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Compression of Douglas Fir Plywood in Various Hot-Pressing Cycles

By Raymond A. Currier

Information Circular 17
September 1962

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The Forest Research Laboratory is part of the Forest Research Division of the Agricultural Experiment Station, Oregon State University. The industry-supported program of the Laboratory is aimed at improving and expanding values from timberlands of the State.

A team of forest scientists is investigating problems in forestry research of growing and protecting the crop, while wood scientists engaged in forest products research endeavor to make the most of the timber produced.

The current report stems from studies of forest products.

Purpose . . .

Fully utilize the resource by:

- developing more by-products from mill and logging residues to use the material burned or left in the woods.
- expanding markets for forest products through advanced treatments, improved drying, and new designs.
- directing the prospective user's attention to available wood and bark supplies, and to species as yet not fully utilized.
- creating new jobs and additional dollar returns by suggesting an increased variety of salable products. New products and growing values can offset rising costs.

Further the interests of forestry and forest products industries within the State.

Program . . .

Identify and develop uses for chemicals in wood and bark to provide markets for residues.

Improve pulping of residue materials.

Develop manufacturing techniques to improve products of wood industries.

Extend service life of wood products by improved preserving methods.

Develop and improve methods of seasoning wood to raise quality of wood products.

Create new uses and products for wood.

Evaluate mechanical properties of wood and wood-based materials and structures to increase and improve use of wood.

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ACKNOWLEDGMENTS

This research resulted from a cooperative effort between the United States Plywood Corporation, Eugene, Oregon, and the Forest Research Laboratory. Veneer and glue were provided by the U. S. Plywood Corporation. In addition, the services of Leo Sunnell were made available by the company, and his assistance in pressing the experimental plywood is acknowledged gratefully.

W. W. Dostalik, a student aide, provided valuable assistance in the laboratory.

SUMMARY

In an attempt to limit compression of Douglas fir veneers during hot pressing, an evaluation was made of plywood produced by five different pressing cycles involving pressures below the normal operating condition of 175 psi. Other variables included three different types of glue and both soft- and hard-grained veneer.

Results were compared by various methods, including percentage of compression and recovery, reduction in compression, and thickness of panel. Numerous tests were made to determine glue-bond quality of plywood pressed with and without reduction in pressure.

Use of lowered pressures during hot pressing reduced permanent compression by 26 to 57 per cent without accompanying decrease in quality of glue bonds, thus offering an opportunity for substantial potential saving of veneer.

Compression of Douglas Fir Plywood in Various Hot-Pressing Cycles

by

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INTRODUCTION

Lessening the present 5-8 per cent compression of Douglas fir plywood veneers during hot pressing could result in considerable savings, as veneers thinner than now customary could be used.

A decrease of three percentage points in compression of the almost 6 1/2 billion square feet (basis, 3/8-inch thickness) of Douglas fir plywood hot-pressed in 1960 out of the total amount of 8 billion square feet would have allowed production of about 190 million square feet more.

Possibility that compression in hot pressing could be reduced by adjusting the pressure had been indicated by previous research. Present work was aimed at testing this possibility.

<u>Previous work at FRL</u>

Initial research at the Laboratory on control of plywood compression was reported in 1951 (10)*. Several major factors involved in compression of veneer during hot pressing were studied, including temperature (220, 240, 260, 280, 300, and 320 F), pressure (100, 140, 180, 220, and 260 psi) and time (5 and 20 minutes).

In addition, a method for controlling amount of compression by use of a pressure-control device was outlined. The device was successful in producing plywood under conditions where total compression in the hot press was limited to 7, 5, and 3 per cent. Under similar conditions without pressure control, compression was about 9 per cent. Shear tests of the plywood indicated satisfactory joints were obtained.

Measuring compression occurring in plywood made of Douglas fir veneer containing white-pocket rot was a secondary objective of an unpublished report (9).

Most recent research at the Laboratory on control of compression in plywood involved further study of white-pocket Douglas fir veneer (6). The panels were pressed under similar conditions, except that compression was limited in half of them by controlling pressure through use of a control device. Amount of compression in the 5 plies of 1/8-inch veneer after storing for 4 weeks at conditions for 12 per cent equilibrium moisture content was reduced as much as 2-4 percentage points, with high resistance to delamination.

*Numbers in parentheses indicate similarly numbered reference in the list cited.

Previous work by others

In 1945, Redfern and Fawthop (12) reported results of a study of 3-ply, 7/16-inch, Douglas fir plywood hot-pressed with liquid-phenolic glue. They learned that compression increased with pressure and moisture content.

Cheo (5) also studied compression during hot pressing of 3 plies of 1/8-inch Douglas fir veneer. Variables included 3 types of glue (phenolic film, liquid phenolic, and soybean); 3 moisture contents of veneer (1 to 2, 5 to 6, and 10 to 12 per cent); 5 pressures (120, 140, 160, 180, and 200 psi); and 2 or 3 temperatures depending upon type of glue involved (film, 300 and 320 F; phenolic, 280, 300 and 320 F; and soybean, 240, 260 and 280 F). Pressing time was held constant at 7 minutes. Compression varied from 1.8 to 28.8 per cent, and pressure and moisture content of veneer were found to have greatest effect upon compression. Temperature did not influence compression significantly.

Two recent reports from Great Britain are concerned in part with compression of veneer during hot pressing. Curry (7) was interested in effect of compression upon strength of plywood. Since compression increases density, an increase in strength may be expected. Based upon data from gaboon plywood with 3, 7, 11, 15, and 19 plies glued with phenolic resin, urea resin, or animal glue, compression increased as number of plies increased, and was greatest with phenolic resin and least with animal glue. Curry concluded that compression in plywood is confined to thin layers at the gluelines, and that plywood actually consists of layers of strong and weak wood separated by thin, irregular bands of compressed, impregnated wood.

Carruthers (4) studied rate at which heat penetrated 1/2-inch plywood from 4 hardwood species while pressing. Compression increased with increase in pressing time, temperature, and moisture content of veneer.

Preston (11) found compression increased with increased number of glue lines in plywood of equal thickness. He hot-pressed yellow poplar plywood from veneers that were 1/10, 1/20, 1/40 and 1/60 inch in thickness. With phenol-resorcinol glue, compression was 2.5, 5.7, 10.2 and 14.5 per cent.

