STRENGTH AND RELATED PROPERTIES OF KNOBCONE PINE[1]

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ABSTRACT

The mechanical properties of knobcone pine (*Pinus attenuata* Lemm.) were evaluated using the second 8-ft log from the butt of ten trees selected from a stand in Siskiyou County, California. The trees, averaging 71 ft in height and 14 in. dbh, had a growth rate of 12 rings per inch at the stump and a specific gravity of 0.38, based on green volume and oven-dry mass. Specimens were selected and tested in accordance with ASTM D143-52 in both green and air-dry conditions. Adjusted to 12% moisture content, knobcone pine has a modulus of rupture and modulus of elasticity in static bending of 10,800 psi and 1,500,000 psi, respectively, a maximum crushing strength parallel-to-grain of 5,640 psi, and a shear strength parallel-to-grain of 980 psi. These results show that knobcone pine is similar to ponderosa pine in strength and stiffness.

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

Knobcone pine (*Pinus attenuata* Lemm.) is a close relative of Monterey pine (*P. radiata*) and bishop pine (*P. muricata*). It is found in the coastal mountains of California and southern Oregon, and also in the southern Cascades of Oregon and the Sierra Nevada of northern California (Sudworth 1908; Critchfield and Little 1966). Trees are often 15 to 30 ft high and 6 to 12 in. in diameter, but can reach heights of 60 to 80 ft and diameters of 18 to 20 in., frequently forming extensive, pure forests (Sudworth 1908). Little has been reported about the properties of the wood, except for some limited tests on lumber containing knots (Sargent 1884) which indicated that the wood was of no more than moderate density and strength.

The objective of the present project was to study the strength and related properties of knobcone pine in more detail, in order to provide a basis for utilizing this hitherto little-used resource.

MATERIAL AND METHODS

Ten trees of knobcone pine were selected from a stand in E ½ Section 16, T39N, R1E (MDBM), Bull Creek drainage. The trees were chosen as represen-

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TABLE 1. *Sample tree characteristics.*

	Mean	Range
Dbh (in.)	14.0	8.3–18.1
Height (ft)	71	54–79
Height to 4-in. top (ft)	57	31–65
Height to fork (ft)	45	19–55
Ring count at stump	76	73–78

tative of the size, form, and vigor of the stand, which consisted of an overstory of knobcone pine and an understory of white fir saplings and extensive brush. The knobcone pine trees were quite uniform, aged about 80 years, and ranged mainly from 12 to 16 in. in diameter at breast height, and 70 to 80 ft in height. The majority of the trees had forks at 45 to 55 ft.

The sample material consisted of the second 8-ft log from the butt and cross-sectional discs taken at the stump and from there at 16-ft intervals up to a 4-in. top. The discs were put into plastic bags, and all sample material was promptly shipped to the University of California Forest Products Laboratory, Richmond, California. There the logs were put under sprinklers, and the discs were put into cold storage.

The discs were taken from cold storage within two weeks of receipt, and diameter measurements and ring counts were made on each one. They were debarked, and when knots were present, these were removed by cutting wedges containing the knots from the bark to the pith. The remaining discs or partial discs of clear wood were then weighed for determination of the original moisture content, soaked in water overnight to counter the effects of any possible surface drying that might have taken place, and then weighed in air and in water to determine their volume. The discs were then oven-dried, and the specific gravity based on oven-dry mass and green volume was calculated.

The sample logs were sawn one month after receipt into 1- × 1- and 2- × 2-in. test sticks according to the pattern provided for in "Standard Methods of Testing Small Clear Specimens of Timber, Part II. Secondary Methods," ANSI/ASTM D143-52 (ASTM 1980), as dictated by the size of the available logs. Test sticks were divided into two lots, to be tested green and air-dry, respectively. Green material was tested as soon as possible, care being taken at all times to prevent drying. Air-dry material was set on stickers in a humidity room maintained at

TABLE 2. *Specific gravity, based on oven-dry mass and green volume, and growth rate of discs.*

Location	Specific gravity		Rings per inch	
	Mean	Range	Mean	Range
Stump	0.42	0.40–0.44	12.1	9.0–19.5
16 ft	0.37	0.34–0.40	10.6	7.8–17.7
32 ft	0.35	0.33–0.40	8.9	6.6–10.9
48 ft	0.35	0.31–0.39	9.0	6.3–11.5
Weighted tree means[1]	0.38	0.35–0.40	—	—

[1] Volume weighted using square of disc diameter and giving the stump disc one-half the weight of the others.

TABLE 3. *Specific gravity from strength test specimens and shrinkage.*

Specific gravity:	
Green volume basis	0.37
Oven-dry volume basis	0.42
Percent shrinkage, green to air-dry:	
Radial	2.1
Tangential	3.7
Longitudinal	0.07
Volumetric	5.8
Percent shrinkage, green to oven-dry:	
Radial	4.1
Tangential	6.6
Longitudinal	0.24
Volumetric	10.6

nominal 12% equilibrium moisture content conditions. Air-dry tests were made after about 5 months of conditioning.

