SOME WOOD PROPERTIES OF PLANTATION PINES, *PINUS CARIBAEA* AND *PINUS OOCARPA*[1]

H. Resch and *K. Bastendorff*

Professor and Technical Assistant, Department of Forest Products, School of Forestry, Oregon State University, Corvallis, OR 97331

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ABSTRACT

Pinus caribaea and *Pinus oocarpa* plantations in Brazil provided test trees from 4 to 17 years old. Wood of *Pinus oocarpa* exhibited slightly higher stiffness and bending and compression strengths than that of Caribbean pine. Increasing age was correlated with increases in these mechanical properties, and, in many cases, specific gravity.

Patterns of wood density distribution were determined by X-ray and water-displacement methods within cross sections from different heights of trees. In both species, tracheid length increased steadily with age and was greater in latewood than in earlywood.

Keywords: *Pinus caribaea*, *Pinus oocarpa*, plantation pines, bending strength, compression strength, stiffness, specific gravity, tracheid length, age relationships, modulus of elasticity, modulus of rupture.

INTRODUCTION

Among the conifers, the genus Pinus is the most widely distributed. In the western hemisphere, two pines occupy the southernmost part of the range of natural distribution of coniferous trees. *Pinus oocarpa* Schiede ranges from Sonora and Chihuaha in Northern Mexico to Central America and from an altitude of 1,900 ft to 8,100 ft. Trees extend from the mountains to the lowland of Lake Nicaragua. *Pinus caribaea* Morlet grows along the Caribbean coasts of Honduras, Guatemala, Nicaragua, and the Bahama Islands, in contrast to most Central American pines that grow in the mountains. Trees reach an altitude of about 3,000 ft (Mirov 1967).

Originally, no pines of the American continent were found south of the equator. In recent times, however, man expanded pine forests mainly in the southern hemisphere. Today, nearly 5 million acres are covered with planted pine forests in South America, South Africa, Australia, and New Zealand.

In a world symposium on man-made forests and their industrial importance, the Food and Agricultural Organization of the United Nations brought together pertinent information on the choice of pines for lowland tropical sites (Lamb 1968) and the utilization of the wood of low-altitude tropical pines (Hughes 1968).

Since that time, some attention has been directed toward the physical properties of wood obtained from plantation pines (Kukachka 1969). Focus was mainly on Caribbean pines. Boone and Chudnoff (1972) found a large amount of compression wood in 8- to 10-year-old trees in Puerto Rico. Bower et al. (1976) found

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bending strength, modulus of elasticity, and specific gravity alarmingly lower in trees from plantations in Brazil.

Because of government incentives, many pine plantations have been established in Brazil, and many approach the desired rotation age. Knowledge of physical wood properties of these trees, therefore, became important.

OBJECTIVES

The objectives were to determine the specific gravity (SG), ring count (RC), moduli of elasticity (MOE) and rupture (MOR) in static bending, fiber stress at the proportional limit (FSPL) and load in compression perpendicular-to-the-grain at one-tenth-inch deformation (COMP).

Further, the relationship of these physical properties with location, species, age, height (HEIT), and diameter at breast height (DBH) of sample trees was to be analyzed.

Additional objectives were to determine the patterns of wood density distribution within annual rings, by means of X-ray densitometry, as well as distributions of tracheid length in a few samples.

MATERIALS AND PROCEDURES

During a thinning operation in the early part of 1976, *Pinus oocarpa* and *Pinus caribaea* trees were cut in the provinces of São Paolo and Minas Gerais in Brazil. The plantations were near the towns of Freudenberg (Monte Alegro) and Bugre.

Forty-inch-long bolts were obtained from different heights within each tree. The bolts were air-freighted for rapid sample preparation. First, 2-inch-thick cross sections were cut from different heights within trees. After being conditioned to 12% moisture content, samples extending from bark through the pith to bark, 12 mm high and 50 mm wide, were sawn from the disks for X-ray densitometry.

