EFFECTS OF SPECIES, DENSITY, MOISTURE CONTENT AND SIZE ON SHEAR PROPERTIES OF SELECTED TIMBER IN SOUTH-WEST NIGERIA

Tumininu Deborah Amusan*

Department of Civil Engineering, Federal University Oye-Ekiti, Oye-Are Road, Oye-Ekiti, Ekiti State, Nigeria

*Corresponding author
tumininu.amusan.192003
@fuoye.edu.ng

Graphical abstract

Abstract

Timber remains a renewable and environmentally sustainable construction material, yet its variations in shear strength are not well understood, particularly with respect to species, density, moisture content, and size. This study was conducted to investigate these variations in four hardwood species commonly used in Southwestern Nigeria: Ayin (*Anogeissus leiocarpus*), Eru (*Ricinodendron heudelotii*), Ayere (*Pterocarpus erinaceus*), and Alakrity (*Albizia ferruginea*). Timber samples were obtained from Johnson Sawmill, Ikole Ekiti, Nigeria, and prepared in accordance with British Standard (BS 373). A total of 36 control samples and 192 test samples were analyzed for moisture content, density, and shear strength using a universal testing machine. Initial moisture content ranged from 17% to 25%, while post-drying values stabilized between 11% and 12%. Density values varied from 676.87 kg/m³ for Ayere to 971.33 kg/m³ for Ayin. Analysis of variance (ANOVA) confirmed that, at 12% moisture content, Ayere exhibited the lowest density, whereas Ayin recorded the highest. Shear strength results revealed that oven-dried samples demonstrated significantly higher values than wet samples. A positive correlation was observed between density and shear strength, with higher-density timbers exhibiting greater resistance. Cross-sectional analysis indicated a general decrease in shear strength with increasing area, largely reflecting the influence of defects. This study highlights the relationship between moisture content, density, size, grain orientation, and shear strength, and practical recommendations for the selection and application of hardwoods in structural engineering.

Keywords: Timber, Shear strength, Moisture content, Density, Sustainability

1.0 INTRODUCTION

Timber has long been an important material in construction, valued not only for being renewable but also for its favourable strength-to-weight ratio, ease of use, and relatively low environmental footprint when it is properly treated and seasoned (Kumar, Dhiman, & Sharma, 2020). Its applications extend across both traditional and modern construction, ranging from bridges and building frameworks to flooring and furniture, demonstrating its versatility (Chaowana, 2013). Yet, behind this apparent simplicity lies a complex internal structure that strongly influences how timber behaves under load. One property that demands special consideration is shear strength, as it defines the wood's ability to resist sliding forces within its structure. If timber cannot adequately resist these forces, its integrity may be compromised, which is especially concerning in members where splitting or sliding along the grain could result in failure (Sholadoye & Abubakar, 2020a; Nweze, Ojua, Ajuziogu, & Ngele, 2021). While the significance of shear strength is recognised, the extent of its variation across timber species and under different physical conditions is less well understood. Factors such as density, moisture content, and cross-sectional size interact in ways that substantially affect performance. For instance, denser species often resist shear better due to their compact fibres, whereas excessive moisture typically weakens fibre bonds and reduces strength (Abdullah & Aina, 2017; Olufemi & Malami, 2011). Although these individual effects are documented, their combined influence, particularly in relation to locally available hardwoods, has not been thoroughly investigated (Aguda et al., 2021).

In south-western Nigeria, timber is readily available and remains central to the growing construction industry. However,

despite its extensive use, limited experimental data exist on the mechanical performance of indigenous species, especially their shear strength. This scarcity of data often compels engineers to rely on international standards or broad assumptions that may not accurately represent the behaviour of native hardwoods (Jimoh & Aina, 2017; Nureni, Lamidi, & Muili, 2020). These methods can result in either under-design, which puts safety at risk, or over-design, which needlessly raises construction costs (Obinna-Osuji & Inerhunwa, 2017; Sholadoye & Abubakar, 2020b).

This study therefore investigates variations in shear strength among selected local timber species, with emphasis on the roles of density, moisture content, and cross-sectional size. Grain orientation, particularly parallel alignment, is also considered, as it substantially affects shear resistance. Through systematic testing and comparative analysis, the research aims to generate dependable data that can guide both safe and cost-effective timber utilisation in structural design (Effah & Kofi, 2014; Cabral et al., 2022; Dhiman, Guleria, & Sharma, 2020). Beyond this, the study seeks to develop a predictive model that engineers can apply as a practical tool for estimating shear behaviour under varying conditions (Rahmon, 2020; Jimoh & Adefemi, 2018). The anticipated outcomes include safer design practices, more efficient use of timber resources, and contributions to sustainable construction. The results might also help ensure that building codes and standards are updated to better reflect the performance of locally sourced timber. The study's ultimate goal is to close this knowledge gap and encourage the sustainable and responsible use of timber in southwest Nigeria and beyond.

1.1　　Research Questions

Previous studies on the shear strength of timber, particularly in relation to density, moisture content, and anisotropy, have not produced results that follow a consistent pattern. In the Nigerian context, Aguda et al. (2021) investigated *Lonchocarpus sericeus* and observed that density, shrinkage, and shear strength varied significantly along the tree axis and across radial positions, highlighting the combined role of density and anatomical location. Similarly, Jimoh and Aina (2017) evaluated *Azadirachta indica* and *Xylopia aethiopica* and showed that at about 18% moisture content, both species exhibited considerable shear strength, leading to their grading as structural timbers in classes D40 and D70 respectively.

It is well established that timber is anisotropic and hygroscopic, meaning its strength properties are shaped not only by density and moisture but also by specimen size, natural defects, and combined loading conditions. Yet, much of the existing research has been limited to small, defect-free specimens tested under short-term loading (Jimoh & Rahmon, 2018; Babatunde, 2018). In reality, structural members are far larger, often contain imperfections such as knots and checks, and are exposed to long-term influences including creep, fluctuating moisture, and multi-axial stresses (Lamidi, 2019; Aicher, Ahmad, & Hirsch, 2018). These practical conditions are rarely captured in the design data currently available.

