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Flexural Properties of Laminated Veneer Lumber Manufactured From Ultrasonically Rated Red Maple Veneer

A Pilot Study

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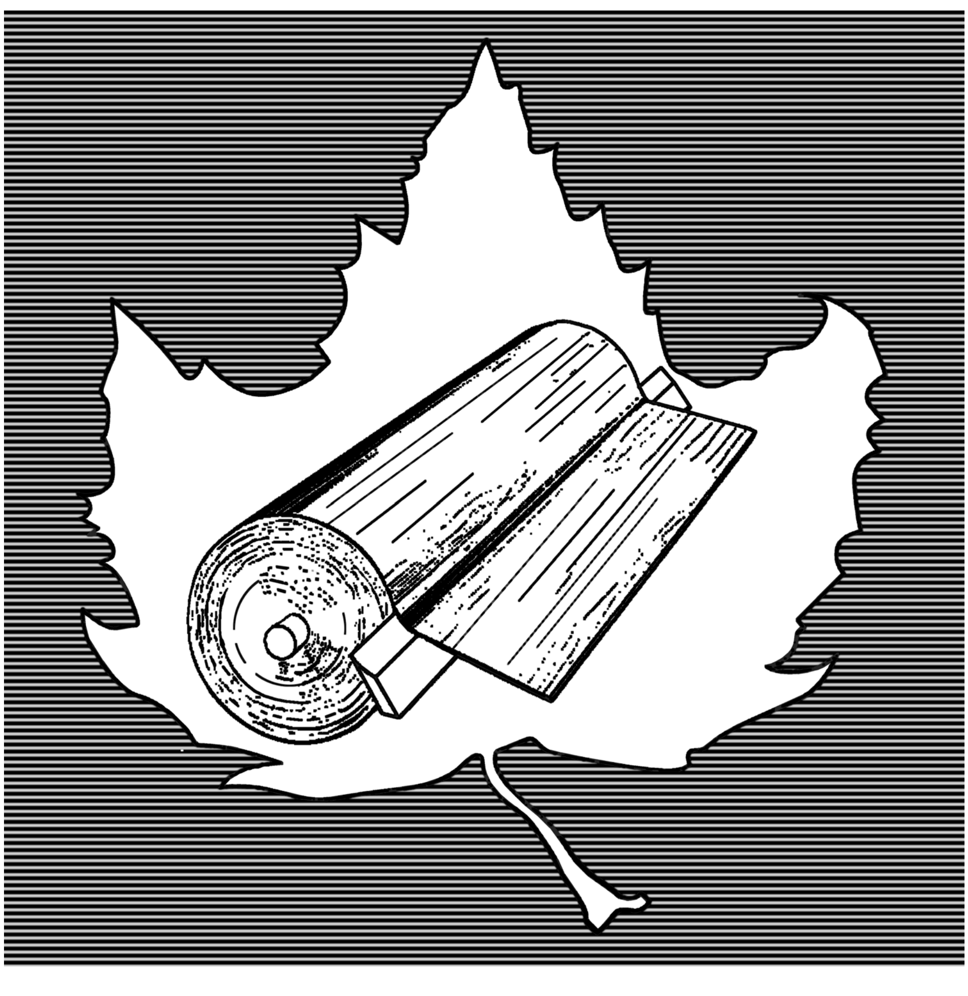

Abstract

The study described in this report was conducted to examine the flexural properties of laminated veneer lumber (LVL) manufactured from red maple veneer. Ultrasonically rated veneer, which was peeled from low value red maple sawlogs, was fabricated into 1/2-in.- (1.3-cm-) and 2-in.- (5-cm-) thick LVL billets. The flexural properties of the billets and of corresponding small specimens cut from the billets were determined through flatwise and edgewise static bending tests. Ultrasonic wave propagation time and corresponding dynamic modulus of elasticity of red maple veneer were found to be well correlated to strength and stiffness of LVL billets. The edgewise bending modulus of elasticity of the 2-in.- (5-cm-) thick LVL showed a positive relationship to the veneer layup pattern in terms of ultrasonic rating of veneer. The results of this preliminary study demonstrate that veneer peeled from low value red maple sawlogs may be used to manufacture high quality LVL products. The structural performance of red maple LVL billets might be improved through ultrasonic rating of individual veneer sheets.

Keywords: red maple veneer, laminated veneer lumber, flexural properties, ultrasonic rating

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Introduction

A major shift is occurring in the ecology of eastern deciduous forests. There is an aggressive proliferation of red maple as a consequence of past forest harvesting and use. Prior to the 20th century, red maple was confined to lowlands. As a result of fire suppression and forest fragmentation triggered by urban sprawl, red maple has become an increasingly significant component of the forest. 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.

