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Characterization of Three Selected Timber Species According to BS 5268 (2002), EN 338 (2009) & NCP 2 (1973)

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Abstract

This study primarily focuses on establishing strength classes for three indigenous Northern Nigerian timber species—Mangifera indica, Terminalia catappa, and Phoenix dactylifera by characterising and grading them in accordance with BS 5268 (2002), EN 338 (2009) and NCP 2 (1973), with the aim of possibly reducing overreliance on commonly used timber species. The research involved laboratory experiments to assess physical and mechanical properties, followed by classification into specific strength classes using the bending stress, density, and modulus of elasticity. After characterisation and grading, Mangifera indica, Terminalia catappa, and Phoenix dactylifera were assigned to strength classes C35, C35, and C14 respectively, according to BS 5268-2 (2002). According to NCP 2 (1973), the timber species were assigned to strength classes N5, N5, and N7 in the same order. The samples were also assigned to strength classes C30, D30, and C14 respectively, according to EN 338 (2009). Results show that Mangifera indica and Phoenix dactylifera are softwoods offering potential applications in boat-making, light construction formwork and furniture works while Terminalia catappa is a hardwood which is applicable for roofing materials, and general construction. These classes would help architects, engineers, and builders select the appropriate timber species for various uses and reduce their over reliance on the commonly used timber species like teak, iroko and oak.

1. Introduction

The rapid growth of the global population is placing an unprecedented strain on our planet's resources, with a particularly pronounced impact on structural and infrastructural materials. This escalating demand underscores the critical need for a fresh perspective on construction materials [1]. While steel and concrete have been stalwarts in the construction industry, their widespread use comes at a considerable environmental cost. The production processes of these materials release copious amounts of pollution into the atmosphere, contributing to climate change and environmental degradation [2].

To combat these challenges and steer construction towards a more sustainable future, the spotlight is increasingly turning to timber. Timber, in contrast to its industrial counterparts, offers a multitude of advantages. It is a renewable resource, drawing from forests that can be replenished through responsible forestry management. This renewability stands in stark contrast to the finite nature of steel and concrete resources [3] [4].

Timber is a complex building material owing to its heterogeneity and species diversity [5]. Timber's appeal extends beyond its eco-friendliness. Its aesthetic qualities, including natural textures and visual warmth, have made it a favored choice for interior finishing and primary structural elements. The versatility of timber allows it to be easily customized into a wide array of shapes and sizes, enabling architects and builders to explore creative designs and solutions [6].

Moreover, timber boasts a remarkable strength-to-weight ratio, which makes it an ideal material for structural applications [7]. It also exhibits excellent thermal insulation properties, helping reduce energy consumption in buildings. Timber's value is further enhanced by its compatibility with other construction materials like concrete and steel, facilitating the creation of composite structures [8] [9].

Perhaps one of timber's most compelling attributes is its minimal environmental impact. Unlike steel and concrete, which contribute significantly to greenhouse gas emissions during production, timber is a carbon sink. It sequesters carbondioxide from the atmosphere, helping mitigate climate change. Additionally, the energy required to transform trees into structural timber is notably lower than that needed for steel and concrete production. Timber's resistance to corrosion-related issues that plague materials like steel adds to its allure [10].

Timber's application as a construction material has evolved over centuries, and its significance in contemporary and future construction remains undeniable. For example, analogous to built-up sections available in steel structures where larger bearing capacities are required, built-up timber sections exist for the increment of timber sections beyond the natural and commercially available sizes, which leads to increase in the carrying capacity of the timber section [11]. Its structural timber variant, favored for its strength, is integral to framing and load-bearing structures.

In summary, timber emerges as a compelling, sustainable alternative to traditional construction materials like steel and concrete. Its eco-friendliness, aesthetic appeal, strength, and versatility position it as a valuable choice in our quest for more sustainable construction practices. Timber offers not just a solution to our current challenges but a bridge to a greener, more sustainable future in construction [4].

