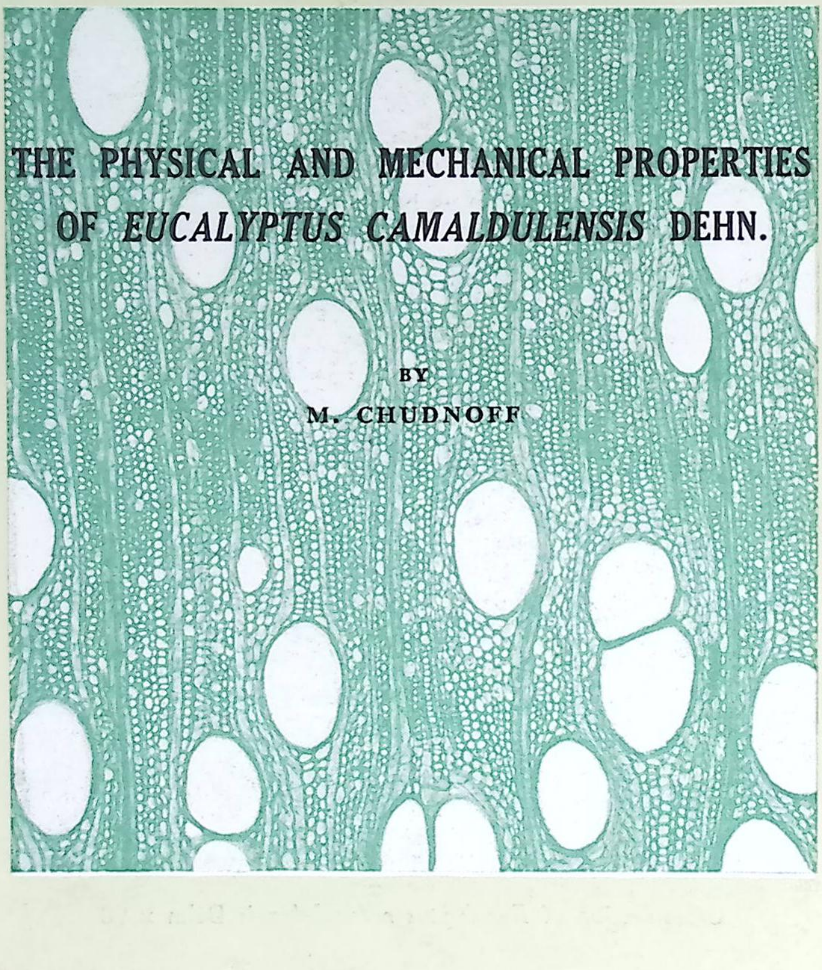
THE HEBREW UNIVERSITY OF JERUSALEM • THE ISRAEL MINISTRY OF AGRICULTURE
THE NATIONAL AND UNIVERSITY INSTITUTE OF AGRICULTURE



Bulletin No. 66



# THE PHYSICAL AND MECHANICAL PROPERTIES OF *EUCALYPTUS CAMALDULENSIS* DEHN.

BY

M. CHUDNOFF

DIVISION OF PUBLICATIONS
BEIT DAGAN • OCTOBER 1961

Cross section of *Eucalyptus camaldulensis* Dehn × 90

THE HEBREW UNIVERSITY OF JERUSALEM • THE ISRAEL MINISTRY OF AGRICULTURE

THE NATIONAL AND UNIVERSITY INSTITUTE OF AGRICULTURE

Bulletin No. 66

# THE PHYSICAL AND MECHANICAL PROPERTIES OF *EUCALYPTUS CAMALDULENSIS* DEHN.

BY

M. CHUDNOFF



DIVISION OF PUBLICATIONS

BEIT DAGAN • OCTOBER 1961

Supplement of The Israel Journal
of Agricultural Research (Ktavim)

Division of Publications
Beit Dagan, October 1961

Printed by the Government Printer

# CONTENTS

THE PRESENT BULLETIN IS THE FIFTH OF A SERIES ON FORESTRY AND FOREST PRODUCTS RESEARCH. THE FIRST FOUR APPEARED IN *Ilanot.* WITH THE TRANSFER OF THE RESEARCH UNIT OF THE FOREST DEPARTMENT FROM THE MINISTRY OF AGRICULTURE TO THE NATIONAL AND UNIVERSITY INSTITUTE OF AGRICULTURE, FUTURE BULLETINS ON FORESTRY WILL APPEAR IN THIS SERIES AT IRREGULAR INTERVALS.

# THE PHYSICAL AND MECHANICAL PROPERTIES OF *EUCALYPTUS CAMALDULENSIS* DEHN.

*By*

M. CHUDNOFF

## I. INTRODUCTION

This report is one of a series being prepared on the properties and utilization potential of home-grown timbers. The lack of information on the technical properties of fast-growing *Eucalyptus camaldulensis* Dehn. (=*E. rostrata* Schlecht.) at various stages of maturity has been a serious deterrent in planning the most rational use of this timber. A more complete understanding of the mechanical properties and their relation to certain physical characteristics, together with a knowledge of the chemical composition and pulping potentials, are essential for establishing a long-term forest management and forest utilization program.

More diversified and extensive use of this wood can be contemplated as more information is made available, particularly concerning response to various seasoning methods. As eucalypts in general, and this species in particular, are refractory, we are less concerned with determining representative averages of the various pertinent properties by statistical sampling than with determining the variability within the stem or between sites, and whether or not this variability need be considered in log break-down methods and seasoning programs for particular uses.

## II. GROSS AND MICROSCOPIC FEATURES OF THE WOOD

*Gross Features*: Sapwood whitish to pale brown; heartwood light to dark reddish-brown; wood without characteristic odor or taste; grain varying from moderately straight to interlocked forming an attractive ribbon grain when quarter sawn. Growth zones present but not always distinct.

Publication of the National and University Institute of Agriculture, Rehovot. 1961 Series, No. 419—E. Received August 1961.

*Minute Features*: Diffuse-porous. Pores mostly solitary, occasionally in multiples of 2–3 with a distinct to indistinct oblique arrangement; medium sized, maximum tangential diameter 175 microns; numerous but not crowded. Vessels in heartwood with thin-walled tyloses and gummy deposits; spiral thickenings absent; pits alternate, vestured, medium sized, 7 to 10 microns; perforations simple, mostly horizontal. Parenchyma diffuse and loosely vasicentric. Rays weakly heterogenous, upright cells in low marginal tiers and interspersed with the procumbent cells; one to two, occasionally three cells wide; up to 25 cells high; approximately 20 per mm measured tangentially on a tangential section; ray-vessel pitting medium to coarse, up to 10–12 microns, pit outline circular to oval. Vasicentric tracheids present. Fibers with numerous large distinctly bordered pits; walls thin to very thick. Vertical traumatic gum-ducts frequently present and occluded with a dark reddish-brown gum (kino).

It is of interest to note that though Lewin and Reibenbach (21) did not detect the presence of starch in the material sampled for chemical analyses, and therefore concluded that *E. camaldulensis* is probably resistant to powder post beetle attack, we observed almost complete occlusion with starch grains of the lumina of ray and wood parenchyma in sapwood material collected throughout the year. Presence of starch was also noted by Fahn (13) during the evaluation of cambial activity. However, in this same work, Fahn reported the presence of spiral thickenings in the vessel elements; these were neither observed in any of our material nor described for this genus by Metcalf and Chalk (25).

## III. MECHANICAL PROPERTIES

### SELECTION AND PREPARATION OF TEST MATERIAL

Nine trees, authenticated by herbarium material, were selected from two sites: one near Kefar Sirkin and the other in the vicinity of Hadera. The Kefar Sirkin trees were growing in a single row along a railroad track, and the Hadera trees were from a wide shelterbelt. All of the trees were 18 to 20 year-old vigorous coppice growth with an average growth rate of 1.5 rings per centimeter. Relevant data on soil and climate are shown in Table 1.

In general, the methods outlined in A.S.T.M. standards for testing

TABLE 1.

SITE DESCRIPTION

| *Location* | *Soil* | *Elevation above sea level (m)* | *Mean annual rainfall (mm)** | *Mean minimum temp. coldest month °C* | *Mean maximum temp. hottest month °C* | *Mean relative humidity %* |
|---|---|---|---|---|---|---|
| Kefar Sirkin | Brown-red sandy soil on Quaternary alluvium | 50 | 543 | 7.1 | 31.9 | 50 |
| Hadera | Brown-grey clay loan on Quaternary alluvium | 25 | 618 | 8.8 | 30.1 | 55 |

*Rainfall is confined essentially to the months December to March.

small clear specimens of timber (1) for preparation of test bolts, marking of test sticks, and end and side matching for testing green and seasoned material, were followed. However, due to seasoning irregularities peculiar to eucalypts and the size and quality of the logs available, some modifications were made. Kefar Sirkin trees (trees No. 1, 2, 4, 9 and 11) were felled in May 1959 and butt logs of nominal two meter length to yield *a* and *b* bolts were obtained. Mid-length diameters outside bark varied between 35 and 40 centimeters. Within ten days of felling, the logs were split on a head saw and the half round cants were converted into 30 mm thick boards on a gang saw. Each board was marked to indicate its log number and its position in the log. Immediately after sawing, the boards were stacked in a fully automatic experimental dry kiln and dried to an average moisture content of 12 percent. The schedule was as follows:

| *Moisture content* % | *Dry bulb temp.* °C | *Wet bulb temp.* °C | *Relative humidity* % | *Equilibrium moisture content* % |
|---|---|---|---|---|
| Gr.–45 | 37 | 36 | 96 | 22 |
| 45–35 | 37 | 35 | 90 | 19 |
| 35–30 | 37 | 34 | 82 | 16 |
| 30–25 | 44 | 38 | 71 | 12 |
| 25–15 | 49 | 40 | 60 | 10 |
| 15–12 | 54 | 43 | 50 | 8 |

At an average moisture content of 30 percent, the charge was steamed at atmospheric pressure for 8 hours to remove collapse. At the end of the run, the conventional procedure for equalizing and stress relief was applied. Total time in the kiln was 28 days.

The boards were then marked and machined to yield sticks in the North-South axis only. Sticks designated for testing in the green condition were bundled and submerged in water, for four consecutive months, for soaking to a moisture content of not less than 40 percent.

Hadera trees were felled in January 1960, and butt logs of nominal two meter length to yield *a* and *b* bolts were obtained from trees No. 12, 20, 22 and 33. In addition, *c* and *d* bolts were obtained from trees No. 12 and 33, and *e* and *f* bolts from tree No. 33. Within one week after felling, the logs were converted to 30 mm thick boards in the same way as the Kefar Sirkin logs. To avoid the need for resoaking after conversion to sticks, side or edge matching of North-South boards were made for comparing the various strength properties in the green and seasoned condition. Boards designated for conversion into green test material were immediately submerged and stored in water until testing. Boards designated for testing in the seasoned condition were kiln dried according to the schedule used for the Kefar Sirkin material.

## METHODS OF INVESTIGATION

After machining the boards or rough sticks to 2 × 2 cm, the sticks were marked to yield the following test specimens: static bending — one from each pair of sticks; compression parallel to the grain — one from each stick; toughness — two from each pair of sticks; hardness — one from each pair of sticks; shear — two from each pair of sticks; cleavage — two from each pair of sticks; and tension perpendicular to the grain — two from each pair of sticks.

The test specimens were based on the "Monnin" system using the 2-cm standard according to British specifications (8). Deviations, if any, from this standard are noted below. An Amsler 4,000 kg capacity universal wood testing machine type 4 DBZF 120 was used. The loading system is hand-operated, but the rate of loading can be controlled within the desired limits by timing the movement of the loading ram.