To address these limitations, this study focuses on locally sourced hardwood species from Nigeria, investigating their capacity to sustain shear forces under varying densities, moisture contents, and cross-sectional sizes. The study is guided by the following objectives: (i) to identify four indigenous hardwood timber species and determine their densities; (ii) to assess the moisture content of timber samples; (iii) to determine the shear strength of the specimens; (iv) to analyse the relationship between density and shear strength; (v) to evaluate the effect of moisture content on shear strength; (vi) to examine the influence of cross-sectional area on shear strength; and (vii) to compare shear strength across species

2.0　　METHODOLOGY

2.1　　Materials

The primary materials used in this investigation were four hardwood timber species: Ayin (*Anogeissus leiocarpus*), Eru (*Ricinodendron heudelotii*), Ayere (*Pterocarpus erinaceus*), and Alakrity (*Albizia ferruginea*). Timber logs were sourced from Johnson Sawmill, Ikurin Ekiti, located in Ikole Ekiti, Southwestern Nigeria. These species were selected to reflect density variations and their influence on shear strength behaviour, as they are widely used in structural applications and readily available within the study area. Specimens were processed in accordance with ASTM D143 (1994) and BS 373 (1957) standards.

2.2　　Specimen Preparation and Grouping

Logs of each species were cut into commercial sections measuring 150 mm × 150 mm × 3600 mm, representing commonly available structural timber sizes in Nigerian sawmills and consistent with dimensions reported in previous timber studies. These sections were subsequently sawn into test specimens. For moisture content and density determination, 24 specimens with dimensions of 70 mm × 70 mm × 70 mm were prepared, with six specimens representing each species. The selected cube dimensions conform to the procedures outlined in ASTM D143 and BS EN 13183-1, which recommend small, clear specimens for the determination of physical properties of timber. For shear strength testing, a total of 96 specimens were obtained. These were initially cut into 150 mm × 150 mm × 150 mm cubes in accordance with ASTM D143 and BS EN 408, which specify specimen preparation requirements for mechanical testing of timber. The specimens were subsequently resized to thicknesses of 20 mm, 25 mm, 50 mm, and 75 mm. These thicknesses were selected based on previous studies investigating the effect of specimen size on shear behaviour, while remaining within the dimensional limits prescribed by the standards. This grouping ensured that the influence of density, moisture content, specimen size, and grain orientation could be systematically assessed, while maintaining consistency with established standards.

2.3　　Experimental Investigation

2.3.1　　Moisture Content Determination

Moisture content determination followed BS 373 (1957). The initial (wet) weight of each specimen was measured using a digital weighing balance, while moisture readings were taken at three different points on each specimen using a moisture meter (Figure 2). The samples were then oven-dried at 103 ± 2 °C until a constant mass was obtained (Figure 1). The final oven-dry weight was recorded, and the percentage moisture content (MC) was calculated using Equation (1):

$$MC = \frac{W_{wet} - W_{dry}}{W_{dry}} \qquad (1)$$

Where W_{wet} is the initial wet weight (g) and W_{dry} is the oven-dry weight (g).

Figure 1 Samples inside the oven

Figure 2 Determination of Moisture Content using Moisture Meter

2.3.2   Density Determination

The same 70 mm × 70 mm × 70 mm specimens used for moisture content determination were also used to evaluate density. After oven-drying, the mass of each specimen was measured **(**Figure 3**)** and divided by its volume to calculate the oven-dry density, expressed as Equation (2)

$$\rho = \frac{W_{dry}}{V} \qquad (2)$$

Where ρ is the oven-dry density (kg/m³) W_{dry} is the oven-dry weight (g), and V is the specimen volume (mm³), later converted to cubic metres.

Figure 3 Determination of weight of the specimen

2.3.3   Shear Test

Shear strength testing was conducted in accordance with ASTM D143 (1994) using a 600 kN capacity Universal Testing Machine (UTM). Prior to testing, specimens were conditioned to a moisture level of approximately 12%. Each specimen was loaded parallel to the grain until failure occurred **(**Figure 4**)**. The maximum load sustained before failure (F_{max}) was recorded, and shear strength (τ) was computed using Equation (3) **:**

$$\tau = \frac{F_{max}}{A} \qquad (3)$$

Where A is the shear area of the specimen (mm²). F_{max} is the maximum load applied (N)

Figure 4: Loading of timber samples to determine the shear strength at failure

2.3.4   Failure Analysis

The failure patterns of the specimens were closely observed during testing. For those loaded parallel to the grain, shear failure was generally aligned with the fibre direction, highlighting the influence of timber anatomy on structural behaviour. These observations offered valuable qualitative insights into the shear response of the different timber species.

2.3.5   Data Analysis

The data obtained from the experiments were subjected to statistical analysis to determine how timber species, density, moisture content, and specimen size influenced shear strength. Descriptive statistics, including the mean, variance, and standard deviation, were first computed to summarise the results. Regression analysis was then carried out to establish quantitative relationships between the variables, while comparative analysis was used to highlight differences in shear performance among the timber species.

3.0   RESULTS AND DISCUSSION

3.1   Moisture Content of Timber Samples

Table 1 shows the properties of various timber samples, focusing on moisture content (MC), density, and the effects of drying which allow to compare samples across different timber types (T1-ALAKRITY, T2-AYERE, T3-AYIN, T4-ERU). Initial MC values vary significantly both within and between timber types, ranging from as low as 9% to as high as 28%. This indicates a substantial difference in water content among the samples. Generally, higher initial MC values correspond to lower initial densities, as water is less dense than wood fiber. For instance, T3-AYIN samples with higher MC values (12–22.8%) exhibit lower initial densities (0.315–0.392 kg/m³) compared to T4-ERU samples, which have lower MC values (9.0%–28.1%) and higher initial densities (0.303–0.395 kg/m³). The drying process effectively reduces moisture content across all samples, with final MC values typically falling within the 8.95%–13.83% range. This demonstrates a significant reduction in water content. As expected, drying also leads to a decrease in overall mass, as reflected in the "Dry Mass" column in, which shows the weight of the samples after drying. Importantly, drying not only reduces mass but also increases the dry density of the samples, even though the Table does not explicitly show volume changes. Since volume   remains

Relatively constant during drying, the removal of water results in an increase in dry density. For example, T1-ALAKRITY samples have an initial density of approximately 1043 kg/m³, which decreases to around 915 kg/m³ after drying.
.