The tests included static bending, compression perpendicular and parallel-to-grain, hardness, tension parallel-to-grain, shear parallel-to-grain, cleavage, and toughness. Shrinkage measurements were also made, using 1- × 1- × 4-in. specimens with the grain parallel to the long dimension in place of the standard specimens. Radial, longitudinal, tangential, and volumetric shrinkage were all determined on a given specimen. Five shrinkage specimens were taken from each tree, using material from green test sticks where available, the others being taken from the quadrants that remained after test sticks were sawn. Specific gravity and moisture content measurements were made on each strength test specimen after the test.

RESULTS AND DISCUSSION

Characteristics of the sample trees are summarized in Table 1. All trees were about the same age and, except for one, very similar in height (68 to 79 ft).

Specific gravity and growth rate data from discs are summarized in Table 2. The specific gravity is seen to be decreasing with increasing height in the tree, which is a normal pattern of variation. Rings/inch follow a similar pattern with height, but there is no meaningful difference between the 32-ft and 48-ft locations. The mean specific gravity of each tree was calculated on a volume weighted basis. Accordingly, disc specific gravity was weighted according to the square of the diameter. Since each disc except the first one at the stump represents material both below and above it with respect to location in the tree, the disc at the stump was additionally given half weight and all others full weight. The grand average of the weighted tree specific gravities is 0.38, the same as ponderosa pine (U.S. Forest Products Laboratory 1974). The number of rings per inch indicates that the material was moderately fast-grown as compared to other conifers.

Specific gravity data from strength test data and shrinkage data are summarized in Table 3. The average specific gravity value obtained from strength test specimens is virtually the same as the volume weighted average obtained from the discs, the difference being only 0.01. The shrinkage values are very similar to,

TABLE 4. *Strength and stiffness values as tested and adjusted to mean tree specific gravity.*

Property[a]	Average when green		Average at 12% MC	
	As tested	Adjusted from regression[b]	As tested[c]	Adjusted from regression[d]
Static bending:				
FSPL (psi)	2,770	2,730	5,530	5,410
MOR (psi)	5,670	5,560	10,800	10,600
MOE (10^6 psi)	1.19	1.16	1.50	1.47
Compression parallel:				
MCS (psi)	2,530	2,560	5,640	5,610
MOE (10^6 psi)	1.23	1.24	1.60	1.59
Compression perpendicular:				
FSPL (psi)	229	233	518	529
Shear parallel-to-grain (psi)	667	673	984	993
Tension parallel:				
MTS (psi)	13,200	12,900	15,000	14,000
MOE (10^6 psi)	1.38	1.35	1.70	1.55
Hardness:				
Side (lbs)	377	382	503	499
End (lbs)	367	372	649	645
Cleavage (lbs/in. of width)	181	180	220	220
Toughness:				
Radial (in.-lbs)	167	163	140	131
Tangential (in.-lbs)	193	189	157	144

[a] FSPL = fiber stress at proportional limit; MOR = modulus of rupture; MOE = modulus of elasticity; MCS = maximum crushing strength; MTS = maximum tensile strength; radial and tangential toughness: load applied to radial-longitudinal and tangential-longitudinal face, respectively.

[b] Strength or stiffness values adjusted to average whole tree specific gravity (green volume) of 0.377 from regression equations.

[c] As tested but adjusted to 12% MC except for toughness (12.4% MC).

[d] Adjusted to whole tree specific gravity (oven-dry volume) of 0.421. The oven-dry specific gravity (SG_o) of each disc was calculated from the measured values (SG_g) using the formula $SG_o = SG_g/(1 - 0.27*SG_g)$, 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.

but slightly greater than, those of ponderosa pine (U.S. Forest Products Laboratory 1974).

Average strength and stiffness data are given in Table 4. Table 4 shows data for both the green and air-dry condition. Under each moisture condition, strength values are first given as tested. This is strictly true only for the specimens tested green. Those tested air-dry were adjusted from the moisture content at test, which was 12.6% on the average, to the standard condition of 12%. Adjustments were made on a tree-by-tree basis, using an exponential equation (U.S. Forest Products Laboratory 1974).