From the remaining bolts, specimens for bending and compression tests were obtained, kiln-dried to 12% moisture content at 120 F, and then surfaced in accordance with specifications for testing of various physical properties.

Bending test specifications ASTM D-143:45–52 (1976) were followed as closely as possible. Specimens, 30 inches long, 2 inches wide, and 2 inches thick, were center-loaded with a span of 28 inches. Not all bending specimens could be prepared to contain entirely clear wood. Some had knots near the supports and away from the center span. These samples were tested and analyzed in a separate group.

Compression tests were carried out in accordance with ASTM D-143:77–82. Loads were applied to the radial surface.

Specific gravity and moisture contents were determined from a single 2- × 2- × 1-inch section from each broken bending sample (U.S. Forest Products Laboratory 1974). The ring count was performed on the same samples. In addition, we determined the wood density distribution within and between annual rings by X-raying wood samples, using a method and apparatus developed by Echols (1970). The negatives were analyzed with a densitometer that produced chart tracings representing the wood density variations. Wood uniformity was assessed numerically by expressing the density distribution in a sample by means of a single

TABLE 1. *Comparison of average values of specific gravity, stiffness, and bending strength of plantation pines with conifers of the United States.*

Species	Location	Data source[a]	Tree age[b] (years)	Specific gravity[c]	MOE[d] (10^6 psi)	MOR[d] (psi)
Pinus oocarpa Schiede	Bugre, Brazil	OSU	5	0.42	0.67	5,100
	Freudenberg, Brazil	OSU	4	0.41	0.73	8,190
	Freudenberg, Brazil	OSU	10	0.44	0.97	9,490
	Freudenberg, Brazil	OSU	15	0.45	1.31	10,640
	Honduras	USFS	*	0.55	2.25	14,900
Pinus caribaea Morlet	Bugre, Brazil	OSU	5	0.36	0.54	4,810
	Freudenberg, Brazil	OSU	4	0.36	0.52	5,180
	Freudenberg, Brazil	OSU	10	0.38	0.73	6,970
	Freudenberg, Brazil	OSU	17	0.44	1.25	10,910
	Viscosa, Brazil	Purdue Univ.	5	0.35	0.53	4,773
	Puerto Rico	USFS	10	0.38	0.92	8,830
	Central America	USFS	*	0.68	2.03	15,200
Pinus palustris Mill.	South East, United States	USFS	*	0.54	1.98	14,500
Pinus elliottii Engelm.	South East, United States	USFS	*	0.54	1.98	16,300
Pseudotsuga menziesii (Mirb.) Franco	West Coast, United States	USFS	*	0.45	1.95	12,400
Tsuga heterophylla (Raf.) Sarg.	West Coast, United States	USFS	*	0.42	1.64	11,300

[a] OSU is Oregon State Univ. Corvallis, OR; USFS is USDA For. Serv.
[b] * is assumed to be from mature trees.
[c] Green volume and oven-dry weight.
[d] At 12% moisture content.

uniformity number (Echols 1972). With the mean density as a base, the percentage of wood in each 0.05-density class above and below the mean was multiplied by weighting factors, 1, 2, 3 . . . n, then added to the percentage of wood in the class containing the mean. The result is a combined number, the distribution coefficient, derived from the relative distribution of wood in all density classes. The number 100 indicates uniform, virtually homogeneous wood (with density variation ± 0.05).

Changes in fiber length were determined on disks from butt logs at a height of about 3.5 ft, one from a 17-year-old *Pinus caribaea,* and one from a 15-year-old *Pinus oocarpa,* both grown at Freudenberg. Matchstick-size pieces were cut with a razor blade, subsequently macerated with acetic acid and sodium chlorite (Wilson 1951). The tracheids were stained with acid fuchsin for better visibility.

