STRENGTH AND RELATED PROPERTIES OF BISHOP PINE I. STRENGTH OF "BLUE RACE" BISHOP PINE FROM THREE LOCATIONS

Arno P. Schniewind and *Barry Gammon*

College of Natural Resources, Forest Products Laboratory, University of California, 47th Street & Hoffman Blvd., Richmond, CA 94804

(Received 14 January 1980)

ABSTRACT

Tests were made of mechanical properties, according to ASTM methods D143-52, of "Blue Race" Bishop pine from locations in Mendocino and Humboldt counties in California. Bishop pine was found to be equal in strength to coast-type Douglas-fir in some respects (modulus of rupture values at 12% moisture content of 12,900 and 12,400 psi, respectively, for Bishop pine and Douglas-fir) but to be more like ponderosa pine in other respects (maximum crushing strength parallel-to-grain at 12% moisture content of 5,540 and 5,320 psi, respectively, for Bishop pine and ponderosa pine). There were significant differences in strength according to location, which appeared to be due to site conditions rather than geographical location.

Keywords: *Pinus muricata*, strength, mechanical properties, shrinkage, specific gravity, static bending, compression parallel-to-grain, compression perpendicular-to-grain, tension parallel-to-grain, toughness, shear, cleavage, modulus of rupture, modulus of elasticity, hardness.

INTRODUCTION

Bishop pine (*Pinus muricata* D. Don) occurs in several widely separated locations ranging from Santa Rosa and Santa Cruz islands off the coast of southern California to Humboldt County in northern California (Sudworth 1908; Critchfield and Little 1966). The species exhibits considerable genetic variation and may or may not include a variety (*P. muricata* var. *cedrosensis*) growing on Cedros island off the coast of Mexico (Shelbourne 1974). According to Sudworth, Bishop pine is found in swamps and sandy plains in the coastal region, or on dry, sandy, or gravelly hills near the ocean. It reaches a height of 30 to 60 feet and a diameter of 12 to 20 inches, but larger trees 75 to 80 feet high and 24 to 36 inches in diameter can also be found.

In northern California, Bishop pine is cut for lumber on rare occasions. It is being considered as a species for planting in New Zealand, with the thought that because of its greater frost resistance it might be grown where radiata pine could not (Shelbourne 1974). The "Blue Strain" of Bishop pine that occurs from Annapolis in the northern part of Sonoma County northward is of primary promise in this connection. The Blue Strain populations also appear to be those that produce the largest trees.

Strength tests of native trees appear to be limited to two tests each in bending and compression of material from Marin County, a location that would place it in the "Green Strain" (Sargent 1884). Strength tests of plantation-grown material were made in New Zealand but are as yet unpublished (Shelbourne 1974).

The present work originally came about because a provenance trial of Bishop pine, originally designed as a Christmas tree plantation but later converted to a general plantation, was being thinned and we had occasion to examine some

Wood and Fiber, 12(2), 1980, pp. 131–141

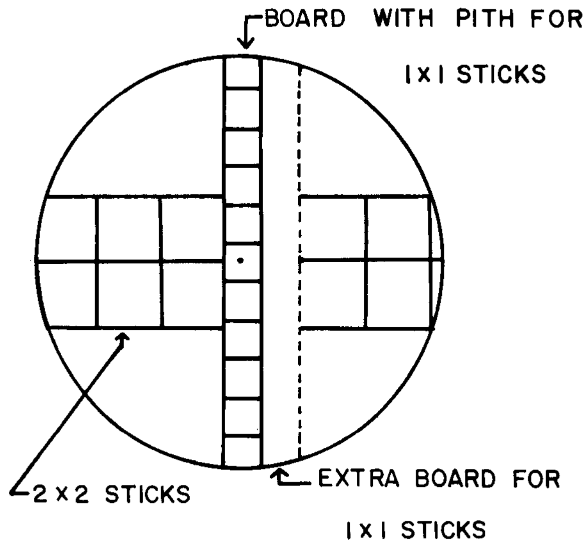

FIG. 1. Cutting plan for sample logs. First a board containing the pith is cut following the longest diameter, for cutting into 1- × 1-inch sticks (rough green size 1⅜ × 1⅜ inch). A second board was cut on a few of the larger logs only. Finally, 2- × 2-inch sticks (rough green size 2½ × 2½ inch) were cut in two rows perpendicular to the boards.

