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## Characterization and grading of some Potential Nigerian Timbers species in accordance to Eurocode EN 338(2009)

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### ABSTRACT

This paper is aimed at the characterisation and grading of five potential timber species grown in Nigeria using EN338 (2009) strength classification for Eurocode 5 timber design. The timber species namely *Rhizophora racemosa*, *Syzgium guineense*, *Vitex doniana*, *Ceiba pentandra* and *Pseudocedrela kotschy* were obtained in Kwara state in the North-central part of Nigeria. Physical and Mechanical properties of the selected timber species were determined in accordance with EN 13183-1 (2002) and EN 408 (2003) for structural applications. Four point bending tests based on EN 408 (2003) with specimen size 50x50x1000 mm was carried out using a Universal testing machine (UTM) to determine the bending strength and Modulus of Elasticity of each timber specie. Characteristic values of Bending strength, Modulus of Rupture and Density were determined using EN 384(2004) procedure. The timber species; *Rhizophora racemosa*, *Syzgium guineense*, *Vitex doniana*, *Ceiba pentandra* and *Pseudocedrela kotschy* had equilibrium moisture content (EMC) of 10.59 %, 22.34 %, 15.70%, 13.71 % and 24.28 % respectively. Strength grading of timber species were then conducted by adjusting the material property values at 12 % moisture content using the required adjustment factors. The timber species were then graded according to EN338 (2009). *Rhizophora racemosa*, *Syzgium guineense* *Vitex doniana*, *Ceiba pentandra* and *Pseudocedrela kotschy* were assigned to strength class C14, D24, D30, C16 and D35 respectively.

**Keywords:** Characterisation, Eurocode5, Kwara state, Mechanical properties, Physical properties

### 1 INTRODUCTION

Global demand for timber is increasing annually at the rate of 1.7 per cent. At the same time, forestry resources are not adequate to meet current demands. The scope for enlargement of forested areas is limited. This trend creates pressure on the economy that encourages the commercial exploitation of natural forests unless supply can be increased through the establishment of high yielding plantations (Saravanan et al., 2014). According to Aguwa (2016), timber remains a very important structural material in technological advancement and high level engineering production. Timbers grow best in temperate and moist tropical climates but do not grow in cold or very dry areas of Nigeria. Furthermore, Nigeria as a nation is now allocating huge resources on importation of steel which is not necessary even in fabrication of long span trusses for sophisticated structures because timber can be used to achieve strength, durability, aesthetic and even time conservation (Ezeagu et al., 2015).

Structural timber is the timber used in framing and load-bearing structures, where strength is the major factor in its selection and use. Most woods used in the building construction are softwoods but in structures like bridges and railway sleepers, hardwoods are specially used (Aguwa, 2012). Classification of this timbers to standards then becomes of great importance because of diverse and also similar properties of some of them. When a timber is classified and graded, designers can easily use different available timbers for a purpose. For structural usage, the properties of large size specimens are preferred to those of small clear specimens because of unavoidable defects

such as shakes, knots other defects found in wood (Appiah-Kubi et al., 2012).

This paper intends to classify potential Nigerian timbers in accordance with EN 338(2009) which is the limit state design. This will give an opportunity to adopt the Eurocode 5 design procedure in the Nigerian standard. The objective of the study is as follows:

1. To determine the physical and mechanical properties of selected timbers according to EN 408 and adjustment of characteristic values with respect to moisture content at 12%.
2. Examine the variation in properties among the five Nigeria timbers by subjecting the results obtained from the various tests to ANOVA test and Regression Analysis
3. To classify selected Timber species to strength grades according to EN 338

### 2 METHODOLOGY

#### 2.1 MATERIALS

The materials used in this paper are timber species logs, obtained from Kwara state in North-central part of Nigeria. This local names, botanical names and family names of the timbers are shown in Table 1

Table 1: Timber species Nomenclature

| S/N | Local Name | Botanical Name             | Family         |
|-----|------------|----------------------------|----------------|
| 1.  | Igba       | <i>Rhizophora racemosa</i> | Rhizophoraceae |

|    |             |                              |           |
|----|-------------|------------------------------|-----------|
| 2. | Adere       | <i>Syzgium guineense</i>     | Myrtaceae |
| 3. | Eriri       | <i>Vitex doniana</i>         | Lamiaceae |
| 4. | Somi        | <i>Ceiba pentandra</i>       | Malvaceae |
| 5. | Emi Gbegiri | <i>Pseudocedrela kotschy</i> | Maliaceae |

### 2.1.1 PREPARATION OF TEST SPECIMEN

For bending strength and Modulus of Elasticity (MOE) tests, 20 number of beam size 50 mm×50 mm×1000 mm pieces were prepared for each property. This operation was carried out at the wood processing unit of the department of Civil Engineering, University of Ilorin, Ilorin, Nigeria. For moisture content and density, number of specimens for each property was 20 with size 50mm×50mm×50 mm sawn after bending tests from timber beams section and close to fracture point.