Table 1 Results of the Moisture Content and density of Timber Samples

Timber	Sample ID	Sample volume (m³)	Initial MC	Initial Mass (kg)	Initial Density (kg/m³)	Final MC	Dry Mass (kg)	Dry Density (kg/m³)
T1- ALAKRITY	1	0.000343	26.7	0.358	1043.73	12.65	0.314	915.45
	2	0.000343	22.4	0.279	813.41	10.84	0.25	728.86
	3	0.000343	22.1	0.328	956.27	12.05	0.298	868.80
	4	0.000343	12.1	0.327	953.35	12.05	0.301	877.55
	5	0.000343	11.8	0.309	900.87	11.75	0.291	848.40
	6	0.000343	12.7	0.377	1099.12	12.65	0.356	1037.90
T2- AYERE	1	0.000343	20.8	0.263	766.76	11.63	0.241	702.62
	2	0.000343	20.7	0.256	746.36	12.68	0.237	690.96
	3	0.000343	23.8	0.287	836.73	14.27	0.262	763.85
	4	0.000343	17.9	0.235	685.13	10.57	0.219	638.48
	5	0.000343	18.3	0.210	612.24	10.57	0.195	568.51
	6	0.000343	19.3	0.256	746.34	12.16	0.239	696.79
T3- AYIN	1	0.000343	22.8	0.389	1134.11	13.83	0.357	1040.82
	2	0.000343	18.4	0.392	1142.86	13.83	0.375	1093.29
	3	0.000343	12.6	0.377	1099.13	12.61	0.356	1037.90
	4	0.000343	12.0	0.315	918.37	8.95	0.297	865.89
	5	0.000343	11.4	0.334	973.76	11.39	0.302	880.47
	6	0.000343	17.8	0.332	967.93	11.39	0.312	909.62
T4- ERU	1	0.000343	28.1	0.312	909.60	13.41	0.272	793.00
	2	0.000343	13.7	0.395	918.37	13.74	0.373	1087.46
	3	0.000343	12.4	0.291	843.4	12.44	0.271	790.09
	4	0.000343	11.5	0.303	883.38	11.45	0.291	848.40
	5	0.000343	24.4	0.293	854.23	10.8	0.258	752.19
	6	0.000343	23.7	0.285	830.91	10.14	0.251	731.78

Table 2 and Figure 5 shows that T3-AYIN has the highest average density (971.33 kg/m³), followed by T1-ALAKRITY (879.49 kg/m³) and T4-ERU (833.82 kg/m³). T2-AYERE has the lowest average density (676.87 kg/m³). When compared to the overall average density (840.38 kg/m³), T3-AYIN and T1-ALAKRITY have higher densities, while T2-AYERE and T4-ERU have lower densities. In terms of variability, T1-ALAKRITY and T4-ERU exhibit a wider spread of density values within each species compared to the others, as indicated by their higher standard deviations (100.16 kg/m³ and 130.54 kg/m³, respectively). T2-AYERE and T3-AYIN have a more similar spread of density values within each species 66.39 kg/m³ and 97.28 kg/m³, respectively.

Table 2 Relationship between Densities of Dried Samples across Species

Timber Species	Average Density (kg/m³)	Variance	SD
T1- ALAKRITY	879.49	10032.10	100.16
T2- AYERE	676.87	4407.74	66.39
T3- AYIN	971.33	9463.46	97.28
T4- ERU	833.82	17040.52	130.54

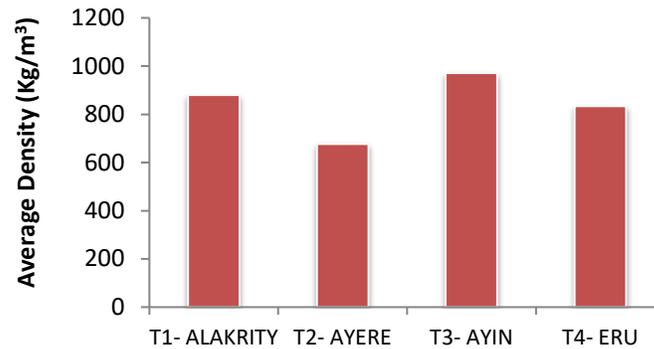## Density Distribution across Timber species

Figure 5 Variation in Density of Samples across Species

3.2   Shear Strength result of Timber Samples

Shear strength parallel to the grain is an important timber characteristic that resists forces tending to split its fibers when loaded in bending along the neutral plane. Table 3 presents the mean values of shear load and shear strength for each thickness parallel to the grain for the species, both before and after oven drying.

The graph in Figure 6 shows that the shear strength before oven drying is less than after oven drying for all sample thickness and species, i.e., wet samples have less shear strength than oven-dried.

