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Determination of the Properties of Some Selected Timber Species for Structural Application

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Abstract

One of the alternative sustainable and green construction materials to concrete is timber. Timber is of numerous varieties, and this acts as a barrier to the extent of its usage, especially in structural application. Despite many researches on wood's mechanical and physical properties, only a few are geared toward the structural application of wood. The present work investigated the mechanical properties of five timber species; Gmelina arborea, Tectona grandis (Teak), Terminalia superba (Afara), Ayin (Anogeissus leiocarpus), and Acacia (Robinia pseudoacacia), to determine their suitability for constructing long-span roof trusses. These are available in the South Western part of Nigeria. Their mechanical properties; bending strength, compressive strength, shear strength, tensile strength, Modulus of Elasticity (MOE), Modulus of Rupture (MOR), and density, were determined in the laboratory. The results obtained showed that all the timber types, except Terminalia superba (Afara), have higher values of mechanical properties than the values that are obtainable for classes of strength D30 to class D70 in the British Code of Practice. It means these species are of higher quality than the stipulated strength classes in the British code. The results also show that the order of relevance of the species for structural design (or work) is Acacia (Robinia pseudoacacia), Ayin (Anogeissus leiocarpus), Gmelina Arborea, and Tectona grandis (Teak). Terminalia superba (Afara) is not recommended for structural works.

Keywords

Timber, Wood Species, Bending Strength, Compression, Mechanical Properties

1. Introduction

Timber is defined as a complex and heterogeneous building material made up of various species that has been prepared for use in construction and carpentry. It is wood in a shape that can be used for manufacturing, carpentry, joinery, or other construction projects [1] [2] [3]. Timber is a naturally occurring and renewable building material that is abundant and readily available [1], light, easy to handle and has good workability [4], versatile, high thermal insulating, high elasticity and strength but low weight, aesthetically pleasing and environmentally friendly [5]. If the properties are carefully explored or harnessed, they would make the woods adequate for the design of an environmentally friendly structure that is cost effective. The strength of structural timbers, which are employed in framing and load-bearing constructions, is a key consideration in their choice and application.

It is a very important building material whose many qualities [6] and structures determine how best to use it [7] [8]. Wood or timber is the second-oldest building material after stone and is inexpensive, renewable, and widely accessible [9] [10]. Hardwoods, which come from angiosperm (broad-leaved) trees, and softwoods, which come from coniferous (trees with needle-like leaves), are the two (2) classes of wood that are globally recognized as acceptable [9] [11]. Hardwoods, as opposed to softwoods, have high strength and durability [11], making them suitable for structural design of building elements and construction. The choices of the different types of wood species as construction material are dependent on a number of factors (or properties of the woods); such as durability, workability, strength, appearance, process ability, availability, cost/price, resistant to insect attack and splitting [7] [8] [11].

Appropriate use of timber for structural purposes requires that the mechanical properties be suitable for the required structural application in term of quality enhancement [12]. The numerous advantages of this naturally and readily available material need to be explored for structural purposes. Useful data of the available timber species will promote their adoption by the stakeholders, discourage importation and, on the long run, will improve the economy of the nation [13]. However, useful structural information or design data of these timber species are lacking and not readily available. This has been a major barrier to the right selection or decision on the appropriate and economic use of timber for structural works [2]. One of the results of this inadequacy is the excessively high margins of safety that are sometimes adopted in the design of timber for structural construction. Based on lack of database of the mechanical properties of these timber species, their strength properties are either assumed or estimated. This further leads to too weak (under-designed) or too strong (over-design) of construction members [4].

Therefore, adopting the use of the available timber in Nigeria for structural applications will require that their properties be determined and made available to the stakeholders in Nigeria. This research explored the mechanical properties of some selected wood species in South Western part of Nigeria to determine their suitability for the construction of long span roof trusses.

2. Materials and Methods

2.1. Research Materials and Sample Collection

The research materials are Gmelina arborea, Tectona grandis (Teak), Terminalia superba (Afara), Ayin (Anogeissus leiocarpus), and Acacia (Robinia pseudoacacia). These species were chosen because of their availability in abundance in the South West of Nigeria. The materials were obtained at a furniture workshop in Iwo, Osun State (South Western region of Nigeria). The wood samples had been air dried for two months as at the time of collection.

2.2. Research Methods

Mechanical tests conducted on the selected wood species includes MOR, MOE, bending strength test, hardness, compressive strength and shear strength tests. The test samples of selected wood species were machined and trimmed to standard sizes specified by corresponding ASTM codes used for the determination of their mechanical properties. All the experiments were done at the Department of Metallurgical and Material Engineering Laboratory of Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria.

2.3. Bending Strength Test of the Selected Wood Species

Sample preparation and testing for bending strength were in accordance with the specification in [13]. All the samples were seasoned by air-drying because drying increases the physical properties, mechanical properties and the dimensional stability of wood [14]. Wood bending strength frame with digital dial gauge (Universal Testing Machine), operated at a load rate of 0.2 MPa/s, was used to carry out the tests using samples' dimension of 10 mm × 10 mm × 300 mm. Samples were loaded to failure in three-point loading over a span of 280 mm. The loads at elastic limit (P) were recorded and used for computations of MOR in Nmm^{-2} using Equations (1). To obtain stress—strain curves, a dial gauge with precision of 0.001 mm was used to determine sample's deformation under load. The deformation was measured from the change in distance between the loading plates.