The Douglas Fir Plywood Association has reported results of a limited investigation into effects of uniform, compared to controlled pressure while pressing 5-ply, 13/16-inch, Douglas fir plywood (14). With blood-resin pressed at 275 F for 5 1/4 minutes, compression was reduced by control, but quality of the glue bond was lowered by reducing the pressure to 100 psi after the first minute.

Objective

Major objective of the present study was to determine effect on compression and glue bonds of reducing pressure while hot pressing Douglas fir plywood. This major objective may be subdivided as follows:

1. Determine effect of 6 different pressure cycles on compression during hot pressing.
2. Determine differences in compression due to 3 different glues.
3. Determine recovery from compression resulting from rehumidification of plywood after pressing.
4. Determine quality of glue bonds by various test methods.
5. Determine possible differences between gluing hard- and soft-grained Douglas fir veneer when hot-pressed with 1 type of interior glue.

EXPERIMENTAL PROCEDURE

Veneer was separated into 2 groups according to hardness, made into plywood with various combinations of manufacturing variables, then the plywood was tested.

<u>Soft-grained</u> <u>veneer</u>

About 1200 square feet of 1/8-inch, soft-grained, Douglas fir heartwood veneer were obtained from the U. S. Plywood Corporation's mill at Eugene, Oregon. Sheets as received were 27 by 51 inches in size, and moisture content averaged 2.1 per cent. In general, the veneer had excellent surfaces resulting from a smooth, tight peel.

Pieces 1 foot square were cut to construct 180 five-ply, 5/8-inch panels. Squares containing defects such as knots and pitch pockets were used for trial runs or checks of glue spread. The entire lot of squares was randomized by thorough mixing and shuffling, and 5-ply assemblies were constructed with grain direction of each ply at right angles to the adjacent sheet. In all panels, loose-cut faces of core veneers were oriented against loose-cut faces of the two outer plies.

Each assembly was numbered, and each face sheet from the first 120 panels pressed was marked with 4 reference points as shown in Figure 1. After code marking, all assemblies were stored under conditions to maintain moisture content at about 4 per cent.

<u>Hard-grained</u> <u>veneer</u>

Hard-grained veneer comes from Douglas fir growing on the western slope of the Coast Range from central Oregon into northern California. The wood differs from soft-grained Douglas fir in that it has a high percentage of dense summerwood. Stensrud (15) has reported the history of hard-grained Douglas fir veneer, and has studied problems in gluing associated with it. Also, the Douglas Fir Plywood Association has issued a publication concerned with differences in gluability of hard- and soft-grained veneer when bonded with exterior-phenolic resins (13).

From the operations of U. S. Plywood Corporation at Gold Beach, Oregon, typical hard-grained, 1/8-inch, Douglas fir heartwood veneer was obtained in 27- by 51-inch sheets. Following the same procedure outlined for preparation of soft-grained veneer, 60 five-ply, 5/8-inch panels a foot square were prepared and stored. Face sheets of the assemblies were numbered, but no reference points were marked.

<u>Pressing</u> <u>procedure</u>

Ten panels were pressed for each group (one particular combination of glue, veneer type and pressure cycle) of plywood (Tables 1, 2). The only exceptions occurred in the series pressed with exterior phenolic

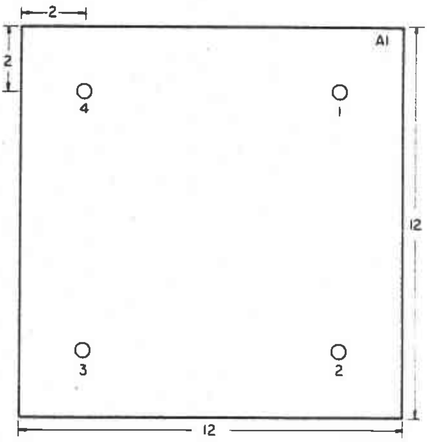


Figure 1. Locations of reference points for determining thickness with a plane table. Code number for each specimen was in the upper right hand corner; measurements were in inches.

glue (groups A-3 to G); here only 7 panels were pressed for each group. Reasons for lowering the number of specimens in a group from 10 to 7 were two-fold; an extra pressure cycle was added, and the original supply of veneer was nearing depletion.

For determining compression of veneers during hot pressing and recovery of plywood due to reconditioning, each corner of the 12-inch-square, laboratory hot press was fitted with a dial gauge (Figure 2). Previous research on compression of white-pocket Douglas fir veneers (6) showed thickness should be measured at all four corners to average out differences caused by localized variations present in the veneers.

Initial thickness. Shortly before hot pressing, groups of 10 assemblies were removed from storage. Initial thickness of each 5-ply panel was determined by the following procedure:

1. The 12- by 12-inch press was cold-flushed to minimize variation from expansion or contraction of the platens. Temperature during cold flushing ranged from 55 to 65 F. The empty press was closed, but without pressure. Ames dials mounted on the corners were set at one inch.
2. Each 5-ply assembly, without glue, was inserted in the press with code number oriented uppermost in the right rear corner of the press. The press was closed, and without applied pressure, all 4 dial gauges were read. By subtracting the average reading of the 4 dial gauges from 1.000, average initial thickness of the panel was determined.
3. For groups A-1 to F-1 and A-2 to F-2 (Table 1), initial thickness of each assembly also was obtained by measuring on a plane table the 4 reference points located on the face veneer (Figures 1 and 4).

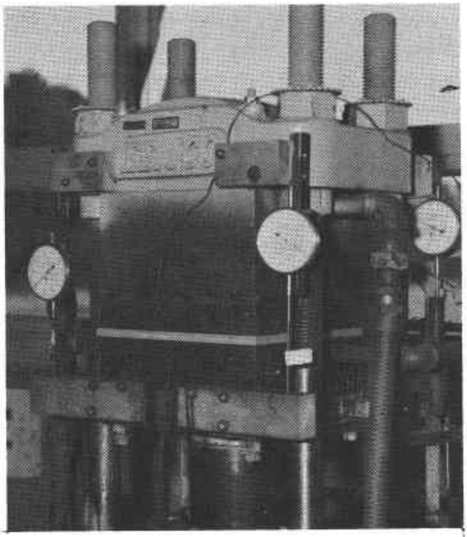


Figure 2. View of 12-inch-square press and dial gauges for measuring compression.

Glue spreading. Blood-resin, interior-, and exterior-phenolic glues were obtained directly from the mill's supply of mixed glue at U. S. Plywood Corporation, Eugene, Oregon. The glue was transported in a 5-gallon can which was placed in a cold-water bath upon arrival at the Laboratory. No difficulty was experienced in spreading any of the glues.

