Quantitative Wood Anatomical Characteristics in Static Bending Strength of Some Commercial Timbers of Nigeria

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Abstract

Seventeen commercial timbers of Nigeria were assessed with respect to their quantitative anatomical characteristics and static bending strength along the grain. The results showed positive correlations between static bending strength of the timbers and fibre cell wall thickness, Runkel ratio, slenderness ratio and fibre content. Negative correlations were recorded between static bending strength and fibre length, fibre diameter, fibre lumen diameter, fibre coefficient of flexibility, vessel diameter and vessel length. Prediction equations from regression analyses between static bending strength and the various anatomical parameters were statistically valid for fibre length, fibre coefficient of flexibility, slenderness ratio and vessel diameter. From the foregoing indications, it would appear that prediction of static bending strength of timbers from quantitative anatomical characteristics stands as an alternative to the laboratory and service tests currently available to structural engineers.

Keywords: Quantitative anatomy, Bending strength, Timber

Introduction

Over the years, wood has found tremendous usage in shipbuilding, housing, railway sleepers, transmission poles, pit props in mines, fencing posts, bridges, furniture and in the manufacture of various semi-synthetic products (Tsoumis, 1968). According to Anon (1974), timber is wood obtained from tree trunks and prepared specially for building construction and carpentry. It is cut exclusively from conifers and dicotyledons. The strength properties of timbers are relevant to their utilization.

There is considerable variability in the structural and strength properties of timbers and the problem that these pose to the utilization of the material in most situations where uniformity and stability are desirable are rather challenging. In making use of timber in his work, where heavy load is involved for example, the structural engineer is expected to use timber commensurate in size and strength. This goes a long way in the erection of long-lasting structures, thus reducing the chances of accidents due to structural failures. The application of a sound knowledge of strength and other properties of timber definitely gives the timber greater reliability in service.

Providing the essential anatomical principles, Esau (1965), indicated that the composition of the xylem tissue and the structural arrangement of the component elements considerably determine the physical properties of woods and their suitability for commercial usage. The author further pointed out that such factors as fibre content of wood, fibre length, fibre cell wall thickness, vessel abundance and distribution, axial parenchyma abundance and distribution, percentage ray volume, growth layer width and proportion of late wood, had direct or indirect influence on the specific gravity and strength properties of wood. The relationships were, however, not spelt out for specific timber species.

To determine the strength properties of wood, two standard alternative test methods are available; the service test and the laboratory methods (Desch and Dinwoodie, 1981). Service tests are carried out under the conditions to which the timber is exposed in service, and data collection takes a long period. In the laboratory methods, two classes of tests are made; tests on small, clear specimens and tests on timbers of structural size. These alternative test methods are rigorous and expensive to perform. In the circumstance, the need arises to explore any other reliable approach for determining the strengths of structural timbers. The present paper presents our studies on the possibility of the quantitative anatomical approach.

Materials and Methods

Seventeen commercial timbers of Nigeria of marketable size and age were selected across ten families (Table 1).

Table 1: Selected timber species and their families

	Species	Families
1.	*Alstonia boonei* De wild	Apocynaceae
2.	*Ceiba pentandra* (Linn.) Gaerth.	Bombacaceae
3.	*Canarium schweinturthii* Engl.	Burseraceae
4.	*Terminalia superba* Engl and Diels	Combretaceae
5.	*Diospyros mespiliformis* Linn.	Ebenaceae
6.	*Afzelia Africana* sm.	Fabaceae-Caesalpinoidae
7	*Berlinia auriculata* (Benth)	Fabaceae-Caesalpinoidae
8.	*Brachystagia nigerica* Hoyle and A. P. D. Jones	Fabaceae-Caesalpinoidae
9.	*Detarium microcarpum* Guil. and perr.	Fabaceae-Caesalpinoidae
10.	*Gossweilerodendron balsamiferum* (verm) Harms	Fabaceae-Caesalpinoidae
11.	*Periscopsis elata*	Fabaceae papilionoidae
12.	*Khaya ivorensis* A. Chev.	Meliaceae
13.	*Antiaris toxicaria* var. *africana*	Moraceae
14.	*Milicia excelsa* (Welw.) CL Berg	Moraceae
15.	*Mansonia altissima* A. Chev.	Sterculiaceae
16.	*Triplochiton scleroxylong*. K schum	Sterculiaceae
17.	*Gmelina arborea* Roxb.	Verbenaceae