The slope of the linear part of the stress-strain curves was used to determine the MOE of the samples [15], which is the load carrying capacity of members in bending and it is proportional to maximum moment borne by the wood species [11]. MOE and MOR are important properties of structural timbers and are commonly used in different standards as a basis for classifying timbers [16]. Forty test samples were tested per wood property per timber specie [16].

$$MOR = \frac{3PL}{2bd^2} \tag{1}$$

where, P is Maximum Load (N), L is Length of sample (mm), which is 280 mm, b is width of the sample (mm), which is 10 mm, d is thickness of the sample (mm), which is 10 mm.

The ruptured surfaces of the tested specimen were examined to ensure that failures were not due to internal hidden defects and tests results from specimens with failure modes due to hidden defects were rejected [16].

2.4. Compressive Strength of the Selected Wood Species

The compressive strength test was conducted in accordance with [13] [17]. The dimension of the samples was measured using a vernier caliper. The samples were placed in the Universal Testing Machine (UTM) in such a way that the grain fibers were parallel to the applied compressive load. Deflection dial gauge was attached to the sample and adjusted to zero. The UTM was operated at a rate of 0.6 mm/min and the sample was gradually loaded in compression. The load was adjusted to its maximum capacity. The deflection reading from the dial gauge for each regular load increment was recorded. The deflection gauge was removed gradually when cracks were observed appearing in the sample. Then the sample was loaded to failure and the maximum crushing load, P_{max}, was recorded. The compressive strength of the wood sample was then calculated from the maximum crushing load and the contact area as shown in Equation (2).

$$\sigma_c = \frac{P_{max}}{bd} \tag{2}$$

where b is the width of the sample and d is the depth of the sample.

2.5. Shear Strength Test of the Selected Wood Species

Shear strength of the timber samples was carried out following the specification in [17]. The size of the sample used for this test is 50 mm × 50 mm × 63 mm notched at one end (as shown in **Figure 1**) in order for the failure to occur on a 50 mm × 50 mm surface. The samples were held in position by gripping one end in the upper portion of the UTM and the other end gripped in the lower position in such a way that the edges of the samples were vertical and the end rest evenly on the support over the contact area. The UTM was switched on and the load was applied continuously throughout the test at a rate of motion of the movable cross head of 0.6 mm/min until the specimen shears. The load, F_{max}, at which the samples shear was noted and recorded. The machine was stopped and the specimen was removed. The experiment was repeated for all the samples of the species. The shear stress (τ) was calculated from Equation (3).

$$\tau = \frac{F_{max}}{bL} \tag{3}$$

where b is the width of the test piece, L is the length of the shearing plane and F is highest load.

2.6. Tensile Strength of Selected Wood Species

Tensile test was also done in accordance with the method outlined in [13] [17]. The initial length (Li), initial cross-sectional area (Ai) and the initial diameter

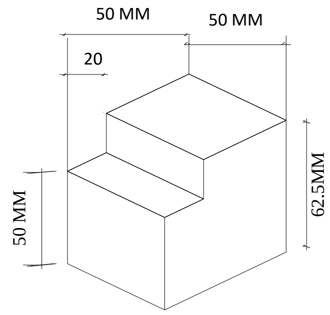


Figure 1. Shear parallel to grain test specimen [17].

(di) of the sample were measured and recorded. The specimen was then inserted into the grips of the testing machine which has strain-measuring device attached to it. Loads were applied in succession to the test sample and recorded with the corresponding elongation or extension. The readings were taken frequently as the yield point, due to the loads, were approached. The values of the elongations were measured with the aid of divider and a ruler. The test was run till fracture occurs. The final length (L_f) and the final diameter (d_f) of the sample were measured by joining the two broken halves of the sample. The Ultimate load (F) after the sample breaking was also recorded.

2.7. Hardness Test of Wood Species

Brinell method of hardness test was used to test the hardness of all the species following procedure [17]. A steel ball of diameter 5 mm was inserted in the ball holder of Brinell hardness testing machine that was used to perform the experiment. With the aid of a Jack adjusting wheel, the ball was made to have contact with the test sample, whose surfaces were free from oil, grease, dust and the likes. The samples were loaded one after the other with a force of 30 KN for 15 seconds. The samples were then removed from the machine and their indentations were located, viewed through microscope and their diameters were measured using micro meter fixed on the microscope. The procedure was replicated for all the species' test samples. The Brinell hardness of each of the samples of the species were estimated from Equation (4).

$$BHN = \frac{\text{Load applied}(N)}{\text{Special surface area of indentation}} = \frac{2P}{\pi D\left(D - \sqrt{\left(D^2 - d^2\right)}\right)} \quad (4)$$

where D is the diameter of the ball, d is diameter of indentation and P is load.

