Available online at www.ijrp.org

International Journal of Research Publications

Grade (Design) Stresses for Boswellia papyrifera (Gafal) Wood Grown in Blue Nile State. Sudan

Tageldin H. Nasroun[a]; Elamin E. Elamin[b]*; Yousif E. A. Mohammed[b]

a. College of Forestry and Range Sciences, Sudan University of Science and Technology.
b. Forestry and Gum Arabic Research Center, Agricultural Research Corporation.
* Tel. +249912441157 – e-mail: elamin.elhadi@gmail.com

Abstract

Timber is a natural and very variable material affected by many factors. This makes it important to determine mechanical properties by standard methods using small clear specimens. As clear wood is not available for use, it is important to apply all the necessary reduction factors to reach design stresses for structural sizes and the appropriate duration of load. Unlike other Man-made materials wood is also an anisotropic material, ie properties differ in the different directions to the grain. Both static bending and compression parallel to the grain tests were carried out according to standard procedures. Test results gave short duration ultimate stresses for clear wood (without defects). The basic stresses for the two properties were derived first by using two reduction factors to the mean ultimate stresses from test results to cater for wood variability, safety and duration of load. The Factors influencing strength were studied for grading the timber according to the size of strength reducing defects. This was followed by assigning a strength ratio to each grade. Grade (or design) stresses were then calculated by multiplying basic stress by the strength ratio for each grade. These Results revealed that the basic stress for bending for gafal wood was 10.8 MPa and 13.6 MPa for compression parallel to the grain. Grade (design) stresses in MPa, for the two properties were as follows:

	Grade 1	Grade 2	Grade 3	Grade 4
For Bending	8.64	7.02	5.40	4.32
For compression	10.53	8.55	6.58	5.26

These results indicate that gafal wood with its low density and low strength values can only be used for light constructions as columns and non-load bearing members in wood frame buildings. This procedure will be followed for structural timbers with higher strength which can be used for heavy constructions.

Key Words: Structural timber – Timber grading – Design stresses.

Introduction

Wood is a natural renewable resource. Its biological origin makes it such a variable material that man has very little control over its properties. Wood differs from other construction materials because it is produced in a living tree. It is necessary for the engineer to have a general understanding of the properties and characteristics that affect the strength and performance of wood in constructional applications (Nasroun, 1981). The strength of material such as wood refers to its ability to resist applied forces that could lead to its failure, while its elasticity determines the amount of deformation that would occur under the same applied forces.

For an isotropic material with equal properties in all directions, elastic properties are described by three elastic constants: modulus of elasticity (E), shear modulus (G), and Poisson's ratio (μ). Because wood is orthotropic (anisotropic), 12 constants are required to describe elastic behavior: 3 moduli of elasticity, 3 moduli of rigidity, and 6 Poisson's ratios. These elastic constants vary within and among species and with moisture content and specific gravity. The only constant that has been extensively derived from test data, or is required in most constructions, is the modulus of elasticity in the longitudinal direction. Other constants may be available from limited test data but are most frequently developed from material relationships or by regression equations that predict behavior as a function of density (Barnes and Winandy, 1986; Kollman and Cote, 1996).

Strength properties mean the ultimate resistance of a material to applied loads. With wood, strength varies significantly depending on species, loading condition, load duration, natural defects and a number of assorted material and environmental factors.

Elastic properties relate a material's resistance to deformation under an applied stress to the ability of the material to regain its original dimensions when the stress is removed. For an ideally elastic material loaded below the proportional (elastic) limit, all deformation is recoverable, and the body returns to its original shape when the stress is removed. Wood is not ideally elastic, in that some deformation from loading is not immediately recovered when the load is removed; however, residual deformations are generally recoverable over a period of time. Although wood is technically considered a viscoelastic material, it is usually assumed to behave as an elastic material for most engineering applications, except for time-related deformations (creep).

For an isotropic material with equal properties in all directions, elastic properties are described by three elastic constants: modulus of elasticity (E), shear modulus (G), and Poisson's ratio (μ). Because wood is anisotropic, mechanical properties also vary in the three principal axes. Property values in the longitudinal axis are generally significantly higher than those in the tangential or radial axes. Strength related properties in the longitudinal axis are usually referred to as parallel-to-grain properties. For most engineering design purposes, simply differentiating between parallel- and perpendicular-to-grain properties is sufficient (Desch and Dinwoodi, 1996). Natural defects in wood must be taken into account in assessing the actual properties or estimating the actual performance of structural wood. Timber grading is based on these natural defects like slope of grain, knots, fissures and others.

This study aimed at explaining the procedure for deriving design stresses for timber and providing engineers with information which will help them in designing timber structures.

