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Original Research Article

Strength Classification of Some Selected African Hardwood Species following the BS 5756 Code

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ABSTRACT

Timber is one of the naturally occurring engineering materials, and has been used for the construction of buildings, ship and many other structural elements. The near lack of information on the mechanical properties of some of the timber species in Nigeria is a call for concern for all stakeholders in the construction industry where this material is often used. This work carried out physical and mechanical tests such as compressive, tensile and bending strength tests on five timber species from Abeokuta, Southwest Nigeria. The species are Mahogany tree (Afzelia africana), Albizia tree (Albizia zygia), African birch tree (Anogeissus leiocarpus), Beech tree (Gmelina arborea) and Salt and oil tree (Cleistopholis patens). The results from the tests were used to determine the strength class of each wood based on the BS 5756 classification. Salt and oil tree was classified as D60, Beech wood and Mahogany were D40, while both Albizia and African birch woods were classified as D70, which is the highest strength.

1. INTRODUCTION

The construction industry has grown over time, and the use of different construction materials has evolved. Of all the construction materials that exist, timber is the only uniquely naturally occurring material that does not require the effort of man to manufacture compared to steel, concrete, cement and many others. Timber does not have consistent, predictable, reproducible and uniform properties as the properties vary with species, age, soil and environmental conditions (Jimoh and Aina, 2017). Whilst this gave it a deserved aesthetic appeal and advantage, it also creates a problem for the structural engineer who needs to carry out the design of structures and recommend the type of materials to be used (Trevor, 1999). Since it is a naturally occurring material, there is no control over its strength properties and quality that are critical in the design of structures (Trevor, 1999).

The strength and physical classification of softwood and hardwood has been used to determine their uses. Many research work have been carried out in this area and different recommendation has been proposed based on design codes like BS 373 (1957), and BS 5268- (2002) for the United Kingdom, Euro code 5, (IS EN 1995) for Europe and the ASTM D4761-19 (2019) for the United States (de Borst *et al*., 2012; Li *et al.,* 2017; Bello and Jimoh, 2018). Most of the woods classified by these different codes are those in the temperate region of the world which are mainly softwoods. Although there is the classification for some hardwoods, most of the classified hardwoods are not common in Africa. This explains the huge interest and considerable intellectual resources being invested in understanding the mechanical or structural properties of the Nigerian timber (Aguwa and Sadiku, 2011).

The primary goal of engineered construction is to produce a structure that optimally combines safety, economy, functionality and aesthetics. Timber, like other building materials, has inherent advantages that make it especially attractive in specific applications (Afolayan and Adeyeye, 1998).

Apart from the classifications from different codes of practice, some other researchers have also carried out classification checks on some woods that were not listed by exiting codes, especially wood that is of African origin. There was no sufficient information on most of the hardwoods in Africa. If adequate information on the magnitude of load, rate of loading and the duration of load that a timber specie can accommodate are provided, the appropriate timber species may be selected from the different timber strength groups and natural durability classes (Fuwape, 2000). This lack of sufficient information on them has been the basis for their misuse and failure as a structural member. Ataguba *et al*. (2015), did a comparative study of the mechanical properties of *Gmelina Arborea*, *Parkia biglobosa* and *Prosopis africana* timbers for structural use and concluded that the three species proved to have physical and mechanical properties that make them suitable for structural engineering use as hardwoods by grading them into strength classes between D30 – D70.

The main challenge in design with timber as a structural member is to be acquainted with sufficient data about a given species of timber to ensure that the relevant performance criteria are met, as specified in relevant standards and codes. This implies that failure risk is reduced to the extent to which structural information about a given species of timber is readily available to timber designers, specifies and construction regulators. A significant element of uncertainty is associated with lack of information on the physical variability as well as structural behaviour of the material under load (Aguwa, 2012)

The aim of this work, therefore, is to classify more of the African woods not listed on the BS 5268 index, for information during the structural design of timbers especially when such species are to be used.