properties of 5-year-old stems. The results of some strength tests were rather astonishing. Since there were no data for comparison, Sargent's data being unsuitable because of the limited number of specimens, the primitive test methods, and the presence of defects in the samples, interest in developing a full set of strength data developed. Since there was potential of cutting Bishop pine for lumber in the North Coast counties, and since the species does seem to have potential for planting in many parts of the world, it was finally decided to go ahead with a full-scale determination of the strength properties of Bishop pine.

The results of the entire study are presented in two parts. The first deals with the standard strength properties, specific gravity, and shrinkage of wood from 10 trees in Mendocino and 5 in Humboldt counties. The second part (to be published later) presents the results of limited strength tests on 5-year-old stems of various provenances of Bishop pine grown in Mendocino county.

MATERIAL AND METHODS

Five representative trees were selected at each of three locations. Two of these were in Mendocino County, location G north of Navarro Head (Sect. 36, T16N, R17W) and location L near the town of Point Arena (Sect. 25 and 26, T12N, R16W). The third, location H, was in Humboldt County north of Trinidad Head (Sect. 36, T9N, R1W).

At locations G and L, DBH and tree height were measured and recorded, but this was inadvertently omitted at location H. However, DBH at location H had been measured to make sure it fell in the range from 12 to 18 inches, and the height range of the sample trees had been estimated. Trees were felled, the butt end was trimmed, and a cross-sectional disc was taken at the butt and at 16-ft

TABLE 1. *Tree characteristics and physical properties of Bishop pine.*

Parameter	Trees in location L	Trees in location G	Trees in location H	All trees
Age (based on ring count of basal disc)	60	56	26	
DBH (inches)	17	15	12–18	
Tree height (feet)	93	60	50–55	
Rings per inch[a]	8.7	9.8	3.6	7.4
Specific gravity, green volume basis				
Average of strength test samples	0.49	0.49	0.37	0.45
Average of discs[b]	0.47	0.48	0.39	0.45
Specific gravity, oven-dry volume basis				
Average of strength test samples	0.57	0.57	0.42	0.52
Average of discs[b,c]	0.53	0.56	0.44	0.51
Percent shrinkage, green to air-dry				
Radial	2.6	2.7	1.7	2.3
Tangential	4.5	4.6	4.4	4.5
Longitudinal	0.23	0.23	0.27	0.24
Volumetric	7.2	7.4	6.3	7.0
Percent shrinkage, green to oven-dry				
Radial	5.1	5.1	3.4	4.5
Tangential	8.2	8.1	7.6	8.0
Longitudinal	0.37	0.41	0.46	0.41
Volumetric	13.2	13.2	11.2	12.5

[a] Obtained from ring count and diameter of basal disc.
[b] Average tree specific gravity obtained by weighting the disc specific gravity by the square of the disc diameter.
[c] The specific gravity of each disc on the oven-dry volume basis was calculated using the formula: $SG_d = SG_g/(1 - 0.27^* SG_g)$, as based on an equation given by Siau (1971) assuming values of 1.115 for the specific gravity of the adsorbed water and 30% for the fiber saturation point.

intervals up to a minimum diameter of 4 inches inside bark. In addition to the discs, the first 8-ft log was removed for testing and all material was shipped immediately to the Forest Products Laboratory in Richmond, California.

Discs were stored in a cold room for approximately two weeks to prevent drying. Depending on size or the presence of knots, they were cut into wedges either to reduce size to fit the available equipment or to remove the knots. The specific gravity was then measured by weighing either the entire disc or the cut wedges in air and under water in the green condition, followed by oven-drying to determine the oven-dry weight.