For each growth ring, from year 7 to 17 for the *Pinus caribaea* and from year 5 to year 15 for the *Pinus oocarpa,* ten earlywood and ten latewood tracheids were measured at random and regression equations calculated. Because growth rings of earlier years were not that distinct, we only recorded and averaged fiber length values at the pith.

RESULTS AND DISCUSSION

Table 1 summarizes the physical properties of the investigated trees and contrasts them with those of the same species studied by other investigators on other sites and with several major commercial conifers of the United States.

At Bugre and Freudenberg, *Pinus oocarpa,* with about the same average ring count, showed higher physical properties than *Pinus caribaea,* with the exception of diameter at breast height (Table 2). *Pinus caribaea* appeared to have produced a larger amount of wood fiber as expressed by the product of diameter at breast height and specific gravity. An accurate calculation of total fiber mass produced, however, needs inclusion of the form factor of trees and their height at a specific age.

Pinus oocarpa, on the other hand, may have a slightly greater potential for structural uses because of higher strength and stiffness of clear wood. A final conclusion on this, however, can only be drawn when sizes and patterns of knots and other characteristics have been determined in the two species. To derive working stresses for structural lumber, the clear wood values must be reduced according to frequency and location of such characteristics.

Relationships statistically significant at the 95% confidence level are expressed numerically in the form of multiple and simple straight line regression equations (Table 2). These equations may be interpreted as follows:

(1) Age certainly influences diameter at breast height. When all age classes were combined for the analyses, increasing age was correlated with increasing modulus of elasticity in static bending and compression strength. For *Pinus caribaea,* a positive relationship was also proven between age and specific gravity.

(2) Diameter at breast height showed a positive relationship with modulus of elasticity when data from both locations, both species, and all age classes were combined for analysis. Diameter growth increased more with age for *Pinus oocarpa* than for *Pinus caribaea.*

(3) Specific gravity proved to be a good predictor for many other properties.

TABLE 2. *Statistically significant relations of physical properties of plantation pines with location, species, age, HEIT, and DBH.*

Physical properties	Location[a]	Species *Pinus*[b]	Age class		Regression equations	r^2
DBH, inches	F	*o*	All	=	3.446 + 4.224 E-1 AGE	0.63
	F	*c*	All	=	4.064 + 4.032 E-1 AGE	0.54
SG	B + F	*o* + *c*	All	=	0.2315 + 9.861 E-1 COMP + 5.876 E-8 MOE	c
	B	*o* + *c*	5	=	0.1213 + 2.092 E-3 COMP	0.67
	F	*o* + *c*	10	=	0.1812 + 1.249 E-4 COMP + 8.621 E-8 MOE	c
	B + F	*o* + *c*	All	=	0.3575 + 7.695 E-3 DBH	0.13
	B + F	*o* + *c*	All	=	0.3924 + 2.226 E-2 PITH	0.16
	B + F	*o* + *c*	All	=	0.3877 + 1.1718 E-2 RC	c
	B	*o* + *c*	5	=	0.4400 − 2.0750 E-2 RC	c
	F	*c*	All	=	0.3436 + 2.3137 E-2 RC	c
	F	*c*	All	=	0.3172 + 7.271 E-3 AGE	0.27
	F	*o*	All	=	0.3982 + 3.663 E-3 AGE	0.17
MOE, psi	B + F	*o* + *c*	All	=	9.848 E5 + 4.757 E3 HEIT	0.03
	B + F	*o* + *c*	All	=	3.588 E5 + 7.826 E4 DBH	0.26
	B + F	*o* + *c*	All	=	−1.156 E6 + 5.191 E6 SG	0.51
	B + F	*o* + *c*	All	=	7.422 E5 + 2.084 E5 PITH	0.26
	F	*o* + *c*	10	=	2.618 E4 + 2.011 E6 SG	0.25
	F	*o*	All	=	4.173 E5 + 5.980 E4 AGE	0.51
	F	*c*	All	=	1.349 E5 + 6.533 E4 AGE	0.51
MOR, psi	B + F	*o* + *c*	All	=	1.780 E3 + 8.211 E2 DBH	0.32
	B + F	*o* + *c*	All	=	−8.542 E3 + 4.128 E4 SG	0.63
	B + F	*o* + *c*	All	=	5.878 E3 + 1.882 E3 PITH	0.35
	F	*o* + *c*	10	=	9.451 E2 + 1.614 E4 SG	0.25
	F	*c*	All	=	2.115 E3 + 5.175 E2 AGE	0.54
FSPL, psi	B + F	*o* + *c*	All	=	−2.901 E2 + 1.945 E3 SG	0.50
	B + F	*o* + *c*	All	=	4.960 E2 + 2.756 E1 PITH	0.04
	F	*o* + *c*	10	=	−1.153 E2 + 1.545 E3 SG	0.37
COMP, psi	B + F	*o* + *c*	All	=	−4.256 E2 + 4.152 E3 SG	0.57
	B + F	*o* + *c*	All	=	1.225 E3 + 7.537 E1 PITH	0.07
	B	*o* + *c*	5	=	5.321 E1 + 3.185 E3 SG	0.67
	F	*o* + *c*	10	=	−3.571 E2 + 3.942 E3 SG	0.51

