ranta-Maunus, et al., 2011).

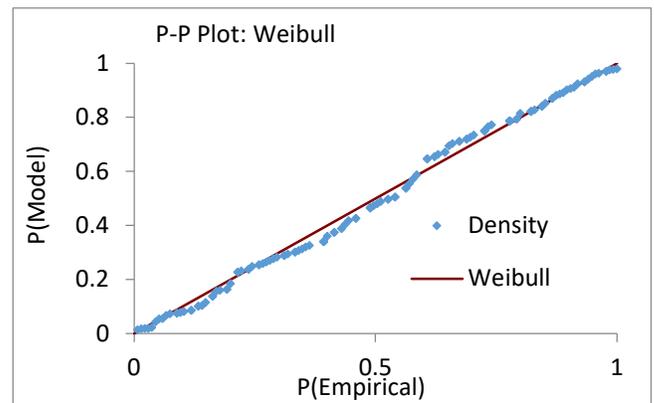
**Figure 15: Comparison between properties of *Gmelina* with those of European softwoods**

As shown in Figure 15, the properties of *Gmelina* from this study are comparable to those of European softwoods, suggesting that *Gmelina* could serve as a viable source for mass timber production.

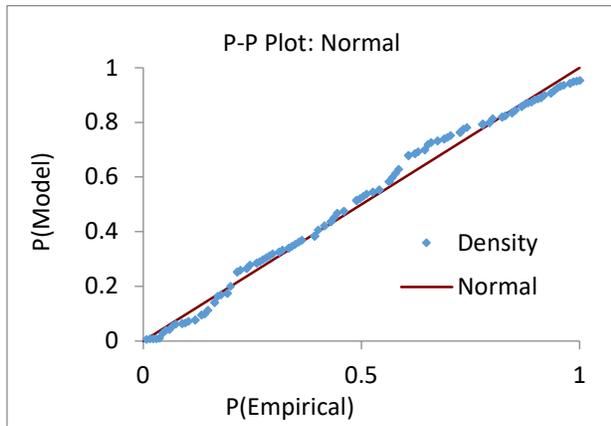
**C. Statistical Analyses and Goodness of Fit**

**a) Distribution Models and Characteristics Values for the Basic material Properties**

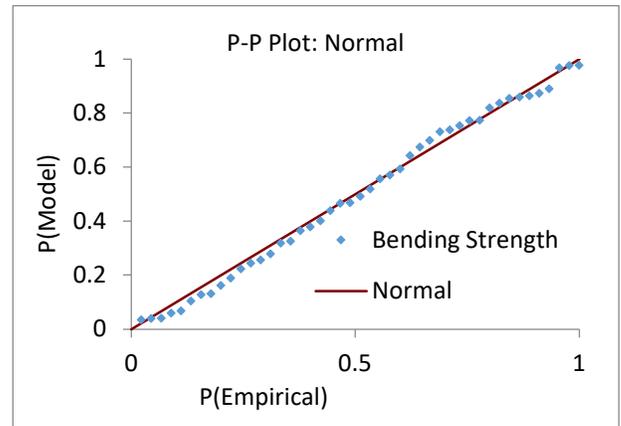
The experimental dataset for density and bending strength can be visualized as P-P plots in Figure 16 and 17, showing the results of fitting the several distributions.



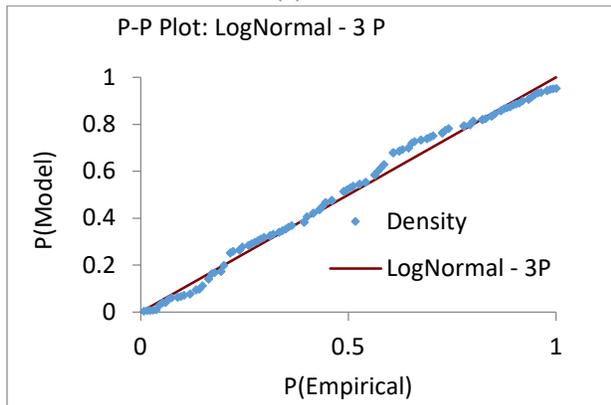
(a)



