

End jointing of laminated veneer lumber for structural use

J.A. Youngquist
T.L. Laufenberg
B.S. Bryant

Abstract

Laminated veneer lumber (LVL) materials represent a design alternative for structural lumber users. The study of processing options for producing LVL in plywood manufacturing and glued-laminating facilities is of interest as this would allow existing production equipment to be used. This study was conducted in three phases to assess the feasibility of using visually graded veneer to produce 8-foot LVL lengths which, when end jointed, could be competitive with existing structural lumber products. Phase I evaluated panel-length 3/4-inch-thick LVL made from C- or D-grade 3/16-, 1/8-, or 1/10-inch-thick veneer, and the effect of specimen width on flexural and tensile properties. Phase II evaluated the use of vertical and horizontal finger joints and scarfjoints to join 3/4-inch thicknesses of LVL. Phase III investigated end-joint configurations for 1-1/2-inch thicknesses of LVL. Comparison of the LVL tensile properties with several grades of structural lumber shows that C-grade veneer in 1/8- and 1/10-inch thicknesses can be used to produce a structural product. No width effects could be detected in this study. The strengths of all of the LVL specimens (both unjointed and jointed) compared favorably with most high-strength lumber grades. The low variability of strength properties of the LVL contributed to this favorable strength comparison.

Parallel-laminated veneer (PLV) panels, when ripped into lumber-width, become laminated veneer lumber (LVL). LVL is proving to be a commercially viable product in markets traditionally held by select grades of stress-rated solid-sawn lumber (6,7). The LVL products on the U.S. market at present (6,8) utilize a

proprietary process for manufacturing extremely long lengths of the material both in panel widths and in LVL form. The proprietary process requires a substantial capital investment, limiting production of LVL. If existing plywood facilities were adapted to processing of 5/8-inch- to 1-1/2-inch-thick panels, subsequent panel ripping and end jointing of the resultant structural components could conceivably compete both in price and performance with the highest structural grades of lumber. Herein lies the major concern of this study: Is it technically feasible to manufacture end-jointed LVL from PLV panels made in conventional plywood presses?

An evaluation of the production and marketing feasibility of LVL products made from panel lengths (16) indicated that the most promising of these applications were engineered products in long lengths such as headers, truss chords, tension lamination stock, or manufactured housing components. Another area shown to have market potential for LVL included products requiring reliable strength properties, availability

The authors are, respectively, Project Leader and Engineer, Composite Products, USDA Forest Serv., Forest Prod. Lab., P.O. Box 5130, Madison, WI 53705; and Professor, Wood Utilization Tech., College of Forest Resour., Univ. of Washington, Seattle, Wash. This research was funded by a cooperative agreement between the Univ. of Washington College of Forest Resour. and the Forest Prod. Lab.. The contributions of Raymond Nizolek, Dennis Sampson, and William W. Chastain, graduate student research assistants, are gratefully acknowledged. This research would not have been possible without the wholehearted cooperation of the American Institute of Timber Construction, The American Plywood Assoc., and industry. The assistance of Catherine Marx, Research Engineer at the Forest Prod. Lab., in providing advice and review comments on this report is greatly appreciated. This paper was received for publication in November 1983.

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in satisfactory sizes, and the capability of being treated with preservatives. Such products would include truck decks, scaffold planking, crossarms, and ladder rail stock

In light of the potential markets for LVL products, it was of interest to evaluate some of the anticipated LVL constructions that utilized various thicknesses and grades of veneer without end joints, and then to study the properties of the more promising of these in the end-jointed form. This study was an outgrowth of earlier work at the Forest Products Laboratory on PLV products made from thick veneer (11, 17).

This study was divided into three phases. Phase I evaluated the processing variables of veneer grade, veneer thickness, and LVL width on the mechanical properties of 3/4-inch Douglas-fir LVL. Phase II involved study of vertical and horizontal finger joints and plain scarfjoints in panel-length 3/4-inch LVL and their performance under tensile loading. Phase III considered jointing and face laminating of 3/4-inch (nominal 1-in.) material to produce 1-1/2-inch (nominal 2-in.) LVL with offset scarf and a three-stage – or folded – scarf joint.

No attempt was made to develop design properties for any material in this study. Sample sizes were selected for assessment of technical feasibility of producing high-strength LVL using plywood and glued-laminating (glulam) facilities.

Phase I — LVL performance study

The objective of Phase I was to study the effect of veneer grade, veneer thickness, and LVL width on the bending strength, bending modulus of elasticity, tensile strength, and tensile modulus of elasticity of LVL made from 3/4-inch, 8-foot panels of PLV.