Both core veneers from each 5-ply assembly were double-spread at a rate recommended by the glue manufacturer (Figure 3). Moisture

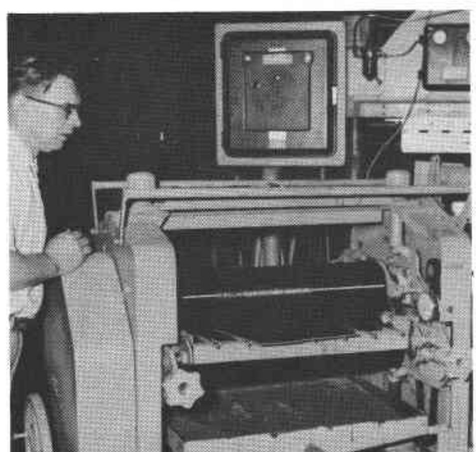


Figure 3. Applying glue with 26-inch spreader. Note dial gauge mounted on frame to indicate opening between rolls.

Table 1. Condition Followed in Pressing Panels from Five Plies of 1/8-Inch Soft-Grained Douglas Fir Veneer at 3.2 Per Cent Moisture Content.

Pressure cycle group	Pressure-cycle conditions: Initial		First change		Second change		Compression limited to:
	Pressure	Time	Pressure	Time	Pressure	Time	
	Psi	Minutes	Psi	Minutes	Psi	Minutes	Per cent
American-Marietta Co.; L-1CR blood-resin glue[1]							
A-1	175	5	---	---	---	---	---
B-1	175	1	100	4	---	---	---
C-1	175	2	100	3	---	---	---
D-1	175	1.5	140	1.5	100	2	---
E-1	175	5	---	---	---	---	5
F-1	175	5	---	---	---	---	3
Monsanto Chemical Co.; PF 4041 interior phenolic glue[2]							
A-2	175	6.5	---	---	---	---	---
B-2	175	1	100	5.5	---	---	---
C-2	175	2	100	4.5	---	---	---
D-2	175	2	140	2	100	2.5	---
E-2	175	6.5	---	---	---	---	5
F-2	175	6.5	---	---	---	---	3
Borden Chemical Co.; Cascophen 312 exterior phenolic glue[3]							
A-3	175	5.5	---	---	---	---	---
B-3	175	1	100	4.5	---	---	---
C-3	175	2	100	3.5	---	---	---
D-3	175	1.75	140	1.75	100	2	---
E-3	175	5.5	---	---	---	---	5
F-3	175	5.5	---	---	---	---	3
G	100	3	175	2.5	---	---	---

[1] Glue spread at rate of 77 pounds to a thousand square feet of double glue line, with press at 245 F.

[2] Glue spread at rate of 50 pounds to a thousand square feet of double glue line, with press at 285 F.

[3] Glue spread at rate of 57 pounds to a thousand square feet of double glue line, with press at 285 F.

content of veneer at time of spreading averaged 3.3 per cent. Rates of spread on a thousand square feet of double glue line were as follows:

Glue	Manufacturer	Spread rate
		Lb
L-1-CR blood resin	American Marietta Co.	77
PF 4041 interior phenolic	Monsanto Chemical Co.	50
Cascophen 312 exterior phenolic	Borden Chemical Co.	57

A dial gauge was mounted on the frame of the glue spreader to indicate the opening between top and bottom rolls (Figure 3). With the gauge, the desired opening for various glues and veneers could be set and maintained.

After spreading the core veneers, each panel was reassembled carefully with each veneer in the same orientation as when thickness was measured initially (Figure 5). All panels were permitted a closed assembly time of 5 minutes.

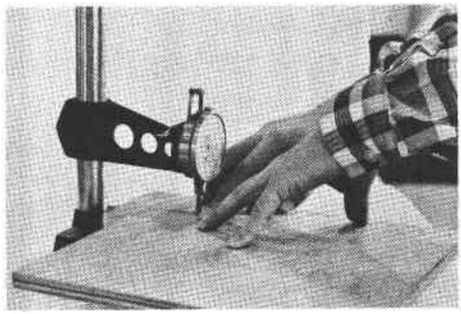
Pressure cycles. For all glues, the manufacturer's instructions for mixing, spreading and pressing were followed except for pressure,

Table 2. Conditions Followed in Pressing Panels from Five Plies of 1/8-Inch Hard-Grained Douglas Fir Veneer at 3.3 Per Cent Moisture Content.

Pressure cycle group	Pressure-cycle conditions: Initial		First change		Second change		Compression limited to:
	Pressure	Time	Pressure	Time	Pressure	Time	
	Psi	Minutes	Psi	Minutes	Psi	Minutes	Per cent
American-Marietta Co.; L-1-CR blood-resin[1]							
A-1	175	5	---	---	---	---	---
B-1	175	1	100	4	---	---	---
C-1	175	2	100	3	---	---	---
D-1	175	1.5	140	1.5	100	2	---
E-1	175	---	---	---	---	---	5
F-1	175	---	---	---	---	---	3

[1]Glue spread at rate of 77 pounds to a thousand square feet of double glue line, with press at 245 F.

Figure 4. Measuring thickness of plywood by plane table.



which was the major variable under observation. An outline of the entire study is given in Table 1 (soft-grained veneer), and Table 2 (hard-grained veneer).

The tables show soft-grained veneer was bonded by all 3 glues, and hard-grained veneer only with blood-resin glue. Six pressure cycles were investigated with blood-resin and interior-phenolic glues, and 7 pressure cycles with exterior-phenolic glue.

The first cycle for each glue, which may be called a control cycle, consisted of applying 175 psi for the full pressing time recommended by the manufacturer of the particular glue. This cycle would be typical of many present commercial plywood operations.

The next 2 cycles were 2-stage, with an initial pressure of 175 psi for either 1 or 2 minutes, followed by an abrupt drop in pressure to 100 psi for remainder of the pressing time. In theory, high initial pressure brings the veneers into intimate contact necessary for good bonding, and completes transference and penetration of glue from the cores to the unspread centers and faces. By lowering pressure before rise in temperature and formation of steam have overly plasticized the wood, total compression may be minimized. Optional time to lower the pressure will vary with type of glue, and may be critical. An abrupt drop in pressure during initial stages of bonding may result in poor bonding.