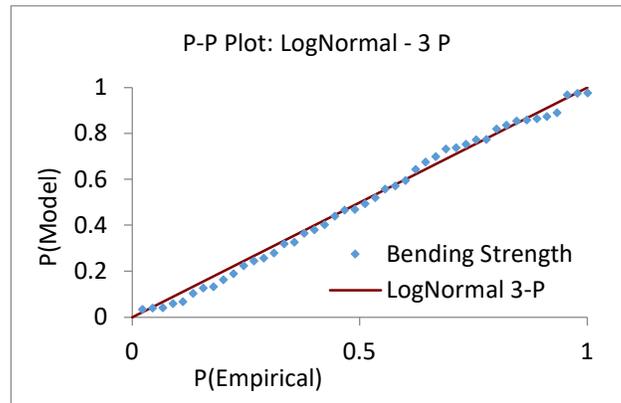
(b)



(b)



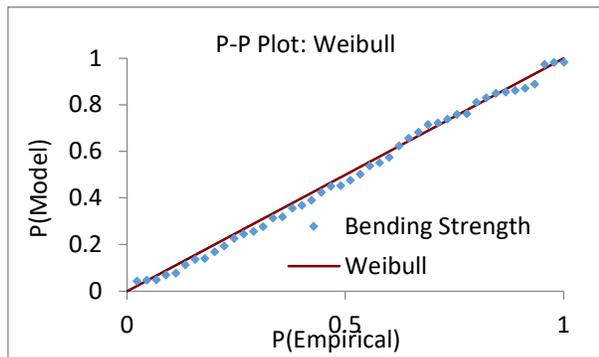
(c)



(c)

**Figure 16: Fitting the different distribution models to density data**

**Figure 17: Fitting the different distribution models to bending strength data**



(a)

Figures 16 and 17 show the extent of fit of the density and bending strength data respectively with the Weibull, Normal and the LogNormal-3P distributions. The bending strength data aligns well with all three distribution functions that were tested (all with p-values > 0.05). However, Weibull distribution is seen to have fit the bending data better than Normal and 3P-LogNormal, having the least AIC value of 373.8 as compared to that of Normal and 3P-LogNormal (374.1 and 376.1). Table 5 shows the p-values and AIC values of the several distributions functions for each of the material properties.

**Table 5: Distribution functions fitting the experimental data**

Property	Normal		LogNormal		3P-LogNormal		Weibull	
	p-value	AIC	p-value	AIC	p-value	AIC	p-value	AIC
$f_m$	0.837	374.1	-	-	0.833	376.1	>0.25	373.8*
$f_t$	-	-	0.336	371.3	0.614	368.9*	-	-
$f_{c,0}$	-	-	-	-	0.568	362.8*	>0.25	363.7
$f_{c,90}$	0.638	255.4	0.896	254.5*	-	-	>0.25	255.8
$f_v$	0.347	263.5*	0.327	268.3	0.347	271.4	-	-
$E_m$	0.63	817.4*	-	-	0.578	819.4	>0.25	818
$E_t$	-	-	0.002	735.7	0.674	728.2*	>0.25	730.6
$\rho$	0.008	1442	-	-	0.008	1452.1	>0.25	1440.4*

\*Distribution models used for further analysis in this study (with highest p-value or AIC)

Based on the result of goodness of fit, the characteristics values of the mechanical properties of *Gmelina Arborea* timber were determine from the chosen distribution models that best fit the experimental data (Table 5). The statistical models and characteristic values are presented in Table 6. Characteristic

values are the weighted mean of sample lower 5-percentiles for strength properties and density, whereas for MOE are the weighted mean of sample averages (50-percentile or mean) as specified in BS EN 384.

