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Mechanical and Physical Properties of Plantation Grown Timber in Zambia

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Abstract
Zambia is endowed with thousands of square kilometers of land on which both plantation grown and indigenous species of timber flourish. The Zambian standard on structural use of locally grown timber, ZS 032, gives physical and mechanical properties for several indigenous species but only two plantation grown species, namely Eucalyptus Grandis (blue gum) and Pinus Kesiya. In view of the economic potential of plantation grown timbers, such as controlled growth and development of plantations and processing plants, country-wide, it is necessary to enhance the utilization of these species for structural, carpentry and other purposes. Greater structural usage, however, can only be realized after determination and dissemination of the physical and mechanical properties.

This paper presents test results for physical and mechanical properties of four plantation grown timbers, Eucalyptus Grandis, Eucalyptus Cloesina, Pinus Kesiya, and Pinus Oorcapa, grown by Copperbelt Forestry Company. The tests were carried out at the Civil and Environmental Engineering laboratories of the University of Zambia. The physical and mechanical properties determined for Eucalyptus Grandis and Pinus Kesiya, exceed those specified in ZS 032 (1986), when the total factors of safety are applied. The physical and mechanical properties determined in this study for Eucalyptus Cloesina and Pinus Oorcapa are reasonable estimates, in the absence of code values.

Keywords: softwood, hardwood, clear specimens, plantation grown, indigenous species, radial, tangential, perpendicular and parallel to grain.

Introduction

In Zambia, commercial timbers consist of both softwoods and hard woods. The timber is mainly used for carpentry works, joinery and structural purposes. For select quality carpentry and joinery works, indigenous species such as mukwa (*Pterrocapus Angullansis*) are widely used. The plantation-grown species such as *Eucalyptus Grandis* and *Pinus Kesiya* have wide application in carpentry and joinery as well as in structural and non-structural works (such as false work). In most applications, it is preferred that the timber is treated and preserved. For structural purposes, the timber has to meet minimum strength properties, as per ZS 032 (1986).

According to the ZS 032 (1986), timber has to be seasoned to allowable moisture contents of 12% for joinery works such as window and door frames, and 15% for structural purposes.

Testing of Clear Specimens

Four species of timber, namely, *Eucalyptus Cloesina* (E. CL), *Eucalyptus Grandis* (E. GR), *Pinus Kesiya* (P. KE) and *Pinus Oocarpa* (P. OO) were tested. Clear specimens (without defects such as knots) were prepared from the samples for various tests. Tests were carried out in accordance with, BS373 (1986), wherever possible. All tests were carried out at the Civil and Environmental Engineering laboratories of the University of Zambia. The specific tests carried out were:

1 Static bending test (BN series)
2 Moisture content
3 Density
4 Compression parallel to grain (CPR series)
5 Compression perpendicular to grain (CPE series)
6 Indentation (IND series)
7 Shear parallel to grain (SP series), and,
8 Tension parallel to grain (TPR series)

The principal directions for timber used in the tests are shown in Fig. 1.

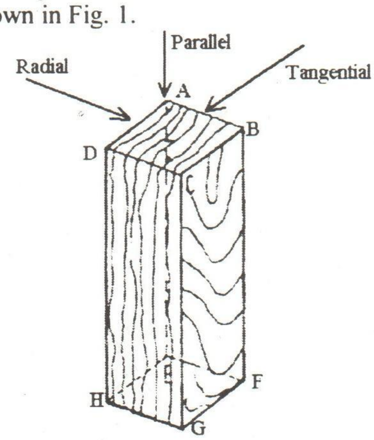

Fig. 1 Principal directions in timber

For all tests other than the tension parallel to grain test (TPR series), 7 samples were tested for each of the species, other than for E. CL where 5 samples were tested. For the tension tests, the number of samples ranged from 4 to 6, due to difficulty in preparation of samples. The dimensions of specimens used in the various tests are given in the Appendix. The results presented in the following discussion are the average values for each species.

Static bending test (for modulus of elasticity and modulus of rupture

The static bending test was carried out on specimens of nominal size of 50x50x750mm (See Appendix 1 for dimensions of specimens). The test was carried out using the central (or three-point) loading setup as shown in Fig. 2, over a span of 700mm. The applied load and the resulting deflections were monitored. A dial gauge of accuracy 0.01mm was used in determining the deflections.

Table 1 presents the relevant mechanical properties. It was also observed that, E. CL indicated the highest resistance in nearly all the properties computed while P. OO exhibited the least strength. For all species other than *P. Oorcapa*, failure was gradual with splitting of the fibres at failure. *P. Oorcapa* on the other hand, exhibited abrupt brittle failure, with fibres breaking at failure.

