Structural lumber from suppressed-growth ponderosa pine from northern Arizona

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Abstract

Lumber was sawn from 150 suppressed-growth ponderosa pine trees, 6 to 16 inches in diameter, harvested near Flagstaff, Arizona. This paper presents grade recover and properties for dry 2 by 4's sawn from the logs and graded by a variety of structural grading systems. Flexural properties met or exceeded those listed in the National Design Specification. When graded as Light Framing 43 percent of the 2 by 4's made Standard and Better and as Structural Light Framing, 34 percent made No. 2 and better. Warp was the biggest factor limiting grade yield. About 7 percent of the lumber would make a machine stress-rated (MSR) lumber grade of 1450f, but with no established market such production is not recommended. If graded as laminating stock, about 8 percent of the lumber qualified as L3 or better. A comparison of the results from this study with those from a companion study indicates that appearance grades offer the highest value alternative for lumber produced from this resource.

Ponderosa pine (*Pinus ponderosa,* L.) is one of the most important softwood species in western North America. It is found in commercial quantities in every state west of the Great Plains. Wood from mature trees is relatively lightweight, nondurable, nearly white, and has straight grain and a medium texture. It is easy to work with hand tools, glues well, and is average in paint- and fastener-holding abilities. It is a principal millwork species, being used for window framing, sashes, doors, moulding, shelving, and paneling. In roundwood form, it is used for posts, poles, and house logs (Lowery 1984). As structural lumber, it is sold as part of the Western Woods species grouping (NDS 2005).

Natural regeneration of ponderosa pine is sporadic over much of its range, with successful germination thought to be the result of the chance combination of a heavy seed crop and favorable weather during the following growing season (Burns and Honkala 1990). Historically, the ponderosa pine forests were primarily open stands of mature trees interspersed with pockets of younger trees and grassland. Prior to the early 1900s, frequent low-intensity fires killed off competing vegetation, including ponderosa pine seedlings, and help maintained open stands of large, fire-resistant trees (Fiedler et al. 1997). Fire suppression, along with livestock grazing and timber harvest, has promoted the conversion of

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the historical forest to dense stands containing a preponderance of small-diameter trees. Under these conditions, tree growth is often suppressed. Because ponderosa pine is intolerant of shade, rapid growth of seedlings prior to crown closure will produce a relatively large core of juvenile wood, generally defined as the first 20-years of growth (Shuler et al. 1989, Voorhies and Groman 1982). Juvenile wood tends to have higher than normal longitudinal shrinkage and may warp excessively. This has been identified as a primary problem in the utilization of small-diameter ponderosa pine (Fahey et al. 1986).

Management goals for ponderosa pine forests include reducing stand density to increase resistance to insect and disease attack, reduce the risk of catastrophic wildfires, provide diverse mosaics of wildlife habitat, and provide economic benefit to local communities (Willits et al. 1997). Increasing product utilization, along with reducing harvesting and processing costs, is critical for restoring ecological processes in ponderosa pine forests (Fiedler et al. 1997, Larson and Mirth 1998, Rummer et al. 2003). Several studies have shown that old growth trees (generally defined as more than 150 years old) produce a larger proportion of high value "shop and select" grades of lumber than do younger ("blackjack") trees (Ernst and Pong 1985, Fahey and Sachet 1993, Fahey et al. 1986). Fahey and Sachet (1993) concluded that lumber from second growth ponderosa pine logs is primarily in the Dimension grades. These older studies, however, were not specific to suppressed stands and often were limited in the lumber grading options investigated, especially for engineered product applications. Recent studies have shown that small-diameter trees growing in dense stands may have higher annual ring density and smaller knots than more open-grown trees and can be used as an input raw material for higher value products ranging from visually and mechanically graded lumber to veneer for structural composite lumber (Willits et al. 1997, Erickson et al. 2000, Green et al. 2005).

In a previous paper we compared volume and value recovery from 6- to 16-inch (152- to 406-mm) diameter breast height (DBH) suppressed-growth ponderosa pine harvested near Flagstaff, Arizona (Lowell and Green 2001), which was manufactured into structural and nonstructural lumber. In that paper, the structural dimension lumber was limited to the Structural Light Framing grading system (WWPA 1998). The objective of this paper is to further investigate the yield of structural lumber graded under a wider range of structural grading systems.