Past research has shown that red maple has excellent potential as a structural material. These studies have demonstrated, for example, that solid sawn red maple can perform well in commonly used engineered components such as trusses and prefabricated I-joists (Brashaw and others 2001). In addition, red maple lumber can be used in glued-laminated timber (Janowiak and others 1995). These efforts are based upon 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% 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 that specific performance characteristics can be incorporated into its design. 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, such as commodity structural components, wind turbine blades, and other specialty products. Although Southern Pine and Douglas Fir are the dominant raw materials currently used in LVL production, LVL can be manufactured from a wide range of wood species.

Of critical importance to using a specific species in LVL is being able to accurately assess the mechanical properties of individual veneer sheets. In addition, knowledge of the range of mechanical properties is important. 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 used to grade red maple veneer. More important, the results from this study showed that the veneer produced from red maple has good potential for LVL.

Based on these positive results, an extensive study was undertaken to investigate the properties and yield of LVL-grade veneer from red maple logs (Brashaw and others, in press). In that study, 56 red maple logs from seven states (Michigan, Minnesota, Wisconsin, New York, Pennsylvania, Vermont, and West Virginia) were processed into veneer. The veneer was dried and tested in a commercially available ultrasonic veneer grader, and yields were determined.

The purpose of the pilot study reported here was to examine the flexural properties of LVL manufactured from ultrasonically rated red maple veneer sheets that were obtained in the previous study (Brashaw and others, in press). The specific objectives were as follows:

1. To determine the flatwise and edgewise bending properties of 1/2-in.- and 2-in.- (1.3- and 5-cm-) thick red maple LVL billets
2. To examine the relationship between nondestructive parameters of red maple veneer and flexural properties of LVL billets
3. To demonstrate the use of ultrasonic veneer grading for improving the structural performance of red maple LVL

Materials and Methods

In the first phase of the study, we determined the flatwise and edgewise bending properties of LVL billets and explored the predictability of their structural performance. The experimental procedure is shown in Figure 1. Twelve red maple veneer sheets that had been ultrasonically rated in a previous study (Brashaw and others, in press) were manufactured into 12 LVL billets in the laboratory. The sheets were selected on the basis of their corresponding dynamic modulus of elasticity (MOE_d) values. The MOE_d of red maple veneer was calculated from wave propagation time (T), gauge length (L), and veneer density (ρ) using the equation

$$MOE_d = \left(\frac{L}{T}\right)^2 \rho$$

The moisture content of the veneer was 5% to 8% at the time of ultrasonic testing.

Each 50- by 101- by 1/2-in. (127- by 257- by 1.3-cm) veneer sheet was first cut into four 25- by 50- by 1/2-in. (64- by 257- by 1.3-cm) sheets. The four sheets were then pressed into a 1/2-in.- (1.3-cm-) thick LVL billet (hereafter called "thin" billet). A phenol formaldehyde resin was applied at a rate of 34 lb/10^3 ft^2 (166 g/m^2) in LVL fabrication. Each billet was hot pressed at 175 lb/in^2 (1.21 MPa) for approximately 3 min at a platen temperature of 300°F (149°C). After hot pressing, billets were allowed to cool for 24 h. They were then trimmed and tested nondestructively using stress-wave and static bending (center-line loading) test methods to obtain estimates of modulus of elasticity.

Six 1- by 20- by 1/2-in. (2.5- by 51- by 1.3-cm) specimens were cut from each billet, parallel to grain. These specimens were conditioned at 74°F (23°C) and 65% relative humidity (12% equilibrium moisture content) for several weeks. Specimens were then tested to failure in edgewise bending using third-point loading. Both edgewise bending MOE (MOE_{ew}) and modulus of rupture (MOR) values were then determined.

In the second phase of the study, we examined the enhancement of structural performance of red maple LVL products. Forty-eight 25-1/2- by 101- by 1/8-in. (65- by 257- by 0.3-cm) ultrasonically rated veneer sheets from a previous study (Brashaw and others, in press) were used to make four 2-in.- (5-cm-) thick, 12-ply billets at the laboratory The veneer sheets were segregated into three MOE classes (low, medium, and high) based on their dynamic MOE values. The procedure of hot pressing in this phase was similar to that used in phase 1. First, four plies of the veneer were pressed to form a 1/2-in.- (1.3-cm-) thick panel. Three of these panels were then pressed to form a 2-in.- (5-cm-) thick billet (hereafter called "thick" billet). The layup patterns for the thick billets and dynamic MOE of the veneer are shown in Table 1.