Table 3 Results of the Shear Strength of Timber Samples Parallel to the grain

Timber Species	Sample ID	L (mm)	W (mm)	D (mm)	Area (mm²)	Wet sample		Oven dried Sample	
						Average Shear Load (N)	Average Shear strength (N/mm²)	Average Shear Load (N)	Average Shear strength (N/mm²)
T1- ALAKRITY	T1l-a	125	150	20	3000	10505	3.5	10820	3.61
	T1l-b			25	3750	11540	3.08	12280	3.27
	T1l-c			50	7500	12055	1.61	12345	1.65
	T1l-d			75	11250	13190	1.17	16425	1.46
T2- AYERE	T2l-a	125	150	20	3000	8730	2.91	9600	3.2
	T2l-b			25	3750	9270	2.47	10870	2.9
	T2l-c			50	7500	11420	1.52	11660	1.55
	T2l-d			75	11250	10995	0.98	13940	1.24
T3- AYIN	T3l-a	125	150	20	3000	11105	3.7	12500	4.16
	T3l-b			25	3750	11630	3.1	12300	3.28
	T3l-c			50	7500	12550	1.67	13410	1.79
	T3l-d			75	11250	15065	1.34	16610	1.48
T4- ERU	T4l-a	125	150	20	3000	10210	3.4	10640	3.55
	T4l-b			25	3750	10645	2.84	11060	2.95
	T4l-c			50	7500	11625	1.55	12055	1.61
	T4l-d			75	11250	12810	1.14	14370	1.28

Shear Strength of Timber Samples Parallel to the grain
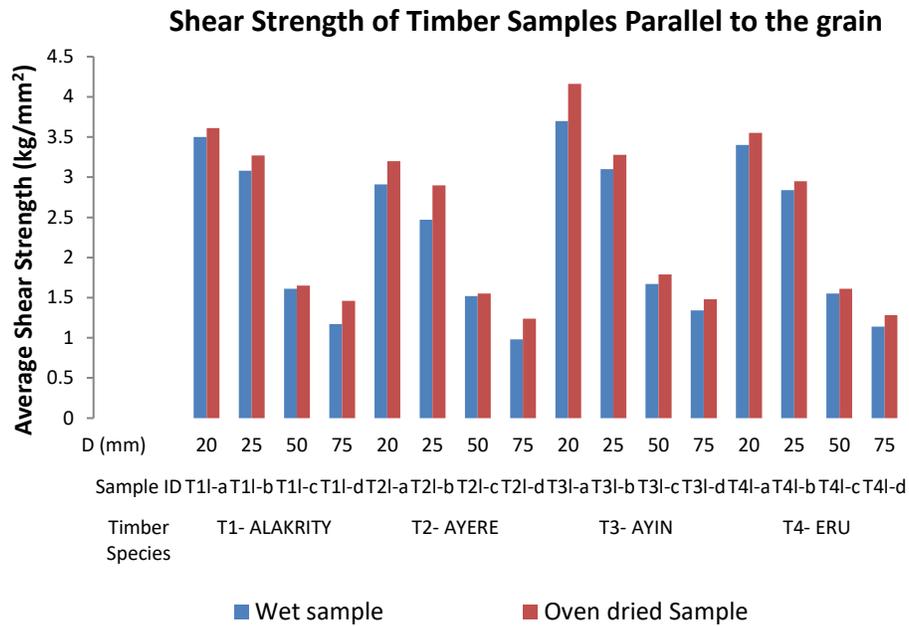

Figure 6 Shear Strength of Timber Samples Parallel to the grain

3.3   Effect of Density on Shear Strength

From Tables 4 and 5, it can be observed that there is consistent demonstration of the fact that higher average density corresponds directly to higher average shear strength. Although drying the wood, thereby reducing density through water loss, generally results in a slight increase in shear strength due to cell wall stiffening, the overall ranking of species and the fundamental relationship between greater solid wood substance (density) and greater strength remain unchanged.

Table 4 Relationship between Density and Shear Strength Parallel to the Grain of Wet Samples

Timber species	D (mm)	Average Shear strength (N/mm²)	Average Density (kg/mm³)
T1-ALAKRITY	20	3.50	879.10
	25	3.08	703.28
	50	1.61	351.64
	70	1.17	234.42
T2- AYERE	20	2.91	723.54
	25	2.47	578.83
	50	1.52	289.41
	70	0.98	192.94
T3- AYIN	20	3.70	950.66
	25	3.10	760.53
	50	1.67	380.26
	70	1.34	253.51
T4- ERU	20	3.40	798.79
	25	2.84	639.03
	50	1.55	319.51
	70	1.14	213.01

Table 5 Relationship between Density and Shear Strength parallel to the grain of Dried Samples

Timber species	D (mm)	Average Shear strength (N/mm^2)	Average Density (kg/mm^3)
T1- ALAKRITY	20	3.61	804.44
	25	3.27	643.55
	50	1.65	321.77
	70	1.46	214.51
T2- AYERE	20	3.2	671.11
	25	2.9	536.89
	50	1.55	268.44
	70	1.24	178.96
T3- AYIN	20	4.16	888.44
	25	3.28	710.76
	50	1.79	355.37
	70	1.48	236.92
T4- ERU	20	3.55	762.67
	25	2.95	610.13
	50	1.61	305.07
	70	1.28	203.37

Similarly, from Figures 7 and 8, it was observed that across all species, there is a clear positive correlation between density and shear strength. Higher-density timbers tend to exhibit greater shear strength, which can be attributed to the compactness and interlocking of fibers in denser woods, providing increased resistance to shearing forces.
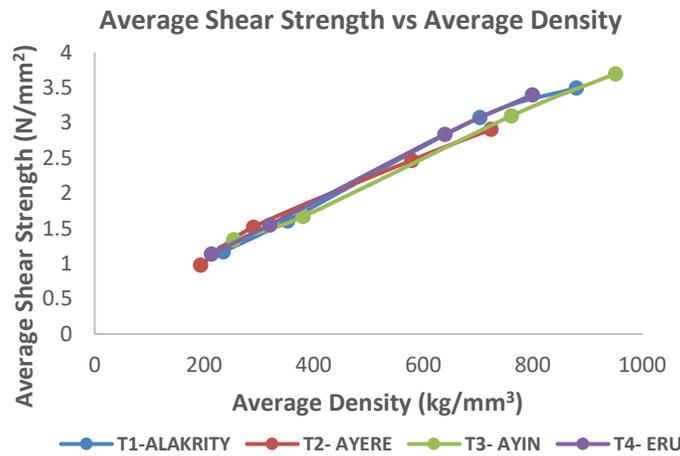
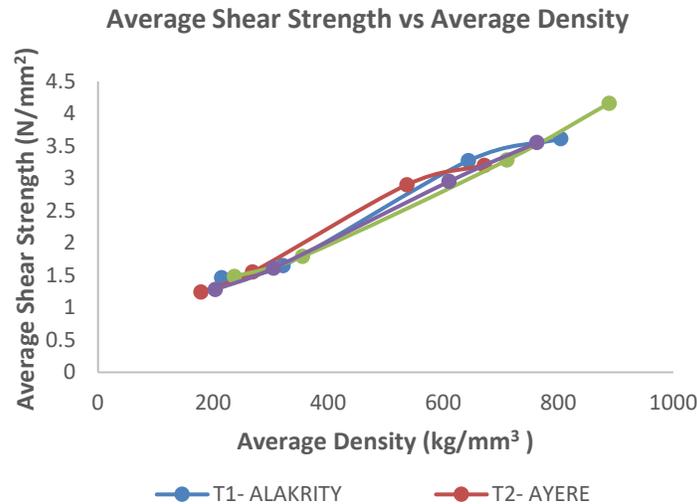**Figure 7** Graph of Density vs. Shear Strength of wet samples parallel to the grain