A brief description of each test and the properties evaluated is given below.

*Static Bending*: Center loaded beam, 30 cm long, over a 28 cm span. Load applied to the radial face (growth rings parallel to the direction of loading). Bearing block and rolling supports have a 28 mm radius. Rate of loading is 1 mm per minute. The rate of loading was calculated to give a rate of fiber strain equivalent to that of the 2–inch standard. Load-deflection curves were plotted for all beams until the specimen failed to support a load of ten kilograms. Fiber stress at the proportional limit, modulus of rupture, modulus of elasticity, work to proportional limit, work to maximum load, as well as all other evaluations given below were calculated by formulas as given in the A.S.T.M. standard (1).

*Toughness*: A $2 \times 2 \times 28$ cm beam, center loaded over a 24 cm span, is ruptured by a pendulum impact as incorporated in the Amsler machine. One specimen is loaded on the radial face, and its matched pair on the tangential face. Readings are obtained in kilogram-meters directly from a sliding scale.

*Compression Parallel to the Grain*: A $2 \times 2 \times 8$ cm specimen was used, and the load applied by a spherically-seated compression tool. Rate of loading was 0.2 mm per minute, based on a strain of 0.003 cm per centimeter of specimen length. Stress-strain curves were not plotted, only the maximum crushing strength being determined.

*Janka Hardness*: The load required to inbed a steel ball, with a diameter of 11.28 mm, to one half its diameter was recorded. Penetrations were made only on radial and tangential faces of specimens having dimensions of $2 \times 2 \times 8$ cm. Rate of loading was 6 mm per minute.

*Shear Parallel to the Grain*: Test specimens having the dimensions $2 \times 2 \times 2$ cm were loaded on a radial and tangential face. The shearing tool was an adaptation of that specified in the British standard (8). Rate of loading was 0.6 mm per minute. The shearing strength per square centimeter is determined from the maximum load.

*Cleavage*: A 2x2 cm "Monnin" type specimen having an overall length of 45 mm was loaded at a rate of 2 mm per minute to failure. A radial and a matched tangential face were tested. The load per centimeter width was calculated.

*Tension Perpendicular to the Grain*: A 2x2 cm "Monnin" type specimen having an overall length of 70 mm was loaded at a rate of 2 mm per minute to failure. The strength in tension perpendicular to

T A B

STRENGTH PROPERTIES OF *Eucalyptus camaldulensis*

| Location | Tree no. | Specific Gravity o.d. wt. and gr. vol. | a.d. vol. | o.d. vol. | Moisture content % | Static: Fiber stress at P.L. kg/cm² | Modulus of rupture kg/cm² | Modulus of elasticity kg/cm² |
|---|---|---|---|---|---|---|---|---|
| Kefar Sirkin | 1 | .691 | .777 | .808 | 12 | 830 | 1240 | 123,500 |
| | | | | | 47 | 395 | 715 | 80,900 |
| | 2 | .680 | .770 | .831 | 12 | 640 | 1250 | 123,500 |
| | | | | | 55 | 467 | 835 | 94,500 |
| | 4 | .650 | .741 | .772 | 12 | 770 | 1210 | 124,000 |
| | | | | | 50 | 477 | 840 | 96,400 |
| | 9 | .732 | .788 | .828 | 12 | 600 | 860 | 93,000 |
| | | | | | 42 | 376 | 687 | 70,100 |
| | 11 | .725 | .780 | .828 | 12 | 620 | 980 | 98,500 |
| | | | | | 45 | 430 | 750 | 81,300 |
| | Average | .696 | .771 | .813 | 12 | 692 | 1110 | 112,500 |
| | | | | | 48 | 430 | 765 | 84,500 |
| Hadera | 12 | .638 | .710 | .755 | 12 | 580 | 950 | 92,500 |
| | | | | | 76 | 400 | 705 | 83,000 |
| | 20 | .633 | .767 | .804 | 12 | 820 | 1330 | 134,000 |
| | | | | | 79 | 572 | 880 | 97,500 |
| | 22 | .688 | .775 | .828 | 12 | 775 | 1220 | 118,000 |
| | | | | | 72 | 600 | 930 | 108,000 |
| | 33 | .580 | .650 | .705 | 12 | 640 | 1080 | 103,000 |
| | | | | | 97 | 487 | 735 | 85,000 |
| | Average | .630 | .725 | .773 | 12 | 705 | 1140 | 112,000 |
| | | | | | 81 | 515 | 810 | 93,500 |
| Grand average | | .665 | .750 | .795 | 12 | 700 | 1125 | 112,500 |
| Standard deviation | | .061 | | | | 129 | 191 | 18,500 |
| Coefficient of variation % | | 9 | | | | 18.50 | 17 | 16.50 |
| Grand average | | | | | 63 | 470 | 785 | 88,500 |
| Standard deviation | | | | | | 88 | 116 | 16,000 |
| Coefficient of variation % | | | | | | 19.25 | 14.75 | 18 |

L E 2

GROWN IN ISRAEL (ALL LOGS *a* and *b* BOLTS)

| Bending: Work to P.L. | Bending: Work to max. load | Bending: Work to total | Compression parallel to grain max. crush. strength | Toughness work per specimen | Shear | Tension perpendicular to grain | Cleavage | Side hardness |
|---|---|---|---|---|---|---|---|---|
| cm–kg/cm³ | | | kg/cm² | m–kg | kg/cm² | kg/cm² | kg per cm width | kg |
| .312 | 1.06 | 3.10 | 645 | 2.8 | 170 | 33 | 28 | 720 |
| .107 | .93 | 2.22 | 340 | 2.6 | 124 | 31 | 17 | 475 |
| .186 | 1.68 | 4.23 | 645 | 3.4 | 203 | 41 | 25 | 690 |
| .128 | 1.10 | 2.98 | 380 | 3.4 | 131 | 35 | 18 | 491 |
| .263 | 1.31 | 3.25 | 650 | 3.0 | 175 | 29 | 22 | 660 |
| .131 | .98 | 2.63 | 368 | 2.8 | 126 | 34 | 19 | 465 |
| .195 | .54 | 1.66 | 570 | 1.5 | 220 | 31 | 24 | 795 |
| .110 | .64 | 2.31 | 347 | 2.3 | 173 | 32 | 24 | 640 |
| .218 | .80 | 2.07 | 560 | 2.7 | 197 | 30 | 22 | 760 |
| .128 | .61 | 2.70 | 382 | 2.9 | 157 | 34 | 22 | 613 |
| .235 | 1.08 | 2.86 | 615 | 2.7 | 195 | 33 | 24 | 725 |
| .120 | .85 | 2.55 | 365 | 2.8 | 143 | 33 | 20 | 535 |
| .209 | .97 | 2.00 | 530 | 2.2 | 230 | 30 | 22 | 715 |
| .108 | .85 | 2.74 | 343 | 3.8 | 141 | 28 | 19 | 545 |
| .286 | 1.37 | 3.70 | 710 | 3.1 | 245 | 41 | 31 | 720 |
| .188 | 1.12 | 3.48 | 415 | 4.0 | 136 | 32 | 20 | 480 |
| .291 | 1.37 | 3.54 | 670 | 2.7 | 240 | 37 | 27 | 780 |
| .186 | 1.40 | 3.46 | 422 | 3.9 | 140 | 32 | 17 | 490 |
| .220 | 1.20 | 2.70 | 595 | 2.2 | 216 | 39 | 24 | 660 |
| .158 | 1.04 | 2.80 | 345 | 3.4 | 118 | 27 | 17 | 440 |
| .251 | 1.23 | 2.99 | 625 | 2.6 | 230 | 37 | 26 | 720 |
| .160 | 1.10 | 3.10 | 380 | 3.8 | 133 | 31 | 18 | 490 |
| .242 | 1.14 | 2.92 | 620 | 2.6 | 210 | 35 | 25 | 725 |
| .069 | .47 | 1.05 | 84 | .9 | 28 | 7 | 6 | 98 |
| 28.50 | .41 | .36 | 13.50 | 35.50 | 13.25 | 19.50 | 22.50 | 13.50 |
| .138 | .96 | 2.80 | 370 | 3.2 | 138 | 32 | 19 | 515 |
| .036 | .35 | .63 | 50 | .9 | 21 | 4 | 3 | 90 |
| 26 | 37 | 22.50 | 13.50 | 27 | 15.25 | 12.50 | 15.75 | 17.50 |

the grain was calculated from the maximum load and the area of the minimum section.

Immediately after each test, all or part of each specimen was used to determine the moisture content at time of test. The specific gravity, based on the green or seasoned volume and the oven-dry weight, was also determined from all beam and column test specimens. No controls were available for maintaining a constant temperature at the time of test, and room temperatures varied between 15 and 30°C.

## RESULTS

Average results of each tree, averages for the two sites, and the coefficients of variation and the standard deviations for individual measurements from all of the trees are listed in Table 2. Since moisture content at the time of test of the seasoned material was not exactly 12 percent, but varied by approximately ± 3 percent, adjustments were made using the equation derived by Wilson (39) for moisture content-strength relations. Statistical tests for seasoned material show that differences between the two sites are not significant for all strength properties evaluated. However, the same analysis for green material shows that all properties differ significantly except modulus of rupture, shear, and maximum crushing strength. Specifically, we find that fiber stress to the proportional limit, work to proportional limit, total work, toughness and tension perpendicular to the grain, differ significantly at the 0.1 percent level of probability; work to maximum load and cleavage differences are significant at the 1 percent probability level; modulus of elasticity and hardness differences are significant at the 5 percent level.

These results strongly indicate that drying green wood to a relatively low moisture content, and then resoaking to a moisture content above the fiber saturation point will not, in most cases, give strength values similar to those of green wood tested in the original wet condition. Not only is there a loss in resilience, as noted by Koehler and Thelen (19) and Wangaard (35), but there even may be a slight but significant increase in hardness, cleavage, and tension perpendicular to the grain. These discrepancies may be attributed, at least in part, to Urquhart and Williams' (34) explanation for the hysteresis loop in adsorption-desorption curves. It is suggested that upon drying and resoaking, part of the secondary valence bonds of the hydroxyl groups of the cellulose molecules have become mutually satisfied and are not freed for water adsorption. Water bound to the free hydroxyl groups could, in our case, act as a plasticizing agent, which modifies the various mechanical properties, particularly resilience.

Drying and resoaking to obtain matched green material may be necessary to obtain satisfactory end and side matching of sticks, required in the A.S.T.M. standard (1) when evaluating woods with refractory seasoning properties, but the dry-green strength ratios may not be truly representative. The side or edge matching of boards, as used for the Hadera material, though not conforming to the above standard, appears to be a more suitable procedure.

A comparison of the dry-green strength ratios of *E. camaldulensis* from Kefar Sirkin, Hadera, Australia (32), averages of 113 hardwoods grown in the United States (24), and averages of South American hardwoods (37) is presented in Table 3. The Kefar Sirkin values compare quite favorably with the Australian and the North and South American data in orders of magnitude, in most cases even more so than the Hadera values. Thus, though there are discrepancies in procedure and results, as reviewed above, it appears to be justified to include the green strength values obtained from the Kefar Sirkin material.

