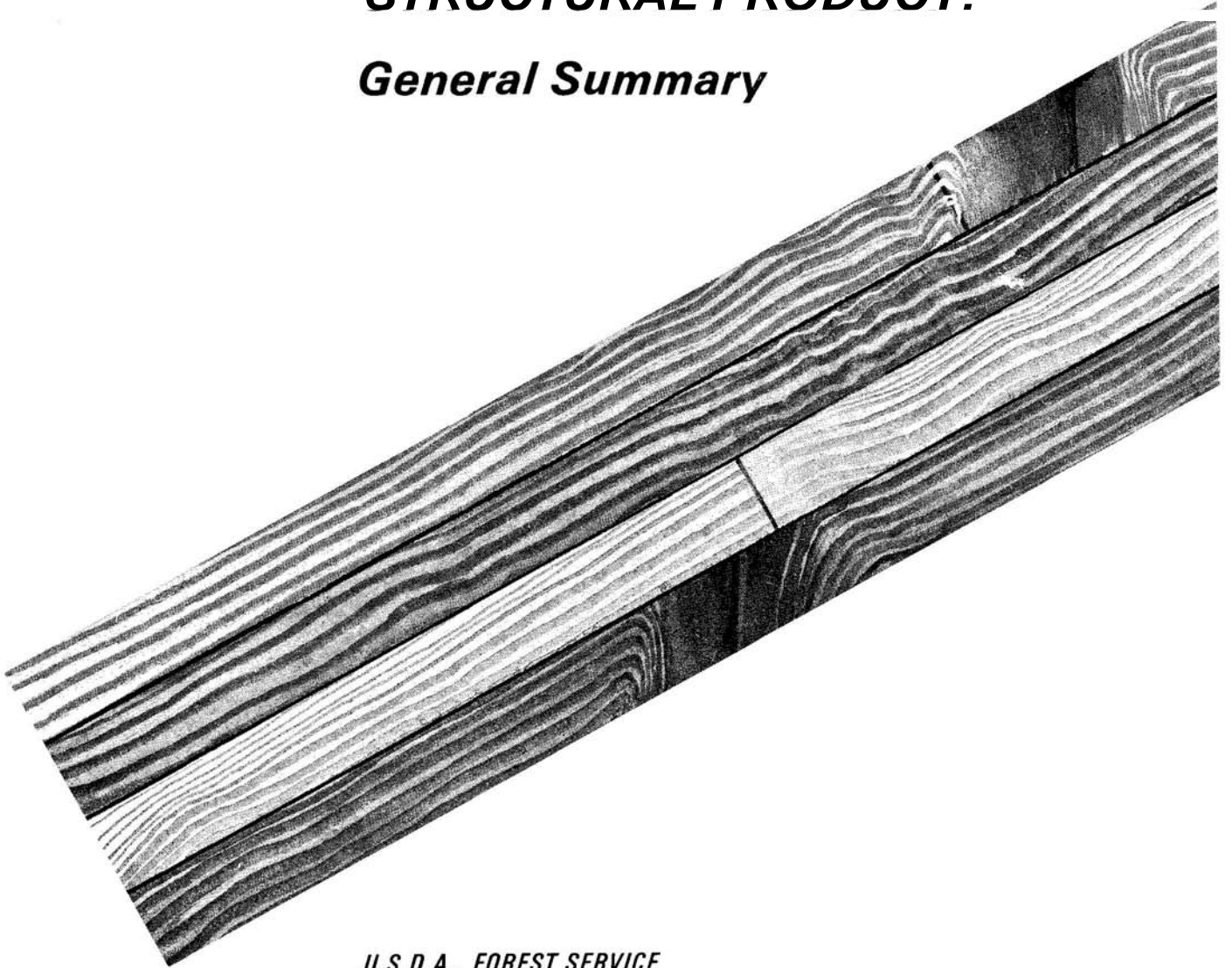


**FEASIBILITY OF PRODUCING
A HIGH-YIELD LAMINATED
STRUCTURAL PRODUCT:**

General Summary



***U.S.D.A., FOREST SERVICE
RESEARCH PAPER
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***U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
MADISON. WISCONSIN***

FOREWORD

This publication summarizes the progress of a U.S. Forest Products Laboratory research team in estimating the technical and economic potential of producing a laminated structural product by a log-to-product system,

Team members collectively defined the anticipated problems and sought practical solutions. Individual team members, and their contributions to this effort, were:

- E. L. Schaffer, Engineer--team leader, economic analysis
- R. W. Jokerst, Forest Products Technologist--adhesive, bond quality, laminating
- R. C. Moody, Engineer--laminated material strength properties, structural performance
- C. C. Peters, Mechanical Engineer--rotary cutting, log yield
- J. L. Tschernitz, Chemical Engineer--drying, economic analysis
- J. J. Zahn, Engineer--structural performance

This summary report will be followed by more detailed reports on individual phases of the research.

ABSTRACT

Production of a structural wood product by an innovative system which markedly improves yield at competitive costs is now technically feasible.

The system consists of rotary cutting of up to 1/2-inch-thick veneer from logs, press drying the thick veneer in less than 13 minutes, applying glue to the hot sheets, and laminating into a thick structural material. The entire processing time from log to finished product is about 30 minutes and the yield is about 60 percent. This contrasts to a processing time of 5 days or more and a yield of 40 percent for conventional softwood lumber.

Indications are that vertically laminating several plies together to form a structural beam can result in a product with greater uniformity (superior strength and equivalent stiffness) than comparable high-volume solid-sawn lumber.

The proposed system was tested with the final product as vertically laminated joists of three, four, or six plies of southern pine. An economic analysis of the results indicates the estimated selling price to be about equal to that of the majority of sawn structural lumber used for housing.

Recommendations for future effort include specific studies of (1) reduction of material and processing costs and (2) assessing the effects of variations in product processing on product quality.

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General Summary'

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BACKGROUND

Today the United States is confronted with many environmental problems which at times conflict with the needs of the population. While certain groups ask for continuous preservation of the forest, others urge a maximum volume of wood to meet housing and other wood product needs. To balance these two competing demands, more efficient methods of producing structural material are obviously needed. A recent study in the Pacific Northwest area of the United States showed that about 45 percent of a sawlog becomes dry surfaced lumber while 55 percent is some form of residue.³ Other areas are not expected to exceed this utili-

zation. If new methods of producing structural material can improve the yield from logs, fewer trees will be needed.

In 1968 the Forest Products Laboratory decided to intensify research on new systems that speedily convert logs into finished products in such a manner as to reduce residues. The feasibility of rotary cutting of logs into thick sheets, followed by press drying and laminating into wood pallet components, appeared economical.⁴ The success of this wood-processing technique, hereafter called "FPL press-lam," suggested that it be examined for structural lumber production.

¹Special recognition is due H. Habermann who assisted members of this research team in planning studies and analyzing results.

²Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

³Gedney, D. R., and Henley, J. W. Utilization estimates for western softwoods--Trees, Logs, and Residue. U.S. Forest Service Res. Note PNW-158, 1971. Pacific Northwest Forest and Range Exp. Sta., Portland, Oreg.

⁴Hann, R. A., Jokerst, R. W., Kurtenacker, R. S., Peters, C. C., and Tschernitz, J. L. Rapid Production of Pallet Deckboards from Low-Grade Logs. USDA Forest Serv. Res. Pap. FPL 154. Forest Prod. Lab., Madison, Wis. 1971.

The general processing technique is similar to that reported in FPL 154⁴ and is as follows:

- (1) Rotary cut thick veneer from greenbolts on a conventional veneer lathe.
- (2) Clip the veneer into sheets convenient for press drying.
- (3) Press dry the veneer sheets to an acceptable average moisture content.
- (4) Apply the adhesive in beadlike ribbons with an extruder to the still-hot sheets.
- (5) Lay up the plies into the required configuration.
- (6) Clamp the assembly for a short period while the heat stored in the plies during drying cures the adhesive.