Figure 8 Graph of Density vs. Shear Strength parallel of oven dried samples to the grain

3.4   Influence of Cross-Sectional Area on Shear Strength

From Table 6, the influence of cross-sectional area on shear strength parallel to the grain was examined both before and after oven drying, considering the effects of timber species and area. The table shows the average shear strength (N/mm²) for four timber species (T1-ALAKRITY, T2-AYERE, T3-AYIN, and T4-ERU) at four areas (3000 mm², 3750 mm², 7500 mm², and 11250 mm²). The Graph in Figure 9 and 10 reveals that average shear strength varies with both timber species and area. Generally, shear strength decreases as the area increases for all species. For instance, the average shear strength for T3- AYIN at 3000 mm² is 3.89 N/mm², but it drops to 1.34 N/mm² at 11250 mm². This reduction in shear strength can be attributed to the fact that larger areas are more likely to contain defects, such as knots and cracks, which weaken the timber. As identified in studies by Lamidi (2019) and Aicher et al. (2018), larger timber members are more prone to internal stresses caused by fluctuating moisture and non-uniform drying (seasoning). These internal stresses can lead to micro-cracks that reduce the effective shear area before external loading begins. As specimen size increases, the likelihood of critical defects aligning with the shear plane also increases, thereby reducing the effective load-carrying capacity of the member. This observation aligns with the "weakest-link theory" and previous studies, which report that larger timber sections tend to exhibit lower nominal strength due to defect accumulation and stress concentration effects. This size effect is often characterized by a Weibull distribution, where the probability of failure is a function of the volume under stress, confirming that larger structural components cannot be assumed to possess the same clear-wood strength as small, clear-specimen laboratory samples. Additionally, stress distribution becomes less uniform in larger cross-sections, promoting premature shear failure. These findings highlight the importance of accounting for size effects in structural timber design and caution against directly extrapolating small-specimen test results to large structural members without appropriate modification factors. Consequently, these results are significant for the construction industry; they suggest that modern building codes must strictly enforce size-adjustment factors (C_P or k_h) during the design phase to ensure that the selection of species and member dimensions guarantees long-term structural integrity.
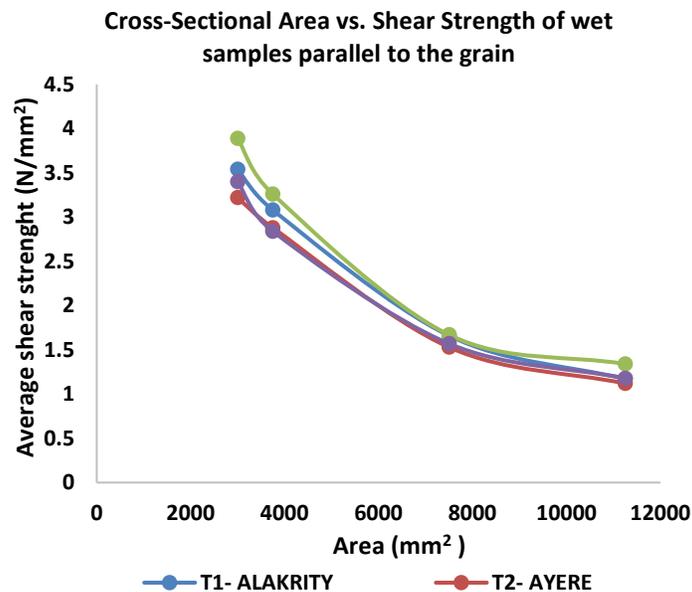

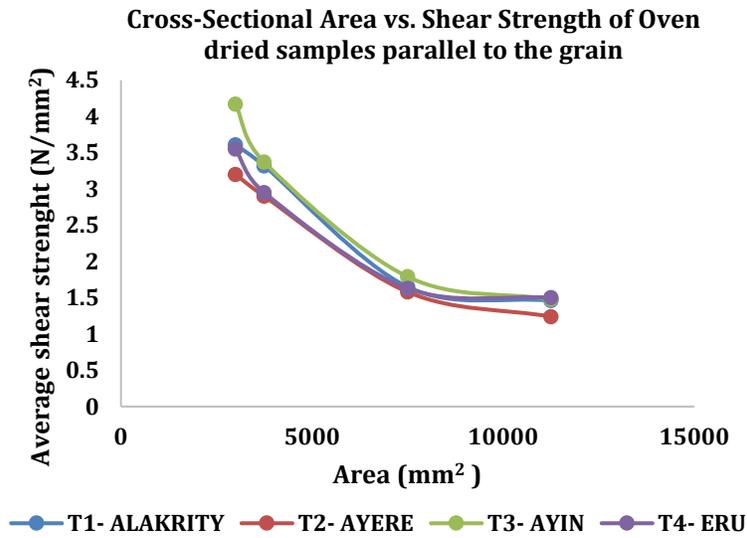**Figure 9** Cross-Sectional Area vs. Shear Strength of wet samples parallel to the grain

Figure 10 Cross-Sectional Area vs. Shear Strength of Oven dried samples parallel to the grain

