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A Review of Mechanical Strength Properties of Some Selected Timbers in Nigeria

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Abstract:
The variation in mechanical properties of eight different timber species was reviewed from the project works on timber carried out in the Department of Civil Engineering, University of Ilorin. Kwara state, Nigeria. These species include Iroko (Chlorophora excelsa), Mahogany (Khaya ivorensis), Fanpalm (Borassus aethoiopum), Ekki (Lophira alata), Opepe (Nauclea diderrichii), Apa (Afzelia, bipindensis), Ayin (Anogeissus leiocarpus), Afara (Terminalia superba). The Annual Book of ASTM Standard Section 4, (D143), method of testing small clear specimens of timber was adopted to evaluate the variation of strength properties of the species from standard speed and dimension specifications. The strength properties reviewed were, compression parallel to grain, compression perpendicular to grain, static bending (flexure) and tensile strength parallel to grain. From the review, it was found that strength of timbers along the grain is far greater than across or perpendicular to grain showing the anisotropic nature of timber. Prior soaking of the specimen before test accounts for reduction in strength. Also deviations from the specified dimensions and speed of testing of specimen will in one way or the other affect the accuracy of strength obtained in the test. It is therefore recommended that strict adherence to the test procedure and specifications should be followed so as to achieve the exact strength values of timbers and that further research work be done on other timbers in order to maximize their usefulness as a construction material.

Keywords: *Timber, grain, species, specimen, strength properties, compression, tensile strength, flexure*

1. Introduction

Timber is a complex building material owing to its heterogeneity and species diversity. It does not have consistent, predictable, reproducible and uniform properties as the properties vary with species, age, site and environmental conditions. Unlike steel and concrete, timber is a natural material and is not manufactured with consistent structural properties. It does not behave equally in all directions. It can be used as a replacement for steel and concrete, it has a higher strength and stiffness per unit of embodied energy, (which is the energy required to extract, manufacture and transport timber as well as the energy required to assemble and finish it), but it is not early as durable. It must be protected from fine rot. (Biggs 1991). As shown in figures 1 below, for a relatively similar stiffness there is a greatly reduced embodied energy for wood and brick compared to concrete, steel and aluminum.

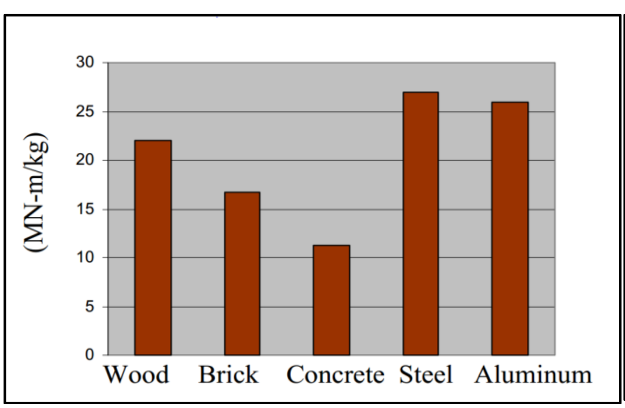

Figure 1a: Embodied Energy per stiffness (Biggs 1991)

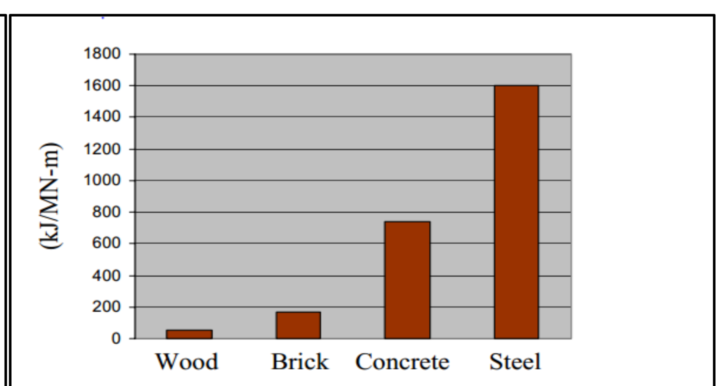

Figure 1b: Stiffness per unit weight (Biggs 1991)

Timber strength parallel to the grain is vastly different from strength and stiffness normal to the grain. Compared to other building materials, timber is light in weight and highly resilient. Countless bridges, towers and wooden structures all over the world bear testimony to this. Wooden houses, roof trusses, walls, floors and stairs have been in use for generations. Wood dwellings over 700 years old, yet still inhabited today, are proof of wood's lifelong durability as a building material. (Godesberger, 2007).
Therefore, reviewing various works on strength properties of timber is of daring importance. This will help in understanding the property each timber exhibits and its use in construction. It is also geared towards having a unique, uniform value of strength for various timbers like steel.