Procedures

Log selection and processing

Trees were selected from the Fort Valley Research and Demonstration Forest, Flagstaff, Arizona, and harvested in summer 2006. The demonstration project contained three experimental blocks with four treatment plots each. The experimental blocks represented different initial stand conditions: blackjack (young growth), yellow pine (old growth), and a mixture of the two age groups. The treatments within blocks were different thinning prescriptions designed to return stands to presettlement conditions. This involved thinning from below in which the larger, older trees were retained. Trees to be left had been marked, but no thinning treatment had been applied prior to sample selection for this study. Sample trees came from three of the four treatment plots in the mixed age block.

A sample of 150 trees ranging in DBH from 6 to 16 inches (152 to 406 mm) was selected. A matrix of five 2-inch (51-mm) diameter classes was used, and the trees selected represented those that would have been removed under the silvicultural prescription. The trees had an average age of 88 years. The sample was randomly divided into two subsamples, one to be sawn for dimension lumber and the other for appearance-grade lumber. Only the 2 by 4's from the dimension lumber sample are discussed in this report. The logs were sawn and the lumber kiln-dried by the Fremont Lumber Company, Lakeview, Oregon, owned by the Collins Companies. A more detailed discussion on selection and processing procedures and the overall results for both subsamples are presented in Lowell and Green (2001). Simpson and Green (2001) give additional information on kiln-drying procedures in the Fremont Lumber Company sample.

Grading and testing

The dry and surfaced 2 by 4's were shipped from the sawmill to the University of Idaho where they were graded as structural products by a lumber inspector of the Western Wood Products Association (WWPA). Each 2 by 4 was graded under several structural grading systems including Structural Light Framing, Light Framing, and the visual requirements for machine stress-rated (MSR) lumber and laminating grades (AITC 1993, WWPA 1998). If the grade of the lumber could be increased by trimming 2 to 4 feet (0.6 to 1.2 m) from the end, the trimmed length and trimmed grade were recorded. The lumber was conditioned for several months at approximately 70 °F (21 °C) and 55 percent relative humidity.

Modulus of elasticity (MOE) was determined by transverse vibration (Etv) using a E-Computer (Metriguard, Inc., Pullman, Washington) with specimens supported at the ends and vibrated in the flatwise orientation. Specimens were then tested to failure on edge in static bending using third-point loading and a span-to-depth ratio of 21:1 following the procedures of ASTM D 198 (ASTM 2005). The rate of loading was approximately 2 inches (51 mm) per minute. In accordance with ASTM Standards D 2395 and D 4442–92, ovendry moisture content (MC) and specific gravity (SG) based on ovendry weight and ovendry volume were determined from sections taken near the failure region after testing (ASTM 2005).

MSR simulation

Simulations of MSR grades were conducted for a range of potential grades having static edgewise MOE values ranging from 1.0 to 2.4 × 10^6 psi (6.9 to 16.5 GPa). Individual pieces in the simulation of MSR grades had to meet four criteria to qualify for a specified grade: (1) fifth percentile (minimum) MOE, (2) fifth percentile (minimum) modulus of rupture (MOR), (3) grade average MOE, and (4) visual grading requirements for edge knots. Traditionally, for mechanically graded lumber, the fifth percentile non-parametric point estimate must equal 82 percent of the target average MOE value (i.e., 0.82 × average grade MOE). This limits the variability of the lower half of the MOE distribution of the grade to a coefficient of variation (COV) of 11 percent. Thus, the minimum MOE for a 1.3E grade would be $0.82 \times 1.3 = 1.07 \times 10^6$ psi (7.4 GPa). The minimum MOR value would be 2.1 times the allowable bending strength (Fb) for the specified grade. In addition to the MOE and MOR requirements, knot size is limited by grade category. More information on MSR lumber may be found in Galligan and McDonald (2000) and the Summer 1997 issue of *Wood Design Focus* (FPS 1997). A more comprehensive discussion of our MSR simulation procedures, along with several grading alternatives, is given in Green et al. (2005).