## 2.2 METHODS OF TEST

### 2.2.1 PHYSICAL PROPERTY

#### i) Moisture content

The timber species moisture content (MC) were determined in accordance with EN 13153-1(2002). The MC for each timber was obtained by first measuring its initial mass before drying using an electronic weighing balance. The test sample were then oven dried at a temperature of  $103 \pm 2^\circ\text{C}$ . A total of 20 samples were dried until the final weight of oven-dried timber is constant after two successive weighing. The initial and oven dry mass of each specimen sample were recorded and the MC was then computed from equation 1:

$$\text{Moisture content} = \frac{m_1 - m_2}{m_2} \times 100\% \quad (1)$$

where  $m_1$ ,  $m_2$  and MC are the initial mass, oven dry mass and moisture content of test specimens respectively. The mean Moisture content was then obtained by finding the mean value of MC for the 20 specimens of each timber species.

#### ii) Density

The density of timber is its mass per unit volume at a specified value of MC. The density of specimen was determined in accordance with EN408 (2004) using equation 2 with its characteristic values determined in accordance with EN 384(2004) from equation 3. 20 samples of each timber species were tested.

$$\text{Density} = \rho = \frac{\text{Mass}}{\text{Volume}} \text{ g/cm}^3 \quad (2)$$

$$\rho_k = \rho_{05} = (\rho - 1.65s) \quad (3)$$

where  $\rho_k$  is the characteristic density,  $\rho_{05}$  is the 5-percentile density,  $\rho$  and  $s$  are the mean and the standard deviation of densities of all specimen (in  $\text{kg/m}^3$ ), respectively.

### 2.2.2 MECHANICAL PROPERTIES OF TIMBER

Mechanical strength properties are affected by variation in moisture content below the fibre saturated point. Generally, many of the strength properties increase as wood is dried. Above the fibre saturation point (FSP), most of the mechanical properties are not affected by changes in moisture content (EN 384, 2004).

#### i) Bending Strength

This was carried out in accordance with EN 408 for structural size timber specimen. The strength tests were carried out with the aid of a Universal Testing Machine (UTM) with a maximum load capacity of 300kN at the Agricultural Engineering laboratory of the university of Ilorin with loading rate at 5mm/min. The Modulus of rupture was computed from equation 4.

$$f_m = \frac{a F_{\max}}{2W} \quad (4)$$

Where  $a$  is the distance between loading position and the nearest support (mm),  $F_{\max}$  is the maximum load (N),  $W$  is the section modulus ( $\text{mm}^3$ ) and  $f_m$  is the bending strength ( $\text{N/mm}^2$ ).

According to Abubakar and Nabade (2013), the characteristic values of strength properties based on the measured MC were computed from equation 5 derived from EN 384:

$$f_k = 1.12f_{05} \quad (5)$$

Where  $f_k$  and  $f_{05}$  are the characteristic and 5th-percentile values of bending strength, respectively. Figure 1 shows a sketch of the four point loading test setup.

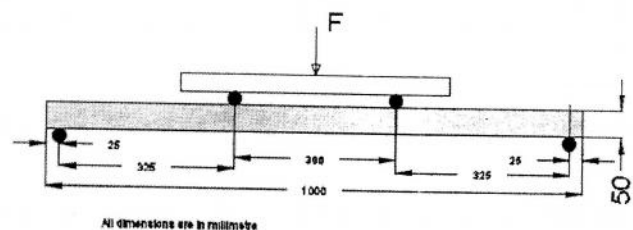


Figure 1: Schematic diagram for bending strength test setup

#### ii) Modulus of Elasticity

The Local modulus of Elasticity was derived from the four point bending test as prescribed in EN 408. The rate of movement of the loading head was adjusted not to be greater than 5mm/min. The guage length was 250mm and 20 samples were tested with mean failure stress derived. The local modulus of elasticity was then computed using the following expression:

$$E_{m,l} = \frac{al_1^2(F_2 - F_1)}{16l(w_2 - w_1)} \quad (6)$$

Where  $E_{m,l}$  is the local MOE in bending,  $a$  is the distance between inner point loads and supports (mm),  $l_1$  is the gauge length (250mm)

$(F_2 - F_1)$  is the increment load (in Newton) on the regression line with a correlation coefficient of 0.99 and  $(w_2 - w_1)$  is the increment of deformation (mm) corresponding to  $(F_2 - F_1)$ .