A thickness of 3/4 inch was selected for several reasons: 1) a market exists for nominal 1-inch structural lumber, used, for example, in lightweight trusses for mobile homes; and 2) some softwood plywood plants in the Douglas-fir region may prefer to manufacture 3/4-inch-thick panels because the "daylight" (the opening between press plates) may be too small for the more conventional, thicker panels.

'specimen fabrication and testing

The three Douglas-fir veneer thicknesses selected were nominal 3/16-, 1/8-, and 1/10-inch, commonly available in West Coast plywood plants. To make 3/4-inch-thick PLV billets, four, six, and eight plies of veneer, respectively, were required. Mill-run veneer, from mixed old-growth and young-growth Douglas-fir of both C and D grades, as defined by Product Standard PS 1-74 (15), was used throughout.

Since width effects have been found to influence the strength properties of structural lumber, and since knots and knotholes in Douglas-fir veneer tend to occur in rows across the veneer width, it was felt prudent to include a side-matched width factor in the experiment. Thus 3-1/2-, 7-1/4-, and 11-1/4-inch widths were selected as representative of the normal widths of structural lumber used in the glulam, industry.

A commercially produced phenol-formaldehyde resin formulation, commonly used in the plywood in-

dustry, was applied to the veneer with a double roll spreader. Normal resin spread rates (typically 60 lb./1,000 ft.² of glueline) were used. Typical pressing times for plywood with similar veneer thickness constructions were used (11 min. at 285°F for the 1/10-in. veneer), but a lower-than-normal pressure (150 psi) was used to reduce compression losses in the PLV. In all, 72 nominal 2- by 8-foot half panels (billets) of PLV were pressed at a commercial plywood plant in Tacoma, Wash. After pressing, the PLV panels were taken to a remanufacturing operation where they were trimmed and ripped into 12 sets of the 3 widths.

Half of the 8-foot-long, side-matched sets of three widths were tested in full-span tension to determine both stress at failure and tensile modulus of elasticity (MOE). Testing procedures outlined in ASTM D 198-76 (3) were used. A 48-inch gauge-length was used to measure the specimen stiffness. The other half of the side-matched sets were tested for modulus of rupture (MOR) and MOE in flatwise bending, using the test procedures outlined in ASTM D 3043-76 (4). The test machine imposed flexural stresses on the specimen by applying a pure moment force perpendicular to the plane of the panel.

Results and discussion — Phase I

The tensile MOE values were distributed about a mean of 2.09×10^6 psi for all C-grade veneer specimens and 1.72×10^6 psi for all D-grade veneer specimens (Tables 1 and 2). The flexural MOE average for C-grade material was 2.23×10^6 psi and for D-grade equaled 1.88×10^6 psi (Tables 1 and 2). These differences in both tensile and flexural MOE were deemed significant. Specimen width and veneer thickness did not significantly affect either the tensile or flexural MOE. Comparisons of different populations of data were performed by an analysis of variance (ANOVA) at a confidence interval of 95 percent.

The overall average tensile strengths of the C-grade constructions were significantly greater than the D-grade material (5,130 psi vs. 3,990 psi). The overall average MOR values for flatwise bending specimens also showed this result (7,190 psi vs. 5,780 psi). For both C- and D-grade veneer, the overall average MOR for flatwise bending of 3/16-inch-thick veneer LVL was significantly lower than that obtained from 1/8- and 1/10-inch veneer LVL. Specimen width did not significantly affect the flatwise bending MOR. The overall averages for both strength properties tested for LVL made with D-grade veneer were significantly lower than LVL with C-grade veneer, except for material made from 1/10-inch veneer, where a nonsignificant difference was found between grades.

Thus, significant differences for both MOE, tensile strength, and MOR for C and D veneer grades, suggest that D-grade veneer, from some mills at least, might produce satisfactory LVL if restrictions could be imposed on existing grading rules to eliminate large areas of sloped grain that are associated with burls, knots, and knotholes of Douglas-fir, but that are not measured as part of the knot or the knothole for grading purposes.

TABLE 1. - Detailed summary of test results for Phase I.