TABLE 3

AVERAGE STRENGTH RATIOS IN DRYING FROM A GREEN CONDITION TO 12 PERCENT MOISTURE CONTENT

| *Strength property* | *E. camaldulensis Kefar Sirkin* | *E. camaldulensis Hadera* | *E. camaldulensis Australia* | *Average U.S. hardwoods* | *Average South American hardwoods* |
|---|---|---|---|---|---|
| Fiber stress at P.L. | 1.60 | 1.37 | 1.52 | 1.80 | 1.52 |
| Mod. of rupture | 1.45 | 1.41 | 1.61 | 1.59 | 1.44 |
| Mod. of elasticity | 1.33 | 1.20 | 1.38 | 1.31 | 1.16 |
| Work to P.L. | 1.95 | 1.57 | — | 2.49 | 1.98 |
| Work to max. load | 1.27 | 1.12 | — | 1.05 | 1.42 |
| Total work | 1.12 | .97 | — | — | — |
| Toughness | .97 | .69 | .79 | — | — |
| Max. crushing strength | 1.68 | 1.64 | 1.76 | 1.95 | 1.63 |
| Shear | 1.36 | 1.73 | 1.61 | 1.43 | 1.24 |
| Tension perpendicular to grain | 1.00 | 1.19 | — | 1.20 | .86 |
| Side hardness | 1.36 | 1.47 | 1.57 | 1.33 | 1.17 |
| Cleavage | 1.20 | 1.44 | 1.27 | — | .85 |

## TABLE 4

AVERAGE STRENGTH PROPERTIES AT VARIOUS HEIGHTS

| Tree and bolt no. | Specific Gravity o.d. wt. and gr. vol. | Specific Gravity o.d. wt. and a.d. vol. | Specific Gravity o.d. wt. and o.d. vol. | Moisture content % | Static Bending: Fiber stress at P.L. kg/cm² | Static Bending: Modulus of rupture kg/cm² | Static Bending: Modulus of elasticity kg/cm² | Static Bending: Work to P.L. cm–kg/cm³ | Static Bending: Work to max. load cm–kg/cm³ | Static Bending: Work to total cm–kg/cm³ | Compression parallel to grain max. crushing strength kg/cm² | Toughness work per specimen m–kg | Shear kg/cm² | Tension perpendicular to grain kg/cm² | Cleavage kg per cm width | Side hardness kg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 *a* and *b* | .580 | .650 | .705 | 12 | 640 | 1080 | 103,000 | .220 | 1.20 | 2.70 | 595 | 2.2 | 216 | 39 | 24 | 660 |
| | | | | 97 | 487 | 735 | 85,000 | .158 | 1.04 | 2.80 | 345 | 3.4 | 118 | 27 | 17 | 440 |
| *c* and *d* | .620 | .705 | .772 | 12 | 680 | 965 | 100,800 | .258 | .86 | 2.14 | 570 | 2.1 | 210 | 45 | 27 | 670 |
| | | | | 86 | 462 | 760 | 92,000 | .133 | 1.07 | 2.98 | 380 | 4.0 | 129 | 30 | 19 | 460 |
| *e* and *f* | .600 | .678 | .732 | 12 | 720 | 1190 | 129,000 | .220 | 1.34 | 3.28 | 580 | 2.5 | 210 | 39 | 23 | — |
| | | | | 89 | 490 | 695 | 90,000 | .150 | .54 | 2.44 | 357 | 3.1 | 125 | 23 | 17 | 450 |
| 12 *a* and *b* | .638 | .710 | .755 | 12 | 580 | 945 | 92,500 | .198 | .91 | 2.41 | 530 | 2.2 | 235 | 32 | 23 | 720 |
| | | | | 76 | 400 | 705 | 83,000 | .108 | .85 | 2.74 | 343 | 3.8 | 141 | 28 | 19 | 545 |
| *c* and *d* | .632 | .702 | .755 | 12 | 630 | 945 | 98,000 | .228 | .96 | 2.48 | 545 | 2.6 | 250 | 38 | 20 | 700 |
| | | | | 80 | 545 | 820 | 94,000 | .178 | 1.03 | 2.82 | 395 | 3.7 | 145 | 29 | 20 | 500 |

Table 4 lists the seasoned and green strength values at various heights for two trees from Hadera. The analyses of variance show that differences due to height are not significant. Thus, values shown in Table 2 for *a* and *b* bolts only, can also be representative of butt log lengths of at least six meters.

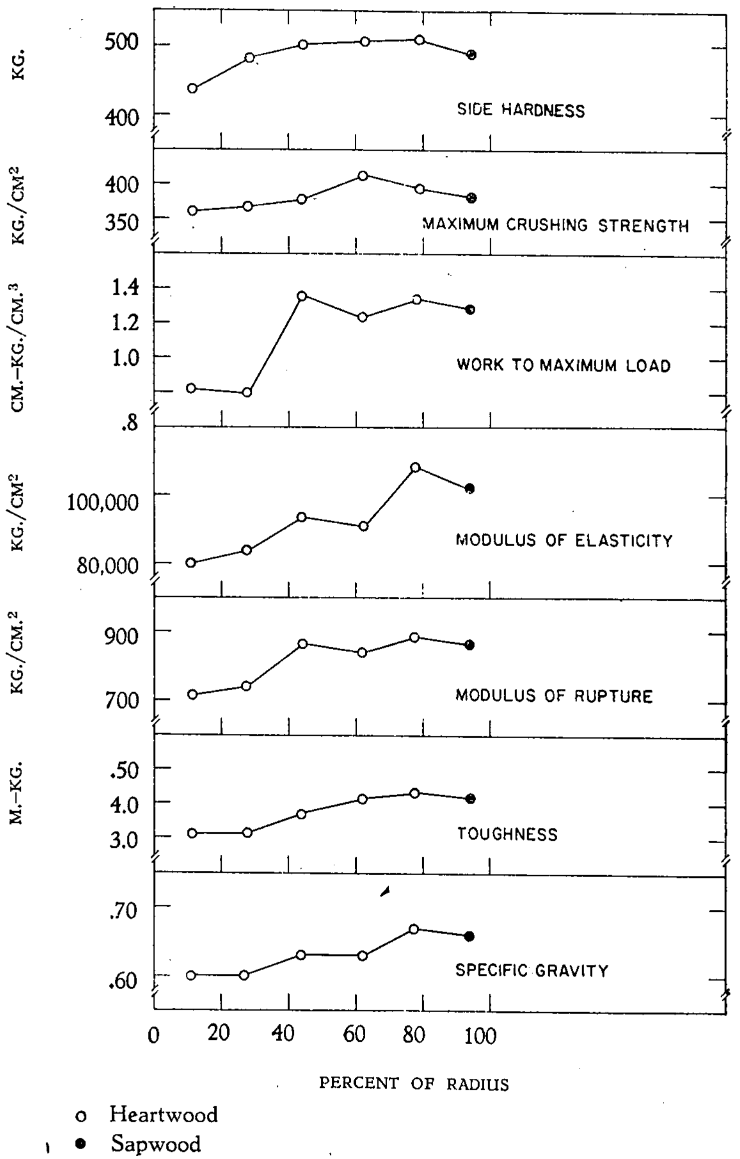
Variations in strength properties from pith to bark, however, are considerable. Fig. 1 shows a series of curves representing several green strength properties of cross-sections of the *a* and *b* bolts of the four Hadera trees. Except for maximum crushing strength parallel to the grain, variations in specific gravity do not account for all of the differences observed. If the various strength values are adjusted for differences in specific gravity, using the formula developed by the U.S. Forest Products Laboratory (2), a central core having low resistance to bending and impact persists. This condition, described by Dadswell and Langlands as "brittle heart", is believed to be caused by compression failures in the living tree; the central core of "brittle heart" expands in area as the tree increases in diameter (12). The "brittle heart" zone of our material is not only low in all strength properties and specific gravity, but also has a very high total volumetric shrinkage (collapse plus normal shrinkage) from the green to the oven-dry condition. Total volumetric shrinkage in the core can be as high as 30 percent as compared to a low of 10 percent in the outer heartwood zone.

The sapwood zone has a lower specific gravity than the adjacent heartwood zone, and in all cases the strength properties are similarly lower in value. The development of heartwood with the deposition of extractives accounts for these differences. In general, increases in strength due to extractives amount to 2 to 4 percent, except for modulus of elasticity which increases by 6.5 percent. Increases in strength as the result of infiltration of extractives have been noted for several American woods by Luxford (22).

## DISCUSSION

In Table 5, various strength properties of plantation-grown *E. camaldulensis* from six countries are given in addition to values obtained from natural growth in Australia. To make these comparisons as valid as possible, all strength values based on the 2–inch standard have been adjusted to the 2–cm standard by the use of combined ratios of strength means presented by Armstrong (4).

Fig. 1. Variation of green strength properties from pith to bark.



## TABLE 5

COMPARISON OF STRENGTH VALUES OF *E. camaldulensis* GROWN IN SEVERAL COUNTRIES

| Country | Reference | Specific gravity | | Moisture content % | Modulus of | | Max. crushing strength kg/cm² | Shear kg/cm² | Cleavage kg per cm width | Side hardness kg. | Toughness work per specimen m–kg | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | gr. vol. o.d. wt. | vol. and wt. at 12% m.c. | | rupture kg/cm² | elasticity kg/cm² | | | | | | |
| Israel (Ilanot) | | .67 | .81 | 12 | 1125 | 112,500 | 620 | 210 | 25 | 725 | 2.6 | 2–cm standard |
| | | | | 63 | 785 | 88,500 | 370 | 138 | 19 | 515 | 3.2 | 2–cm standard |
| Israel (Technion) | (27) | — | .80 | 12 | 895 | 91,000 | 470 | 182 | 20 | 672 | — | 2–inch standard adjusted to 2–cm standard ; av. log diam. 24 cm |
| Australia | (32) | .70 | .93 | 12 | 1135 | 105,000 | 610 | 198 | 23 | 1100 | — | |
| | | | | Green | 704 | 75,500 | 345 | 123 | 18 | 700 | — | 2–inch standard adjusted |
| Italy | (14) | — | .75 | 12 | 1140 | — | 565 | — | — | — | 3.7 | 2–cm standard |
| Italy | (11) | .70 | — | 12 | — | — | 600 | — | — | — | — | 2–cm standard |
| Spain | (26) | — | .71 | 12 | 890 | — | 517 | — | — | — | 2.1 | 2–cm standard |
| Turkey | (33) | — | .51 | 12 | 852 | — | 444 | — | — | — | 2.7 | 2–cm standard. Max. log diameter 22 cm |
| South Africa | (7) | — | .97 | 12 | 1200 | — | 700 | — | — | — | — | 2–inch standard adjusted |
| U.S.A. | (5) | — | — | 60 | 820 | 94,000 | 378 | 139 | — | — | — | 2–inch standard adjusted, specific gravity (gr. vol. and gr. wt.) = 1.1 |

All strength values obtained at our laboratory compare very favorably with those representing Australian timber except for side hardness. Though the specific gravity of the wood from both sources is almost identical, the Australian wood has a side hardness about 30 percent higher. It was believed that a possible explanation for this discrepancy could be attributed to differences in growth rate. To check this assumption two trees growing on sand dunes near Hadera were felled and tested in the green condition. The growth rates of these were about half of those of the Hadera trees (3 rings per centimeter as compared to 1.5 rings respectively). The specific gravity for the sand dune and Hadera trees was identical (0.63), and the side hardness of the former was 504 kilograms as compared to 490 kilograms for the latter. These variations in growth rate, at least at the levels measured in our experiments, do not modify the hardness values. The hot water solubility of the Hadera wood is about one fourth of that of the Australian timber (4.3% and 15.2% respectively (20, 21). The large differences in extractives could result in higher hardness values as shown in Fig. 1, but should also result in a higher maximum crushing strength parallel to the grain (24); but this is not so, for the local and Australian values are almost identical.