In an attempt to alleviate the abrupt drop from high to low pressure typical of a 2-stage cycle, a 3-stage pressing cycle was developed. Total pressing time required for each glue was divided roughly into thirds, and full pressure of 175 psi was applied for the initial third of the cycle, 140 psi for the middle third, and 100 psi for the remaining third. Exact time at each of the 3 pressures varied according to type of glue, since each glue had a different total pressing time.

In the last type of pressing cycle, pressure also was 175 psi initially, but was reduced automatically after a predetermined degree of compression (either 5 or 3 per cent) had been reached. Reduction in

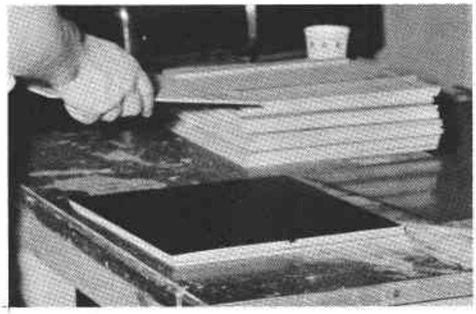


Figure 5. Reassembling veneers after applying glue.

pressure was accomplished through use of a control device which is described in detail in a previous report from the Laboratory (10).

In this study, plywood pressed with compression limited to 5 per cent had initial pressure of 175 psi maintained 1-4 minutes. Because of automatic reduction, pressure at completion of the cycle had dropped to between 110 and 140 psi. When compression was limited to 3 per cent, full pressure was maintained for not more than 45 seconds; pressure at the end of the cycle was between 60 and 90 psi.

In addition to 6 major pressing cycles discussed, 1 more was followed for soft-grained veneer glued with exterior-phenolic resin. This cycle (group G, Table 1) was the reverse of the original 2-stage type, in that initial pressure was low at 100 psi for about half the pressing time, then pressure was raised quickly to 175 psi for remainder of the cycle. This particular schedule of pressures was suggested by a glue manufacturer. The reasoning was that low pressure initially would decrease amount of penetration by glue into adjacent wood. Furthermore, by the time high pressure was applied, partial polymerization of the glue would have increased its viscosity and subsequent mobility to the point where overpenetration could not occur. Glue spread possibly could be reduced without sacrifice in quality of the bond. Total compression occurring during hot pressing might be lowered, since full pressure would be applied only after a portion of moisture contained in the veneers or added by the glue would have escaped during the low-pressure phase of the cycle.

Measuring compression and recovery. After the veneers had been spread with glue and reassembled in their original position, and the closed-assembly time of 5 minutes had elapsed, one 5-ply assembly was inserted in the hot press. Again, the code number was oriented uppermost in the right-rear corner of the press. All dials had been adjusted to read 1.000 inch when the hot press had reached required temperature for the particular glue being pressed.

Regardless of the pressure cycle, data on compression during hot pressing were gathered (Figure 6) by reading all 4 dials after 1/2, 1, 1 1/2, 2, 3, and 5 minutes' pressing time with blood-resin glue; 1/2, 1, 1 1/2, 2, 3 1/2, and 5 1/2 minutes with exterior-phenolic; and 1/2, 1, 1 1/2, 2, 3, 4, and 6 1/2 minutes with interior-phenolic glue.

At the end of the pressing cycle, panels glued with blood-resin, or interior-phenolic glue (groups A-1 to F-2, Table 1) were remeasured for thickness at their 4 reference points by the plane-table technique. All panels were stacked in an oven at 140 F for 2 hours to complete curing the glue.

After hot-stacking, panels were stickered in a room maintained at 70 F and 65 per cent relative humidity, where wood ordinarily comes to moisture content of 12 per cent. Reconditioning in this atmosphere caused panels to regain moisture, thus inducing some recovery in thickness. This increase in thickness of plywood can be substantial, but the benefit is lost if sanding is done before hot-pressed plywood has opportunity to recover from compression.

Thickness of all panels in a particular group (Table 1, 2) was remeasured by the original procedure after 1, 7, and 14 days in the conditioning room.

Special data were collected for soft-grained veneers glued with exterior-phenolic resin at 175 psi (group A-3, Table 1). Thickness of these panels was recorded by plane-table technique immediately after hot pressing, after 1/4, 1/2, 1, and 2 hours of hot stacking in the oven at 140 F, and after 2 and 6 hours and 1, 7, and 14 days in the conditioning room. This procedure was followed to learn if the panels underwent thermal expansion in the press, then decreased in thickness by cooling after removal from the press, as reported by Sisterhenm (14).

Glue-bond testing

Primary objective of this research was to reduce compression occurring during hot pressing of Douglas fir plywood by manipulating pressure during the curing cycle. However, nothing would be gained if reduced pressures contributed to inferior glue bonds. Therefore, a rigorous procedure was developed to determine glue-bond quality of plywood produced under various pressure cycles investigated.

Interior-type bonds. Plywood glue lines of blood-resin or interior-phenolic glue (group A-1 to F-2, Table 1, and A-1 to F-1, Table 2) were checked by 5 different test procedures. The cutting plan for test specimens is shown in Figure 7.

One 2- by 5-inch specimen from each panel was judged by the CS 45-60 test (2). This test of the Douglas fir plywood industry for quality control of interior-type plywood consists of soaking 2- by 5- inch specimens in water at room temperature for 4 hours, then drying at 100-105 F for 19 hours. The soak-dry cycle is repeated 3 times. Failure is interpreted as total continuous visible delamination of 1/4 inch or more in depth and over 2 inches in length along edges of the test specimen.

For the wet and dry shear tests, standard 3 1/4- by 1-inch specimens were prepared. Four specimens for each plywood panel were sheared dry, and a like number were sheared wet after soaking in water for 48 hours at 70 F. In each group of 4 shear specimens, 2 were kerfed to pull lathe checks closed and 2 to pull lathe checks open when tested. Breaking load was recorded and percentage of wood failure was estimated.

The D-test (8) is another cyclic soak-dry test for interior plywood, based upon a 1- by 10-inch specimen. This size, plus the orientation of grain, results in severe stresses being set up within the glue lines, as soaking and drying are accelerated. One test specimen from each plywood panel was soaked in water at 70 F for 16 hours, then dried for 8 hours in an oven at 150 F; this procedure was repeated until 10 cycles had been completed. Amount of delamination 1/4 inch or more in depth was determined after cycles 1, 2, 3, 4, 5, and 10, and percentage of delamination was computed, based upon total length of glue line.

