Yield and ultrasonic modulus of elasticity of red maple veneer

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Abstract

The purpose of the study was to assess the potential for using red maple sawlogs to manufacture laminated veneer lumber (LVL). The primary objective was to determine the yield of ultrasonically graded veneer from red maple logs. A sample of 48 logs was obtained from six Eastern and Lake States in the United States. The logs were visually graded and shipped to a plywood manufacturing facility in northern Michigan where they were debarked, steamed for 72 hours, and then rotary peeled into nominal 1/8-inch- (standard 3-mm-) thick veneer. Special care was taken to ensure that each veneer sheet could be traced back to the log from which it came. The veneer sheets were dried to approximately 12 percent moisture content at the plywood mill, shipped to the USDA Forest Service, Forest Products Laboratory in Madison, Wisconsin, and nondestructively tested using a commercially available ultrasonic veneer grader. The average stress wave speed, obtained from the veneer grader, and the density of each sheet was used to compute its modulus of elasticity (MOE). Veneer yield and MOE were compared on the basis of geographical region of log origin: Lake States (Michigan and Wisconsin) and Eastern States (New York, Pennsylvania, Vermont, and West Virginia). Veneer yield was tabulated based on four categories: 54-inch- (137-cm-) wide sheets, 36-inch- (91-cm-) wide sheets, strips, and fishtails. The only major difference in yield between the two regions was observed in the No. 2 logs. The Eastern States' No. 2 logs yielded approximately 13 percent more of the original log volume as 54-inch (137-cm) sheets. The MOE comparisons were based on results from the 54-inch (137-cm) sheets because the yield of 36-inch (91-cm) sheets was low. When grouped, the yield of 54-inch (137-cm) veneer sheets was similar for the No. 1 and No. 2 logs, but lower from the No. 3 logs. Decreases in the total veneer yield corresponded with decreases in log quality. The MOE values of veneer from all logs had a mean value of 1.80×10^6 lb./in.^{2} (12.4 GPa) and a standard deviation of 0.33×10^6 lb./in.^{2} (2.3 GPa).

A major shift is occurring in the ecology of eastern deciduous forests. There is an aggressive proliferation of red maple (*Acer rubrum*) as a consequence of past forest harvesting and use. Prior to the 20th century, red maple was confined to lowlands. Fire suppression and forest fragmentation triggered by urban sprawl have enabled red maple to become an increasingly significant component of the forest. Additionally, wildlife such as deer and turkeys rely heavily on oaks for food. Burgeoning populations of these species have a negative impact on oak generation, thereby providing opportunities for red maple. To provide for greater diversity in these forests, markets for red maple wood must be found so that cost-effective, active management can take place.

Research has shown that red maple has excellent potential as a structural material. For example, solid-sawn red maple can perform well in commonly used engineered components such as trusses and prefabricated I-joists (Brashaw et al. 2001). Red maple lumber can also be used in glued-laminated timber

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Table 1. — Log suppliers by state.

State	Supplier
Michigan	School of Forestry and Environmental Science Michigan Technological University Houghton, MI 49931
New York	Potter Lumber Co., Inc. PO Box 10 Allegany, NY 14706
Pennsylvania	Kane Hardwoods, A Collins Pine Company PO Box 807 Kane, PA 16735
Vermont	Mill River Lumber, Ltd. PO Box 100 North Clarendon, VT 05759
	Killington Wood Products PO Box 696 Rutland, VT 05701
West Virginia	Cranberry Hardwoods 263 White Oak Drive Beckley, WV 25801
Wisconsin	Kretz Lumber Co., Inc. W11143 Highway G PO Box 160 Antigo, WI 54409

Table 2. — Red maple sawn logs by state and visual grade.

	Number of logs by visual grade				
State	Total	Grade 1	Grade 2	Grade 3	Other
Lake States	23	10	4	5	4
Michigan	14	7	1	2	4
Wisconsin	9	3	3	3	--
Eastern States	25	5	12	8	--
New York	7	0	4	3	--
Pennsylvania	6	1	4	1	--
Vermont	6	2	2	2	--
West Virginia	6	2	2	2	--

(Janowiak et al. 1995). These efforts were based on earlier research that showed the good to excellent mechanical properties of red maple wood (Green and McDonald 1993).