Logs from G and L locations were sawn the day after felling; logs from location H were stored under sprinklers for two and a half months before sawing. The sawing pattern differed from the one given by ASTM D 143-52 (ASTM, 1975) as shown in Fig. 1. The reason for this variance was twofold: first, the logs were somewhat small, and difficulty in obtaining a sufficient number of static bending specimens of the 2- × 2-inch size was anticipated, and second, 1- × 1-inch specimen material was needed from the area surrounding the pith for comparison with the tests on 5-year-old stems. Thus, the pattern shown in Fig. 1 was adopted, and in addition the remaining quadrants were sawn into as many 2- × 2-inch and 1- × 1-inch sticks as could be obtained.

Before sawing, the 8-ft logs were divided into upper and lower 4-foot bolts.

TABLE 2. *Average tree specific gravity from discs based on green volume and oven-dry weight.*

Tree	Location		
	L	G	H
1	0.450	0.466	0.377
2	0.475	0.473	0.392
3	0.426	0.484	0.398
4	0.464	0.516	0.378
5	0.518	0.478	0.418
Mean	0.467	0.483	0.393

From each log, one half of the sticks from the upper bolt and one half from the lower bolt were selected at random for testing in the green condition, and the remaining sticks were placed into a 12% EMC humidity room for drying and conditioning. In this procedure the 2- × 2-inch and the 1- × 1-inch sticks were accounted for separately.

Specimen selection from the sticks and testing was done substantially according to ASTM D 143-52. However, compression parallel-to-grain and static bending tests were made on both 2- × 2-inch and 1- × 1-inch material. The impact bending test, tension perpendicular-to-grain test, and the nail withdrawal test were omitted. The standard specimens for the measurement of volumetric, radial, and tangential specimens were replaced by a single specimen 1 × 1 × 4 inches, where the 4-inch dimension extended in the direction parallel-to-grain. Radial, tangential, and longitudinal shrinkage were all measured on this specimen. Specific gravity was determined for each strength test specimen simultaneously with moisture content determinations.

RESULTS AND DISCUSSION

Some tree characteristics and physical properties of the wood are shown in Table 1, giving values for the three locations as well as overall average values. The trees in locations L and G (Mendocino County) were of similar age and DBH, but the trees at location L had the greater height growth. The trees at location H (Humboldt County) were much younger and had a much faster growth rate.

Similar differences are reflected in the specific gravity values. Taking the specific gravity based on green volume and oven-dry weight as determined from all test specimens tested in the green condition, the values are the same for locations L and G and the value for location H is considerably lower. As for shrinkage from green to oven-dry, the longitudinal shrinkage is about the same for all locations, while the radial and tangential shrinkage values are about the same at locations L and G, and lower values at location H for tangential and especially radial values. As tested on a tree-average basis, there was a negative correlation between average ring width and specific gravity width $R^2 = 0.83$.

According to the information collected by Shelbourne (1974), all of the sample material of this study should be of the northern or blue race, so that the observed differences are probably a matter of differences in site conditions.

Specific gravity averages were obtained by two methods: one by taking samples from each specimen tested for strength, which was thus sampling confined to the first 8-ft log above the stump; and the other by taking discs at intervals over the

TABLE 3. *Average strength and stiffness values by location and for all trees.*

Property[a]		Location L Green	Location L 12% M.C.	Location G Green	Location G 12% M.C.	Location H Green	Location H 12% M.C.	All trees Green	All trees 12% M.C.
1 × 1 C ‖	MOE (10^6 psi)	1.72	2.09	1.39	1.78	0.83	1.23	1.31	1.70
	MCS (psi)	3,190	6,140	2,910	5,820	2,070	4,130	2,720	5,360
2 × 2 C ‖	MOE (10^6 psi)	1.88	2.59	1.38	2.26	1.24	1.29	1.59	1.99
	MCS (psi)	3,460	6,760	3,270	6,770	2,240	3,780	3,060	5,520
1 × 1 SB	FSPL (psi)	3,420	8,500	3,060	6,860	2,350	5,110	2,940	6,820
	MOE (10^6 psi)	1.59	2.14	1.49	1.81	0.95	1.31	1.34	1.75
	MOR (psi)	6,980	14,580	6,540	13,650	4,750	9,480	6,090	12,490
2 × 2 SB	FSPL (psi)	3,360	8,140	—	7,910	2,280	5,600	2,880	7,270
	MOE (10^6 psi)	1.69	2.21	—	2.28	1.07	1.50	1.41	1.98
	MOR (psi)	7,460	15,250	—	14,980	4,880	9,510	6,310	13,310
T ‖	MOE (10^6 psi)	2.00	2.47	1.92	2.03	1.27	1.50	1.73	2.00
	MTS (psi)	15,410	25,430	14,280	20,000	9,270	14,480	12,990	19,970
Hardness	Side (lbs)	497	865	492	893	315	478	435	745
	End (lbs)	460	901	436	882	304	527	400	770
Shear	(psi)	893	1,590	878	1,600	689	1,180	820	1,460
Cleavage	(lbs/inch)	209	345	212	344	176	262	199	317
Toughness[b]	R (in-lbs)	287	228	290	219	198	135	259	194
	T (in-lbs)	340	282	348	269	212	145	300	232
	Avg. (in-lbs)	313	255	319	244	205	140	279	213
C⊥	FSPL (psi)	301	672	288	670	165	371	252	571

