STRENGTH AND RELATED PROPERTIES OF BISHOP PINE II. PROPERTIES OF JUVENILE WOOD FROM YOUNG STEMS OF VARIOUS PROVENANCES[1]

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ABSTRACT

Thinnings from a provenance trial of Bishop pine, including some Monterey pine, planted in 1969, were taken in 1974 (17 stems) and 1982 (8 stems). Specific gravity and strength properties of the thinnings were lower than juvenile wood of mature trees tested previously. This could be attributed to very large fibril angles (over 40 degrees) which were found in both Bishop and Monterey pine. These morphological features in turn are thought to be the consequence of site conditions, such as the close proximity to the ocean. There appeared to be no major differences between the four races of Bishop pine, namely Southern Bishop, Central Bishop, Northern Bishop, and Island pine. Southern Bishop appeared to be least strong and Northern Bishop highest in strength, but the replications in these races were few.

Keywords: Bishop pine, Monterey pine, *Pinus muricata, Pinus radiata,* chemical composition, fibril angle, fiber length, bending strength, modulus of elasticity, compression strength, specific gravity, provenance.

INTRODUCTION

In the first part of this study (Schniewind and Gammon 1980), the strength and related properties of mature Bishop pine were investigated. The material was obtained from two locations in Mendocino County and a third location in Humboldt County, and therefore was of the "Blue Race," also known as Northern Bishop pine. The results indicated that Bishop pine has strength properties that are generally comparable to those of ponderosa pine, but in some respects Bishop pine compares favorably to Douglas-fir, as for instance in bending strength in the air-dry condition.

The work to be reported here represents an attempt to evaluate the mechanical properties of the juvenile wood of thinnings from a provenance trial of Bishop pine, to determine if possible differences between provenances might be manifest at an early stage. The work of Pearson and Ross (1984) and Talbert et al. (1983) indicates that this is a strong possibility.

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SOURCE OF MATERIAL

The material for this part of the study consisted of thinnings from a plantation of mostly Bishop pine but including some Monterey pine, a closely related species. The trees originated from wind-pollinated seed lots from the W. J. Libby collection, grown in the 1968 nursery of the Institute of Forest Genetics, Placerville, California, and were planted in January 1969 (Passof 1974). Each population in that collection was represented by 25 mother trees (5 trees from each of 5 stands). Trees for the plantation were selected randomly from the populations, but extant plantation records only show population numbers.

The plantation, originally intended as a Christmas tree plantation but not maintained as such because of several changes in ownership, is located about 1 mile south of Fort Bragg, California, and ¼ mile east of the ocean. Originally sixty trees were planted with a spacing of 4 by 4 ft. They represented two populations of Monterey pine and ten of Bishop pine, the latter including two populations of southern Bishop pine, three of central Bishop pine, one of northern Bishop pine, and four of Island pine (cf. Shelbourne 1974).

Thinnings were taken in May 1974 and September 1982. In each case they were cut as close as possible to the ground, and the stems were shipped promptly to the Forest Products Laboratory, Richmond. The number of stems received was 17 from the 1974 thinning, and 9 from the 1982 thinning. One of the latter proved to be unusable because of a large scar 5½ ft long and extensive heart rot.

The trees from the first thinning in 1974 had an average DBH of 2.2 in. with a range of 1.0 to 3.0 in., and an average height of 13.4 ft with a range of 8 to 17 ft. The (8 usable) trees from the second thinning, which had had an average DBH of 2.6 in. and height of 13.4 ft in 1974, had an average DBH of 6.0 in. (ranging from 4.0 to 8.5 in.) and an average height of 34.1 ft (ranging from 23 to 46 ft) when they were cut in 1982.