Specimen width	Veneer grade	Veneer thickness	Tension ^{a,b}		Flat-wise bending ^{a,b}	
			Avg. strength	Avg. MOE	Avg. MOR	Avg. MOE
(in.)		(in.)	(psi)	(million psi)	(thousand psi)	(million psi)
3-1/2	C	3/16	4,130 (14.7)	2.07 (13.7)	5,670 (24.3)	2.14 (14.7)
		1/8	5,420 (21.9)	1.94 (7.2)	8,080 (20.9)	2.21 (10.2)
		1/10	5,594 (16.1)	2.11 (10.4)	7,970 (21.5)	2.28 (6.9)
	D	3/16	2,730 (33.2)	1.60 (13.7)	3,970 (39.8)	1.80 (13.1)
		1/8	4,300 (24.9)	1.75 (6.2)	5,670 (25.0)	1.80 (9.5)
		1/10	5,440 (22.5)	1.77 (8.1)	7,470 (14.8)	1.86 (10.4)
7-1/4	C	3/16	3,950 (22.2)	2.04 (16.3)	6,530 (37.1)	2.20 (7.3)
		1/8	5,700 (9.6)	2.09 (8.4)	8,150 (8.2)	2.24 (6.4)
		1/10	5,850 (16.3)	2.21 (9.8)	7,340 (15.3)	2.28 (5.3)
	D	3/16	2,710 (28.8)	1.62 (14.8)	4,800 (23.2)	1.82 (9.1)
		1/8	3,660 (13.9)	1.71 (5.7)	6,340 (22.1)	1.92 (18.6)
		1/10	5,640 (17.5)	1.86 (6.9)	6,800 (8.5)	1.86 (10.5)
11-1/4	C	3/16	4,170 (25.6)	2.00 (10.7)	5,650 (16.9)	2.23 (7.4)
		1/8	5,830 (8.7)	2.13 (2.7)	7,960 (7.4)	2.25 (8.5)
		1/10	5,500 (17.0)	2.20 (7.2)	7,420 (11.1)	2.28 (6.7)
	D	3/16	2,540 (12.4)	1.63 (11.3)	4,810 (21.1)	1.89 (5.1)
		1/8	3,460 (23.5)	1.77 (11.3)	5,900 (12.3)	2.01 (12.0)
		1/10	5,460 (12.4)	1.80 (5.8)	6,260 (13.9)	1.93 (7.6)
All widths	C	3/16	4,080 (20.4)	2.3 (13.4)	5,950 (27.8)	2.19 (9.8)
		1/8	5,650 (13.9)	2.05 (7.4)	8,060 (12.9)	2.25 (8.0)
		1/10	5,650 (15.9)	2.17 (9.0)	7,580 (16.3)	2.28 (6.0)
	D	3/16	2,660 (25.7)	1.61 (12.7)	4,530 (27.7)	1.84 (9.0)
		1/8	3,810 (22.8)	1.75 (7.6)	5,970 (19.9)	1.91 (13.9)
		1/10	5,520 (17.5)	1.80 (6.2)	6,840 (14.2)	1.88 (9.2)

^aNumerical average of seven tests; moisture content averaged 9.5% for tension tests, 7.2% for bending tests.

^bNumbers in parentheses are coefficients of variation (COV).

TABLE 2. - Overall summary of test results for Phase I.

Specimens	Veneer grade	Veneer thickness	Tension ^a			Flat-wise bending ^a	
			Avg. strength	5% exclusion limit ^b	Avg. MOE	Avg. MOR	Avg. MOE
		(in.)	(psi)	(psi)	(million psi)	(thousand psi)	(million psi)
All widths ^c	C	3/16	4,080 (20.4)	2,650	2.03 (13.4)	5,950 (27.8)	2.19 (9.8)
		1/8	5,650 (13.9)	4,300	2.05 (7.4)	8,060 (12.9)	2.25 (8.0)
		1/10	5,650 (15.9)	4,100	2.17 (9.0)	7,580 (16.3)	2.28 (6.0)
	D	3/16	2,660 (25.7)	1,480	1.61 (12.7)	4,530 (27.7)	1.84 (9.0)
		1/8	3,810 (22.8)	2,310	1.75 (7.6)	5,970 (19.9)	1.91 (13.9)
		1/10	5,520 (17.5)	3,860	1.80 (6.2)	6,840 (14.2)	1.88 (9.2)
All widths and all thickness	C	—	5,130		2.09	7,190	2.24
	D	—	3,990		1.72	5,780	1.88

^aNumbers in parentheses are coefficients of variation (COV).

^bLower 5% exclusion limit = $x - t_{0.05}x COV/100$.

^cNumerical average of 21 tests; moisture content averaged 9.5% for tension tests, 7.2% for bending tests.

^dNumerical average of 63 tests.

Statistical analysis revealed that the width effect was not significant for any property tested. Thus, chance combination of defects (knots, knotholes, and sloped grain) between plies within the critical section of any individual piece of LVL (i.e., veneer grade) was more important than the influence of defects across the width of any one ply of the three side-matched specimens. Even in the narrow boards, the relatively high proportion of the width affected by wild grain of a single

veneer layer apparently was not as important as the combined effect of grain deviations through the entire cross section.