For timber to be harnessed for structural purposes, it has to be characterized. Characterization of structural timber entails determining its physical and strength or mechanical properties which enables its placement in the right strength class (depending on the code of interest), from which its purpose and application are specified. A number of Nigerian timbers have been characterized for example, the Nigerian eucalyptus timber is considered a D60 and N1 timber by the EN 338 (2009) and NCP 2 (1973) respectively [12] and the Nigerian-grown African birch is of the N2 class [13]. *Vitex doniana*, *Diospyros mespliformis*, *Parkia biglobosa* and *Isoberlinia doka* were assigned to strength classes D30, D40, C40 and D30 in accordance with BS 5268-2 (2002) respectively [14], and in accordance with the NCP 2 (1973), these species belong to N4, N3, N4 and N3 respectively. Compared to common timbers like mahogany, teak, or oak, the timber species assigned to these strength classes may not be suitable for high-stress structural elements like load-bearing beams and columns. However, they have their place in construction due to their aesthetic appeal, workability, and use in applications where structural demands are moderate or low.

It's essential for architects and engineers to carefully assess the specific requirements of a project and select the appropriate timber species based on their inherent properties, including strength, appearance, and ease of working. This ensures that the chosen timber meets the demands of the application while optimizing the use of available resources.

The aim of this research therefore is to characterize three selected timber species namely *Mangifera indica, Terminalia catappa, and Phoenix dactylifera* according to [15][16][17][18]. This involves identifying these three timber species that are not commonly used; describing, naming and classifying the timber samples; testing the properties of each sample to standard codes [15][17][18]; analyzing the data results obtained from the property testing of the samples and categorizing each sample into its strength class according to standard codes (BS, EN and NCP).

2.0 Materials and Method

Timber strength grading is based on three key grade determining properties: strength, stiffness and density [19]. Cuts of tree trunks of the different species were obtained from different villages and timber sheds in Kano State. These tree trunks were then split apart using a motorized chain saw, forming different big pieces and shapes. These pieces were marked for identification before taken to the timber workshop to be further split into definite sizes and dimensions (width and depth) as specified in the codes (2cm x 2cm, 2in x 2in to [20][18] and 3cm x 3cm to [21]). The lengths of the timber pieces were made with respect to the mechanical tests to be carried out on them, and 20 samples of each species are used for each test. The trees are shown in Plate 1.

Plate 1: *Mangifera indica* (left) [22], *Terminalia catappa* (center) [8] and *Phoenix dactilyfera* (right) [23].

2.1 Determination of Moisture Content and Weight Density

The 2cm x 2cm x 2cm samples cut were used for the determination of the moisture content and weight density in accordance with [15][18][24]. The samples were weighed before they were placed in the oven for 24hrs at a temperature of 103±2°C. After collection, they were reweighed and the equations 1 to 3 were used in estimating the volume, percentage moisture content and weight densities of the three different samples respectively.

$$\text{Volume} = l \times b \times h \quad (1)$$

$$\%\ \text{moisture content} = \frac{initial\ weight - final\ weight}{final\ weight} \quad (2)$$

$$\text{Weight density} = \frac{final\ weight}{volume} \quad (3)$$

The densities computed above were adjusted to values at 12% and 18% moisture content in accordance with [15][18] using the equations 4 and 5.

$\rho_{12} = \rho_w[1 - \frac{(1-0.5)(u-12)}{100}]$ 4

$\rho_{18} = \rho_w[1 - \frac{(1-0.5)(u-18)}{100}]$ 5

Where is ρ_{12} = density at 12% moisture content in kg/m^3, ρ_{18} = density at 18% moisture content in kg/m^3, ρ_w = density at experimental moisture content, u = experimental moisture content in %.

2.2 Determination of Physical and Mechanical Properties

Tests were done according to the standards, and as was done by [25][26][27]. In each set of the tests, failure loads and/or deflections are recorded for computation of failure stresses, mean failure stress, standard deviation and coefficient of variation. These failure loads are used in calculating the characteristic bending strengths parallel to grain, characteristic compressive strengths parallel to grain, characteristic tensile strengths parallel to grain, characteristic shear strengths parallel to grain, and characteristic compressive strengths perpendicular to grain of the samples according to [15][16].