Engineered composite materials represent one of the fastest growing segments of the wood products industry. Wood composite I-joists are used in more than 40 percent of new residential construction in North America, and laminated veneer lumber (LVL) is the primary material in I-joist manufacture. LVL is made in large billets from veneer sheets that are bonded together with an adhesive system. The billets can be produced to a specified thickness and cut to a desired width. One of the most significant technical advantages of LVL is the adaptability of its design to specific performance characteristics. By strategically placing selected veneer sheets within the composite, it is possible to manufacture a wood-based product that has well-controlled physical and mechanical properties. This enables LVL to be used in a variety of products, including commodity structural components, wind turbine blades, and other specialty products. The dominant raw materials used in current LVL production are southern pine and Douglas-fir, but LVL can be manufactured from a wide range of wood species.

Of critical importance to using a specific species in LVL is the ability to accurately assess the mechanical properties of individual veneer sheets. Also important is knowledge of the range of mechanical properties obtained from available sources. An excellent study by Kimmel and Janowiak (1995) showed that red maple can be used in LVL and that available ultrasonic veneer grading equipment used in LVL manufacturing facilities can be effectively used to grade red maple veneer. More importantly, the results from their testing showed that red maple would produce veneer that has good potential for LVL. The red maple veneer used in the study by Kimmel and Janowiak was obtained from a small sample of logs from one location. The purpose of the study reported in this paper was to expand on their positive results by investigating the ultrasonic grade yield from a larger sample of red maple veneer obtained from a range of sites throughout the Eastern and Lake States regions of the United States.

Materials and methods

Red maple logs were obtained from cooperating sawmills in six states (**Table 1**) and were graded according to Forest Service specifications (Rast et al. 1973). An attempt was made to secure two logs from visual grades No. 1, No. 2, and No. 3 from each state, but only the log suppliers from Vermont, West Virginia, and Wisconsin provided at least two sawlogs of each visual grade (**Table 2**). In total, 48 suitable logs were obtained. Because of the inconsistency in the number of logs supplied from each state, veneer yield could be compared only on the basis of geographic region of origin. The logs were grouped into either the Lake States region (Michigan and Wisconsin) or Eastern States region (New York, Pennsylvania, Vermont, and West Virginia). The number of logs by region and grade is given in **Table 2**.

The average diameter (calculated from inside the bark at each end of the log) and length were used to estimate total wood volume in each log. The logs were then debarked, steamed for 72 hours, and rotary peeled into nominal 1/8-inch- (standard 3-mm-) thick veneer. The diameter of the peeler core was set at 4 inches (102 mm). Individual sheets, strips, and fishtails were numbered to identify the log from which they were derived. To avoid mislabeling the veneer, one log was completely processed and labeled before another was rotary peeled. The veneer was dried to approximately 10 to 12 percent moisture content (MC) and shipped to the USDA Forest Service, Forest Products Laboratory (FPL) in Madison, Wisconsin, for ultrasonic testing.

At FPL, the 36- and 54-inch- (91- and 137-cm-) wide veneer sheets were hand fed through an ultrasonic veneer grader (Metriguard Model 2600) (**Fig. 1**). Three stress wave time readings (parallel to grain) were collected for the 36-inch (91-cm) sheets. Four measurements of stress wave time were taken on the 54-inch- (137-cm-) wide sheets. The stress wave time values were averaged to arrive at a single value for each sheet, and the modulus of elasticity (MOE) was calculated using the following equation (Pellerin and Ross 2002):

$$MOE = c^2 \cdot \rho \qquad [1]$$

$$MOE = 2.156(10^8)\left(\frac{1}{\Delta t^2}\right)\rho \qquad [2]$$

where:

Δt = stress wave time (μs/ft.) and

ρ = density of the veneer sheet (lb./ft.^{3}).

Data obtained from the ultrasonic veneer grader was verified by independently testing randomly selected sheets with a portable stress wave timer (Metriguard Model 239A). MC samples were also randomly selected during veneer measurement and ultrasonic grading process; MC was measured by the oven-dry method (ASTM D4442–92, ASTM 1999). Average MC was 6.3 percent and standard deviation (SD) was 1.15 percent.