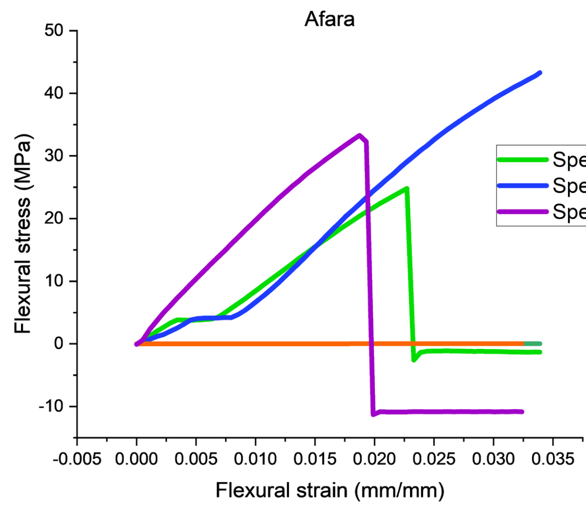
3. Results and Discussion

3.1. Mean Bending/Flexural Strength, Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) of the Different Wood Species

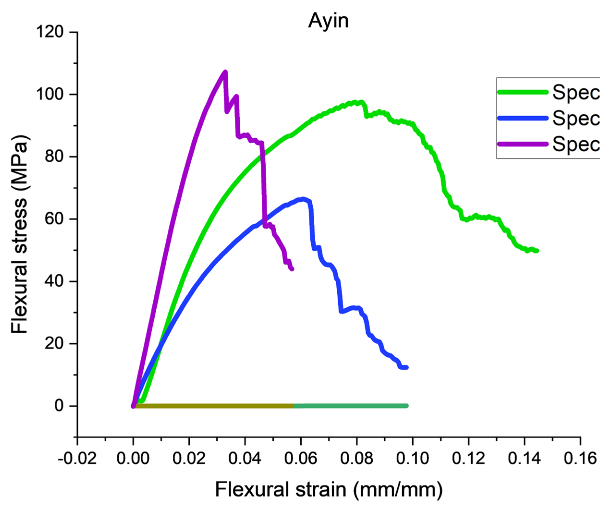
The results of bending strength tests on all the species presented in Figures 2(a)-(e) is the graphical relationship between the flexural stress and flexural strain. The graphs indicated the results of resistance of the species to bending using three-point bending test. Table 1 shows that Anogeissus Leiocarpus (Ayin) has the highest modulus of rupture (averagely, 361.75 N/mm^2) and has the highest bending strength (90.44 N/mm^2 averagely) respectively. This is followed by Acacia (Robinia Pseudoacacia), Gmelina Arborea, and Tectona Grandis (Teak) respectively. Terminalia Superba (Afara) has the least MOR and has the least resistance to bending or flexural load.

Table 1. Mean bending strength, MOR and MOE properties of the different wood species.

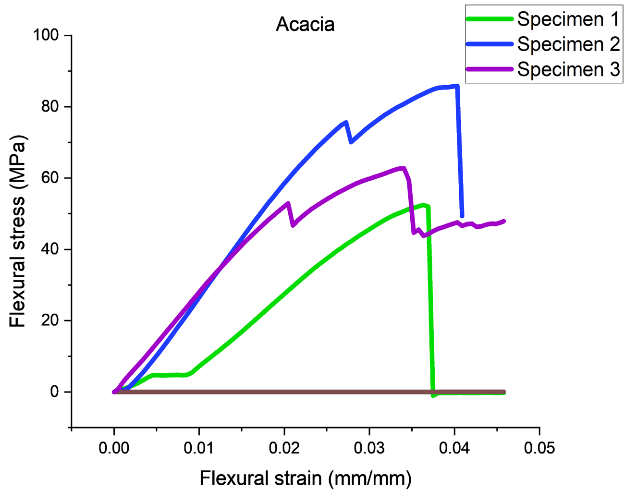
Wood species	Maximum Bending Stress (N/mm^2)	MOR (N/mm^2)	MOE (N/mm^2)
Acacia (Robinia pseudoacacia)	66.9898	267.9591	2713.7230
Anogeissus leiocarpus (Ayin)	90.4383	361.7532	2815.8214
Gmelina arborea	65.0393	260.1574	3071.1130
Tectona grandis (Teak)	51.2391	204.9562	1648.9292
Terminalia superba (Afara)	34.1467	136.5868	1868.5175



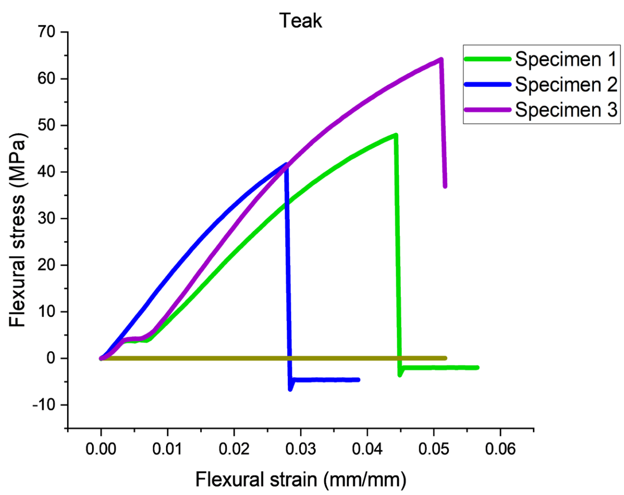
(a)