This process was evaluated for three reasons: It promised increased log yield over conventional sawing because there is no kerf loss or sawdust and rotary cutting permits wide widths of material. Press drying is rapid compared to conventional methods. Laminating several plies together to form a structural element disperses knots and other strength-reducing characteristics so the

product can be more uniform than solid-sawn lumber cut from the same log.

The FPL press-lam technique definitely produced acceptable results when red oak pallet components were the final product.⁴ But additional data were required to evaluate the flexibility of the process, processing effects on material properties and product performance, processing efficiency, and economics.

One concern, for instance, was whether deep knife checks produced in thick veneer during rotary cutting can be tolerated in a structural laminated material. In pallet components, performance was adequate. In structural members the effect of deep knife checks could be serious.

Specifically, the three key questions for which answers must eventually be given are:

- (1) Can the yield of press-lam be greater than that now attained by sawing practices?
- (2) Is the structural performance of press-lam satisfactory for given applications?
- (3) Is the processing economical?

THE PRODUCT

“Press-Lam”

The FPL press-lam material can be visualized as a continuous sheet of laminated wood assembled from thick veneer. Butt joints are staggered, permitting a product of any width, length, and thickness for the desired end product. Advantages of such a laminated material, in addition to those already cited, are many

- (1) Produce a structural product of size and grade to customer order with minimum delay.
- (2) Produce a structural product of any reasonable size, thereby eliminating weakening splices between members.
- (3) Produce a material of desired performance using any grade of log as input (within reasonable limits).
- (4) Use logs less than 8 feet long (which moves residue material into high-quality product).
- (5) Reduce wood losses because the sheet is large enough for efficient layout of products.

From FPL press-lam material, then, one should be able to derive structural products

tailored to a specific application--beams, joists, studs, and panels--as well as nonconventional shapes.

“Press-Lam” Joist

To evaluate how press-lam would be affected by processing, structural joists were selected as the product because they represent a large-volume market in the housing industry. The objective was to determine if the FPL press-lam process could produce a joist equal to or better than joists presently used and at the same costs.

Based on engineering considerations, one would expect the quality of laminated material (as measured by strength) of a given size to increase with the number of laminations. However, cost would also increase. As this material must eventually compete with solid-sawn lumber, which is probably America's lowest cost construction material, it was felt necessary to concentrate on a minimum-cost product whose properties were

adequate to serve the largest structural wood-using market--housing. The word "adequate," for this work, is defined as performance equivalent to the performance of the bulk of the southern pine structural lumber--No. 2.

Accordingly, an estimate was made of the adequacy of material produced from veneer that was cut as thick as possible; all the material was used

exactly as it came from a log (subject only to the temporary experimental restriction that at least one or two laminations must be straight-grained and knot free) and employing a minimum of machining and handling. This requirement dictated the choice of simple unbonded butt joints and in turn a vertically laminated product.

FEASIBILITY INDICATORS

In the work conducted, a sense of the potential increase in yield, structural performance, and economics of producing press-lam were emphasized. The results are given here.

Yield

In the press-lam process, yield of product is primarily governed by the yield of green veneer attained in the rotary cutting of bolts. These yield data were obtained by measuring the total length of green veneer cut to acceptable thickness, calculating its volume, and dividing by the initial green bolt volume. Losses were attributable to bolt roundup, insufficient veneer thickness, and core loss.

Forty-nine 4-foot-long bolts ranging in diameter from 12 to 18 inches and cut at thicknesses of 0.413 or 0.500 inch averaged 66.6 percent yield

of green veneer. The green veneer yield is plotted versus bolt diameter (average of small end) in figures 1 and 2. Yield increased with bolt diameter and ranged from 48 to 78 percent of the initial volume.

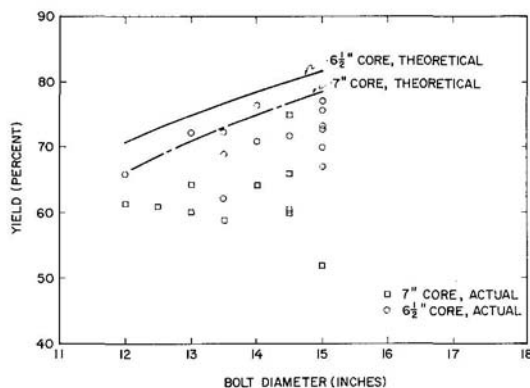


Figure 1.--Yield of green veneer for various bolt diameters (6-1/2 and 7 inch cores) and a 0.413-inch-thick cut.

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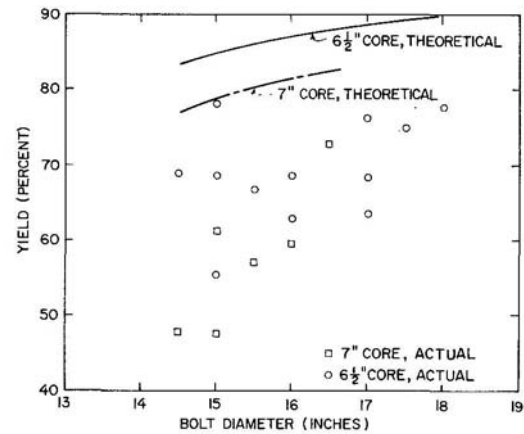


Figure 2.--Yield of green veneer for various bolt diameters (6-1/2 and 7 inch cores) and a 0.500-inch-thick cut.

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Additional losses occur during subsequent drying and manufacturing, the amount depending on the finished product. Limited data indicate that 60 percent of the log in the 12- to 18-inch-diameter range may be converted to press-lam. This includes the recognition that the relatively smooth exposed knife-cut, press-dried surface does not have to be surfaced.

Yield from these logs indicates that logs with minimum diameter of 12 inches will yield more dry product than by sawing. In addition yield of press-lam will increase with log diameter.

Structural Performance

As joists were selected for structural product evaluation, these questions were explored pertaining to joist performance:

1. How are mechanical properties improved with increasing number of laminations?
2. Can elementary beam theory predict the bending strength?
3. Is shear failure evidenced after bending tests at small span-to-depth ratios?
4. What is the minimum strength and stiffness expected in a larger population of joists?
5. Is structural performance affected by any processing steps?

Partial answers follow:

Joist Assemblies.--Joists were assembled having three, four, and sixplies to produce a 1.5-inch-thick vertically laminated member (tables 1,2 and fig. 3).

Since 1/2-inch-thick veneer is the thickest presently considered practical to rotary cut, at least three laminations are needed for a total product thickness of 1.5 inches. The three-ply material consisted of three 1/2-inch-thick laminations, one clear⁵ and two with significant

strength-reducing characteristics (type A).

Four 3/8-inch laminations, two clear and two with strength-reducing characteristics were also employed (types B, D, and E). The worstpossible cross section has a butt joint, two laminations with large strength-reducing characteristics, and one clear lamination. Taking the clear lamination's strength as 80 percent of clear wood strength equal to 10,000 psi (pounds per square inch) and completely discounting the effectiveness of the other three layers, the estimated gross stress at failure would be $8,000/4 = 2,000$ psi. Due to dispersion of defects, however, the true strength is greater than this. Specimens were tested at a smaller span-depth ratio (type D in table 1) to investigate the possibility of failure in horizontal shear due to the presence of lathe checks. The type E specimens were developed to span 12 feet to experimentally determine if this material had some unusual size effect.

The six-ply construction (type C) was chosen to determine if quality improves significantly with increasing number of laminations. This construction resembled the three-ply construction in all respects except the number of laminations.

Table 1.--Description of experimental joists

Specimen type	Number of laminations		Length Ft.	Depth In.	Span-depth ratio	Average lamination thickness			Number of specimens
	Total	Clear ¹				Nominal dry	Actual green	Actual dry	
						In.	In.	In.	
A	3	1	8	4.5	20	0.50	0.550	0.509	15
B	4	2	8	4.5	20	.375	.413	.379	45
C	6	2	8	4.5	20	.25	.275	.255	15
D	4	2	8	7	13	.375	.413	.381	15
E	4	2	12.5	6.5	20	.375	.413	.378	15

¹Clear--Defined as having a strength-ratio of at least 80 pct. (Free of large knots, and general slope of grain of 1:12 or flatter.)