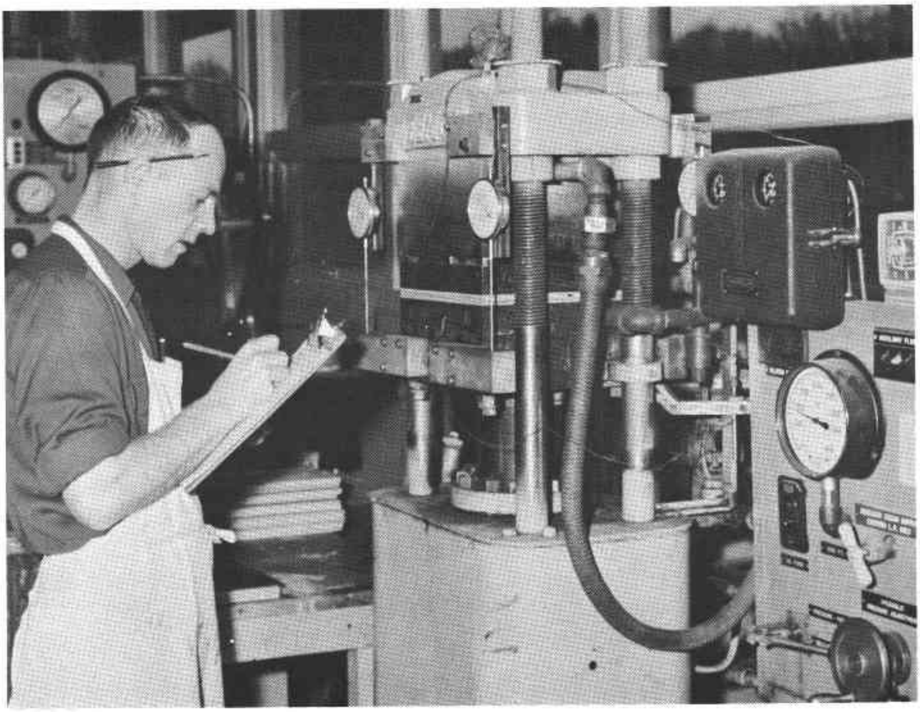


Figure 6. Measuring and recording thickness of plywood during hot pressing.

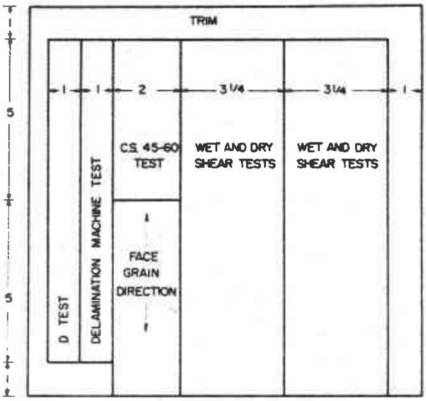


Figure 7. Cutting plan for tests of interior-type plywood. Measurements are in inches.

One 1- by 10-inch specimen from each panel was subjected to a delamination-machine test (3), which is similar to the D-test except that soak-dry cycling is accomplished automatically by machine. This particular test procedure was performed by U. S. Plywood Corporation, Seattle, Washington, and consisted of soaking specimens in water at 70 F for 1 hour, followed by drying for 3 hours at 145 F. This cycle was repeated 6 times in 1 day, then all delamination 1/8 inch or more in depth and 1/4 inch or more in length was determined. Percentage of delamination was computed, based upon total length of glue line.

Exterior-type bonds. Bonds in exterior-phenolic glue (groups A-3 to G, Table 1) were evaluated by 3 different test procedures: CS 45-60 cold-soak shear test, CS 45-60 2-cycle-boil shear test, and the delamination-machine test of U. S. Plywood Corporation. Cutting plan for exterior plywood test specimens is shown in Figure 8. Selection of specimens for shear tests followed the same plan outlined for interior plywood.

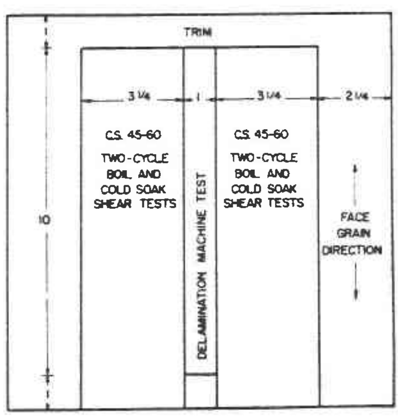


Figure 8. Cutting plan for tests of exterior-type plywood. Measurements are in inches.

Cold-soak shear specimens were subjected to the following schedule:

1. Soak in water at 70 F for 48 hours.
2. Dry at 145 F for 8 hours.
3. Soak in water at 70 F for 16 hours.
4. Dry at 145 F for 8 hours.
5. Repeat steps 3 and 4.
6. Soak in water at 70 F for 16 hours.

Specimens were shear-tested while wet; breaking load was recorded and percentage of wood failure was estimated after the chips had dried.

In the 2-cycle-boil shear test, specimens were boiled in water for 4 hours, dried in an oven at 145 F for 16 hours, and boiled again for 4 hours. After cooling, the specimens were tested wet. Breaking load was recorded and percentage of wood failure was estimated after the chips had dried.

As in the delamination-machine test for interior plywood, one 1- by 10-inch specimen was prepared from each exterior-plywood panel. The machine cycle for exterior-type glue lines was as follows:

1. Soak in water at 70 F for 1 hour.
2. Dry at 160 F for 3 hours.
3. Boil in water for 1 hour.
4. Dry at 160 F for 3 hours.
5. Steps 3 and 4 repeated 4 additional times.

Upon completion of cycling, delamination 1/8 inch or more in depth and 1/4 inch or more in length was determined. Percentage of delamination was based upon total length of glue line.

RESULTS AND DISCUSSION

Measurements and tests were aimed at determining the influence of manufacturing variables in compression, recovery from compression, thickness, and glue-bond quality of Douglas fir plywood.

Compression and recovery

Since the study included 25 different groups of plywood involving a total of 229 panels, presentation of data became a problem. To compare directly various plywood groups where variables included type of glue, type of veneer and pressing cycles, a common basis was required. Percentage of compression, based upon initial thickness of panel prior to hot pressing, filled this need.