Table 2: Mean values of quantitative anatomical parameters and static bending strength of the timbers investigated

Timber species	Mean fibre length	Mean fibre diameter	Mean fibre lumen diameter	Mean fibre wall thickness	mean runkel ratio	Mean Coefficient of flexibility	Mean Slenderness ration	Mean Vessel member length	Mean Vessel dia. In rad. dir.	Mean vessel dia. In tan. Dia.	Mean No of fibre per field of view	Mean No of vessels per field of view	Static bending strength along the grains
1	1.374±1.816	0.056±0.014	0.043±0.013	0.006±0.002	0.302±0.122	0.773±0.064	26.248±7.710	0.903±0 173	0.243±0.070	0 203±0.043	8.000±2.037	8.133±3.803	58.333N
2	1.660±0.274	0.036±0.006	0.025±0.005	0.005±0.001	0 453±0.182	0.698±0.070	47 258±10 650	0.560±0.100	0.277±0.069	0.232±0.053	7.033±1.771	5.633±2.539	26.667N
3	1 208±0.251	0.030±0.007	0.021±0.005	0.004±0.001	0.442±0.146	0.711±0.075	42 197±11.825	0.498±0.119	0.205±0.046	0.174±0.037	17.567±2.825	7.500±1.717	76.667N
4	1.157±0 163	0.030±0.005	0.021±0.006	0.005±0.002	0.532±0.308	0.685±0 104	40.180±13.987	0 489±0.125	0.217±0.061	0.204±0.055	15.667±2.716	5.467±1.943	96.667N
5	0.921±0.183	0.018±0.003	0.008±0.002	0.005±0.001	1.249±0.496	0 451±0.107	52.097±13.256	0.478±0.117	0 112±0.035	0.096±0.018	19.600±4.391	14 100±4.100	113.333N
6	1.552±0.278	0.029±0.004	0.015±0.005	0.007±0.002	1 182±0.748	0.512±0 130	55.907±13.879	0.424±0.099	0.233±0.062	0.195±0.035	16.667±3.907	5 433±1.888	100.167N
7	1.310±0.242	0.024±0.004	0.014±0.004	0.005±0.001	0.767±0.236	0.594±0.080	56.393±14 463	0 404±0.080	0.214±0.066	0.178±0.050	17.800±6.025	5.133±2.623	90.000N
8	1.161±0.259	0.020±0.003	0.010±0.002	0.005±0.001	1.075±0.336	0.504±0.083	59.597±14.968	0.426±0.085	0.214±0.069	0.173±0.046	30.133±9.468	5.433±2.192	73.500N
9	1.181±0.201	0.023±0.004	0.015±0.004	0.004±0.001	0.619±0.210	0.618±0.082	52.513±11.853	0 421±0.086	0.188±0.055	0.186±0.033	20.562±7.166	4.667±1.626	90.167N
10	1.264±0.201	0.032±0.008	0.023±0.008	0.005±0.001	0.459±0.181	0.700±0.081	40.997±11.260	0.438±0.080	0.227±0.105	0.178±0.075	14.967±3.987	4 767±2.096	60.000N
11	1.171±0.194	0.021±0.004	0.007±0.002	0.007±0.002	2.358±1.548	0.327±0 115	56.958±11.068	0.331±0.034	0.103±0.030	0.096±0.019	16.367±40856	34 400±5.531	150.000N
12	1.622±0.005	0.023±0.005	0 012±0.006	0.006±0.002	1.261±0.805	0 494±0.153	74.615±25.790	0 432±0.107	0.201±0.056	0 160±0.051	18.000±4 000	11 700±5.207	103.333N
13	1.178±0.260	0.027±0.004	0.016±0.004	0.006±0.002	0.789±0.280	0.589±0.085	44.769±10 904	0.435±0.080	0.236±0.033	0.181±0.026	15 433±4 606	5.467±1.008	37.500N
14	1.303±0.199	0.020±0.004	0.012±0.004	0.005±0.001	0.909±0.424	0.533±0 110	63.283±18.807	0 405±0.091	0.264±0.049	0.198±0.038	25.033±4 476	4.800±1.562	114.167N
15	0.974±0 165	0.022±0.003	0.013±0.004	0.005±0.001	0.867±0.388	0.572±0 116	46.020±11.517	0.380±0.046	0 144±0.039	0.087±0.027	11.667±3.745	64.300±14.077	137.333N
16	1 403±0.271	0.023±0.004	0.011±0.004	0.006±0.002	1.272±0.703	0 471±0 117	62.000±14.748	0.296±0.039	0.186±0.039	0 152±0.030	13.733±2.559	4.733±1.799	56.833N
17	1.207±0.190	0.033±0.007	0.024±0.007	0.004±0.001	0.394±0.117	0.731±0.052	38.957±11.467	0.286±0.085	0.190±0.035	0.156±0.048	17.967±4.694	5.867±7.792	96.000N