⁵Clear veneer was considered to be that having a bending strength ratio of at least 80 percent as given in ASTM D 245.

Table 2.--Moisture content and specific gravity data

Type	Moisture content, pct.		Specific gravity ¹	
	Mean	Standard deviation	Mean	Standard deviation
A	12.6	0.82	0.54	0.010
B	11.1	1.13	.56	.016
C	12.6	.81	.55	.009
D	12.0	.85	.58	.015
E	11.6	1.00	.55	.016
B + D + E	11.4		.56	.018

¹Corrected for glue and lathe checks.

Thus, any improvement in quality could be attributed to (a) thinner cutting and (b) better dispersion of defects and greater mixing of variations (greater homogeneity).

Joist Mechanical Properties.--The results of bending tests under two-point load for all of the joists investigated are summarized in table 3.

Illustrated in figures 4 and 5 are the means and extremes of the modulus of rupture and calculated modulus of elasticity as a function of

number of plies in the joists. Plotted along the vertical axis are the properties of structural solid-sawn southern pine for comparative purposes. By analysis of table 3 and figures 4 and 5 one may conclude the following:

(1) The four- and six-ply constructions are feasible for vertically laminated structural products. The three-ply construction was significantly inferior to four- or six-ply constructions and is probably not suitable for wood products where strength is important.

The six-ply construction proved to have less variability than either the three- or four-ply assemblies and could have a design strength (as indicated by the minimum calculated modulus of rupture) nearly twice that of No. 2 southern pine structural grade (fig. 4). In addition, variability of the calculated modulus of elasticity was reduced over three- or four-ply assemblies.

(2) Regarding four-ply constructions:

(a) The near-minimum modulus of rupture of 4,100 psi (the estimated 5 percent exclusion limit) is equal to or better than that of select structural grade southern pine joists and planks (fig. 4).

(b) The average bending modulus of elasticity of 1,700,000 psi is equal to that of No. 2 medium grain (MG) southern pine structural joists and planks (fig. 5).

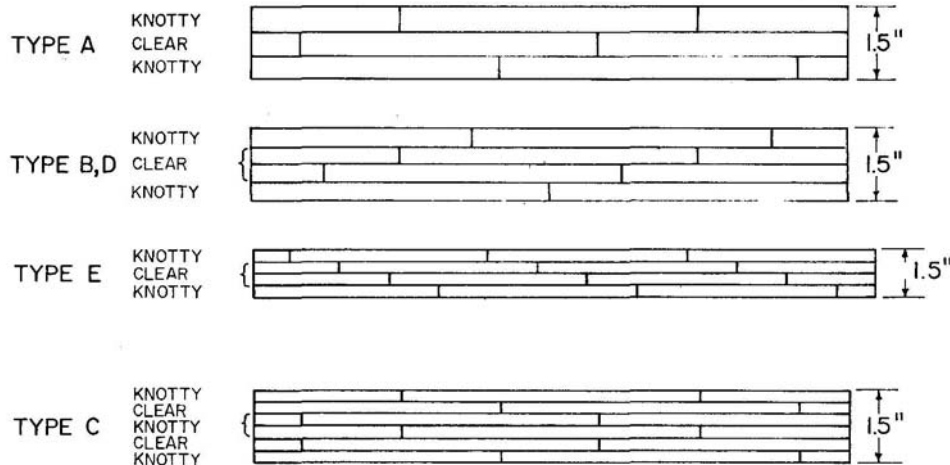


Figure 3.--Layup of five specimen types; beams A, B, C, and D were 96 inches long and beam E was 150 inches long.

Table 3.--Summary of strength and stiffness data
for laminated joists

Specimen	Modulus of rupture		Bending, E_b		Short span, E_s	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
	:P.s.i.:	:P.s.i.:	:Million: :p.s.i.:	:Million: :p.s.i.:	:Million: :p.s.i.:	:Million: :p.s.i.:
A	: 4,730 :	: 1,070 :	: 1.44 :	: 0.117 :	: 1.52 :	: 0.179 :
B	: 6,550 :	: 886 :	: 1.76 :	: .146 :	: 1.77 :	: .156 :
C	: 6,470 :	: 671 :	: 1.71 :	: .096 :	: 1.74 :	: .152 :
D	: 6,380 :	: 1,340 :	: 1.54 :	: .166 :	: 1.63 :	: .209 :
E	: 6,390 :	: 682 :	: 1.76 :	: .086 :	: 1.89 :	: .163 :
B + D + E	: 6,480 :	: 948 :	: 1.71 :	: .165 :	: 1.77 :	: .186 :

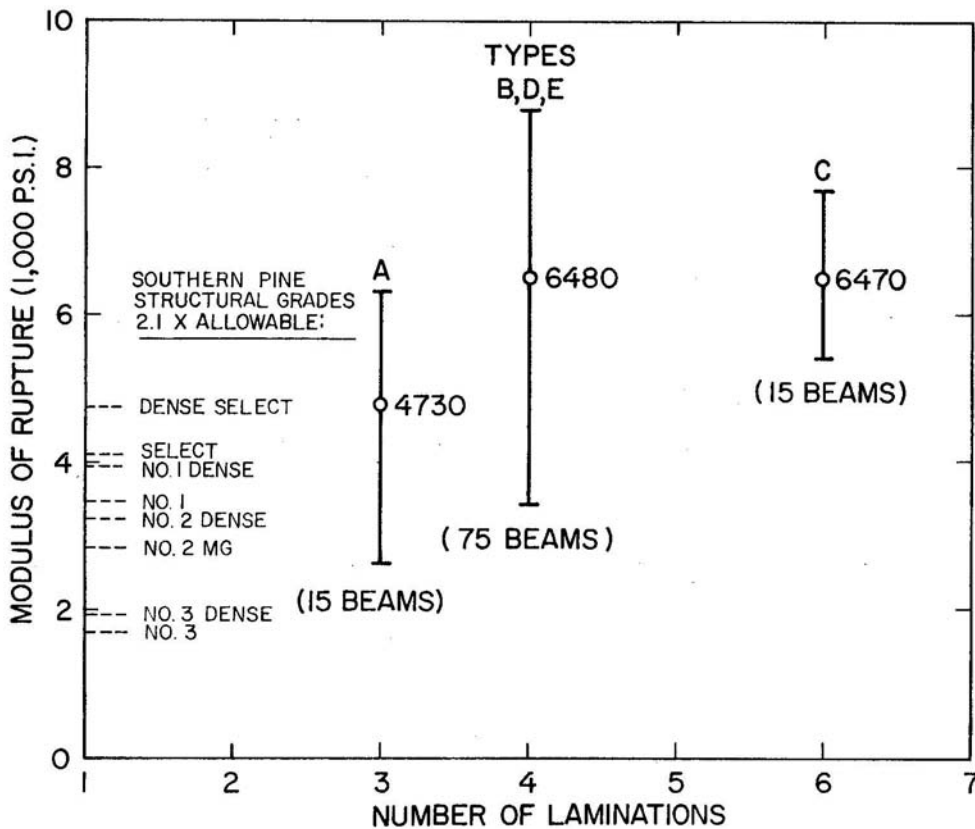


Figure 4.--Variation of average values and range of modulus of rupture with number of laminations for structural joists manufactured using the FPL press-lam process.