Percentage compression for all groups of plywood at 2 intervals during the study is summarized in Table 3 for completion of the hot-pressing cycle with pressure still applied, and after 14 days of reconditioning at 70 F and 65 per cent relative humidity.

To show effectiveness of reduced pressure cycles, percentage of reduction in compression based upon readings after reconditioning is included in Table 3. For each type of glue, reduction in compression was determined by subtracting percentage of compression for each reduced pressure cycle from percentage of compression of the 175-psi control, and dividing by the compression of the control.

Percentage of recovery also is given in Table 3. This was computed for each pressure cycle by determining differences in percentage of compression between the end of the hot-pressing cycle and after 14 days of reconditioning, then dividing by compression at the end of the hot-pressing cycle. All data on recovery are based upon measurements obtained in the press; data resulting from plane-table thickness-measuring technique averaged 0.004-inch thicker, and varied considerably. This variation most likely was caused by nonuniformity of pressure applied by hand compared to measurements obtained within the press.

In addition to data contained in Table 3, graphs typifying average percentage of compression and average thickness of plywood during hot pressing and reconditioning have been constructed. The graphs include plywood bonded with exterior-phenolic glue by 7 different pressure cycles (Figures 9 to 15), and plywood from soft-grained veneer bonded with blood-resin glue by 6 different pressure cycles (Figures 16 to 21).

Of the major pressure cycles involving reduced pressures during pressing, all showed significant reduction in compression when compared to the control-pressure cycle of 175 psi, regardless of type of glue or veneer (Table 3). Actual degree of reduction in compression ranged from a low of 26 to a high of 57 per cent, with an average of 39

Table 3. Effect of Various Pressure Cycles on Compression and Recovery of Five Plies of 1/8-Inch Douglas Fir Veneer.

Pressure cycle	Soft-grained veneer												Hard-grained veneer			
	Exterior-phenolic glue				Interior-phenolic glue				Interior blood-resin glue				Interior blood-resin glue			
	Compression			Recovery	Compression			Recovery	Compression			Recovery	Compression			Recovery
	After:		Reduction		After:		Reduction		After:		Reduction		After:		Reduction	
	5.5 min	14 days			6.5 min	14 days			5 min	14 days			5 min	14 days		
	Per cent[1]	Per cent[2]	Per cent[3]	Per cent[4]	Per cent[1]	Per cent[2]	Per cent[3]	Per cent[4]	Per cent[1]	Per cent[2]	Per cent[3]	Per cent[4]	Per cent[1]	Per cent[2]	Per cent[3]	Per cent[4]
A-1,2,3	8.9	6.2	Basis	30	10.5	7.6	Basis	28	11.1	4.9	Basis	56	9.2	4.7	Basis	49
B-1,2,3	4.5	3.4	45	24	5.3	4.1	46	23	5.4	2.7	45	50	4.9	3.1	34	37
C-1,2,3	4.7	3.8	39	19	5.6	4.4	42	21	5.5	2.7	45	51	5.2	3.3	30	37
D-1,2,3	5.0	3.9	37	22	6.9	5.6	26	19	6.3	2.7	45	57	5.0	3.3	30	34
E-1,2,3	5.8	4.6	26	21	5.9	4.5	41	24	5.9	2.8	43	53	5.6	3.3	30	41
F-1,2,3	4.8	3.8	39	21	4.2	3.3	57	21	4.2	2.3	53	45	4.3	3.0	36	30
G	8.8	6.1	2	31	---	---	---	---	---	---	---	---	---	---	---	---

[1] In press, under pressure, based on thickness at start of pressing.
[2] After reconditioning at 70 F and 65 per cent relative humidity; based on thickness at start of pressing.
[3] Based on compression remaining at end of conditioning plywood from cycle A-1,2,3.
[4] At end of conditioning, based on compression at end of pressing.

per cent. In order of decreasing effectiveness upon reduction in compression during hot pressing, and considering the average for all types of glue and veneer, the 5 pressure cycles may be listed as follows:

1. Compression control set at 3 per cent; 46 per cent reduction (groups F-1, 2, 3).

2. 175 psi for 1 minute, 100 psi remainder; 43 per cent reduction (groups B-1, 2, 3).

3. 175 psi for 2 minutes, 100 psi remainder; 39 per cent reduction (groups C-1, 2, 3).

4. Compression control set at 5 per cent; 35 per cent reduction (groups E-1, 2, 3).

5. 175 psi for 1/3 cycle, 140 psi for 1/3 cycle, and 100 psi for 1/3 cycle; 35 per cent reduction (groups D-1, 2, 3).

For exterior-phenolic glue, largest reduction in compression of 45 per cent was found in plywood pressed with the 2-stage cycle of 175 psi for 1 minute and 100 psi for remainder of the pressing time. The special reversed 2-stage cycle of low followed by high pressure tried with exterior-phenolic glue (group G) resulted in reduction in compression of only 2 per cent.

When high pressure of 175 psi was applied to group G (Figure 15), compression increased at a rate greater than normal for the exterior-phenolic glue; compare slope of the curves with those for straight pressure of 175 psi (Figure 9). Evidently, during low initial pressure of 100 psi, the wood had opportunity to heat, and moisture had a chance to penetrate a substantial portion of the veneer. This combination resulted in optimal conditions for plasticization by the time high pressure of 175 psi

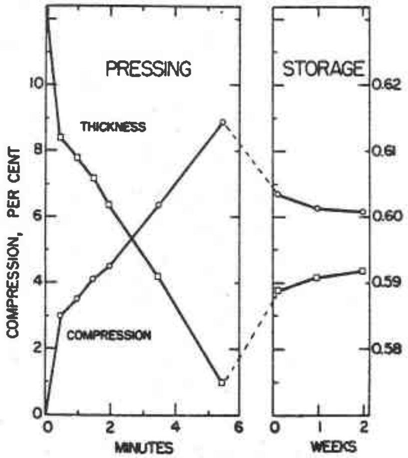


Figure 9. Average compression and thickness of soft-grained Douglas fir plywood spread with exterior-phenolic glue and pressed for 5.5 minutes at 175 psi (pressure-cycle group A-3, Table 1).

Average compression and thickness of soft-grain Douglas fir plywood spread with exterior-phenolic glue.