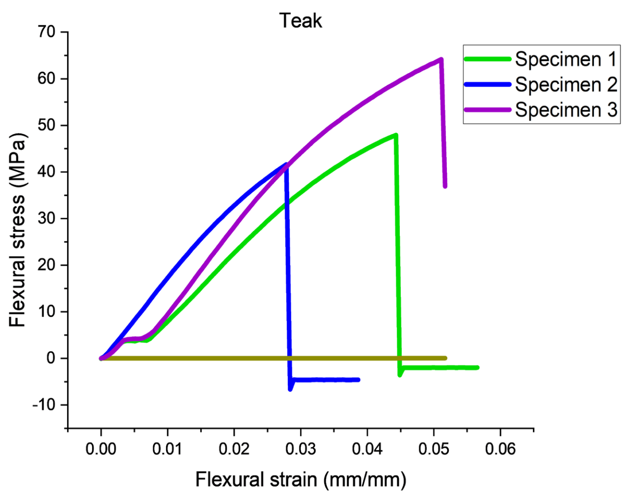
(b)



(c)



(d)



(e)

Figure 2. (a)-(e): The graph showing the flexural stress against flexural strain of the different wood species.

However, in terms of the stiffness of the species which is measured by MOE, Gmelina arborea has the highest value (on the average) of MOE (3071.11 N/mm^2), followed by Anogeissus leiocarpus (Ayin, 2815.55 N/mm^2), Acacia (Robinia pseudoacacia, 2713.72 N/mm^2), Terminalia superba (Afara) and Tectona grandis (Teak) respectively. This means that, in this set of species, Anogeissus leiocarpus (Ayin) is most reliable in bending than others while Terminalia superba (Afara) has the least reliability being least reliable does not indicate that it is not useful but it is just that the use has its own limit.

3.2. Compressive Strength Properties of the Different Wood Species

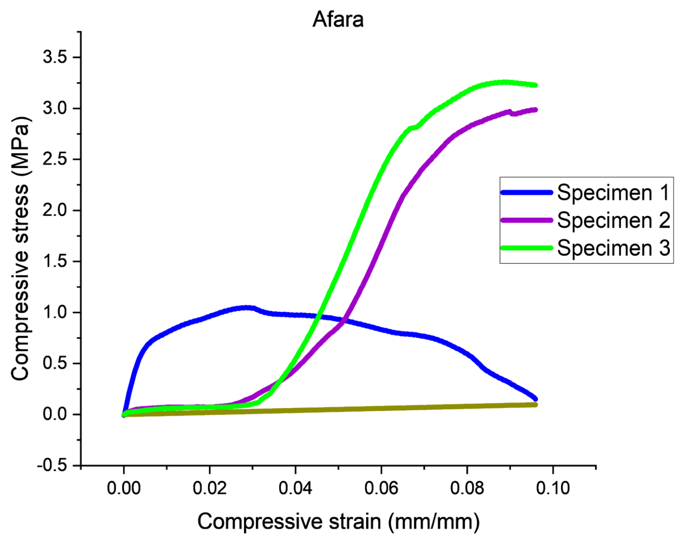
Properties of wood which include; compressive strength, tensile strength, MOE, MOR, moisture content, density, seasoning and shrinkage characteristics, anatomy, chemical characteristics and technology of utilization are among the major factors that determines the quality, suitability and material utilization of wood [7]. The compressive strength properties of Anogeissus leiocarpus (Ayin), Robinia pseudoacacia (Acacia), Gmelina arborea, Tectona grandis (Teak) and Terminalia superba (Afara) were graphically represented in **Figures 3(a)-(e)** The maximum compressive strengths of each of the species were read from the graph and presented in **Figure 4**. This represents the maximum compressive stress that each of the species can withstand without breaking and beyond which they will fail to sustain the load causing the compressive stress. The Anogeissus leiocarpus (Ayin) has the maximum resistance to compressive stress followed by Acacia (Robinia pseudoacacia) while Terminalia superba (Afara) has the least compressive strength.

3.3. Tensile Strength Properties of the Different Wood Species

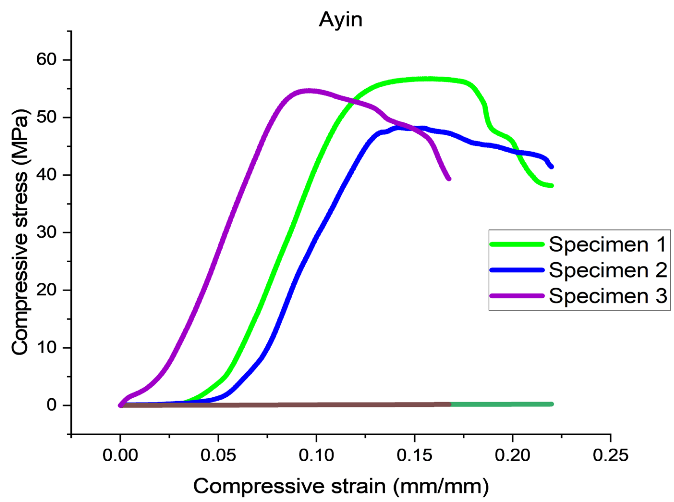
Figures 5(a)-(e) shows the graphs of the responses of each of the species to tensile loads applied to the woods during the laboratory experiments. The maximum resistance that each of the species can offer against stretching due to the applied tensile loads were read from the graphs and were presented in **Figure 6**. The results show that Acacia (Robinia pseudoacacia) has the highest resistance to tensile stress followed by Anogeissus leiocarpus (Ayin) and Terminalia superba (Afara) has the least tensile stress resistance. Gmelina arborea and Tectona grandis (Teak) have very close values of tensile strength, although that of Gmelina arborea is still insignificantly higher than that of Tectona grandis (Teak).