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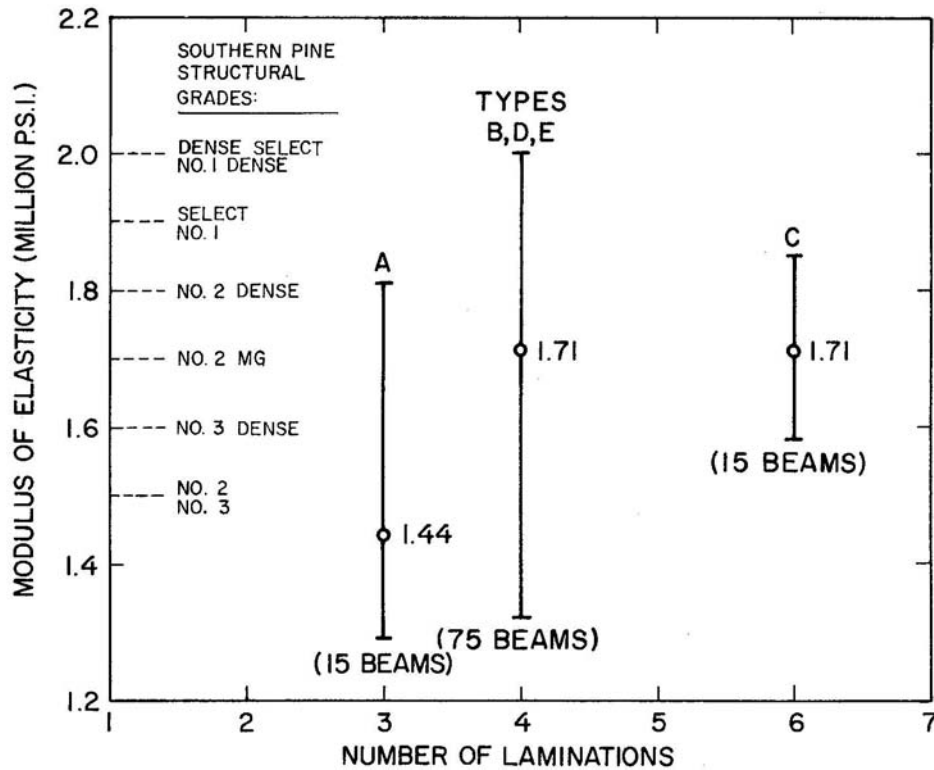


Figure 5.--Variation in average and range of modulus of elasticity values with number of laminations for structural joists manufactured using the FPL press-lam process. Moduli of elasticity were determined over full span and not corrected for shear deflection.

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(c) The beam shear strength appears to be adequate since no shear failures were obtained in any bending test, including 15 tests with a span-depth ratio of 13. In addition, no unusual size effect on strength was found.

(d) Based on observed bending strength, stiffness, and apparently adequate shear strength, four- and six-ply press-lam joists can be expected to have sufficient strength and stiffness for use in residential housing.

(3) To produce a higher quality product, attention must be given the most significant weakpoint in all three constructions, namely the butt joint. A butt joint was involved in every failure and some evidence suggests that they may have reduced bending stiffness as well. Improvement could be obtained by using more laminations, or a structural end joint rather than the simple butt joint.

(4) Hot-glued assembly of press-dried material employing staggered nonglued butt joints is a feasible method of construction. With careful time-temperature control, it provided consistently adequate interlaminar bonds despite variations in cutting thickness of as much as 0.04 inch. The same could not be said of cold-glued assembly.

(5) Generally the quality of this material increased with the number of laminations. The six-ply construction (type C) was 37 percent stronger than the three-ply construction (type A) in this study. As a corollary to this, one may infer that the potential forest yield will increase with the number of laminations since lower quality logs could be tolerated as input and thinner peeling involves less waste. However, as number of plies increase, the possibility of higher cost must be considered.

(6) The mean values of modulus of rupture (MOR) and bending modulus of elasticity (MOE) found for the FPL press-lam material in this study are nearly equal to those found by Doyle and Markwardt⁶ for solid-sawn southern pine dimension lumber. However, the standard deviations found in this study are only about one-half of those reported by Doyle and Markwardt. Though this reduction in variability is promising, the sampling procedures in each case are much different so that direct comparison of results is questionable. If variability is reduced to one-half and the mean values are equivalent, then design strength benefits greatly from the dispersion of defects because it is based on near-minimum value for the population. Design stiffness, however, stays about the same since it is based on the mean value for the population. A reduced

variability in stiffness would promise that structures made of this material would be more uniform and perform more satisfactorily.

Warp Tendency of Joists

Because warp of members can severely limit their use, warp measurements were made on the various joist specimens. These beams were assembled at 10 percent average moisture content and conditioned for 1 to 2 weeks at 10 percent equilibrium moisture content conditions. According to the grading rules,⁷ all of these were classified "light" for bow, 92 percent in the "very light" twist classification and the remaining 8 percent in the "light" twist class.

PROCESSING COSTS

The FPL press-lam system lends itself to a fast, high-volume manufacturing line. Rotary cutting of bolts and clipping of sheets takes only a few minutes, press-drying in less than 13 minutes, and laminating a maximum of 10 minutes. This means that log-to-product time is about 30 minutes.

Total product cost figures developed here (\$126 per thousand board feet, at the mill) should not be used literally. Rather the intent of this analysis was to choose the most correct of three possible answers: The costs are (1) significantly lower than conventional dimension lumber; (2) equal or close to; or (3) considerably greater than lumber.

The analysis found that costs are equal or close to those of conventional lumber.

TWO processing alternatives are proposed: continuous and semibatch. Since no continuous press dryer or assembler is available from manufacturers, no cost estimate for the continuous process is offered. While the costs of a continuous press dryer would be high including unknown development costs, certain cost advantages might arise through reduced auxiliary equipment and labor

costs. With modification, all the equipment needed for the semibatch process is available, and preliminary cost analysis of this concept is presented.

A sketch of the semibatch process flow pattern is shown in figure 6. Since the process uses a number of integrally sized equipment units in series, the capacity is limited by the most expensive unit. In this case, this is the multiopening press dryer. The press dryer (8 by 8 feet by 24 openings) has an overall board capacity of 27,600,000 board feet per year (assuming 100 percent efficiency, operating 20 hours per day, 250 days per year, at platen temperatures of 400° F., veneer thickness = 0.41 inch, 10 percent moisture content from the press and a green moisture content of 100 pct.) for a four-ply 1-1/2-inch-thick product. If nonproductive time of 35 percent is included for: (1) Loading-unloading time, (2) area loss by size variation, (3) cleaning (resin deposits, etc.), and (4) maintenance, the capacity would be 18,000,000 board feet per year (at 65 pct. efficiency).

Estimated cost factors are summarized in table 4 for laminated structural material having

⁶Doyle, D. V., and Markwardt, L. J. Properties of Southern Pine in Relation to the Strength Grading of Dimension Lumber. U.S. Forest Serv. Res. Pap. FPL 64. Forest Prod. Lab., Madison, Wis. 1966.

⁷Southern Pine Inspection Bureau. Standard Grading Rules for Southern Pine Lumber. Pensacola, Fla. 1970.