EXPERIMENTAL METHODS

In the case of the first thinnings, as many 1- × 1-in. sticks as possible were cut from the first internode near the base. A cross-sectional disc was also taken near the base. The second thinnings were supplied in the form of the first 8-ft logs. Each log was cut into two or three 20-in. sections spanning long internodes, so that 1- × 1- × 16-in. static bending test specimans might be obtained. Two discs were cut at the base of each log, avoiding knot whorls, for specific gravity determinations. From each 20-in. section, a board 1¼ in. thick was taken through the pith from bark to bark, to be further cut into 1- × 1-in. sticks.

One of each pair of discs from the second thinning was trimmed to the inner core of the first five growth rings, to make them comparable to the discs from the first thinnings. All other discs were debarked and used for specific gravity determination of the entire cross section. Specific gravity measurements were made for all discs based on green volume and oven-dry weight.

The 1- × 1-in. sticks were cut into either 1- × 1- × 4-in. compression parallel to grain specimens or 1- × 1- × 16-in. static bending specimens. Specimens were tested in the green condition according to the applicable provisions of ASTM standard D143-52, Standard Methods of Testing Small Clear Specimens of Timber, Part II, Secondary Methods (ASTM 1974). For the material from the first thinnings, some compression parallel to grain tests were also made at a nominal moisture content of 12%. Because the material from the first thinnings was so very limited, some of the compression parallel to grain specimens were taken from the undamaged ends of previously tested static bending specimens.

In addition to the measurements on discs, specific gravity was also determined on samples taken from each of the static bending specimens from the first thinning, and from both static bending and compression specimens from the second thinning.

Samples were selected from one tree of each of the four races of Bishop pine and Monterey pine of the plantation material, and two trees of mature Bishop pine for determination of extractive and lignin contents, and for measurement of fiber length and fibril angle. Duplicate chemical analyses were made following the applicable provisions of Tappi standard T11 os-74 for sample preparation. The extraction was done according to Tappi standard T12 os-75, except that extraction was confined to 95% ethanol, omitting extraction with ethanol-benzene mixture. Acid-insoluble lignin was determined according to Tappi standard T222 os-74. Acid-soluble lignin was determined with a Beckman ACTA III spectrophotometer, as suggested in the standard.

Fiber length and fibril angle determinations of mature trees were made at radial positions near the pith, near the bark, and two intermediate locations, as well as at vertical positions at the stump and 16 ft above it.

Fiber length measurements were made by cutting samples into thin slivers and placing them into a macerating solution (Jeffrey's solution) overnight. Fibers were stained and mounted in glycerin on glass slides and projected on a flat screen. Fiber lengths were measured with a digitizer connected to a microcomputer. The number of fibers measured for each determination ranged from 34 to 92.

Fibril angle measurements were made following the method suggested by Leney (1981), which involves cutting thin, tangential sections followed by maceration. The resulting single cell walls of abundant cut cells can then be examined in polarized light and the fibril angle determined. Each determination is based on measurement of 20 fibers.

RESULTS AND DISCUSSION

Average values of specific gravity, and bending and compression test data are given in Table 1, along with values for mature wood. The difference between the values for juvenile wood and mature wood is striking, but a significant difference is to be expected based on experience with other pines (Zobel et al. 1972). As might also be expected, values for 1982 thinnings are intermediate to the other two groups. Although Monterey pine is not the principal object of this investigation, values for it are included because the results rather closely parallel those for Bishop pine. The number of trees, however, is too small to allow any independent conclusions regarding Monterey pine.

Pearson and Gilmore (1971) found for loblolly pine that juvenile wood and mature wood had comparable bending strength properties if adjustments are made for differences in density. In other words, the same regression of modulus of rupture or modulus of elasticity on specific gravity could be used, provided that material from the 5-ft-long butt logs was excluded. One difficulty with their finding

TABLE 1. *Some strength properties of juvenile and mature wood of Bishop and Monterey pines.*

