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Influence of Age on the Strength of Different Species of Timber

[1*]Ojo, Olaniyi. Segun. and [2]Idieunmah, Fidelis. Monday.

[1]Department of Building, Niger Delta University, Wilberforce Island, Bayelsa, Nigeria
[2]Department of Building, University of Benin, Benin, Nigeria.

*Corresponding Author's Email: shigo12002@gmail.com; Tel: 07038320019

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Abstract

Timbers are used as structural members in various areas of construction works. Hence the knowledge of properties of wood especially strength and factors affecting the strength of timber is very important. This study was conducted to determine the effect of age on the structural strength of timber. The wood species studied are Iroko (Chlorophora Excelsa), Nigerian Mahogany (Khaya Anthotheca) and Ita (Celtis Mildbraedii). The age of timber were determined by counting the number of annual growth rings, which is the combination of early wood and late wood and samples of different ages of timber, were obtained by personal visit to the forest where fresh timber was cut. The samples obtained were machined and trimmed to standard size with respect to BS 373 1957 (imprint 1999), 20mm X 20mm X 60mm for the determination of maximum compressive strength parallel to grain (MCS//), 20mm X 20mm X 20mm for static shear strength and 20mm X 20mm X 300mm to determine the bending strength. The samples obtained were carried to the laboratory at Forestry Research Institutes of Nigeria (FRIN) in Ibadan for testing using Instron Tensiometer machine. SPSS was used to analyze the relationship between strength and age of timber. The result obtained showed that the maximum compressive and Shear strength for Iroko, were at 120years, whereas it has maximum bending strength at 70years. Nigeria Mahogany and Ita has maximum compressive, bending and shear strength at 80 years, and 70 years respectively and among the three timber samples Ita is better in compression and shear strength and iroko is better in bending strength. It was concluded that age of timber has significant influence on timber strength.

Keywords: Strength, Age of timber, Iroko, Nigerian Mahogany, Ita.

Introduction

For centuries, timber has been one of the most common and useful building materials known to man. From earliest recorded times, timber has been a ubiquitous materials. The ancient Egyptians produced furniture, sculptures coffin and death mask from it as early as 2500BC. But during the industrial era of the 19th century timbers were used widely for the construction not only of roofs but also of furniture water wheels, rails, sleepers, signal poles bobbins and boats (Dinwoodie, 2001).

Timber products are widely used in the construction industry, by research carried out in the United States, in 2006, about 187.5 million m^3 of timber were consumed and about 50% - 67% were used for construction (Mckeever, 2009). Further, Food and Agriculture Organisation of United Nation (FAO) reported in 2016 that global consumption of timber in the construction industry increased from (0.5%-3%) for different timber product from 2012-2016 (FAO, 2016). In the present, timber has seen an extension of its use in certain area and a decline in others due to its replacement by newer materials (Jim Ilistion et al 2002).

Timber is a complex building material owing to its heterogeneity and species diversity. Timber does not have consistent, predictable, reproducible and uniform properties as the properties vary with species, age, site and environmental conditions (Kliger, 2000). The demand for quality timber for construction is on the rise in Nigeria due to a boom in the building construction industry. With overexploitation and scarcity of traditional timber species such as Mahogany and Iroko which has become a concern, couple with the fact that the uses of timber are been substituted with other composite material such as steel, effective and efficient use of timber becomes paramount.

Unlike so many other materials, especially those used in the construction industry, timber cannot be manufactured to a particular specification. Instead, the best use has to be made of the material already produced, though it is possible from the wide range available to select timbers with the most desirable range of properties, and many of these properties can either increase or decrease with age of timber. In this study, influence of ages on strength of timbers of different species was assessed.

Materials and Methods

According to the data presented in the bulletin 50 of the former Forest Product Research Laboratory, it showed that as density increases strength increase (cited by Dinwoodie, 2011). The same density has a major influence on the age of timbers. It follows that variation in ring width will change the density of the timber and hence its strength. Since there is a correlation between the density and the strength of timber, then there will be a corresponding effect between the age of timber and its strength.

Determination of age of timber: When the seasonal growth commenced the dominant function is conduction while in the latter part, the dominant factor is support. This change in emphasis manifest with the presence of thin-walled tracheid (about 2micrometer) in the early part of the season (the wood being known as early wood) and thick-walled (up to 10micrometer) and slightly longer (10%) in the latter part of the season (the late wood).
The combination of the early wood and late wood constitute the annual growth ring and this is produce yearly. In other to select each samples of timber for this study, the annual growth rings (consisting of early wood and late wood) were counted.
The annual growth rings are easily counted if the logs were fetched newly, although Iroko timber (age 90 and 120) used for this research were obtained from sawmill and magnifying lens was used for easy counting.