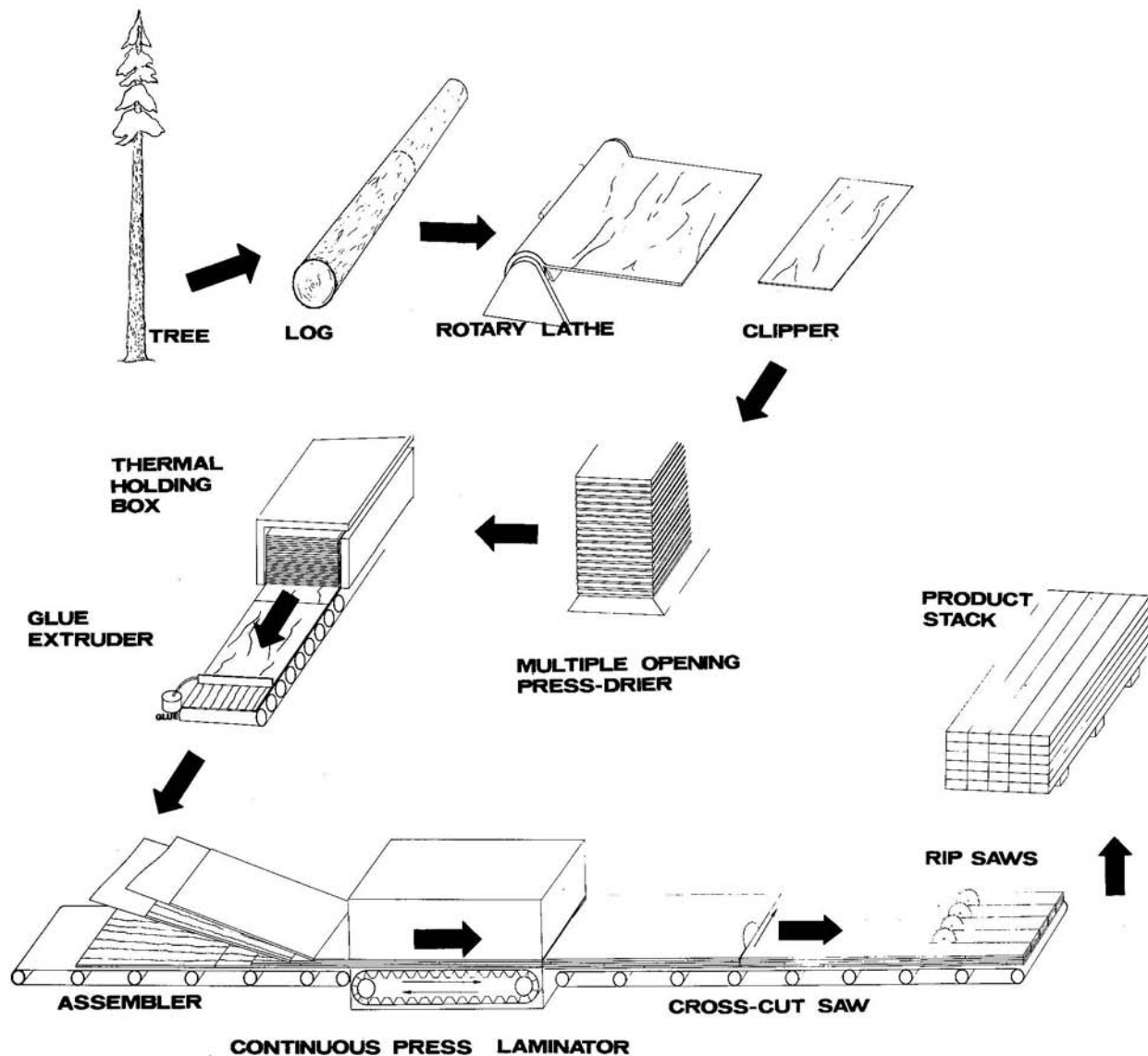


Figure 6.--A proposed flow pattern for a semibatch technique for manufacturing of press-lam.

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three to six plies. There is an increased production rate for the same major equipment with increased number of plies (per 1-1/2-inch-thick board) because of increased rate of press dryer output. Therefore, equipment and labor cost per board foot would decrease; however, adhesive and additional handling equipment costs increase with increasing number of plies.

These same cost figures are shown in table 5 as a percentage of total costs. Major individual items in decreasing cost order are logs, labor, and adhesive. The adhesive employed cost \$0.28 per

pound and glueline spread rate was 60 pounds per 1000 square feet. Equipment and other costs are significantly lower.

Profit and marketing costs must be added to the production costs in table 4 in order to arrive at a selling price. These two costs are difficult to estimate but would likely result in a selling price between \$150 and \$200 per thousand board feet. This is comparable to the present retail selling price of \$175 per thousand board feet for the grade of 2 by 8 southern pine dimension lumber now used for housing joists.

Table 4.--Estimated production cost per 1,000 board feet^{1,2,3}

Factor	Number of plies			
	3	4	5	6
	Dollars per 1,000 bd. ft.	Dollars per 1,000 bd. ft.	Dollars per 1,000 bd. ft.	Dollars per 1,000 bd. ft.
Logs ⁴	42.00	42.00	42.00	42.00
Adhesive	17.80	26.70	35.50	44.50
Equipment (and plant)	16.40	14.30	13.60	12.30
Labor	42.50	37.20	35.20	31.80
Power	3.60	3.16	3.00	2.72
Depreciation	<u>3.05</u>	<u>2.68</u>	<u>2.54</u>	<u>2.30</u>
Total dollars per thousand bd. ft.	125.35	126.04	131.84	135.62
Production rate Million bd. ft. per yr.	15.8	18	19	21

¹Board foot = 3/4 by 11-1/2 by 12 in.

²(Limiting equipment: Multiopening press dryer
size : 8 by 8 feet by 24 openings
temp.: 400° F., 10 pct. lamina moisture content
(green, 100 pct.)

³Assume 60 pct. yield per 15-in. logs.

⁴Hair, D., and Ulrich, A. H. The Demand and Price Situation for Forest Products 1969-1970 (table 5, p. 47). USDA Misc. Pub. No, 1165.

Table 5.--Percent breakdown of production cost

Factor	Number of plies			
	3	4	5	6
	Pct.	Pct.	Pct.	Pct.
Logs	34	33	32	31
Adhesive	14	21	27	33
Equipment (and plant)	13	11	10	9
Labor	34	30	27	23
Power	3	3	2	2
Depreciation	2	2	2	2

SPECIFIC PROCESSING EFFECTS

During the processing of press-lam, the wood is subjected to a series of processing steps--cutting, clipping, press-drying, gluing, and laminating. The changes in the material and conditions that produce the change are important in adequately assessing process flexibility, speed, and cost. These aspects are explored for southern pine (primarily loblolly) as a raw material.

Raw Material

Southern pine was selected for this work because it is one of the major structural species. Fifty so-called "woods-run" logs, 47 loblolly and three longleaf, all 17 feet long, were purchased from a plywood plant in east Texas. Logs ranged in small-end diameter from 12 to 23 inches.

The logs were cut, end-coated with aluminum paint, and shipped to the Laboratory by rail in a 1-week period during late December 1970. To preserve log freshness after arrival, the logs were either ponded at temperatures below 40° F. or maintained frozen till use.

Prior to rotary cutting, the logs were cut into 4-foot bolts, debarked, and heated in 140°F. water for at least 12 hours.

Rotary Cutting

Rotary cutting was preferred over slicing for the production process because a uniform, continuous sheet is produced (once the log is rounded up). From this sheet any perpendicular-to-the-grain width desired can be cut, regardless of original tree diameter.

Previous work⁴ had shown that material up to 1/2 inch thick could be cut on the FPL lathe. In this work, green veneer thicknesses from 0.125 to 0.554 inch were rotary cut.

The three most common material effects observed during cutting were the production of lathe checks in the sheet along the grain, variation in thickness of the green veneer cut with sheet length, and scuffing of the surface. All can create problems in further processing or product performance.

Checks were deep, ranging from 70 to 95 percent of the 1/2-inch veneer thickness. Checks were due mainly to inherent species characteristics and, to a lesser extent, the lack of sufficient cutting bar pressure (a machine limitation).

As the knife and bar feed into the log, a state of force-deflection unbalance exists. Eventually equilibrium is reached and, associated with it, uniform veneer thickness. Unfortunately a loss of usable material occurs here as at least one revolution is required before equilibrium is reached. After equilibrium is reached, the uniformity in thickness along the sheet length is related to cutting thickness. Thickness variations ranged from 0.095 inch for average green veneer thicknesses of 0.554 inch to as little as 0.006 inch when average veneer thickness is 0.250 inch.

Of particular importance from a gluing standpoint is the quality of the surface produced during cutting. Normally rotary cutting results in a surface much smoother than rough sawing. In fact, the surface is likely adequate for a structural product without sanding or planing. However, severe surface scuffing and loosening, called shelling, was observed for most of the rotary-cut southern pine material. Fortunately, press drying resulted in some resmoothing of the surface, which resulted in apparently adequate bond quality.

Press Drying

Press drying studies affirmed the following advantages for producing a laminated product by this means:

(1) Rapid drying.--With 375°F. platen temperature, southern pine sapwood boards up to 1/2 inch thick can be dried to an average of 10 percent in about 11 minutes and 6 percent moisture content in about 13 minutes.

(2) Bonding surface.--Press drying produces a surface sufficiently smooth for a good bond quality with one adhesive when pressed hot even though green veneer was somewhat rough.

(3) Surface temperatures of the wood after drying of 150° to 250° F. can be maintained by thermal energy stored in the veneer and utilized to cure

thermosetting adhesives used in laminating.

(4) Restraint during drying in general provides flat surfaces around knots not usually obtained by conventional kiln-drying methods.