Characteristic values of MOE which is the mean modulus of elasticity based on measured moisture content is then calculated from equation 7 given in EN 384.

$$E_{\text{mean}} = \left( \frac{\sum E_i}{n} \right) 1.3 - 2690 \quad (7)$$

where  $E_i$  is the  $i$ th value of MOE,  $n$  is the number of specimens and  $E_{\text{mean}}$  is the mean value of MOE in bending. Figure 4 shows the local modulus of Elasticity test in Bending setup.

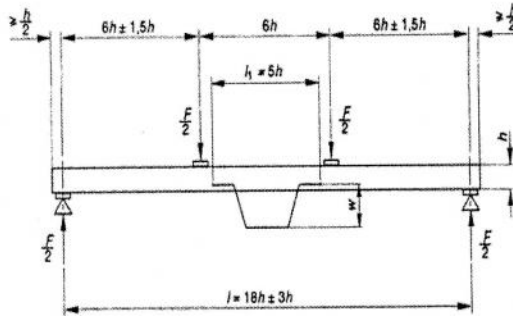


Figure 4: Test setup for local modulus of Elasticity in Bending (Appiah-Kubi et al., 2012)

### 2.2.3 ADJUSTING VALUES AT 12% MOISTURE CONTENT EQUIVALENT

Strength class values according to EN 338 for structural timbers are derived from timbers at about 12% moisture content, which is taken as a reference moisture content. Thus the strength characteristics of timber were adjusted to 12% reference moisture content using equation 8

$$F_{12} = F_w(1 + \alpha(W - 12)) \quad (8)$$

Where;

$F_{12}$  = the ultimate strength at 12% moisture content,

$W$  = the moisture content at the time of testing,

$F_w$  = the ultimate strength at the moisture content at the time of testing,

$\alpha$  = the adjustment factor for moisture content, equivalent to the percentage change in strength values for 1% change in moisture content. This is contained in Table 2

Table 2: Adjustment factor for Wood state of stress

| State of stress                          | $\alpha$ (for all wood specie) | Reference                  |
|------------------------------------------|--------------------------------|----------------------------|
| Modulus of Elasticity ( $E_m, E_{c,0}$ ) | 0.02                           | EN384(2004)                |
| Bending Strength                         | 0.04                           | Zziwa et al., 2016         |
| Density                                  | -0.005                         | Abubakar and Nabade (2014) |

### 2.2.4 DERIVED MECHANICAL PROPERTIES

Characteristic values of other mechanical properties at 12% MC such as tensile strengths parallel and perpendicular to grain, shear modulus, compressive strength parallel and perpendicular to grain and other stiffness properties of the timbers were determined using equations 9-20 from Annex A of EN 338 (2009).

The characteristic values of tensile strength parallel to grain ( $f_{t,0,k}$ ) and compressive strength parallel to grain ( $f_{c,0,k}$ ) are computed from equations 9 and 10 respectively:

$$f_{t,0,k} = 0.6 f_{m,k} \quad (9)$$

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

The characteristic values of tensile strength perpendicular to grain ( $f_{t,90,k}$ ) and compressive strength perpendicular to grain ( $f_{c,90,k}$ ) are computed using equations 11-14:

$$f_{t,90,k} = 0.4 \text{ N/mm}^2 \text{ for softwoods} \quad (11)$$

$$f_{t,90,k} = 0.6 \text{ N/mm}^2 \text{ for hardwoods} \quad (12)$$

$$f_{c,90,k} = 0.007 \rho_k \text{ for softwoods} \quad (13)$$

$$f_{c,90,k} = 0.015 \rho_k \text{ for hardwoods} \quad (14)$$

Fractile 5<sup>th</sup> percentile values of MOE parallel to grain ( $E_{0,0.05}$ ) was computed from equations 15 and 16 respectively:

$$E_{0,0.05} = 0.67 E_{0,\text{mean}} \text{ for softwoods} \quad (15)$$

$$E_{0,0.05} = 0.84 E_{0,\text{mean}} \text{ for hardwoods} \quad (16)$$

The characteristic values of mean modulus of elasticity perpendicular to grain ( $E_{90,\text{mean}}$ ) for the timbers were computed from the equations 17 and 18:

$$E_{90,\text{mean}} = E_{0,\text{mean}} / 30 \text{ for softwoods} \quad (17)$$

$$E_{90,\text{mean}} = E_{0,\text{mean}} / 15 \text{ for hardwoods} \quad (18)$$

The characteristic values of mean shear modulus ( $G_{\text{mean}}$ ) were computed from equation 19:

$$G_{\text{mean}} = E_{0,\text{mean}} / 16 \quad (19)$$

The characteristic mean density ( $\rho_{\text{mean}}$ ) is computed from equation 20:

$$\rho_{\text{mean}} = 1.2 \times \rho_k \quad (20)$$

$E_{0,\text{mean}}$  is the mean MOE parallel to grain,  $\rho_k$  is the characteristic density while  $f_{m,k}$  is the characteristic bending strength all which are used to derive the other mechanical properties. Shear strength  $f_{v,k}$  was taken from Table 1 of EN 338 as put forward by the code.

### 3. RESULTS AND DISCUSSION

#### 3.1 PHYSICAL PROPERTIES OF TIMBERS

Table 3 and Table 4 show the results for MC of the five (5) timber species. This is the equilibrium moisture content (EMC) of timber at which it does not either loose or absorbs moisture from its surroundings. It was also observed that *Emi-gbegi* had the highest value of moisture content, closely followed by *Adere*, while *Eri* ranked third followed by *Somi* and *Igba*. Moisture content values of the five species were below fiber saturation point (FSP) which is between 25 - 30 % as recorded in Aguwa (2016).

Table 3: Moisture content of test samples for timber species

| S/N                       | Eri     | Igba    | Somi    | Emi-gbegi | Adere |
|---------------------------|---------|---------|---------|-----------|-------|
| 1.                        | 15.27   | 11.28   | 14.09   | 23.46     | 27.43 |
| 2.                        | 14.88   | 10.22   | 11.58   | 29.29     | 17.42 |
| 3.                        | 16.78   | 10.51   | 14.20   | 17.38     | 23.61 |
| 4.                        | 17.43   | 11.46   | 14.46   | 28.54     | 19.46 |
| 5.                        | 13.60   | 10.66   | 14.57   | 21.60     | 22.59 |
| 6.                        | 15.49   | 7.72    | 13.50   | 16.88     | 20.61 |
| 7.                        | 14.12   | 11.05   | 13.07   | 25.07     | 21.97 |
| 8.                        | 16.93   | 10.39   | 13.61   | 28.76     | 26.45 |
| 9.                        | 16.67   | 10.84   | 14.44   | 24.81     | 24.32 |
| 10.                       | 15.81   | 11.75   | 13.55   | 26.99     | 19.53 |
| 11.                       | 16.74   | 10.49   | 14.39   | 17.36     | 23.68 |
| 12.                       | 13.78   | 10.61   | 14.28   | 21.68     | 22.88 |
| 13.                       | 13.99   | 11.2    | 13.12   | 24.5      | 21.86 |
| 14.                       | 16.2    | 10.78   | 14.59   | 24.92     | 24.4  |
| 15.                       | 15.68   | 10.6    | 13.65   | 24.35     | 22.48 |
| 16.                       | 14.85   | 10.25   | 11.67   | 29.31     | 18.88 |
| 17.                       | 17.47   | 11.49   | 14.57   | 28.24     | 20.36 |
| 18.                       | 15.53   | 7.78    | 13.55   | 16.85     | 22.97 |
| 19.                       | 16.97   | 10.23   | 13.57   | 28.72     | 26.34 |
| 20.                       | 15.78   | 12.5    | 13.69   | 26.87     | 19.58 |
| Mean Moisture content (%) | 15.6979 | 10.5903 | 13.7079 | 24.2801   | 22.34 |

Table 4: Summary of Moisture content result

| Timber specie | Mean Moisture content (%) | Standard Deviation (%) | Coefficient of variation (%) |
|---------------|---------------------------|------------------------|------------------------------|
| Igba          | 10.59                     | 1.130                  | 10.67%                       |
| Somi          | 13.71                     | 0.861                  | 6.28%                        |
| Emi-Gbegi     | 24.28                     | 4.348                  | 17.91%                       |
| Adere         | 22.34                     | 2.699                  | 12.08%                       |
| Eri           | 15.70                     | 1.211                  | 7.72%                        |