3.4. Shear Strength Properties of the Different Wood Species

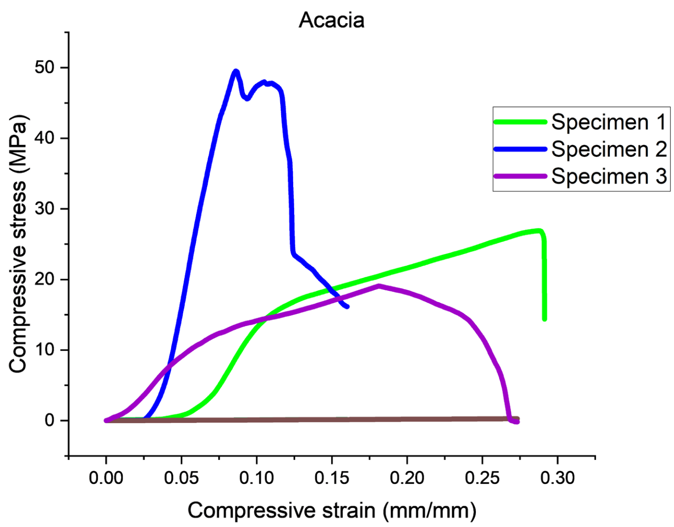
Figure 7 shows the results of the shear strength of the tested wood species. It indicates that Tectona grandis (Teak) has the highest resistant to shear. Next in the order is Acacia (Robinia pseudoacacia) and Anogeissus leiocarpus (Ayin). The least shear resistant of all the studied species is Terminalia superba (Afara).


Afara
Compressive stress (MPa)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0.00
0.02
0.04
0.06
0.08
0.10
Compressive strain (mm/mm)
Specimen 1
Specimen 2
Specimen 3

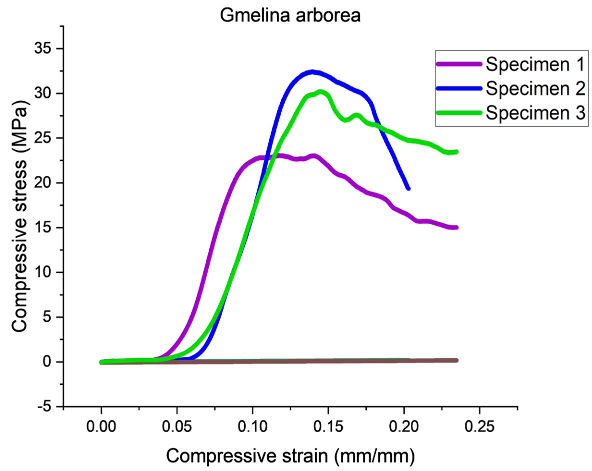
(a)


Ayin
Compressive stress (MPa)
60
50
40
30
20
10
0
0.00
0.05
0.10
0.15
0.20
0.25
Compressive strain (mm/mm)
Specimen 1
Specimen 2
Specimen 3

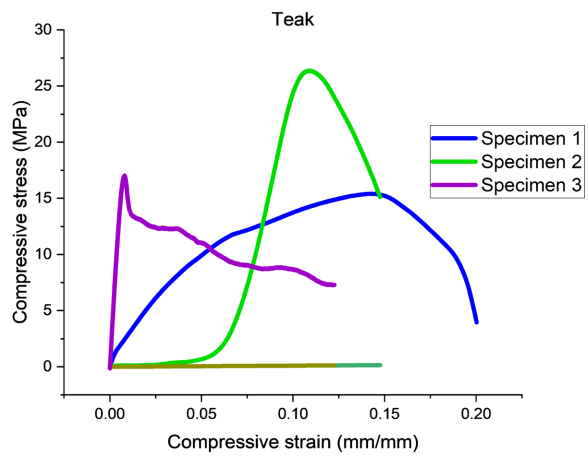
(b)


Acacia
Compressive stress (MPa)
50
40
30
20
10
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Compressive strain (mm/mm)
Specimen 1
Specimen 2
Specimen 3

(c)



(d)



(e)

Figure 3. (a)-(e): The graph showing the compressive stress against the compressive strain of the wood species.