[a] F is Freudenberg and B is Bugre.
[b] *o* is *oocarpa*, *c* is *carbaea*.
[c] Undetermined.

The higher the specific gravity, the higher the compression strength, and in some instances, the modulus of elasticity. Specific gravity increased with an increase in DBH, distance from the pith (PITH) and, therefore, age. Except for the 5-year-old trees at Bugre, specific gravity was higher when the ring count increased.

(4) Modulus of elasticity in bending proved to be higher in samples taken at a greater height in the tree. It further increased with an increase in DBH, specific gravity, distance from the pith, and age.

(5) Modulus of rupture in static bending increased with an increase in DBH, specific gravity, distance from the pith, and therefore, age.

(6) Fiber stress at proportional limit in compression showed a significant in-

TABLE 3. *Density distribution within plantation pines.*

Species	Number of trees	Age of tree (years)	Height within tree (feet)	Average specific gravity	Average distribution coefficient
Pinus caribaea	4	17	0.5	0.42	217
	5	17	3.8	0.42	225
	5	17	7.2	0.42	215
	4	17	10.5	0.41	210
	2	17	13.8	0.40	164
	1	17	17.2	0.38	148
	5	10	0.5	0.38	160
	5	10	3.8	0.37	154
	5	10	7.2	0.38	135
	13	4 + 5	0.5	0.35	118
	5	4 + 5	3.8	0.36	117
Pinus oocarpa	5	15	0.5	0.41	170
	5	15	3.8	0.42	187
	5	15	7.2	0.40	166
	5	15	10.5	0.41	162
	5	10	0.5	0.44	180
	5	10	3.8	0.40	163
	5	10	7.2	0.42	149
	9	5	0.5	0.40	129
	2	5	3.8	0.40	127

crease with increases in specific gravity and distance from the pith. So did compression strength expressed as load at one-tenth-inch deformation, as one might expect.

Values for physical properties obtained by Purdue University researchers on 5-year-old Caribbean pines (Bower et al. 1976) and by investigators of the U.S. Forest Products Laboratory (1974) on 10-year trees were similar to our data. Strong indications are that neither *Pinus oocarpa* at 15 years of age nor *Pinus caribaea* at 17 years has reached full maturity in the sense of attaining the density, stiffness, and bending strength of trees grown in Central America. Neither have the plantation pines reached the strength and stiffness of the United States species listed in Table 1.

Distribution coefficients for specific gravity given in Table 3 express uniformity, or if viewed in another way, the magnitude of density variation within the cross section. The lower the distribution coefficient, the more uniform or the more homogeneous is the wood. High distribution coefficients, especially when coupled with high specific gravity, indicate a more pronounced formation of latewood. Although young trees in the 4- and 5-year classes exhibited the least variation, older trees, from 15 to 17 years of age, showed the greatest variability. Such variability was not always because of "true" annual rings, but sometimes because of the formation of "false" rings that could be seen from individual density tracings.