The results given in Table 5 for Israel material tested by the Technion were obtained from bolts having a diameter of not more than 24 cm. Similarly, the logs tested in Turkey had diameters not exceeding 22 cm. Though not stated, it is believed that the logs evaluated in Spain also had very small diameters. The modulus of rupture and maximum crushing strength from these three sources are quite similar, though there are large differences in specific gravity based on the weight and volume at 12 percent moisture content. Strength properties of material from the United States, South Africa, Italy, Australia, and Israel (Ilanot) are very similar, except for side hardness, as already noted. The very large range of specific gravity (air-dry weight and volume) from 0.51 to 0.97 is not, we believe, due to differences in site conditions, but rather to size of trees sampled and test methods used. Very small diameter logs will usually give much lower density values than more mature wood. Also, the use of air-dry weight and volume to calculate the specific gravity of highly collapse-prone woods, such as eucalypts, is not reliable and should be avoided. If large, more mature timber is evaluated, there do not appear to be any marked differences in the mechanical properties of natural or planted *E. camaldulensis*, even though growing continents apart. There may be additional exceptions to this similarity,

## TABLE 6

COMPARISON OF THE STRENGTH PROPERTIES OF ISRAEL–GROWN *E. camaldulensis* WITH OTHER HARDWOODS OF THE SAME DENSITY

(LOCAL WOOD CONSIDERED AS 100 PERCENT)

| Species | Country and reference no. | Specific gravity | | Moisture content % | Modulus of | | Max. crush strength % | Shear % | Work to max. load % | Side hardness % |
|---|---|---|---|---|---|---|---|---|---|---|
| | | gr. vol. o.d. wt. | vol. and wt. at 12% m.c. | | rupture % | elasticity % | | | | |
| *Carya glabra* | U.S.A. (24) | .66 | — | 12 | 132 | 133 | 108 | 83 | 226 | — |
| *Robinia pseudoacacia* | U.S.A. (24) | .66 | — | 12 | 127 | 120 | 120 | 94 | 139 | 106 |
| *Quercus chrysolepis* | U.S.A. (24) | .70 | — | 12 | 85 | 94 | 107 | 88 | 75 | 153 |
| *Afzelia* spp. | West Africa (3) | — | .81 | 12 | 113 | 118 | 131 | 81 | 90 | 111 |
| *Celtis soyauxii* | West Africa (3) | — | .79 | 12 | 131 | 145 | 121 | 87 | 138 | 106 |
| *Dipterocarpus zeylanicus* | Ceylon (3) | — | .80 | 12 | 113 | 145 | 116 | 68 | 96 | 87 |
| *Dipterocarpus* spp. | Malaya (3) | — | .79 | 12 | 132 | 182 | 133 | — | 130 | 83 |
| *Terminalia amazonia* | Br. Honduras (3) | — | .79 | 12 | 120 | 133 | 118 | 80 | 134 | 109 |
| *Albizzia caribaea* | Venezuela (37) | .66 | — | 12 | 95 | 105 | 86 | 65 | 95 | 83 |
| *Tetragastris balsamifera* | Puerto Rico (37) | .67 | — | 11 | 105 | 110 | 99 | 68 | 100 | 134 |
| *Peltogyne venusa* | Surinam (38) | .67 | — | 13 | 126 | 133 | 120 | 85 | 132 | 116 |
| *Humiria balsamifera* | Surinam (38) | .66 | — | 14 | 122 | 146 | 106 | 82 | 148 | 101 |
| Average | | | | | 117 | 130 | 114 | 79 | 113 | 108 |

besides hardness, but either data are insufficient or, as for toughness evaluations, it is not possible to adjust results from different test methods.

In Table 6, local *E. camaldulensis* is compared with other hardwoods having a similar density, the values for eucalypt being considered as 100 percent. The average for these hardwoods is about 10 percent higher in side hardness; cleavage, maximum crushing strength, work to maximum load, and bending strength are higher by about 15 percent; and stiffness is superior by 30 percent. In shear parallel to the grain, the mean hardwood value is lower by about 20 percent. These deviations from the "normal" can be partially attributed to the interlocked grain that is prevalent in our material. The lower strength-weight ratios of the eucalypt are not critical for most uses, and should not be considered as detrimental when developing a utilization program for this species.

## IV. PHYSICAL PROPERTIES

### SELECTION OF MATERIAL AND METHODS OF INVESTIGATION

At the same time that trees were felled at Hadera to obtain material for evaluation of the mechanical properties, three trees (No. 12, 18, 24) were selected to determine the total volumetric shrinkage, specific gravity, and moisture content variations, if any, from bark to pith at various height levels in the tree. Immediately after felling, a reference line was marked along the full tree length, and cross-sectional disks, not less than 20 centimeters in thickness, were obtained from several heights. After sectioning, the disks were packed in wet sacks and stored until evaluated (not more than 48 hours). Table 7 presents data on section diameters, percent bark, and percent heartwood of section areas.

A strip 7 cm wide was laid out through the diameter of each section, and specimens 2.5 cm wide in the radial direction were removed in series. Each strip was oriented in the same direction according to the reference line marked in the field. Specimens were then trimmed along the grain to a final length of 4 cm. Thus each test specimen had a nominal 7 cm width in the tangential direction, 2.5 cm thickness in the radial direction, and 4 cm length along the grain.

Green volumes and weights were determined immediately after machining. The specimens were then air-seasoned for two months to a moisture content of approximately 16 percent, and volumes and weights were again measured. The specimens were then over-dried for 48 hours at 105°C, and the moisture-free volumes and weights determined. Volumetric measurements were made by water displacement. From this series of measurements, it is possible to calculate the specific gravity (based on the green volume and the oven-dry weight), the initial green moisture content, the air-seasoned moisture content, the volumetric shrinkage from the green to the oven-dry condition, the volumetric shrinkage from the green to the air-dry condition, the intersection point, the void volume, and the maximum moisture content. This information was obtained from each of 217 specimens representing the three trees.

TABLE 7

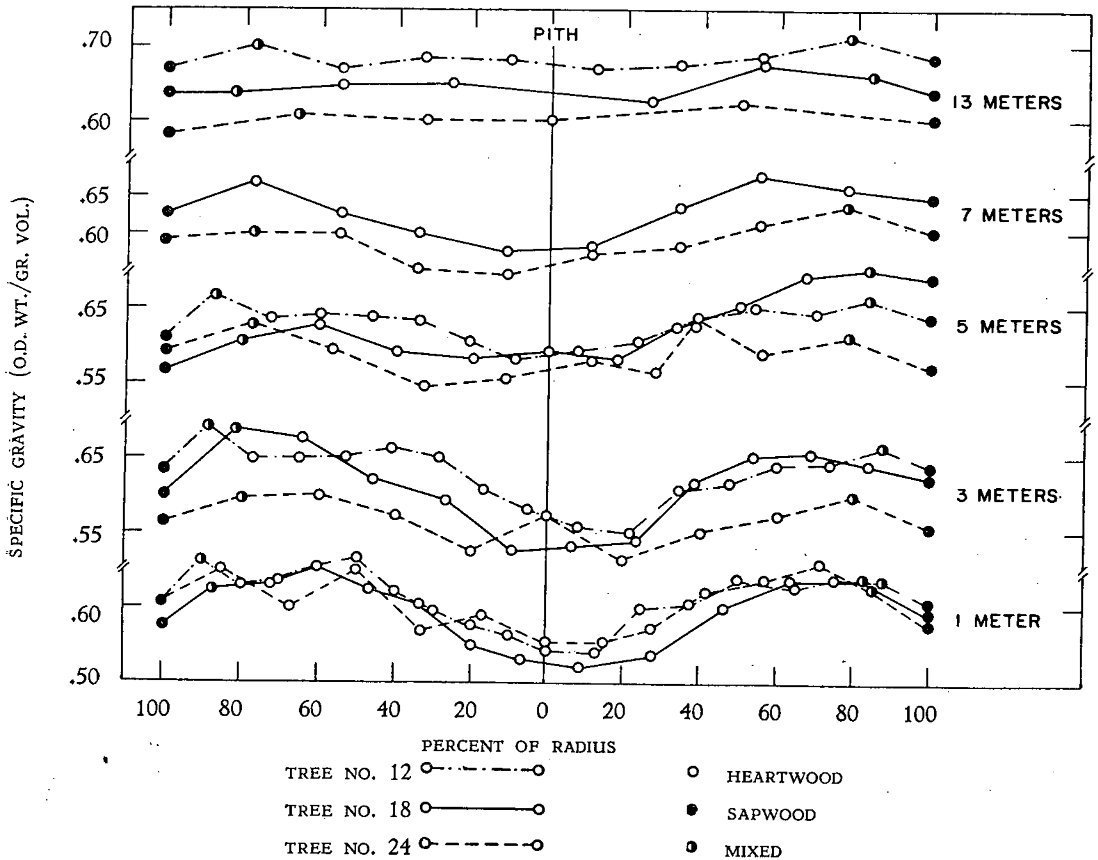
DIAMETERS OF CROSS-SECTIONAL DISCS AND PERCENT AREAS OF BARK AND HEARTWOOD AT VARIOUS HEIGHTS

| *Tree no.* | *Disk height above ground* | *Diameter outside bark* | *Diameter inside bark* | *Diameter of heartwood* | *Percent* bark* | *Percent** heartwood* |
|---|---|---|---|---|---|---|
| | *m* | *cm* | *cm* | *cm* | | |
| 24 | 1.0 | 43.0 | 39.4 | 31.0 | 15.9 | 62 |
| | 3.0 | 32.0 | 30.0 | 22.0 | 12.1 | 54 |
| | 5.0 | 29.0 | 27.6 | 19.0 | 10.3 | 48 |
| | 7.0 | 27.5 | 26.1 | 17.0 | 10.5 | 43 |
| | 9.0 | 22.0 | 20.8 | 13.5 | 9.2 | 41 |
| | 12.0 | 19.5 | 18.5 | 10.0 | 10.0 | 29 |
| 12 | 1.5 | 54.0 | 49.0 | 41.0 | 17.6 | 70 |
| | 3.5 | 44.8 | 41.8 | 35.5 | 12.9 | 71 |
| | 5.5 | 42.0 | 39.2 | 32.5 | 13.7 | 69 |
| | 8.5 | 37.5 | 35.5 | 28.0 | 10.0 | 62 |
| | 11.0 | 29.0 | 27.4 | 20.0 | 10.6 | 53 |
| | 13.0 | 27.5 | 25.9 | 18.5 | 10.2 | 51 |
| 18 | 1.0 | 39.0 | 35.4 | 31.0 | 17.1 | 76 |
| | 3.0 | 34.0 | 31.6 | 28.0 | 14.7 | 79 |
| | 5.0 | 32.5 | 30.5 | 26.5 | 12.1 | 76 |
| | 7.0 | 28.7 | 26.9 | 23.0 | 13.3 | 73 |
| | 9.0 | 27.5 | 25.7 | 22.0 | 16.0 | 76 |
| | 11.0 | 22.3 | 20.9 | 16.6 | 11.3 | 62 |
| | 13.0 | 21.3 | 19.9 | 16.5 | 11.8 | 68 |

*based on total cross-sectional area

**based on bark-free cross-sectional area

Fig. 2. Variation of specific gravity from pith to bark at various heights.