2. Review Study

Different works have been done on evaluation of strength properties of various timbers. Table 1 below shows the various timbers reviewed and their authors.

Timber	No of Authors
Fanpalm (*Borassus aethoiopum)*	4
Opepe (*Nauclea diderrichii*)	1
Ekki (*Lophira alata*)	1
Iroko (*Chlorophora excelsa)*	3
Mahogany *(Khaya ivorensis)*	2
Afara (*Terminalia superba*)	1
Apa (*Afzelia bipindensis*)	1
Ayin (*Anogeissus leiocarpus*)	2
Total	**15**

Table 1: Various Timbers and the Number of Authors

In 2003, Buhari worked on the effect of moisture on the strength properties of Fanpalm having soaked the specimen in water for several days. From his test result, the average compression parallel to grain strength was 33.15N/mm^2. Similar test was already carried out by Olawepo (2001), without soaking the specimen, who from his test arrived at a compressive strength value of 55.52N/mm^2. Both authors tested their specimen according to the standard ratio specifications for dimension of (15 x 15 x 60) i.e. for short column. The length should be four times the thickness or thickness is less than or equal to an inch or 25mm) and speed of 1.5mm/min using machine capacity of 50kN (UTM).
Unlike Buhari and Olawepo, Bakare (2004) performed similar test on Fanpalm, using the same machine capacity but different speed of testing, and the specimen length was reduced by 20mm (15 x 15 x 40); the resulting compressive strength value was 53.34 N/mm^2. Jimoh (2000) worked on the Ultimate strength Design of Axially loaded Fanpalm column using the standard ratio specimen dimension of 25 x 25 x 100mm, arriving at a compressive strength value of 112.56N/mm^2. The results are as tabulated below;

Author	Strength value(N/mm^2)	Dimension(mm)	Machine speed(mm/min)
Buhari, 2003	33.15	15 x 15 x 60	1.5
Olawepo, 2001	55.52	15 x 15 x 60	1.5
Bakare, 2004	53.34	15 x 15 x 40	-
Jimoh 2000	112.56	25 x 25 x 100	Not specified
Average Compression strength =	**84.85**		
Standard Deviation	**34.13**		

Table 2: Showing Authors Dimension, Machine Speed and strength Value for Compression parallel to grain of Fanpalm.

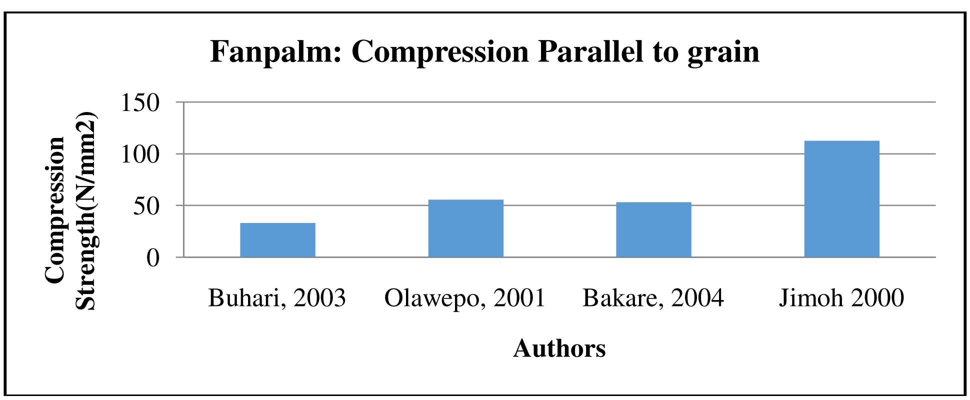

Figure 2: Compression Parallel to grain of Fanpalm

Still on Fanpalm, Buhari, (2003) and Bakare (2004) carried out static bending (Flexural strength test). According to Buhari (2003), the static bending strength value was 73.26 N/mm^2 for a 15 x 15 x 225mm (scaled down) standard ratio specimen dimension and speed of testing of 2.5mm/min. Bakare (2004) on his own part arrived at a value of 119 N/mm^2 also for the same speed and standard dimension of 50 x 50 x 750. This is shown in table below.