Patterns of wood density distributions (Table 3), determined by X-rays, substantiated the findings of the specific gravity determined by the water displace-

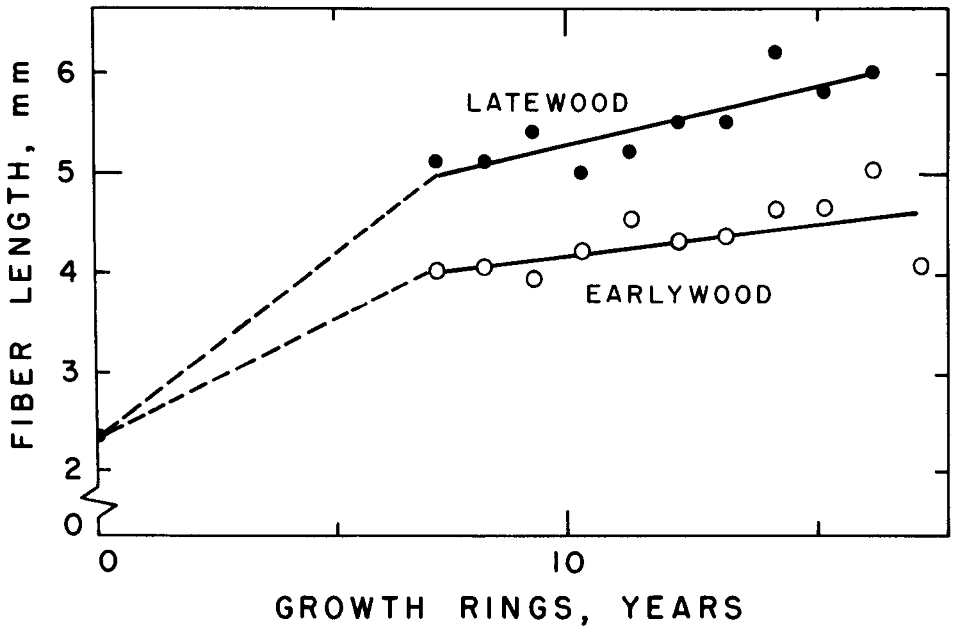

FIG. 1. Lengths of tracheids in a *Pinus caribaea*.

ment method. In comparing the two methods of density determination, one should note that on an average, the X-ray method gives values lower by about 0.02 grams per cubic centimeter than the displacement method.

At Freudenberg, wood from 5-year-old trees of both species showed much lower density than that of older trees, which was expected because conifers form