1 = Alstonia boonei 2 = Ceiba pentandra 3 = Canarium schweinfurthii 4 = Terminalia superba 5 = Diopyros mespiliformis 6 = Afzelia africana 7 = Berlinia auriculata 8 = Brachystagia nigerica 9 = Detarium microcarpum 10 = Gossweilerodendron balsamiferum 11 = Periscopsis elata 12 = khaya ivorensis 13 = Antiaris toxicria 14 = Milicia excelsa 15 = Mansonia altissima 16 = Triplochiton scleroxylon 17 = Gmelina arborea

Table 3: Mean separation using Duncan's new multiple range test (DNMRT) for the timber species studied

Timber Species	(a) Fibre length		(b) Fibre Diameter		(c) Fibre Lumen Diameter		(d) Fibre Cell wall Thickness		(e) Runkel Ratio		(f) Coefficient of Flexibility	
	Mean	DNMRT	Mean	DNMRT	Mean	DNMRT	Mean	DNMRT	Mean	DNMRT	Mean	DNMRT
1.	1.374	bc	0.056	a	0.043	a	0.006	b	0.302	g	0.773	a
2.	1.660	a	0.036	b	0.025	b	0.005	c	0.453	g	0.698	b
3.	1.208	de	0.030	cde	0.021	d	0.004	d	0.442	g	0.711	b
4.	1.157	e	0.030	cde	0.021	d	0.005	c	0.532	fg	0.685	b
5.	0.921	f	0.018	i	0.008	k	0.005	c	1.249	b	0.451	g
6.	1.552	a	0.029	de	0.015	fg	0.007	a	1.182	bc	0.512	ef
7.	1.310	bcd	0.024	fg	0014	fgh	0.005	c	0.767	def	0.594	c
8.	0.161	e	0.020	h	0.010	jk	0.005	c	1.075	bcd	0.504	efg
9.	0.181	de	0.023	gh	0.015	fg	0.004	d	0.619	efg	0.618	c
10.	1.264	cde	0.032	cd	0.023	bc	0.005	c	0.459	g	0.700	b
11.	1.171	de	0.021	gh	0.007	k	0.007	a	2.358	a	0.327	h
12.	1.622	a	0.023	gh	0.012	hij	0.006	b	1.261	b	0.494	efg
13.	1.178	de	0.027	ef	0.016	ef	0.006	b	0.789	def	0.589	c
14.	1.303	bcd	0.020	h	0.012	hij	0.005	c	0.909	cde	0.533	de
15.	0.974	f	0.022	gh	0.013	ghi	0.005	c	0.867	de	0.572	cd
16.	1.403	d	0.023	gh	0.011	ij	0.006	b	1.272	b	0.471	fg
17.	1.207	de	0.003	bc	0.024	b	0.004	d	0.394	g	0.731	ab