**Table 6: Statistical Models for the Material Properties of Gmelina Arborea**

Properties	Strength (N/mm <sup>2</sup> )					Stiffness (N/mm <sup>2</sup> )		Density (kg/m <sup>3</sup> )
	$f_m$	$f_{c,0}$	$f_{c,90}$	$f_v$	$f_t$	$E_m$	$E_t$	$\rho$
Mean	58.82	35.82	5.89	7.65	63.74	11980	7741.1	505
SD	14.91	8.76	2.2	2.47	16.19	2048.8	920.74	40.21
COV	0.253	0.244	0.37	0.32	0.254	0.187	0.119	0.08
5 <sup>th</sup> Percentile	33.24	21.67	2.84	4.37	43.83	7610	6689	416.71
90 <sup>th</sup> Percentile	77.74	47.12	9.14	10.37	84.69	13606	8904.9	546.53
95 <sup>th</sup> Percentile	82.45	50.46	9.46	12.57	94.23	14350	9483.7	555.22

b) Characteristic values for the other mechanical properties of Gmelina Timber

Research has shown that all important characteristic such as strength and stiffness properties can be calculated from either bending strength, MOE or density (Harte, 2009). Various studies have used the equation provided in Annex A based on EN 338 (2016) to compute other mechanical properties (Adejiji et al., 2023; Lamidi et al., 2022; Ibitolu et al., 2019; Jimoh and Ibitolu, 2018). Apart from the characteristic values of the basic material properties presented in Table 6, there are other properties such as tension perpendicular to grain ( $f_{t,90,k}$ ), MOE perpendicular to grain ( $E_{90,mean}$ ) and shear modulus ( $G_{mean}$ ), which were not determine experimentally. However, these properties were alternatively determined using Equations

(11), (12) and (13) respectively, as provided in Annex A based on EN 338 (2016), by inputting the experimental results for characteristic density ( $\rho_k$ ) and mean MOE in bending ( $E_{0,mean}$ ). The results of these properties are as displayed in Table 7.

$$f_{t,90,k} = 0.6 f_{m,k} \tag{11}$$

$$E_{90,mean} = \frac{E_{0,mean}}{30} \tag{12}$$

$$G_{mean} = \frac{E_{0,mean}}{16} \tag{13}$$

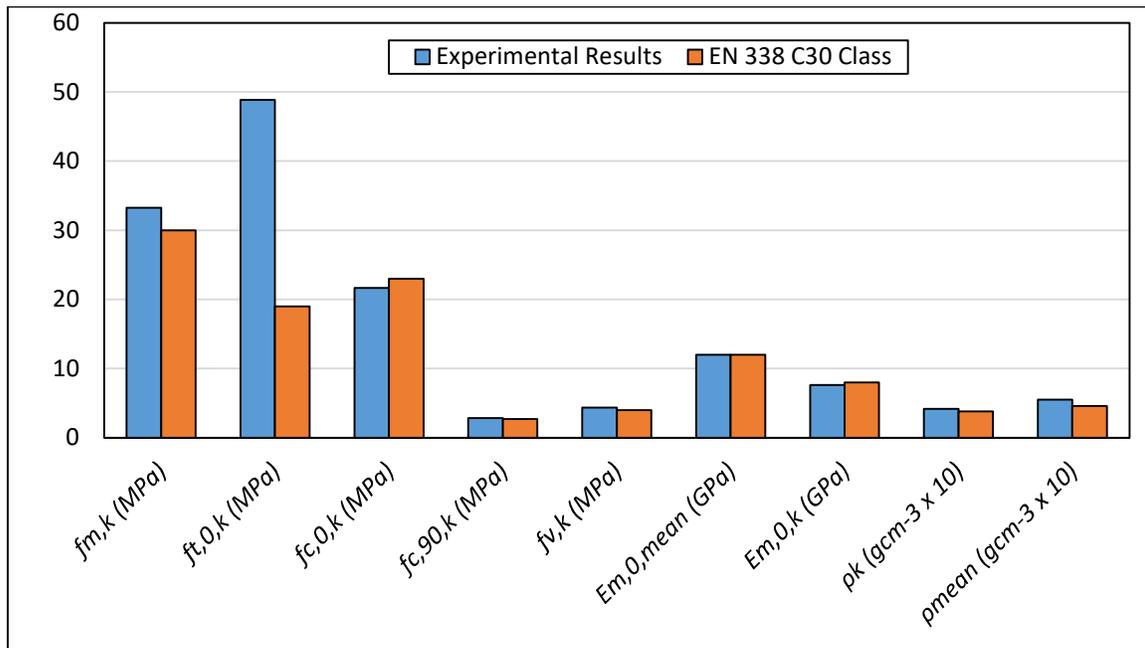
**Table 7: Values of other Mechanical Properties**