Laminating grades

Traditional ponderosa pine lumber used in glulam is referenced in glulam standards as part of a species grouping called Western Species. As part of this grouping, only visual grading of the lumber was conducted. The rules for visual rating are based entirely on the characteristics that are readily apparent to the human eye, such as knot size, slope of grain, and wane. The following tabulation is an example of the knot size limitations for visual glulam grades:

Grade	Maximum knot size
L1	1/4 width
L2	1/3 width
L3	1/2 width

Laminating lumber assigned to the Softwood Species grouping has relatively low values for mechanical properties. Thus ponderosa pine in this species grouping was historically restricted to homogeneous L3 combinations. Other species, such as Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and southern pine (*Pinus* spp.), employ measurement of MOE (E-rating) of the outer laminations to make efficient use of the timber resource. Recent research has demonstrated that it is possible to produce glulam beams with only ponderosa pine lumber using a combination of E-rated lumber and visual characteristics (Hernandez et al. 2005). These grades are expressed in terms of MOE followed by the limiting knot size. Thus, a 2.0E-1/6 grade has a MOE of 2.0×10^6 psi (13.8 GPa) and a maximum edge knot size of 1/6 the lumber width. The L-grades for our lumber were determined by the WWPA lumber inspector.

Results

Visual grading

Grade yield. — In this paper, grade yield is based on the total volume of 2 by 4's produced from all the logs, rather than being relative to the volume of wood in each individual log as was done in our previous paper (Lowell and Green 2001). This was necessary because only the 2 by 4 lumber was evaluated for structural products. This decision also removes the sawing efficiency of a given sawmill as a limitation and makes the results more applicable to other mills that might have different equipment configurations to process the logs.

Under the Structural Light Framing system, most of the 2 by 4's were either grades No. 2 or No. 3, with only a little more than 7 percent making the higher grades of Select Structural No. 1 (**Table 1**). These results are similar to those we previously found for lumber cut from small-diameter ponderosa pine from Grangeville, Idaho (**Table 2**). Here the lumber that did not make at least No. 3 grade is termed "No. 4", to avoid confusion with the lumber that did not make at least Utility grade in the Light Framing grading system, which is called "Economy." The primary characteristics that limited grade were warp (43%), wane (17%), and knots (7%). Likewise, when graded as Light Framing (Table 1), only about 13 percent of the lumber made Construction grade. Grade limiting characteristics were essentially the same as those for Structural Light Framing. Thus, as has been shown in previous studies, warp is the primary grade limiting problem. Prevention of warp could significantly increase utilization of lumber from small-diameter ponderosa pine trees (Simpson and Green 2001, Simpson 2004).

Table 1. — Grade yield for visually graded 2 by 4's from suppressed ponderosa pine from Flagstaff, Arizona.

Grade	No. of pieces	Volume	Yield
		(BF)	(%)
	Structural light framing		
Select structural	21	141	2.4
No. 1	39	287	4.9
No. 2	200	1555	26.7
No. 3	224	1883	32.3
No. 4	223	1961	33.7
Total	707	5827	100
	Light framing		
Construction	104	763	13.1
Standard	219	1739	29.8
Utility	179	1517	26.0
Economy	205	1815	31.1
Total	707	5834	100

Mechanical properties. — To reduce the amount of lumber that was tested, only the 2 by 4's that were broken in this study had potential for mechanical grading and glulam. Generally, these were at least a No. 3 visual grade and met other required visual characteristics, as determined by the WWPA lumber inspector. Only a small proportion (< 10%) of the No. 3 visual grade qualified for MSR and was tested, and only a few pieces (< 5%) of the No. 2 grade were not tested. In the Light Framing system, only one piece of Utility grade lumber qualified for MSR, whereas only a few pieces of Standard grade did not qualify.

Table 3 shows the flexural properties when the lumber is graded as Structural Light Framing. The lumber had a MC of about 10 percent. The SG of all the lumber averaged about 0.41 based on ovendry weight and volume. This is slightly lower than the value of 0.43 given in the National Design Specifications (NDS 2005). When adjusted to 15 percent MC as per ASTM Standard D1990 (ASTM 2005, Evans et al. 1989), the allowable bending strength, Fb, and MOEs of the Structural Light Framing and Light Framing grades were at least as high as those specified in the NDS (**Table 4**). Property values are not shown for the No. 3 and Utility grades because too many pieces in these grades were not tested. Light framing grades for ponderosa pine were not tested in the in-grade program (Green and Evans 1987).