Two hydraulic presses were employed during this research--one steam heated (fig. 7) and the other oil heated. (The oil-heated press was capable of producing higher platen temperatures.) Perforated cauls were placed on the platens to vent the steam produced from the drying boards and prevent board explosion. Another possibly cheaper but effective means found to remove drying vapor was the employment of used Fourdrinier screen (60 mesh bronze). Rotary-cut boards dried at the same rate as solid-sawn boards (as tested at one temperature and board thickness), indicating that lathe checks did not enhance drying rate.

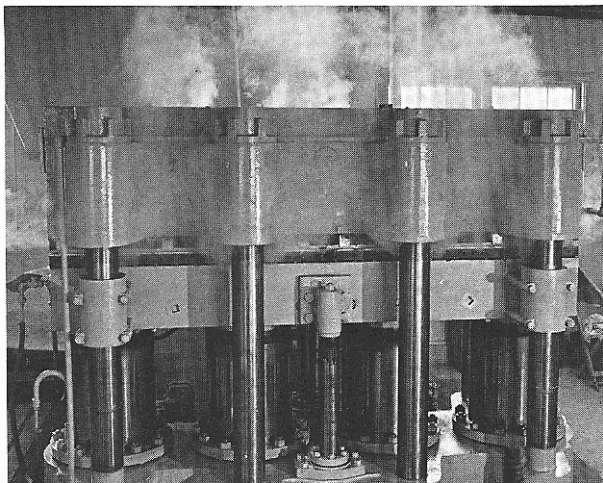


Figure 7.--Press drying clipped sheets.

M 138 699-15

Thickness loss during press drying was affected by platen pressure and final moisture content. At a 50 psi press-drying pressure, thickness loss at several thicknesses or temperatures was less than 10 percent for drying to any moisture content. Above 50 psi platen pressure, thickness loss greatly increased and resulted in densification of the veneer (fig. 8). Drying rate increased only slightly with increased pressure. Thickness loss to a given moisture content was the same for sawn and rotary-cut material and was independent of platen temperature,

The effect of temperature on drying rate for

1/2-inch-thick southern pine boards is illustrated in figure 9. No measured significant effect of drying at surface temperatures to 500° F. was found upon the thickness loss, bending strength, or stiffness of lamina. The latter results indicate that even though the surface properties maybe altered by exposure to high temperature, the laminae are not degraded for any substantial depth below the surface. However, the effect of high temperature on gluability of the resulting surface has not as yet been examined.

Within the range of thickness studied (1/8 to 1/2 in.), the time to press dry a sheet of veneer to a given moisture content depends upon a power of the thickness (fig. 10). This function was determined to be of the form

$$\theta = C\ell^n$$

where θ = time to dry to a given moisture content

C = constant

ℓ = thickness

n = constant

The magnitude of n was less than the theoretically expected value of 2 and experimentally determined to be 1.5. This expression indicates, for instance, that doubling the thickness results in nearly three times the required drying time.

Also examined was the effect of press drying on equilibrium moisture content levels at various relative humidity conditions. Achieved equilibrium moisture contents were similar to those expected for either kiln-dried and air-dried wood.

When batches of material in thicknesses of about 0.4 inch (deviations in thickness of 0.08 inch) are press dried to attain a given moisture content, differences in average moisture content of up to 4 percent were found in the material--thinner plies having the higher level. Differences in average moisture content decreased proportionately as the thickness became more uniform

Gluing and Laminating

By using the residual heat of drying to accelerate adhesive cure, continuity in and speed of processing can be achieved. Reheating before bonding of previously dried veneer is unnecessary, thereby effecting a saving in both time and energy, as well as eliminating a possible effect on bond quality and strength.

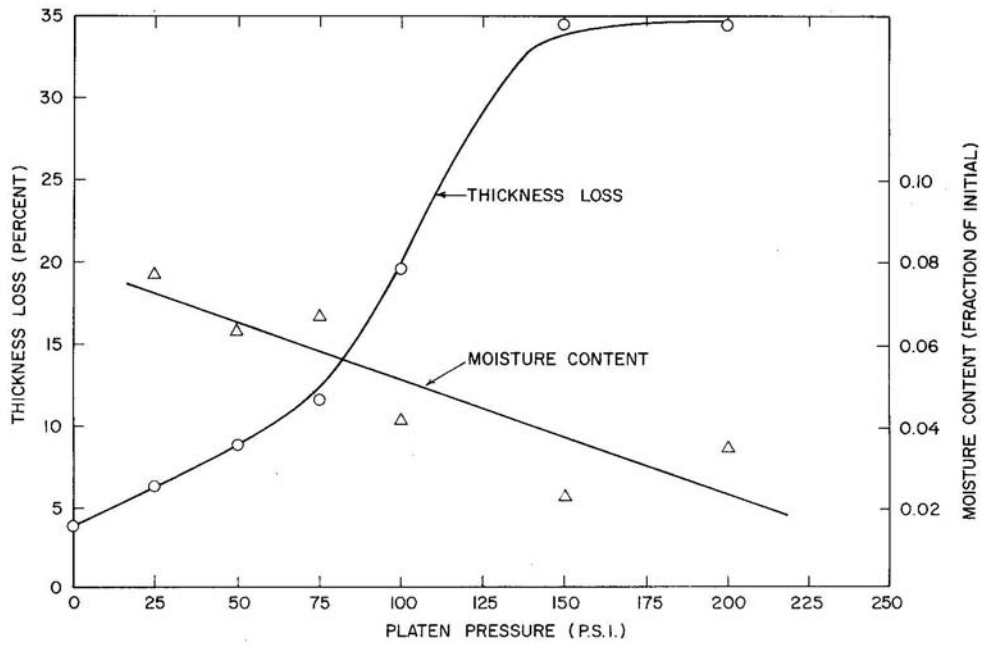


Figure 8.--Effect of platen pressure on the thickness loss and moisture content during press drying. M 140 212

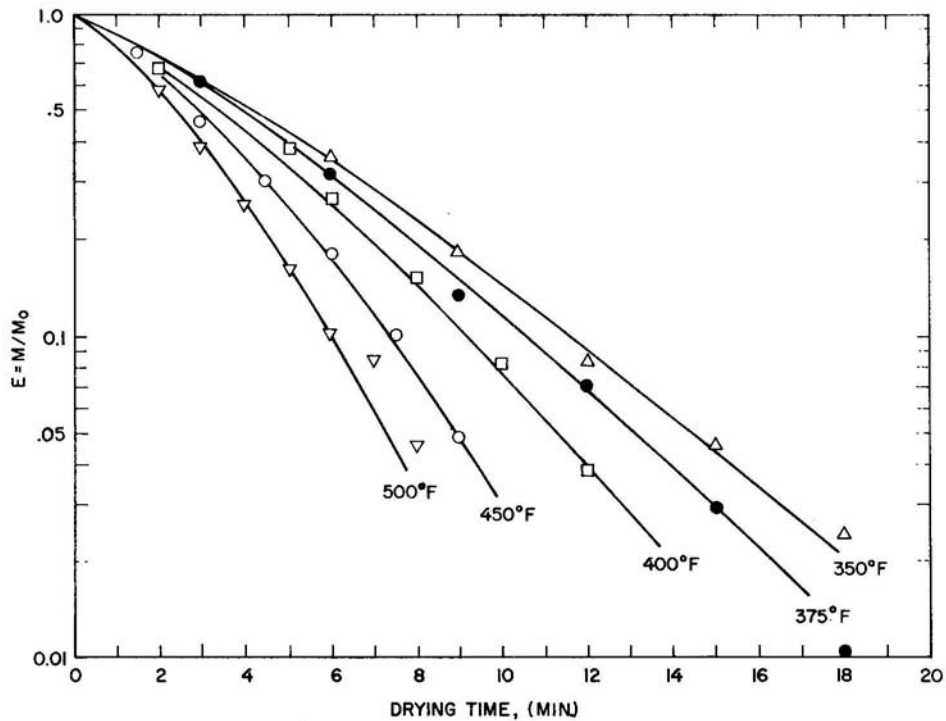


Figure 9.--Effect of platen temperature on the drying rate of 1/2-inch southern pine veneer.