Property	Experimental values	EN 338
Tension perpendicular to grain $f_{t,90,k}$	0.63 N/mm <sup>2</sup>	0.4 N/mm <sup>2</sup>
MOE perpendicular to grain $E_{90,mean}$	399 N/mm <sup>2</sup>	400 N/mm <sup>2</sup>
Shear modulus $G_{mean}$	749 mm <sup>2</sup>	750 mm <sup>2</sup>

c) Strength Classification: BS EN 338 Strength Class Allocation

Considering the results obtained in this study as presented in Tables 5 and 6, the *Gmelina arborea* timber species is assigned and allocated a strength class of C30. In general, to compare

the experimental results of the material properties obtained in this study with those given in Table 1 based on EN 338 standard for strength class C30, Figure 18 clearly showed the extent to which the results are comparable.



**Figure 18: Comparison between experimental results and values in EN 338 for C30**

From Figure 18, it can be seen clearly that the experimental results and EN 338 standard for C30 strength class values are comparable to each other, with only tensile strength parallel to grain, showing a significantly higher value.

**V. CONCLUSIONS**

The strength evaluation and characterization of *Gmelina arborea* timber to investigate its suitability for structural applications were examined. The physical and strength properties of the timber determined experimentally are a mean green moisture content (MC) of 141.28%, a basic density of 505.03 kg/m<sup>3</sup>, a dry density of 540.28 kg/m<sup>3</sup>, and a density of 565.17 kg/m<sup>3</sup> at 12% MC. The mean specific gravity was 0.51. The mean strength properties are a tensile strength of 63.74 N/mm<sup>2</sup>, a compressive strength parallel to the grain of 35.83 N/mm<sup>2</sup>, a compressive strength perpendicular to the grain of 7.65 N/mm<sup>2</sup>, and a bending strength of 58.82 N/mm<sup>2</sup>. Also, the stiffness properties include modulus of elasticities (MOEs) in tension, compression parallel to grain, compression perpendicular to grain, and bending of 7741.1 N/mm<sup>2</sup>, 6850

N/mm<sup>2</sup>, 450 N/mm<sup>2</sup> and 11980 N/mm<sup>2</sup> respectively. The material properties of *Gmelina arborea* timber established in this research indicate its suitability for use in construction and structural applications. Based on the statistical analysis conducted, the distribution model that best fit the experimental dataset for density and bending strength was the Weibull distribution function. However, MOE in bending and shear strength followed the normal distribution functions. As for compressive strength parallel to grain, tensile strength and its MOE, followed the LogNormal with 3-parameters distribution function, compressive strength perpendicular to grain followed LogNormal with 2-parameters distribution function. The characteristic values of *Gmelina* for density, bending strength and MOE in bending were obtained as 416.71 kg/m<sup>3</sup>, 33.24 N/mm<sup>2</sup> and 11980 N/mm<sup>2</sup>, respectively. As for the other material properties, the values were obtained as 43.83 N/mm<sup>2</sup>, 4.37 N/mm<sup>2</sup>, 21.67 N/mm<sup>2</sup> and 2.84 N/mm<sup>2</sup> for tensile strength, shear strength, compressive strength parallel to grain and compressive strength perpendicular to grain, respectively.

*Gmelina arborea* considered in this study has material properties similar to those of softwoods.

#### ACKNOWLEDGEMENTS

The support and assistance of the technical staff from the Carpentry Workshop and Heavy-Duty Structural Laboratory of the Civil Engineering Department are gratefully acknowledged.

#### AUTHOR CONTRIBUTIONS

**Y. Yau:** Conceptualization, Methodology, Software, Validation, Writing – original draft. **A. Ocholi:** Conceptualization, Methodology, Supervision. **J. M. Kaura:** Conceptualization, Methodology, Supervision. **A. Lawan:** Conceptualization, Methodology, Supervision. **T. A. Sulaiman and H. Aliyu:** Writing – review & editing.