Mechanical grading

There is a good relationship between MOE and Etv and between MOR and MOE (**Table 5**, **Fig. 1**). Although the r^2 values are a little lower than expected, our previous studies on ponderosa pine from small-diameter trees found higher r^2 values; thus, there is no reason to expect a problem with mechanically grading this lumber. The lower 90 percent confidence interval on the MOE-MOR relationship is shown in **Figure 1**. Five percent of the data would be expected to be below this

Table 2. — Grade yield of Structural Light Framing for 2 by 4's cut from small-diameter ponderosa pine trees from interior west locations.

Location	Situation	Sample size	Grade yield, %[a] S.S.	No.1	No.2	No.3	Econ.	Reference[c]
Emmit, ID	Plantation[b]	200	0	1.6	11.4	31.9	55.1	1
Grangeville, ID	Plantation[b]	388	0.2	14.0	33.2	3.2	49.4	2
Flagstaff, AZ	Suppressed	707	2.4	4.9	26.7	32.3	33.7	3

[a]Percent of the BD FT volume of 2 by 4's in a grade relative to the total volume of 2 by 4's.
[b]Planted initially at a given spacing, not a commercial plantation.
[c]1, Erickson et al. 2000; 2, Gorman and Green 2000; 3, current study.

Table 3. — Mechanical properties of visually graded ponderosa pine 2 by 4's.

Grade	N	MC (%)	SG (OD/OD)	MOE[a] (10^6 psi) Mean	MOE SD	MOR (10^3 psi) Mean	MOR SD	MOR fifth
				Structural light framing				
SS	17	9.8	0.431	1.374	0.173	7.841	2.553	4.258
No. 1	35	9.8	0.409	1.248	0.189	5.511	1.605	2.874
No. 2	181	9.7	0.407	1.106	0.181	4.418	1.814	2.062
				Light framing				
Construction	94	9.7	0.409	1.193	0.205	5.257	2.290	2.300
Standard	192	9.7	0.407	1.079	0.190	4.198	1.791	1.880

[a]10^3 psi × 6.894 = MPa, 10^6 psi × 6.894 = GPa.

Table 4. — Flexural properties of ponderosa pine 2 by 4's adjusted to 15 percent MC.

Grade	Current study MOE[c]	Current study $R_{05}/2.1$	NDS - 2 by 4's[a] E	NDS Fb	In-grade program[b] MOE	In-grade $R_{05}/2.1$[d]
		Structural light framing				
S.S.	1.270	--	1.2	1.350	1.078	2.056
No. 1	1.153	1.331	1.1	1.012	--	--
No. 2	1.021	0.982	1.0	1.012	0.932	1.260
		Light framing				
Construction	1.101	1.095	1.0	0.775	--	--
Standard	0.996	0.895	0.9	0.425	--	--

[a]Western Woods species group, NDS, 2005.
[b]Green and Evans 1987.
[c]MOE has units of 10^6 psi, $R_{05/2.1}$ has units of 10^3 psi, 10^3 psi × 6.894 = MPa, 10^6 psi × 6.894 = GPa.
[d]R_{05} is the non-parametric fifth percentile.

Table 5. — Property relationships for 2 by 4's cut from suppressed-growth ponderosa pine.

Property[a]	X	Sample size	Property = A + BX: A	B	r^2	RMSE[b]
MOE	Etv	293	0.179	0.777	0.63	0.124
MOR	MOE	293	−3.346	7.093	0.49	1.476

[a]MOE, Etv has units of 10^6 psi, MOR has units of 10^3 psi, 10^3 psi × 6.894 = MPa, 10^6 psi × 6.894 = GPa.
[b]Root mean square error, in 10^3 psi.

line and is the basis for establishing mechanical grades. The equation that we used for the lower confidence interval is:

$$MOR_{0.9LCI} = 7.093 \times MOE - 5.786$$

This lumber was evaluated for the production of a number of MSR grading alternatives (Cisternas 2000). While a significant amount of the lumber would make a grade of 900Fb-1.0E, there is currently no market for such a grade. In fact, the