Property	Bishop pine			Monterey pine		
	1974	1982	Mature[1]	1974	1982	Mature[2]
No. of trees	16[3]	6	15	1	2	6
Specific gravity[4]	0.33	0.40	0.45	0.32	0.40	0.46
Static bending (green)						
MOR (psi)	2,600	3,950	6,610	2,910	3,620	6,620
E (10^6 psi)	0.279	0.667	1.49	0.305	0.518	1.42
Compression strength						
Green (psi)	1,140	1,760	2,990	1,140	1,410	3,330
Air-dry (psi)	2,460	—	5,540	2,650	—	7,380

[1] Data from Schniewind and Gammon (1980), 2 × 2 specimens only.
[2] Data from Cockrell (1959).
[3] One tree too small (DBH 1 in.) for all but specific gravity measurements.
[4] Specific gravity, based on green volume and oven-dry weight, of bottom discs (except for mature wood).

is that the comparison between butt logs and upper logs was not based on the same population of trees, since only some of their study trees had both butt logs and upper logs represented, while some trees were represented by either only butt logs or only upper logs. However, their results suggest that factors other than density may affect differences between the properties of juvenile and mature wood. Variations in chemical composition and structural factors such as fiber length and fibril angle are part of normal variations from pith to bark and may affect strength properties. The most common pattern in softwoods is increasing fiber length and extractive content and decreasing lignin content and fibril angle from pith to bark (Panshin and de Zeeuw 1980).

TABLE 2. *Comparison of properties of mature wood and juvenile wood of mature and immature trees of Bishop pine.*

	Mature trees[1]		Immature trees[2]	
	Average	Juvenile wood	Test values	Predicted from regression[3]
Specific gravity[4]	0.45	0.41	0.33	—
Static bending (green)				
MOR (psi)	6,090	—	2,550	3,840
E (10^6 psi)	1.34	—	0.273	0.701
Compression strength				
Green (psi)	2,670	2,050	1,130	1,620
Air-dry (psi)	5,270	4,140	2,410	3,260[5]
Composition				
Extractives (%)	8.9	—	4.4	—
Lignin (%)	26.2	—	28.6	—
Structure				
Fiber length (mm)	3.5	1.4	1.6	—
Fibril angle (degrees)	25.3	32.2	41.3	—

[1] Trees of Part I of this study (Schniewind and Gammon 1980), 1 × 1 specimens only.
[2] Trees from 1974 thinning, excluding Island pine.
[3] Regressions as reported by Schniewind and Gammon (1980).
[4] Based on green volume and oven-dry weight. Values for mature trees are based on all specimens tested in green condition and for immature trees on the bottom disc.
[5] Specific gravity based on oven-dry weight and volume of 0.36, as estimated from value for green volume, used in the calculation.

TABLE 3. *Specific gravity and strength properties in the green condition for individual trees.*

Tree no.[1]	Pop. no.	Race	Spec. grav.[2]	Mod. rupt. (psi)	Mod. elast. (10^6 psi)	Compr. str. (psi)
A1	06	South. Bishop	0.330	2,640	0.272	1,240
A2	06	South. Bishop	0.329	2,480	0.268	1,050
D1	06	South. Bishop	0.329	2,270	0.223	1,130
A3	07	Central Bishop	0.314	2,670	0.205	1,400
A4	07	Central Bishop	0.298	2,150	0.215	930
A5	07	Central Bishop	0.335	2,910	0.282	1,420
D2	07	Central Bishop	0.374	3,200	0.404	1,370
A6	08	Central Bishop	0.357	2,080	0.178	800
A7	16	Central Bishop	0.306	2,350	0.259	1,070
A8	16	Central Bishop	0.319	2,270	0.301	960
A9	16	Central Bishop	0.353	2,730	0.266	1,210
D4	16	Central Bishop	0.416	4,020	0.828	1,880
A10	09	North. Bishop	0.325	—	—	—
A11	09	North. Bishop	0.338	3,250	0.483	1,200
D3	09	North. Bishop	0.426	3,870	0.476	1,430
B1	11	Island pine	0.331	2,380	0.274	1,200
B2	12	Island pine	0.309	3,090	0.310	1,340
B3	12	Island pine	0.316	2,420	0.266	900
B4	13	Island pine	0.321	2,730	0.327	1,240
B5	13	Island pine	0.336	2,770	0.275	1,160
E2	13	Island pine	0.402	3,050	0.416	1,560
E3	15	Island pine	0.437	4,320	0.588	1,840
F2	01	Monterey pine	0.378	2,400	0.277	1,150
C1	02	Monterey pine	0.318	2,910	0.305	1,140
F1	02	Monterey pine	0.355	3,330	0.370	1,260