2.3 Mechanical Testing to BS 373 (1957) and NCP 2 (1973)

The test procedures used were in accordance with [20]. Test loads were applied to the samples until failure occurred and equations 6 to 11 were used in determining their strength properties.

Modulus of Rupture (MOR) = $\frac{3Pa}{2bd^2} N/mm^2$ 6

Modulus of Elasticity (MOE) = $\frac{PL^3}{4\Delta bd^3} N/mm^2$ 7

MOR at 12% MC, F_{12} = (1 + ($W - 12$) 8

MOR at 18% MC, $F_{18\%} = \frac{F_{12\%}\, x\, 18}{12}$ 9

MOE at 12% MC, $E_{m12} = \frac{E_{measured}}{1+0.0143(12-u)}$ 10

Minimum MOE, $E_{min} = E_{mean} \frac{2.33\sigma}{\sqrt{N}}$ 11

2.4 Mechanical Testing to EN 408:2010

The test procedures used were in accordance to [21]. Test loads were applied to the samples until failure occurred as shown in Figure 1 and equations 12 to 34 were used in determining their strength properties.

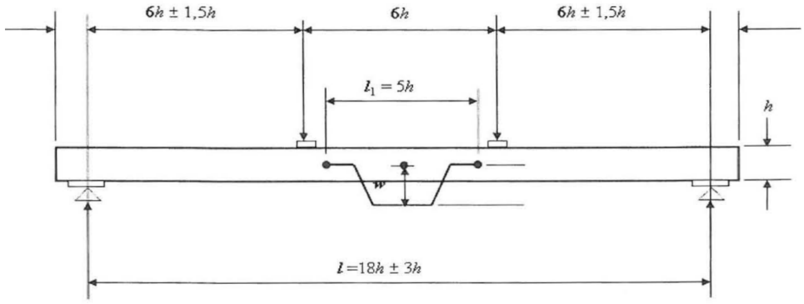

Figure 1: Four Point Bending Test Setup

Moisture content, $MC = \frac{m_1 - m_2}{m_0} x\ 100$ 12

Dry density, $p_d = \frac{m_0}{v}$ 13

Bulk density, $p_b = \frac{m_1}{v}$ 14

5th percentile value of density, $p_{05} = (\bar{p} - 1.65s)$ 15

Characteristic density, $p_k = \frac{\sum p_{05}, n_j}{\sum n_j}$ 16

Mean density, $p_{mean} = 1.2p_k$ 17

12% density value, $p_{k,12\%} = p_w(1 - \frac{(1-0.5)(u-12)}{100}$ 18

Measured bending strength value, $f_m = \frac{af_{max}}{2w}$ 19

Characteristic bending strength value, $f_k = 1.12f_{0.5}$ 20

12% MC value of bending strength, $f_{m,12\%} = \frac{f_{measured}}{1+0.0295(12-u)}$ 21

MOE, $E_m = \frac{l^3(F_2-F_1)}{4.7bh^3(w_2-w_1)}$ 22

mean MOE, $\bar{E} = [\frac{\sum Ei}{n}]1.3 - 2690$ 23

12%MC of MOE, $E_{m,12\%} = \frac{E_{measured}}{1+0.0143(12-u)}$ 24

2.4.1 Other Properties to EN 408:2010

Equations 25 to 34 were used to determine the other strength properties of the samples according to [21]

Tensile stress stress parallel to grain

$f_{t,0,k} = 0.6f_{m,k}$ 25

Compressive stress parallel to grain

$f_{c,0,k} = 5(f_{m,k})^{0.45}$ 26

Compressive stress perpendicular to grain

$f_{c,0,k} = min.\begin{cases} 3.8 \\ 0.2(f_{m,k})^{0.8} \end{cases}$ 27

Compressive stress perpendicular to grain

$f_{c,90,k} = 0.007p_k \, for \, softwoods$ 28

$f_{c,90,k} = 0.015p_k \, for \, hardwoods$ 29

Modulus of elasticity parallel to grain

$E_{0.05} = 0.67E_{0,mean} for \, softwoods$ 30

$E_{0.05} = 0.84E_{0,mean} for \, hardwoods$ 31

Mean modulus of elasticity perpendicular to grain

$E_{90,mean} = \frac{E_{0,mean}}{30} for \, softwoods$ 32

$E_{90,mean} = \frac{E_{0,mean}}{15} for \, hardwoods$ 33

Mean shear modulus

$G_{mean} = \frac{E_{0,mean}}{16}$ 34

2.5 Basic and Grade Stresses

Basic stresses for bending, tensile, compressive, shear parallel to the grain, compressive stress perpendicular to the grain, are calculated from failure stresses. Equation 35 was used for the computation. Various grade stresses at 80%, 63%, 50% and 40% values respectively were also be calculated[24].

