

Strength Characterization and Grading of Eku (*Brachystegia eurycoma*) Timber grown in Kwara State, Nigeria in accordance to BS 5268

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Abstract

Strength grading of timber offers a number of advantages both to the designer and the supplier of timber. This study reveals characterization and grading of Nigerian grown Eku (*Brachystegia eurycoma*) timber using BS 5268 (2002). Specimens used in the experiment were obtained from sawmills in Kwara State, Nigeria. The samples were seasoned naturally for seven months and prepared according to British Standard BS 373 (1957) Methods of Testing Small Clear Specimen of Timber. Test carried out on the prepared specimens were bending, tension, compression and shear parallel to grain, compression perpendicular to grain, moisture content and density. The timber properties determined were adjusted to the values at 12% and 18% moisture content in conformity with BS 5268 (2002) and NCP 2 (1973) for application in the Northern part of Nigeria. All the results were analyzed statistically. Eku has an average moisture content of 11.78% and mean air-dried density of 1148.25kg/m³. The Basic and grade stresses were computed using experimental failure stresses. The material properties showed that, Eku (*Brachystegia eurycoma*) can be graded and assigned to strength class D40. Therefore Eku timber has been successfully characterized and graded in accordance to British Standard and thereby recommended for load bearing structure like bridge beams.

Keywords

Characterization, grading, strength properties, three point bending

1. Introduction

Timber is a complex building material owing to its heterogeneity and species diversity. Nigeria is one of the countries that have timber in surplus quantity (Zziwa, *et. al.*, 2016). If this natural resources is properly utilized, it will be of immense benefit to the country in terms of reduction in the cost of construction (Aguwa, 2012; Ibitolu and Jimoh, 2017). Timber does not have consistent, predictable, reproducible and uniform properties as the properties vary with species, age, site and environmental conditions (Kliger, 2000). The strength of a timber depends on its species and the effects of certain growth characteristics (Yeomans, 2003). Different wood species have different strength characteristics. And also within a species these characteristics may vary. Therefore, in practice, a classification system of strength classes is used (Jamala, *et. al.*, 2013). The need for local content in construction of engineering infrastructure is now a serious engineering challenge in Nigeria. This is because vast quantities of local raw materials, which must be processed and used for cost effective abound (Aguwa, 2010). Construction activities based on these locally available raw materials are major steps towards industrialization and economic independence for developing countries. This explains huge interest and considerable intellectual resources being invested in understanding the mechanical or structural properties of the Nigerian timber (Aguwa and Sadiku, 2011).

Brachystegia eurycoma is an economic tree crop that grows in the tropical rainforest of West Africa. It belongs to the caesalpiniaceae family, the spermatophyte phylum and of the order of fabaceae. *Brachystegia eurycoma* is a woody plant mostly found in the forest zone. The tree is about 40m tall, with bole of 2m diameter. It is vaguely buttressed, has low branching, large, flat crown common on river banks of the forest zone in southern Nigeria and Cameroun. It is also a very popular plant in the Western and Eastern part of Nigeria. The sap wood is white, not durable and quickly rotting on exposure. It may be readily recognized by its large size, irregular bole and huge twisted spreading branches and by the rough fibrous bark which peels off in untidy patches and often exudes a brownish buttery gum. It is also a very popular plant in the Southern (Eastern and Western) part of Nigeria. In Nigeria, it is commonly called Achi (Igbo), Akalado or Eku (Yoruba), Akpakpa or Apaupan (Ijaw), Dewen (Bini), Okung (Efik).

Brachystegia eurycoma timber is commonly used in Nigeria mostly in South Eastern and Western part as roof truss materials without knowledge of its engineering properties because this specie has not been characterized and graded or listed in NCP2 (1973) or any other acceptable international code (Ogunwusi, *et. al.*, 2013). There is need to determine the physical and mechanical properties of *Brachystegia eurycoma* since it is locally grown and used as structural materials in construction. Some timber strength properties listed in British Standard or European code were based on timber obtained from trees in those areas and the laboratory tests were conducted there (Aguwa, 2010). The determined properties like density, grade bending stress and mean modulus of elasticity were used for grading and assigning strength class according to international code (BS 5268 part 2, 2002). The aim of this study was to characterize and grade South Western Nigeria grown *Brachystegia eurycoma* timber in accordance with BS 5268 (2002). The specific objectives were to purchase, season, prepare samples of *Brachystegia eurycoma*, determine its physical and mechanical properties according to BS 373 (1957) and to grade *Brachystegia eurycoma* timber specie in accordance with BS 5268 (2002). Forgetting can be reduced by repetition and/or more elaborate cognitive processing of information.