Determination of Mechanical Properties: For the purpose of this research sampling employed is sequential sampling. This is because different ages of timber were picked sequentially, although in order to give a distinct difference in strength value a minimum of five years space were given for each timber.
Mechanical parameters of timber sections were determined with the appropriate sizes in accordance with BS 5268: part 2 (2002). Timber section samples were obtained at the breast height of the species for all specimens.
The samples were tested at the Timber Mechanics Unit, Forestry Research Institute of Nigeria (FRIN) situated at Jericho, Ibadan, Oyo state using the Hounse field Tensiometer machine (plate 1)

Determination of compressive strength parallel to grain (MCS)

Wood samples were loaded at the rate of 0.01mm/sec, and the corresponding forces at the point of failure were taken directly. This was divided by the cross-sectional area of the test specimen to obtain value for maximum compressive strength parallel to grain.
The formula in equation 1, below was used to compute the maximum compression strength parallel to grain, using standard size of 20 x 20 x 60 mm. (Ogunsanwo and Akinlade, 2012). Different ages of timber tested are 25, 30, 35, 40, 45, 60, 70, 90 and 120 years for Iroko (Chlorophora Excelsa), 20, 30, 40, 50, 60, 70 and 80 years for Nigeria Mahogany (Khaya Anthotheca) and 30, 40, 50, 60, and 70 for Ita (Celtis Mildbraedii).

Plate 1: Instron Tensiometer.

The compressive strength was determined according to BS 5268: part 2 (2002)

$$\text{MCS} = \frac{p}{bd} N/mm^2 \tag{1}$$

Where: p = load (N)
b = breath of the sample (mm)
d = thickness of the sample (mm)
bd is the cross-section area (A)

Determination of the bending strength

The bending strength of wood is usually expressed as MOR, which is the equivalent fibre stress in the extreme fibres of the specimen at the point of failure was then calculated using the expression in equation 2 below. Different ages tested were the same for Iroko (Chlorophora Excelsa), Nigeria Mahogany (Khaya Anthotheca) and Ita (Celtis Mildbraedii) tested for compressive strength. The size tested is 20 x 20 x 300mm.

$$\text{MOR} = \frac{3pl}{2bd^2} N/mm^2 \tag{2}$$

Where P is load in Newton (N)
L is length of sample in (mm)
b is breath in (mm)
d is width in (mm)

Determination of shear strength

The shear strength was computed using sample size 20 x 20x 20 mm (Dinwoodie, 2011).with the formula in equation 4 below. The timber samples and timber ages tested are the same as tested for compressive and Bending Strength.

$$\text{Shear Strength} = \frac{p}{bd} N/mm^2 \tag{3}$$

Where p = load (N)
b = breath of the sample (mm)
d = thickness of the sample (mm)

Results and Discussion

Mechanical properties

Compressive Strength Parallel to Grain (MCS//): Table 1, 2, and 3 presented the results of the mean compression strength parallel to grain for Iroko, Nigerian Mahogany, and Ita. The maximum value as observed were 47N/mm^2 (at 120 years), 41N/mm^2 (at 80 years), and 44N/mm^2 (at 70years) for Iroko, Nigerian Mahogany, and Ita respectively. It can also be observed at year 70, Iroko has 35.50N/mm^2, Nigerian Mahogany 38.00N/mm^2 and Ita 44N/mm^2. This showed that Ita is better in compression. However, from other results, Bush Mango 65.58N/mm^2 and Ire 19.32N/mm^2 (Rahmon et al., 2020), Apa 28.59N/mm^2 (Adefemi, 2015). The results were within 71.97N/mm^2 >20.01N/mm^2.