Table 5 and Table 6 present the density of test samples and the adjusted 12 % characteristic density of the timber species to be used for timber classification in accordance with EN338. *Emi-gbegi* had the highest density amongst the Nigerian timbers while *Igba* had the lowest density. *Emi-gbegi* was found to have a lower density when compared with some known specie like Ekki( 940.06 Kg/m<sup>3</sup> ) as reported by Mohammed (2014), but higher than Opepe(676 Kg/m<sup>3</sup> ) given by Abubakar and Nabade (2014)

Table 5: Density of test samples for timber species

| S/N                               | Eri    | Igba     | Somi    | Emi-gbegi | Adere    |
|-----------------------------------|--------|----------|---------|-----------|----------|
| 1.                                | 927.78 | 415.8    | 408.11  | 1075.89   | 608.12   |
| 2.                                | 855.83 | 424      | 436.4   | 1023.81   | 712.34   |
| 3.                                | 672    | 423.89   | 431.8   | 947.77    | 709.95   |
| 4.                                | 871.91 | 495.7    | 456.22  | 1015.88   | 768.38   |
| 5.                                | 847.79 | 431.95   | 471.77  | 847.94    | 639.86   |
| 6.                                | 768.1  | 359.67   | 432.34  | 1135.82   | 767.87   |
| 7.                                | 871.8  | 511.94   | 480.42  | 1055.65   | 768.45   |
| 8.                                | 847.75 | 399.89   | 428.39  | 915.83    | 712.29   |
| 9.                                | 832    | 440.75   | 463.78  | 1000.12   | 647.79   |
| 10.                               | 847.63 | 423.75   | 495     | 998.3     | 791.67   |
| 11.                               | 834    | 420.78   | 413.67  | 1077.39   | 617.21   |
| 12.                               | 832    | 424.4    | 429.14  | 957.22    | 719      |
| 13.                               | 928    | 433.85   | 475.54  | 839.51    | 654.8    |
| 14.                               | 850.75 | 517.2    | 477.64  | 1089.51   | 720      |
| 15.                               | 873    | 435.43   | 464.88  | 933.81    | 655.3    |
| 16.                               | 847.78 | 431.96   | 437.79  | 1051.91   | 716      |
| 17.                               | 770    | 498.41   | 460     | 1033.52   | 778.64   |
| 18.                               | 678    | 349.82   | 432.69  | 1121.81   | 769.09   |
| 19.                               | 890    | 393.49   | 426     | 908.09    | 728.91   |
| 20.                               | 839    | 420.71   | 486.94  | 1004.7    | 768.44   |
| Mean Density (kg/m <sup>3</sup> ) | 834.26 | 432.6695 | 450.426 | 1001.724  | 712.7055 |

Table 6: Mean and Characteristic density of Timbers

| Timber Type | Mean Density<br>$\rho$<br>(Kg/m <sup>3</sup> ) | Standard Deviation<br>(Kg/m <sup>3</sup> ) | Characteristic Density<br>$\rho_k$<br>(Kg/m <sup>3</sup> ) | 12% MC<br>Density<br>$\rho_{k,12\%}$<br>(Kg/m <sup>3</sup> ) | 18% MC<br>Density<br>$\rho_{k,18\%}$<br>(Kg/m <sup>3</sup> ) |
|-------------|------------------------------------------------|--------------------------------------------|------------------------------------------------------------|--------------------------------------------------------------|--------------------------------------------------------------|
| Igba        | 433                                            | 44.41                                      | 360                                                        | 363                                                          | 544                                                          |
| Somi        | 450                                            | 25.73                                      | 405                                                        | 402                                                          | 603                                                          |
| Emi-Gbegi   | 1002                                           | 84.01                                      | 866                                                        | 813                                                          | 1219                                                         |
| Adere       | 713                                            | 57.45                                      | 608                                                        | 577                                                          | 865                                                          |
| Eriri       | 834                                            | 67.17                                      | 720                                                        | 706                                                          | 1060                                                         |

### 3.2 MECHANICAL PROPERTIES OF TIMBERS

According to EN 384, characteristic value are values that represents a fractile of the statistical distribution of timber properties. The Characteristic values of mechanical properties and density for structural timber are used for assigning grades to the strength classes of EN 338 at 12% moisture content. This is achieved with only three characteristic values of bending strength, mean modulus of elasticity parallel to grain and density.