Author	Strength value(N/mm^2)	Dimension(mm)	Machine Speed(mm/min)
Buhari, 2003	73.26	15 x 15 x 225	2.5
Bakare, 2004	119	50 x 50 x 760	2.5
Average Flexural strength =	**96.13**		
Standard Deviation	**33.34**		

Table 3: Showing Authors, Dimension, Machine Speed and strength Value for Flexural strength of Fanpalm.

Also, t ensile strength test parallel to grain was carried out on Fanpalm by Olawepo (2001) and Bakare (2004) both used a non-standard specimen sizes, but of the same standard speed of testing of 1mm/min. Olawepo (2001) arrived at a strength value of 98.88 N/mm^2 while Bakare (2004) got 79.85 N/mm^2 as shown below.

Author	Strength value(N/mm^2)	Dimension(mm)	Machine speed(mm/min)
Olawepo, 2001	98.85	6 x 15 x 150	1.0
Bakare, 2004	79.85	4 x 8 x 200	1.0
Average Tensile parallel to grain strength =	**89.35**		
Standard Deviation	**13.44**		

Table 4: Showing Authors, Dimension, Machine Speed and strength Value for Tensile strength of Fanpalm.

Bakare (2004) went further to test his specimen for compression perpendicular to grain using a standard specimen size of 15 x15 x 60, but the speed of testing used was not according to specification. His strength value was 18.97N/mm^2.

For Mahogany Timber, Adewumi (2006) tested samples for compression with the orientation parallel to grain using non-standard specimen size and dimension, from the results, the Mean compression parallel to grain strength value was 34.34 N/mm^2 for 15 x 15 x 40mm specimen size. Adefemi (2011) made use of the manual compression testing machine of 1560kN Capacity and unspecified speed, the dimensions of the specimen were 25 x 25 x 100 (scaled down). His result shows that the compression parallel to grain strength value was 43.20 N/mm^2 as shown below.

Author	Strength value(N/mm^2)	Dimension(mm)	Machine speed(mm/min)
Adewumi, 2006	34.34	15 x 15 x 40	**20**
Adefemi, 2011	43.20	25 x 25 x 100	Not specified
Average Compression parallel to grain strength	**38.77**		
Standard Deviation	**6.26**		

Table 5: Showing Authors, Dimension, Machine Speed and Strength Value strength for Compression parallel to grain of Mahogany.

From Static Bending result of Adewumi (2006), the strength value was 98.22 N/mm^2, for a non- standard speed and specimen dimension of 10 x 10 x 200mm.

Tensile Strength value parallel to grain of Mahogany according to Adewumi (2006) was 61.47 N/mm^2 for a non-standard specimen dimension of 6 x 20 x 170mm and speed.

Oyelami (2005), carried out his compression parallel to grain test on Iroko timber stem and arrived at a strength value of 35.19 N/mm^2 for 25 x 25 x 100mm (scaled down) standard specimen dimension, but the speed used was different from the specified. Whereas Agarry (2003) who also worked on the same timber arrived at a strength value of 48.94 N/mm^2 for a 15 x 15 x 60 standard specimen dimension (scaled down) using the specified speed. Jimoh (2007) in his own case worked on the Continuous Column design formula at Ultimate strength for Axially loaded Iroko timber, and from his findings, the Compressive strength value for 20 x 20 x 80mm (scaled down) specimen dimension was 51.50N/mm^2 using a UTM machine. The table below shows a summary of the results.

Author	Strength value(N/mm^2)	Dimension(mm)	Machine speed(mm/min)
Oyelami (2005)	35.19	25 x 25x 100	**10**
Agarry (2003)	48.94	15 x 15 x 60	1.5
Jimoh (2007)	51.5	20 x 20 x 80	NS
Average	**45.21**		
Standard deviation	**8.77**		

Table 6: Showing Authors, Dimension, Machine Speed and Strength Value for Compression parallel to grain of Iroko timber stem.

The three Authors also worked on the static bending (flexural strength) of the Iroko timber. From their results, Oyelami (2005) had his flexural strength value to be 61.61 N/mm^2 using the specified speed but the dimension used was not what is recommended. Unlike

Oyelami (2005), Agarry (2003) had a higher strength value 71.38 N/mm^2, using the standard speed of testing and standard dimension. Similarly, Jimoh (2007) arrived at a flexural strength value of 71.38N/mm^{2}in agreement to Agarry's result. The results are shown in the table below.