$f_b = \frac{f_m - k_p\sigma}{k_r}$ 35

3.0 Results and Discussion

3.1 Moisture Contents and Weight Densities of Samples

The value of percentage moisture contents of the samples are shown in Table 1, which also shows the results of the following:

- Volume of samples length x breadth x height (2 cm x 2 cm x 2 cm)
- Weight (g) of sample before putting in the oven
- Weight (g) of samples after 24 hours in the oven with a controlled temperature of 105^0C
- Moisture content (%) of the different samples
- Weight Density of samples (g/cm^3), 12% and 18% weight density values.

Table 1: Moisture Contents and Weight Densities of Samples

	Mangifera indica	*Terminalia catappa*	*Phoenix dactylifera*
Volume (cm^3)	8	8	8
Initial Weight (g)	5.4	4.1	3.4
Final Weight (g)	4.7	3.6	2.6
Moisture Content (%)	14.2	13.9	30.5
Weight Density (g/cm^3)	0.53	0.54	0.29
ρ_{12} (g/cm^3)	0.52	0.54	0.27
ρ_{18} (g/cm^3)	0.54	0.55	0.28

The *Phoenix dactylifera* has the highest average amount of moisture (30.5%) and the least dense (0.29 g/cm^3), while *Terminalia catappa* has the least amount of moisture content (13.9%), and also the most dense (0.54 g/cm^3).

3.2 Testing Results to BS 373 (1957)

3.2.1 Test Results of Samples

The *Mangifera indica* showed the highest level of resistance to the applied bending load (29.17 N/mm^2), compressive stress parallel (26.95 N/mm^2), compressive stress perpendicular (3.83 N/mm^2) and shear stress (6.27 N/mm^2). *Terminalia catappa* has the highest resistance value to tensile stress (18.85 N/mm^2). While *Phoenix dactylifera* has the lowest value for all the tests. A summary of this can be seen in Table 2.

Table 2: Obtained Values of Sample Stresses

	Mangifera indica	*Terminalia catappa*	*Phoenix dactylifera*
Failure load (kN)	11.7	11.6	3.9
Area (mm^2)	400	400	400
Bending stress (N/mm^2)	29.17	28.93	9.70
Maximum Deflection(mm)	10	10	5
MOR (N/mm^2)	306.24	303.74	101.87
MOE (N/mm^2)	49216.61	48814.65	32744.25

$F_{12\%}$ (N/mm^2)	572.82	538.26	855.90
$F_{18\%}$ (N/mm^2)	859.22	807.39	1283.85
E_{m12} (N/mm^2)	50797.44	50200.38	44526.71
E_{min} (N/mm^2)	15056.56	14818.44	3385.11
Compressive stress (N/mm^2)	26.95	26.93	11.54
Compressive perpendicular (N/mm^2)	3.83	3.12	2.14
Tensile stress (N/mm^2)	17.70	18.85	7.48
Shear stress (N/mm^2)	6.27	4.41	1.64

3.2.2 Basic Stresses of Samples and Grading to BS 5268

Table 8 of the [15] was used for the characterization. All the three samples are classified as softwoods. Table 7 (moisture content below 18%) of [18] was used to characterize *Mangifera indica* and *Terminalia catappa*, while table 6 (moisture content above 18%) was used to characterize *Phoenix dactylifera* and the summary is shown in Table 3.