Since the intent of this study was to show feasibility, the sample sizes do not lend themselves to definitive statements regarding allowable stresses for the LVL constructions. A comparison that may prove informative is one between tensile tests of solid-sawn single-ply 2 by 6 members (AITC uses two or more plies

as a basis for assigning design allowables) and the LVL members tested in this study. Recently reported (9) tensile strength values for single plies of several laminating grades are summarized in Table 3 along with the coefficient of variation (COV) and the 5 percent exclusion limit for each group. The C-grade 1/10-inch veneer material had a 5 percent exclusion limit (Table 2) that has the same value for the 301A grade (1) of laminating stock (4,100 vs. 4,080 psi, respectively), assuming normal distribution of both populations (see Tables 2 and 3). A number of LVL configurations appear to be capable structural substitutes for the 301B grade (1). All of the LVL configurations, except the 3/16-inch D grade, are shown to be feasible substitutes for the L2 grade (13). All of the C-grade LVL made from either 3/16-, 1/8-, or 1/10-inch veneer appear to be capable of being substituted for either the L1 or L2 grades (13). The favorably low COV for the LVL material is readily seen in this comparison.

Summary — Phase I

LVL made from the 1/10- and 1/8-inch Douglas-fir unselected, visually graded C-grade veneer used in this study has sufficient tensile strength to be feasible as a substitute for high-grade structural lumber. Laminating grades of LVL can also be made from C-grade 3/16-inch veneer. There was no effect of width for either grade or thickness of veneer used. With some visual grading restrictions with respect to sloped grain, 1/B- and 1/10-inch D-grade veneer might also be used to make LVL suitable as a substitute for intermediate grades of structural lumber.

Phase II — 3/4-inch LVL end joints

The objective of Phase II was to determine if 1/10-inch C-grade LVL could be end jointed to produce material of satisfactory tensile strength using conventional equipment found in typical plants producing structural glulam timbers.

Materials and methods

The 3/4-inch LVL test material was fabricated using 1/10-inch-thick veneers. Specimen joints tested

included a plain scarf, a horizontal finger joint, and a vertical finger joint (Fig. 1), as well as a control (no joint).

Douglas-fir veneer was produced at a Washington mill using second-growth, small-diameter logs (average block diam. = 10.5 in.) and at an Oregon mill that used typical old-growth logs with a wide range of diameters. All veneer was judged by mill graders to be representative of the C-grade (14) quality classification. Before laminating, the defects in each 25-inch-wide by 100-inch-long veneer sheet were carefully mapped, and the sheet's MOE was determined (10) by a non-destructive stress wave timing-test method.

Panel layup was as in Phase I, except that the panels were pressed in a single-opening hot press at the American Plywood Association laboratory in Tacoma, Wash. The B-foot-long panels of PLV were ripped to 5-1/2-inch-wide by B-foot-long pieces of LVL. Each type of end joint in the LVL was produced by one of three different glulam plants using commercial procedures. The scarf joint was cut with a slope length of 6-1/4 inches on the 3/4-inch LVL, a slope of 1:8.3. A phenol-resorcinol-formaldehyde adhesive was applied to the scarf, and the material was clamped and allowed to cure overnight at 110°F.

The horizontal and vertical finger joints had a finger length of 1.11 inches, a pitch of 0.23 inch, and a tip thickness of 0.03 inch. The LVL was machined using a production line setup that included an impression glue applicator, a crowder mechanism to develop end pressure, and a radiofrequency tunnel for adhesive cure. A melamine urea-formaldehyde adhesive was used for these two joint types.

Tensile tests of the three joint types and the control specimens were made with a long-span machine to test the B-foot-long specimens in accordance with ASTM D 198-76 (3). Gauge length of each test specimen was approximately 4 feet. A total of 136 specimens was tested to failure and the results analyzed statistically.

TABLE 3. — Summary of tensile strength of lumber grades for single-ply Douglas-fir 2 by 6's.

Grade	No. of specimens (9)	Average ultimate tensile strength (psi) (9)	Coefficient of variation (%) (9)	5% exclusion limit ^a (psi)
301A ^b	20	7,450	26.2	4,080
301B ^c	21	5,220	36.1	1,980
Select structural ^d	26	4,710	33.6	2,010
L1 ^e	19	4,230	38.5	1,410
L2 ^e	22	3,370	37.5	1,200

^aLower 5% exclusion limit = $\bar{x} - t_{.05} \bar{x} COV/100$. Calculation made based on data presented in reference (9).

^bIdentical to 301-24 laminating grade lumber described in AITC (1) except that a 4-ft., rather than 2-ft, spacing was required between maximum strength-reducing characteristics.

^cIdentical to 302-22 (see (1)).

^dSee (14).

^eSee (13).