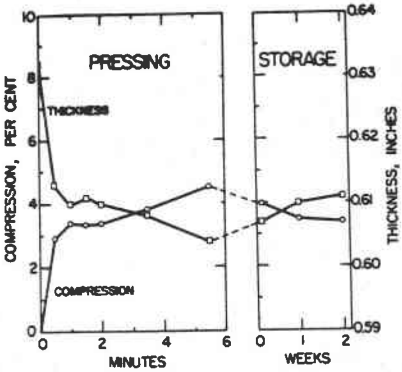


Figure 10. Pressed for 1 minute at 175 psi, then 4.5 minutes at 100 psi (pressure-cycle group B-3, Table 1).

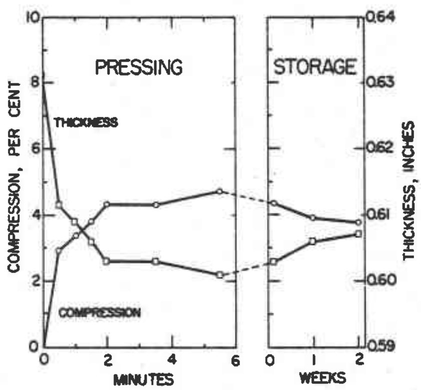


Figure 11. Pressed at 175 psi for 2 minutes, then 100 psi for 3.5 minutes (pressure-cycle group C-3, Table 1).

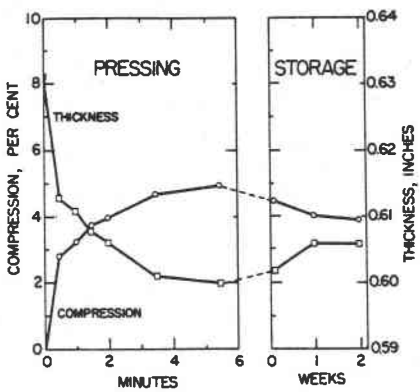
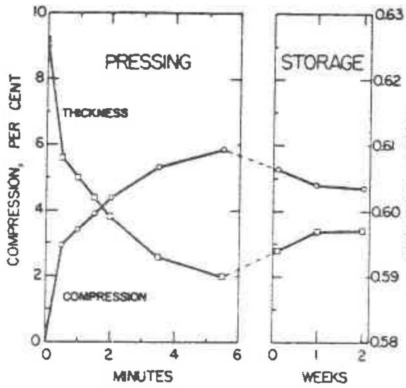


Figure 12. Pressed at 175 psi for 1.75 minutes, 140 psi for 1.75 minutes, then 100 psi for 2 minutes (pressure-cycle group D-3, Table 1).

Average compression and thickness of soft-grain Douglas fir plywood spread with exterior-phenolic glue.

Figure 13. Pressed for 5.5 minutes with initial pressure of 175 psi, and compression controlled at 5 per cent (pressure-cycle group E-3, Table 1).



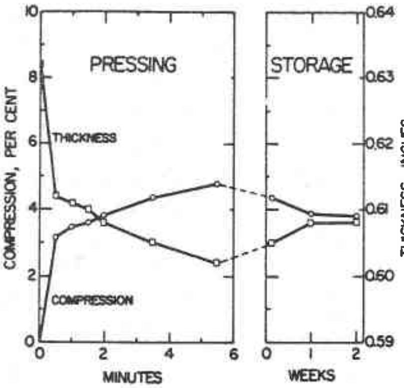
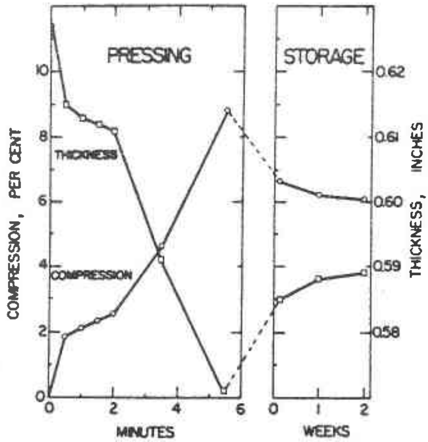


Figure 14. Pressed for 5.5 minutes with initial pressure of 175 psi, and compression controlled at 3 per cent (pressure-cycle group F-3, Table 1).

Figure 15. Pressed at 100 psi for 3 minutes, then 175 psi for 2.5 minutes (pressure-cycle group G, Table 1).



was applied, thus inducing rapid compression of wood. Undoubtedly, results from this type of cycle would change if ratio of time at low pressure to time at high pressure were investigated more fully.

Limitation of compression to 3 per cent by automatic pressure-control device resulted in the largest reduction in compression for plywood glued with interior-phenolic or blood-resin adhesives. For interior-phenolic glue, reduction in compression was 57 per cent; for blood-resin with soft-grained veneer, 53 per cent, and with hard-grained veneer 36 per cent.

In comparing percentage of compression for soft-grained veneer at completion of the hot-pressing cycle (pressure still maintained) and after 14 days reconditioning at 70 F and 65 per cent relative humidity, an anomalous situation is seen. Compared to exterior or interior phenolics, plywood pressed with blood-resin glue usually exhibited higher percentage of compression during hot pressing, but consistently had lowest compression after reconditioning. Conversely, phenolic-glued plywood generally had compression lower than that of blood-resin-bonded plywood during the actual hot-pressing operation, and higher compression after reconditioning.

Percentage-recovery columns in Table 3 assist in explaining these differences in compression due to type of glue. Both exterior and interior phenolics recovered about the same, percentage-wise, for each of the various pressure cycles. Average percentage of recovery for both phenolic glues was 23, while average recovery for blood-resin glue with soft-grained veneer was 52 per cent, or more than double the recovery compared to phenolic glues. The conclusion is that phenolic glues tended to retain a larger degree of compression occurring during hot pressing than did the blood-resin type of glue. The curves in Figures 22 and 23 also point out this relationship.

With aid from Table 3, effect of soft- and hard-grained Douglas fir veneer on compression of hot-pressed plywood may be ascertained. Both types of veneer were bonded with the same blood-resin glue under identical pressing conditions. Hard-grained veneer did not compress as much as did soft-grained veneer during the hot-pressing cycle (exception: compression controlled at 3 per cent), but more of the compression was permanent because compression after reconditioning was greater in the hard-grained plywood (exception: pressure of 175 psi). Recovery for soft-grained plywood averaged 52 per cent, and for hard-grained, 38 per cent.