Results and discussion

Veneer yield

The veneer from each log was grouped into four categories: 54-inch- (137-cm-) wide sheets, 36-inch- (91-cm-) wide sheets, strips, and fishtails. Measurements of length, width, thickness, and weight were used to calculate the volume and density of each sheet. The volume of strips and fishtails was estimated by weighing the veneer and using the average density of the 54-inch (137-cm) sheets from the same log to calculate volume.

Total veneer volume by region, visual log grade, veneer type, and veneer density is presented in **Table 3**. The density values found in this experiment were higher than those reported in the *Wood Handbook* (USDA 1999). Average density values for the red maple veneer were between 34.6 and 37.0 lb./ft.^{3} (554 and 542 kg/m^3), whereas the density of red maple reported in the *Wood Handbook* is 33.7 lb./ft.^{3} (539 kg/m^3). The higher density values of the experimental data are likely caused by errors in drying or dimension measurements of the veneer.

The veneer volumes in **Table 3** were converted to percentages based on corresponding total log volumes (**Table 4**). In general, the largest portion of veneer was recovered as 54-inch (137-cm) sheets, followed by strips, fishtails, and 36-inch (91-cm) sheets. The only exception occurred in the case of No. 1 logs from the Eastern States, where more veneer was recovered as 36-inch (91-cm) sheets than as fishtails.

Close examination of the yields and regional comparisons between the same log grades revealed that the Eastern States logs consistently yielded between 4 and 8 percent more veneer than yielded by the Lake States logs. When these comparisons are restricted to the amounts of veneer recovered in each of the four forms, there was an obvious difference between the No. 2 logs from the Lake States and the Eastern States. There is a large disparity in the amount of veneer recovered as 54-inch (137-cm) sheets: 41.4 percent of the log volume from the Eastern States logs was converted to full-sized sheets compared with only 28.4 percent of the log volume from the Lake States logs. Correspondingly, the Lake States logs yielded higher percentages of strips and fishtails.

It may be expected that the highest overall yield would come from the logs with the fewest defects (No. 1 logs) and

Figure 1. — Ultrasonic veneer grading at the Forest Products Laboratory in Madison, WI.

Table 3. — Red maple veneer yield from visual log grades.[a]

Region and log grade	Veneer volume (ft.^{3}) 54-inch sheets	36-inch sheets	Strips	Fishtails	Total from tree	Veneer density
						(lb./ft.^{3})
Lake States						
1	34.3	2.8	11.3	5.0	53.3	36.7
2	9.0	0.0	5.6	2.7	17.2	34.7
3	6.5	0.3	6.9	1.7	15.4	37.0
Eastern States						
1	23.8	3.3	8.7	2.3	38.1	35.0
2	19.0	1.3	15.8	8.2	74.2	34.6
3	21.7	3.1	16.8	6.5	47.9	35.4

[a] 1 ft.^{3} = 0.028 m^3; 1 lb./ft.^{3} = 16.0 kg/m^3; 1 inch = 25.4 mm.

Table 4. — Red maple veneer yield by log volume.

Region and log grade	Total log volume	Total % yield	Breakdown of yield (% yield from original log volume) 54-inch sheets	36-inch sheets	Strips	Fishtails	Waste and core
	(ft.^{3})	(by log volume)					
Lake States							
1	84.1	63.4	40.7	3.4	13.4	5.9	36.6
2	31.7	54.4	28.4	0.0	17.6	8.4	45.7
3	28.0	54.9	23.1	0.9	24.8	6.2	45.1
Eastern States							
1	55.9	68.2	42.6	5.8	15.6	4.1	31.8
2	118.3	62.7	41.4	1.1	13.3	6.9	37.3
3	80.7	59.4	26.8	3.8	20.8	8.0	40.6

Table 5. — Combined Eastern and Lake States red maple veneer yield.

Log grade	Total log volume	54-inch sheets	36-inch sheets	Strips	Fishtails	Total from tree
	(ft.^{3})					
		Veneer volume (ft.^{3})				
1	140.0	58.1	6.1	20.0	7.3	91.4
2	150.0	58.0	1.3	21.3	10.8	91.4
3	108.7	28.1	3.3	23.7	8.2	63.3
		Percentage of yield (by log volume)				
1	--	41.5	4.4	14.3	5.2	65.3
2	--	38.6	0.9	14.2	7.2	60.9
3	--	25.9	3.0	21.8	7.5	58.3

Table 6. — Average diameter of red maple sawlogs.