Author	Strength value(N/mm^2)	Dimension(mm)	Machine Speed(mm/min)
Oyelami (2005)	61.16	16 x 20 x 150	**2.5**
Agarry (2003)	71.38	15 x 15 x 225	2.5
Jimoh (2007)	71.38	25 x 25 x 380	Not specified
Average Static Bending strength	**67.97**		
Standard Deviation	**5.90**		

Table 7: Author Specimen Dimension, Speed and strength for Static Bending of Iroko timber stem.

Tensile strength parallel to grain test was also carried out by Oyelami (2005) and Agarry (2003). Agarry (2003) tested his specimens of 15 x 25 x 200mm non- standard dimension using the recommended speed. A strength of 123.80 N/mm^2 was gotten from that work. But Oyelami (2005) obtained a strength of 67.16 N/mm^2 for 16 x 20 x 150mm non-standard specimen dimension and speed. The mean Tensile Strength parallel to grain was found to be 95.48N/mm^2

Sijuwola (2009) worked on Ayin timber column. From that research, the compression strength parallel to grain was 28.65N/mm^2 for varying dimensions. While Subair (2012) had a value of 50.72N/mm^2 for 25 x 25 x 100mm (scaled down), using manual compression machine with unspecified speed. Jimoh (2005) also worked on Ultimate strength design of axially loaded Ayin (*Anogeissus leiocarpus*) timber columns having the Compression parallel to grain value of 54.35 N/mm^{2}for 20 x 20 x 80mm standard specimen dimension (scaled down). Below is the summary of the results.

Author	Strength value(N/mm^2)	Dimension(mm)	Machine Speed (mm/min)
Sijuwola (2009)	28.65		Not specified
Subair (2012)	50.72	25 x 25 x 100	Not specified
Jimoh (2005)	54.34	20 x 20 x 80	Not specified
Average	**44.57**		
Standard deviation	**13.91**		

Table 8: Authors, Specimen Dimensions, Speed and strength for Compression parallel to grain of Ayin timber stem.

Adegbite (2012) used a standard dimension of 25 x 25 x 100mm (scaled down) to determine the compressive strength of Apa timber column. Using the manual compression machine with unspecified speed, a mean strength of 31.04N/mm^2 was obtained.

Olaloti (2015) worked on the properties of Afara timber stem having the compression parallel to grain strength of 25.05N/mm^2, using a standard dimension of 25 x 25 x 100mm (scaled down), but the speed of testing was not specified. The value for Tensile Strength parallel to grain was 19.54N/mm^2 for non- standard specimen size and unspecified speed, while the compression perpendicular to grain strength value was 7.088N/mm^2 for standard dimension but the speed used was not specified.

Ominrinde (2002) compared the strength properties of Ekki with that of Opepe timber stem, arriving at the strength values given in table below.

Author	Timber	Strength value (N/mm^2)	Dimension(mm)	Machine Speed(mm/min)
Ominrinde 2002	Ekki	65.27	**15 x 15 x 60**	**2.5**
Ominrinde 2002	Opepe	51.57	**15 x 15 x 60**	2.5

Table 9: Author, Timber type, Specimen Dimension, Speed and compression parallel to grain strength of Opepe and Ekki timberstem.

Author	Timber	Strength value (N/mm^2)	Dimension(mm)	Machine Speed(mm/min)
Ominrinde 2002	Ekki	137.27	**10 x 10 x 150**	**0.05**
Ominrinde 2002	Opepe	104.24	**10 x 10 x 150**	0.05

Table 10: Author Specimen Dimension, Speed and Flexural strength of Opepe and Ekki timber stem.

Author	Timber	Strength value (N/mm^2)	Dimension(mm)	Machine Speed(mm/min)
Ominrinde 2002	Ekki	135.77	**10 x 10 x 200**	**2.5**
Ominrinde 2002	Opepe	94.75	**10 x 10 x 200**	2.5

Table 11: Author Specimen Dimension, Speed and Tensile parallel to grain strength of Opepe and Ekki timber stem.

