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# Characterization, Grading and Flexural Modelling of Rubberwood (*Hevea brasiliensis*); For the Local and International Construction Industry

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Author OIA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author HU managed the analyses of the study. Author DE managed the literature searches. All authors read and approved the final manuscript.*

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## ABSTRACT

Rubberwood, hitherto solely employed as fuel wood has found fairly suitable use in the Nigerian construction industry. This paper investigated the engineering properties of this low cost, alternative, timber material, produced from Rubber trees (*Hevea brasiliensis*); often employed within two weeks of felling, for the construction of formworks and related wood works. No real attempt has been made to formally grade or coordinate the properties of rubber wood as employed in the Nigerian construction industry. The research was aimed to achieve the determination of the physical and mechanical properties of naturally seasoned rubber wood obtained from the Niger Delta region of Nigeria, and assigned to it a strength/grade class. Specific properties required for grading were determined using suitable standard methods. The structural and mechanical properties of the timber wood were determined using the three point bending test in accordance with standards presented by BS EN 408 and ASTM D193, but with an aspect ratio of 12.

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Characteristic values for the wood properties (at the tested moisture content "MC") were determined in accordance with BS EN 384. Adjustments were made to the characteristic values for the mechanical properties, and the density of the timber species at the test MC; to conform with the international reference MC condition of 12% (as specified by BS EN 338), and also 18% MC, to suit standards required for the Nigerian environmental condition (NCP 2). Grading was carried out in accordance with BS EN 338. The characteristic values for the mechanical properties (at 12% and 18% MC) evaluated from test results are as follows; characteristic values for MOR and MOE were 20.191 N/mm$^2$ and 19.283 N/mm$^2$, and 2285.784 N/mm$^2$ and 2195.606 N/mm$^2$ respectively. Mean values for densities (at 12% and 18% MC) were 406.169 Kg/m$^3$ and 431.058 Kg/m$^3$, while the characteristic values for the related densities were 338.474 Kg/m$^3$ and 359.215 Kg/m$^3$. Furthermore, the mean green density and characteristic green density for the rubberwood were 988.148 Kg/m$^3$ and 900.352 Kg/m$^3$ respectively. From the results obtained, rubberwood procured from the Niger Delta region was categorized as a grade D30 and D35 timber material at 18% MC and 12% MC respectively. Rubberwood from the Niger Delta can be conveniently employed as an alternative material to conventional timber, in both the furniture and the construction industry, but with special considerations.

*Keywords: Rubber wood; physical properties; mechanical properties; characteristic values; timber grade; alternative; non-conventional.*

## NOTATIONS

| | |
|---|---|
| *A* | *Cross-sectional area; perpendicular to the direction of the grain* |
| *af* | *Distance between inner load points = 6h* |
| $\alpha$ | *Adjustment/correction factors for 1% change in moisture content related to an equivalent percentage change in the required parameter or strength value* |
| *b* | *Breadth of the cross-section perpendicular grain/breath of loaded area width of the specimen* |
| *CoV* | *Coefficient of Variation* |
| *d* | *Depth of the cross-section perpendicular to grain* |
| *E* | *Young's Modulus/Modulus of Elasticity (MOE)* |
| $E_m = E_{0\ mean}$ | *Moment of elasticity (MOE) in bending* |
| $\bar{E} = E_{mean}$ | *Mean value of MOE in bending* |
| $E_{0,mean}$ | *Mean modulus of elasticity parallel to grain.* |
| $E_{0,0.5}$ | *Characteristic 5th percentile modulus of elasticity parallel to grain* |
| $E_{90,mean}$ | *Characteristic mean modulus of elasticity perpendicular to grain* |
| $E_i$ | *$i^{th}$ value of MOE for the $i^{th}$ specimen* |
| $E_{m.k} = E_W$ | *Characteristic value of MOE in bending at test (measured) moisture content (MC)* |
| $E_W$ | *Characteristic value of MOE, also referred to as the Mean value of MOE in bending at test MC measured in N/mm$^2$.* |
| $E_{m,k,12\%}$ | *Adjusted characteristic value for MOE at equivalent moisture content value of 12%* |
| $E_{m,k,18\%}$ | *Adjusted characteristic value for MOE at equivalent moisture content value of 18%* |
| $\epsilon_{c,0}$ | *Strain parallel to grain* |
| $\epsilon_{c,90}$ | *Strain perpendicular to grain* |
| $\epsilon_{max}$ | *Maximum Strain within elastic limit* |
| $E_{c,0}$ | *Young's Modulus parallel to grain* |
| $E_{c,90}$ | *Young's Modulus* |
| $E_{90\ mean}$ | *Mean Shear Modulus perpendicular to grain* |
| $(F_2 - F_1)/(w_2 - w_1)$ | *Slope of the regression line* |
| $(F_2 - F_1)$ | *Incremental load in Newton (N) based on regression analysis within the elastic range with correlation coefficients > 0.95* |
| $F_{c,max,90}$ | *Maximum compressive load perpendicular to grain* |
| $F_{c,max,0}$ | *Maximum compressive load at failure parallel to grain* |
| $\bar{f}$ | *Mean value of MOR for samples based on test/ measured MC* |
| $\bar{f}_{0.5}$ | *Mean of 5-percentile value of MOR for set of samples* |

| | |
|---|---|
| $f_{0.5}$ | 5-percentile value of MOR for single set of sample |
| $f_{c,0}$ | Maximum compressive stress Parallel to grain |
| $f_{c,90}$ | Maximum compressive stress Perpendicular to grain |
| $f_{c,0,k}$ | Characteristic compressive strength parallel to grain |
| $f_{c,90,k}$ | Characteristic compressive strength parallel to grain |
| $f_m$ | Bending /flexural strength |
| $f_{m,k}$ | Characteristic value of bending/flexural strength |
| $f_{m,k,12\%}$ | Adjusted value for characteristic bending strength at equivalent moisture content value of 12% |
| $f_{m,k,18\%}$ | Adjusted value for characteristic bending strength at equivalent moisture content value of 18% |
| $f_{t,0,k}$ | Characteristic tensile strength parallel to grain |
| $f_{t,90,k}$ | Characteristic Tensile strength perpendicular to grain |
| $f_{v,k}$ | Characteristic shear strength (parallel to grain) |
| $F_{max}$ | Maximum load at failure / yield load |
| $F_{max}$ | Maximum load at failure within elastic limit |
| $f_w$ | Characteristic ultimate strength at failure (at the test MC) |
| $G_{mean}$ | Mean shear modulus |
| h | Height of the specimen in millimeters (mm). |
| h | Depth adopted for the test specimen. The 5-percentile bending strength shall be adjusted by dividing by the expression $ll_{es}$ and $l_{et}$ are calculated as $l_{es}$ and $l_{et}$ = $l + 5a_f$ |
| I | Second moment of area for the cross-section of the specimens |
| K | Bending stiffness (flexural rigidity) |
| $k_h$ | Depth adjustment factor |
| $k_S$ | Adjustment with respect to the number of samples and the sample size as obtained from fig 1 of BS EN 384:2004 and taken as 0.7 |
| $k_V$ | Factor to allow for lower variability of $f_{0.5}$ ; taken as 1.12 |
| $l_{es}$ | Effective length for standard test procedure (for a span L = 18h and distance between load point and support, af = 6h in accordance with BS EN 384 |
| $l_{et}$ | Effective length for the test arrangement |
| L | Total length of the specimen > 18h |
| l | Span length/ length of specimen between supports |
| MC | Moisture content |
| $MC_i$ | Individual measured values of MC |
| $\overline{MC}$ | Mean moisture content, |
| $\overline{MC}$ | Mean value of MC for specimens at test condition |
| M | Mass of Specimen/slice/cube |
| $m_1$ | Initial mass |
| $m_2$ | Final constant mass of the specimen |
| MOE | Modulus of Elasticity |
| MOR | Moment of Rupture |
| n | Number of specimen in the sample. |
| $\rho$ | Density |
| $\bar{\rho}$ | Mean value of density for the sample |
| $(\rho_w = \rho_k)$ | Characteristic density at test MC (in $Kg/m^3$), |
| $\rho_k$ | Characteristic density |
| $(\rho_k = \rho_{0.5})$ | Characteristic density for a 95% confidence level |
| $\rho_{0.5}$ | 5-percentile value for density (value for which no more than 5% of test values fall below), |
| $\rho_{k,(w_{ref})\%}$ | Characteristic density at the reference MC |
| $(w_{ref})\%$ | Reference moisture content in percentage |
| $\rho_{k,12\%}$ | Characteristic density at 12%reference MC |
| $\rho_{k,18\%}$ | Characteristic density at 18% reference MC |
| s | Standard deviation (S.D.) for the sample |
| V | Volume of the slice/cube at the test/seasoned moisture content (MC) |
| W | MC at the point/time of testing. |