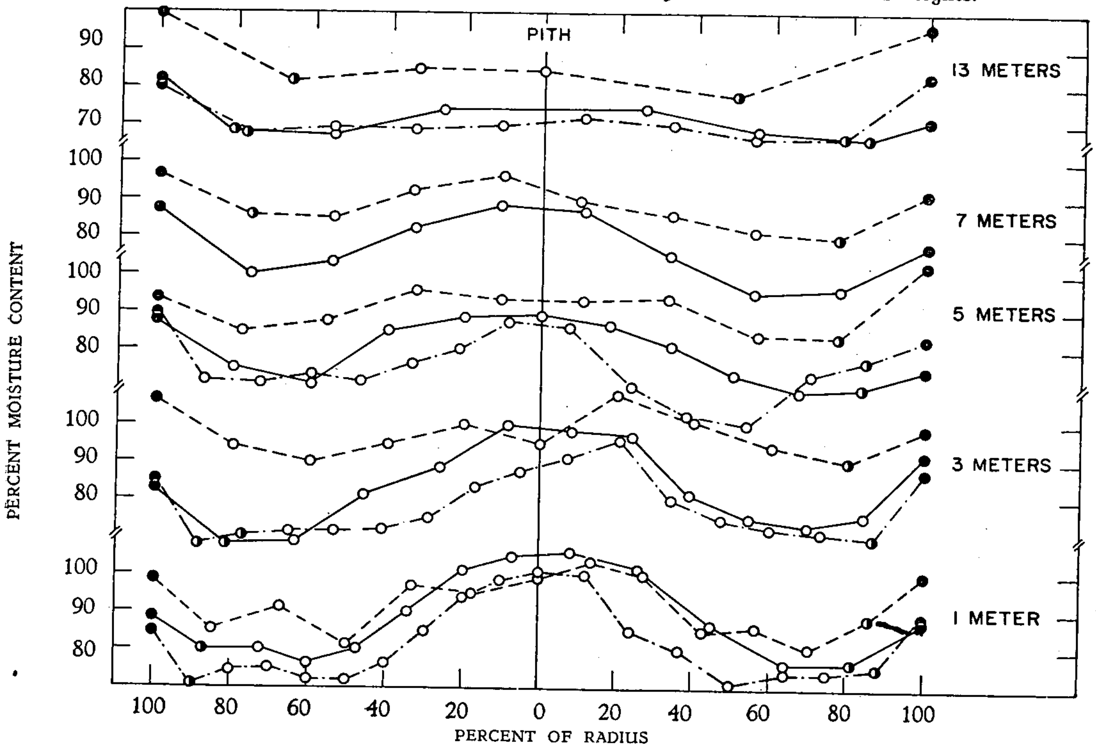
## RESULTS

*Specific Gravity*: In Fig. 2, curves are presented to show the variation of specific gravity from the pith to the bark at five height levels (unless otherwise noted specific gravity refers to that based on the green volume and oven-dry weight). The figure shows that at the one meter height, there is a central core of low density, an outer zone of high density, and again a sapwood zone of low density due to a minimum of extractives. These variations through the cross-section become less extreme towards the top, being almost uniform at the 13 meter level. In Fig. 6, curves were fitted statistically to the combined data from the three trees to show the variation of specific gravity with height within four zones. Zone "A" is 2.5 cm from the bark (sapwood only), zone "C" 7.5 cm from the bark, zone "D" and zone "E" 10 and 12.5 cm from the bark respectively. Zone "B" is not included, as most of this material comprises both sapwood and heartwood. By using the xylem-phloem margin as a reference, we are assured that within reasonable limits each zone, from the base to the upper part of the tree, represents wood of the same period of cambial activity and the same degree of maturity. For each curve, the correlation coefficient ($r$) and the regression coefficient ($b$) are shown.

In the sapwood zone, the increase of specific gravity with height is highly signficant, whereas in all the heartwood zones there are no significant changes with height. The discrepancy is probably due to an unequal deposition of extractives along the tree length during the conversion of sapwood to heartwood. Zavarin (40) and Nikitin (29) report a decrease in heartwood extractives, from the base to the top of the tree, for incense cedar and oak. Cold water solubility determinations were made of our zone "C" material, and significant decreases of extractives were found with increases in tree height, i.e. about 9 percent at the one meter height and 5 percent at the 13 meter level. The fact that the specific gravity is constant along the full tree length within any particular heartwood growth zone, at least to a 13 meter height, confirms our previous findings with material used for the mechanical tests.

*Moisture Content*: Data presented in Fig. 3 represent the moisture content distribution in the standing tree (all moisture content calculations are based on the oven-dry weight). At the one meter height, there is a central core of high moisture content, an outer heartwood zone of low moisture content, and a sapwood zone of high moisture content. These

Fig. 3. Variation of moisture content from pith to bark at various heights.




TREE NO. 12 o-·-·-o
TREE NO. 18 o———o
TREE NO. 24 o- - - -o

○ HEARTWOOD
● SAPWOOD
◐ MIXED

variations between inner and outer heartwood are most pronounced at the base of the tree, and least at the 13 meter level. A comparison with the specific gravity curves in Fig. 2 shows that the moisture content varies inversely with specific gravity at all levels. As for the specific gravity data, curves are shown in Fig. 7 to indicate the relationship between moisture content and height. In all zones, except zone "D", there is a significant decrease in moisture content with height, but the correlation coefficients are significant only for zones "A" and "C".

Curro (10) measured the variations in moisture content and specific gravity of *E. camaldulensis* cultivated in Italy and reports an increase in specific gravity and a decrease in moisture content with height; for combined height levels, there is a decrease in moisture content and an increase in specific gravity from the pith to the bark. Though the significance of these variations was not determined, the trends are identical to those found in this study.

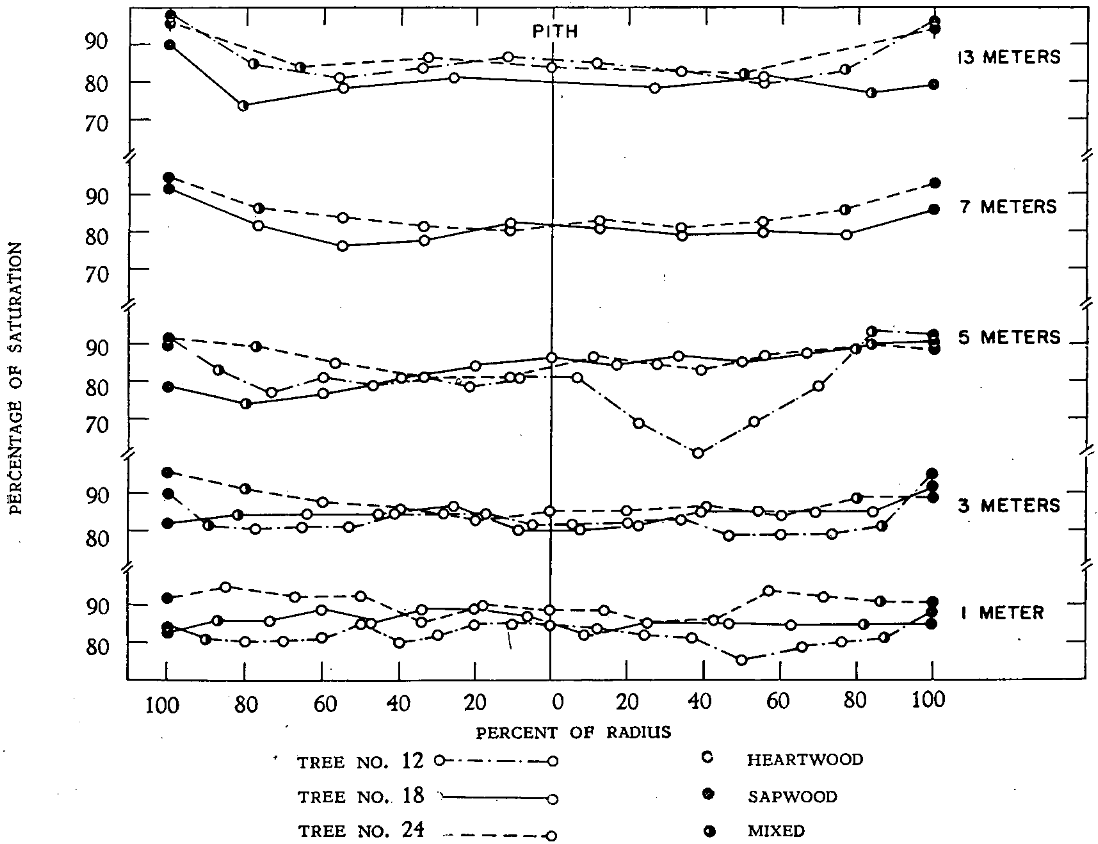
*Ratio Moisture Content to Maximum Moisture Content*: The maximum moisture content potential of each specimen was calculated by the formula:

$$\text{Max. Moisture Content } (\%) = \frac{1 - \frac{\text{specific gravity}}{1.53}}{\text{specific gravity}} \times 100$$

The assumed specific gravity of wood substance as determined by water displacement is 1.53 (23).

From Figs. 2 and 3, it appears that the moisture content variations are essentially a function of specific gravity and are not due to some peculiar physiological requirements. This is more apparent when the ratios of moisture content to the maximum moisture content, expressed as percentages, are plotted as shown in Fig. 4. These percentages of saturation are fairly uniform from pith to bark, and only at the 7 and 13 meter height levels are there marked differences between the sapwood and adjacent heartwood ratios. In tree No. 12, at the 5 meter level, there is an unusual drop in moisture content to 60 percent of maximum, which is probably due to some physiological trauma not detected in the test material. The relationship between this ratio and height is shown in Fig. 7. The percentage of saturation in the sapwood zone is constant with height, whereas there are highly significant decreases in the "C" and "D" zones and a significant decrease in the "E" zone.

Fig. 4. Variation of percentage of saturation from pith to bark at various heights.



The percentages of saturation for all heartwood material ranged from 74 to 94 percent (except for the aberration in tree No. 12), averaging about 83 percent. The green heartwood moisture content is a very close function of specific gravity or void volume, as demonstrated in Fig. 8. The average moisture content at each specific gravity level has been plotted, and a smooth curve fitted. The calculated maximum moisture content is also plotted. Within the specific gravity range of 0.51 to 0.72, the ratio of moisture content to maximum moisture content is nearly constant at 0.83. Though there are wide variations in moisture content, particularly at the one meter level, the percentages of saturation are almost identical, with 83 percent of the available void volume being filled with water. The specific gravity-moisture content relationship for sapwood will be presented in a future report.

*Volumetric Shrinkage*: Total volumetric shrinkages (collapse plus normal shrinkage) from the initial green condition to the oven-dry condition, at various locations from pith to bark, and at the several height levels, are shown in Fig. 5. At the one meter level the central core has a very high total shrinkage, the outer heartwood has a low shrinkage, and the sapwood zone has a high shrinkage. These differences are at a minimum at the 13 meter level. In Fig. 6 the relationship between height and total volumetric shrinkage is shown for the various zones. The sapwood zone has a significant decrease in shrinkage with height, whereas in all the other zones the regression and correlation coefficients are not significant.

Since only the sapwood zone shows both a significant increase in specific gravity with height, and a decrease in total volumetric shrinkage with height, there appears to be a definite relationship between density and collapse (collapse-free wood would tend to increase in shrinkage with increase in density). That collapse may increase with decrease in density is shown by Bisset and Ellwood (6) in their study on early and latewood shrinkage of growth rings of collapse-prone *Eucalyptus regnans*. Pankevicius (30) reports a decrease in total shrinkage with height for both sapwood and heartwood of *E. regnans* and *E. gigantea*, but no data are given on the specific gravity variation of the test material used.

*Normal Shrinkage and Collapse*:—Though no direct measurements were made to distinguish between true shrinkage and collapse by reconditioning techniques (15), excellent estimates can be made. The intersection

Fig. 5. Variation of volumetric shrinkage from pith to bark at various heights.