Materials and Methods

Material

The material used for this investigation is Boswellia papyrifera (gafal) wood which belongs to a tropical family called Burseraceae (Fitchl and Admasu 1994). The tree is distinguished by the presence of resin ducts in the bark (Groom 1981). B. papyrifera is a deciduous tree which reaches up to 12 m in height, with a round crown and a straight regular bole. The bark is whitish to pale brown, peeling off in large flakes; slash red-brown and exuding a fragrant resin. The wood is fine grained with medium low density. It is suitable for making match boxes and splints, particleboard, plywood, veneer, pencils, picture frames…etc.

Methods

Gafal logs were sawn and random samples were selected, from which small clear specimens were prepared. Compression parallel to the grain tests specimens were prepared with dimension 20×20 ×60 mm, while static bending test specimens were 20×2 0× 300 mm. Static bending test was carried out according to Sudanese standard no. 5175/20/2012 (adopted form ISO 3133/1975) Determination of ultimate strength in static bending. Compression Parallel to the grain test was carried out according to ISO standard procedure no. 3787/1979. The two tests were carried out on air-dry small clear specimens.

The mean ultimate stresses for short duration and the standard deviations were obtained for the two properties from the tests results as starting points for deriving basic stresses in two steps : In step one using a statistical method the minimum ultimate stress (X min) below which there is a specified probability of a specimen failing was calculated, to cater for the problem of wood variability, as a natural material, and safety. The second step was to apply another reduction factor to cater for duration of load and more safety and get to the basic stress, which is the stress that can safely be permanently sustained by clear wood (free of defects).

Using the properties Gaussian distribution, we can easily calculate this minimum stress, below which there is a specified probability of a specimen failing, but it is difficult to decide what is an appropriate probability, to take into account the variability of timber. It is assumed that for most strength properties the chance of getting lower value than the statistically estimated minimum 1 in 100 times (1%) probability is reasonable. Using 1% probability and the properties of the Gaussian distribution 98 per cent of the results lie within the range determined by the mean ± 2.33 times the standard deviation or, put in another way, 1 per cent of the results lie below the value computed from the mean minus 2.33 times the standard deviation .(Booth and Reece, 1967).

The minimum ultimate stress was obtained from the following equation:

$X_{\mathbf{min}} = X_{\mathbf{mean}} - k\,.\sigma$ ……………………………… (1)

Where $X_{\mathbf{mean}}$ is the mean ultimate short duration stress from test results.

σ = the standard deviation.

K = a constant that depends on the selected probability as shown in table1 and represents the number of standard deviations to be deducted from $X_{\mathbf{mean}}$ to get $X_{\mathbf{min}}$.

Table1. K-values for the selected probabilities

Probability %	50	20	10	5	2.5	1	0.1
k-value	Zero	0.68	1.28	1.65	1.96	2.33	3.0

Source: British Standard 373, 1986

K-value for 1% probability is 2.33

$X_{min} = X_{mean} - 2.33\sigma$ …………………………………. (2)

The second step for deriving the basic stress is the application of a combined reduction factor to cater for both duration of load and more safety. The strength of timber decreases significantly with increased duration of load. This factor was applied to the statistically estimated minimum (X_{min}). Equation 2 applies for both bending and compression parallel to the grain, whereas the above mentioned factor varies between the two properties .X_{min} was divided by the appropriate factor for each property. According to Booth and Reece (1967) the reduction factor for bending is 2.25 and 1.40 for compression parallel to the grain. Therefore, basic stress (B.S.) for bending was calculated from the following equation:

B. S. (bending) =X_{min} / 2.25………………….. (3)

While basic stress for compression parallel to the grain (C//g) was calculated from:

B. S. (C//g) = X_{min} / 1.40………………………… (4)

Where C//g = Compression parallel to the grain

Stress-grading of timber.

So far we are still dealing with the strength of small clear specimens. As clear wood is not available for structural sizes of timber, grading rules were used to check the effect of strength reducing defects on the strength and using these to grade the timber and determine grade (design) stresses. Tentative grading rules were suggested by Nasroun (1981); Nasroun (2005), for some hardwoods grown in Sudan, (table2). In these rules four grades were suggested, grades 1, 2, 3 and 4. Under each grade the maximum allowable size of defects are listed, and each grade is assigned a strength ratio. This can be used for calculating grade (design) stresses for timber.

Table 2. Tentative grading rules*****

Defect	Grade 1	Grade 2	Grade 3	Grade 4
Slope of grain for bending	1/16	1/12	1/9	1/6
Slope of grain for compression parallel	1/12	1/10	1/8	1/6
Face knot ratio	1/4	3/8	1/2	5/8

Marginal knot ratio	1/8	1/6	1/4	1/3
Strength ratios %	80	65	50	40

*Modified from British Standard 3819. 1964.