M_0 = initial wood moisture content.

M = final wood moisture content.

M 140 214

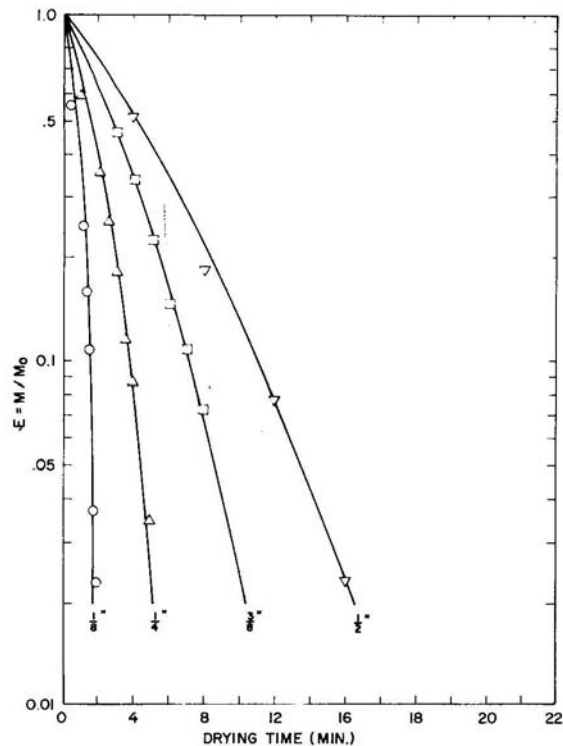


Figure 10.--Effect of thickness on press-drying rate of knife-cut southern pine.

M_0 = initial moisture content.

M = final moisture content.

M 140 210

Essentially all gluing was conducted with one formulation of a phenol-resorcinol adhesive. This adhesive was selected because of its relatively long 'pot life' (about 2 hr. at room temperature) and its rapid rate of cure at intermediate temperatures of 150° to 200° F. It is probable that other commercially available adhesives could also function in the FPL press-lam process; however, none were investigated at this time.

By extruding the adhesive on one surface of the hot press-dried plies in continuous thick ribbons (fig. 11) at a spread rate of 60 lbs. per 1000 square feet, the plies were laminated at glueline temperatures of 150° to 200° F. without having the adhesive precure before assembly. At these glueline temperatures, only a 2- to 4-minute clamp time is required to affect adhesive cure.

Bond quality of the material was found to be consistently good when the green veneer was press-dried and assembled hot by three different means:

- (1) Laminating immediately after press-drying
- (2) Laminating after storage in the insulated or heated chambers for periods up to 2 hours
- (3) Laminating after reheating the previously press-dried veneers by heated air

By contrast, when press-dried southern pine was cooled to room temperature before laminating, bonds were poor even though the same adhesive was used. Indications were that the problem was also in part due to surface irregularities. Apparently the increased conformability and plasticity of the hot wood allows it to deform under gluing pressure. The deformability thus results in better bond quality, due to mating of the two veneer surfaces, than is possible at room temperature (fig. 12).

A study of the effect of assembly time in the hot-gluing process indicated that the FPL press-lam process is quite flexible. Consistently good bond quality resulted over long assembly times.

After a three-cycle vacuum-pressure-soak exposure (ASTM D 2559), the average shear strength of the specimens decreased about 20 percent while the percentage of wood failure remained the same as nonexposed specimens. This shear strength reduction may have been significant but the integrity of the glue bond apparently did not change, as wood failure remained the same. Any loss in shear strength can only, therefore, be attributed to the wood degradation.

Mechanical Properties of Clear Press-Lam

One factor considered in assigning engineering properties to structural lumber is clear wood strength. Thus, standard small specimens were evaluated according to ASTM D 143 to compare basic strength properties of clear laminated 1/2-inch-thick veneer produced by the FPL press-lam process with clear sawn material. All specimens were 2 by 2 inches in cross-section and of compatible test length. Properties compared were stiffness and bending, compression, and shear strengths. The results are shown in tables 6, 7, and 8.

In bending, the FPL clear press-lam material showed a significant (18 pct.) reduction in bending strength as compared to clear sawn material. The stiffness, as reflected by a calculated modulus of elasticity, for the FPL press-lam material was 5 percent lower than that of the sawn material. When vertically laminated FPL press-lam material was tested to failure in bending, two-thirds of the specimens failed in horizontal shear along lathe checks at an average shear stress of 410 psi.

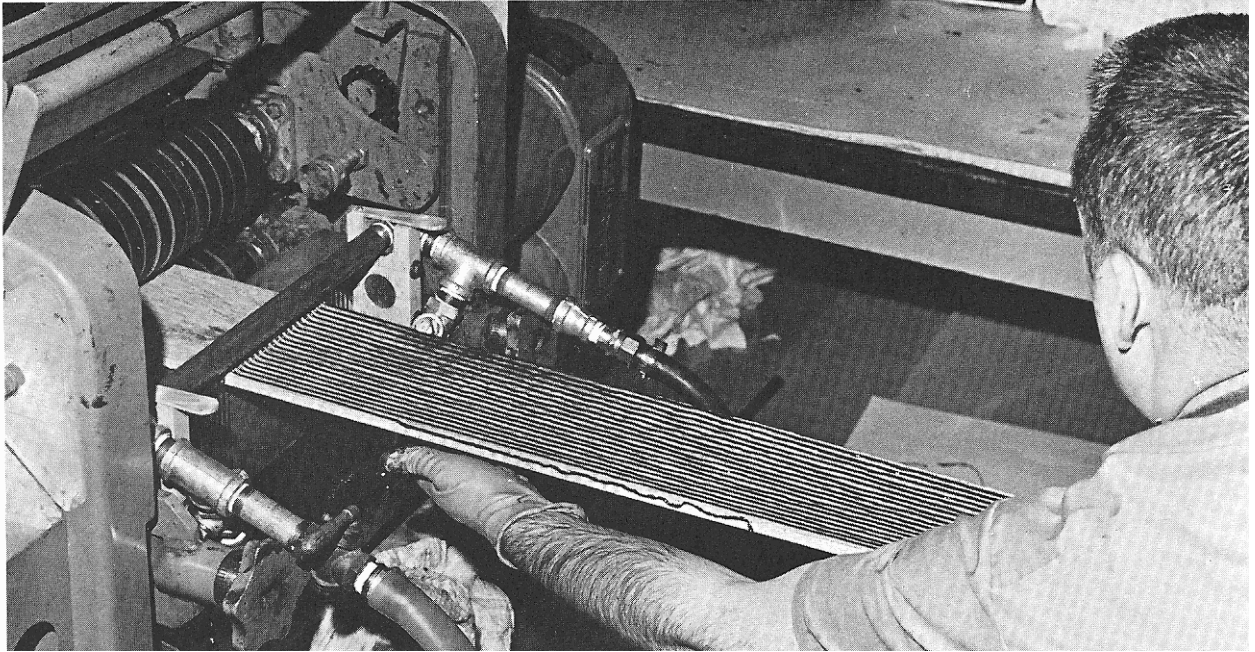


Figure 11.--Laboratory-built adhesive extruder applying adhesive to hot press-dried laminae.