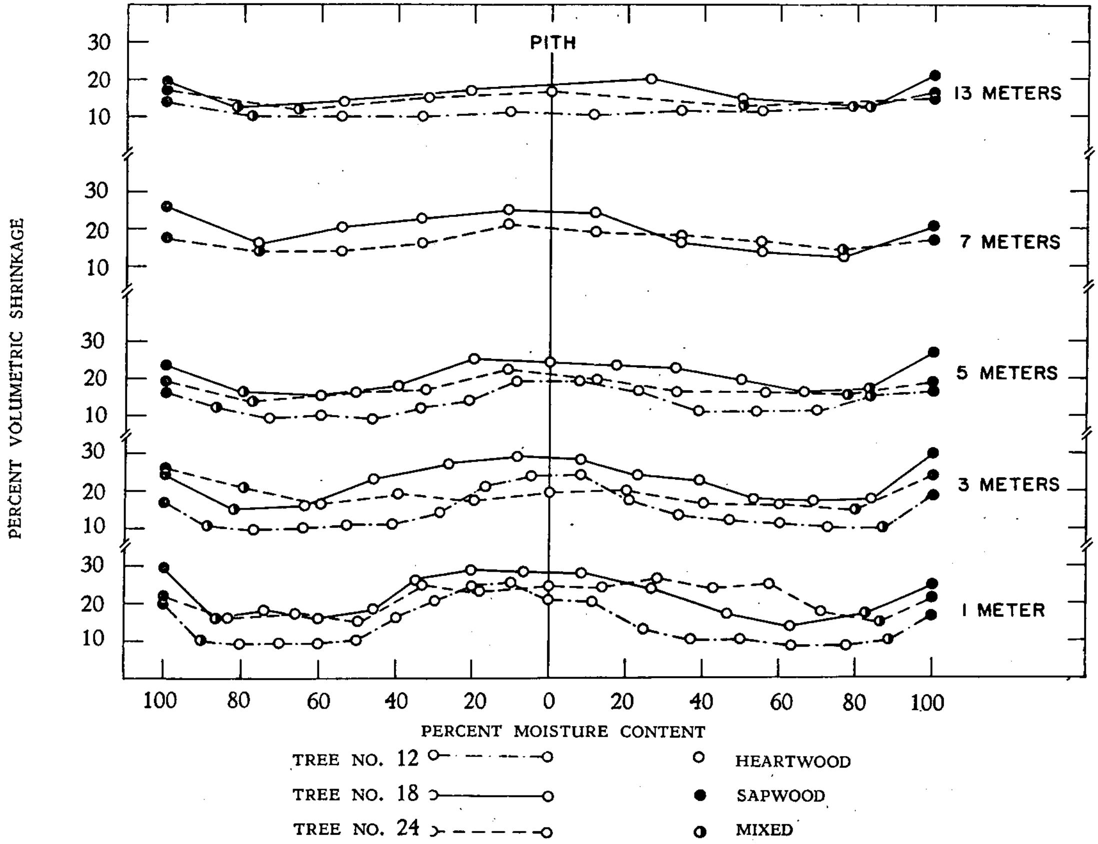
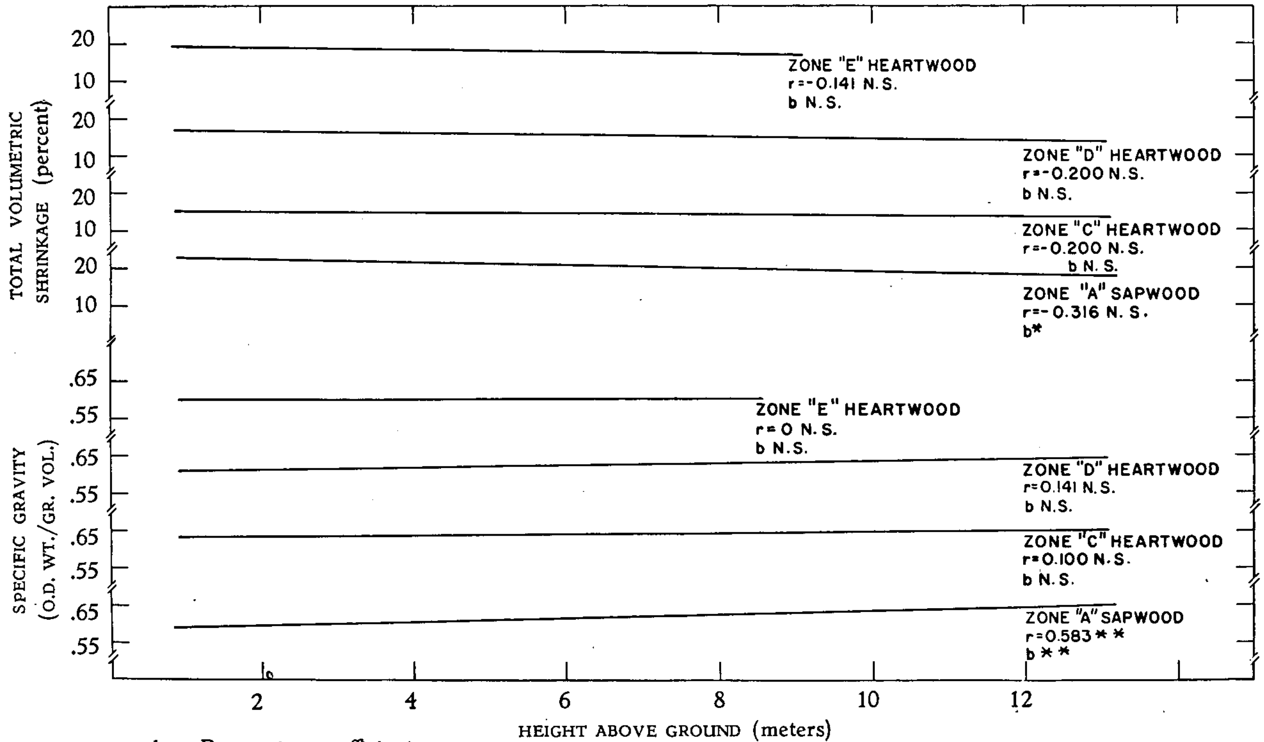
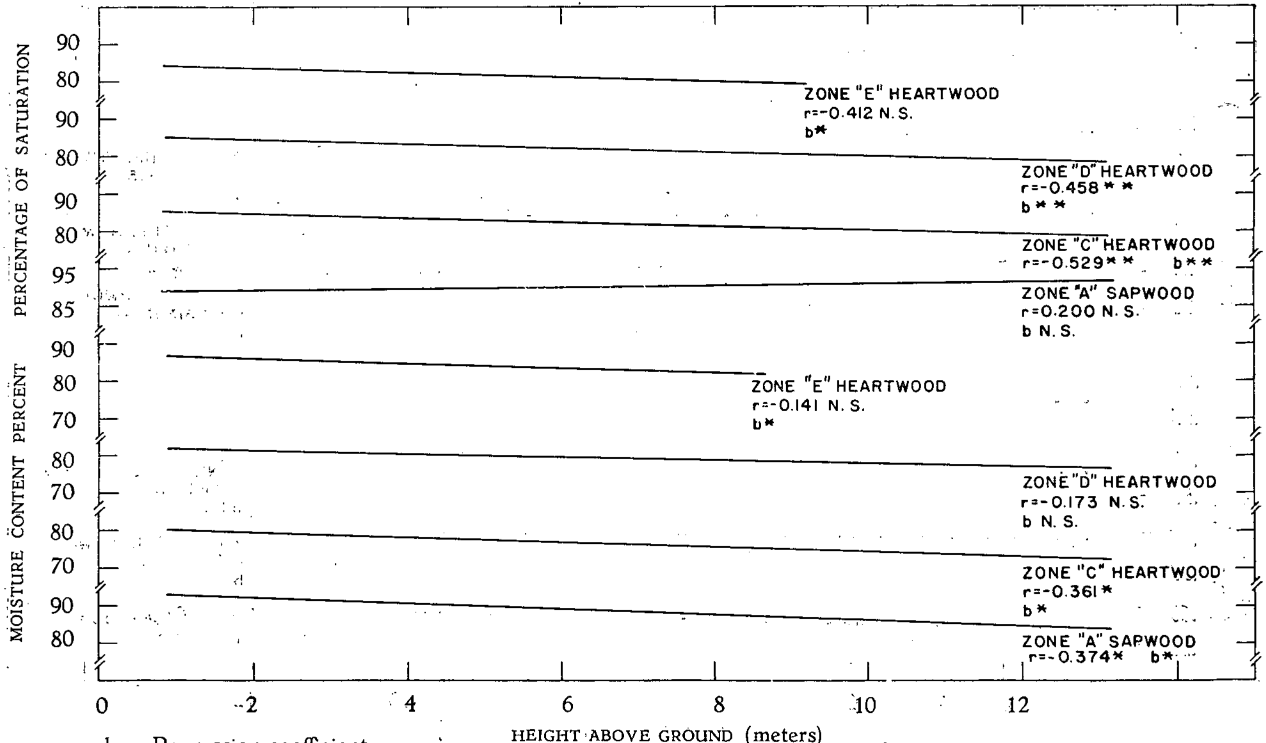


Fig. 6. Variation of specific gravity and volumetric shrinkage with height.



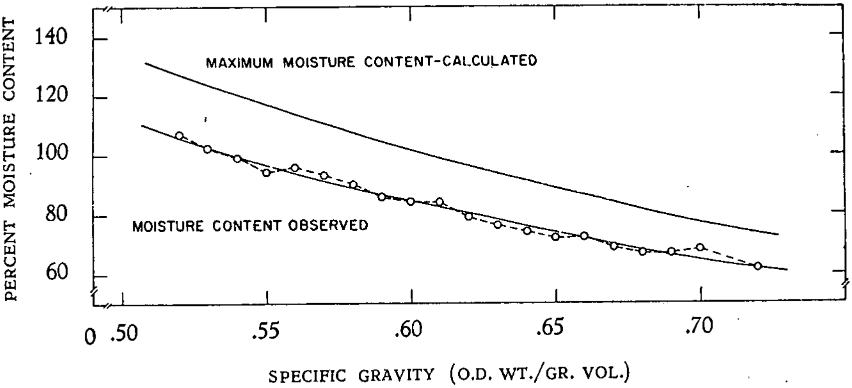

b = Regression coefficient.
r = Correlation coefficient.

Fig. 7. Variation of moisture content and percentage of saturation with height.




b = Regression coefficient.
r = Correlation coefficient.

Fig. 8. Specific gravity-moisture content relationship (heartwood).




point (fiber saturation point) was calculated for each specimen by the formula:

$$\text{Intersection point} = \frac{\text{air-dry M.C. (\%)} \times \text{shrinkage from green to oven-dry (\%)}}{\text{shrinkage from air-dry to oven-dry (\%)}}$$

This formula is based on the assumption that shrinkage and moisture content are linear below the intersection point. Though there is a slight departure from this linearity at very low moisture contents, the errors induced by this deviation are very small (16). For most tropical and temperate zone timbers, the intersection point will vary between 20 to 35 percent. If collapse is present, the intersection point, as determined by shrinkage measurements, will be abnormally high. Collapse as low as three percent, can result in a calculated intersection point as high as 50 percent. On this basis, every specimen that had an intersection point not higher than 35 percent, was considered to be collapse-free. Fifty specimens from tree No. 12 indicated true collapse-free volumetric shrinkage; tree No. 18 had 3 specimens, and tree No. 24 had 2 specimens that were collapse-free. In all cases, the collapse-free material was found only in the outer heartwood zone. From the numerous measurements available from tree No. 12, it was possible to estimate true volumetric shrinkage from the green to the oven-dry condition to be 10.5 percent, and the shrinkage to 12 percent moisture content to be 6.3 percent. The average specific gravity of this material is 0.65, and the intersection point is 30.0 percent.