Tables 7 and 8 show the failure stresses of Modulus of Elasticity and Bending tests respectively for the timber species. Adjusted Characteristic Density, MOE and Bending strength values of Material Properties for the timber species at 12 % MC are given in Table 9

It was observed that *Emi-Gbegi* had the highest grade stress at 12% MOE while *Somi* had the lowest grade stress amongst the timber species. This makes *Emi gbegi* more viable timber species for structural purposes because of its greater resistance to bending. *Emi-gbegi* had lower MOE when compared with white Afara (13.32kN/mm<sup>2</sup>) in Kuara et al.(2015), Ekki (16.709kN/mm<sup>2</sup>) in Mohammed (2014) but higher than Opepe (11.054 kN/mm<sup>2</sup>) in Abubakar and Nabade (2014).

*Emi-gbegi* had the highest bending strength grade followed by *Eriri*, *Adere*, *Somi* and *Igba*. This means that *Igba* has the lowest resistance to deformation under load amongst the timber species considered. *Emi-gbegi* had

higher bending strength when compared with Black Afara (24.00N/mm<sup>2</sup>) in Kuara et al., (2015) but lower than Opepe (54.45N/mm<sup>2</sup>) in Abubakar and Nabade (2014). Obeche(45.63N/mm<sup>2</sup>) and Black Afara (50.13N/mm<sup>2</sup>). *Emi-gbegi* is similar to Ahun(39.36N/mm<sup>2</sup>) as given in Mohammed (2014).

Table 7: Failure stresses for Modulus of Elasticity test

| S/N                                      | Emi-gbegi | Somi     | Igba     | Eriri    | Adere    |
|------------------------------------------|-----------|----------|----------|----------|----------|
| 1.                                       | 14373.31  | 7186.655 | 7186.655 | 8006.801 | 7339.566 |
| 2.                                       | 14998.29  | 14373.18 | 19088.51 | 14373.69 | 7186.655 |
| 3.                                       | 8674.034  | 7186.655 | 8006.728 | 8674.034 | 14373.44 |
| 4.                                       | 7339.633  | 7186.119 | 14998.26 | 14998.39 | 7186.655 |
| 5.                                       | 8674.034  | 7339.6   | 7186.655 | 7339.566 | 14373.44 |
| 6.                                       | 8673.995  | 7168.6   | 7839.988 | 13066.76 | 7186.655 |
| 7.                                       | 10520     | 7189.44  | 14373.44 | 7339.6   | 7839.988 |
| 8.                                       | 8674.034  | 7432.62  | 7839.918 | 13634.9  | 7186.655 |
| 9.                                       | 6672.273  | 14355.67 | 7186.655 | 8522.25  | 7186.655 |
| 10.                                      | 7345      | 7188.12  | 18155.79 | 13634.65 | 15679.84 |
| 11.                                      | 14310     | 7182.98  | 18149.98 | 13670.13 | 7329.69  |
| 12.                                      | 8680      | 7181.94  | 7190     | 6523.92  | 14368.32 |
| 13.                                      | 8681.98   | 7351.4   | 7845.2   | 13640.44 | 14375.11 |
| 14.                                      | 10558     | 14370.27 | 14368.99 | 7355.1   | 7847.34  |
| 15.                                      | 6695.88   | 7179.22  | 7832.76  | 13031.13 | 7196.12  |
| 16.                                      | 14889     | 7178.47  | 7180.45  | 7327.23  | 15673.23 |
| 17.                                      | 7390      | 7186.58  | 15019.1  | 14992.56 | 7188.613 |
| 18.                                      | 8681.75   | 7341.56  | 8015.43  | 8667.89  | 7186.23  |
| 19.                                      | 8671      | 14350.24 | 19067.92 | 8015.23  | 7185.73  |
| 20.                                      | 7387      | 7161.87  | 7193     | 14376.79 | 7189.309 |
| Mean failure stress (N/mm <sup>2</sup> ) | 9594.461  | 8654.56  | 11186.27 | 10760.11 | 9553.965 |

Table 8: Failure stresses for Bending test

| S/N | Igba   | Somi   | Adere  | Eriri  | Emi-gbegi |
|-----|--------|--------|--------|--------|-----------|
| 1.  | 13.482 | 36.968 | 49.787 | 47.695 | 14.746    |
| 2.  | 17.783 | 18.547 | 37.358 | 77.675 | 40.715    |
| 3.  | 24.56  | 26.292 | 34.255 | 19.648 | 64.781    |
| 4.  | 26.83  | 36.38  | 50.408 | 50.282 | 63.672    |
| 5.  | 17.976 | 41.017 | 46.846 | 71.274 | 47.636    |
| 6.  | 23.092 | 30.46  | 16.178 | 34.247 | 65.083    |
| 7.  | 12.685 | 35.453 | 46.662 | 43.344 | 77.54     |
| 8.  | 25.57  | 40.43  | 26.552 | 67.04  | 42.16     |
| 9.  | 28.526 | 20.13  | 35.62  | 64.747 | 48.241    |
| 10. | 25.234 | 17.67  | 20.278 | 62.42  | 49.34     |
| 11. | 13.23  | 36.94  | 49.91  | 47.71  | 14.68     |