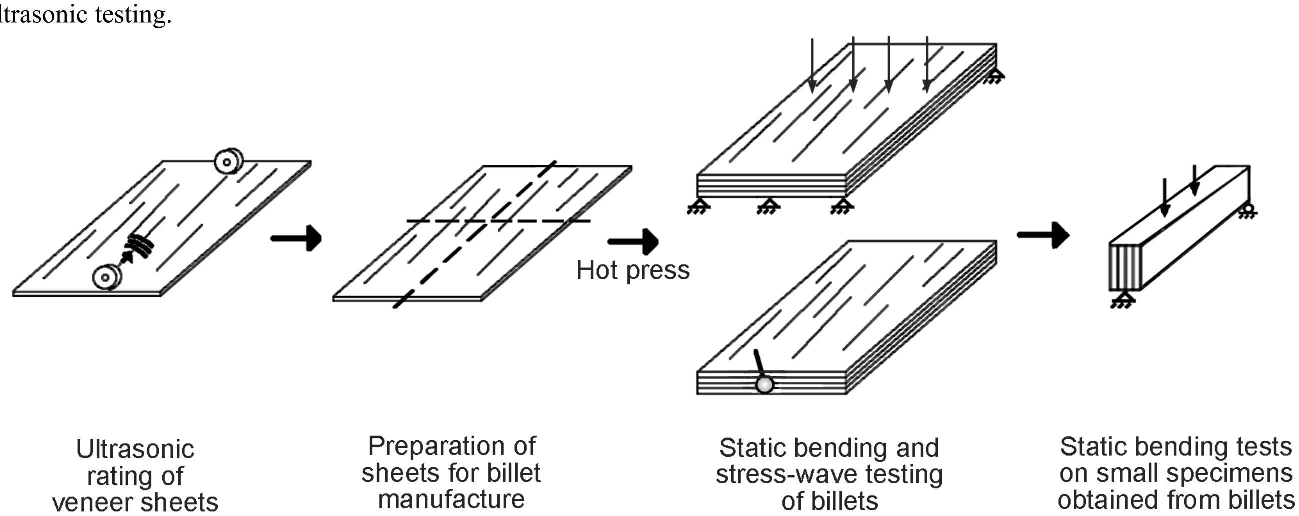

Figure 1—Flow chart for phase 1 of the study.

Table 1—Veneer layup pattern for thick[a] LVL billets and dynamic modulus of elasticity (MOE) of veneer

LVL billet	Layup pattern	Average dynamic MOE of veneer ($\times 10^6$ lb/in^2)
1	Homogeneous, low MOE	1.61
2	Homogeneous, medium MOE	1.80
3	Homogeneous, high MOE	2.10 2.04 (outer 1/3)
4	Nonhomogeneous, mixed quality	1.33 (inner 1/3) 2.04 (outer 1/3)

[a]2-in. (5-cm) thick.

Table 2—Results of tests on thin[a] LVL billets and corresponding small specimens[b]

Billet	Veneer MOE_d ($\times 10^6$ lb/in^2)	Billet MOE_{fw} ($\times 10^6$ lb/in^2)	Small specimen MOE_{ew} ($\times 10^6$ lb/in^2)	Small specimen MOR (lb/in^2)
1	1.51	1.09	1.44	9,930
2	1.80	1.91	1.67	12,034
3	2.32	2.06	1.82	13,605
4	1.67	1.68	1.43	12,210
5	1.75	1.69	1.50	13,637
6	2.10	1.87	1.72	14,414
7	1.37	1.40	1.41	8,265
8	1.34	1.09	1.20	8,600
9	2.04	1.81	1.81	14,218
10	1.44	1.47	1.28	11,296
11	1.64	1.75	1.64	11,204
12	2.13	1.82	1.78	15,564
Average	1.76	1.64	1.56	12,081
STD	0.311	0.299	0.202	2,228.5

[a]1/2-in. (1.3-cm) thick.
[b]MOE_d, dynamic modulus of elasticity
MOE_{fw}, flatwise bending modulus of elasticity
MOE_{ew}, edgewise bending modulus of elasticity
MOR, modulus of rupture
STD, standard deviation

The first three LVL billets were manufactured from veneer that had similar quality based on ultrasonic rating, and had low, medium, and high dynamic MOE values, respectively (Table 1). The fourth billet was manufactured from veneer that had mixed quality, with the veneer that had high dynamic MOE values on the outer layers and the veneer that had low dynamic MOE values in the core. The billets were pressed and cooled overnight. Each billet was then cut into five 2-by 4-in. (5- by 10-cm) by 8-ft- (2.4-m-) long specimens. Edgewise bending tests were performed on these specimens through third-point loading (ASTM 1999) to obtain estimates of flexural properties.