Table 1. Compressive, Bending and Static Shear test for Iroko

S/N	Age of Timber	Type of Wood	Compressive Test		Bending Test		Shear Test	
			Max. Load (N)*10^3	Max. Strength (N/mm^2)	Max. Load (N)*10^3	Max. Strength (N/mm^2)	Max. Load (N)*10^3	Max. Strength (N/mm^2)
1	25	Sapwood	14.00	35.00	444.00	74.00	4.12	10.30
2	30	Sapwood	14.20	35.50	445.80	74.30	4.32	10.80
3	35	Sapwood	15.30	38.25	447.80	74.80	4.52	11.30
4	40	Sapwood	16.00	40.00	456.60	76.10	4.68	11.70
5	45	Sapwood	17.00	42.50	464.40	77.40	4.92	12.30
6	60	Heartwood	10.20	25.50	560.00	93.33	3.64	9.10
7	70	Heartwood	14.20	35.50	575.50	95.90	3.80	9.50
8	90	Sapwood	17.80	44.50	480.60	80.10	5.24	13.10
9	120	Sapwood	18.80	47.00	500.40	83.40	5.60	14.00

Table 2. Compressive, Bending and Static Shear test for Nigeria Mahogany

S/N	Age of Timber	Type of Wood	Compressive Test		Bending Test		Shear Test	
			Max. Load (N)*10^3	Max. Strength (N/mm^2)	Max. Load (N)*10^3	Max. Strength (N/mm^2)	Max. Load (N)*10^3	Max. Strength (N/mm^2)
1	20	Sapwood	11.20	28.00	255.00	42.50	2.68	6.70
2	30	Sapwood	12.10	30.25	261.00	43.50	2.82	7.05
3	40	Sapwood	12.40	31.00	264.00	44.00	2.96	7.40
4	50	Sapwood	14.20	35.50	270.00	45.00	2.98	7.45
5	60	Sapwood	13.80	34.50	288.00	48.00	3.11	7.77
6	70	Sapwood	15.20	38.00	295.20	49.20	3.21	8.02
7	80	Sapwood	16.60	41.50	312.00	52.00	3.26	8.14

Table 3. Compressive, Bending and Static Shear test for Ita

S/N	Age of Timber	Type of Wood	Compressive Test		Bending Test		Shear Test	
			Max. Load (N)*10^3	Max. Strength (N/mm^2)	Max. Load (N)*10^3	Max. Strength (N/mm^2)	Max. Load (N)*10^3	Max. Strength (N/mm^2)
1	30	Sapwood	14.20	35.50	390.00	65.00	4.48	11.20
2	35	Sapwood	14.48	36.20	399.00	66.50	4.76	11.90
3	40	Sapwood	14.80	37.00	402.00	67.00	4.96	12.40
4	50	Sapwood	15.00	37.50	423.00	70.50	5.12	12.80
5	60	Sapwood	16.20	40.50	450.00	75.00	5.21	13.02
6	70	Sapwood	17.60	44.00	463.20	77.20	5.36	13.40

Bending Strength or Modulus of Rupture (MOR): In Table 1, 2, and 3, the maximum Bending Strength at year 70 is 95.90N/mm^2 for Iroko, at 80 is 52.00N/mm^2 for Nigerian Mahogany and at 70 years is 77.20N/mm^2 for Ita. Using 70 years as benchmark, it can be observed among the three that Iroko has the highest bending strength of 95.90N/mm^2. In other results, Bush mango is 190.40N/mm^2 and Ire 60.33 N/mm^2 (Rahmon et al., 2020), Black Afara 50.13N/mm^2 (Kaura et al., 2015), D. Fusca 65.14 N/mm^2 and D. Rappa, 61.32N/mm^2 (Duju and Badorul, 2015), Ahun, 39.36 N/mm^2 (Mohammed, 2014), and Meliceae Excelsa (Jamala et al., 2013).

Shear Strength: The Maximum Shear Strength results for all the three timber samples (Table 1, 2 and 3) were Iroko (120 years) is 14.00 N/mm^2, Nigerian Mahogany (80 years) is 8.14 N/mm^2, and Ita (70 years) is 13.40 N/mm^2. At year 70, Iroko, Nigerian Mahogany and Ita have shear strength of 9.50 N/mm^2, 8.02 N/mm^2, and 13.40 N/mm^2 respectively. Ita is also better in shear resistance. In other results, we have Bush Mango 4.48 N/mm^2 and Ire 3.69 N/mm^2 (Rahmon et al., 2020).

Regression analysis on Iroko, Nigerian Mahogany and Ita samples

For the regression analysis in the built function of SPSS 16.0 for window was used as it allows one to store the data, performed transformative, analysis and produce chart and graph results.
In this regard, the explanatory variables identify for serious variability in strength of timber (Dependent variable) were;

Age of timber, X_1 (kN/m^2)
Cross-sectional area, X_2 (kN/m^2)
Maximum load, X_3 (kN/m^2)

The Correlation Analysis was run twice; the first run showed that it is only Age of Timber that has significant relationship with strength of timber as it has a Pearson's correlation high enough (above 0.250) (Table 4). The second run was required to eliminate all the insignificant variables and the resulting Regression coefficients table (Table 5-13) were used to generate the models. Table 5-13 showed linear relationship between age of timber and the strength of timber as observed from the models. Several other researches carried out on density and strength of timber showed a corresponding linear relationship similar to age of timber.