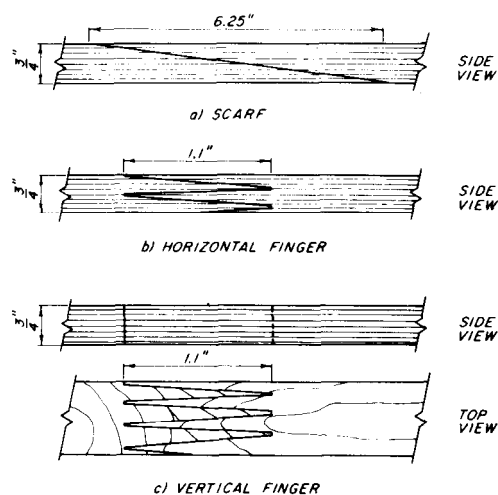


Figure 1.—End joints investigated for use with 3/4-inch LVL.

Results and discussion — Phase II

Machining of the vertical and horizontal finger joints in the LVL resulted in fast dulling of the cutter-head. This was especially apparent in the horizontal finger joints where the hard gluelines wore the cutters at one location on the tool. An estimate of the usable time for each cutter assembly was 5 minutes compared to 4 hours for solid wood. The cutting of vertical finger joints in the LVL was estimated to shorten cutterhead life to 30 minutes.

The LVL from old-growth Oregon veneer was consistently stronger in tensile tests than the Washington second-growth veneer LVL, and this effect was statistically significant for all joints tested and for the control specimens (Fig. 2). The veneer from both log sources had the same specific gravity (0.45 oven-dry weight and volume), but the veneer from small (Washington) logs had wider growth rings and hence a higher percentage of earlywood exposed in single fingers of the end joints. After lamination, the Oregon LVL had a higher specific gravity (0.55) than the Washington LVL (0.53), due to higher compression losses during processing.

The scarf joint showed the highest ultimate tensile strength, averaging 5,210 psi for both types of veneer (Fig. 2). This compared favorably with the unjointed controls, which averaged 5,480 psi. The joint efficiency (average joint strength/control strength) of this material averaged 95 percent (10). The vertical and horizontal finger joints showed both lower composite averages — 4,550 and 3,890 psi, respectively — and correspondingly lower joint efficiencies — 83 and 71 percent, respectively.

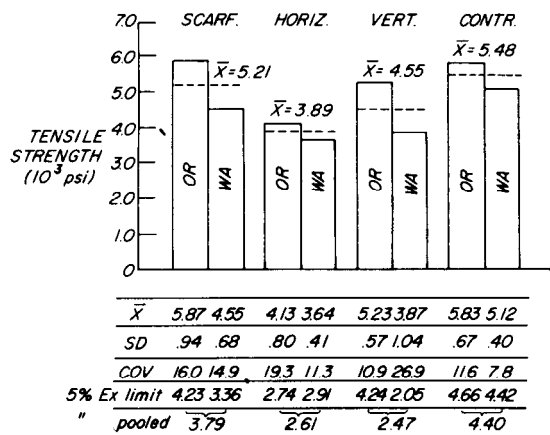


Figure 2. — LVL end-joint tensile strength for end-matched scarf joints, horizontal and vertical finger joints, and controls, made from eight plies of 1/10-inch C-grade old-growth (Oregon) and young-growth (Washington) Douglas-fir veneer, for 18 and 16 specimens, respectively, for each joint type.

5% Ex limit = lower 5% exclusion limit = $\bar{x} - 1.755$ SD.
(Note: This assumes a normal distribution with 16 degrees of freedom).

\bar{x} = average tensile strength.

--- = average tensile strength pooled for species.

For example, $\bar{x} = 5.21$ is the average of 5.87 and 4.55 and is the result of averaging 34 tests.

As in Phase I, the sample size precludes an accurate assignment of allowable tensile strengths for these jointed LVL configurations. Comparison of the Figure 2 data with that in Table 3 allows some inferences regarding the capability of jointed 3/4-inch LVL. Assuming normality and using the 5 percent exclusion limits for comparison purposes, all of the joint types provided performance equal to or better than all the lumber grades except for the 301A grade (1).

Differences in strength between scarf and finger joints could be due to the different glues used, or to the fact that different assembly and curing techniques were used for the two-joint assemblies.

Imperfect bonding and veneer defects initiated failures in the finger-jointed specimens. A fairly thick bondline was evident on the finger joints. This could be attributed to poor machining, low pressure on the joint surfaces as the adhesive was cured, and/or excessive assembly time (Fig. 3). Defects in the veneers outside of the joint area accounted for the failure in some of the specimens with vertical finger joints. On the other hand, veneer defects outside the joint area did not influence failures of the horizontal finger joints, as these failures occurred almost entirely within the joint. Knots and sloping grain, when encountered in close proximity to the joint and stacked in a single location in the LVL, provided a low fracture-energy path away from the joint so that failure was only partly in the joint. Another common failure observed in the vertical finger joints was not associated with a specific type of defect but with stacked areas of low-density earlywood in adjacent plies (Fig. 4). Failures in scarf joints typically were associ-

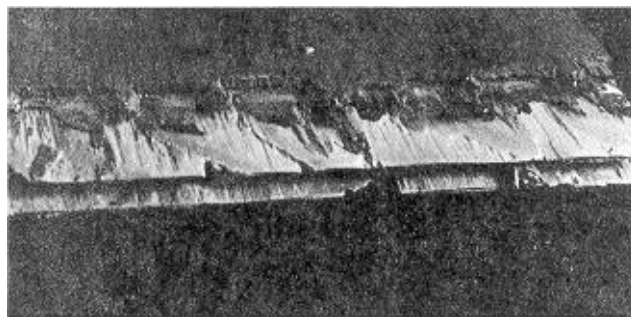


Figure 3. — Failure surfaces of a horizontal finger joint (10).