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|---|---|
| $w$ | *Flexural deflection* |
| $(w_2 - w_1)$ | *Corresponding deflection (in mm) to Incremental load within the elastic range* |
| $w_1$ | *Initial value of deflection* |
| $w_2$ | *Final value of deflection* |
| $w_{max}$ | *Maximum deflection within elastic limit* |

## 1. INTRODUCTION

Internationally, the use of timber as a structural material is not new [1]. This is particularly true in the construction industry. The prominence of timber comes from its low density, and its cellular, polymeric and composite nature, which makes it compatible with other construction materials [2]. Also, the fact that timber is considered environmentally friendly and cost effective, has encouraged its commercial exploitation; but there has not been a commensurate replenishment of conventional timber species and adequate rejuvenation of forests to meet demand [3]. Jimoh and Ibitolu [2] and Saravanan et al. [3] noted the limited scope for enlargement of forested areas, highlighting that forestry reserves are presently not adequate to meet current global demands for timber; which they claim is increasing at the rate of 1.7% annually. Presently, deforestation is a major problem driven by several factors which include; structural demand for timber (mainly from the construction industry) and high logging residue, amongst other factors [4,5]. Logging of under aged or under developed trees, exacerbated by institutional lack of quality control and grading, has also contributed to the problem, resulting further in rapid deforestation.

Generally, grading which basically refers to the classification of a species of timber, based on some prescribed characteristic property values for the material, is necessary for quality control [1]. Since timber is not a man-made material, its character and composition are largely dependent on "nature", for the progressive development of its structural properties [1,6]. This is with particular reference to its growth rate and physical characteristics, which in turn influences its physical and mechanical properties. Osuji and Inerhunwa [1] affirmed that the mechanical properties of timbers cannot be artificially adjusted by changing their composition or raw materials; this is because, these properties are naturally controlled by growth, maturity and environmental conditions. Therefore, grading ensures that the mechanical properties (particularly its flexural strength, stiffness and density) are within desirable and predictable limits that can be ascertained, consequently forming the criteria by which the timber is employed for a desired structural purpose [1,6]. Grading therefore forms the rational basis for classification of timber into strength/grade classes for purpose of design and analysis.

Globally, several strength/class grading systems exist [1], however, BS EN 338 [7] requirements which basically relates to the determination of the characteristic values of three basic properties; the Bending strength or Modulus of Rupture (MOR), the Flexural Modulus of Elasticity (MOE) parallel to the grain, and the density of the timber material [1,8], is commonly employed. The characteristic values of these basic properties are obtained from observed test values at the test moisture content and adjusted to its 12% and 18% values as required by [7,9,10]. The characteristic values for other relevant properties for the timber material (which can also be determined experimentally), are determined empirically from their basic grading properties values employing equations specified in Annex A of BS EN 338 and section 7 of BS EN 384. According BS EN 338 [7], a timber population may be assigned to a strength/grade class if it's characteristic MOR, MOE and its Density, at 12% Moisture Content, equals or exceeds the values for that strength class as given in Table 1 [7]. The timber assigned to a given strength class, is referred to as graded timber and it is presented to the market as an assessed material with discernable properties. The knowledge of the value of the properties required for grading, will assist in making the most suitable use of a selected timber material for a given purpose [1,7]. In Nigeria the quality and characteristics of conventional timber species such as Teak Wood (*Tectona grandis*), Mahogany (*Khaya spp.*), Apa, (*Afzelia africana*), Iyip Okoyo (*Stauditiastpitata*), African birch (*Anogeissus leiocarpus*), etc., have received renewed attention [11,12,13]. Localized alternatives such as Rubber trees (*Hevea brasiliensis), African oil palm (Elaeis Guineensis),* African fan palm or African palmyra palm (*Borassus aethiopum) and* Bamboo *(Bambusa vulgaris*) also require some attention for economic reasons as well as for environmental concerns [1].

Rubber (*H. brasiliensis*) is a deciduous hardwood tree, which belongs to the *Euphorbiaceae* family, is found either growing wild or cultivated in most parts of the world [14,15]. Rubber trees are of strategic importance because they are the only commercially viable source of natural rubber (latex) globally [16]. Rubber is a native of Brazil in South America, and the tree can grow up to 40 m height and trunk diameter of about 0.8 m, if undisturbed and the soil is fertile [14,17]. The Food Agriculture Organization (FAO) stated that about 12 million hectares (ha) is cultivated with rubber worldwide, mostly in the tropical regions of Asia and Africa, where they had been introduced as exotic species, but are now naturalized [18,19,20]. In Nigeria, about 362,000 ha are cultivated with rubber plantations, mostly in the rural and semi urban areas, mainly for latex production; in 2018, Nigeria produced about 145,200 tons of natural rubber [20].

Rubber trees thrive well on flat, plain, well drained lands with deep water tables [14,21]. They also thrive well on lands with gentle slopes and undulating terrain; with good soil aeration and fertile top soils, rich in organic matter. The Bureau of Plant Industry [21] pointed out that suitable soil pH requirements generally range between 4.5 – 6.5 units, while climatic conditions include, a temperature range of between $20^0$C and $34^0$C, an atmospheric humidity of about 80% (with moderate wind speeds), and an average annual rainfall of about 2000 mm – evenly distributed throughout the year, with about 2000 hours of bright sunshine at a rate of six hours/day. These conditions are largely prevalent in the southern parts of Nigeria, and endemic to most of the West African sub region. After some years, when the latex production drops drastically, it is usually economical to cut down the old trees and replant new ones at this stage [22,23]. It is however common to see plantations with matured trees abandoned, or otherwise cut down, and allowed to decompose naturally to make way for new infrastructural investments or urban development. The cut down trees are often extensively used either as fuel wood (Fig. 1), or as building construction materials (Fig. 2).

The trunk of Rubber trees are generally straight and free of branches up to about 15 m above the ground level, if planted at a close spacing of 4 m x 4 m [17]. Rubberwood has a dense grain character that is easily controlled in kiln drying processes [15]. Its texture is moderately coarse and even, its specific gravity ranges between 0.46 and 0.52, and it is easy to saw and plane, but tends to split upon nailing [24,25]. Rubberwood is highly susceptible to boring insects; but chemical treatments (boron impregnation and Copper, Chromium and Arsenic (CCA) impregnation, etc.) or other specialized treatments (superheated steam treatement, etc.) can help to improve its durability and strength [22,26]. Rubberwood generally dries rapidly and suffers severe shrinkage upon drying, having shrinkage (green to oven dry volume) of about 5.1% tangentially and 2.3% along its radials [22,24,27].