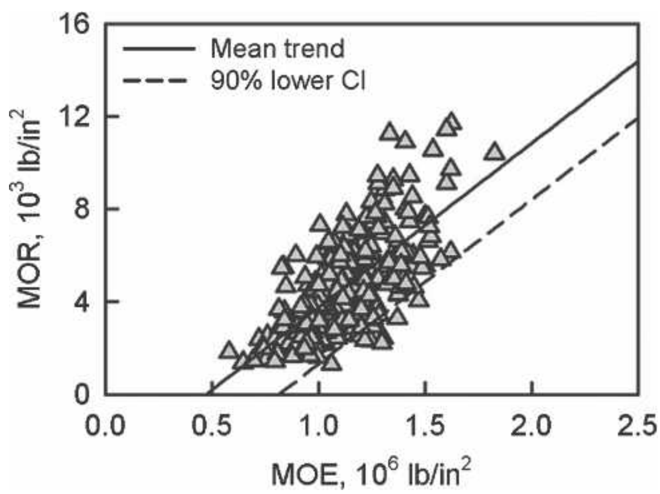

Figure 1. — Relationship between modulus of rupture (MOR) and modulus of elasticity (MOE) in static bending for 2 by 4's cut from suppressed-growth ponderosa pine.

lowest MSR grade with much of an established market is 1450f-1.3E (James 2001). Only about 7 percent of the volume (425 BF) of these 2 by 4's would make 1450f. With no established market for ponderosa pine (or Western Woods) MSR, it would not be economical to consider such production. This conclusion is consistent with what we found in our previous study for ponderosa pine from near Grangeville, Idaho (Erickson et al. 2000).

Glulam

Table 6 shows the distribution of flatwise Etv values for our data by edge knot size classes. Most of the pieces were either in the classes with 1/6- or 1/2-in. edge knots, and had Etv values below 1.4 million pounds per square inch (9.8 GPa). When graded by the visual glulam grades, only about 20 percent of the lumber would make at least an L3 grade (**Table 7**). The largest single grade-limiting factor for glulam with this

Table 6. — Distribution of flatwise MOE values by transverse vibration (Etv) by knot size class for 2 by 4's cut from suppressed-growth ponderosa pine.

Etv[b]	No. of pieces by edge knot displacement[a]			
	1/6	1/4	1/3	1/2
(10^6 psi)				
0.9[c]	4	2	3	18
1.0	14	6	10	14
1.1	20	4	3	18
1.2	14	10	14	22
1.3	18	8	7	15
1.4	14	10	2	10
1.5	8	1	1	3
1.6	4	3	4	1
1.7	5	0	1	0
1.8	2	0	0	0
Mean Etv value for knot class, 10^6 psi	1.259	1.241	1.202	1.140
Number of samples	103	44	45	101
COV of Etv[d]	18.1	15.1	16.5	15.4

[a]Fraction of cross section occupied by edge knot.
[b]10^6 psi × 6.894 = GPa
[c]Values represent the average of the range. The range is from 0.05 below to 0.05 above the listed average.
[d]COV = coefficient of variation (%)

Table 7. — Grade yield of laminating stock from suppressed-growth ponderosa pine 2 by 4's from Flagstaff, Arizona.

Grade	No. of pieces	Volume (BF)	Percentage yield
L1	29	204	3.5
L2	36	249	4.3
L3	89	736	12.6
Reject	553	4641	79.6
Total	707	5830	100

lumber was warp (36%). Because laminations are pressed during the manufacturing process, bow is a less critical form of warp than are cup and twist. About 22 percent of the lumber was limited by cup, 7 percent by bow, and 6 percent by twist. These percentages are based on the primary limiting characteristic listed by the WWPA lumber inspector. It is common for more than one type of warp to occur simultaneously. About 1 percent of the limitations were just listed as "warp" (kind of warp unspecified). About 23 percent of the pieces had wane listed as the grade limiting characteristic. Had this lumber been sawn knowing that it was to be used for glulam production, it could have been sawn a little over size so that when planed to standard dimension there would have been less grade loss due to wane.