2. Materials and methodology

2.1 Materials

Timber materials used in this study were collected from matured *Brachystegia eurycoma* tree at green condition from Irewolede sawmill, Ilorin, Nigeria and sawn to size 100x150x3600mm. Five logs of timber free from defects were carefully selected and they were reduced to 100x150x1800mm for easy transportation to the Wood section of the Department of Civil Engineering laboratory, University of Ilorin, Nigeria for seasoning, preparation and testing.

2.2 Preparation of Test Specimens

Test specimens were seasoned for seven months to reach equilibrium moisture condition (EMC) at Wood section of Department of Civil Engineering Laboratory, University of Ilorin, Nigeria. Natural seasoning method was adopted in line with Aguwa (2010). Forty (40) samples were prepared for different laboratory tests which include three point bending strength parallel to the grain, shear strength parallel to the grain, tension

strength parallel to the grain, compressive strength parallel to the grain, compressive strength perpendicular to the grain, natural moisture content and density according to BS 373 (1957).

2.3 Determination of Physical and Mechanical Properties

Physical and strength properties for the various mechanical tests were determined using the prepared samples in the Department of Agricultural and Biosystems Engineering, University of Ilorin, Kwara State using Universal Testing Machine (UTM), Testometric Model DBBMTCL of 300kN capacity with computer interface for data acquisition and analysis. Tests carried out include three point bending strength parallel to the grain, shear strength parallel to the grain, tension strength parallel to the grain, compressive strength parallel to the grain, compressive strength perpendicular to the grain, natural moisture content and density according to BS 373 (1957). In each set of the tests, failure loads were recorded for computation of failure stresses, mean failure stress, standard deviation and coefficient of variation. The corresponding load deformation graphs were plotted automatically.

2.3.1 Stresses at 12% and 18% Moisture Content

Failure stresses for bending parallel to the grain, tension parallel to the grain, compression parallel to the grain, compression perpendicular to the grain and shear parallel to the grain were adjusted to values at 12% and 18% moisture content in accordance with BS 5268 (2002) and NCP 2 (1973). Equation (1) and (2) was used for the adjustment.

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

$$F_{18} = F_w(1 + \alpha(W - 18)) \quad (2)$$

where F_{12} = failure stress at 12% moisture content, F_{18} = failure stress at 18% moisture content w = experimental moisture content in (%), F_w = experimental failure stress, α = correction factor (Bending = 0.04, compression = 0.05, shear = 0.03, tension = 0.05 and MOE = 0.02).

2.3.2 Modulus of Elasticity

Based on three points bending test, Equation (3) from the strength of materials applied to straight beams was used, in conformity with Aguwa, et al., (2010).

$$E_{L3} = \frac{l^3}{4eh^3} k \quad (3)$$

where E_{L3} is the three point bending modulus of elasticity, l is the distance between the two supports (280mm), e is the width of the beam (20mm), h is the height of the beam (20mm) and k is the slope of load deformation graph that is $\frac{\Delta p}{\Delta f}$. Minimum modulus of elasticity was determined with Equation (4)

which shows the relationship between mean modulus of elasticity, E_{mean} and the minimum modulus of elasticity, E_{min} .

$$E_{min} = E_{mean} - \frac{2.33\sigma}{\sqrt{N}} \quad (4)$$

where N is the number of specimens, σ is the standard deviation

2.3.3 Modulus of Elasticity at 12% and 18% Moisture Content

Moduli of elasticity at experimental moisture content were adjusted to values at 12% and 18% moisture content in conformity with BS 5268 (2002) and NCP 2 (1973). The adjusted values were computed with Equation (5) and (6).

$$E_{m12} = \frac{E_{measured}}{1 + 0.0143(12 - u)} \quad (5)$$

$$E_{m18} = \frac{E_{measured}}{1 + 0.0143(18 - u)} \quad (6)$$

Where $E_{measured}$ = the modulus of elasticity at experimental moisture content, E_{m12} = Modulus of elasticity at 12% moisture content, E_{m18} = Modulus of elasticity at 18% moisture content and U = experimental moisture content.

2.3.4 Determination of Moisture Content

Samples of size 20x20x40mm were cut from the seasoned timber and used for the determination of the moisture content in accordance with BS 373 (1957). The oven temperature was maintained constantly at $103 \pm 2^\circ\text{C}$ for

several hours until a stable mass was obtained. Equation (7) was used for the calculation of moisture content.

$$MC = \frac{m_1 - m_2}{m_2} \times 100\% \quad (7)$$

Where MC = moisture content, m_1 = Initial mass of timber before oven dried, m_2 = final mass of timber after oven dried.