**Fig. 1. Rubberwood Stacked for sale as fuel wood; Ozoro Delta State, Nigeria**

**Fig. 2. Rubberwood boards and props as construction materials; Ozoro Delta State, Nigeria**

According to Gerhard [28], most of the mechanical properties of timber commonly increase with a decrease in moisture content below a Fibre Saturation Point (FSP) of about 30%. The mechanical properties of wood generally, increase exponentially with a decrease in the moisture content below the FSP. It is however common to linearly relate mechanical properties to the MC, below the FSP [28]. For MC above the FSP and beyond, most mechanical properties remain fairly constant [27], with no further significant variation in values occurring beyond this point; this behaviour is also applicable to rubberwood. Sulaiman *et al.* [27] established the FSP for rubberwood to be within the range of 25% and 27%. In Nigeria, not much has been presented with respect to the physical and Mechanical properties of rubberwood particularly with regards to its requirements for grading. This is in spite of the adoption of rubberwood as an alternative to convention timber for the production of struts and boarding materials in some parts of the country; where it is usually employed at moisture contents above the FSP. Rubberwood is presently extensively seasoned and utilized as furniture wood in Asia [25], some of its documented properties at 17.2% MC are: MOR~ 66N/mm$^2$, MOE ~ 9240N/mm$^2$ and $\rho$ ~ 640kg/m$^3$, $f_{c,0}$ ~ 32.3N/mm$^3$, $f_{c,90}$ ~ 4.67N/mm$^3$ and $f_{v,k}$ ~11.0N/mm$^2$. These values indicate fairly good material qualities for rubberwood as a structural material, and categorize it as a medium-dense timber [17,22,23]

Rubberwood in Nigeria is of interest with regards to its present utility in the Nigerian construction industry, which is without reference to any form of characterization of its structural properties and the environment in which it is derived and employed. Despite the promising prospects of rubberwood in the construction industry, very little research work has been done on the grading and suitability of Nigeria rubberwood. This is generally due to its non-conventional status as a timber material and the lack of awareness of the value of this abundant resource in the Nigerian environment. Therefore, this study focused on the investigation, characterization and grading of Nigeria rubberwood obtained from the Niger Delta region of Nigeria. Results of this study will help to enhance material quality and advocate for a cheap alternative and a potential veritable and supplementary source of construction timber.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

The study was conducted at Ozoro in Delta State, in the Niger Delta region of Nigeria. Ozoro is situated on latitude 6$^0$ 12'52'' East of the Prime meridian and on longitude 5$^0$ 32'18'' North of the Equator, with an average annual rainfall of between 2400mm and 2600mm per annum [29]. It is located at an average elevation of about 57 ft, with a seasonal temperature variation of about 28±5$^o$C [30,31]. The vegetation cover is mostly cropland (31% - 42%), with occasional grasslands and forests. Ozoro has a lot of rubber estates; some of which are functional, while others are abandoned. Apart from the rubber estates, rubber trees can be found growing in the wild within the natural vegetation [31].

### 2.2 Materials

The major materials employed are rubberwood specimens obtained from rubber trees (*H. Brasiliensis*) and shaped in the form of timber cubes and beams. A total of 10 beams measuring 75mm x 50mm x 1500mm and 9 cubes measuring 100mm x 100mm x 100mm were employed.

**Fig. 3. Cross section of rubberwood specimen**

The beams and cubes employed were homogeneous clear specimens devoid of knots, cross grains, checks, sapwood, and splits. They were generally free from blemishes in accordance with BS EN 408 [32]. The samples of the rubberwood were obtained from rubber trees found in the local forest within Ozoro community. They were roughly cut to size in the field with a hand held chain saw and then machined to precision (using basic wood workshop machines and tools) in the Woodwork and carpentry workshop of the Department of Civil Engineering Technology, at Delta State Polytechnic, Ozoro (DSPZ). The specimens were all tested at a room temperature of about 26 ± $2^0$C, with a relative humidity of about 78 ± 6%. Three (3) of the cube specimens collected on the field were firmly secured in “air – tight’’ polyethylene bags for field/initial MC determination, while seasoning of the remaining test specimens (Fig. 3) was done by open air method for a period of 2 weeks.

## 2.3 Methods

Laboratory tests were carried out at the Material test laboratory of the Department of Civil Engineering Technology, Delta State Polytechnic, Ozoro, Nigeria, in accordance with EN 408 [32], ASTM D193 [33] and ASTM D143 [34], to determine the physical and mechanical parameters of the rubberwood; density, MC, and strength and stiffness related properties. The MOR and the MOE were obtained by employing the three point bending test setup (Fig. 4), while compressive strength and related properties were obtained by direct application of a compressive force from the Compression testing machine (Fig. 5). Deflections were measured using a dial gauge and a digital vernier caliper. The MOE and other stiffness related properties were determined from load and deflection readings. Characteristic values of these properties were determined for the purpose of strength grading of rubberwood in accordance with BS EN 338, based on three key grade determining properties which are; flexural strength, stiffness and density [1, 8]. The general standard adopted for testing and grading was the British Standard, on which timber designs in Nigeria is predominantly based [1].

## 2.4 Analysis and Determination of Characteristic Properties

The physical and mechanical properties of the rubberwood specimens, as well as their associated characteristic values, determined in accordance to BS EN 408 [32], NPC2 [35] and BS EN 384 [36], are as described below:

## 2.5 Moisture Content (MC)

Moisture content for both field and test moisture conditions were determined from the firmly secured (air tight) cube specimens obtained on the field, and from slices obtained from the beam specimens respectively [32], employing the expression given in equation (1) [2,9,10]. The initial mass of test specimens were obtained with the aid of a digital weighing balance, before laboratory oven drying at a temperature of 103 ± $2^0$C (for 24hours) [9,10], until a constant mass was attained.

$$\text{MC} = \frac{m_1 - m_2}{m_2}\,x\,100 \qquad (1)$$

**Fig. 4. Specimen undergoing flexural test**

The MC of the sample was taken as the mean value of the MC ($\overline{MC}$) for all the specimens [9], and computed using equation (2).

$$\overline{MC} = \frac{\sum MC_i}{n} \quad (2)$$

**Fig. 5. Specimen undergoing compressive test**

## 2.6 Density

The density of specimens at the test MC were determined with the aid of a digital weighing balance and a vernier caliper, in accordance with [2,32], and expressed mathematically as indicated in equation (3).

$$\rho = \frac{M}{V} \quad (3)$$

The Characteristic value for density was determined in accordance with [2,9,10,36], expressed as equation (4).

$$\rho_k = \rho_{0.5} = \bar{\rho} - 1.65s \quad (4)$$

Adjustments were made to the characteristic values for density (at the test MC) using equation (5a) & (5b) [2,13]; to conform to reference grading conditions. This is with reference to conditions provided by [35,36] and provision by international grading standards [7].

$$\rho_{k,(w_{ref})\%} = \rho_{k,12\%} = \rho_W\,(1 + \alpha(W - 12)) \quad (5a)$$

$$\rho_{k,(w_{ref})\%} = \rho_{,k,18\%} = \rho_W\,(1 + \alpha(W - 18)) \quad (5b)$$

$\alpha$ *was taken as*: $0.005$ [2, 36]

## 2.7 MOR and MOE

The three point bending strength test arrangement, as shown in Fig. 6 and as specified by [32,33,34], were adopted for the determination of MOR and MOE of the wood samples [9,10,12,13].

## 2.8 Modulus of Rupture

With reference to the three point test arrangement, failure and maximum deflection occurred approximately at the midpoint of the span, for all the test specimens. The MOR at this point in accordance with ASTM D193 [10] was computed as equation 6.

$$f_m = \frac{3\mathrm{F_{max}}l}{2bh^2} \quad (6)$$

The characteristic value for MOR according to [36] was employed as expressed in equation (7a).

$$f_{m,k} = \bar{f}_{0.5}k_S k_V \quad (7a)$$

This was adapted conservatively for the single set of samples, and expressed as equation (7b).

$$f_{m.k} = f_{0.5}k_S k_V \quad (7b)$$

Equation (7b) was subject to penalty as required by section 5.1 and as specified in section 5.4 of BS EN 384 [9,10,36].