Results and Discussion

Thin Billets

Test results for the thin (1/2-in.-, 1.3-cm-thick) billets and corresponding small specimens are summarized in Table 2. The average values for billet MOE and small specimen MOE are similar to bending MOE values reported in the *Wood Handbook* for clear red maple (Forest Products Laboratory 1999). The observed MOR values for the small specimens are slightly lower than corresponding clear wood values. These results are encouraging as they indicate that the stiffness and strength of LVL manufactured from red maple would be comparable to that of clear wood. While these results are notable, caution should be exercised because the sample size was small.

To explore the predictability of structural performance of LVL billets manufactured from ultrasonically rated red maple veneer, we conducted linear regression analysis to examine the relationship between nondestructive parameters of red maple veneer and static bending properties of corresponding LVL billets. The results of regression analysis are summarized in Table 3.

Figures 2 and 3 illustrate typical relationships between nondestructive parameters of red maple veneer and static bending properties of LVL billets and small specimens. Both wave propagation time and dynamic MOE of veneer are significantly correlated to the static bending properties of the LVL billets. The correlation coefficients for the relationships range from 0.78 to 0.86 for T versus $MOE_{fw/ew}$/MOR and 0.84 to 0.91 for MOE_d versus $MOE_{fw/ew}$/MOR. Dynamic modulus of elasticity of red maple veneer, as calculated from wave propagation time, gauge length, and veneer density, is apparently a better predictor of the structural properties of LVL billets than is wave propagation time. This indicates that both ultrasonic wave propagation time and veneer density should be taken into account when using ultrasonic propagation to sort red maple veneer for LVL manufacture.

Table 3—Results of linear regression analysis of relationship between nondestructive parameters of red maple veneer and flexural properties of thin LVL billets[a]

Nondestructive parameter of veneer (x)	Flexural properties of LVL (y)	$y = a + bx$		r	S_{yx}
		a	b		
T	MOE_{fw} of billet	4.810	-0.0478	0.78	0.203
	MOE_{ew} of small specimen	3.897	-0.0352	0.86	0.114
	MOR of small specimen	36,480.6	-367.4	0.81	1435.47
MOE_d	MOE_{fw} of billet	0.217	0.8068	0.84	0.177
	MOE_{ew} of small specimen	0.517	0.5918	0.91	0.090
	MOR of small specimen	956.3	6,324.1	0.88	1145.36

[a] T, ultrasonic wave propagation time; MOE_d, dynamic modulus of elasticity; MOE_{fw}, flatwise bending modulus of elasticity; MOE_{ew}, edgewise bending modulus of elasticity; r, correlation coefficient; S_{yx}, standard error of estimate.

Thick Billets

The MOE of 2-in.- (5-cm-) thick LVL billets manufactured from ultrasonically rated red maple veneer is shown in Figure 4. The error bar indicates the standard deviation (±1 standard deviation). An analysis of variance (at 95% confidence level) of the MOE values indicated that the separation among the low, medium, and high MOE layups was statistically significant. The average dynamic MOE of red maple veneer was 1.61, 1.80, and 2.10 $\times 10^6$ lb/in^2 (11.10, 12.41, and 14.48 GPa) for low, medium, and high MOE layups, respectively. The corresponding edgewise bending MOE of the billets was 1.73, 1.98, and 2.22 $\times 10^6$ lb/in^2 (11.93, 13.65, and 15.31 GPa), respectively. The layups containing veneer with higher dynamic MOE apparently had higher edgewise bending stiffness. The mixed MOE layup yielded an edgewise bending MOE value equivalent to the mean of the medium MOE layup. In addition, note that the edgewise bending MOE of the billets was about 8%, 10%, and 6% higher than the dynamic MOE of veneer for low, medium, and high MOE layups, respectively. This finding is in agreement with the results reported by Kimmel and Janowiak (1995). It is generally believed that the enhanced stiffness is mainly due to the lamination effect in LVL fabrication. These results suggest that the structural performance of red maple LVL billets might be improved through the application of ultrasonic rating of veneer and the use of optimized layup patterns in LVL fabrication.

Some delamination was found in the thick LVL billets. The delamination usually appeared on one glue line and one edge of the billets. This might have been caused by uneven spread of resin on the veneer sheets, inappropriate resin type (the resin used was designed for Southern Pine plywood), or the not-yet-optimized hot-press schedule. Delamination was not severe overall, but it does require further attention to process variables, such as resin composition, pressing pressure, press temperature, and cycle time.