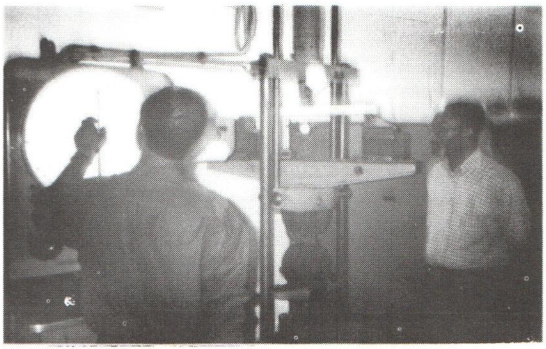

Fig. 2 Static bending test setup

Determination of Moisture content

The moisture content test was conducted on static bending specimens, before and after the bending test. Samples were approximately 50x50x75mm in size. Dimensions and mass were measured to 0.01mm and 0.01g accuracy, respectively. The results are presented in Table 2. The average moisture content for the pines was about 11 %, while for E. CL and E. GR the values were 25 and 13%, respectively.

Table 2: Moisture Content

Species	Moisture content (%)
E. CL	25.00
E. GR	12.65
P. KE	10.89
P. OO	10.49

Determination of Density

The density test was also conducted on the static bending specimens before and after the test, as well as on the indentation test specimens. Samples were 50x50x75mm in size from the static bending samples and 50x50x150mm from the indentation samples (See Appendix 1 for dimensions of specimens). Dimensions and mass were measured to the nearest 0.01mm, 0.01g., respectively

Table 3 presents test results from the static bending specimens. By comparing the specific gravity values at the start of the test, it was observed that E. CL was the densest with a specific gravity of 0.9. E. GR was the next dense species with a specific gravity of 0.63 followed by P. KE with a specific gravity of 0.58. P. OO, which had a specific gravity of 0.42, was the lightest of the species.

Table 1 Static Bending Test Results

Species	FS at LP (N/mm^2)	M of R (N/mm^2)	E (N/mm^2)	HS at LP (N/mm^2)	HS at ML (N/mm^2)
E. CL	30.94	99.85	16851	1.01	3.56
E. GR	34.07	76.65	13049	1.18	2.65
P. KE	23.70	68.99	8667	0.83	2.43
P. OO	8.58	37.69	4908	0.30	1.31

FS at LP: Fibre Stress at Limit of Proportionality
M of R: Modulus of Rupture
E: Modulus of Elasticity
HS at LP: Horizontal Shear stress at Limit of Proportionality
HS at ML: Horizontal Shear stress at Maximum Load

Table 3 Specific Gravity Test Results

Species	Specific gravity at start of the test	Nominal specific gravity, oven-dry
E. CL	0.90	0.73
E. GR	0.63	0.56
P. KE	0.58	0.52
P. OO	0.42	0.38

Compression parallel to grain

The dimensions of samples for the compression parallel to grain tests were 50x50x200mm (See Appendix 1 for dimensions of specimens). An extensometer of precision 0.005mm was used to determine the shortening of the sample, to beyond the limit of proportionality (LP). Fig. 3 shows the setup for the compression parallel to grain test.

Fig. 3 Compression parallel to grain test setup

Table 4 presents test results of the CPR tests. The compression stress at the LP values were similar for all species but differences were observed at the maximum load (ML). *Eucalyptus Cloesina* exhibited the highest compression parallel to grain strength.

Table 4: Compression Parallel to Grain

Species	CS at LP (N/mm^2)	CS at ML (N/mm^2)
E. CL	26.73	52.51
E. GR	23.77	44.98
P. KE	20.57	32.91
P. OO	20.61	31.18

CS at LP: Compressive Stress at Limit of Proportionality
CS at ML: Compressive Stress at Maximum Load

Compression perpendicular to grain

Specimen sizes of 50x50x50mm were used as shown in Appendix 1. The test setup was similar to that for the CPR series described above. The loads at LP and ML were noted. Table 5 presents the relevant mechanical properties.

It was observed that, at failure the fibres separated in all samples except P. OO, which indicated the highest straining before failure. E. CL gave the highest compressive strength (about two to three times) compared to E. GR. On the other hand, the pines exhibited similar strength values.