2. MATERIALS AND METHODS

2.1. Material Procurement and Preparation

Samples of timber species were obtained from Malaaka Village near Abeokuta, Ogun State, Nigeria. Fully grown African Mahogany Tree *(Afzelia Africana*), West African Albizia Tree (*Albizia zygia*), African Birch Tree (*Anogeissus leiocarpus*), Beech Wood Tree (*Gmelina Arborea*) and Salt and Oil Tree (*Cleistopholis patens*) were sourced (500 mm to 600 mm of each). The timbers were identified and labelled as shown in Plate 1, and then transported to a sawmill where the timbers were prepared into different sizes of test piece as specified by BS 373 (1957). The sawn wood was arranged in an open environment protected from rain and the ground. It was arranged in such a way that air will freely circulate it and was left in this state for 2 months (air seasoning). This was done to reduce the risk of fungi and insect attack, twisting and cupping. Samples were taken along the stem, it was ensured that the selected timber was free of defects and was as straight as possible before procuring it. The samples were moved to the National Centre for Agricultural Mechanization (NCAM) at Ilorin, Nigeria, where tests specified by BS 5268-2 (2002) were carried out on the test species.

In the laboratory, the specimens were prepared following BS 373 (1957), which stated both 2 cm and 2 inch standard of testing small clear specimens can be used. The 2 cm standard test method was used in this work.

Plate 1: Identification of timber samples

2.2. Physical Properties

Moisture content of the timber species was determined by weighing and then drying in an oven at a temperature of 103 ± 2 °C for 3 days until the weight was constant. The loss in weight expressed as a percentage of the final oven-dry weight was taken as the moisture content of the test piece. The value so obtained was recorded with the results of the particular test to which it refers. The density of the samples was calculated as a ratio of the mass of the sample to their corresponding volume. The specific gravity of timber is the weight of any given volume of the timber divided by the weight of an equal volume of water. This test was also carried out on all the species.

2.3. Mechanical Properties

The determination of various strength properties was carried out following BS 5268-2 (2002). The strength tests were carried out with the aid of a Testometric Universal Testing Machine with a maximum load capacity of 100 kN at the National Centre for Agricultural Mechanization (NCAM), Ilorin, Nigeria.

2.4. Tension Parallel to Grain Test

Three specimens from individual specie were used for this test. The form and dimensions of the test piece used in determining the tension parallel to grain strength are as illustrated in Figure 1 and Plate 2. The actual dimensions at the minimum cross-section were measured. The load was applied to the 2 cm face of the ends of the test piece by specially fabricated grips into which the wood was placed before the test commenced. These grips were designed to give axial load. The load was applied to the test piece at a constant head speed of 1.27 mm. The tensile strength and modulus of elasticity were obtained from this test. The modulus of elasticity is obtained through the stress –strain properties of the materials under consideration (Durka et al. 1989).

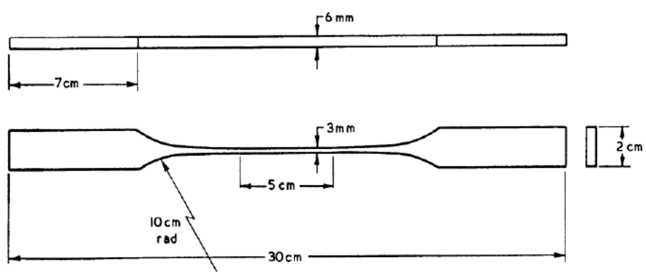

Figure 1: Timber dimensions for tension test

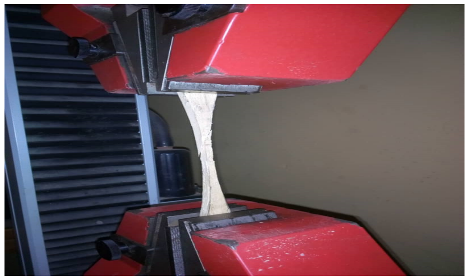

Plate 2: Tensile test strength test parallel to the grain

2.5. Compression Parallel and Perpendicular to Grain Test

Three specimens from each axis and along the height were cut from divisions of the log of individual wood to make samples for each species. The dimension of the test piece is as shown in Figure 2, for the parallel test and Figure 3 for the perpendicular test. It was ensured that the ends of the rectangular test piece are smooth and parallel and normal to the axis and that the testing machines are of such that the plates between which the test piece is placed are parallel or perpendicular to each other and remain so during the whole period of the test. The load was applied to the test piece in such a way that the loading plates approach each other at a rate of 0.0635 mm/min.