(M 137 435)

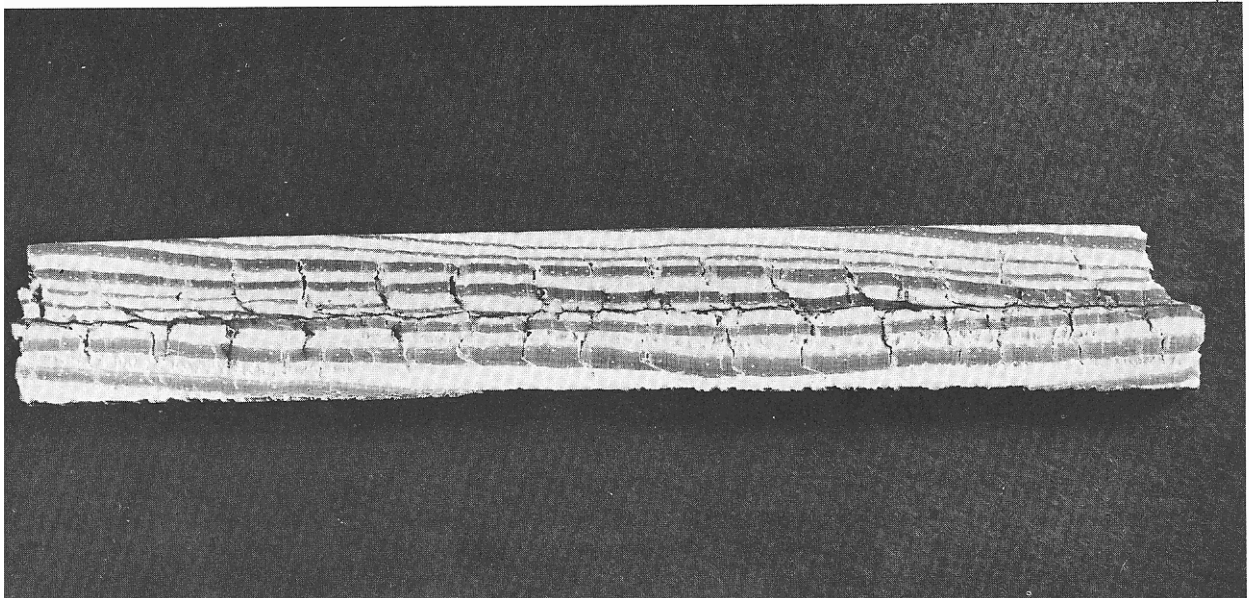


Figure 12.--End view of 1/2-inch FPL press-lam southern pine material showing deformations during gluing that result in excellent mating of the two surfaces.

(M 138 982-9)

Table 6.--Bending properties of solid-sawn and FPL press-lam material

Material Tested	Number of specimens	Modulus of rupture			Modulus of elasticity		
		Mean	Standard deviation	Coefficient of variation	Mean	Standard deviation	Coefficient of variation
		Psi	Psi	Pct	Million psi	Million psi	Pct
Solid sawn							
Horizontal annual rings	24	14,640	1,010	6.9	2.25	0.186	8.3
Vertical annual rings	24	15,050	1,400	9.3	2.16	.383	17.8
FPL press-lam							
Horizontally laminated	24	12,480	1,430	11.5	2.13	.169	8.0
Vertically laminated	24	11,720	1,610	13.8	2.04	.131	6.4

Table 7.--Compressive properties of clear solid-sawn and FPL press-lam material

Material Tested	Number of specimens	Compressive strength		Modulus of elasticity	
		Mean	Percent of dry sawn control	Mean	Percent of dry sawn control
		Psi		Million psi	
Solid-sawn	36	7,500	100	2.56	100
FPL press-lam	36	7,700	103	2.70	105

Table 8.--Shear properties of clear solid-sawn and
FPL press-lam material

Material Tested	Number of specimens	Tangential (shear along annual rings)		Radial (shear along lathe checks)	
		Mean Psi	Percent of sawn control	Mean Psi	Percent of sawn control
Solid-sawn	24	1,570	100	1,570	100
FPL press-lam	24	1,050	67	930	59

The results in table 7 show that no essential difference exists between sawn and FPL press-lam material for either compressive strength or modulus of elasticity in compression parallel to the grain.

The shear strength of the clear FPL press-lam material was significantly lower than the solid-sawn. Tangential direction shear strength was 33 percent less, and in the radial direction, (shear parallel to lathe checks) strength was reduced 41 percent. These results indicate that the radial shear strength is reduced due to lathe checks. No satisfactory explanation for cause of reduced tangential shear strength was found. The discrepancy in shear strength between clear and structural grade press-lam was not understood.

Warp Tendency of Press-Lam

As bow, cup, or twist develop in lumber, they can markedly reduce the quality and acceptance for structural use. Previous work on FPL press-lam of red oak material dried to average moisture contents greater than 20 percent indicated that, though flat immediately after manufacture, severe warp was often observed later.⁷ Limits on warp

are given by the softwood lumber industry in their grading rules. To what extent warp is influenced by differences in ply EMC, grain angle, ply thickness, and arrangement were evaluated. Both a "controlled" assembly and a "mill-run" assembly evaluation were made.

The controlled assembly emphasized characteristic extremes that would enhance warp. The best parallel-grained product was obtained by press drying to 6 percent moisture content. At this moisture content, the number of plies, slight deviations in grain angle, and arrangement had relatively little effect, and the material fell in the "very light" warp classification of the Southern Pine Grading Rules.⁷

The "mill-run" study employed hot assembly with no attempt to select or arrange the wood characteristics in any way. Since moisture content was extremely important in the controlled study, all the 1/2-inch plies for the mill-run study were dried to 6 percent moisture content. After 63 days of conditioning at 12 percent EMC conditions, measurements of the 36 specimens showed that all were classified as "very light" according to Southern Pine Grading Rules.

SUMMARY AND CONCLUSIONS

The press-lamprocessing system of rotary cutting thick veneer, press drying, and laminating into sheets promises an average 50 percent improvement in yield of dry product over that normally obtained by sawing southern pine. Total processing time from log to product can be expected to be less than 30 minutes, with speed of production controlled primarily by the press drying of the veneer.

If four-ply, vertically laminated, nominal 2- by 8-inch joists are considered as a product to be extracted from the continuous "press-lam" sheet, design strengths and stiffness can be expected to be better than or equal to No. 2 medium grain southern pine structural joists. Estimated selling price of a four-ply "press-lam" sheet, 1.5 inches thick, is \$150 to \$200 per thousand board feet, about equal to the price of large-volume sawn structural joists. Warp can be expected to be in the very light class when veneer is laminated after press drying to an average 6 percent moisture content.

Introduction of more plies and an improved joint in the product can significantly increase design strength and stiffness. However, the costs associated with incorporation of an improved end joint in laminates may offset the gained engineering advantage.

The most serious processing defect found that could affect product performance was the knife checks parallel to the grain of thick veneers

produced by rotary cutting. These checks reduced bending and shear properties of small clear specimens but do not appear to seriously affect the bending properties of structural joists. Shear strength is evidently adequate in joists as none indicated a shear rupture in failure,

Press drying thick veneer is not only rapid but it produces a smooth surface, thereby enhancing bond quality and surface appearance. A notable advantage after laminating, then, is that the surface requires little further machining, thereby saving more material. A sanding may be sufficient.

During laminating, advantage is taken of the thermal energy stored in the veneer after press drying to cure an intermediate-temperature-curing adhesive. This can result in the saving of processing time, additional resurfacing, and a cost savings in energy utilization by not requiring the reheating of already dried, but cool, veneer.

The cost of producing press-lam can be immediately markedly reduced by two means: (1) By obtaining a compatible medium-temperature-curing adhesive that costs less than \$0.28 per pound and (2) by using the cheaper, lower grade logs.

The press-lam system consists of equipment and procedures similar to those already existing in plywood and panel processing plants. It therefore is an amenable parallel system which should be attractive to this industry.

RECOMMENDATIONS

Furthering a national goal of promoting the efficient utilization of a renewable natural resource demands that work on log-to-product systems be continued. Considering the observed high product quality in light of the calculated processing yield and costs, it is worthwhile to pursue research oriented to processing alternatives in the production of a structural material similar to press-lam.

The potential improvement in yield, coupled with the production of a reliable and superior engineering material at low cost, has clearly been recognized, but the task of gaining industrial acceptance of the process and product remains. To further this acceptance, research and development work must continue which not only demon-

strates the attributes of the processing technique and product, but also provides answers to questions relating to industrial process limitations and product performance.

Specific additional research needs required to define the processing and performance of press-lam fall under two headings:

- I. Reduction of material and processing costs.
Decrease the costs of adhesive and log raw material. Optimize the processing system.
- II. Assessment of product quality.
Lower quality logs can reduce cost, but the effect on structural performance must be evaluated. Examine processing system flexibility and effect on product performance.