#### REFERENCES

- Adediji, O. C.; U. N. Wilson and I. S. Mohammed (2023).** Characterization of Three Selected Timber Species According to BS 5268 (2002), EN 338 (2009) and NCP 2 (1973). *Journal of Science and Technology Research*, 5(4), 40–50.
- ASTM (2016).** Standard Test Method for Small Clear Specimens of Timber. ASTM D143-14. United State.
- ASTM (2018).** Standard Test Method for Density and Specific Gravity of Wood and Wood based Materials. ASTM D2395-17. United State.
- Ataguba, C. O.; C. Enwelu; W. Aderibigbe and E. O. Okiwe (2015).** A Comparative Study of Some Mechanical Properties of *Gmelina arborea*, *Parkia biglobosa* and *Prosopis africana* Timbers for Structural Use. *International Journal of Technological Research and Applications*, 3(3), 320–324.
- Azmi, A.; Z. Ahmad; W. C. Lum; A. Baharin; N. I. L. Za'ba; N. M. Bhkari and S. H. Lee (2022).** Compressive Strength Characteristics Values of Nine Structural Sized Malaysian Tropical Hardwoods. *Forest*, 13, 1172. <https://doi.org/10.3390/f13081172>
- BS 373 (1957).** Methods of Testing Small Clear Specimens of Timber. British Standard Institution, London.
- BS EN 338 (2016).** Structural Timber – Strength Classes. European Standard, European Committee for Standardization.
- BS EN 384 (2004).** Structural Timber – Determination of Characteristic Values of Mechanical Properties and Density. European Standard, European Committee for Standardization.
- BS EN 392 (1995).** Glued laminated timber - Shear test of glue lines. *London: British Standards Institution*.
- BS EN 408 (2010).** Timber structures - Structural timber and glued laminated timber - Determination of some physical and mechanical properties. European Standard, European Committee for Standardization.
- Dvorak, W. S. (2003).** World View of *Gmelina arborea*: Opportunities and Challenges. In *Recent advances with Gmelina arborea* (eds. W. S. Dvorak, G. R. Hodge, W. C. Woodbridge and J. L. Romero). CD-ROM. CAMCORE, North Carolina State University, Raleigh, NC. USA.
- Ekundayo, O. O.; C. Arum and J. M. Owoyemi (2022).** Evaluation of Physical and Mechanical Properties of Selected Wood Species Obtained from Saw Mills in Akure, Nigeria. *Journal of Applied Science and Environmental Management*, 26(6), 999-1005.
- Freddy, M. and Moya, R. (2008).** Moisture Content Variability in Kiln-Dried *Gmelina Arborea* Wood: effect of radial position and anatomical features, *Journal of Wood Science*, 54, 318–322.
- Harte, A. M. (2009).** Introduction to Timber as an Engineering Material. *Institute of Civil Engineering Manual of construction materials*, 1 – 9.
- Ibitolu, B. J.; A. A. Jimoh and O. Y. Babatunde (2019).** EN 338 Strength Characterization and Grading of Igba (*Rhizophora Racemosa*) and Ade (*Syzgium Guineense*) Timbers for Structural Applications. *Computational Engineering and Physical Modelling*, 2(4), 24 – 37.
- Idris, A. and Muhammad, N.A. (2013).** Development of EN338 (2009) strength classes for some common Nigerian timber species using three point bending test. *International Journal of Civil and Environmental Engineering*, 7(5), 338-342.
- Iwuaha, S. E.; W. Seim and J. C. Onyekwelu (2021).** Mechanical Properties of *Gmelina Arborea* for Engineering Design. *Construction and building materials*, 288, 1-14.
- Jamala, G. Y.; S. O. Olubunmi; D. A. Mada and P. Abraham (2013).** Physical and Mechanical Properties of Selected Wood Species in Tropical Rainforest Ecosystem, Ondo State, Nigeria. *Journal of Agriculture and Veterinary Science*, 5(3), 29 – 33.
- Jimoh, A. A. and Aina, S. T. (2017).** Characterization and Grading of Two Selected Timber Species Grown in Kwara State Nigeria. *Nigerian Journal of Technology*, 36(4), 1002 – 1009.
- Jimoh, A. A. and Ibitolu, B. J. (2018).** Characterization and Grading of Three Selected Timber Species Grown in Kwara State Nigeria According to EN 338 (2009) For Structural Use. *Nigerian Journal of Technology*, 37(2), 322 – 329.
- Karlinasari, L.; M. Wahyuna and N. Nugroho (2008).** Non-Destructive Ultrasonic Testing Method for Determining Bending Strength Properties of *Gmelina* Wood (*Gmelina arborea*). *Journal of Tropical Forest Science*, 20(2), 99 – 104.
- Kaura, J. M.; I. Abubakar and I. Aliyu (2015).** EN 338 Strength grade and uncertainty models of material properties for Nigerian Grown *Terminalia superba* (White Afara) timber specie. *Nigerian Journal of Technology*, 34(1), 21-27.
- Lamidi, N. A.; M. A. Muili; O. O. Akinyemi and O. Q. Ajao (2020).** Characterization and Grading of Two Selected Less Known Timber Species for Structural Applications in Nigeria. *UI Journal of Civil Engineering and Technology*, 2(1), 16 – 27.
- Lamidi, N. A.; Q. O. Hassan; G. O. Ajoje and M. A. Muili (2022).** EN 338 Strength Characterization and Grading of Four Less-used Timber Species Grown in Nigeria for Structural Uses. *LAUTECH Journal of Civil Engineering and Environmental Studies*, 8(1), 29-37.
- Momohara, I.; H. Sokai; H. Kurisaki; W. Ohmura; T. Kakutani; T. Sekizawa and Y. Imamura (2021).** Comparison of natural durability of wood by stake tests