Table 3: Basic and Grade Stresses of Samples and Grading of Samples

	Mangifera indica	*Terminalia catappa*	*Phoenix dactylifera*
Bending Strength $f_{bb,\ par}$ (N/mm^2)	12.35	12.25	4.11
Compression parallel $f_{bc,\ par}$ (N/mm^2)	17.27	16.85	6.15
Compression perpendicular $f_{bc,\ per}$	3.02	2.46	1.69
Tension parallel f_{bt}, par(N/mm^2)	7.25	7.71	2.84
Shear parallel $f_{bv,\ par}$(N/mm^2)	2.38	1.69	0.60
MOE_{mean}(N/mm^2)	49216.61	48814.65	32744.25
E_{min}(N/mm^2)	15056.56	14818.44	3385.11
Density (ρ_w) (g/cm^3)	0.53	0.54	0.29
Final Grading, BS 5268	C35	C35	C14
Final Grading NCP 2	N5	N5	N7

3.2.3 Grade Stresses of Samples to BS 5268 and NCP 2

The grade stresses of the samples at 80%, 63%, 50% and 40% are also calculated and are summarized in Table 4.

Table 4: Grade Stresses of Samples (N/mm^2)

	Mangifera indica	*Terminalia catappa*	*Phoenix dactylifera*
Bending Strength	12.35	12.25	4.11
80%	9.88	9.8	3.288
63%	7.7805	7.7175	2.5893
50%	6.175	6.125	2.055
40%	4.94	4.9	1.644
Compression parallel	17.27	16.85	6.15
80%	13.816	13.48	4.92

63%	10.8801	10.6155	3.8745
50%	8.635	8.425	3.075
40%	6.908	6.74	2.46
Compression perpendicular	3.02	2.46	1.69
80%	2.416	1.968	1.352
63%	1.9026	1.5498	1.0647
50%	1.51	1.23	0.845
40%	1.208	0.984	0.676
Tension parallel	7.25	7.71	2.84
80%	5.8	6.168	2.272
63%	4.5675	4.8573	1.7892
50%	3.625	3.855	1.42
40%	2.9	3.084	1.136
Shear parallel	2.38	1.69	0.6
80%	1.904	1.352	0.48
63%	1.4994	1.0647	0.378
50%	1.19	0.845	0.3
40%	0.952	0.676	0.24

3.3 Testing Results to EN 408:2010

3.3.1 Density Test Result

The wet and dry densities of the samples are obtained from the volume and weight of the samples measured before they were placed in the oven and after removing them from the oven after 24hrs under constant temperature of 105^0C respectively. The values obtained and those of the fifth percentile density, mean density and density at 12% moisture contents calculated are also shown in the Table 5.

Table 5: Density Test Result of Test Samples

	Mangifera indica	*Terminalia catappa*	*Phoenix dactylifera*
Volume (cm^3)	8	8	8
Initial Weight (g)	4.8	4.9	3.1
Final Weight (g)	4.2	4.3	2.4
Moisture Content (%)	14.2	13.9	30.5
Characteristic dry density, ρ_k (kg/m^3)	528.53	542.70	294.30
Wet Density ρ_b (kg/m^3)	603.45	618.30	384.08
ρ_{05} (kg/m^3)	527.93	542.10	293.96
ρ_{mean} (kg/m^3)	633.51	650.52	352.76
$\rho_{k,12\%}$ (kg/m^3)	560.24	575.26	311.96

3.3.2 Four-Point Bending Test Result

The four-point bending test results for the specimens are highlighted in Table 6. The bending strength values, fifth percentile strength values, characteristic values of bending strength properties and 12% moisture content values of the bending strength are all evaluated from the result of the failure load obtained during the four-point loading test.

Table 6: Four-Point Bending Test Results of Samples

	Mangifera indica	*Terminalia catappa*	*Phoenix dactylifera*
Failure load f_{max} (kN)	8.7	10.5	6.3
$f_m = \frac{af_{max}}{2w} (N/mm^2)$	31.42	38.00	22.78
$f_{0.5}$ (N/mm^2)	30.65	37.20	22.12
Characteristic values of bending strength properties f_k	34.32	41.66	24.78
$f_{m,12\%}$ (N/mm^2)	33.58	40.29	50.15
$F_{12} = F_w\ [1 + \alpha(W - 12)]$	34.16	40.93	39.64

3.3.3 Modulus of Elasticity (MOE) Test Result

The MOE values of the samples are obtained concurrently from the four-point loading test and are summarized on Table 7. The 12% moisture content MOE is also estimated for the samples.