|                                          |         |          |          |         |         |
|------------------------------------------|---------|----------|----------|---------|---------|
| 12.                                      | 24.67   | 24.87    | 34.43    | 19.1    | 65.23   |
| 13.                                      | 17.99   | 32.234   | 46.65    | 69.98   | 47.83   |
| 14.                                      | 12.1    | 39.77    | 46.72    | 44.04   | 77.34   |
| 15.                                      | 28.61   | 20.35    | 35.23    | 66.6    | 47.85   |
| 16.                                      | 17.77   | 33.79    | 37.41    | 77.72   | 40.11   |
| 17.                                      | 26.53   | 17.1     | 50.512   | 48.67   | 63.78   |
| 18.                                      | 22.9    | 36.27    | 16.21    | 35.1    | 65.34   |
| 19.                                      | 26.53   | 28.37    | 26.523   | 68.13   | 43.58   |
| 20.                                      | 25.41   | 35.05    | 20.35    | 61.32   | 48.17   |
| Mean failure stress (N/mm <sup>2</sup> ) | 21.5739 | 30.40455 | 36.39445 | 53.8371 | 51.3912 |

Table 9: Adjusted Characteristic values of Material properties to 12 % MC

| Timber Type                   | Density<br>$\rho_{k,12\%}$<br>(Kg/m <sup>3</sup> ) | Modulus of Elasticity<br>$E_{0,mean}$<br>(N/mm <sup>2</sup> ) | Bending Strength<br>$f_{m,k,12\%}$<br>(N/mm <sup>2</sup> ) |
|-------------------------------|----------------------------------------------------|---------------------------------------------------------------|------------------------------------------------------------|
| <i>Rhizophora racemosa</i>    | 363                                                | 11517.91                                                      | 14.00                                                      |
| <i>Syzgium guineense</i>      | 577                                                | 11742.34                                                      | 25.47                                                      |
| <i>Vitex doniana</i>          | 706                                                | 12134.30                                                      | 30.098                                                     |
| <i>ceiba pentandra</i>        | 402                                                | 8853.71                                                       | 21.985                                                     |
| <i>Pseudocedrela kotschyi</i> | 813                                                | 12185.45                                                      | 39.415                                                     |

Table 10 presents the results of the other derived mechanical properties of the Nigerian timber species as computed from equation 9-20.

Table 10: Derived Mechanical properties of the Timber species

|                             | Timber Specie                      |                                |                                            |                                   |                              |
|-----------------------------|------------------------------------|--------------------------------|--------------------------------------------|-----------------------------------|------------------------------|
| Other Mechanical Properties | Igba<br><i>Rhizophora racemosa</i> | Somi<br><i>Ceiba pentandra</i> | Emi-Gbegi<br><i>Pseudocedrela kotschyi</i> | Adere<br><i>Syzgium guineense</i> | Erii<br><i>Vitex doniana</i> |

|                                                                   |       |       |       |       |       |
|-------------------------------------------------------------------|-------|-------|-------|-------|-------|
| Tension Parallel<br>$f_{t,0,k}$<br>(N/mm <sup>2</sup> )           | 8.4   | 13.2  | 23.4  | 15.0  | 18.0  |
| Tension Perpendicular<br>$f_{t,90,k}$<br>(N/mm <sup>2</sup> )     | 0.4   | 0.4   | 0.6   | 0.6   | 0.6   |
| Compression Parallel<br>$f_{c,0,k}$<br>(N/mm <sup>2</sup> )       | 16.39 | 20.09 | 25.99 | 21.28 | 23.10 |
| Compression Perpendicular<br>$f_{c,90,k}$<br>(N/mm <sup>2</sup> ) | 2.5   | 2.8   | 12.2  | 8.6   | 10.6  |
| Shear Strength<br>$f_{v,k}$<br>(N/mm <sup>2</sup> )               | 4.0   | 4.0   | 4.5   | 4.0   | 4.5   |
| 5% MOE, Parallel<br>$E_{0,0.05}$<br>(KN/mm <sup>2</sup> )         | 7.72  | 5.93  | 10.23 | 9.86  | 10.20 |
| Mean MOE, Perpendicular<br>$E_{90,mean}$<br>(KN/mm <sup>2</sup> ) | 0.384 | 0.295 | 0.812 | 0.783 | 0.809 |
| Mean Shear Modulus<br>$G_{mean}$<br>(KN/mm <sup>2</sup> )         | 0.719 | 0.553 | 0.761 | 0.734 | 0.758 |
| Mean Density<br>$\rho_{mean}$<br>(Kg/m <sup>3</sup> )             | 436   | 482   | 976   | 692   | 847   |

### 3.3 ANOVA FOR VARIATION IN PHYSICAL PROPERTIES

Analysis of Variance at 5% level of significance was carried out for the physical properties of timbers used for classification.