Table 5: Compression Perpendicular to Grain

Species	CS at LP (N/mm^2)	CS at ML (N/mm^2)
E. CL	14.94	20.06
E. GR	5.29	11.11
P. KE	3.76	7.06
P. OO	3.84	6.21

CS at LP: Compressive Stress at Limit of Proportionality
CS at ML: Compressive Stress at Maximum Load

Indentation

Specimen sizes of 50x50x150mm (Masani, 1980) were used for the indentation test. However, a 10mm ball was used rather than the 11mm ball specified in BS 373 (1986). Tests were carried out on the radial, tangential and parallel directions to grain, for each specimen. The required 5.00mm indentation was monitored by using a dial gauge of accuracy 0.01mm. Table 6 presents test results.

There were no major differences in indentation resistance for a given species, in the radial and tangential directions. However, the penetration resistance in the parallel direction ranged from about 1.5 times (E. CL) to 5.5 times (P. OO) that in either the radial or tangential directions.

Table 6: Indentation Resistance (10mm dia. ball)

Species	S_1	Pr (N)	Pt (N)	Pp (N)
E. CL	0.87	3460	3928	5100
E. GR	0.54	1629	2086	4806
P. KE	0.57	3083	3363	6327
P. OO	0.44	2056	1550	8477

S_i: *Specific gravity at start of test*
Pr: Indentation resistance in the radial direction
Pt: Indentation resistance in the tangential direction
Pp: Indentation resistance in the parallel direction

Tension

Test specimens were prepared according to BS 373 and tested in a tensile testing machine as shown in Fig. 4. The preparation of tensile specimens took considerable time and accuracy. In addition, gripping of the samples in the tensile machine proved difficult. The extension of the samples was monitored using an extensometer of accuracy 0.005 mm.

Table 7 presents test results. It can be observed that the pines exhibited very similar tensile strength values at both LP and ML. E. CL showed higher strength than E. GR at LP (33% higher) but lower strength (about 25% lower) at ML. The modulus of elasticity may be computed from the tension test stress-strain curve, but as for the compression test, the determination of the strain at limit of proportionality requires more precise instrumentation.

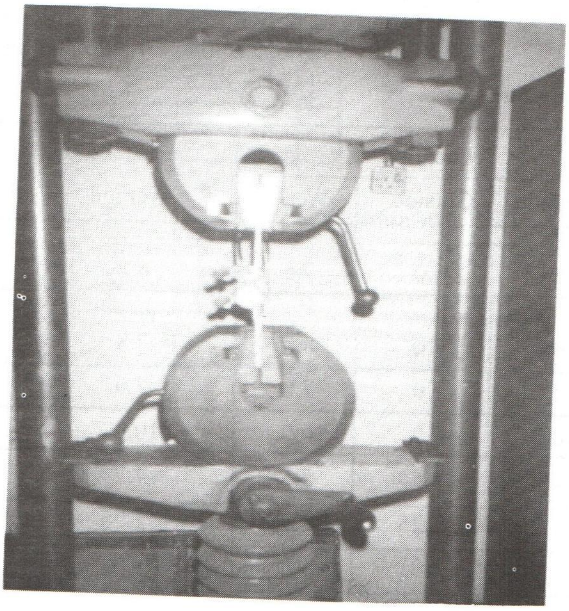

Fig. 4 Tensile test setup

Table 7 Tension Parallel to Grain

Species	TS at LP (N/mm^2)	TS at ML (N/mm^2)
E. CL	31.50	62.02
E. GR	23.74	82.03
P. KE	24.99	31.91
P. OO	25.26	30.29

TS at LP: Tensile Stress at Limit of Proportionality
TS at ML: Tensile Stress at Maximum Load

Shear parallel to grain

For these tests, a specially fabricated clamping mechanism was used (Masani, 1980). The specimens were prepared with a 12.5mm notch on top (Appendix 1). The overall height of each specimen was 62.5 mm. Fig. 5 shows the clamping and loading method for shear tests. The shearing was either on a tangential plane or radial plane, as shown in the Appendix. Table 8 presents test results.

It can be observed that the strength of 6.03 N/mm^2 for E. CL was about 14% higher than that of E. GR while that of P. KE was about 50% higher than that of P. KE.