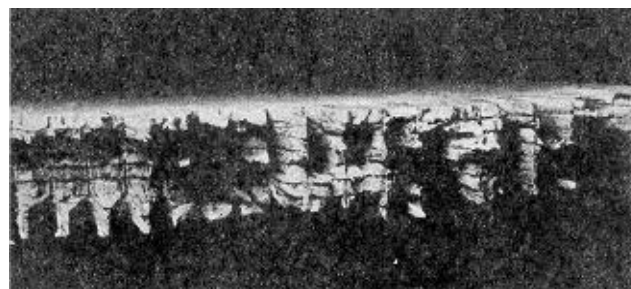


Figure 4. — Brush earlywood tensile failures with bond failures of vertical finger-joint specimen (10).

ated with knots, sloping grain, and poor bonding (Fig. 5). But there were fewer instances of multiple-ply, brash, earlywood failures such as were encountered in the finger-jointed specimens.

Twenty-six percent of the scarf-jointed and 11 percent of the vertical finger-jointed specimens failed independent of the joint. Not only was the horizontal finger joint the weakest of the three, but all failures for this joint were limited to the joint area. Both the lower strength values and the failure mode for the horizontal finger joint are attributed to burnished finger joint surfaces caused by dull cutterheads.

Summary — Phase II

The average tensile strength of end-jointed 1/10-inch LVL made from veneer from young-growth Douglas-fir was consistently lower than LVL made from larger trees, regardless of the joint configuration being tested. Higher density of the old-growth LVL was assumed to be responsible for this difference in strengths. Combining results from both veneer sources, the decreasing order of average joint tensile strengths and joint efficiencies compared with side-matched controls (5,480 psi) was as follows: scarf joints (5,210 psi, 95%), vertical finger joints (4,550 psi, 83%), and horizontal finger joints (3,890 psi, 71%). Excessive cutterhead wear during machining of the horizontal finger joints was deemed to be the cause of their poor performance. Both the controls and the end-jointed material demonstrated, as in Phase I, that the low variability that is characteristic of LVL makes it a plausible substitute for high-quality structural lumber.

Phase III — tensile strength of nominal 2-inch end-jointed LVL

If nonproprietary LVL is to be used in the glued-laminating industry as a substitute for tension laminations (on the tension side) of glulam beams, it will most likely be used in nominal 2-inch dimensions. It has been demonstrated in Phase I that LVL made from C-grade, 1/8-inch or 1/10-inch Douglas-fir veneer is a feasible substitute for some grades of high-strength lumber and in Phase II that 3/4-inch LVL can be end jointed satisfactorily. The primary objective of Phase III

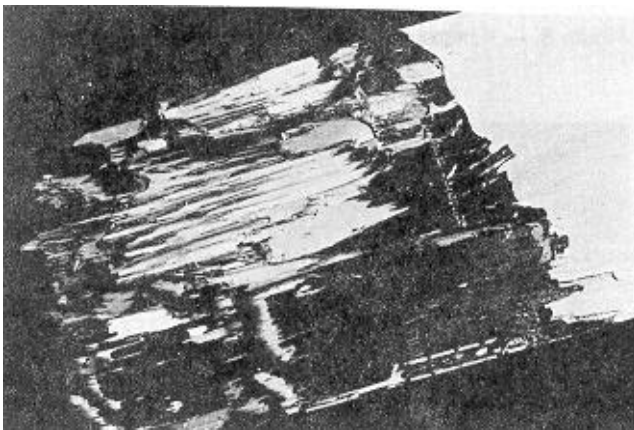


Figure 5. — Scarf-joint failure surface (10)

of the research program was to determine the properties of 1-1/2-inch (nominal 2-in.), end-jointed LVL, produced in a commercial plywood plant and end jointed in a commercial glulam facility.

A secondary objective was to evaluate the destructive tensile testing of end-jointed LVL, using both a portable short-span testing machine and the long-span test machine used in Phase II.