Conclusions

Ultrasonically rated red maple veneer was fabricated into 1/2-in.- (1.3- cm-) and 2-in. (5-cm-) thick LVL billets. The flexural properties of the billets and corresponding small specimens cut from the billets were determined through flatwise and edgewise static bending tests. The results of this preliminary study indicate that veneer peeled from low value red maple logs may be used to manufacture high quality LVL products. Ultrasonic wave propagation time and corresponding dynamic MOE of red maple veneer were well correlated to the flexural properties of the LVL billets. The edgewise bending MOE of the LVL billets showed positive relation to the layup pattern in terms of stress-wave rating of veneer. This implies that the performance of red maple LVL can potentially be enhanced through ultrasonic rating of individual veneer sheets.

The experimental data in this study were obtained from a small sample of specimens. To understand the full potential of red maple veneer as a structural material in LVL production, further research is necessary to investigate the effects of veneer layup pattern, grain angle, resin load, and other process variables on LVL structural performance. We also recommend that a mixture of red maple and other hardwood species be included in future study.

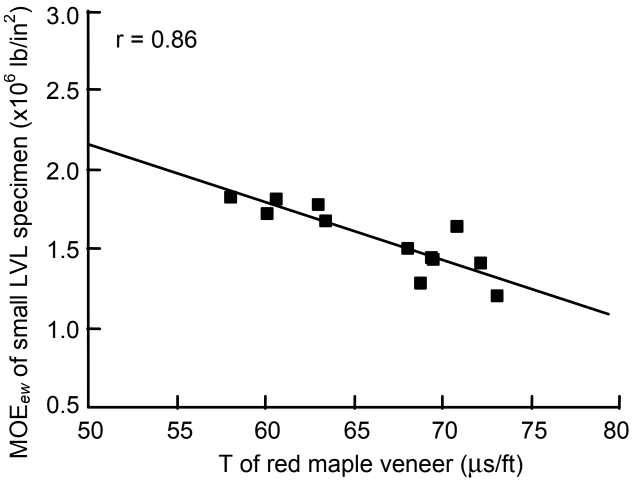

Figure 2—Relationship between ultrasonic wave propagation time (*T*) of red maple veneer and edgewise bending MOE (MOEe$_w$) of small LVL specimens.

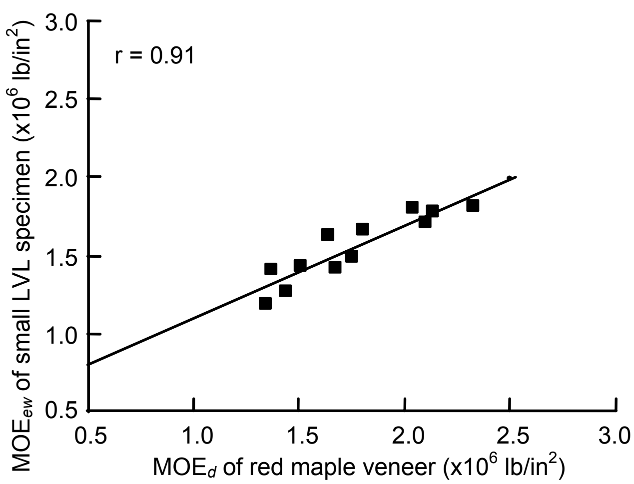

Figure 3—Relationship between stress-wave MOE (MOE$_{sw}$) of red maple veneer and edgewise bending MOE of small LVL specimens.

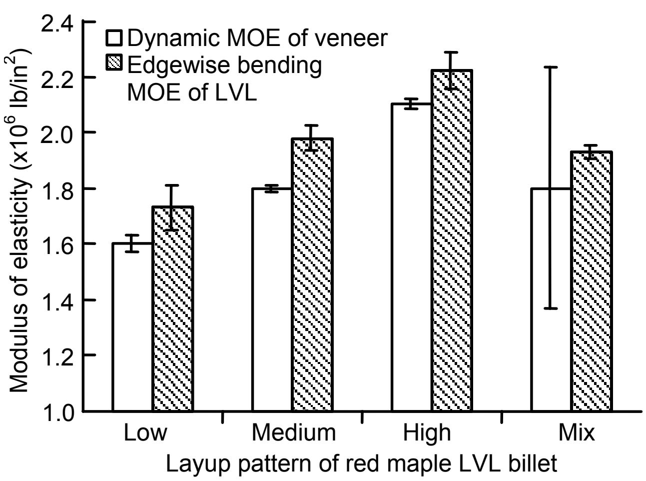

Figure 4—Modulus of elasticity of 2-in.- (5-cm-) thick red maple LVL.

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