Discussion

As has been found in previous studies, warp is the biggest factor limiting the utilization of lumber cut from small-diameter (less than about 16-inches (406 mm) DBH), young growth (less than 150 years old) ponderosa pine. The amount of warp in this study could have been reduced slightly if a top load of 150- to 200-pounds per ft^2 (psf) had been used during kiln-drying. Unfortunately, only enough weights were available to achieve a top load of about 75 psf. It is estimated that the increase in grade recovery might have been up to 17 percent had sufficient top load been applied (Simpson and Green 2001). Additional improvements in warp control could be obtained by employing kiln temperatures of 240 °F, or higher (Simpson 2004). Excess wane was another characteristic that limited grade in this study, especially for production of laminating grades. Sawing the 2 by 4's oversized could have reduced this problem, at the expense of overall yield.

Table 8. — Lumber grade recovery from suppressed-growth ponderosa pine logs sawn for appearance grade products (Lowell and Green 2001).

Board grade	Lumber volume
	(%)
No. 1 Common	3
No. 2 Common	22
No. 3 Common	66
No. 4 Common	7
Molding	<1
No. 3 Clear	<1
No. 1 Shop	1
No. 2 Shop	1

This study supports previous conclusions that structural lumber can be produced from small-diameter trees if careful attention is paid to kiln-drying procedures. However, yields will not likely be as good as those expected from small-diameter trees of other species (Green et al. 2005, Gorman and Green 2000, Willits et al.1997). For mills already cutting small-diameter trees for structural lumber, visual grading in the Light Framing or Structural Light Framing grading systems would provide the highest value. Although not evaluated in this study, production of Stud grade 2 by 4's should also be attractive provided that wane and warp are controlled. Production of MSR lumber is not recommended for this resource. Grade yields would likely be quite low, and no established market currently exists for mechanically graded ponderosa pine or Western Woods. Glulam remains a possible market for ponderosa pine from suppressed-growth ponderosa pine (Hernandez et al. 2005), but potential producers are well advised to investigate the needs of specific glulam buyers before trying to compete in this market.

For this resource, sawing for appearance grades offers a higher value alternative for lumber production from this suppressed-growth ponderosa pine than does structural dimension lumber (Lowell and Green 2001). Had these logs been sawn for appearance-grade products, about 25 percent would have made No. 2 Common or Better with 66 percent grading as No. 3 Common (**Table 8**). The estimated premium for appearance products over dimension lumber at that time was $53 per 1000 cubic feet (gross log scale). Other previous research (Lowell et al. 2000) showed that there are opportunities to increase the value of appearance lumber through further processing into cut-stock material. The Flagstaff resource had a high yield of No. 3 Common appearance lumber, and about 60 percent of the boards were 6 inches (152 mm) wide or wider. While not evaluated in our study, there may be an opportunity to recover additional value by further processing into secondary products.

Conclusions

For the production of 2 by 4 structural lumber from 80- to 100-year-old suppressed-growth ponderosa pine 16 inches and less in diameter, we found that:

1. 34 percent of the 2 by 4's graded as No.2 and better (43% as Standard and Better). Warp (43%) and wane (17%) were the primary grade limiting defects, with only 7 percent of the grades being limited by knots.
2. Sawing the 2 by 4's slightly over size, and kiln-drying with a top load of 150 to 200 pounds per ft^2 would likely have improved the yield of dimension lumber.
3. The flexural properties of this lumber met or exceeded the allowable properties assigned to the species grouping containing ponderosa pine (Western Woods).
4. While about 7 percent of the 2 by 4's could qualify as 1450Fb-1.3E MRS lumber, such production is not recommended. This is the lowest grade of MSR lumber currently sold in any volume, and no market is currently established for this species group. For those already producing structural lumber grading, Light Framing, or Structural Light Framing grades are better alternatives.
5. If a market is readily available, this lumber is suitable for the production of stock for glulam beams. However, careful attention must be paid to the reduction of warp and wane.
6. Appearance grades offer the highest value alternative for lumber production from this suppressed-growth resource. A premium of about $53 per 1000 cubic feet (gross log scale) was estimated in a previous study.

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