2.3.5 Determination of Density

Five samples of the timber with size 20x20x20mm were used for the determination of the density in accordance with BS 373 (1957). Density was calculated using Equation (8).

$$\rho = \frac{m}{v} \quad (8)$$

Where, ρ = density of the timber specimen, m = the mass of the timber specimen, and v = volume of the timber specimen.

2.3.6 Density at 12% and 18% Moisture Content

The densities computed from test results in kg/m^3 were adjusted to values at 12% and 18% moisture content in accordance with BS 5268 (2002) and NCP 2 (1973). Equation (9) and (10) was used for the adjustment.

$$\rho_{12} = \rho_w \left[1 - \frac{(1 - 0.5)(u - 12)}{100} \right] \quad (9)$$

$$\rho_{18} = \rho_w \left[1 - \frac{(1 - 0.5)(u - 18)}{100} \right] \quad (10)$$

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 %.

2.3.7 Basic and Grade Stresses

Basic stresses for bending, tensile, compressive, shear parallel to the grain, compressive stress perpendicular to the grain, were calculated from failure

stresses. Equation (11) was used for the computation. Various grade stresses at 80%, 63%, 50% and 40% values respectively were calculated according to Ozelton and Baird (1982).

$$f_b = \frac{f_m - k_p \sigma}{k_r} \quad (11)$$

Where f_b = basic stress, mean failure stress at 12% moisture content, σ = standard deviation of failure stress, k_r = reduction factor and k_p = modification factor = 2.33, K_r for bending, tension and shear parallel to the grain = 2.25. K_r for compression parallel to the grain = 1.4 while K_r for compression perpendicular to the grain = 1.2 (Aguwa et al., 2015).

2.3.8 Test specimen arrangements

The plates below show the test specimen arrangement for various mechanical/strength tests carried on the timber specie using Testometric Universal Testing Machine (UTM) of capacity 300kN in Agricultural and Biosystems Engineering Laboratory, University of Ilorin, Nigeria.



Figure 1: Compression Test set-up



Figure 2: Bending Test set-up

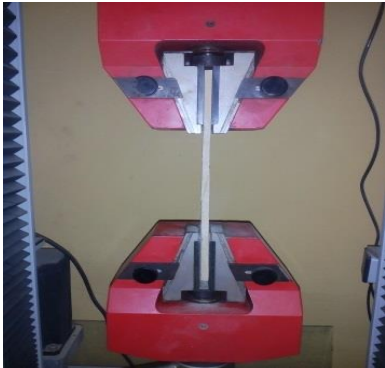


Figure 3: Tension Test set-up



Figure 4: Tension Test set-up

3.0 Results and discussion

Table 1 shows the statistical results for *Brachystegia eurycoma* such as the minimum, maximum, mean, standard deviation, coefficient of variation, 95% and 99% confidence limit of density at experimental moisture content are equally shown in the table. The mean value of the density was 1148.25kg/m³ with standard deviation and coefficient of variation of 62.29kg/m³ and 5.43% respectively. According to Findlay (1975), Bush mango can be classified as a heavy wood. The density obtained fall between 800–1200kg/m³ belonging to strength class of D30-D70. The timber specie is hardwood according to BS 5268 (2002).

Table 1: Summary of the density result

Timber	Density (kg/m ³)						Confidence Limit
	Min.	Max.	Mean	Std. Dev.	COV		
Eku	1038.75	1252.34	1148.25	62.29	5.43	95%	99%
						1123.83≤x≤1172.67	1116.16≤x≤1180.34

Table 2 and 3 present the statistical moisture content results of the following test: Bending parallel to the grain, tension parallel to the grain, compression parallel to the grain, compression perpendicular to the grain and shear

parallel to the grain on *Brachystegia eurycoma* samples and the average moisture content of the experiments. The mean value of moisture content was 11.78% which fall below the fibre saturation point (FSP). The FSP is usually between 25-30% moisture content (Nabade, 2012) while the 95% and 99% confidence limits for the moisture content value of this timber specie was also found to be satisfactory, since the determined value from the test was within the confidence limits.