The 5-percentile value of the single sample, $f_{0.5}$ was computed as expressed by equation (8).

$$f_{0.5} = \bar{f} - 1.65s \quad (8)$$

The final characteristic value for MOR was computed as expressed by equation (9), following the substitution of values ($k_s$ and $k_v$) obtained from BS EN 384 [36], into equation 7a and 7b.

$$f_{m,k} = (0.7)(1.12)f_{0.5} = 0.784f_{0.5} \quad (9)$$

Using equation (10a) and (10b) respectively, MC adjustment was made to the characteristic value of MOR, with respect to the measured MC and with reference to BS EN 338 [36]; to conform to the equivalent reference moisture conditions of 12% and 18% [2, 13].

$$f_{m,k,12\%} = f_W\,(1 + \alpha(W - 12)) \quad (10a)$$

$$f_{m,k,18\%} = f_W\,(1 + \alpha(W - 18)) \quad (10b)$$

$\alpha = 0.04$ [37].

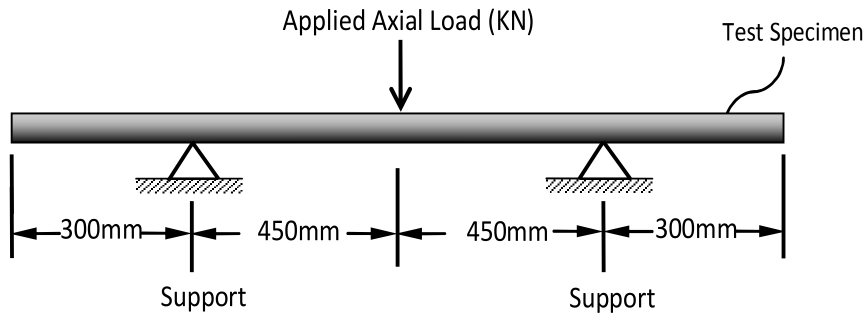


**Fig. 6. Schematic diagram of the three Point loading**

## 2.9 Modulus of Elasticity

The stiffness of the timber specie as measured by the MOE was obtained from graphical plots of the relationship between the applied flexural load and the induced vertical displacement at the mid-span of each beam specimen. This was computed using equation (11) as specified by [10, 32, 33].

$$E_m = \frac{l^3(F_2-F_1)}{48\mathrm{I}(w_2-w_1)} \equiv \frac{l^3(F_2-F_1)}{4bd^3(w_2-w_1)} \qquad (11)$$

The slopes of the individual regression lines to the graphical plots (within elastic limits), is represented by the ratio $(F_2 - F_1)/(w_2 - w_1)$ as implied in equation (11) above.

The characteristic value for MOE (based on the measured MC), also regarded as the mean value ($E_{mean}$ or $\overline{E}$), was computed using equation (12) in accordance to section 5.3.2 of BS EN 384 [2,10, 36].

$$E_{m.k} = \bar{E} = \left[\frac{\sum E_i}{n}\right] 1.3 - 2690 \qquad (12)$$

With reference to [7,36], and with regards to the measured MC, adjustments were also made to the characteristic value of MOE, to conform with the reference MC conditions (12% and 18%) by applying equations (13a) and (13b) as recommended by [2,13].

$$E_{m,k,12\%} = E_W\,(1 + \alpha(W-12)) \qquad (13a)$$

$$E_{m,k,18\%} = E_W\,(1 + \alpha(W-18)) \qquad (13b)$$

$\alpha$ = 0.02 [34]

## 2.10 Compressive Strength

The maximum compressive strength parallel and perpendicular to grain (required for validation) were computed from experimental test data, as expressed in equations (14a) and (14b) respectively.

$$f_{c,0,} = \frac{\mathrm{F_{c,max,0}}}{\mathrm{A}} \qquad (14a)$$

$$f_{c,90,} = \frac{\mathrm{F_{c,max,9\ 0}}}{\mathrm{bL}} \qquad (14b)$$

Estimates for the characteristic values for maximum compressive strength (parallel and perpendicular to grain) at 12% and 18% MC based on the characteristic flexural strength and the characteristic density values, and with reference to [36], are as articulated by the empirical expressions given in equations (15a) and (15b);

$$f_{c,0,k} = 5\left(f_{m,k}\right)^{0.45} \qquad (15a)$$

$$f_{c,90,k} = 0.015\rho_k \ - for\ hardwoods \qquad (15b)$$

The values obtained from (15a) and (15b) were lower than the experimentally computed values, and were not employed for the validation.

## 2.11 Other Properties Required for Grade Validation

The characteristic values (at 12% MC) for other relevant properties required for grade validation were estimated from empirical expressions adopted, and employed as presented in section 7.2.2 of BS EN 384 [36]; as structural test size data were unavailable to obtain these properties. They include; tensile strength parallel to grain ($f_{c,0,k}$); tensile strength perpendicular to grain ($f_{c,90,k}$) ; 5% MOE parallel to grain ($E_{0,0.5}$); Mean MOE perpendicular to grain, ($E_{90\ mean}$) and mean shear modulus, ($G_{mean}$). The expressions are as detailed in equations (16) to (20).

$$f_{t,0,k} = 0.6 f_{m,k} \quad (16)$$

$$f_{t,90,k} = \text{Minimum} \begin{cases} 0.6 \\ 0.0015\rho_k \end{cases} \quad (17)$$

$$E_{0,0.5} = 0.84 E_{0,mean} - hardwoods \quad (18)$$

$$E_{90,mean} = E_{0,mean}/15 - hardwoods \quad (19)$$

$$G_{mean} = E_{0,mean}/16 \quad (20)$$

Shear strength values ($f_{v,k}$); were obtained directly from Table 1 of EN 338 [38]; while allocation to strength/grade class was based on standards presented by BS EN 338 [38].

All tests for the rubberwood were done at field and test conditions, 77.94% MC and 64.29% MC respectively

## 3. RESULTS AND DISCUSSION

The test results and statistical analysis for the physical properties of the rubberwood are presented in Table 1. The characteristic value for green density was established as 903.308 Kg/m$^3$ at the initial mean MC (77.94%), while the characteristic density at the test MC (64.29%) was 815.036 Kg/m$^3$, after one week of open air seasoning; at an average temperature of about 27.4$^o$C and an average relative humidity of 76% (as verified from the DSPZ Weather station). Mean values for the field/green MC typically fell within the 60% – 80% value range [22], while the initial/green density was well above 800 Kg/m$^3$ reported by [26].

Table 2 presents basic flexural properties for the tested rubberwood specimens. The mean and characteristic values for MOR and MOE for the rubberwood at the test MC (64.29%) was 42.110 N/mm$^2$ and 23.337 N/mm$^2$, and 9071.136 N/mm$^2$ and 9012.477 N/mm$^2$ respectively, while the mean and characteristic test values at test condition for deflection was 11.200mm and 9.224mm respectively. These values are comparable to values for conventional timber as presented by [7] at 80% MC, though slightly lower. Lower MOE values imply that for relatively smaller incremental applied loads, comparatively larger deflections will occur in the rubberwood when compared to most conventional timber. The mean Energy required to achieve rupture under test condition was 99.137 N.m, with a characteristic value of 54.396 N.m. This is considerably large when compared to values for conventional timber materials such as African Birch (*Anogeissus leiocarpus*) with a Rupture Energy of 13.651 N.m at 10.1% MC [13]. The relatively large Rupture Energy can be better attributed to the relatively large deflection developed prior to rupture in the rubberwood as a result of its high ductility due to its relatively wet state, rather than the quantum of load required to cause rapture.