followed by survival analysis. *Journal of Wood Science*, 67(44), 1-7.

**ObinnaOsuji, S. and Inerhunwa, I. (2017).** Characterization and Strength Classification of Timber Species in Akwa Ibom State, Nigeria for Structural Engineering Applications. *International Journal of Engineering Research and Application*, 7(10), 1- 9.

**Onyekwelu, J. C.; P. Biber and B. Stimm (2003).** Thinning scenarios for Gmelina arborea plantations in south-western Nigeria using density management diagrams, *Food, Agric. Environ. 1*, 320 – 325.

**Oyediran, A. A.; C. M. Ikumapayi and B. Olufemi (2023).** Determination of the Properties of Some Selected Timber Specie for Structural Application. *World Journal of Engineering and Technology*, 11, 319 – 334.

**Sholadoye, I. O.; I. Abubalar; Q. B. Annafi and S. P. Ejeh (2016).** Evaluation of Some Wood Properties of Nigeria Timber Using Four-Point Bending Test. *Advances in Multidisciplinary and Scientific Research journal*, 2, 33 – 144.

**Smith, R. L.; P. W. Mcdanie and D. Fell (2005).** Opportunities for the Utilization of Alternative Species in Secondary Wood Manufacturing. *Forest Products Journal*, 55(4), 71 – 77.

**Sotannde, A. O. and Riki, J. T. B. (2019).** Wood Quality Studies of Some Wood Species in Sudano-Sahelian Environment of Borno State, Nigeria. *Journal of Research in Forestry, Wildlife and Environment*, 11(3) ISBN: 2141 – 1778.

**Wilson, U. N.; Y. N. Mohammad; I. S. Mohammed and F. O. Adeyemi (2021).** Characterization and Grading of Four Selected Timber Species Grown in Nigeria in Accordance with BS 5268. *Nigerian Journal of Technology*, 40(4), 576 – 583.

**Yau, Y.; T. A. Sulaiman; Z. B. Baba; B. H. S. Amartey; A. A. Sabari and I. Garba (2024a).** Influence of Density and Moisture Content on the Compressive Strength Parallel to Grain of *Gmelina Arborea* Timber Specie. *Proceedings of the 12<sup>nd</sup> Annual and International Conference of Renewable and Alternative Energy of Society of Nigeria (RAESON), Aliko Dangote University of Science and Technology, Kano, Nigeria*, 110 – 117.

**Yau, Y.; A. Ocholi; J. M. Kaura; A. Lawan and T. A. Sulaiman (2024b).** Experimental Evaluation of the Physical and Sorption Properties of *Gmelina Arborea* Timber for Development of Wood-based Materials. *Covenant Journal of Engineering Technology*, 8(2), 84 – 91.