Table 2: Natural moisture content of *Brachystegia eurycoma*

Timber	Bending parallel	Tension parallel	Com. pa.	Com. perp.	Shear par.	Mean MC (%)
<i>Brachystegia eurycoma</i> (Eku)	11.52	11.94	10.95	11.12	11.94	11.78
	10.27	12.15	10.57	12.23	10.84	
	12.79	11.47	11.48	12.67	12.39	
	9.64	11.02	12.34	12.63	11.68	
	11.39	13.87	12.06	13.17	12.28	

Table 3: Summary of the moisture content results

Timber	Moisture content (%)					Confidence Limit 99%
	Min.	Max.	Mean	Std. Dev.	COV	
Eku	9.64	13.87	11.78	0.95	8.05	11.41≤x≤12.15

Table 4: Modulus of Elasticity at Natural moisture content

S/N	MOE (N/mm ²)	S/N	MOE (N/mm ²)	S/N	MOE (N/mm ²)	S/N	MOE (N/mm ²)
1	12427.67	6	10348.46	11	10235.42	16	12953.34
2	11563.43	7	10743.68	12	10578.89	17	10998.46
3	10934.67	8	10823.65	13	11954.34	18	11589.56
4	10583.45	9	11145.90	14	12347.13	19	9426.08
5	10005.74	10	12065.46	15	11869.35	20	11825.10
E _{min.}							9426.08
E _{max}							12953.34
E _{mean}							11220.99
S/D							911.55
COV							8.124

Table 4 shows modulus of elasticity at experimental moisture content, sample 19 have the least modulus of elasticity 9426.08N/mm^2 while sample 16 have the highest value of modulus of elasticity 12953.34N/mm^2 with standard deviation(S/D) and Coefficient of variation(COV) of 911.55N/mm^2 and 8.12%.

Figure 5 shows the relationship between the force and deflection of timber beams (*Brachystegia eurycoma*) under static bending load. Loads were applied at a constants peed of 0.12mm/s until the materials failed. This relation confirms timber as an elastic structural material which does not undergo plastic stage of deformation (Aguwa, 2010). It was also observed that as the force on the beam increased the deformation also increases until elastic limits were attained.

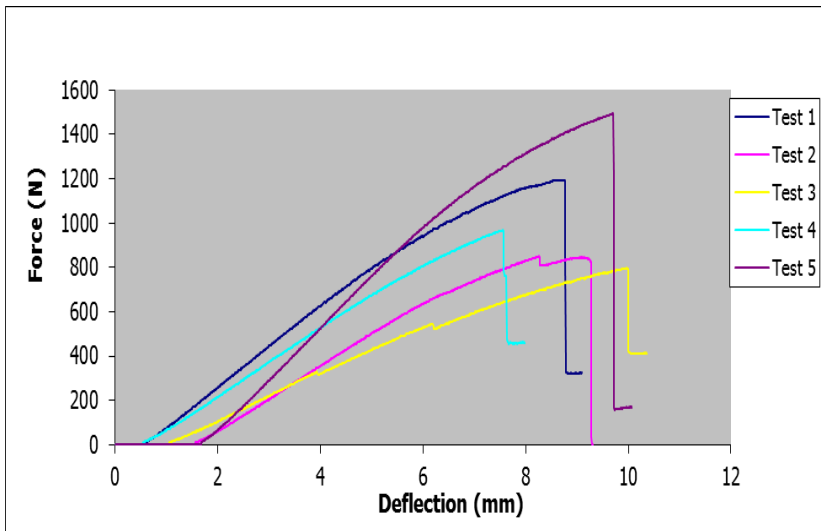


Figure 5: Force-deflection curve of *Brachystegia eurycoma* under static bending load

Table 5 shows modulus of elasticity and density of *Brachystegia eurycoma* timber at 12% moisture content. *Brachystegia eurycoma* properties are comparable with those timbers in strength class D40 because it has density of

1148.25kg/m³, mean modulus of elasticity 11220.99N/mm² that is within the range of D40 in BS 5268 (2002). Based on this result, *Brachystegia* belongs to timber strength class D40.

Table 5: Modulus of elasticity and density of *Brachystegia eurycoma* at natural moisture content

Modulus of Elasticity (N/mm ²)	Value
E _{minimum} (N/mm ²)	9426.08
E _{mean} (N/mm ²)	11220.99
Density (kg/m ³)	1148.25

Table 6 shows basic stresses of *Brachystegia eurycoma* at 12% moisture content calculated from mean failure stresses and standard deviation of failure stresses. Basic stresses calculated were basic bending stress parallel to the grain, basic tensile stress parallel to the grain, basic compressive stress parallel to the grain, basic shear stress parallel to the grain and basic compressive stress perpendicular to the grain .