Table 3 continued

Timber Species	(g) Vessel Diameter in tangential direction		(h) Vessel diameter in the Radial direction		(i) Slenderness Ratio		(j) No of vessels per field of view		(k) No of fibres per field of view		(l) Vessel length		(m) No of axial parenchyma per field of view	
	Mean	DNMRT	Mean	DNMRT	Mean	DNMRT	Mean	DNMRT	Mean	DNMRT	Mean	DNMRT	Mean	DNMRT
1	0.203	b	0.243	bc	26.248	g	8.133	d	8.000	i	0.903	a	1.333	f
2	0.232	a	0.277	a	47.258	de	5.633	ef	7.033	i	0.560	b	4.333	c
3	0.174	cdefg	0.205	def	42.197	ef	7.500	de	17.567	def	0.498	c	5.967	ab
4	0.204	b	0.217	cdef	40.180	ef	5.467	ef	15.667	efg	0.489	cd	3.000	cde
5	0.096	h	0.112	g	52.097	cd	14.100	c	19.600	cd	0.478	cde	3.133	cde
6	0.195	bcd	0.233	bcde	55.907	bc	5.433	ef	16.667	ef	0.424	ef	2.500	def
7	0.178	cdef	0.214	cdef	56.393	bc	5.133	ef	17.800	de	0.404	f	3.333	cd
8	0.173	defg	0.214	cdef	59.597	bc	5.433	ef	30.133	a	0.426	ef	4.167	c
9	0.186	bcd	0.188	f	52.513	cd	4.667	f	20.567	c	0.421	f	3.967	cd
10	0.178	cdef	0.227	cde	40.997	ef	4.767	f	14.967	fg	0.438	def	1.733	ef
11	0.096	h	0.103	g	56.958	bc	34.400	b	16.367	ef	0.331	gh	3.367	cd
12	0.160	efg	0.201	ef	74.615	a	11.700	c	18.000	de	0.432	ef	6.300	a
13	0.181	bcde	0.236	bcd	44.769	def	5.467	ef	15.433	efg	0.435	def	2.833	cde
14	0.198	bc	0.264	ab	63.283	b	4.800	f	25.033	e	0.405	f	2.833	cde
15	0.087	h	0.114	g	40.020	def	64.300	a	11.667	h	0.380	fg	2.533	def
16	0.152	g	0.186	f	62.000	b	4.733	f	13.733	gh	0.296	h	3.533	cd
17	0.156	fg	0.190	f	38.957	f	5.867	def	17.967	de	0.286	h	3.400	cd

Means not followed by the same letters are significantly different at 5% level of probability as determined by the Duncan's New Multiple Range Test (DNMRT). NB: All means are in millimeters. 1 = Alstonia boonei 2 = Ceiba pentandra 3 = Canarium schweinfurthii 4 = Terminalia superba 5 = Diopyros mespiliformis 6 = Afzelia africana 7 = Berlinia auriculata 8 = Brachystagia nigerica 9 = Detarium microcarpum 10 = Gossweilerodendron balsamiferum 11 = Periscopsis elata 12 = Khaya ivorensis 13 = Antiaris toxicria 14 = Milicia excelsa 15 = Mansonia altissima 16 = Triplochiton scleroxylon 17 = Gmelina arborea

Table 4: Prediction equations, correlations coefficient (r), slopes (b), and intercepts (a) of the different parameters measured for the timber species investigated

Timber Species	Parameters	Prediction equations $\hat{Y} = a + bx$	Correlation Coefficient	Slopes (b)	Intercepts (a)	Validity
1	Fibre length	175.580-69.40x	-0.426	69.480**	175.580**	+
2	Fibre diameter	137.050-1.820x	-0.497	1.820^{ns}	137.050^{ns}	-
3	Fibre lumen diameter	120.060-1,932.380x	-0.509	1,932.380^{ns}	120.060^{ns}	-
4	Fibre cell wall	64.440+4,278.890x	0.120	4278.890^{ns}	64.440^{ns}	-
5	Runkel ratio	59.550+30.020x	0.497	30.020*	59.550^{ns}	-
6	Fibre coefficient of flexibility	194.060-148.380x	-0.540	148.380**	194.0600**	+
7	Vessel diameter in tangential direction	179.600-551.960x	-0.680	-551.960**	179.600**	+
8	Vessel diameter in radial direction	179.740-460.000x	-0.703	-460.000**	179.740*	+
9	Fibre slenderness	41.741+0.897x	0.313	0.897**	41.741*	+
10	Number of vessels per field of view	71.679+1.329x	0.619	1.329^{ns}	71.679**	-
11	No. of fibres per field of view	55.750+1.862x	0.312	1.862^{ns}	55.750**	-
12	Vessel length	128.403-92.321x	-0.382	-92.321^{ns}	128.403**	-
13	Number of axial parenchyma per field of view	87.073+0.007x	-1.235	0.007^{ns}	87.073**	-