The relationship between volumetric shrinkage and specific gravity has been derived by the U.S. Forest Products Laboratory for North American woods (28) to be:

Volumetric shrinkage = 28.0 × specific gravity

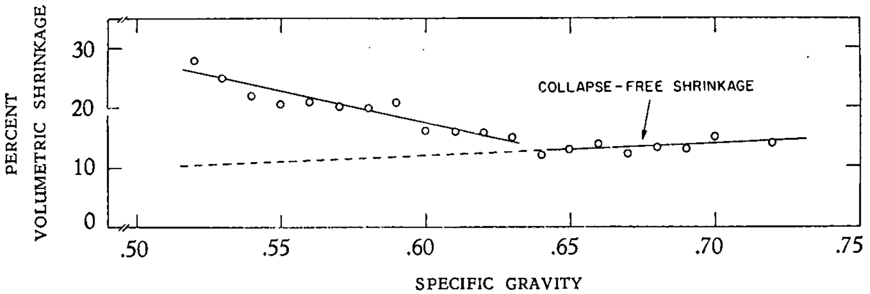
The constant 28.0 represents the intersection or fiber saturation point; if corrected for the compression of absorbed water, this value should be approximately 30 to 31 percent (31).

By using the constant of 18.0, as shown below, to approximate volumetric shrinkage, we do not wish to imply that, in our case, this low value represents the intersection point as well. From our measurements of tree No. 12 and other trees, volumetric shrinkage varied between 14.0 and 22.0 times the specific gravity with an average value of about 18.0. Wangaard (36) found, for some tropical timbers, that the volumetric shrinkage was considerably less than that of timber grown in the United States, i.e. approximately three-fifths as high as that suggested for North American wood, or about 17.0 times the specific gravity.

By using this estimate for normal volumetric shrinkage, we can calculate collapse-free shrinkage values for our data and also determine the percent of collapse, if any, in each specimen. The specific gravity data shown in Fig. 2 multiplied by 18.0 will indicate the true shrinkage. The difference between the calculated shrinkage and the total volumetric shrinkage in Fig. 5 would be equivalent to the percent collapse. The maximum collapse observed was 20 percent in the inner heartwood zone of tree No. 18. It must be stressed that this indirect method to determine collapse is an approximation only, but sufficiently accurate for the purposes of this study.

It is the general practice in the U.S. and Australia (1) to use volumetric shrinkage specimens that are 2″ × 2″ × 6″, and tangential and radial shrinkage data are obtained from material 1″ × 4″ × 1″ (the 4″ dimension is in the radial or tangential direction being measured). Kelsey and Kingston (16, 17, 18) have shown that the error will be small if a single specimen, 1″ × 1″ × 4″ in length, is used to determine radial, tangential, longitudinal, and volumetric shrinkages, and that results will be comparable, for most purposes, with those obtained by the standard test methods. In view of these findings, we believe that our departure from standard shrinkage specimen sizes is not likely to be misleading, particularly when, in this phase of our review, we are interested in demonstrating the variability of shrinkage from pith to bark at various height levels using test material having identical initial green dimensions.

Fig. 9. Relation between total volumetric shrinkage and specific gravity of heartwood.




Previously, we concluded that sapwood collapse may increase with decrease in specific gravity. In Fig. 9, the relationship between total volumetric shrinkage of heartwood to specific gravity is shown (only average values for each specific gravity level are plotted). There is a sharp decrease in shrinkage with increase in specific gravity up to about 0.64. Above this value, there is a gradual increase in shrinkage with increase in density that almost fits the relationship 18.0 × specific gravity, which indicates that this higher density material is probably free of collapse. If this curve is extrapolated, as shown by the broken line, we can compare normal shrinkage with the measured total shrinkage; the difference between these two curves at any specific gravity level within this range is the amount of collapse which occurred. The very high percentages of collapse occurring in the very permeable sapwood material and the large differences in degree of collapse between inner and outer heartwood, though the void volumes occupied by air are identical, suggest that the conventionally accepted theory explaining the collapse phenomenon requires reviewing.

In addition to the volumetric shrinkage data reviewed above, volumetric, radial and tangential measurements were made on representative material from the Hadera and Kefar Sirkin trees used in the tests to evaluate the mechanical properties. Nominal dimensions of the green test specimens were 7, 2.5 and 2.5 cm in the radial, tangential and longitudinal direction respectively. Again, these are not standard shrinkage specimens but, as indicated above, this departure probably will cause very small errors, if any. Except for tree No. 12, collapse-free shrinkage data were obtainable only from the Kefar Sirkin trees. This is not due to the fact that the Kefar Sirkin trees were not susceptible to collapse, but rather because of the drying and wetting treatment given to the wood. Chudnoff (9) demonstrated that drying, resoaking, and redrying of *E. camaldulensis* sapwood will result in collapse-free shrinkage during the second drying cycle. Such a treatment was given the Kefar Sirkin material, and from Table 8 it appears that this method is applicable to heartwood as well. The average specific gravity of this sampling is 0.70, which is the average reported for the Australian *E. camaldulensis*, and the radial and tangential shrinkages to 12 percent moisture content are almost identical to those reported by Greenhill (15) for the same species. After reconditioning (collapse-free), the Australian values are 4.5 and 2.6 percent for tangential and radial shrinkage respectively.

TABLE 8

COLLAPSE-FREE SHRINKAGE VALUES OF *E. camaldulensis*

| *Tree no.* | *Specific gravity gr. vol.– o.d. wt.* | *Shrinkage to 12% m.c.* | | | *Shrinkage to oven-dry* | | | *Intersection point* |
|---|---|---|---|---|---|---|---|---|
| | | *rad.* % | *tan.* % | *vol.* % | *rad.* % | *tan.* % | *vol.* % | % |
| 12 | .65 | 2.0 | 4.2 | 6.3 | 3.5 | 7.5 | 10.5 | 30.0 |
| 1 | .70 | 4.0 | 5.0 | 8.9 | 6.3 | 8.0 | 14.1 | 33.5 |
| 2 | .69 | 3.2 | 6.3 | 9.6 | 5.2 | 10.2 | 15.5 | 31.4 |
| 4 | .63 | 2.8 | 4.5 | 7.2 | 4.6 | 7.6 | 12.3 | 29.5 |
| 9 | .76 | 2.8 | 3.2 | 6.4 | 5.2 | 6.1 | 12.0 | 25.8 |
| 11 | .75 | 2.9 | 4.3 | 6.4 | 4.6 | 7.0 | 10.6 | 30.7 |
| Average | .70 | 3.0 | 4.6 | 7.7 | 4.9 | 7.7 | 12.9 | 30.0 |

Giordano (14) reports volumetric shrinkages, including collapse, to the oven-dry condition of up to 32 percent, while our observed maximum was 30 percent. Relatively low density wood, grown in Turkey, is reported by Toker (33) to have a total shrinkage from the green to the oven-dry condition of 4.0 and 8.6 percent in the radial and tangential direction respectively, and a volumetric shrinkage of 12.7 percent. The calculated intersection point was 31.6 percent. This closely agrees with our values as shown in Table 8.

## V. CONCLUSIONS AND SUMMARY

1. Though there are considerable differences in site conditions and growth rates, the various mechanical and physical properties of local *E. camaldulensis* are almost identical to those of the Australian timber.
2. There is as much, if not greater, variability within trees or between trees on the same site than there is between sites.
3. The dry-green strength ratios of the local wood are comparable, in orders of magnitude, to those in North and South American timbers.
4. At various tree heights, within the same growth zones, the mechanical properties do not vary significantly.
5. Variations in the mechanical properties from the pith to the bark are very pronounced in the butt logs. A central "brittle heart" zone, comprising about 15 percent of the cross-sectional area, has very low strength properties.
6. All sapwood strength properties are lower than those of adjacent heartwood by about 2 to 6.5 percent.
7. Except for shearing strength parallel to the grain, *E. camaldulensis* is weaker, in all strength properties, than the mean values for other hardwoods of the same density.
8. At the base of the tree, the central heartwood core is low in specific gravity and high in moisture content and total volumetric shrinkage.
9. As compared to the adjacent heartwood, the sapwood is low in specific gravity and high in moisture content and total volumetric shrinkage.
10. The percentages of saturation, i.e. ratios of moisture content to maximum moisture content, are fairly uniform from the pith to the bark.
11. There is a decrease in specific gravity with height in the sapwood zone, but not in the several heartwood zones. This difference in behavior between sapwood and heartwood is due to unequal deposition of extractives from the base to the top of the tree.
12. There is a decrease in moisture content with height in all zones.

13. The percentage of saturation is constant with height in the sapwood zone, but there are significant decreases in the heartwood zones.

14. In the standing tree, regardless of large specific gravity variations, about 83 percent of the heartwood void volume is filled with water.

15. Volumetric shrinkage from the green to the oven-dry condition is about three-fifths as large as that of North American woods of the same density.

16. In the sapwood zone, there is a significant decrease in total shrinkage with height. In the heartwood zones, shrinkage does not vary significantly with height.

17. Collapse-free radial, tangential, and volumetric shrinkage values closely agree with those measured in Turkey and Australia.

18. Collapse varied from 0 to 20 percent (volumetric), being most severe in the central heartwood core.

19. Collapse tends to decrease with increase in specific gravity.

## ACKNOWLEDGMENTS

The timber used in this study was made available by the Forestry Department of the Jewish National Fund.

The author gratefully acknowledges the valuable assistance of Messrs. T. Juszczyk and K. Tischler in carrying out many phases of this study.

## REFERENCES

1. AMERICAN SOCIETY FOR TESTING MATERIALS (1954) Standard methods of testing small clear specimens of timber. *A.S.T.M. Standard D*: 143–52.

2. ANON, (1944) Design of Wood Aircraft Structures. Bull. A.N.C. No. 18 (Army-Navy Civil Comm. on Aircraft Design Criteria. Aero Board Washington).

3. ARMSTRONG, F. H. (1953) The Strength Properties of Timbers. Bull. For. Prod. Res., London, No. 28.

4. ———(1955) The Strength Properties of Timber. The 2–cm standard for tests of small clear specimens. Bull. For. Prod. Res. London, No. 34.

5. BETTS, H. S. and SMITH, C. S. (1910) Utilization of California Eucalypts. Circ. U.S. For. Serv. No. 179.

6. BISSET, I. J. W. and ELLWOOD, E. L. (1951) The relation of differential collapse and shrinkage to wood anatomy in *Eucalyptus regnans* F. v. M. and *E. gigantea* HOOK. *Aust. J. app. Sci.* **2** (1): 175–183.

7. BOYD, J. D. and KINGSTON, R. S. T. (1956) Physical and mechanical properties. [Docum.] World Eucalyptus Conference, Rome 1956 No. FO/56/E-7-b.

8. BRITISH STANDARD INSTITUTION (1957) Methods of testing small clear specimens of timber. *B.S.*: 373.

9. CHUDNOFF, M. (1955) Prevention of collapse during seasoning. *Hayaar* **4**: 76–79 (Hebrew with English summary).

10. CURRO, P. (1956) Variazione dell'umiditá e variazione della densita basale in 15 piante di *Eucalyptus camaldulensis Dehn. Pubbl. Centro Sperim. Agric. For.* Roma, **1**: 227–238.

11. ———(1956) Resistenza alla compressione assiale in funzione del peso specifico in *Eucalyptus camaldulensis* Dehn. *Pubbl. Centro Sperim. Agric. For.* Roma, **1**: 239–249.