Table 6: Basic stresses of *Brachystegia eurycoma* at 12% moisture content

Type of stress	Value (N/mm ²)
Bending Parallel to the grain	59.18
Tension Parallel to the grain	63.50
Compression Parallel to the grain	29.36
Compression Perp. to the grain	25.11
Shear Parallel to the grain	4.24

Table 7 shows basic stresses parallel and perpendicular to the grain as well as grade stresses at 12% moisture content. *Brachystegia eurycoma* has grade bending stress of 12.18N/mm² which is comparable to range of grade bending stress of strength class D40 listed in Table 8 of BS 5268 (2002).

Table 7: Various Stresses for *Brachystegia eurycoma*
at 12% Moisture Content

Type of Stress	Value (N/mm ²)
Mean failures bending stress parallel to the grain	59.75
Basic bending Stress parallel to the grain	15.23
Standard deviation of failure bending stress par. to grain	10.94
Grade bending Stress (80%) parallel to the grain	12.18
Grade bending Stress (63%) parallel to the grain	9.60
Grade bending Stress (50%) parallel to the grain	7.62
Grade bending Stress (40%) parallel to the grain	6.09
Mean failures tensile stress parallel to the grain	64.27
Basic tensile Stress parallel to the grain	23.35
Standard deviation of failure tensile stress par. to grain	5.04
Grade tensile Stress (80%) parallel to the grain	18.68
Grade tensile Stress (63%) parallel to the grain	14.71
Grade tensile Stress (50%) parallel to the grain	11.68
Grade tensile Stress (40%) parallel to the grain	9.34
Mean failures comp. stress parallel to the grain	29.72
Basic compressive Stress parallel to the grain	17.41
Standard deviation of failure comp. stress par. to grain	2.30
Grade compressive Stress (80%) parallel to the grain	13.92
Grade compressive Stress (63%) parallel to the grain	10.96
Grade compressive Stress (50%) parallel to the grain	8.70
Grade compressive Stress (40%) parallel to the grain	6.96
Mean failures comp. stress perpendicular to the grain	25.41
Basic compressive Stress perpendicular to the grain	18.76
Standard deviation of failure comp. stress perp. to grain	1.48
Grade compressive Stress (80%) perp. to the grain	15.01
Grade compressive Stress (63%) perp. to the grain	11.82
Grade compressive Stress (50%) perp. to the grain	9.38
Grade compressive Stress (40%) perp. to the grain	7.50
Mean failures shear stress parallel to the grain	4.27
Basic shear Stress parallel to the grain	1.11
Standard deviation of failure shear stress par. to grain	0.76
Grade shear Stress (80%) parallel to the grain	0.89
Grade shear Stress (63%) parallel to the grain	0.70
Grade shear Stress (50%) parallel to the grain	0.56
Grade shear Stress (40%) parallel to the grain	0.44

Table 8 shows the summary results of the experiment for grading of the *Brachystegia eurycoma* in accordance with BS 5268 (2002). According to BS 5268 (2002), strength class may be assigned to a specie, if its characteristic value of grade bending stress and mean density equal or exceed the value for that class giving in Table 8 of BS 5268-2 (2002) and its mean modulus of elasticity in bending equal or exceed 95% of the value given in that strength class. Based on these criteria, *Brachystegia eurycoma* was assigned to strength class D40 due to its grade bending stress parallel to the grain of 12.18N/mm^2 , mean density of 1148.25kg/m^3 and mean modulus of elasticity of 11220.99N/mm^2 . This is in agreement with strength class **D40** listed in BS 5268-2 (2002) of grade bending stress of 12.5N/mm^2 and above, mean density of 700kg/m^3 and above and mean modulus of elasticity 10800N/mm^2 .and above.

Table 8: Strength class for *Brachystegia eurycoma*
according to Table 8 BS 5268-2 (2002)

Grade Stress (80%) (N/mm2)	12.18
Density (kg/m ³)	1148.25
Mean Modulus of Elasticity (N/mm2)	11220.99
Strength Class	D40

4. Conclusion

From the results obtained in this experimental work, *Brachystegia eurycoma* has higher value of density which ascertains its assignment as a strong wood. The moisture content value is lesser than the fibre saturation point (FSP) as stated by Nabade (2012). Therefore *Brachystegia eurycoma* is graded as a D-class wood of D40 strength class with good Engineering properties and can be used as beams, rafters, railway sleepers and timber bridge materials. Having successfully characterized and graded this specie, *Brachystegia eurycoma* timber can be compared with other species on international basis, hence this timber is recommended to engineers for use in design of load bearing structures.

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