Table 11 shows the ANOVA results between moisture content of timbers. It was observed that the F-value was 49.391 while the P-values obtained from the ANOVA of the moisture content was  $6.68 \times 10^{-16}$  which is less than 0.05, (P -value < 0.05) and this signifies that there is significant difference in moisture content within the five timber types. This shows that some timber species have

higher bound water within their wood cells while others have considerably lower bound water within their wood cells.

Table 11: Summary of ANOVA for Moisture content

| Source of Variation | SS       | df | MS       | F     | P-value  | F crit |
|---------------------|----------|----|----------|-------|----------|--------|
| Between Groups      | 1346.047 | 4  | 336.5119 | 49.39 | 6.68E-16 | 2.578  |
| Within Groups       | 306.5916 | 45 | 6.813147 |       |          |        |
| Total               | 1652.639 | 49 |          |       |          |        |

From the ANOVA results shown in Table 12 for density between the species, it was observed that the P-values obtained was  $2.58 \times 10^{-26}$  which is less than 0.05, (P – value < 0.05) and this signifies that there is significant difference between the densities within the five timber types investigated. This means that the timber species considered cannot be used interchangeably for design purposes as they have varying densities. Some are hardwoods which have higher densities while some are softwoods because of lower densities.

Table 12: Summary of ANOVA results for Density

| Source of Variation | SS      | df | MS       | F     | P-value  | F crit |
|---------------------|---------|----|----------|-------|----------|--------|
| Between Groups      | 2420466 | 4  | 605116.5 | 165.8 | 2.58E-26 | 2.578  |
| Within Groups       | 164232  | 45 | 3649.599 |       |          |        |
| Total               | 2584698 | 49 |          |       |          |        |

From experimental results for physical and mechanical properties and their derived values, the Nigerian timbers were allocated to their respective strength class. This assignment was based on EN338 which states that a solid timber may be assigned to a strength class if its characteristic values of bending strength and density are equal to or exceed the values for the strength class given in Table 1 of EN338, and its characteristic mean MOE in bending equals or exceeds 95 % of the value given for that strength class. Based on this, *Vitex doniana* was assigned to strength class D30 due to its minimum characteristic bending strength of 30.1 N/mm<sup>2</sup>, characteristic density of 706 kg/m<sup>3</sup> and minimum mean MOE parallel to grain of 12.13 kN/mm<sup>2</sup>. The characteristic bending strength, mean MOE and density of strength class D30 as provided in EN338 are 30 N/mm<sup>2</sup>, 11 kN/mm<sup>2</sup> and 530 kg/m<sup>3</sup> respectively.

Based on the same criteria, *Ceiba pentandra*, *Pseudocedrela kotschy*, *Rhizophora racemosa*, *Syzygium guineense* timber species were assigned to strength classes C16, D35, C14 and D24 respectively.

#### 4. CONCLUSION

The following conclusions were made from the paper:

The timber species were assigned to appropriate strength classes based on the European structural timber strength classification systems (EN 338, 2009). Igba, Somi, Emigbegi, Adere and Erii were assigned to strength class C14, C16, D35, D24 and D30 respectively. The assignment were based on the reference material properties (density, modulus of elasticity and bending strength) of the species.

Based on the experimental results carried out, Emigbegi, Adere and Erii belong to the D class (that is, the class of hardwoods) while Somi and Igba belong to C class (that is, the class of softwoods) as classified in EN 338. The Hardwood timber species are recommended for engineering applications such as roof rafters, tie beams and other load bearing structures. The softwoods ( Somi and Igba ) can be used for light construction works such as furniture and formworks in casting of concrete mixes. More research should be channeled on classification of less-used timber specie because lack of adequate information (mechanical properties) on the lesser-used species in Nigeria can lead to the over-exploitation of the few commercial species such as Ayin, Mahogany, Obeche and Teak., Milicia. whose properties are well known.

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