** = significant at 5% of level; ** = highly significant at 1% of level n. s = not significant; (+) valid prediction equation (-) = non-valid prediction equation. 1 = Alstonia boonei 2 = Ceiba pentandra 3 = Canarium schweinfurthii 4 = Terminalia superba 5 = Diopyros mespiliformis 6 = Afzelia africana 7 = Berlinia auriculata 8 = Brachystagia nigerica 9 = Detarium microcarpum 10 = Gossweilerodendron balsamiferum 11 = Periscopsis elata 12 = khaya ivorensis 13 = Antiaris toxicria 14 = Milicia excelsa 15 = Mansonia altissima 16 = Triplochiton scleroxylon 17 = Gmelina arborea*

The timbers were properly identified, and their heartwood samples prepared for static bending strength determination along the grain and for quantitative anatomical characterization.

The test method used in the determination of static bending strength was the laboratory test method. Small, clear (free from defects) samples of the timber species cut to the dimensions (20 mm x 20 mm x 300 mm) along the grain were subjected to static bending test (Anon. 1957). The tests were carried out with the Hounsfield Tensometer in the Civil Engineering laboratory of University of Nigeria, Nsukka, and the amount of force (in Newtons) which caused each of the samples to rupture was noted.

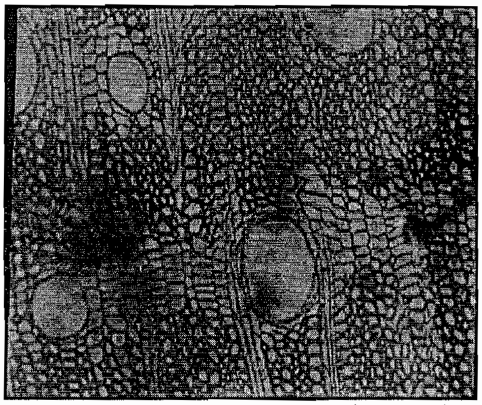
The samples for quantitative anatomical characterization were prepared in two stages. Firstly, sections of about 30μm thick were cut from each of the wood specimens, with the aid of a Reichert sledge microtome, in the transverse, tangential longitudinal and radial longitudinal planes. These were immersed in distilled water in separate Petri-dishes. Some sections were stained with acidified phloroglucinol, others in iodine solution and then examined under a calibrated ordinary light microscope. Thirty counts were taken on each of the wood samples for the following parameters: Number of fibres per field of view (fibre content) at 400 x mag; vessel content at 100 x mag and number of cells in the maximum ray width. Radial and tangential diameters of vessels were measured as seen in the transverse sections (Purvis, 1964).

The second stage of the anatomical studies involved the maceration of the wood samples by the Schultze's method as adopted by Kpikpi and Olatunji (1990) and Uju and Ugwoke (1997), using potassium chlorate ($KClO_3$) crystals and concentrated nitric acid (Conc. HNO_3). Measurements of the wood elements Oladele (1991), were taken under a calibrated ordinary light microscope. The measurements taken were: - Fibre length (L); Fibre cell wall thickness (C); Fibre diameter (D); Fibre lumen diameter (l) and Vessel member length (Vl). The mean values for the thirty measurements were calculated for each of the parameters. Derived fibre values were calculated as follows: - Runkel ratio (RR) = 2C/l; coefficient of flexibility (CF) = l/D and slenderness ratio (SR) = L/D.