	Log diameter					
	No. 1 logs		No. 2 logs		No. 3 logs	
	Lake	Eastern	Lake	Eastern	Lake	Eastern
	11.5	13.3	11.8	12.0	9.8	12.5
	12.1	13.3	12.8	12.3	10.0	12.5
	13.3	15.5	13.5	13.0	10.8	13.5
	13.5	16.8	14.4	13.5	11.6	13.8
	13.8	18.5	--	13.8	12.8	14.0
	14.8	--	--	14.5	--	15.0
	15.0	--	--	14.5	--	16.5
	15.0	--	--	14.8	--	19.5
	18.3	--	--	15.5	--	--
	--	--	--	16.3	--	--
	--	--	--	16.8	--	--
	--	--	--	17.8	--	--
(Mean)	14.1	15.5	13.1	13.8	11.0	14.7

that the lowest yield would come from logs with the greatest number of defects (No. 3 logs). This would almost certainly be expected when considering veneer yield in the form of 54-inch (137-cm) sheets, where defects may limit sheet length. The overall veneer yield from the Eastern States logs did decrease with log quality, but this trend was not observed for the Lake States logs (**Table 5**). Furthermore, when only the yield of 54-inch (137-cm) veneer sheets was considered, two distinct groups of logs were observed:

1. No. 1 logs from Lake and Eastern States and No. 2 logs from Eastern States
   (veneer yield of 41% to 42% as 54-in.- [137-cm-] wide sheets)
2. No. 2 logs from Lake States and No. 3 logs from Lake and Eastern States (veneer yield of 24% to 26% as 54-in.- [137-cm-] wide sheets).

A possible explanation for the lower yield from the Lake States logs is that the Eastern States logs were larger, on average (**Table 6**). The mean diameter of all three visual grades of the Eastern States logs was greater than that of the Lake States logs, especially for the No. 3 logs. Since all logs were peeled to the same 4-inch (102-mm) core diameter, a constant volume was lost from each log. This constant core volume constitutes a larger percentage of a small log's volume and therefore could result in the recovery of a lower percentage of veneer (by overall log volume) from the smaller logs. Statistical hypothesis tests on the data support this logical explanation for No. 3 logs only.

Two-sample Student's t-tests were used to test the hypothesis that the mean diameters of the No. 1, No. 2, and No. 3 logs from the Lake States were smaller than the mean diameters of the corresponding logs from the Eastern States. At the 5 percent level of significance, the mean diameters of No. 1 and No. 2 logs were not significantly different (p = 0.550 and 0.306, respectively). Nevertheless, the yield from the Eastern States logs was approximately 5 percent higher for No. 1 logs and 7 percent higher for No. 2 logs. The mean diameter of the Lake States No. 3 logs was smaller than that of the Eastern States No. 3 logs (p = 0.018), but the total veneer yield was only approximately 4.5 percent lower, despite a 3.7-inch (94-mm) difference in diameter. These results suggest that the observed yield differences may have been due to other factors, such as the presence of defects or differences in roundness (leading to loss when logs are squared to a constant diameter on the lathe).

Veneer MOE

Figures 2 and 3 are histograms of MOE distributions of veneer by region and log grade. The MOE values of veneer from the Lake States logs follow a normal distribution with a mean of 1.80 $\times$ 10^6 lb./in.^{2} (12.4 MPa) and SD of 0.22 $\times$ 10^6 lb./in.^{2} (1.5 MPa). The MOE distribution of veneer from the Eastern States logs was skewed to the left, with a mean of 1.79 $\times$ 10^6 lb./in.^{2} (12.3 MPa) and SD of 0.37 $\times$ 10^6 lb./in.^{2} (2.6 MPa).

When comparing the two distributions, it is interesting to note the contribution of veneer from the No. 3 logs. The low MOE tail in **Figure 3** (Eastern States) can be attributed to veneer from the No. 3 logs. This might be expected because more prevalent knots would lead to lower MOE values. In addition, slope of grain is more prevalent in low visual grade logs, which can cause a decrease in MOE. When the MOE distribution from the Lake States logs is considered (**Fig. 2**), the No. 3 logs contribute to only the upper two-thirds of the distribution. Because of the inconsistency in MOE of veneer from the No. 3 logs, it is interesting to consider the MOE distributions from only the No. 1 and No. 2 logs.