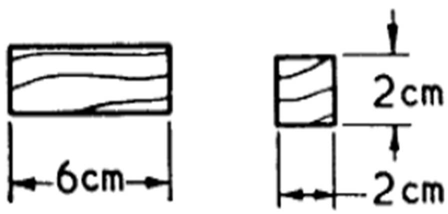

Figure 2: Compressive strength test parallel to grains

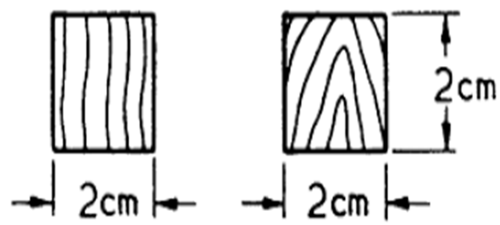

Figure 3: Compressive strength test perpendicular to grains

2.6. Shear Strength Test

Three samples were obtained from each specie of the timber for this test. The load was applied at a constant rate of crosshead movement of 0.0635 mm/min. The direction of shearing was parallel to the longitudinal direction of the grain. The test was made with the plane of shear failure parallel to the tangential direction of the grain and also with the plane of shear failure parallel to the radial direction. This is shown in Plate 3.

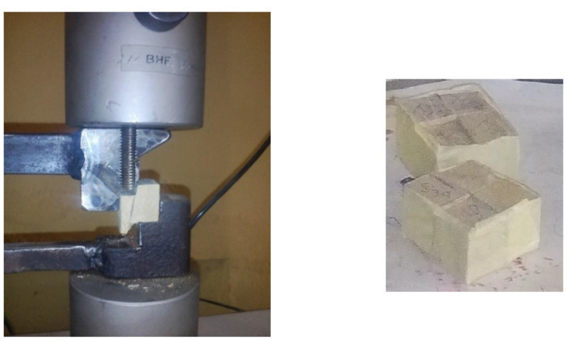

Plate 3: Shear strength tests

3. RESULTS AND DISCUSSION

3.1. Physical Properties

The physical properties of the woods measured in the research are the moisture contents and the densities of each species. Both properties are very important because they contribute to the classification of the woods.

3.1.1. Moisture content

The moisture content in a timber material will help in determining the water retaining nature of the timber, and its effects on the overall strength and performance of the timbre material. Figure 4 shows the moisture content value for each of the timber under investigation. It can be observed from Figure 4 that the mean moisture content of Beechwood, Albizia, African birch, Salt and oil tree and Mahogany were 27.58%, 22.07%, 20.79%, 18.90% and 16.47% respectively. Since the timber samples were subjected to the same period of air seasoning, it can be seen that Beechwood has the highest moisture content, followed by Albizia, African birch, Salt and oil tree and finally Mahogany. Timber is known to continue to absorb or lose moisture until it reaches the same level as the surrounding environment. This process is known as equilibration, and this process can cause a lot of issues like shrinking unequally or becoming damaged if the process occurs too often (TRADA 2011). Hardwoods are typically more difficult to dry due to reduced permeability within the wood structure, unlike softwoods. The amount of moisture present in timbers will affect its weight, strength, stiffness, workability, susceptibility to biological attack and dimensional stability (TRADA 2011).

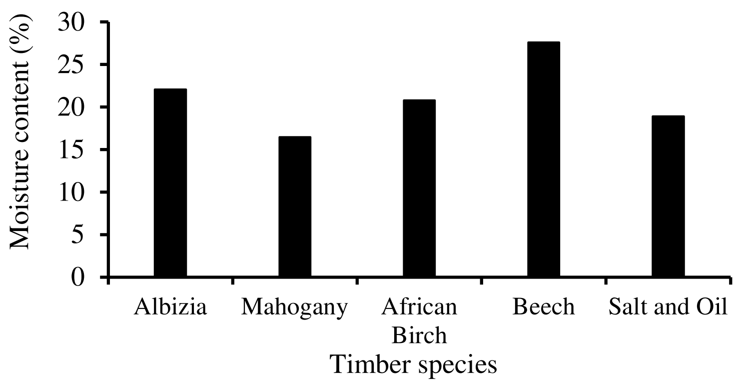

Figure 4: Moisture content of timber species

3.1.2. Density of species

The densities of woods are very important because they are mostly used in the classification of timber species according to BS 5756. From Table 2, the densities of the timber species are; 757 kg/m^3, 859 kg/m^3, 1069 kg/m^3, 731 kg/m^3 and 1093 kg/m^3 for Mahogany, Salt and oil, Albizia, Beech and Birch woods respectively. The woods can be classified based on Table 1 as D70 for Albizia and Birch woods, D60 for Salt and oil, while D40 for Mahogany and Beech woods.

3.2. Mechanical Test

The results in Table 2 shows the outcome of the mechanical test that was carried out on all the timber species. The importance of these tests is to determine the strength and elastic properties of the species. It should be noted that these results are based on the measured moisture contents in the laboratory during the test for individual wood species as shown in Figure 4. This will aid the classification of the timbers according to Table 1 (BS 2002).