[1] A, B, C Nos. cut 1974; D, E, F Nos. cut 1982.
[2] Based on green volume and oven-dry weight, first five rings of bottom disc only.

Initial examination of the strength data of juvenile wood from the 1974 thinnings caused considerable concern because the values appeared abnormally low for the specific gravity values obtained. This was the reason for choosing the unconventional sawing pattern for the mature trees tested for standard strength properties (Schniewind and Gammon 1980), so that values for compression parallel to grain of specimens containing the pith might be obtained from mature trees. Table 2 lists strength properties of mature trees, divided into average values as previously reported, and values for juvenile wood specimens, here defined as specimens containing at least a trace of pith. The immature trees listed in Table 2 include only the 1974 thinnings, because chemical analyses and measurements of fiber characteristics had been confined to that same material. Mature wood average values are for 1- × 1-in. specimens, in contrast to values in Table 1, to make the comparison more specific.

It may be seen that the juvenile wood from mature trees has higher density and higher strength properties than the juvenile wood from the 1974 thinnings, but that both are lower than average values for mature wood. If the regression equations previously reported are used to calculate predicted strength values for the juvenile wood of the 1974 thinnings based on their measured specific gravity, the predicted values are much higher than the experimental ones, as shown in Table

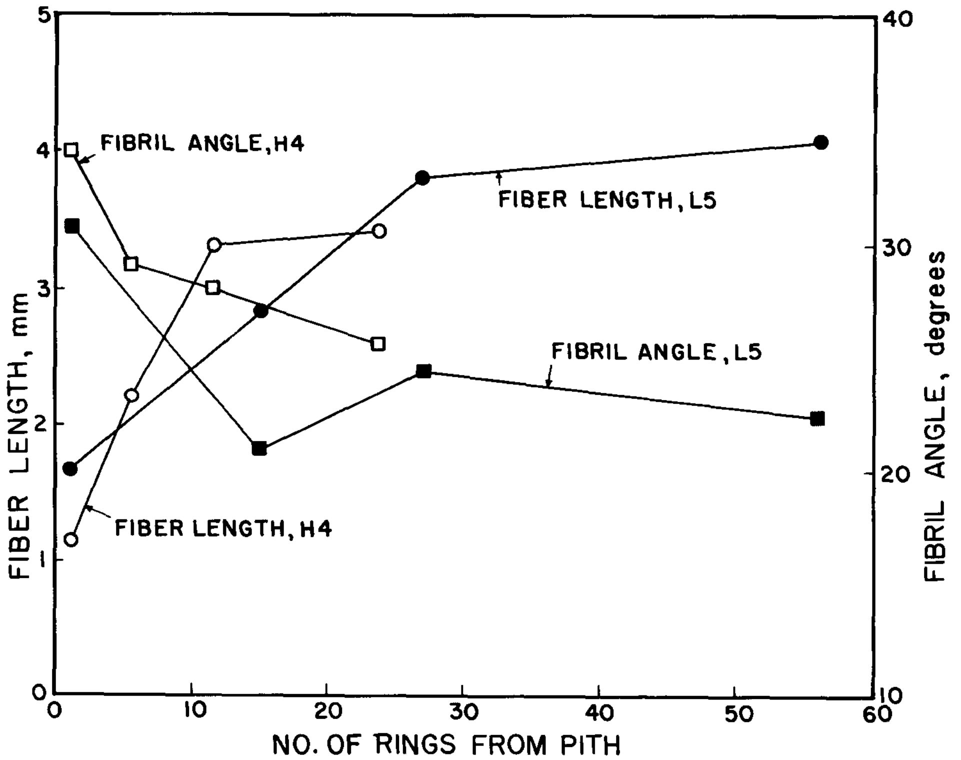

FIG. 1. Fiber length and fibril angle as a function of No. of rings from the pith for one mature tree each from Humboldt (H4) and Mendocino (L5) counties.