Specimen fabrication and testing

Three groups of 1/10-inch C-grade (15) Douglas-fir veneer were used to fabricate 3/4-inch LVL to be face laminated into 1-1/2-inch material (nominal 2 in.). Young-growth small-diameter logs comprised the source material for one group, old-growth logs provided another, and a mix of young- and old-growth logs were peeled for the third veneer group.

Panel size and manufacturing conditions were similar to those used in Phase I except nine plies were used instead of eight to allow for compression and planing losses. An abrasive planing operation was included because of the necessity of face gluing the 3/4-inch LVL material either to itself or to solid-sawn lumber. Following rough trimming and planing on one side to achieve a 3/4-inch finished thickness, the panels were ripped into nominal 1- by 6-inch boards. In an attempt to minimize error due to substrate variation, side-matched specimens, similar to those in Phases I and II, were used.

Because of the machining problems discussed in the Phase II results, no attempt was made to produce finger joints. Of the two joint types tested, one was the plain scarf, used on 3/4-inch-thick LVL pieces with subsequent face lamination of two jointed pieces; joints were separated by 6 inches (Fig. 6, top). The second type was a commercially used three-stage – or folded – scarf joint made after lamination of two 3/4-inch LVL pieces into nominal 2-inch stock (Fig. 6, bottom). A slope of 1:8.3 was used on all the joints. The joints were fabricated in commercial laminating plants and glued into boards approximately 40 feet long. The LVL pieces were then crosscut into 7-1/2-foot lengths with the joint centered on the specimen.

Destructive tensile testing of the 2-inch LVL joints was performed using two devices – the portable AITC short-span (2-ft. gauge length) machine and a longer span machine, at Washington State University, capable of stressing 4 feet of the specimen. A total of 42 tensile tests was made on each of the two joint types using the

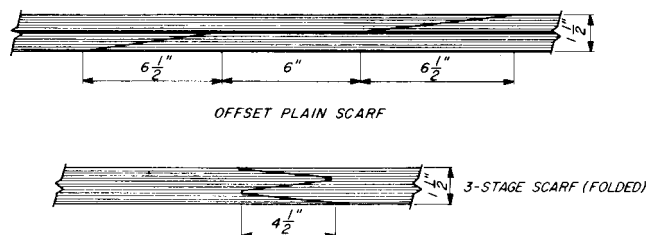


Figure 6. — Jointing methods evaluated with nominal 2-inch LVL.

procedures outlined in ASTM D 198-76 (3). Seven specimens from each of the three material groups were tested to failure on each of the test machines.

Results and discussion — Phase III

Use of the two tension test machines showed similar tensile strengths within each test group (Fig. 7). An exception to this is in the old-growth veneer/offset scarf-joint specimens; no explanation for this anomaly has been postulated. Based upon these relatively few tension tests conducted, the portable test AITC device appears to be as capable as the longer span machine for in-plant certification of new joint configurations as well as for routine quality control. Since a statistical difference could not be substantiated for the results of the two test machines, the results are pooled in all later analyses.

Although the mean strength of the three-stage scarf joint was significantly lower than the offset scarf joint when made with the mixed young-old growth and the young-growth material groups, the variance of the three-stage scarf-jointed material remained consistently lower than the offset scarf joints. For the young-growth and old-growth material groups, the combination of the low mean and small variance of the three-stage scarf test results provided 5 percent exclusion limits that exceeded those of the offset scarf joints (Fig. 7).

Using the pooled tensile test data from the two test machines, the nominal 2-inch end-jointed LVL can be compared with tension tests of structural lumber grades (Table 3). The offset scarf-jointed material for all three material groups had means that exceeded those found

for all lumber grades except the 301A. The only three-stage scarf-jointed material whose mean could not match the 301B material was composed of the mixed young-growth and old-growth veneer source.

If the assumption of a normal distribution (Fig. 8) of strength is valid for the end-jointed 1-1/2-inch LVL and for the lumber grades listed in Table 2, then an estimate of near-minimum strength values for each group may be made as the fifth percentile of the population distribution (5% exclusion limit). This 5 percent exclusion limit is typically used as a starting point for developing design stresses (12). Comparison of these values in Table 2 and Figure 7 shows that all of the lumber grades listed, including the 301A, have 5 percent exclusion limits that are lower than the end-jointed LVL materials. By multiplying the estimated fifth percentiles in Figure 7 by a 0.475 factor (2), design levels of between 2,000 psi and 2,400 psi may be attainable. The low tensile strength variance of this LVL along with high-quality end joints promises to provide a material that can be a viable substitute for the highest grades of structural lumber.