For instance, in 1992, Shepard & Shottafer reported that there is a linear relationship between wood density and mechanical properties of timber. A research conducted by Kiae & Samariha (2011) on fibre dimensions, physical and mechanical properties of five important hardwood plants. The results showed a positive correlation between wood density and bending and compressive strength of timber. In West Africa, a similar research conducted by Okoh (2014) on Ghanaian hardwoods concluded there is a positive linear correlation between wood density and compressive and bending strength. In contrast, age of timber and density of timber has linear correlation and relationship with strength of timber.

Table 4. Correlation Analysis of the Dependent and Independent variables

		Compressive Strength	Age of Timber	Maximum Load	Cross-sectional Area
Compressive Strength	Pearson	1	.487	.000**	b
	Sig.(2-tailed)		.183	.000	
	N	9	9	9	9
Age of Timber	Pearson	.487	1	.487	b
	Sig.(2-tailed)	.183		.183	
	N	9	9	9	9
Maximum Load	Pearson	.000**	.487	1	b
	Sig.(2-tailed)	.000	.183		
	N	9	9	9	9
Cross-sectional Area	Pearson	b	b	b	b
	Sig.(2-tailed)				
	N	9	9	9	9

**Correlation is significant at the 0.01 level (2-tailed).
b.Cannot be computed because at least one of the variables is constant.

Table 5. Regression Coefficients of Iroko Compressive strength

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	32.541	4.312		7.546	.000
Age of Timber	.099	.067	.487	1.477	.183

Table 6. Regression Coefficients of Iroko Bending strength

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	73.654	5.603		13.146	.000
Age of Timber	.129	.087	.489	1.484	.181

Table 7. Regression Coefficients of Iroko Shear strength

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	9.708	1.044		9.295	.000
Age of Timber	.029	.016	.555	1.765	.121

Table 8. Regression Coefficients of Nigerian Mahogany Compressive strength

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	23.482	1.229		19.103	.000
Age of Timber	.213	.023	.972	9.309	.000

Table 9. Regression Coefficients of Nigerian Mahogany Bending strength

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	38.475	.935		41.153	.000
Age of Timber	.157	.017	.971	9.031	.000

Table 10. Regression Coefficients of Nigerian Mahogany Shear strength

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	6.320	.089		71.349	.000
Age of Timber	.024	.002	.988	14.395	.000

Table 11. Regression Coefficients of Ita Compressive strength

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	28.900	1.396		20.697	.000
Age of Timber	.201	.028	.963	7.133	.002

Table 12. Regression Coefficients of Ita Bending strength

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	55.020	.970		56.742	.000
Age of Timber	.320	.020	.993	16.327	.000

Table 13. Regression Coefficients of Ita Shear strength

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	10.113	.416		24.293	.000
Age of Timber	.049	.008	.946	5.862	.000

Iroko timber,
Compressive strength, $Y= 32.541+0.099 X_1$
Static bending strength, $Y = 73.654 + 0.129 X_1$
Shear strength $Y=9.708 + 0.029 X_1$

Nigeria Mahogany,
Compression strength, $Y=23.482 + 0.213 X_1$
Static Bending Strength, $Y= 38.475+ 0.157 X_1$
Shear Strength $Y = 6.32 + 0.024 X_1$

Ita timber,
Compressive strength, $Y= 28.90 + 0.201X_1$
Static Bending strength, $Y = 55.02 + 0.320X_1$
Shear Strength, $Y = 10.113 + 0.049X_1$

Conclusion

It could be concluded that the older the age of (Nigerian Mahogany and Ita) timber the higher the strength properties. Similarly, it could be said that as age of (Iroko) timber increases the compression and shear strength increases, but the bending strength is maximum at 70 years. Furthermore, among the three samples, using a uniform age of 70 years, Ita is the best in compression and shear whereas Iroko is the best in bending. In addition, the three timber samples showed good strength properties when compared with strength values of other timber samples used in the previous studies. This study has shown clearly that there is a linear relationship between age and strength of timber.

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