[a] C ‖ = compression parallel-to-grain. MOE = modulus of elasticity, MCS = maximum crushing strength, 1 × 1 and 2 × 2 refer to specimen cross section, respectively. SB = static bending. FSPL = fiber stress at proportional limit, MOR = modulus or rupture. T ‖ = tension parallel-to-grain. MTS = maximum tensile strength. Hardness: load required to embed indentor to standard depth. Shear = maximum shear strength parallel-to-grain. Cleavage: load per inch of width of the standard specimen to cause cleavage parallel-to-grain. Toughness: Mechanical energy consumed in causing impact bending failure of the standard specimen. R = loaded on radial face, T = loaded on tangential face. C⊥ = compression perpendicular-to-grain.

[b] The dry toughness values are given as tested since no adjustment was possible. The average moisture content of all the toughness samples tested air-dry was 12.7%.

entire length of the bole, and computing a volume weighted grand average for each tree.[1] One would therefore expect that if there are significant density gradients along the height of the tree, these would be reflected in differences between density averages from strength samples and from discs. In most softwoods the density tends to decrease as position moves up the bole, and in such a case the specific gravity from the discs would be lower. In fact, however, the overall average values based on green volume are the same for test samples and for discs, suggesting that there is little or no density gradient with height in Bishop pine. This may well be the case, since Shelbourne (1974) cites unpublished work in New Zealand indicating that radial density gradients, which are closely related, were relatively small in Bishop pine.

[1] Volume weighting was done by using the square of the disc diameter:

$$\text{Tree specific gravity} = \frac{\Sigma(D_i^2 SG_i)}{\Sigma(D_i^2)}$$

where D_i = diameter and SG_i = specific gravity, each at the ith position.

TABLE 4. *Analyses of variance listing estimated standard deviation and significance tests for data in the green condition and at 12% moisture content.*

		Hierarchical ANOVA of the green data[b]					Oneway ANOVA of 12% M.C. Data[b]		
Property[a]		Within tree	Between tree within location		Between location		Within location	Between location	
1 × 1 C ∥	MOE (10^6 psi)	0.354	0.170	**	0.100	**	0.239	0.424	**
	MCS (psi)	302	235	**	538	**	393	1,063	**
2 × 2 C ∥	MOE (10^6 psi)	0.279	—	n.s.	0.415	**	0.227	0.756	**
	MCS (psi)	223	—	**	758	*	462	1,841	**
1 × 1 SB	FSPL (psi)	436	255	**	568	**	787	1,722	**
	MOE (10^6 psi)	0.180	0.152	**	0.347	**	0.251	0.419	**
	MOR (psi)	546	515	**	1,216	**	892	2,762	**
2 × 2 SB	FSPL (psi)	358	499	**	724	*	551	1,769	**
	MOE (10^6 psi)	0.183	0.168	*	0.439	**	0.155	0.494	**
	MOR (psi)	718	166	n.s.	1,789	**	1,017	4,026	**
T ∥	MOE (10^6 psi)	0.372	0.157	n.s.	0.447	**	0.182	0.480	**
	MTS (psi)	2,773	—	n.s.	3,640	**	2,082	5,398	**
Hardness	Side (lbs)	55	40	**	101	**	108	227	**
	End (lbs)	67	36	**	84	**	83	208	**
Shear	SS (psi)	76	32	**	111	**	93	237	**
	Sp. Gr.	0.033	0.024	**	0.076	**	0.025	0.088	**
Cleavage	(lbs/inch)	24	10	**	18	**	17	47	**
Toughness	R (in-lbs)	55	29	**	51	**	22	50	**
	T (in-lbs)	62	23	*	76	**	39	74	**
	Avg. (in-lbs)	63	24	**	65	**	28	62	**
C ⊥	FSPL (psi)	48	28	**	72	**	71	170	**