12. DADSWELL, H. E. and LANGLANDS, I. (1938) Brittle heart and its relation to compression failures. *Emp. For. J.* **17** (1): 58–65.

13. FAHN, A. (1959) Xylem structure and annual rhythm of development in trees and shrubs of the desert. Part III. *Eucalyptus camaldulensis* and *Acacia cyanophylla*. *Bull. Res. Counc. of Israel* **7D** (3–4): 122–131.

14. GIORDANO, G. (1950) Rapport sur les principales caractéristiques du bois d'eucalyptus des reboisements italiens. [Docum.] FAO Subcomm. Medit. For. Probl., Algiers 1950, No. *FAO/CEF/SCM/*30 (Rev. 1).

15. GREENHILL, M. E. (1940) The Shrinkage of Australian Timbers. Part II. Pamphl. Counc. sci. Industr. Res. Aust. No. 97.

16. KELSEY, K. E. (1956) The shrinkage intersection point — its significance and the method of its determination, *For. Prod. J.* **6** (10): 411–417.

17. ———and KINGSTON, R. S. T. (1953) An investigation of standard methods for determining the shrinkage of wood. *J. For. Prod. Res. Soc.* **3** (4): 49–53.

18. ——————(1957) The effect of specimen shape on the shrinkage of wood. *For. Prod. J.* **7** (7): 234–235.

19. KOEHLER, A. and THELEN, R. (1926) The Kiln Drying of Lumber. McGraw-Hill Publ. Co. New York.

20. LEWIN, M. (1955) The eucalyptus in Israel as cellulose raw material. *Hayaar* **4**: 38–45 (Hebrew with English summary).

21. ———and REIBENBACH, A. (1956) The chemical composition of *Eucalyptus rostrata* grown in Israel. *Bull. Res. Counc. of Israel* **5A** (4): 243–252.

22. LUXFORD, R. F. (1931) Effect of extractives on the strength of wood. *J. Agric. Res.* **42**: 801–826.

23. MACLEAN, J. D. (1952) Preservative Treatment of Wood by Pressure Methods. Agric. Handbook U.S. Dep. Agric. No. 40.

24. MARKWARDT, L. J. and WILSON, T. R.C. (1935) Strength and related Properties of Woods grown in the United States. Tech. Bull. U.S. Dep. Agric. No. 479.

25. METCALF, C. R. and CHALK, D. (1950) Anatomy of the Dicotyledons. University Press, Oxford.

26. NAJERA ANGULA, F. *et al.* (1957) Estudios referentes a la desecacion artificial y aplicaciones de la madera de los *Eucalyptus camaldulensis* y *globulus. An. Inst. For. Invest. Exp.*, Madrid, **2**: 97–121.

27. NEUMANN, H. (1945) Report on Tests of Cypress, Pine, and Eucalyptus Wood. Inst. Rep. Materials Testing Laboratory, Technion, Haifa No. 2452.

28. NEWLIN, J. A. and WILSON, T. R. C. (1919) The Relation of the Shrinkage and Strength Properties of Wood to its Specific Gravity. Bull. U.S. Dep. Agric. No. 676.

29. NIKITIN, N. I. *et al.* (1949) Study of the chemical composition of oak wood as influenced by the type of forest. *Zh. prikl. Khim. Leningr.* **22** (1): 67–78. (Russian).

30. PANKEVICIUS, E. R. (1961) Recoverable collapse in wood. *For. Prod. J.* **11** (3): 131–132.

31. STAMM, A. J. (1936) Colloid Chemistry of Cellulosic Materials. Misc. Publ. U.S. Dep. Agric. No. 240.

32. STEWART, A. M. and KLOOT, N. H. (1957) The Mechanical Properties of Australian, New Guinea, and other Timbers. Bull. Counc. Sci. industr. Res. No. 279.

33. TOKER, R. (1952) Turkiyede okaliptus (*E. rostrata*) un maden diregi bakimindan teknik ozellikleri hakkinda arastirmalar. *Istanbul Univ. Orm. Fak. Derg.* **2A** (1): 126–152.

34. URQUHART, A. R. and WILLIAMS, A. M. (1924) *J. Textile Inst.* **15** (T. 138), as cited by STAMM, A. J. (1952) Surface properties of cellulose materials, in Wood Chemistry, Vol. 2, 2nd edition, by WISE and JAHN, New York.

35. WANGAARD, F. F. (1950) The Mechanical Properties of Wood. John Wiley, New York.

36. ———(1951) Tests and Properties of tropical woods. *Proc. For. Prod. Soc.* **5**: 206–214.

37. ———and MUSCHLER, A. F. (1952) Properties and uses of tropical woods. PART III. *Trop. Woods* **98**: 1–190.

38. WANGAARD, F. F., STERN, W. L. and GOODRICH, S. L. (1955) Properties and uses of tropical woods. PART V. *Trop. Woods* **103**: 1–139.

39. WILSON, T. R. C. (1932) Strength-Moisture Relations for Wood. Tech. Bull. U.S. Dep. Agric. No. 282.

40. ZAVARIN, E. (1958) The extraneous substances of incense cedar. Bull. Calif. For. & For. Prod. No. 5.

קונטרס זה הוא החמישי בסידרת פירסומים על מחקר בייעור ובמוצרי־יער. ארבעת הפירסומים הקודמים נדפסו בחוברת "אילנות", אשר הופעתה נפסקה עם העברת יחידת המחקר של המכון לחקר־הייעור ממשרד־החקלאות למכון הלאומי והאוניברסיטאי לחקלאות.

קונטרסים המטפלים בנושאי ייעור יופיעו מדי פעם בפעם בסידרה זו.

16. באיזור הלבנה חלה ירידה ניכרת בהתכווצות עם העלייה לגובה. מאידך, באזורי העצה ההתכווצות איננה משתנה הרבה עם הגובה.

17. כשאין התמוטטות, ערכי ההתכווצות הנפחית, המשקית, והראדיאלית דומים ביותר לערכים שהתקבלו ממדידות באוסטראליה ובתורכיה.

18. ההתמוטטות מישתנה מ־0 עד 20 אחוז (בנפח), והיא חזקה ביותר בחלק המרכזי של העצה

19. ההתמוטטות נוטה לרדת עם העלייה במישקל הסגולי.

# מסקנות

1. למרות שיש הבדלים בולטים בתנאים שבאזורי־הגידול ובקצב־הגידול של אקליפטוס המקור הרי התכונות הפיסיות והמכאניות של העץ המקומי הן כמעט זהות לאלו של העץ האוסטרלי.

2. השונות בתוך העצים או ביניהם, באותו איזור־גידול שווה ואולי אף גדולה מהשונות שבין אזורי הגידול.

3. יחסי החוזק בין עץ יבש לעץ לח (ירוק) בטיפוס המקומי, ניתנים להשוואה מבחינת סדרי־הגודל, לעצים בצפון ובדרום אמריקה.

4. התכונות המכאניות בגבהים שונים בתוך העץ עצמו ובאותן טבעות־גידול, אינן משתנות באופן מובהק.

5. השתנות התכונות המכאניות מן הליבה אל הקליפה, היא בולטת ביותר בבולים שמקורם בבסיס הגזע. איזור „הלב הפריך" ("brittle heart") הכולל 15 אחוז משטח החתך, הוא בעל תכונות־חוזק נמוכות ביותר.

6. כל תכונות החוזק של הלבנה נמוכות בערך ב־2 עד 6.5 אחוזים מאלו של העצה הסמוכה אליה.

7. מלבד בחוזק ההתקשרות המקביל למערכת הסיבים, אקליפטוס המקור הוא חלש יותר בכל תכונות החוזק שלו מאשר הערכים הממוצעים של תכונות עצי עלים (דיקוטילדונים) בעלי אותה צפיפות.

8. החלק המרכזי של העצה שבבסיס העץ הוא בעל מישקל סגולי נמוך, ובעל תכולת רטיבות והתכווצות נפחית כללית גבוהות.

9. בהשוואה לעצה הסמוכה, הלבנה היא בעלת מישקל סגולי נמוך, ובעלת תכולת רטיבות והתכווצות נפחית כללית גבוהות.

10. אחוזי הרוויה, כלומר היחסים שבין תכולת הרטיבות הקיימת לתכולת הרטיבות המאכסימאלית, הם אחידים למדי מן הליבה עד לקליפה.

11. קיימת ירידה במישקל הסגולי עם העלייה לגובה באיזור הלבנה, אולם לא באיזור העצה. ההבדל הזה בין הלבנה והעצה, נובע מהצטברות בלתי־שווה של חומרי־מיצוי (טאנין ואחרים) מן הבסיס עד לקצה העץ.

12. ישנה ירידה בתכולת הרטיבות בכל טבעות הגידול, עם העלייה לגובה.

13. אחוז הרוויה באיזור הלבנה הוא אחיד עם העלייה לגובה, אולם חלה בו ירידה ניכרת באיזור העצה.

14. למרות ההשתנות הניכרת במישקל הסגולי של העץ החי, בערך 83 אחוזים מנפח החללים בעצה מלאים מים.

15. ההתכווצות הנפחית מן העץ הירוק המקומי אל העץ המיובש בתנור, היא בערך שלוש חמישיות מזו של עצים צפון אמריקאיים בעלי אותו מישקל סגולי.

# תקציר

עבודה זו היא אחת מתוך סדרה העוסקת בחקר תכונותיהם של עצים מקומיים ואפשרויות השימוש בהם.

אי הכרת התכונות הטכניות של אקליפטוס המקור מהיר־הגידול בדרגות צמיחתו השונות הגביל את השימוש בעץ זה. לשם תיכנון ארוך־טווח של היערות וניצולם היעיל, מן הדין להכיר את תכונותיו המכאניות של האקליפטוס ויחסיהן לתכונותיו הפיסיות. כן יש ללמוד את הרכבו הכימי ופוטנציאל התאית שלו.

עץ האקליפטוס בכלל ומין זה בפרט קשים לטיפול ולעיבוד ולפיכך יש עניין בקביעת השוניות בתוך הגזע או בין אזורי הגידול יותר מאשר בקביעת ממוצעים אופיינים לתכונותיו של המין. כן רצוי לדעת אם יש להתחשב בשוניות העץ בעת קביעתן של שיטות הניסור ומהן שיטות הייבוש המתאימות למטרות השונות להן נועד העץ.

מפירסומי המכון הלאומי והאוניברסיטאי לחקלאות, סידרת 1961, מס׳ 419.
התקבל במערכת באוגוסט 1961.

תוספת ל„כתבים",
כתבי המכון הלאומי והאוניברסיטאי לחקלאות

המחלקה לפירסומים, בית־דגן, חשון תשכ"א,
אוקטובר, 1961

נדפס בדפוס הממשלה

מדינת ישראל
משרד החקלאות

האוניברסיטה העברית
בירושלים

המכון הלאומי והאוניברסיטאי לחקלאות

קונטרס ס"ו

# התכונות הפיסיקאליות והמכאניות של אקליפטוס המקור

## *EUCALYPTUS CAMALDULENSIS* DEHN.

מאת
מ. צ'דנוב

המחלקה לפירסומים
חשון תשכ"ב - אוקטובר 1961

מדינת ישראל
משרד החקלאות

האוניברסיטה העברית
בירושלים

המכון הלאומי והאוניברסיטאי לחקלאות

קונטרס ס"ו

# התכונות הפיסיקאליות והמכאניות של אקליפטוס המקור

# *EUCALYPTUS CAMALDULENSIS* DEHN.

מאת
מ. צ'דנוב

המחלקה לפירסומים
חשון תשכ"ב - אוקטובר 1961