2. It is not likely that the observed differences in chemical composition, which do show the expected trend, can account for this discrepancy. However, the large differences in fiber length and fibril angle do offer an explanation, since particularly large fibril angles are associated with reduced strength and stiffness parallel to grain (Panshin and de Zeeuw, 1980). The discrepancies between predicted and experimental values of compression strength parallel to grain for the juvenile wood of the mature trees (the predicted values are 2,330 and 4,600 psi in the green and air-dry conditions, respectively) are not nearly as large, but neither is the fibril angle. The rather astonishingly low strength values of the 1974 thinnings can therefore be attributed to very large fibril angles. Large fibril angles were found in all samples tested from that site, including the one Monterey pine thinning of 1974 with an angle of 45.5 degrees. Since juvenile wood of very diverse provenances of Bishop pine and also one tree of Monterey pine all showed the large fibril angle, while juvenile wood of Bishop pine from other sites did not, there is a strong suggestion that site is responsible. A possible factor is the close proximity to the shore with strong prevailing winds from the ocean that can be observed to have a noticeable effect on tree shape.

Table 3 gives a listing of individual tree averages, and includes the population number and the race. Tree numbers starting with A, B, or C designate 1974 thinnings, while D, E, and F refer to those cut in 1982. Specific gravity measure-

TABLE 4. *Specific gravity and strength properties in the green condition of inner core juvenile wood (first five rings) of 1974 and 1982 thinnings.*

Property	Southern Bishop	Central Bishop	Northern Bishop	Island Pine	Monterey Pine
No. of trees	3	9	3(2)[3]	7	3
Specific gravity[1]	0.33	0.34	0.36	0.35	0.35
MOR (psi)[2]	2,460	2,710	3,560	2,970	2,880
E (10^6 psi)	0.254	0.326	0.480	0.351	0.317
Compr. str. (psi)	1,140	1,230	1,320	1,320	1,180

[1] Based on green volume and oven-dry weight, for first five rings of bottom discs.
[2] Mechanical properties of specimens containing pith or from its immediate vicinity.
[3] Strength properties for two trees only.

ments for all trees are based on the first five rings, and mechanical properties are based only on those specimens that either contained some pith or were located immediately adjacent to it, so that the data from both thinning dates should be comparable. Nevertheless, there appears to be a tendency towards higher values in the 1982 thinnings, on the average. It is possible that the selection for thinning produced a bias in wood properties. Since each race is represented by trees from both thinnings, this should not affect the results.

The variation of fiber length and fibril angle with distance from pith for two trees of mature Bishop pine, one from Mendocino and one from Humboldt County, has been plotted in Fig. 1. The data are not detailed enough to determine where the transition from juvenile wood to mature wood might be, but the expected trends of increasing fiber length and decreasing fibril angle from pith to bark are evident.

There are not sufficient replications to attempt comparisons of individual populations, but average values have been computed for each of the four races of Bishop pine and the Monterey pine, and these are shown in Table 4. Specific gravity values range from 0.33 to 0.36, and in view of the small number of trees represented in some of the races, it is difficult to attach much significance to the difference. The highest strength values are found in the Northern race, but unfortunately this potentially most important race is represented by only two trees as far as strength values are concerned. The lowest values are in the Southern race, which is represented by only three trees. On the whole, there appears to be little difference in wood properties between races that can be discerned in this material. The values for Monterey pine are also about the same as the average for all four races of Bishop pine. It would be interesting to examine the growth data not only of the thinnings but also of the trees remaining in the plantation; however, that is beyond the scope of this article.

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