Table 1: Strength classes for hardwood to BS 5268

Strength class	Bending parallel to grain (N/mm^2)	Tension parallel to grain (N/mm^2)	Compression parallel to grain (N/mm^2)	Compression perpendicular to the grain (N/mm^2)		Shear parallel to grain (N/mm^2)	Modulus of elasticity (N/mm^2) Mean	Minimum	Average density (kg/m^3)
D30	9.0	5.4	8.1	2.8	2.2	1.40	9 500	6 000	640
D35	11.0	6.6	8.6	3.4	2.6	1.70	10 000	6 500	670
D40	12.5	7.5	12.6	3.9	3.0	2.00	10 800	7 500	700
D50	16.0	9.6	15.2	4.5	3.5	2.20	15 000	12 600	780
D60	18.0	10.8	18.0	5.2	4.0	2.40	18 500	15 600	840
D70	23.0	13.8	23.0	6.0	4.6	2.60	21 000	18 000	1 080

Table 2: Grade stresses of timber species

Wood type	Bending parallel to the grain (N/mm^2)	Tension parallel to grain (N/mm^2)	Comp. parallel to grain (N/mm^2)	Comp. perp. to grain (N/mm^2)	Shear parallel to grain (N/mm^2)	Modulus of elasticity		Mean density (kg/m^3)
						Mean (N/mm^2)	Min. (N/mm^2)	
Mahogany	78.31	165.54	41.46	5.03	9.17	8827	7731	757
Salt and Oil	72.08	79.28	32.36	1.49	5.58	9596	8960	859
Albizia	59.71	98.88	47.84	8.73	11.16	7272	6897	1069
Beechwood	33.75	122.78	27.44	5.48	7.78	4850	2767	731
Africa birch	102.20	106.37	53.76	16.57	10.18	10499	8793	1093

3.2.1. Compressive strength

The results from Table 2 revealed that the compressive strength parallels to the grains for African birch tree is the highest at 53.76 N/mm^2, followed by Albizia with 47.84 N/mm^2. Mahogany took the next place at 41.46 N/mm^2 the salt and oil wood has 32.36 N/mm^2 while the lowest strength came from Beechwood at 27.44 N/mm^2. The compressive characteristics of timber parallel to the grain are the most important properties of timber for structural purposes (Trevor, 1999). The main stress developed during this phase will be parallel with the axial direction of the wood fibres. The fibre tubes loaded axially are very strong and stable, it can withstand a high load.

When the load is too high, some of the fibres will start to buckle and driven into the other fibres. When the buckling behaviour in the wood starts, the possibility to support higher load will diminish, a behaviour called called plasticizing. Wood in service is continuously interacting with a different type of forces, of which compressive forces are the most prominent. According to Akpan (2006), high strength in longitudinal compression is required of timber used as columns, props and chair legs. In evaluating this property, it is necessary to ensure that the specimen does not buckle during loading thereby subjecting it to bending rather than compressive stress (Desch, 1992).

The value obtained for compressive strength perpendicular to grains are very low. African birch had the highest with 16.57 N/mm^2, while salt and oil wood had the lowest value of 1.49 N/mm^2. In compression perpendicular to the fibre direction, the tube-shaped wood cells are crushed, crushing of tube-shaped cells from the side requires very little force, and hence the strength for this type of loading are very low. This perpendicular compression is however not taken into account when designing a timber structure.

Figure 5 showed the deflection of the different wood species to loading. The deflection of all the samples were gradual as more load was been applied. Virtually all the wood species showed the same deflection pattern, and between 0 mm and 2 mm, the wood species were within their elastic limit under compression. If the load were to be removed at this point, the tendency for the timber to return to their initial state is very high. But at a value above the 2 mm mark, the materials started showing variation in deflection; this is the plastic stage or the yield point. Beechwood yielded earlier at a force of 10976 N, the salt and oil wood yielded next at 15780 N, Mahogany yielded at 18980 N, Albizia was 20879 N while African birch wood showed the highest yield load of 20969 N, all at 2 mm deflection point. The breakpoint of Albizia was highest at about 9 mm, while other sample breakpoints were between 4.5 mm and 5 mm. The characteristic deflection of the timber species is as a result of compressive stress developed within the wood fibres that were resisting the external load; this action causes displacement within the wood fibre matrix since the space within the wood structures cannot be expanded, this resulted in the deflection of the timbers to accommodate the effect of the applied external force.