From this table and the calculated basic stresses, grade (or design) stresses can be calculated from the following equation:

Grade stress = Basic stress x strength ratio……………….. (5)

Grade 1 stress = Basic stress X 0.8

Grade 2 stress = Basic stress X 0.65

Grade 3 stress = Basic stress X 0.5

Grade 4 stress = Basic stress X 0.4

The grade stress is the stress which can safely be permanently sustained by a specific grade of timber with a specified size of defect.

Results and Discussion

Ultimate Stresses

Appendices A and B show the results of the static bending test and compression parallel to the grain, respectively with average short duration ultimate stress values and standard deviations. Table 3 depicts the summary of these test results.

Table 3. Summary of test results

Property	Ultimate Stresses (MPa)				MOE (MPa)	
	Max.	Min.	Mean	St.D.	Mean	St.D.
Bending	45.76	28.47	36.50	5.22	6414	1431
C//g*	38.25	20.02	27.75	4.00	1437	417

*C//g = Compression parallel to the grain.

Basic Stresses

Form table (2), equations (1), (2) and (3) the basic stress for bending was as follows:

$$\text{Basic stress (bending)} = \frac{36.5 - 2.33 \times 5.22}{2.25} = 10.8 \text{ MPa}$$

From table 2, Equations (1) , (2) and (4) the basic stress in compression parallel to grain (C//g) was as follows:

$$\text{Basic stress(C//g)} = \frac{27.75 - 2.33 \times 4}{1.40} = 13.16 \text{ MPa}$$

Basic stress is the stress which can safely be permanently sustained by clear wood.

Grade Stresses

As clear wood is not available for structural sizes, grade stresses were calculated for the two properties as follows:

Bending grade (design) stresses (MPa)

$\text{Grade}_{1} = 10.8 \times 0.8 = 8.64$

$\text{Grade}_{2} = 10.8 \times 0.65 = 7.02$

$\text{Grade}_{3} = 10.8 \times 0.5 = 5.4$

$\text{Grade}_{4} = 10.8 \times 0.4 = 4.32$

Compression parallel to the grain grade stresses (MPa)

$\text{Grade}_{1} = 13.16 \times 0.8 = 10.53$

$\text{Grade}_{2} = 13.16 \times 0.65 = 8.55$

$\text{Grade}_{3} = 13.16 \times 0.5 = 6.58$

$\text{Grade}_{4} = 13.16 \times 0.4 = 5.26$

These results can be summarized in table 2

Table 4. Grade stresses (MPa) for the two properties.

Property	Basic stress	Grade1	Grade2	Grade3	Grade4	Mean MOE
Bending stress	10.8	8.64	7.02	5.4	4.32	6413.8
C//g	13.16	10.53	8.55	6.58	5.26	1437

C//g, as in table 3

Although the mean ultimate bending stress was slightly higher than that of humeid (Sclerocarya birrea) wood (32.7 MPa), which was recorded in Nasroun (2005), the calculated basic stress in bending was less than that of humeid because the number of samples tested was rather small and this resulted in a relatively large standard deviation and thereby a smaller basic stress than that of humeid. The situation could change if adequate number of samples was tested. However, the results are comparable to results obtained by Nasroun (2005) for home-grown Pinus radiata with regards to the mean ultimate bending stress (42.2 MPa) and mean ultimate compression parallel to the grain (24.1 MPa). This indicates that this wood could be used for light construction, light furniture for schools, offices and shoes models. It was successfully peeled to veneer and used for match boxes and splints. It could also be used for making plywood and other wood panels.

According to a Sudanese standard prepared by Sudanese Standard and Metrology Organization (SSMO) for local structural timbers, the results were higher than those for gafal. In this standard Faiderbia albida (Haraz) wood was in the lowest strength group for structural timbers to compare it with gafal bending grade 1, gafal was even less than grade 4 haraz. It is, therefore, risky to stress any gafal members in bending. In compression parallel to the grain, however, grade 1 of gafal was better than grade 3 haraz and, therefore, can be used as columns in light constructions, as well as in non-load bearing members in light constructions.

Wood differs from other construction materials because it is produced in a living tree. As a result, wood possesses material properties that may be significantly different from other materials normally encountered in structural design. Although it is not necessary to have an in-depth knowledge of wood anatomy and properties, it is necessary for the engineer to have a general understanding of the properties and characteristics that affect the strength and performance of wood in construction. This includes not only the anatomical, physical, and mechanical properties of wood as a material, but also the standards and practices related to the manufacture of structural wood products, such as sawn lumber and glulam .

Conclusions and Recommendations

1-This method involved adjusting the strength properties of small clear specimens of timber for the effects of moisture content, duration of load, knots and slope of grain to obtain design values applicable to normal dry conditions of service.

2-Gafal wood belongs to the lowest strength group among the Sudanese timbers.

3- According the results obtained it is risky to stress gafal wood in bending.

4- Good grades of gafal, however, could be used as columns or non-load bearing members in light construction like wood- frame buildings.