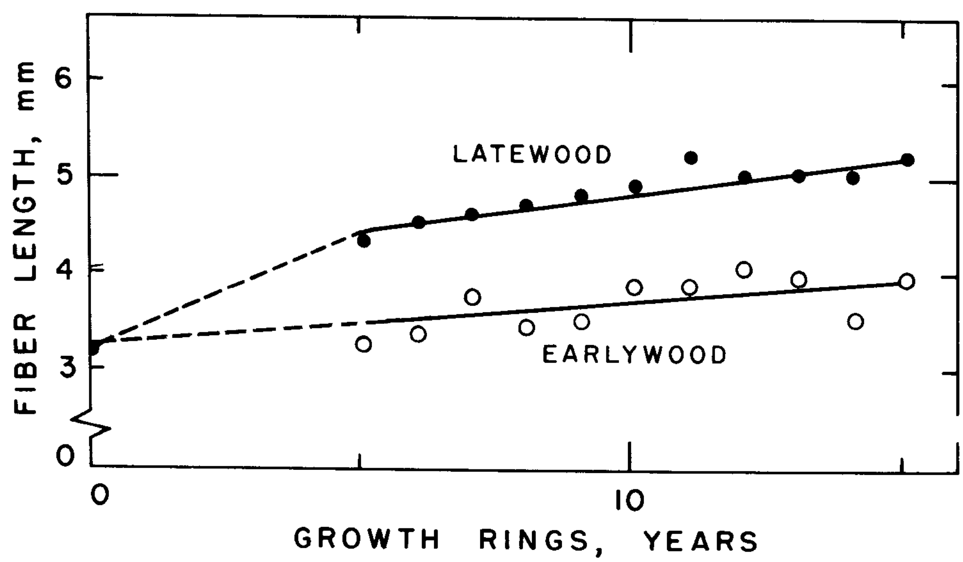

FIG. 2. Lengths of tracheids in a *Pinus oocarpa*.

low-density juvenile wood in early years of development. Within the same age classes, *Pinus oocarpa* shows slightly higher density values than *Pinus caribaea*.

Within older trees, a lower specific gravity is usually expected with increasing height. However, this pattern was not consistent throughout. Lower specific gravity, probably associated with juvenile wood formation, occurred in a number of bolts nearest the ground, but some trees showed an irregular pattern.

The lengths of tracheids increased steadily with increasing age for both the sampled *Pinus caribaea* and *Pinus oocarpa*. The regression lines in Figs. 1 and 2 are based on the recorded mean values for the range from 5 to 17 years. At a given age, tracheids of *Pinus caribaea* were generally longer than those of *Pinus oocarpa*. Within species, tracheid lengths were greater in latewood than in earlywood. Indistinct growth rings formed during the first five years of growth did not permit association with fiber length. All fiber length measurements taken near the pith were averaged and are shown as single values.

REFERENCES

AMERICAN SOCIETY OF TESTING AND MATERIALS (ASTM). 1976. Annual Book of ASTM Standards, Part 22, D7. Philadelphia, PA.

BOONE, R. S., AND M. CHUDNOFF. 1972. Compression wood formation and other characteristics of plantation-grown *Pinus caribaea*. Inst. Trop. Forestry, U.S. For. Serv. Res. Paper ITF-13.

BOWER, R. W., A. DESUZA, AND J. F. SENFT. 1976. Physical and mechanical properties of fast-grown plantation Caribbean pine (*P. caribaea*) from Brazil, South America. Purdue Univ. Res. Bull. 936. Lafayette, IN.

ECHOLS, R. M. 1970. Moving-slit radiography of wood samples for incremental measurements. Pages 34–36 *in* J. H. G. Smith and J. Worrall, eds. Tree-ring analysis with special reference to North America. Univ. B.C. Fac. Forestry, Bull. 7, Vancouver, Canada.

———. 1972. Patterns of wood density distribution and growth rate in ponderosa pine. Proc. Symp. Effect of Growth Acceleration on Properties of Wood. Madison, WI. 1971:H1–H16.

HUGHES, J. F. 1968. Utilization of the wood of low-altitude tropical pines. *In* FAO World Symp. Man-made forests and their industrial importance. FAO, Rome, Italy.

KUKACHKA, B. F. 1969. Properties of imported tropical woods. Paper SC-5/TH-5 (6): Proc. of the Conference on tropical hardwoods. State Univ. Coll. For. Syracuse Univ., Syracuse, NY.

LAMB, A. F. A. 1968. Choice of pines for lowland tropical sites. *In* FAO World Symposium on man-made forests and their industrial importance, FAO, Rome, Italy.

MIROV, N. T. 1967. The genus Pinus. The Ronald Press Company, New York, NY.

U.S. FOREST PRODUCTS LABORATORY. 1974. Wood handbook: wood as an engineering material. USDA Agriculture Handbook #72. Superintendent of Documents, U.S. Government Printing Office, Washington, DC.

WILSON, J. W. 1951. An outline of microtechnique methods for the wood technologist. Univ. B.C. Fac. For., Vancouver, Canada.