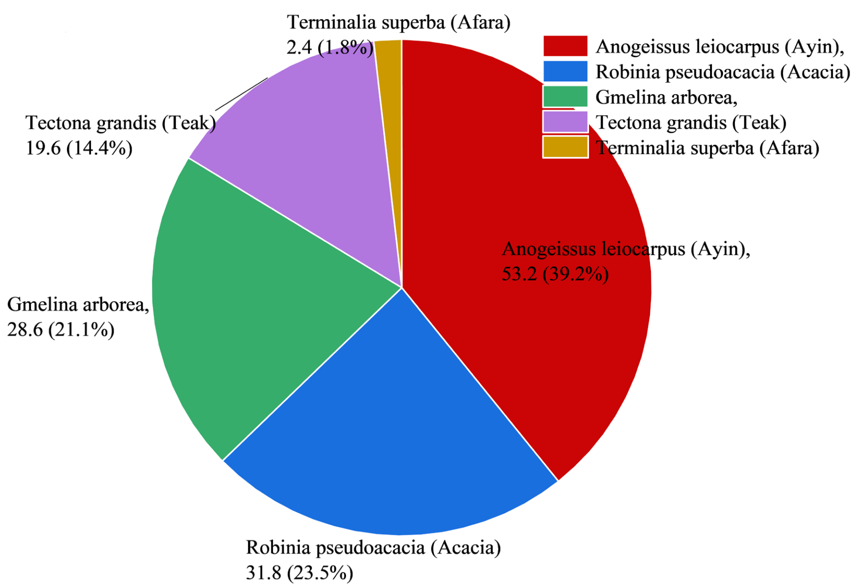
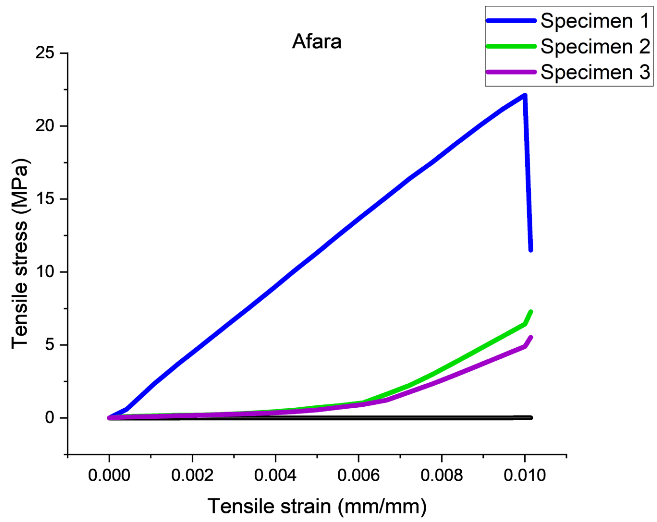
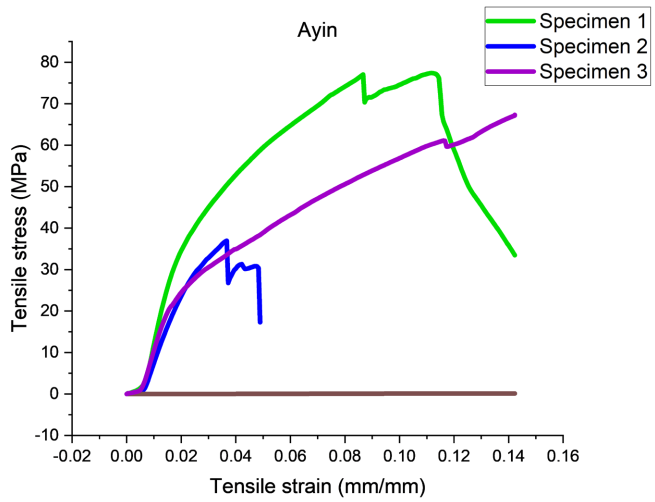


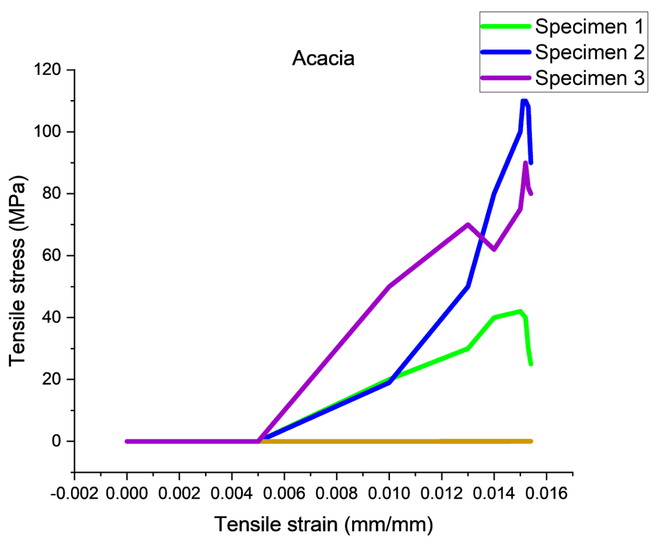
Figure 4. Compressive strength properties of the different wood species.