Table 7: MOE Test Results of Samples ($\boldsymbol{N/mm^2}$)

	Mangifera indica	*Terminalia catappa*	*Phoenix dactylifera*
$E_m = \frac{l^3(F_2 - F_1)}{4.7bh^3(w_2 - w_1)}$	18282.1	19899.8	15563.4
$\bar{E} = [\frac{\sum Ei}{n}]1.3 - 2690$	21076.75	23179.69	17542.38
$E_{m,12\%}$	18870.38	20464.57	21161.69

3.3.4 Derived Mechanical Properties of the Samples and Final Grading of Samples

Comparing the results of the characteristic stresses of the samples with table 8 of [16]. *Mangifera indica* and *Phoenix dactylifera* fall under soft woods while *Terminalia catappa* fall under hardwood. These are shown in Table 8.

Table 8: MOE Test Results of Samples and Grading of Samples ($\boldsymbol{N/mm^2}$)

	Mangifera indica	*Terminalia catappa*	*Phoenix dactylifera*
Bending parallel $f_{m,k}$	31.42	38.00	22.78
Tension parallel $f_{t,0,k}$	18.85	22.80	13.67
Compression parallel $f_{c,0,k}$	23.59	25.70	20.41
Shear parallel $f_{v,k}$	3.15	3.67	2.44
Compression perpendicular $f_{c,90,k}$	7.93	8.14	2.06
Tension perpendicular $f_{t,90,k}$	0.60	0.60	0.40
5% MOE Parallel $E_{0.05}$	15.36	16.72	10.43
MOE mean perpendicular $E_{90\ mean}$	1.22	1.33	0.52
Mean shear modulus G_{mean}	1.14	1.24	0.97

Mean density (kg/m^3)	633.51	650.52	352.76
Final Grading	C30	D30	C14

4.0 Conclusion and Recommendation

4.1 Conclusion

The study conducted laboratory experiments on three selected timber species, namely *Mangifera indica*, *Terminalia catappa* and *Phoenix dactylifera* following BS 373 (1957) and EN 384 (2010) standard methods of testing. The physical and mechanical properties of the timber species were established. The study successfully characterized and graded the selected timber species.

Using the BS and NCP standards, the densities were found to be 530 kg/m^3, 540 kg/m^3, and 290 kg/m^3 for *Mangifera indica, Terminalia catappa,* and *Phoenix dactylifera*, respectively. The basic bending stress value obtained were 12.35 N/mm^2, 12.25 N/mm^2, and 4.11 N/mm^2, and their 80% grade bending stresses were 9.88 N/mm^2, 9.8 N/mm^2, and 3.29 N/mm^2, for *Mangifera indica, Terminalia catappa,* and *Phoenix dactylifera*, respectively.

The EN values for the characteristic densities were 528.53 kg/m^3, 542.7 kg/m^3, and 294.3 kg/m^3, for *Mangifera indica, Terminalia catappa,* and *Phoenix dactylifera.* While the basic bending stress values obtained were 31.42 N/mm^2, 38 N/mm^2, and 22.78 N/mm^2, in the same order.

After characterization and grading, *Mangifera indica, Terminalia catappa,* and *Phoenix dactylifera* were assigned to strength classes C35, C35, and C14 respectively, according to BS 5268-2 (2002). According to NCP 2 (1973), the timber species were assigned to strength classes N5, N5, and N7 in the same order. The samples were also assigned to strength classes C30, D30, and C14 respectively, according to EN 338 (2009).

4.2 Recommendations

Based on the results, *Mangifera indica* and *Phoenix dactylifera* belong to softwood class (C class) and are recommended for lightweight applications such as household furniture. *Terminalia catappa* belong to hardwood class (D class) and is recommended for engineering applications like roof construction and as structural elements in timber structures.

The study suggests exploring lesser-utilized tree species in the region for characterization and grading to diversify the building and construction industries and reduce the over-exploitation of well-known commercial species like Mahogany, Obeche, and Teak.

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