The various measured parameters of the timber species were analyzed and then compared with their static bending strengths. The experimental design used in the study was the completely randomized design (CRD). The means of the various parameters were separated using the Duncan's New Multiple Range Test (DNMRT). The means of the parameters were regressed against the static bending strengths, and regression equations derived. The slopes and the intercepts of the significant (r-values) were further tested for significance to obtain valid prediction equations.

Results

The results are presented in Tables 2 – 4 and in plates 1 a - c and 2a-b. As outlined in table 2, the mean values for the timbers studied ranged from 0.921 ± 0.16 mm in *Diospyros mespiliformis* to 1.660± 0.27 mm in *Ceiba pentandra* for fibre length; 0.018 ± 0.03 mm in *Diospyros mespiliformis* to 0.056 ± 0.014 mm in *Alstonia boonei* for fibre lumen diameter; 0.004 ± 0.001 mm in *Canarium schweinfurthii, Detarium microcapum* and *Gmelina* *arborea* to 0.007 ± 0.002 mm in *Periscopsis elata* for fibre cell wall thickness; 0.302 ± 0.122 in *Alstonia boonei* to 2.358 ± 1.548 in *Periscopsis elata* for Runkel ratio; 0.327± 0.115 in *Periscopsis elata* to 0.773±0.06 in *Alstonia boonei* for Coefficient of flexibility; 26.248±7.710 in *Alstonia boonei* to 74.615±25.790 in *Khaya ivorensis* for slenderness ratio; 0.286 ± 0.085 mm in *Gmelina arborea* to 0.903±0.173 mm in *Alstonia boonei* for vessel member length, 0.103 ± 0.030 mm in *Periscopsis elata* to 0.277 ±0.06 mm in *Ceiba pentandra* for vessel diameter in the radial direction; 0.232±0.027 mm in *Mansonia altissima* to 0.232±0.053 mm in *Ceiba pentandra* for vessel diameter in the tangential direction; 7.033 ±1.771 in *Ceiba pentandra* to 25.033±4.476 in *Milicia excelsa* for fibre content and 4.667±1.62 in *Detarium microcarpum* to 34.400±5.531 in *Periscopsis elata* for vessel content. The static bending strength along the grain ranges from 26.667N in *Ceiba pentandra* to 150.000N in *Periscopsis elata*.



198µm
x650

Plate 1a: Arrangement of wood elements: *Gmelina arborea* in transverse plane

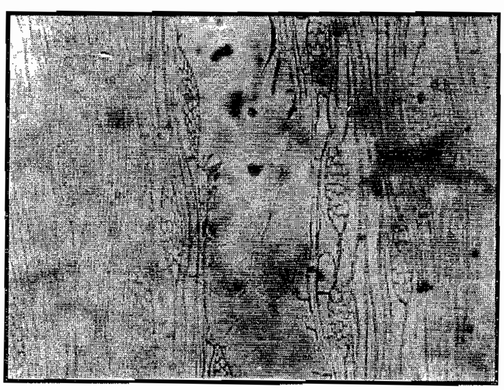


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Plate 1b: Arrangement of wood elements: *Gmelina arborea* in tangential longitudinal plane