[a] See footnote to Table 3 for explanation, except shear data which includes analyses of the shear strength (SS) as well as the specific gravity from the shear tests (the most numerous tests at 186).
[b] Significance levels: ** = 1%, * = 5%, and n.s. = not significant.

When the specific gravity data for discs are plotted against height in the tree, some trends of decreasing specific gravity with height do appear, but they are by no means very clear-cut. The main difference appears to be between the first and second discs. However, if only the values for the first two discs are averaged, the grand average for all trees is 0.45 or the same as for the weighted average over the entire length of the bole. It thus appears that the within-tree variation of specific gravity in Bishop pine is relatively small.

The between-tree variation at a particular location is apparently also not very large, as may be seen from Table 2. However, as already pointed out, there are noticeable differences between locations, particularly between location H and the other two.

Strength and stiffness values obtained from mechanical tests are given in Table 3. The table lists average values for each location as well as grand averages for all trees. It should be noted that here, as well as in the case of the specific gravity and shrinkage data, averages are computed giving each tree equal weight. This is necessary since the number of specimens per tree tends to vary widely.

In testing air-dry material, undetected malfunction of a balance caused erroneous moisture content readings in about 2% of the samples, except for compres-

TABLE 5. *Regression analyses for strength or stiffness on specific gravity, using tree means as individual observations.*

Property[a]		Data in the green condition				Data at 12% moisture content			
		N	R^2	Intercept[b]	Slope[b]	N	R^2	Intercept[b]	Slope[b]
1 × 1 C ‖	MOE (10^6 psi)	15	0.63	−1.63	6.469	15	0.63	−0.86	4.962
	MCS (psi)	15	0.72	−1,320	8,906	15	0.89	−1,564	13,407
2 × 2 C ‖	MOE (10^6 psi)	10	0.37	0.19	3.080	12	0.77	−1.65	7.161
	MCS (psi)	10	0.93	−1,220	9,415	12	0.93	−4,024	18,761
1 × 1 SB	FSPL (psi)	15	0.75	−770	8,284	14	0.72	−3,340	19,676
	MOE (10^6 psi)	15	0.89	−1.08	5.398	14	0.74	−0.95	5.228
	MOR (psi)	15	0.95	−2,470	19,128	14	0.93	−4,868	33,617
2 × 2 SB	FSPL (psi)	9	0.77	−1,340	9,745	9	0.87	−355	14,588
	MOE (10^6 psi)	9	0.85	−0.89	5.326	9	0.78	−0.10	3.982
	MOR (psi)	9	0.96	−2,670	20,740	9	0.95	−4,496	34,072
T ‖	MOE (10^6 psi)	15	0.83	−0.88	5.866	15	0.55	−0.37	4.543
	MTS (psi)	15	0.65	−4,260	38,784	15	0.52	−5,979	49,815
Hardness	Side (lbs)	15	0.94	−182	1,364	15	0.94	−644	2,660
	End (lbs)	15	0.95	−117	1,143	15	0.94	−452	2,339
Shear	(psi)	15	0.93	163	1,449	15	0.92	41	2,692
Cleavage	(lbs/inch)	15	0.78	77	275	15	0.81	63	495
Toughness	R (in-lbs)	15	0.72	−82	771	15	0.85	−85	529
	T (in-lbs)	15	0.78	−191	1,115	15	0.88	−195	813
	Avg. (in-lbs)	15	0.84	−132	933	15	0.90	−143	674
C⊥	FSPL (psi)	15	0.85	−171	941	15	0.93	−426	1,912

[a] See footnote to Table 3.
[b] Intercept, a, and slope, b, in the regression model $y = a + bx$, where y = strength or stiffness and x = specific gravity.

sion perpendicular-to-the-grain where over 50% of the moisture content measurements appeared to be in error. Since all of the specimen material was dried and conditioned together, the average moisture content for each tree and type of strength test was calculated by excluding obvious outliers. In the case of compression perpendicular-to-grain tests, the tree average moisture content was estimated from the average moisture content of all other air-dry test specimens from that tree.