Previous research (5) showed the feasibility of using LVL for tension laminations of glulam beams. The tensile strengths of the two LVL materials used in that work averaged 6,970 psi and 5,510 psi with COV's less than 8 percent. Means of five of the six samples listed in Figure 7 fall between those cited with a COV ranging between 6.7 and 14.2 percent. Thus, the following conclusion from reference (6) seems to be relevant for some configurations of end-jointed LVL as well:

“Glulam beams with LVL tension laminations may have design strengths in bending 10 to 20 percent higher than did beams with conventional lumber-type tension laminations. This improvement was attributed to reduced variability in strength resulting in higher near-minimum strength values.”

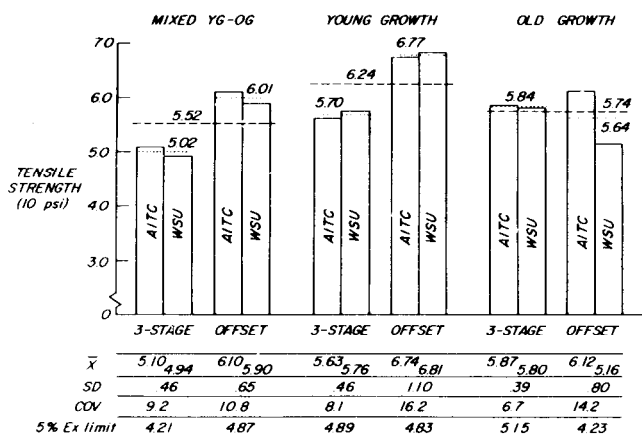


Figure 7. — Tensile strength of three-stage and offset scarf joints from three material groups in nominal 2-inch LVL made with 18 plies 1/10-in. C-grade Douglas-fir veneer and tested with two testing machines, seven specimens of each.

Mixed YG-OG = nominal 2-inch LVL associated with 18 plies of 1/10-inch C-grade young-growth and old-growth Douglas-fir veneer.

\bar{x} = average tensile strength.

. . . . = tensile tests for two test machines.

- - - = average tensile strength pooled for species.

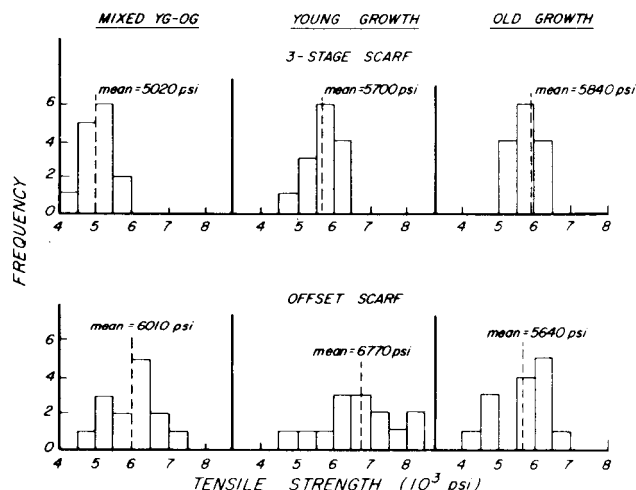


Figure 8. — Distribution of nominal 2-inch end-jointed LVL member tensile strengths (combined test machine results).

Summary — Phase III

Nominal 2-inch LVL appears to be capable of meeting the requirements of structural lumber and can be made in existing plywood plants from readily available Douglas-fir C-grade even when jointed from 8-foot LVL. It can be end jointed efficiently using an offset scarf joint or a three-stage-folded-scarf. Tensile design levels between 2,000 psi and 2,400 psi were deemed attainable. For assessing the ultimate joint strengths in tension, a destructive in-plant test using a portable tension-testing machine was shown to provide data that did not differ significantly from a longer span test machine.

General conclusions

Results indicate that unjointed 8-foot LVL made from mill-run C-grade 1/8- or 1/10-inch veneers can, with adequate processing quality control, be feasible as a substitute for high grades of structural lumber. Preliminary conclusions from this limited testing also show no width effect for different grades or thicknesses of veneer.

End jointing of 3/4-inch LVL with scarf joints with a slope of 1:8.3 resulted in a retention of 95 percent of the material tensile strength. Vertical finger joints retained 83 percent of the material tensile strength and horizontal finger joints yielded 71 percent. End-jointed 3/4-inch LVL provided tensile strengths that exceed the 301B (1) and the Select Structural grades of structural lumber (13). While end jointing of LVL is plausible, the reader should be cautioned to the practical problems of end jointing high-strength material and the extra quality control steps required to assure the result. Two methods of end jointing nominal 2-inch LVL from 8-foot lengths provided tensile strengths with sufficiently low variance to justify preliminary calculated design levels from 2,000 psi to 2,400 psi.

This research opens the door to a number of product and process options. Though additional quality control would be required, structural grades of LVL can be produced in plywood facilities with visually graded veneer. These 8-foot lengths, ripped to lumber widths, can

then be end jointed in a laminating plant, under proper quality control guidelines, to produce lengths of high-grade structural lumber.

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