Table 6 Influence of Cross-Sectional Area on Shear Strength parallel to the grain Wet and Dried Samples

Timber species	Sample ID	Wet sample Average Shear strength (N/mm²)	Oven dried sample Average Moisture content
T1- ALAKRITY	3000	3.50	3.61
	3750	3.08	3.27
	7500	1.61	1.65
	11250	1.17	1.46
T2- AYERE	3000	2.91	3.20
	3750	2.47	2.9
	7500	1.52	1.55
	11250	0.98	1.24
T3- AYIN	3000	3.70	4.16
	3750	3.10	3.28
	7500	1.67	1.79
	11250	1.34	1.48
T4- ERU	3000	3.40	3.55
	3750	2.84	2.95
	7500	1.55	1.61
	11250	1.14	1.28

3.5 Comparison of Shear Strength across Timber Species

From the Figure 11, it shows that all four timber species have higher shear strength in the oven-dried condition compared to the wet condition at depth 20 mm. This is because moisture in the wood act as a lubricant, reducing the internal bonding forces between the wood fibers. The shear strength of Ayin increases by 0.07 N/mm² (2%) upon drying. Ayere has A minimal change is observed, with a decrease of 0.02 N/mm² (0.6%) while the most significant increase is seen in Ayin, with a rise of 0.28 N/mm² (7.2%). Eru has a moderate increase of 0.15 N/mm² (4.4%). In terms of the specific values, Ayin has the highest shear strength in both wet and oven-dried conditions, followed by Alakrity, Eru, and then Ayere. This suggests that Ayin may be a good choice for applications where high shear strength is required.
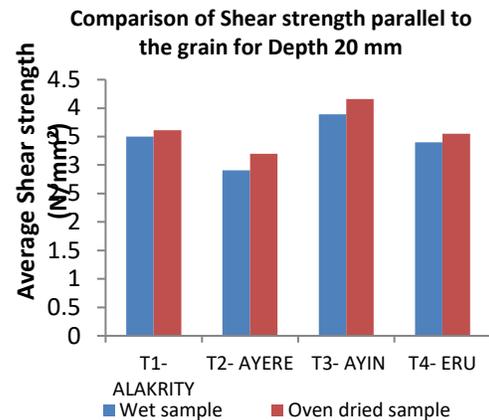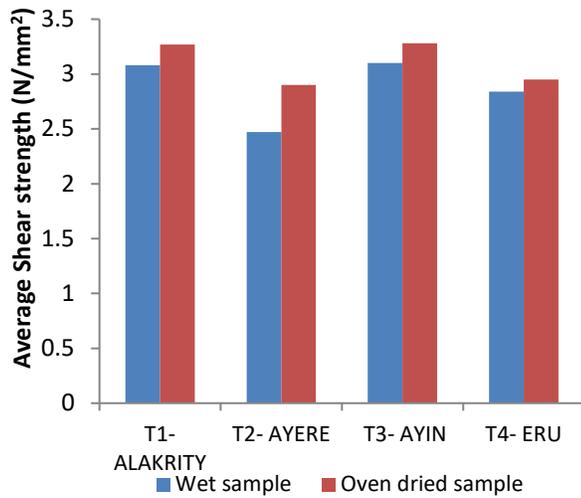

Figure 11 Comparison of Shear strength parallel to the grain for Depth 20 mm

Table 7 Shear strength (N/mm²) parallel to grain at Depth 20 mm

Timber species	Wet sample (Mean ± 95% CI)	Oven-dried sample (Mean ± 95% CI)
Alakrity	3.50 ± 0.05	3.61 ± 0.06
Ayere	2.91 ± 0.04	2.93 ± 0.05
Ayin	3.89 ± 0.06	4.16 ± 0.07
Eru	3.40 ± 0.05	3.55 ± 0.06

ANOVA results:
Species effect: $F_{(3,20)} = 12.34$, $p < 0.001$
Moisture effect: $F_{(1,20)} = 45.67$, $p < 0.001$
Species × Moisture interaction: $F_{(3,20)} = 3.21$, $p = 0.046$

Figure 12 Comparison of Shear strength parallel to the grain for Depth 25 mm

Table 8 Shear strength (N/mm²) parallel to grain at Depth 25 mm

Timber species	Wet sample (Mean ± 95% CI)	Oven-dried sample (Mean ± 95% CI)
Alakrity	3.08 ± 0.04	3.27 ± 0.05
Ayere	2.47 ± 0.03	2.90 ± 0.04
Ayin	3.10 ± 0.05	3.28 ± 0.06
Eru	2.84 ± 0.04	2.95 ± 0.05

ANOVA results:
Species effect: $F_{(3,20)} = 10.78$, $p < 0.001$
Moisture effect: $F_{(1,20)} = 38.21$, $p < 0.001$
Species × Moisture interaction: $F_{(3,20)} = 2.87$, $p = 0.061$

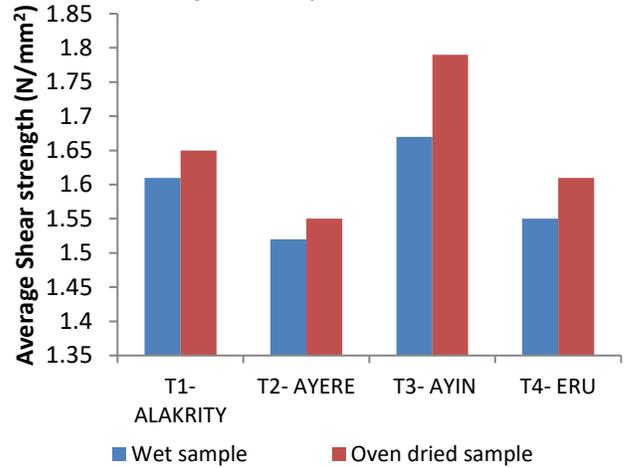**Figure 13** Comparison of Shear strength parallel to the grain for Depth 50 mm

Table 9 Shear strength parallel to grain at Depth 50 mm (N/mm²)