The average moisture content of all samples tested green was 128%, and that of the air-dry samples 12.9%. The air-dry strength and stiffness values were adjusted to standard conditions of 12% moisture content on a tree-by-tree basis, using the customary exponential equation for the adjustment (U.S. Forest Products Laboratory 1974). In a few cases modulus of elasticity values were higher, on the average, for green than for dry specimens of a particular tree. Since the change in modulus of elasticity with moisture content is not very large, such a relationship can occur in trees with few samples because of random variations. In such cases moisture content adjustments were made following the same principles embodied in the exponential equation, but basing the adjustment on the slope (ratio of green to dry values) of all other trees in the same location. Toughness values were not adjusted since there is no established method for doing so.

In machining the green toughness samples, 14 samples (out of a total of 164)

TABLE 6. *Strength and stiffness values adjusted to average tree specific gravity as obtained from discs.*

	Property[a]	Average value when green: As tested	Average value when green: Adjusted from regression[b]	Average value at 12% M.C.: As tested[c]	Average value at 12% M.C.: Adjusted from regression[d]
1 × 1 C ‖	MOE (10^6 psi)	1.31	1.27	1.70	1.67
	MCS (psi)	2,720	2,670	5,360	5,270
2 × 2 C ‖	MOE (10^6 psi)	1.59	1.57	1.99	2.00
	MCS (psi)	3,060	2,990	5,520	5,540
1 × 1 SB	FSPL (psi)	2,940	2,940	6,820	6,690
	MOE (10^6 psi)	1.34	1.34	1.75	1.72
	MOR (psi)	6,090	6,090	12,490	12,280
2 × 2 SB	FSPL (psi)	2,880	3,020	7,270	7,080
	MOE (10^6 psi)	1.41	1.49	1.98	1.93
	MOR (psi)	6,310	6,610	13,310	12,880
T ‖	MOE (10^6 psi)	1.73	1.75	2.00	1.95
	MTS (psi)	13,000	13,100	19,970	19,430
Hardness	Side (lbs)	435	428	745	713
	End (lbs)	400	395	770	741
Shear	(psi)	820	811	1,460	1,410
Cleavage	(lbs/inch)	199	200	317	315
Toughness	R (in-lbs)	259	263	194	184
	T (in-lbs)	300	308	232	220
	Avg. (in-lbs)	279	286	213	201
C ⊥	FSPL (psi)	252	250	571	549

[a] See footnote to Table 3.
[b] Strength or stiffness value corresponding to the average tree specific gravity as determined from discs, as calculated from the regression equations, based on specific gravity (green volume) of 0.448.
[c] As tested but adjusted to 12% moisture content, except for toughness.
[d] Computed from regression equations based on specific gravity (oven-dry volume) of 0.510.

were inadvertently cut undersize. All of these were from location H. Since insufficient extra material was available, the undersize samples were then machined to the former standard size of ⅝ × ⅝ × 10 inch, and the results adjusted to the present standard size using the conversion factor of 1.89 (Gerhards 1968).

The strength and stiffness data of Table 3 reiterate the pattern that was seen in the specific gravity data, with values that are by and large similar for locations L and G but lower for location H. This applies to all of the properties that were determined. The data for each of the test results in the green condition were subjected to a hierarchical analysis of variance (mixed model analysis of variance) to segregate differences between trees in a particular location and those between locations. The results are shown in Table 4, which lists estimated standard deviations (1) within tree, (2) between trees within a location and (3) between locations. The results of significance tests are also listed. Location, as the main factor, was highly significant (1% level) for all but two properties, where it was still significant (5% level). The random factor of the effect of trees within location was also significant in most cases, but for a few of the properties it was not significant at the 5% level. The relative importance of location becomes clear when examining the standard deviation values, since those for the location effect