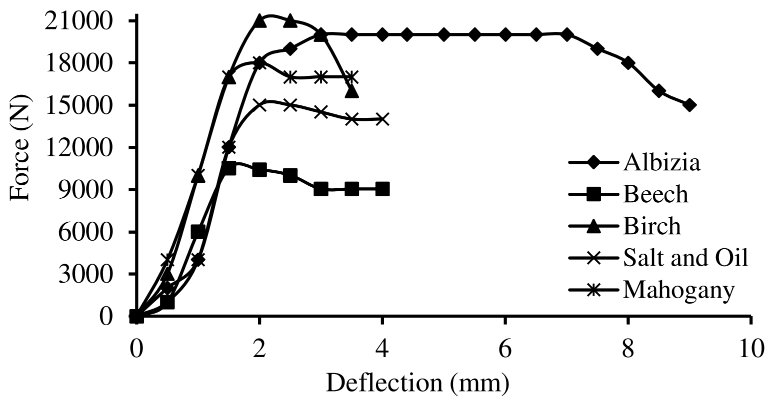

Figure 5: Compressive strength to deflection of timber species

3.2.2. Tensile strength

The tensile strength parallel to grain fibres revealed that Mahogany has the highest value of 37. 27 N/mm^2, while African birch and Beechwood had 34.89 N/mm^2 and 34.74 N/mm^2 respectively. Albizia and salt and Oil wood recorded 15.88 and 14.51 N/mm^2 respectively. When a tensile force is applied in parallel to the direction of the grains, the forces creates a tendency to stretch the wood fibres and to cause them to slip by each other. The strength of timber in tension parallel to the fibre direction is considered the highest strength property of wood (Kliger, 2016). There are two possible mode of failure in wood under tension parallel to the grains; the middle lamella breaks and the fibres are pulled out of their matrix or the fibre breaks. The failure is, however, often very brittle.

Figure 6 showed the elongation of each timber specie under tensile loading. Mahogany and Beechwood were stretched to 2 mm, Albizia was stretched to 1.5 mm, while the two other samples were also stretched above 1 mm. The implication of this elongation test is to determine the bonding strength within the different wood structures, the bond properties in mahogany and Beechwood showed that they were stronger than that of other species, the Salt and oil wood has the least bonding properties. The use of tensile strength is very important if the timber is to be used and tensile members in wood trusses, the higher the bonding strength the more ability for the wood to resist tensile forces under load. The modulus of elasticity results for each timber species is showed in Table 2. The importance of this test is to know the effect of external load on the elastic properties, through the elongation of each species. The results showed that African birch has the highest modulus of elasticity, while Beech wood had the lowest, the implication is that Beech wood will yield earlier than all other species under sustained external load.

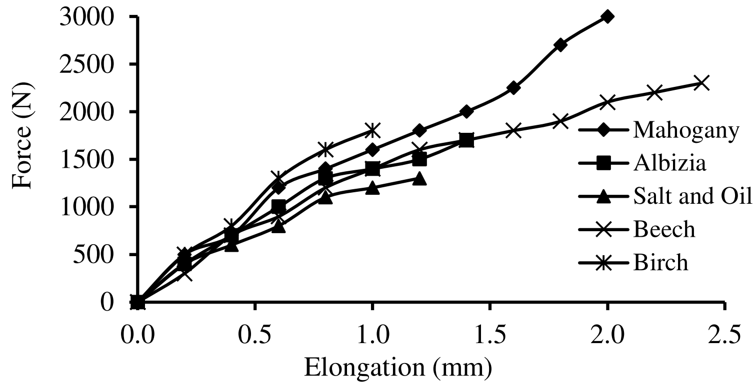

Figure 6: Tensile strength to elongation of timber samples

4. CONCLUSION

The mechanical tests conducted on all the five timber species from Abeokuta Ogun state has revealed that the wood samples are hardwood, but based on the BS 5756, the individual wood falls into the following strength classes: D60 has the Salt and oil wood (*Cleistopholis patens*, locally called "Apako"), D40 has the Beechwood (*Gmelina Arborea*) and Mahogany (*Afzelia Africana*), D70 has both Albizia (*Albizia zygia* locally called "Ayinre") and African Birch (*Anogeissus leiocarpus* locally called "Oridudu") woods in this categories. This research has helped in the proper classification of some of the timber species found in Nigeria, based on the BS code of practice.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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