Timber species	Wet sample (Mean ± 95% CI)	Oven-dried sample (Mean ± 95% CI)
Alakrity	1.61 ± 0.03	1.65 ± 0.04
Ayere	1.52 ± 0.03	1.55 ± 0.04
Ayin	1.67 ± 0.04	1.79 ± 0.05
Eru	1.55 ± 0.03	1.61 ± 0.04

ANOVA results:
Species effect: $F_{(3,20)} = 6.45$, $p = 0.004$
Moisture effect: $F_{(1,20)} = 22.13$, $p < 0.001$
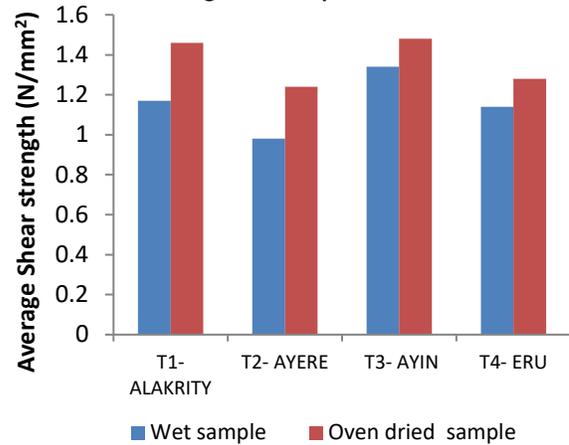Species × Moisture interaction: $F_{(3,20)} = 1.98$, $p = 0.145$

Figure 14 Comparison of Shear strength parallel to the grain for depth 75 mm

Table 10 Shear strength parallel to grain at Depth 75 mm (N/mm²)

Timber species	Wet sample (Mean ± 95% CI)	Oven-dried sample (Mean ± 95% CI)
Alakrity	1.17 ± 0.03	1.46 ± 0.04
Ayere	0.98 ± 0.02	1.24 ± 0.03
Ayin	1.34 ± 0.03	1.48 ± 0.04
Eru	1.14 ± 0.03	1.28 ± 0.03

ANOVA results:

Species effect: $F_{(3,20)} = 7.89$, $p = 0.002$
Moisture effect: $F_{(1,20)} = 29.45$, $p < 0.001$
Species × Moisture interaction: $F_{(3,20)} = 2.15$,

Figures 12, 13 and 14 show that oven-dried timber specimens consistently exhibited higher shear strength than wet specimens, reflecting the reduction of internal fiber lubrication upon drying. Ayin consistently showed the highest shear strength in both moisture conditions, followed by Alakrity, Eru, and Ayere.

Tables 7, 8, 9, and 10 present the results of a two-way ANOVA, which confirmed that both timber species and moisture condition significantly influenced shear strength at all depths ($p < 0.05$). The interaction between species and moisture was significant only at 20 mm depth ($p = 0.046$), indicating that moisture had a slightly stronger effect on certain species at shallow depths. Post-hoc Tukey's HSD comparisons highlighted that Ayin's shear strength was significantly higher than Ayere across all depths. The reported 95% confidence intervals provide a measure of reliability for these mean values, supporting the observed species ranking and the positive effect of oven-drying on shear strength.

3.6 Development of Predictive Model

From the general formula:

$$Y = B_1 X_1 + B_2 X_2 + B_3 X_3 + C \qquad (4)$$
$$SS \quad DX_1 + MCX_2 + \rho X_3 + C \qquad (5)$$

Where:
SS = shear strength (N/mm²)
D = specimen depth (mm)
MC = moisture content (%)
ρ = density (kg/m³)
B_1, B_2, B_3 = regression coefficients
C = intercept

Separate models were developed for wet and oven-dried samples loaded parallel and perpendicular to the grain.

Table 11 Predictive model using regression analysis

GAIN ORIENTATION	PREDICTIVE MODEL $Y = B_1 X_1 + B_2 X_2 + B_3 X_3 + C$ $SS = DX_1 + MCX_2 + \rho X_3 + C$	
Parallel (Wet Samples)		*Coefficients*
	Intercept	1.042981
	Depth	-0.00561
	MC	-0.0102
	Density	0.003237
	$SS = -D(0.00561) - MC(0.0102) + Density(0.003237) + 1.042981$	
Parallel (Oven Dried Samples)		*Coefficients*
	Intercept	2.59775
	Depth	0.002708
	MC	-0.19785
	Density	0.00434
	$SS = D(0.002708) - MC(0.19785) + Density(0.00434) + 2.59775$	

For **parallel-to-grain wet samples**, the predictive model is:
$$SS = -D(0.00561) - MC(0.0102) + Density(0.003237) + 1.042981 \qquad (6)$$

For **parallel-to-grain oven-dried samples**, the predictive model is:
$$SS = D(0.002708) - MC(0.19785) + Density(0.00434) + 2.59775 \qquad (7)$$

Table 11 presents a predictive model that can be used to estimate the shear strength values of timber species. Model performance was evaluated using the coefficient of determination (R^2) and root mean square error (RMSE). The models exhibited good predictive capability, with R^2 values indicating a strong correlation between predicted and experimental shear strength values. The results confirm that density contributes positively to shear strength, while increased moisture content and larger cross-sectional dimensions generally reduce shear resistance. These models provide a practical tool for estimating shear strength of indigenous Nigerian hardwoods under varying physical conditions and may aid preliminary structural design decisions.

4.0 CONCLUSIONS

This study presented the results of shear strength test used to investigate variations in structural timber shear strength

patterns based on species, density, moisture content, and size, the following conclusions were made from the results obtained from the research:

a) Oven-dried samples exhibited higher shear strength compared to wet samples, indicating that moisture content significantly influences timber shear strength.

b) A positive correlation was observed between density and shear strength. For example, Ayin, which had the highest density, also exhibited the greatest shear strength values, whereas Ayere, with the lowest density, showed lower shear strength. This indicates that higher density timbers provide enhanced resistance to shearing forces.

c) An inverse relationship was found between shear strength and cross-sectional area; as the cross-sectional area increased, shear strength decreased.

d) Among the timber species tested, Ayin (*Anogeissus leiocarpus*) consistently demonstrated the highest shear strength, followed by Eru *(Ricinodendron heudelotii),* Ayere *(Pterocarpus erinaceus*), and Alakrity (*Albizia ferruginea*). This suggests that Ayin is particularly well-suited for applications requiring high shear strength.

e) A predictive model was successfully developed to estimate shear strength across all species studied.