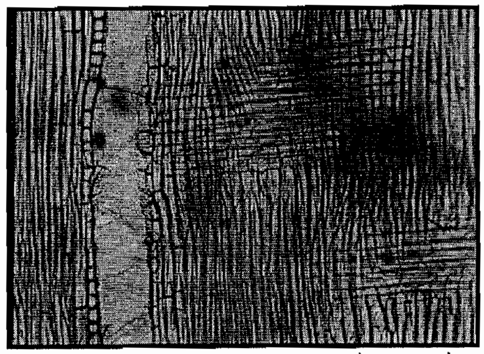

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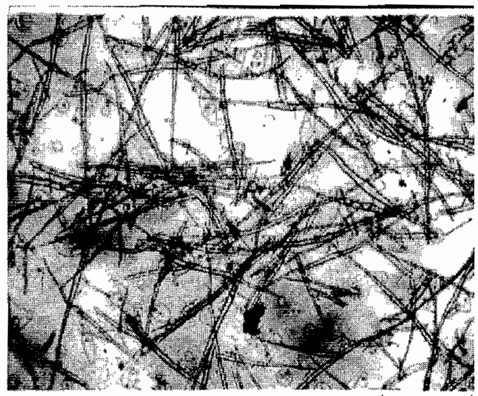
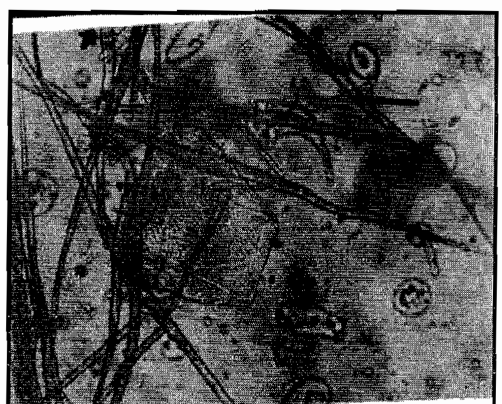
Plate 1c: Arrangement of wood elements: *Gmelina arborea* in radial longitudinal plane



198µm
x240

Plate 2a: fibres of *Gmelina arborea* from the macerated wood tissue



198µm
x650

Plate 2b: fibres and vessel member of *Gmelina arborea* from the macerated wood tissue

There were highly significant differences among the species in all the parameters measured ($p=0.01$). The mean separations using the (DNMRT) are shown in Table 3. Table 2 shows the Mean values of the quantitative anatomical parameters and the static bending strengths of the timber species. Table 4 shows the prediction equations $\hat{Y} = a + bx$ correlation coefficient (r), slopes (b) and intercepts (a) of the different parameters. Plate 1 a to c shows the arrangement of the wood elements of *Gmelina arborea* in the transverse, tangential longitudinal and radial longitudinal planes respectively. Plate 2a and b show the fibres and vessel members of *Gmelina arborea* from the macerated wood respectively.

Discussion

The results presented show that species with thick fibre cell wall are mostly associated with high static bending strength as against those with thin walls. *Periscopsis elata* which has a cell wall thickness of 0.007 ± 0.002 mm has the highest static bending strength of 150.000N, while *Ceiba pentandra* of wall thickness of 0.005 ± 0.001 mm has strength of 26.667 N. Some species show deviation from this, and the explanation could come from other factors within the specimens.

Species with narrow fibre lumen show higher static bending strength than those whose lumina were wide. This was seen in *Periscopsis elata*, *Afzelia africana*, *Diospyros mespiliformis*, *Khaya ivorensis*, *Milicia excelsa* and *Mansonia altissima*, whose fibre lumina were narrow and static bending strength high. Species with high coefficient of flexibility showed low bending strength as against those with low coefficient of flexibility whose bending strengths were found to be high. *Alstonia boonei*, *Ceiba pentandra* and *Antiaris toxicaria* had high Coefficient of flexibility and low static bending strength. *Diospyros mespiliformis, Afzelia africana, Periscopsis elata, Khaya ivorensis* and *Milicia excelsa* showed low coefficient of flexibility and a corresponding high bending strength.

Species with narrow vessel diameter, high fibre content and high vessel content showed high static bending strength, while those with wide vessel diameter, low fibre content and low vessel content showed low bending strength.

The results therefore support the earlier indications of Esau (1965), that the composition of the xylem tissue and the structural arrangement of the component elements considerably determine the strengths of wood and their suitability for commercial usage.

The various quantitative anatomical parameters whose prediction equations are valid can serve as reliable indicators of static bending strength along the grain. These as in table 4 include fibre length, fibre coefficient of flexibility, slenderness ratio, and vessel diameter. If the mean value of any of these valid parameters is substituted for (X) in the equation $\hat{Y} = a + bx$, the static bending strength can be calculated without using the Tensometer. Thus the static bending strengths along the grain of these timbers could be reliably determined using the quantitative wood anatomical approach.

It must however be pointed out that the present study is limited to relationships with static bending strength and if strength in general, the collectivity of properties enabling the wood to resist various forces or loads Esau (1965), is to be brought in full view, further studies are needed to explore the relationships with other strength parameters.

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