Table 3 is a presentation of compression related mechanical properties for the rubberwood at the test MC (64.29%). The characteristic compressive strength for the rubberwood, parallel to and perpendicular to grain were obtained as 14.109 N/m$^2$ and 6.776 N/m$^2$ respectively. The characteristic value for strain developed perpendicular to grain was larger than the value developed parallel to grain, with corresponding effects in terms of energy required up to yield point. This can be attributed to the relatively large deflections witnessed when loading perpendicular to grain.

**Table 1. Physical Properties for rubberwood at Field and test conditions**

| Statistical Parameters | Initial/ Field Density, $\rho$ (Kg/m$^3$) | Initial/ Field Moisture Content (%) | Test Density, $\rho$ (Kg/m$^3$) | Test Moisture Content (%) |
|---|---|---|---|---|
| **Minimum** | 994.67 | 54.80 | 834.81 | 42.90 |
| **Maximum** | 1083.48 | 96.14 | 1012.43 | 91.14 |
| **Mean** | 996.148 | **77.94** | 920.071 | **64.29** |
| **S.D.** | 56.448 | 14.747 | 63.657 | 15.108 |
| **C. of V. (%)** | 5.665 | 18.922 | 6.919 | 23.501 |
| **Characteristic Value[a]** | **903.308** | na | **815.036** | Na |

*na – not applicable*

**Table 2. Mechanical Properties; Flexural Strength/Bending Strength Test Results at 64.29% MC**

| Statistical Parameters | Bending Strength/Stress at Yield, MOR, $\sigma$ (N/mm$^2$) | Deflection at Yield, $\delta$ (mm) | Bending Modulus, MOE, $\epsilon$ (N/mm$^2$) | Rupture Energy (N.m)/2 |
|---|---|---|---|---|
| **Minimum** | 36.00 | 9.30 | 6203.52 | 71.145 |
| **Maximum** | 52.80 | 12.90 | 15094.08 | 141.900 |
| **Mean** | **42.110** | **11.200** | **9071.136** | **99.137** |
| **S.D.** | 7.45 | 1.20 | 2697.49 | 25.314 |
| **C. of V. (%)** | 17.69 | 10.69 | 29.74 | 25.534 |
| **Characteristic Value** | **23.337** | **9.224** | **9012.477** | **54.396** |

**Table 3. Mechanical Properties; Compressive Strength test Results (at 64.29% MC)**

| Statistical Parameters | Compressive Strength/Stress at Yield, $\sigma$ (N/mm$^2$) | Strain at Yield, $\epsilon$ (%) | Deflection at Yield, $\delta$ (mm) | Youngs Modulus, E (N/mm$^2$) | Energy to Yield (N.m)/$^2$ |
|---|---|---|---|---|---|
| **Compressive Strength Parallel to Grain** | | | | | |
| **Minimum** | 16.00 | 2.67 | 2.67 | 228.20 | 1176.00 |
| **Maximum** | 26.00 | 7.36 | 7.35 | 848.30 | 1433.50 |
| **Mean** | **20.700** | **5.39** | **5.390** | **568.42** | **1119.94** |
| **S.D.** | 3.88 | 1.62 | 1.62 | 214.83 | 367.20 |
| **C. of V.** | 19.30 | 30.09 | 30.05 | 37.79 | 32.79 |
| **Characteristic Value** | **14.109** | **2.715** | **2.717** | **213.953** | **514.055** |
| **Compressive Strength Perpendicular to Grain** | | | | | |
| **Minimum** | 7.01 | 14.54 | 11.25 | 38.63 | 435.86 |
| **Maximum** | 7.98 | 16.73 | 12.40 | 42.36 | 558.00 |
| **Mean** | **7.385** | **15.57** | **11.866** | **41.138** | **490.80** |
| **S.D.** | 0.37 | 0.70 | 0.37 | 2.08 | 43.21 |
| **C. of V.** | 4.99 | 4.79 | 3.12 | 5.06 | 8.62 |
| **Characteristic Value** | **6.776** | **14.34** | **11.256** | **37.705** | **420.979** |

**Table 4a. Mean Strength values and density for rubber wood (at test MC, 64.29%), and adjusted mean values (at 12% MC and 18% MC)**

| Statistical Parameters | Bending Modulus, MOE ($N/mm^2$) | Static Bending Strength, MOR ($N/mm^2$) | Maximum Compressive Strength Parallel to Grain ($N/mm^2$) | Maximum Compressive Strength Perpendicular to Grain ($N/mm^2$) | Density ($Kg/m^3$) |
|---|---|---|---|---|---|
| **at test condition (64.29% MC)** | | | | | |
| **Mean Strength at 64.29% (Test) MC** | 9071.136 | 42.110 | 20.700 | 7.385 | 920.071 |
| **In accordance with Nigerian Standards (18% MC)** | | | | | |
| **Mean Strength at 18% MC** | 12336.745 | 57.270 | 30.015 | 10.708 | 707.141 |
| **In accordance with BS EN 348:2016 (12% MC)** | | | | | |
| **Mean Strength at 12% MC** | 14513.818 | 67.377 | 36.225 | 12.923 | 679.539 |

**Table 4b. Characteristic Strength values and density for rubber wood (at test MC, 64.29%), and adjusted mean values (at 12% MC and 18% MC)**

| Statistical Parameters | Bending Modulus, MOE ($N/mm^2$) | Static Bending Strength, MOR ($N/mm^2$) | Maximum Compressive Strength Parallel to Grain ($N/mm^2$) | Maximum Compressive Strength Perpendicular to Grain ($N/mm^2$) | Density ($Kg/m^3$) |
|---|---|---|---|---|---|
| **at test condition (64.29% MC)** | | | | | |
| **Characteristic Strength at** 64.29% **(Test) MC** | 9102.48 | 23.377 | 14.109 | 6.776 | 815.036 |
| In accordance with Nigerian Standards (18% MC) | | | | | |
| **Characteristic Strength at 18% MC** | 10740.923 | 31.793 | 20.458 | 9.826 | 626.414 |
| In accordance with BS EN 348:2016 (12% MC) | | | | | |
| **Characteristic Strength at 12% MC** | 11833.220 | 37.404 | 24.691 | 11.859 | 601.963 |

Table 4a is a comparative presentation of the mean strength values and the density for the rubberwood at the test MC (62.29%), and at both reference moisture conditions (12% and 18% MC) required for grading. The values presented are in close conformity with test values for rubberwood from related research works. Mean adjusted values for density at 12% and 18% respectively were 679.539Kg/m$^3$ and 707.141 Kg/m$^3$, while the mean values for MOR and MOE at 12% and 18% were 67.377 N/mm$^2$ and 57.270 N/mm$^2$, and 14513.818 N/mm$^2$ and 12336.745 N/mm$^2$ respectively. Values for MOE were slightly higher when compared to general results from previous research [22]; indicating that smaller deflections resulted from larger incremental changes in applied loads (within the proportional limit) when compared to results on rubberwood from Asia. The mean compressive strength parallel and perpendicular to grain at the reference grading moisture conditions (12% MC and 18% MC) were 36.225 N/mm$^2$ and 12.923 N/mm$^2$, and 30.015 N/mm$^2$ and 10.708 N/mm$^2$ respectively. The mean values were within the range of values for conventional timber materials found in Nigeria.