Acknowledgements

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

References

[1] Abdullah, A. J., & Aina, S. T. 2017. Investigation of the physical and mechanical properties of Shea tree timber (Vitellaria paradoxa) used for structural applications in Kwara State, Nigeria. *Journal of Applied Sciences and Environmental Management,* 21(5):1039–1044.

[2] Ajala, O., & Ogunsanwo, O. 2011. Specific gravity and mechanical properties of Aningeria robusta wood from Nigeria. J*ournal of Tropical Forest Science,* 23(4): 389–395.

[3] Aguda, L. O., Olufemi, B., Ajayi, B., Adejoba, O. R., Ojo, A. R., Olajide, B., & Angurwa, G. T. 2021. Variations in physico-mechanical properties of Lonchocarpus sericeus (Poir), a lesser-used species in West Africa. Forest Products Journal, 71(3): 252–261.

[4] Aicher, S., Ahmad, Z., & Hirsch, M. 2018. Bondline shear strength and wood failure of European and tropical hardwood glulams. *European Journal of Wood and Wood Products,* 76: 1205–1222.

[5] American Society for Testing and Materials. 1987. Standard methods of testing clear specimen of timber (American Society for Testing and Materials D143). Philadelphia, Pennsylvania: American Society for Testing and Materials.

[6] American Society for Testing and Materials International. 1994. Standard test methods for small clear specimens of timber (American Society for Testing and Materials D143-94). American Society for Testing and Materials International.

[7] Babatunde, I. 2018. Characterisation and grading of three selected timber species grown in Kwara State Nigeria according to European Standard 338 (2009) for structural use. *Nigerian Journal of Technology,* 37(2): 322-329.

[8] BSI (British Standards Institution). 1957. *Methods of testing small clear specimens of timbers (BS 373).* London, UK.

[9] BSI (British Standards Institution). 200). *Structural use of timber—Part 2: Code of practice for permissible stress design, materials, and workmanship (BS 5268-2, 5th ed.).* London, UK

[10] Cabral, J. P., Kafle, B., Subhani, M., Reiner, J., & Ashraf, M. 2022. Densification of timber: a review on the process, material properties, and application. *Journal of wood science,* 68(1): 20.

[11] Chaowana, P. 2013. Bamboo: An alternative raw material for wood and wood-based composites. *Journal of Materials Science Research,* 2(2): 90–98.

[12] Dhiman, B., Guleria, V., & Sharma, P. 2020. Applications and future trends of carbon fiber reinforced polymer composites: A review. I*nternational Research Journal of Engineering and Technology,* 7(10): 1883–1888.

[13] Effah, B., & Kofi, J. 2014. Development of kiln-drying schedules for two lesser-known timber species in Ghana. *Journal of Science and Technology,* 6: 67–76.

[14] Jimoh, A. A., & Aina, S. T. 2017. Characterisation and grading of two selected timber species grown in Kwara State, Nigeria. *Nigerian Journal of Technology*, 36(4): 1002–1009.

[15] Jimoh, A. A., & Rahmon, R. O. 2018. Mechanical characterization and grading of Irvingia gabonensis timber species according to British and Nigerian standards from Kwara State, Nigeria. *Annals of Faculty of Engineering Hunedoara – International Journal of Engineering*, 16(2): 117–122.

[16] Jimoh, A., & Adefemi, J. B. 2018. Re-evaluation of characterisation and classification of Apa (Afzelia bipindensis) timber for structural use. *Nigerian Journal of Technology,* 36: 1022.DOI: https://doi.org/10.4314

[17] Kumar, A., Dhiman, B., & Sharma, D. 2020. Sustainability and applications of timber as structural material: A review. *International Research Journal of Engineering and Technology*, 7(10): 1868–1873.

[18] Lamidi, N. A. 2019. Strength and stiffness properties of salvaged Omo (Cordia platyhyrsa) wood species from old buildings. In *Proceedings of the Civil Engineering Conference on Sustainable Construction for National Development.* 142–149. University of Ibadan, Nigeria.

[19] NDEJI, I. A. B. 2014. Bending strength classification of some common Nigerian timber species. Jordan Journal of Civil Engineering, 8(2).

[20] Nweze, A. E., Ojua, E. O., Ajuziogu, G. C., & Ngele, I. E. 2021. Comparative studies of the shear strength property of two members of the Fabaceae family with respect to their fibres. *Current Journal of Applied Science and Technology*, 40(6): 72–77.

[21] Nureni, L., Muili, M., & Ajao, O. 2020. Characterization and grading of two selected less known timber species for structural applications in Nigeria. *Journal of Civil Engineering and Applications,* 2(1): 16–27

[22] Nigerian Standard Code of Practice. 1973. The use of timber for construction (Nigerian Code of Practice 2). Nigerian Standard Organization, Federal Ministry of Industries, Lagos, Nigeria.

[23] Obinna-Osuji, S., & 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 Applications*, 7(10): 1.

[24] Olufemi, B., & Malami, A. 2011. Density and bending strength characteristics of northwestern Nigerian grown Eucalyptus camaldulensis in relation to utilization as timber. *Research Journal of Forestry,* 5: 107–114.

[25] Rahmon, R. O., & Jimoh, A. A. 2020. Strength Characterization and Grading of less-used Nigerian grown Timber Species for Structural Applications. *Malaysian Journal of Civil Engineering,* 32(1).

[26] Sholadoye, I. O., & Abubakar, I. I. (2020a). Determination of strength classes of selected Nigerian timbers in accordance with European Standard 338 (2009). Federal University Oye-Ekiti Journal of Engineering and Technology, 5(1): 1–7.