3. Discussion of Results

Author	Speed	Dimension	Strength value (N/mm^2)
Buhari (2003)	Standard	Standard	33.15
Olawepo (2001)	Standard	Standard	55.52
Bakare (2004)	Unspecified	Unspecified	53.34
Jimoh (2000)	Non-Standard	Standard	112.56
		Average	**84.85**
		Standard deviation	**34.13**

Table 12: Summary of result for Compression Parallel to grain (Fanpalm)

From Table 12, it can be seen that the deviation from the mean value of the compression parallel to grain is high enough (34.13N/mm^2). This is owing to the fact that samples of (Buhari, 2003) were soaked in water which results in strength reduction despite the fact that the standard test procedure, dimension and speed were used. Bakare (2004) did not make use of the specified speed of testing and dimension but still had a converging result with that of Olawepo (2001). The fact that the scaled dimension ratio used by Jimoh (2000) resulted in higher strength as compared to others points to the fact that the greater the dimension, the higher the strength. The figure below shows the relationship.

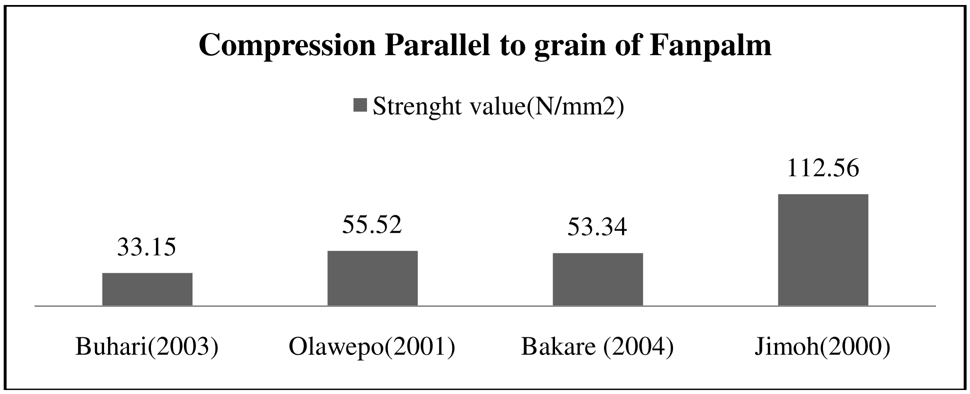

Figure 3: Compression Parallel to grain of Fanpalm

Also looking at the static Bending (Flexural) of Fanpalm, the mean value is 96.13N/mm^2, with a deviation of 33.34N/mm^2, which is also large enough. That Buhari's specimen were soaked and the dimensions were scaled down are reasons for why Buhari's result was significantly low.

For the tensile test, the mean value was 89.35N/mm^2, with a deviation of 13.44N/mm^2, which is acceptable, though Bakare (2004) did not use the standard dimension, His compression perpendicular to grain value was 18.97N/mm^2 for non-specified speed but standard dimension was used.

For Mahogany Timber, the mean compression parallel to grain strength is 38.77N/mm^2, with a deviation of 6.26N/mm^2 which must have resulted from the non- standard speed of testing of both Authors, wrong dimension of Adewumi (2006) and the use of Manual Compression testing machine of Adefemi (2011) and his scaled down dimensions.

Adewumi (2006) also had his static bending test value to be 98.22N/mm^2 and Tensile strength value to be 61.47N/mm^2. Both cases involved the use of non-standard speed and dimension specification.

For **Iroko** timber, the mean compression parallel to grain strength was 45.21N/mm^2 with the deviation of 8.77N/mm^2. This might have occurred from the non-standard speed used by Oyelami (2005), and non-specified speed of Jimoh (2007).