Table 4b presents adjusted characteristic values for mechanical properties and density in conformity with reference MC conditions (12% and 18%) for the purpose of grade allocation. It also reflects the differences in the values of the major characteristic properties for the rubberwood required for grading at 12% and 18% MC, and the values obtained at test condition (64.29%). The characteristic values for density (601.963 Kg/m$^3$, 626.414 Kg/m$^3$) at the respective reference moisture conditions (12% and 18% MC), fall within limits, for consideration of the rubberwood as a medium dense tropical hardwood as specified in [7,15,25]. The characteristic values for MOR and MOE (338.474 Kg/m$^3$, 359.212 Kg/m$^3$), at the respective reference moisture conditions (12% and 18% MC), also fall within limits specified by EN 338 [7] for consideration of the rubberwood as a hardwood. As such, based on the values presented in Table 4b, the properties of the rubberwood best fits the strength grade class D35 at 12% MC, with reference to [36], and D30 at 18% MC, in accordance with [35]; as presented in Table 5.

Comparing property values in Table 4a and 4b; the characteristic values (Table 4b) were as expected generally lower than the mean values (Table 4a) as a result of the safety considerations implied by the principles behind the concept of the term ”characteristic values” as required for purposes of design and construction.

The mean and characteristic values of the physical and mechanical properties of the rubberwood at the test condition (64.29% MC), is important in this study for the purpose of comparing values obtained at the test condition with values obtained at the reference MC conditions. This is necessary because the test

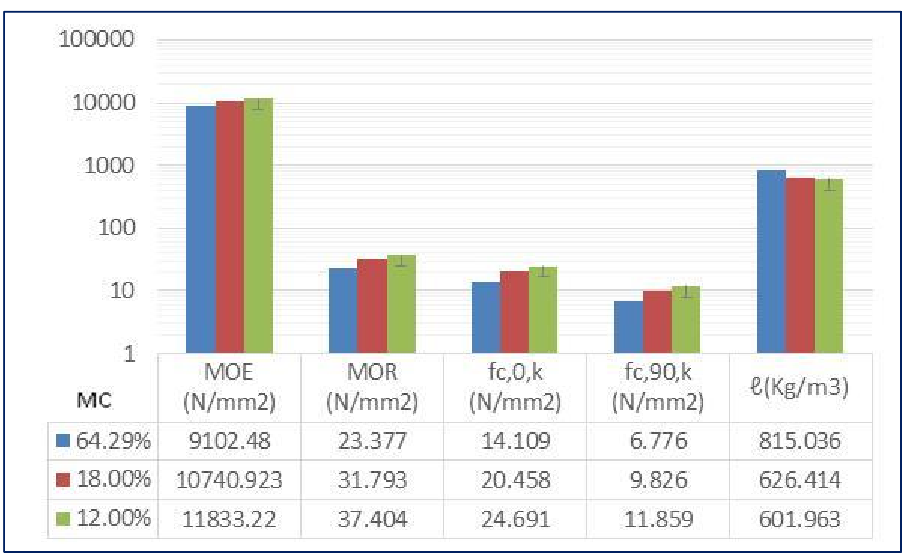


**Fig. 7. Relative characteristic values for MOR, MOE, $Fc_{,90}$ $Fc_{,0}$ and density at test condition (67.29% MC; two weeks of open air after seasoning), and at 18% MC and 12% MC**

condition represents the prevailing conditions (two weeks after felling), within which rubberwood in the Nigeria (generally), and in the Niger Delta region (in particular), is most likely to be utilized for on-site construction work. Characteristic values at the test condition for MOR, MOE, $F_{c,90}$ and $F_{c,0}$ respectively, were 76.92%, 62.39%, 57.14% and 57.14% of their respective characteristic values at the internationally stipulated reference moisture condition required for grading (12% MC). This indicates that they are generally employed for utilization under conditions in which their prevailing characteristic property values are lower (between 24% – 43%) than their perceived international standard grade values. The density of the rubberwood at the test condition (64.29% MC) was however 26.14% higher than its density at 12% MC. Values for MOR, MOE, $F_{c,90}$ and $F_{c,0}$ at the test condition (64.29% MC), were 90.77%, 85.00%, 82.84% and 82.85% respectively, of their related values at 18% MC (stipulated for the Nigerian environmental condition); that is, between 9% – 15% lower. The density of the rubberwood at the test condition (64.29% MC) was about 3.9% higher than the value at 18% MC. Characteristic property values at 18% MC were generally within 80% of the values at 12% MC. Fig. 7 shows the relative characteristic property values at the test condition (after two weeks of open air seasoning; 67.29% MC), at 18% MC and at 12% MC, with a 33% mark indicator for MOR, MOE, $F_{c,90}$ and $F_{c,0}$, with respect to values at 12% MC (referenced as 100.00%). Also reflected, are the relative characteristic values for density, for the three moisture content conditions (64.29% MC, 18% MC and 12% MC).

Table 5 presents a confirmation of the selected grade classes. It presents a comprehensive and comparative representation of the characteristic values and the required validations for the confirmation of the allocated grade classes. All observed/estimated characteristic values fall within 95% [7] of the values specified for the relevant grade classes. The study revealed that the specified grade classes for the rubberwood, D30 and D35 (at 18% MC and 12% MC respectively) fall within the D24 and D70 grade class range for hardwoods; with the letter D in the grade classification standing for deciduous tree species, while the numbers (30 and 35), stand for the characteristic bending strength (in N/mm$^2$) of the timber species at the respective moisture contents [1, 9, 10, 13].

Table 6 presents other related structural properties which further qualify the structural behaviour and characteristics of the rubberwood (as found in Nigeria) for use as a structural material. These structural properties are not strictly required for purpose of grading, but may be necessary for design, construction and research purposes.

Fig. 8 is a graphical presentation of the load/deflection behaviour of the 50 x 75 x 500mm specimens up to the point of failure, while Fig. 9 is a presentation of the load/deflection behavior (within elastic limits), for the individual rubberwood specimens employed for the test, and the respective regression lines employed in the determination of their individual MOE. Also indicated alongside the regression lines, are their representative mathematical expressions and the coefficient of determination, $R^2$, which ranged between 0.964 and 0.991, indicating fairly good fit and representations by the regression lines.

Fig. 10 presents a generalized graphical and mathematical model of the load deflection behaviour for the rubberwood within elastic limits; produced from a scatterplot of the load/deflection behaviour for all the specimens employed. The mathematical representation of the model is represented by equation (21), with a significant quality of fit indicated by a coefficient of determination, $R^2$ of 0.805, indicating a strong and positive linear relationship, but with a significant initial delay in deflection with load application.

$$F_x = Kw + 1.222 \tag{21}$$

Where; $F_x$ = applied load,

K = the bending stiffness (flexural rigidity) obtained as the slope of the load deflection plot (K= 0.848), and

w = is vertical deflection at mid-span.

From this modeled relationship, the maximum stress (MOR) and strain within the elastic limit are 43.68N/mm$^2$ and 4.39E-3 as obtained from expression (22) and (23) respectively, while the representative MOE for the model is 9293.405N/mm$^2$ as obtained from expression (24).