TABLE 7. *Strength and stiffness of Bishop pine in comparison with some other species.*

Property	M.C.	Bishop pine[a]	Douglas-fir coast type[b]	Ponderosa pine[b]	Grand fir[b]
Compression parallel to grain[c], maximum crushing strength, psi	green	2,990	3,780	2,450	2,940
	12%	5,540	7,240	5,320	5,290
Compression perpendicular to grain, fiber stress at proportional limit, psi	green	250	380	280	270
	12%	549	800	580	500
Static bending[c]					
Modulus of rupture, psi	green	6,610	7,700	5,100	5,800
	12%	12,900	12,400	9,400	8,800
Modulus of elasticity, 10^6 psi	green	1.49	1.56	1.00	1.25
	12%	1.93	1.95	1.29	1.57
Shear strength parallel to grain, psi	green	811	900	700	740
	12%	1,410	1,130	1,130	910
Side hardness, lbs.	green	428	500	320	360
	12%	710	710	460	490

[a] Results adjusted to whole tree specific gravity.
[b] Data from the Wood Handbook (U.S. Forest Products Lab. 1974).
[c] Only the data from 2 × 2 specimens were used here since the published data are also based on the larger size.

are on the order of two to three times greater than the standard deviations of the tree effect within location. The same analyses were done with the air-dry data before adjustment to 12% moisture content, and the results were substantially the same.

There are some differences to be noted between test results for the 1 × 1 and 2 × 2 sizes in the compression parallel and the static bending tests. The larger specimens generally have higher strength and stiffness values. Normally, if there is any difference due to size, smaller specimens tend to be stronger, on the average. In this case, however, the difference is probably due to sampling. The larger sizes are available in clear specimen form only from the outer portions of the trees, and a number of trees yielded no 2 × 2 specimens at all. In this study, the two sizes therefore tend to sample slightly different populations.

In addition to the above two-way analyses of variance, one-way analyses were also made using tree averages as single observations and location as the factor of interest. These were made for green, air-dry, and 12% (adjusted) data, covering all of the tests made, and location was found to be statistically significant at the 5% level in all cases, and at the 1% level in the vast majority of cases. The one-way analyses of variance also made it possible to look for orthogonal contrasts. The data for 2 × 2 compression parallel-to-grain and for 2 × 2 static bending could not be used for these particular statistical tests because a few trees did not yield specimens of that size, and unequal replications could not be accommodated in this instance. The results showed that for all the test results examined, Location H was different from the average of locations L and G, whereas no statistically significant difference could be found between locations L and G, all tests being on the 5% level or better.

As mentioned before, available information on Bishop pine indicates that all of the test material comes from the same racial strain. It may thus be a misnomer to refer to the observed differences as "location" differences since this suggests that there are fixed geographical differences. More likely the differences are really due to site differences, as the height and diameter data in Table 1 tend to support. A more definitive answer to this question would require a density survey of the species, which is outside the scope of the present study.

Assuming that the results of a density survey were available, regression equations of strength on specific gravity as calculated from the present data could be used to make a more refined estimate of species average strength and stiffness values. Accordingly, regression equations were computed for each property and the results are summarized in Table 5. In order to preserve the principle of giving each tree equal weight, and since adjustments of 12% moisture content were made on a tree by tree basis, regressions for all data were computed by treating each tree average as a single observation. All of the regressions at both moisture content conditions were significant at the 1% level, except for modulus of elasticity of 2 × 2 compression parallel-to-grain data in the green condition, which was not significant.

The regression equations were used to adjust the strength and stiffness data of Table 3 (grand average values only) for whole tree specific gravity. The justification for such an adjustment is that the tested samples were from butt logs only, and thus represent a limited part of the total population. The average specific gravity obtained from discs, on the other hand, represents the entire tree stem. Strength and stiffness values adjusted to whole stem specific gravity can therefore be considered as the better estimate of the properties of Bishop pine as a whole. The results of the adjustment are shown in Table 6. As may be seen in the table, the adjustments are generally small because there was not much difference between specific gravity values from tested samples and those from discs. Since the regressions were different for each property, and since the average specific gravity of, for instance, all of the shear test samples was not necessarily quite the same as that of all of the static bending samples, the amount of adjustment varies with each property.