Table 8: Shear Parallel to Grain

Species	Apparent Average Shear Stress (N/mm^2)
E. CL	6.03
E. GR	5.31
P. KE	4.73
P. OO	3.15

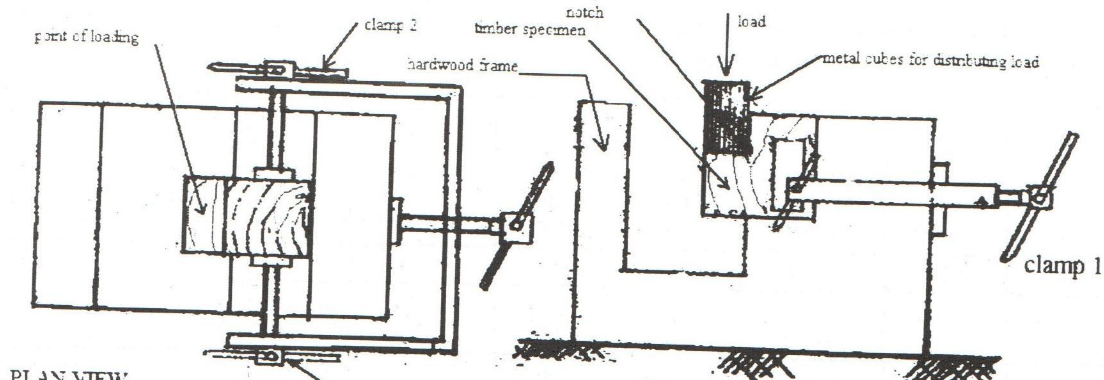

Fig. 5 Shear test clamping and loading setup (from Masani, 1980)

Discussion of Test Results

In deriving safe working stresses, ZS 032 (1986) uses total factors of safety, depending on the location of application of the timber. The factors of safety increase with severity of the environment (inside, outside and wet locations). Table 9 presents the various factors and computed averages for each of the fundamental stresses, to aid comparison with values given in ZS 032 (1986). It can be observed that the outside location factor of safety closely approximates the computed average and will be used in the foregoing comparisons.

Table 10 compares selected average physical and mechanical test values to common grade values in the ZS 032 for the outside location, , where possible, for each of the four test species. There is reasonable agreement in the values for modulus of elasticity and shear parallel to grain, otherwise the test values exceed the values given in ZS 032 (1986), in most cases

Conclusion and Recommendations

The physical and mechanical properties for the species of timber were determined, with reasonable accuracy. The values for *E. Grandis* and *P. Kesiya* exceed those in the ZS 032 (1986), when the specified total factors of safety are applied. The test results for *E. Cloesina* and *P. Oorcapa*, may be the best estimates since there are no values for these species in ZS 032 (1986).

Due to difficulties in accurately determining the compression at the limit of proportionality for compression specimens, and carrying out the tensile test, the bending test gives the more simpler method for the determination of the modulus of elasticity, as the proportional limit was determined with reasonable accuracy.

References

1 ZS 032 (1986), Zambian standard code of practice for structural use of locally grown timber, Zambia Bureau of Standards, Lusaka, Zambia.

2 BS 373 (1986), Methods for testing small clear specimens of timber, British Standard Institution, United Kingdom, Milton Keynes, UK.

3 Masani, N.J. (1980), Guideline procedures for standard tests to derive fundamental stresses, TDAU, University of Zambia, Lusaka, Zambia.

Table 9 Total Factors of Safety to obtain Safe Working Stresses

Mechanical property	Location			Average
	Inside	Outside	Wet	
Extreme fibre stress (f_b) in beams for hardwoods e.g. eucalyptus	5.0	6.0	7.5	6.2
Extreme fibre stress (f_b) in beams for softwood e.g. pine	6.0	7.0	8.5	7.8
Shear along grain (f_s)	7.0	7.0	7.0	7.0
Horizontal shear in beams (H)	10.0	10.0	10.0	10.0
Maximum compressive stress along grain (f_{cp})	4.0	4.5	5.5	4.7
Compressive stress across grain (f_{cn})	1.75	2.25	2.75	2.25
Modulus of Elasticity (E)	1.0	1.0	1.0	1.0

(*Source:* Table 9, Masani , 1980)

Table 10 Comparison of Density, Young's Modulus, Moisture Content, Bending, Shear and Compression Strengths with ZS 032 (bracketed values)

Species	Density (kg m3)	Modulus of Elasticity (N/mm^2)	Moisture Content (%)	Bending Strength (N/mm^2)	Shear Stress parallel to Grain (N/mm^2)	Compressive Stress parallel to Grain (N/mm^2)	Compressive Stress Perpendicular to Grain (N/mm^2)
E. CL	629	16851	12.7	16.64	0.86	11.67	8.92
E. GR	904	13049 (11000)	25. 0 (7.29)	12.78 (1.02)	0.75 (5.70)	10.00 (1.72)	4.94
P. KE	580	8667 (9250)	10.9	9.86 (5.00)	0.67 (0.68)	7.31 (3.70)	3.14 (1.14)
P. OO	418	4908	10.5	5.38	0.45	6.93	2.76

APPENDIX 1: Specimens for standard tests (dimensions in mm)