$$\epsilon_{\max} = \frac{6w_{max}\mathrm{h}}{l^2} \tag{22}$$

**Table 5. Basic Strength Grading Requirements and Observed/Estimated Characteristic Properties, and strength values for Rubber wood at 12% and 18% MC**

| S/N | Material Properties | GRADE REQUIREMENTS BS EN 384 | | OBSERVED/ESTIMATED VALUES (adjusted characteristic values) | |
|---|---|---|---|---|---|
| | | Assigned grade/Strength class at 12% MC (D35) | Assigned grade/Strength class at 18% MC (D30) | 12% | 18% |
| | **Strength Properties** | | | | |
| i | Bending strength (MOR) , $f_{m,k}$ (N/mm$^2$) | 35 | 30 | 37.404 | 31.793 |
| ii | Tensile Strength Parallel to grain, $f_{t,0,k}$(N/mm$^2$) | 21 | 18 | 22.442* | 19.076* |
| iii | Tensile Strength Perpendicular to grain, $f_{t,90,k}$ (N/mm$^2$) | 0.6 | 0.6 | 0.6* | 0.6* |
| iv | Compressive stress Parallel to grain, $f_{c,0,k}$ (N/mm$^2$) | 25 | 23 | 25.514*/24.691 | 23.715*/20.458 |
| v | Compressive stress Perpendicular to grain, $f_{c,90,k}$ (N/mm$^2$) | 8.1 | 8.0 | 9.029*/11.859 | 9.396*/9.826 |
| vi | Shear Strength, $f_{v,k}$ (N/mm$^2$) | 4.0 | 4.0 | 4.0* | 4.0* |
| | **Stiffness Properties** | | | | |
| i | Mean MOE parallel to grain, $E_{0\ mean}$(KN/mm$^2$) | 12 | 11 | 11.833220 | 10.740923 |
| ii | 5% MOE parallel to grain, $E_{0,05}$ (KN/mm$^2$) | 10.1 | 9.2 | 9.939905* | 9.022375* |
| iii | Mean MOE perpendicular to grain, $E_{90\ mean}$ (KN/mm$^2$) | 0.80 | 0.73 | 0.788881* | 0.716062* |
| iv | Mean Shear Modulus, $G_{mean}$ (KN/mm$^2$) | 0.75 | 0.69 | 0.739.576* | 0.671308* |
| | **Density** | | | | |
| i | Characteristic Density,$\rho_k$ (Kg/m$^3$) | 530 | 540 | 601.963 | 626.414 |
| ii | Mean Density,$\rho_{mean}$(Kg/m$^3$) | 640 | 650 | 722.356*/679.539 | 751.697*/707.141 |

**Estimated values form Table 4 [7]*

**Table 6. Other significant strength/stiffness related properties for rubberwood**

| S/N | Material Properties | GRADE REQUIREMENTS | | OBSERVED/ESTIMATED VALUES Rubber (adjusted characteristic values) | |
|---|---|---|---|---|---|
| | | Grade designation for Palm at 12 % MC BS EN 384:2004 (D24 ) | Grade designation for Palm at 18 % MC BS EN 384:2004 (D18) | 12% | 18% |
| I | Young's Modulus in compression Parallel to grain, $E_{c,0}$ (KN/mm$^2$) | ns | ns | 0.279138 | 0.252464 |
| ii | Young's Modulus in compression Perpendicular to grain, $E_{c,90}$ (KN/mm$^2$) | ns | ns | 0.049016 | 0. 044491 |
| iii | Compressive strain at yield parallel to grain, $\epsilon_{c,0}$ (%) | ns | ns | 4.75 | 3. 94 |
| iv | Compressive strain at yield Perpendicular to grain, $\epsilon_{c,90}$ (%) | ns | Ns | 25.1 | 20.8 |

*ns – not supplied*

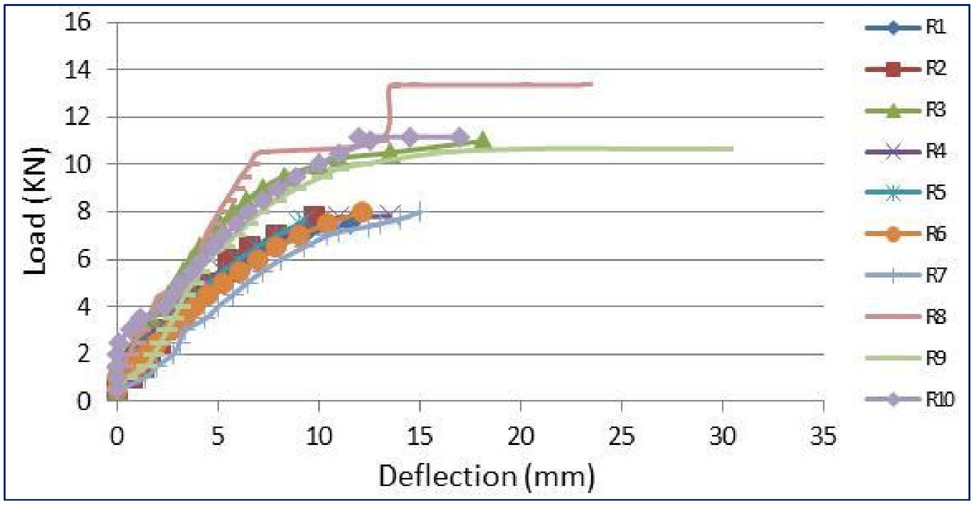


**Fig. 8. Flexual load/deflection behaviour for rubberwood specimens up to failure point**

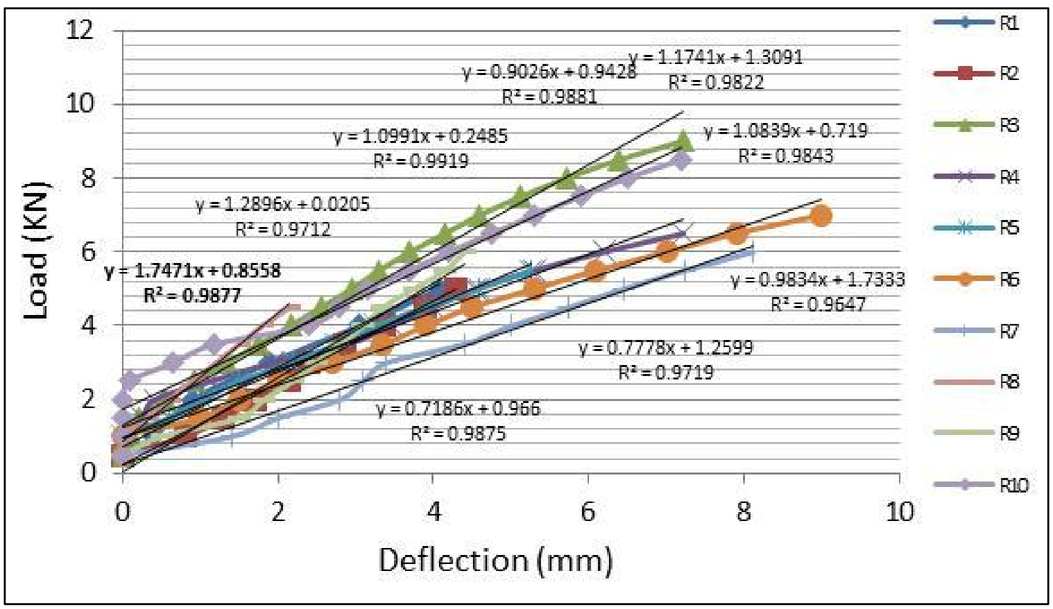


**Fig. 9. Flexual load/deflection behaviour for rubberwood specimens within elastic limits**

$$\sigma_{\max} = \frac{3F_{max}l}{2bh^2} \quad (23)$$

$$E_m = \frac{l^3(F_{max})}{48I(w_{max})} \quad (24)$$

where $F_{max}$ employed in the determination of $E_m$ takes into consideration the lag between load application and the inducement of deflection as indicated in the graphical models.

Fig. 11 is the resulting graphical stress-strain model (within elastic limits) for the rubberwood at test condition (two weeks after open air seasoning) arising from the load-deflection model developed, and here expressed mathematically as;

$$\sigma = E\epsilon + 2.88 \quad (25)$$

where E = 9293N/mm$^2$

Results from the models do not represent characteristic values. Values obtained from the models are however similar to mean values of results obtained from the test.