Afara
Specimen 1
Specimen 2
Specimen 3
Tensile stress (MPa)
Tensile strain (mm/mm)
0
5
10
15
20
25
0.000
0.002
0.004
0.006
0.008
0.010

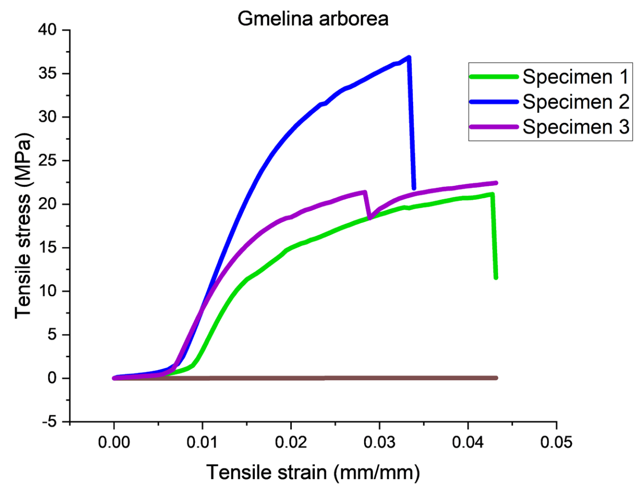
(a)


Ayin
Specimen 1
Specimen 2
Specimen 3
Tensile stress (MPa)
Tensile strain (mm/mm)
-10
0
10
20
30
40
50
60
70
80
-0.02
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16

(b)


Acacia
Specimen 1
Specimen 2
Specimen 3
Tensile stress (MPa)
Tensile strain (mm/mm)
0
20
40
60
80
100
120
-0.002
0.000
0.002
0.004
0.006
0.008
0.010
0.012
0.014
0.016

(c)



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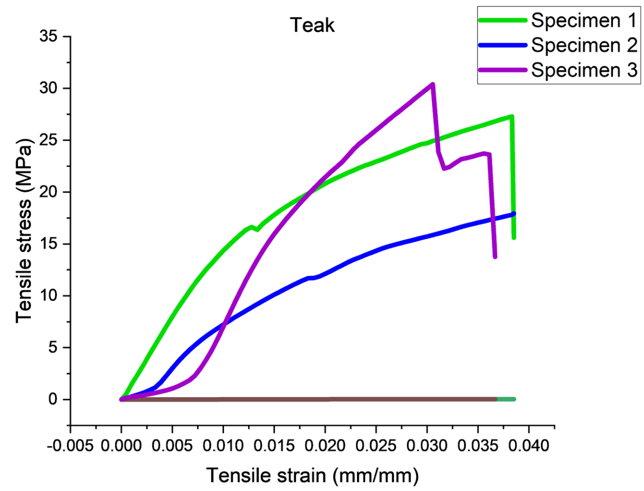

(e)

Figure 5. (a)-(e): The graphs of the responses of each of the species to tensile loads applied to the woods during the laboratory experiments.

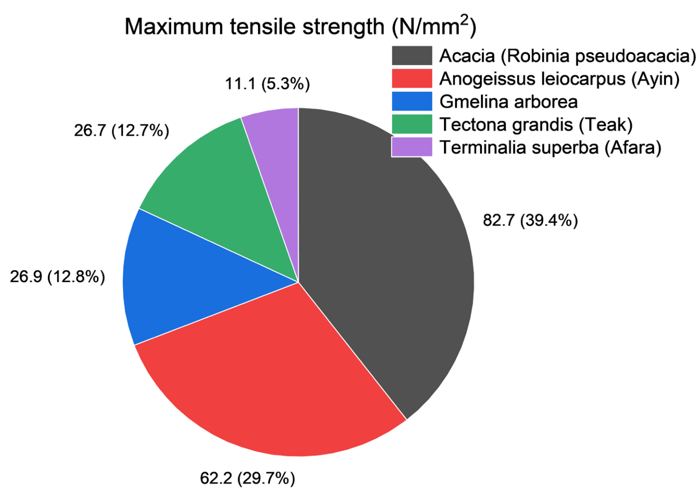

Figure 6. Tensile strength properties of the different wood species.

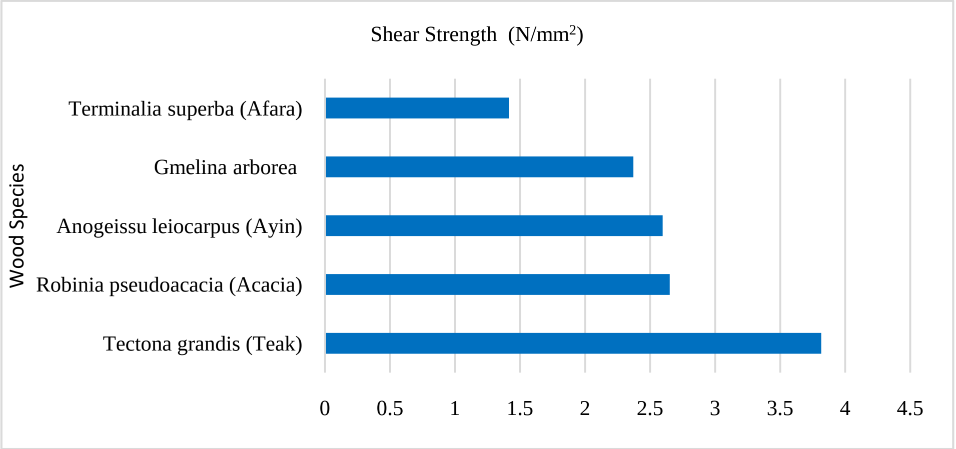

Figure 7. Shear strength properties of the different wood species.