For each of the strength or stiffness properties listed in Table 4, linear regression equations of strength on specific gravity were computed. In the case of data in the green condition, these were computed using all samples as individual observations. Since moisture content adjustments have to be made on a tree average basis, these averages had to be used as single observations for the air-dry data. Results of the regression equations are shown in Table 5. For the green data, all of the regressions except that for cleavage are statistically significant at the 5%

TABLE 5. *Regression analyses for strength or stiffness on specific gravity.*

	Property	All samples in the green condition				Tree means at 12% MC			
		N	R^2	Intercept	Slope	N	R^2	Intercept	Slope
C//	MOE (10^6 psi)	44	0.13	−.33	4.157 *	10	0.58	−1.00	6.142 *
	MCS (psi)	44	0.46	−503	8,121 **	10	0.75	−2,073	18,275 **
SB	FSPL (psi)	50	0.51	−927	9,680 **	10	0.34	−939	15,091 NS
	MOE (10^6 psi)	50	0.35	−.26	3,761 **	10	0.56	−.62	4.958 *
	MOR (psi)	50	0.60	−1,660	19,130 **	10	0.64	−252	25,850 **
T//	MOE (10^6 psi)	27	0.41	−.37	4.557 **	9	0.49	−1.31	6.793 *
	MTS (psi)	27	0.25	−4,160	45,200 **	9	0.40	−6,734	49,243 NS
Hardness	Side (lbs)	30	0.50	−74.6	1,210 **	10	0.74	−648	2,727 **
	End (lbs)	30	0.32	−6.5	1,002 **	10	0.51	−337	2,335 *
Shear	(psi)	66	0.25	244	1,136 **	10	0.57	101	2,121 *
Cleavage	(lbs/inch)	53	0.02	222	−111 NS	10	0.00	3	219 NS
Toughness	R (in.-lb)	44	0.22	−92.8	678.4 **	10	0.25	16	280 **
	T (in.-lb)	43	0.12	−29.4	579.2 *	10	0.43	−163	733 **
C⊥	(psi)	31	0.21	−66.0	794 **	10	0.60	−217	1,774 **

level. Coefficients of determination, R^2, range from 0.12 to 0.60, which means that even for statistically significant regressions, specific gravity explains as little as 12%, and in no case more than 60%, of the total variation. Among the regressions at 12% moisture content, all but three are significant at the 5% level. The exceptions are fiber stress at proportional limit in static bending, maximum tensile strength, and cleavage. Coefficients of determination of the other regression analyses range from 0.25 to 0.75. Although the number of observations is much smaller, using tree averages does eliminate some of the variation, leading to a better apparent correlation.

Since the strength tests were all made on material from the second 8-ft log, and since the data in Table 2 show that there is variation in specific gravity with height in the tree, an estimate can be made of strength and stiffness values that are representative of all of the material in the tree. To do this, the volume-weighted average tree specific gravity is substituted into the regression equations. The resulting strength and stiffness values are shown in Table 4, along with the "as tested" values. The values calculated from regression are higher or lower, depending on whether the average specific gravity of the particular group of test specimens was higher or lower than the volume weighted grand average value from the discs. Major differences are absent, since the grand average specific gravity of the test specimens and the volume weighted grand average from the discs differed only slightly.

As already noted, knobcone pine is botanically related to bishop pine and Monterey pine, but with respect to properties, it appears to most closely resemble ponderosa pine. Specific gravity and shrinkage characteristics of the two species are about the same, as discussed above, and a comparison of strength and stiff-

TABLE 6. *Strength and stiffness of knobcone pine and ponderosa pine.*

Property	MC	Knobcone pine	Ponderosa pine[a]
Static bending:			
Modulus of rupture, psi	green	5,670	5,100
	12%	10,800	9,400
Modulus of elasticity, 10^6 psi	green	1.19	1.00
	12%	1.50	1.29
Compression parallel-to-grain, maximum crushing strength, psi	green	2,530	2,450
	12%	5,640	5,320
Compression perpendicular-to-grain, fiber stress at proportional limit, psi	green	230	280
	12%	520	580
Shear strength parallel-to-grain, psi	green	670	700
	12%	980	1,130
Side hardness, lb	green	380	320
	12%	500	460
Toughness:			
Radial, in.-lbs	green	170	190
	12%[b]	140	150
Tangential, in.-lbs	green	190	270
	12%[b]	160	190

[a] From Wood Handbook (U.S. Forest Products Laboratory 1974).
[b] For toughness, the actual moisture content was 12.4% and 11% for knobcone pine and ponderosa pine, respectively.

ness data is shown in Table 6. In static bending, probably the most important single test with respect to structural applications, knobcone pine has more than 10% higher strength (MOR) and more than 15% higher stiffness (MOE) than ponderosa pine, either green or at 12% moisture content. Compression parallel-to-grain values and side hardness are also somewhat higher for knobcone pine. Compression perpendicular-to-grain strength is somewhat less, but this may be due to the fact that most of the data listed in the Wood Handbook are based on tests made long before modern recording equipment became available. Fiber stress at proportional limit values obtained by the use of such equipment, which includes the present values for knobcone pine, tend to be lower than obtained by older methods. Finally, shear parallel-to-grain strength and toughness are somewhat lower for knobcone pine. On balance, however, the two species are remarkably similar in their strength and stiffness properties, and there appears to be no reason why the two could not be considered equal for practical purposes.

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