When veneer from only the No. 1 and No. 2 logs is considered, both distributions are normal (**Figs. 4 and 5**). The veneer from the Lake States logs had an average MOE of 1.77 $\times$ 10^6 lb./in.^{2} (12.2 MPa) with a SD of 0.20 $\times$ 10^6 lb./in.^{2} (1.4 MPa), whereas the average MOE of veneer from the Eastern States was 1.89 $\times$ 10^6 lb./in.^{2} (13 MPa) with a SD of 0.25 $\times$ 10^6 lb./in.^{2} (1.7 MPa). Since the

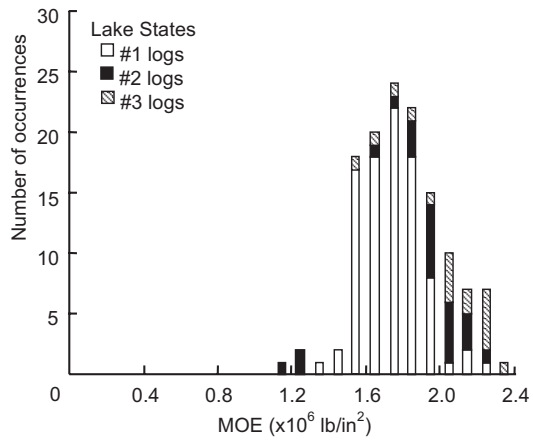

Figure 2. — Histogram of MOE results from Lakes States red maple sawlogs.

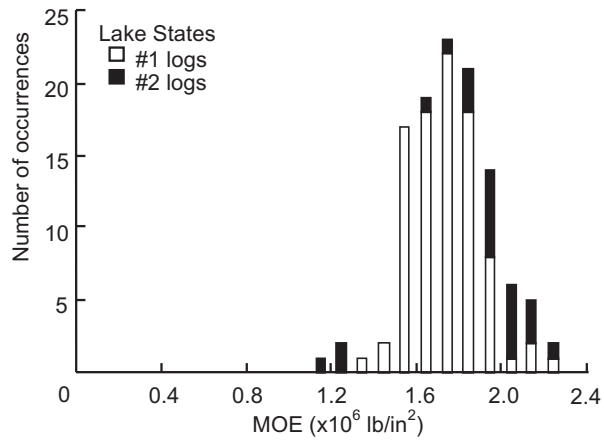

Figure 4. — Histogram of MOE of veneer from Lake States No. 1 and No. 2 grade red maple sawlogs.

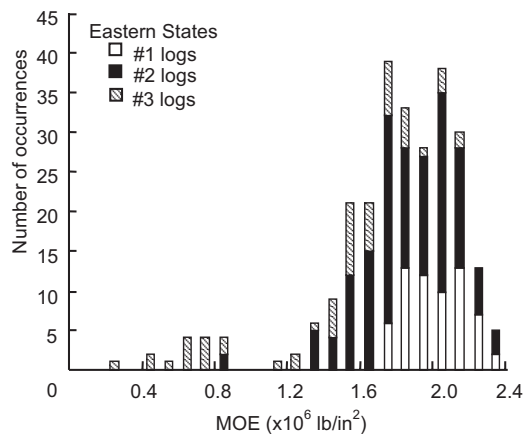

Figure 3. — Histogram of MOE of veneer from Eastern States red maple sawlogs.

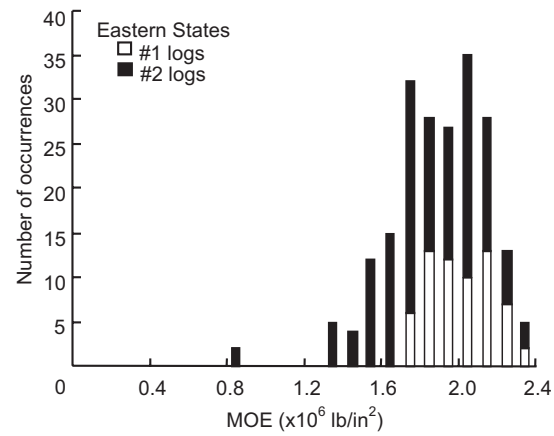

Figure 5. — Histogram of MOE of veneer from Eastern States No. 1 and No. 2 grade red maple sawlogs.