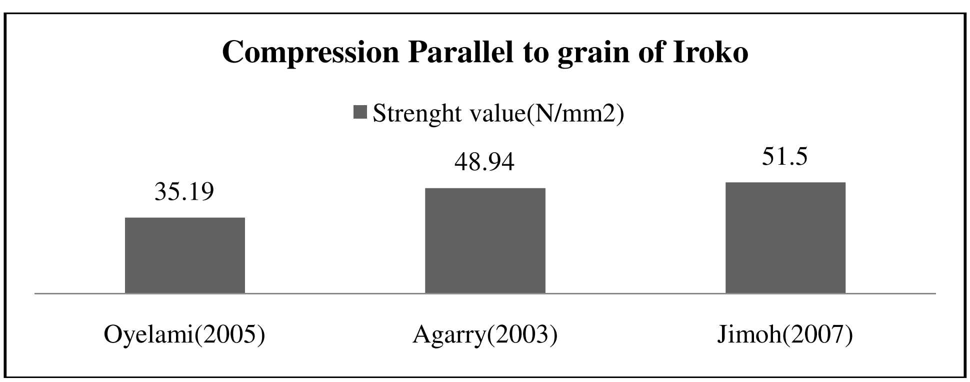

Figure 4: Compression Parallel to grain of Iroko

For the static bending test, the mean strength value is 67.97N/mm^2 with a deviation of 5.90N/mm^2, which is less enough. Also the deviation could be from non-standard dimension of Oyelami (2005).
For tensile parallel to grain the mean value was 95.48N/mm^2 with a very large deviation of 40.05N/mm^2 which must have resulted from the non-standard dimension specification by both authors, and non – standard speed specification by Oyelami (2005).
The **Ayin** timber had the mean compression parallel to grain strength value as 44.57N/mm^2 and a deviation of 13.91N/mm^2, resulting from Subair (2012) utilizing a manual compression testing machine, scaled down dimension of Jimoh (2005) and all authors not specifying the speed of testing.
For **Apa** timber, Adegbite (2012) arrived at a compression parallel to grain strength value at 31.04N/mm^2 using the standard dimension but unspecified speed of testing.
Olaloti (2015) had the mean compression parallel to grain strength of **Afara** as 25.05N/mm^2, for unspecified speed of testing. His tensile parallel to grain strength was 19.54N/mm^2 for unspecified speed and non-standard dimension. The tensile perpendicular to grain value was 7.088N/mm^2, for standard dimension but non-specified speed.
Finally, Ominrinde (2002) had his compression parallel to grain strength for Ekki and Opepe timbers as 65.27N/mm^2 and 51.57N/mm^2 respectively using non-standard speed of testing. His results for flexural strength gave a value of 137.27N/mm^2 and 104.77N/mm^2 for Ekki and Opepe timbers respectively. In both cases, non- standard speed and dimensions were used. This also goes for his Tensile strength with 135.77N/mm^2 and 94.75N/mm^2 for Ekki and Opepe timbers respectively.
Out of a total of 34 tests out by reviewed from all the Authors for the 8 timbers,14 of them (41% approximately) used a different speed of testing other than the specified, 10(29%) made use of the specified speed while, 10 (29%) did not specify. Similarly, for specimen dimension, 14(41%) did not use the specified dimension, while 20(59%) made use of the specified dimension, and 0% did not specify.

	Total No of Tests	Standard specification	Not Standard	Not specify
Speed	34	10(29%)	14(41%)	10(29%)
Dimension	34	20(59%)	14(41%)	0%

Table 13: Summary of comparison with standards

The average compression parallel to grain was 48.29N/mm^2, with Fanpalm having the highest strength value of 84.85N/mm^2 and Afara having the lowest strength value of 25.05N/mm^2. For static bending test, Ekki timber has the highest strength of 135.27N/mm^2 while Iroko has the lowest strength of 67.97N/mm^2 with the average of 100.37N/mm^2. The tensile test mean value was 82.73N/mm^2 with 135.77 maximum strength for Ekki timber and 19.54N/mm^2 as minimum for Afara timber. 13.03N/mm^2 was the mean strength value for the compression parallel to grain for the two timbers.

Timber	Compression parallel to grain(N/mm^2)	Static Bending (N/mm^2)	Tension parallel to grain (N/mm^2)	Compression Perpendicular to grain (N/mm^2)	Max.
FanPalm	84.85	96.13	89.35	18.97*	**96.13**
Mahogany	38.77	98.22*	61.47*	-	**98.22**
Iroko	45.21	67.97	95.48	-	**95.48**
Ayin	44.57	-	-	-	**44.57**
Apa	31.04*	-	-	-	**31.04**
Afara	25.05	-	19.54	7.088	**25.05**
Opepe	51.57*	104.24*	94.75*	-	**104.24**
Ekki	65.27*	135.27*	135.77*	-	**135.77**
AVERAGE	**48.29**	**100.37**	**82.73**	**13.03**	

Table 14: Summary of strength properties
** Single Author.*

4. Conclusion

From the review, it can be deduced that;
1. prior soaking the samples before test reduces the strength
2. The order of increase in strength of timber is Compression perpendicular <Compression parallel to grain< Tensile < Flexural.
3. Also, strengths along the grain are greater than strength perpendicular to the grain. This is of reflective of the anisotropic nature of timber.
4. There are often deviations from the specified dimensions and speed of testing of specimen, which in one way or the other affect the strength.

5. Recommendation

1. It is thus recommended that further research work be done on other timbers in order to maximize their usefulness as a construction material.
2. Further studies can be done on physical properties of timber.
3. Strict adherence to the test procedure and specifications can definitely give the exact strength value of timbers.

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