3.5. Mean Wood Density of the Different Wood Species

Density has a strong influence on the physical characteristics, seasoning and shrinkage rate, defects and mechanical characteristics of wood. The mean densities of the selected species were calculated from the experimental results, recorded and arranged in descending order in Figure 8. The results show that Acacia (Robinia pseudoacacia) is the densest of all the species, followed by Tectona grandis (Teak), Anogeissus leiocarpus (Ayin) and Gmelina arborea respectively. The least dense in the rank is Terminalia superba (Afara).

3.6. Comparison of the Experimental Results with the Classes of Strength in BS 5268

Table 8 of [18] has timber species' strength classes based on the values of their mechanical properties; tension parallel to grain, compression parallel to grain, bending parallel to grain, shear parallel to grain, density and MOE. The results of the experiments conducted on the test species were compared with the values in this code to ascertain the classes that these test species may fall into. The highest strength class in the code is class D70 while the lowest is C14. Reference [18] states that the strength classes C14 to C40 are softwood and D30 to D70 are hardwood.

All the tested species cannot be categorized into any of the classes of strength in the code because all the species have very lower values of MOE to the classes in the code, four (4) of the species; Anogeissus leiocarpus (Ayin), Acacia (Robinia pseudoacacia), Gmelina arborea, and Tectona grandis (Teak), have values of their tension parallel to grain, compression parallel to grain and bending parallel to grain far higher than the values of the same parameters for Class D70 timber in the code, hence cannot be classified as any of the classes in the code. Terminalia superba (Afara) values of the parameters does not only lower the value of class D70 but each parameter; tension parallel to grain, compression parallel to grain and bending parallel, falls into three different classes; Class D60, Class D30 and Class D70 respectively.

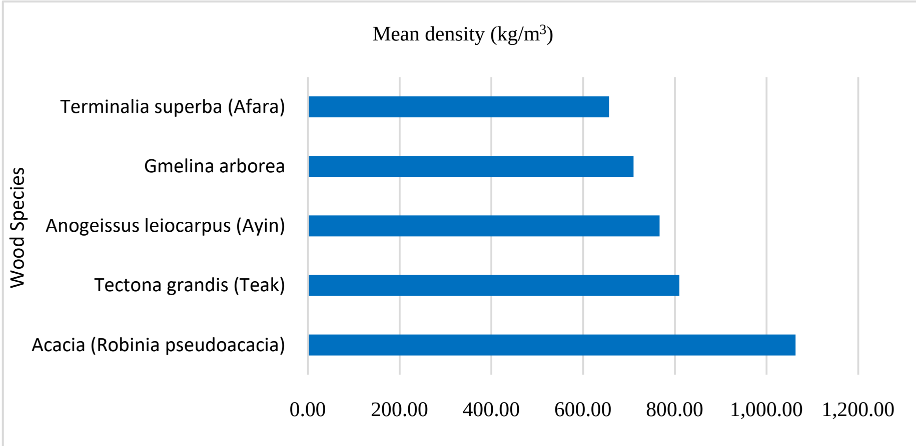

Figure 8. Mean wood density of the different wood species.

The result is the same for all the species in terms of shear parallel to grain, density and MOE. There is no clear-cut class of strength for all the species. Although, the experimental values are not higher than the code provisions but for a species, the three parameters can fall into different classes. For example, in terms of shear, Anogeissus leiocarpus (Ayin) falls into class D40 and class D50.

4. Conclusions

Because the experimental values obtained are higher than the values quoted for strength classes of timber in Table 8 of BS 5268-2:2002, except for Terminalia superba (Afara), it can be concluded that the studied wood species; Anogeissus leiocarpus (Ayin), Acacia (Robinia pseudoacacia), Gmelina arborea, and Tectona grandis (Teak), are of higher good qualities than the classes in the British code of practice. Anogeissus leiocarpus (Ayin), Acacia (Robinia pseudoacacia), and Tectona grandis (Teak) are dense and have mechanical properties that suggested that they are very useful structural timber. Gmelina arborea and Terminalia superba (Afara) are also hardwood but have limited structural use and therefore should be used where no structural timber is required.

In conclusion, the values obtained from the experiments are higher than the values of the classes in the code except for Terminalia superba (Afara). Therefore, these wood species can perform better than D70 in term of tension parallel to grain, compression parallel to grain and bending parallel to grain.

5. Recommendations

1) Anogeissus leiocarpus (Ayin) is recommended for roof members, such as rafter, king post, column and strut, where compressive stresses are to be resisted. Acacia (Robinia pseudoacacia), Gmelina arborea and Tectona grandis (Teak) could also be used for similar purpose but when the compressive stress to be resisted is lower. Terminalia superba (Afara) is not recommended at all.

2) Anogeissus leiocarpus (Ayin) and Acacia (Robinia pseudoacacia) are highly recommended for roof member in tension; which is tie beam. Gmelina arborea

and Tectona grandis (Teak) can only be used in tie beam where tension in the member is very minimal. Also, Terminalia superba (Afara) is not advisable for use.

3) Where combined bending and tension occurred (or likely to occur) in a member, Anogeissus leiocarpus (Ayin) is the most recommended timber for use because it has very good and best bending and tensile strength properties. Acacia (Robinia pseudoacacia), Gmelina arborea and Tectona grandis (Teak) can also be moderately used especially when Anogeissus leiocarpus (Ayin) is not readily available. Also, Terminalia superba (Afara) is not suitable for usage.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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