MOE values of veneer from both regions appear to be adequately modeled by a normal distribution, a two-sample Student's t-test can be used to compare their means. When the hypothesis that the MOE of veneer from the Eastern States logs is greater than that of the veneer from the Lake States logs is tested at the 5 percent significance level, the mean MOE of the Eastern States veneer is higher ($p < 0.000$).

A statistical comparison of the means of the two distributions, not including No. 3 logs, suggests that the difference of 120×10^6 lb./in.^{2} (8.3 MPa) is significant. However, in reality, this difference is not likely to have a physical consequence in the overall evaluation of the resource. The difference only becomes apparent when the No. 3 logs are ignored so as not to consider the low strength tail in the MOE distribution from Eastern States logs. The MOE of veneer from the No. 3 logs, and their yield as 54-inch (137-cm) sheets, is actually quite important to this work. These logs are the lowest cost raw material that was studied in this project. They typically sell for pulpwood prices. If a good yield of acceptable quality veneer were obtained, these logs could be a highly valuable resource for LVL manufacture.

Although the veneer yield from the Eastern States logs was found to be slightly higher than that from the Lake States logs, it may be best to combine all data. The data set is then a representative sample of the red maple resource, without regional comparison (**Fig. 6**). After all data are pooled, the MOE distribution still has a low MOE tail, with a mean of 1.80×10^6 lb./in.^{2} (12.4 MPa) and SD of 0.33×10^6 lb./in.^{2} (2.3 MPa). The combined data set (**Table 5**) suggests that the No. 1 and No. 2 logs yield similar amounts of veneer in the form of 54-inch (137-cm) sheets (41.5% and 38.6%, respectively) and strips (14.3% and 14.2%, respectively). The MOE values of the 54-inch (137-cm) sheets from the No. 1 and No. 2 logs follow a normal distribution with relatively low SD (**Fig. 6**). The No. 3 logs yielded 25.9 percent of the original volume as 54-inch (137-cm) sheets. The MOE of this veneer varied widely (**Table 5, Fig. 6**) but when the low price of these logs is considered, their use may provide an acceptable economic return. During LVL lay-up, the veneer from these logs would be sorted along with the rest of the veneer – low MOE material would go to the core and high strength material would go to the faces. The overall veneer yield generally decreased with decreased log quality, but by only approximately 7 percent (65.3% to 58.3%) (**Table 5**).

Conclusions

Comparisons of red maple veneer yield and MOE based on geographic re-

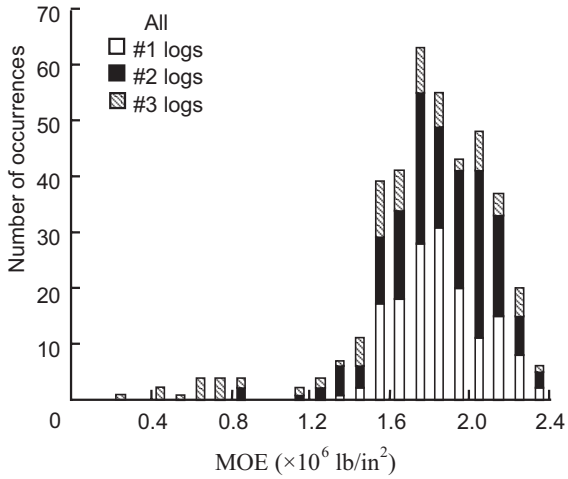

Figure 6. — Composite histogram of MOE of veneer from all red maple sawlogs.

gion of origin were attempted, but the data were best considered as a whole. In terms of the original log volume, veneer yield decreased with log quality, but only by 7 percent. The veneer yields from No. 1 and No. 2 logs as 54-inch (137-cm) sheets were actually quite similar – approximately 42 percent of log volume. While the No. 3 logs only yielded approximately 26 percent of the original log volume as 54-inch (137-cm) sheets, the low cost of these logs may make them a viable resource for LVL production. The MOE values of the veneer are normally distributed, with moderate variation: mean = 1.8×10^3 lb./in.^{2} (12.4 MPa); SD = 0.33×10^3 lb./in.^{2} (2.3 MPa). These values represent adequate strength properties for LVL manufacture. As may be expected, the distribution had a low strength tail that was attributed to veneer from the No. 3 logs. This material would likely be sorted out and used in the core, where high-quality veneer is not needed.

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