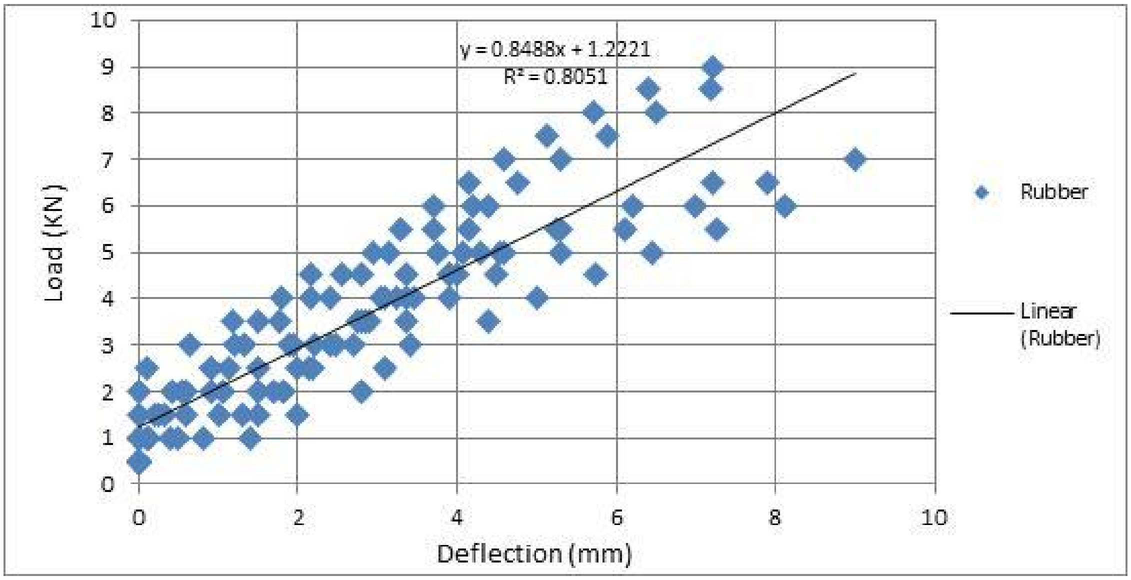


**Fig. 10. Graphical regression model; load/deflection behaviour for rubberwood specimens within elastic limits**

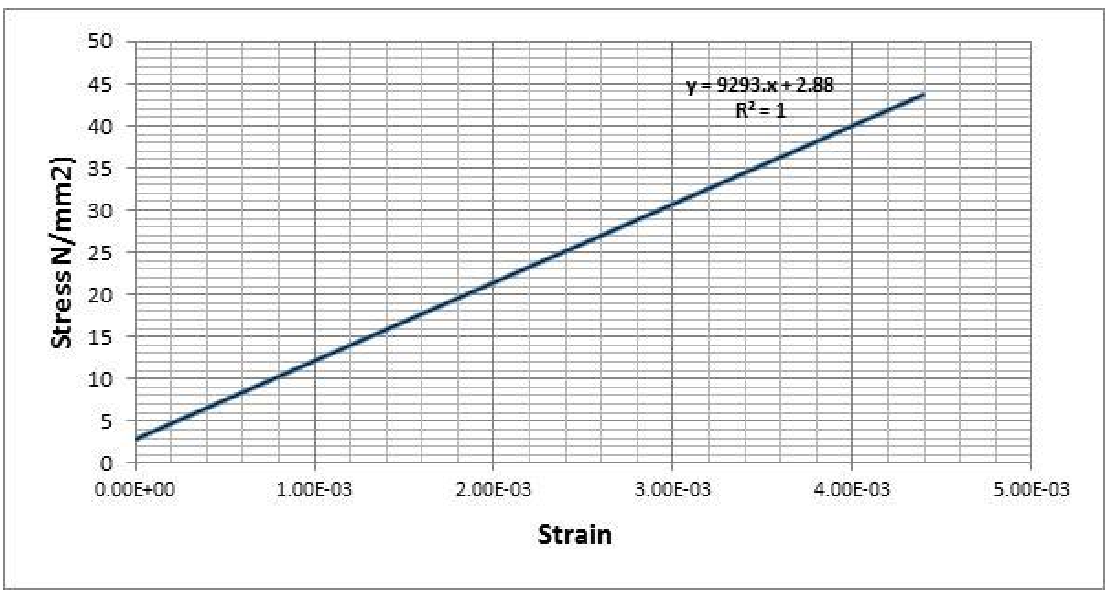


**Fig. 11. Graphical regression model; load/deflection behaviour for rubberwood in the Niger Delta within elastic limits**

## 4. CONCLUSION

Laboratory test were conducted to determine the physical and mechanical properties of rubberwood obtained from the Niger Delta region of Nigeria, at three moisture content conditions; that is, at the test condition (64.29% MC), at 12% MC and at 18% MC. Three basic properties were required for grading; MOE, MOR and the material density. The flexural properties of the rubberwood (MOE, MOR) were determined using the three point bending test, while density was obtained gravimetrically. Other related mechanical properties were obtained using compressive test specimens, and estimations based on BS EN 408 [32], BS EN 338 [7] and BS EN 384 [12] requirements. The characteristic values for the material properties were adjusted to the reference moisture conditions (12% MC and 18% MC) based on requirements provided by BS EN 338 [7] for international conditions, and NCP 2 [35] (specified for the local Nigerian environment).

Mean and characteristic values for MOR and MOE, at the time of testing (two weeks after open air seasoning), were 42.11N/mm$^2$ and 23.337N/mm$^2$, and 9071.136N/mm$^2$ and 9102.480N/mm$^2$ respectively, with mean and characteristic densities of 920.071kg/m$^3$ and 815.036kg/m$^3$; while the characteristic values for MOR and MOE at 12% MC and 18% MC, were 67.377N/mm$^2$ and 37.404N/mm$^2$, and 57.270N/mm$^2$ and 31.793N/mm$^2$ respectively. The mean and characteristic density at 12% MC and 18% MC, were 679.539kg/m$^3$ and 707.141kg/m$^3$, and 601.963kg/m$^3$ and 626.414kg/m$^3$ correspondingly. Under field conditions, the mean and characteristic green density was established as 996.148kg/m$^3$ and 903.308kg/m$^3$. Values at the three moisture content conditions varied significantly (P<5). The characteristic values were generally lower than the Mean values based on safety considerations; required for application in design. Generally also, the values of the mechanical properties after two weeks of open air seasoning (67.29% MC), at which time the rubberwood is usually employed for construction work, were between 24% - 43% lower than their related values at 12% MC, while mechanical properties values at 18% MC were within 80% of their related values at 12% MC. The test values at 67.29% MC were between 12% - 15% lower than the values at 18% MC. The density of the rubberwood at 12% MC was 3.9% lower than the density at 18% MC, and 26% lower than the density at test condition (67.29% MC).

Conventional grading based on the characteristic values for MOR, MOE and density, at 12% and 18% MC respectively, placed rubberwood obtained from the Niger Delta area of Nigeria in the strength/grade classes, D30 and D35 respectively, and within the strength range of common conventional hardwood timber found in Nigeria. The results characterize rubberwood obtained from the region as a medium density hardwood. From the results obtained, rubberwood as acquired from the Niger Delta region can be conveniently employed as an alternative to local conventional hardwood timber. Also, they compare favorably with rubberwood employed extensively as furniture wood in other regions of world. However, adequate treatment must also be provided to ensure durability immediately after felling (boron impregnation, CCA impregnation, etc.) while strength generally may be further enhanced by supplementary treatment involving superheated steam treatments.

Finally, representative graphical and mathematical models for the elastic behaviour (force-deflection and stress-strain relationships) for rubberwood as obtained from the Niger Delta area of Nigeria, and employed within two weeks of felling, are presented; from a regression analysis of the scatterplot of the flexural test results. The mathematical expression for the stress-strain relationship is given as; $\sigma = E\epsilon + 2.88$ , while the force-deflection relationship is given as; $F_x$ = Kw + 1.222. For both models, the values for MOR, MOE and w were similar to mean values from test results. The flexural models are suitable for simulating the flexural behaviour of the rubberwood within two weeks of felling and under serviceability conditions, but they do not however represent characteristic values.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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