Table 7 shows comparative strength and stiffness data for Bishop pine, Douglas-fir, ponderosa pine, and grand fir. Grand fir was included because it has the lowest strength of the species included in the hem-fir group of commercial lumber. Douglas-fir and hem-fir are the western woods most commonly used for construction. The inclusion of ponderosa pine is appropriate because it is a widely distributed and extensively used western pine species. The data of Table 7 show that in many respects Bishop pine has strength properties that equal or excel those of Douglas-fir. This is particularly true for dry lumber with respect to modulus of rupture, modulus of elasticity, and shear strength parallel-to-grain, all of which are important properties in determining the load-carrying capacity of joists and beams. On the other hand, in compression, both parallel- and perpendicular-to-grain, Bishop pine does not measure up to Douglas-fir. In these properties Bishop pine is more like ponderosa pine and grand fir. This means that in terms of strength and stiffness, Bishop pine might be grouped and marketed together with the hem-fir group, but in terms of appearance such a grouping is not very logical. A more likely grouping therefore would be either with ponderosa pine-sugar pine or with ponderosa pine-lodgepole pine, if such a grouping should be found acceptable by the appropriate grading agencies. This is not to suggest that Bishop pine could not stand on its own, except that there might not be the economic justification to develop separate grades and markets.

It would have been possible to include Monterey pine among the species used in the comparison above, especially since Monterey pine and Bishop pine are closely related. The strength and stiffness values in the green condition are actually very similar, as comparison with the clear wood values in ASTM standard D2555 shows (ASTM 1979). However, Monterey pine is not a major commercial species with recognized grades in the United States, and thus the comparison was omitted from Table 7.

SUMMARY AND CONCLUSION

Five trees of Bishop pine were obtained from each of three locations, two in Mendocino County and one in Humboldt County, and tests were made of the strength and stiffness and certain physical properties of wood from these trees. The material from Humboldt County differed significantly from the rest, but there was no difference between the two Mendocino locations. It is suggested that these differences are due to site conditions rather than purely geographical differences. The results show Bishop pine to be equal in strength to Douglas-fir in some respects, but to be more like ponderosa pine and grand fir (one of the species included in the hem-fir group) in other strength properties. The properties of Bishop pine are such that it could be safely grouped together with existing grade combinations for ponderosa pine and either sugar pine or lodgepole pine.

ACKNOWLEDGMENTS

The authors are indebted to Louisiana-Pacific Corporation, Fred Henchell and Charles L. Ciancio for making available the experimental material from two of the locations, and to Georgia-Pacific Corporation and Jere L. Melo for the material from the third location. The assistance of Peter C. Passof and Paul C. Smith, Cooperative Extension, University of California, in obtaining the experimental material is also gratefully acknowledged.

REFERENCES

American Society for Testing and Materials. 1975. Annual book of ASTM standards, Pt. 22. ASTM, Philadelphia, Pa.

American Society for Testing and Materials. 1979. Annual book of ASTM standards, Pt. 22. ASTM, Philadelphia, Pa.

Critchfield, W. B., and E. L. Little. 1966. Geographic distribution of the pines of the world. USDA, Misc. Pub. 991, Washington, D.C.

Gerhards, C. C. 1968. Effects of type of testing equipment and specimen size on toughness of wood. USDA, Forest Serv., Res. Pap. FPL-97, Forest Products Lab., Madison, Wisconsin.

Sargent, C. S. 1884. Report on the forests of North America. Dep. Interior, Census Office, Washington, D.C.

Shelbourne, C. J. A. 1974. Recent investigations of wood properties and growth performance in *Pinus muricata*. N. Z. J. For. 19(1):13–45.

Siau, J. F. 1971. Flow in wood. Syracuse Univ. Press, Syracuse, N.Y.

Sudworth, G. B. 1908. Forest trees of the Pacific slope. U.S. Forest Service, Washington, D.C.

U.S. Forest Products Laboratory. 1974. Wood handbook. Agric. Handb. 72, USDA, Washington, D.C.