References

Barnes, H.M.; Winandy, J.E. 1986. Effects of seasoning and preservatives on the properties of treated wood. Proceedings of the American Wood Preservers' Association 82: 95-105.

Booth, L.G. and P.O. Reece 1967. The Structural Use of Timber. E &F.Spon Ltd. London. 265p.

British Standard 373. 1986. Methods of testing small clear specimens of timber. BSI, London.

British Standard 3819. 1964. Grading rules for sawn home-grown softwoods.

Desch, H. E and J. M. Dinwoodie. (1996). Timber structure, Properties, Conversion and Use (seventh ed) Revised by Dinwoodi). Macmillan press Ltd. London 306 P.

Fichtle, R. and A. Admasu. 1994. Honeybee flora of Ethiopia. Margraf Verlag, Weikersheim.

Goom, N. 1981. Frankincence and myrrh: A study on the Arabian incense trade. Longman, London.

ISO.1979. Standard procedure no. 3787/ 1979. Testing compression parallel to the grain for wood

kollmann and Cote, (1968) Principles of wood science and technology Springer-Verlag, Berlin, Heidelberg, New York,.

Nasroun, T. H. (1981). Specifying Local timber for structures. Sudan Silva. IV (24) : 38-51.

Nasroun, T. H. (2005) Wood Properties and Technology. Dar Aalam Al-kutub, Riyadh. 326 pp. (in arabic).

SSMO.2012.Sudanese standard no. 5176/ 2012. Determination of ultimate strength in static bending.

Appendix A. Test results for static bending

Serial Number	**Maximum load(kN)**	**Ultimate bending stress (MPa)**	**Modulus of elasticity (MPa)**
1	0.550	34.625	6141.475
2	0.560	34.532	6246.809
3	0.720	44.238	7068.171
4	0.480	29.999	4698.230
5	0.830	45.761	8389.315
6	0.880	30.271	7277.555
7	0.470	28.656	4639.220
8	0.770	42.776	6072.783
9	0.560	34.532	6559.149
10	0.200	28.474	2423.663
11	1.280	40.093	9202.081
12	0.560	34.782	7904.925
13	0.060	37.750	7315.227
14	0.650	40.837	7011.796
15	0.420	29.823	6361.803
16	0.360	32.395	4832.315
17	0.420	30.141	5829.043
18	0.610	38.662	7679.536
19	0.650	40.603	6009.125
20	0.640	39.856	4852.628
21	0.640	39.669	6864.122
22	0.340	40.049	7557.2
23	0.790	42.044	6582.892
Average	**0.58**	**36.5**	**6413.9**
SD	**0.24**	**5.22**	**1430.8**

Appendix B. Test results for compression parallel to the grain.

Serial number	Maximum load (kN)	Ultimate compressive stress(MPa)	Modulus of elasticity(MPa)
1	8.550	22.836	1007.034
2	10.790	28.478	1312.236
3	10.820	27.798	1645.520
4	7.470	25.797	1193.762
5	18.270	31.127	2288.061
6	14.560	38.251	1626.953
7	11.120	30.102	1599.660
8	11.210	30.126	1553.741
9	6.810	26.001	774.335
10	10.170	26.828	1582.664
11	9.930	26.316	1526.516
12	10.000	26.958	1451.513
13	6.740	28.001	935.859
14	8.470	22.390	1327.697
15	12.970	33.028	1556.342
16	9.350	24.882	1085.657
17	11.790	30.911	1462.376
18	11.270	29.654	1269.816
19	7.960	21.359	1365.402
20	7.600	20.018	1034.821
21	10.880	28.760	1803.658
22	9.370	24.769	901.735
23	9.040	23.921	949.551
24	9.040	24.589	933.621
25	10.330	27.236	1094.968
26	11.850	31.180	1394.764
27	12.070	32.539	1380.524
28	16.980	29.257	2013.317

29	9.530	25.127	1324.914
30	12.000	31.917	1574.380
31	10.730	28.613	1347.290
32	10.010	26.721	1266.456
33	9.020	24.128	1219.245
34	10.320	27.706	1952.829
35	10.170	27.632	1148.533
36	16.400	33.442	2597.538
37	10.980	29.523	1424.344
38	8.480	22.731	1183.892
39	9.600	25.054	1365.756
40	7.370	23.714	984.532
41	16.500	32.228	2484.960
42	10.670	29.433	1481.829
43	12.880	35.343	2469.348
44	11.680	30.765	1845.030
45	8.630	23.181	1151.190
46	11.530	31.050	1581.597
47	8.060	21.262	968.414
48	10.180	26.813	1510.693
49	8.480	22.416	1090.186
50	13.370	35.875	1806.273
Average	**10.6**	**27.75**	**1437**
SD	**2.56**	**4.00**	**417.4**