<u>Panel thickness</u>

The commercial producer of Douglas fir plywood also is interested in a different aspect of compression, actual thickness of the veneer assembly during and after hot pressing. Commercial Standard CS

45-60 (2) allows tolerance in thickness of ± 1/64 inch (0.016) on sanded, and ± 1/32 inch (0.031) on unsanded panels. Thus, final thickness for 5/8-inch unsanded plywood must not go below 0.594 inch. For plywood to be sanded, minimum thickness of the panel will be 0.609 inch, plus allowance for sanding (commonly 0.030 to 0.050 inch). The construction of 5 plies of 1/8-inch veneer used in this study is suitable for making 5/8-inch, unsanded, sheathing-grade plywood, but is not thick enough for 5/8-inch, sanded panels.

For all 25 groups of experimental plywood, average initial thickness prior to hot pressing, and average thickness after hot pressing and reconditioning are presented in Table 4. In addition, average thickness during hot pressing and reconditioning of plywood bonded with exterior-phenolic and interior blood-resin glues has been plotted in Figures 9 to 21.

From Table 4, only 4 of the 25 groups of plywood after reconditioning had average thicknesses below the minimum of 0.594 inch required by CS 45-60 for unsanded plywood. All reject groups involved soft-grained veneer bonded with either exterior- or interior-phenolic resin. Two resulted from the control-pressure cycle of 175 psi when used in conjunction with exterior or interior phenolics (Figure 23). Another group below minimum thickness consisted of interior-phenolic resin pressed with the 3-stage pressure cycle. The last group was made with exterior phenolic using the experimental 2-stage pressure cycle of low to high pressure (Figure 15). Plywood bonded with blood-resin glue was thicker than the minimum in every instance; this was true for both soft- and hard-grained veneer.

Average initial thickness for panels constructed with soft-grained veneer ranged from 0.624 to 0.633 inch; for hard-grained veneer, thickness was somewhat greater, and ranged from 0.632 to 0.648 inch. This was to be expected, since the soft- and hard-grained veneer was peeled on different lathes.

Thus, on the basis of panel thickness, plywood produced with either exterior- or interior-phenolic resin at 175 psi would have been rejected because of insufficient thickness. By changing to some form of manipulating pressure, such as 2-stage high-to-low pressure, or automatic control of compression, acceptable panels were produced. Even with blood-resin glue, use of modified pressures during hot pressing resulted in production of plywood with margin of safety in thickness that was greater than that for plywood produced at constant pressure of 175 psi.

Superior recovery of blood-resin-bonded plywood, mentioned previously during the discussion concerning compression and recovery, may

Average compression and thickness of soft-grain Douglas fir plywood spread with blood-resin glue.

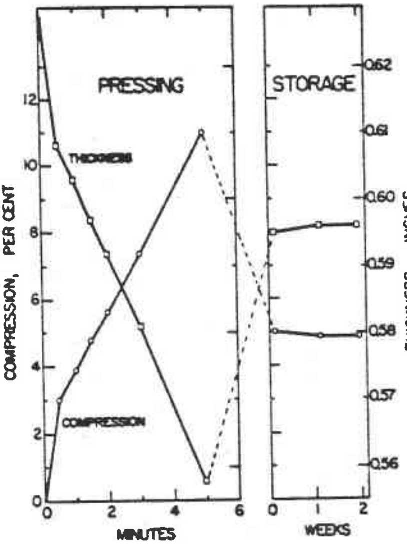
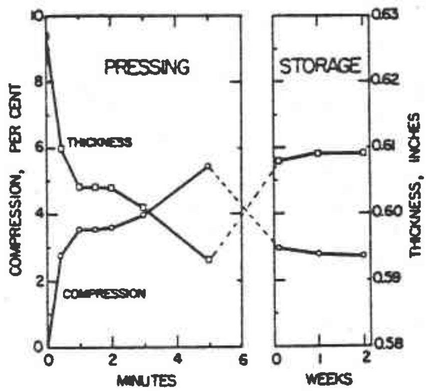


Figure 16. Pressed at 175 psi for 5 minutes (pressure-cycle group A-1, Table 1).

Figure 17. Pressed at 175 psi for 1 minute, then 100 psi for 4 minutes (pressure-cycle group B-1, Table 1).



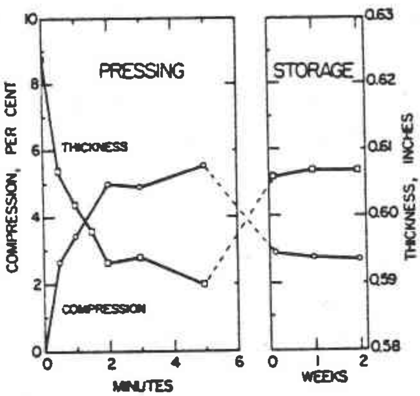
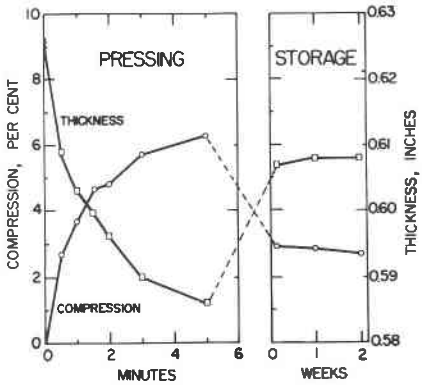


Figure 18. Pressed at 175 psi for 2 minutes, then 100 psi for 3 minutes (pressure-cycle group C-1, Table 1).

Average compression and thickness of soft-grain Douglas fir plywood spread with blood-resin glue.

Figure 19. Pressed at 175 psi for 1.5 minutes, 140 psi for 1.5 minutes, then 100 psi for 2 minutes (pressure cycle group D-1, Table 1).



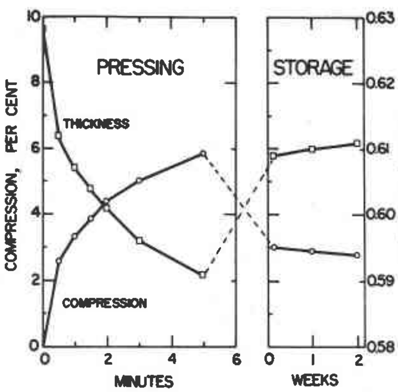


Figure 20. Pressed for 5.5 minutes at initial pressure of 175 psi with compression controlled at 5 per cent (pressure-cycle group E-1, Table 1).

Figure 21. Pressed for 5.5 minutes at initial pressure of 175 psi with compression controlled at 3 per cent (pressure-cycle group F-1, Table 1).

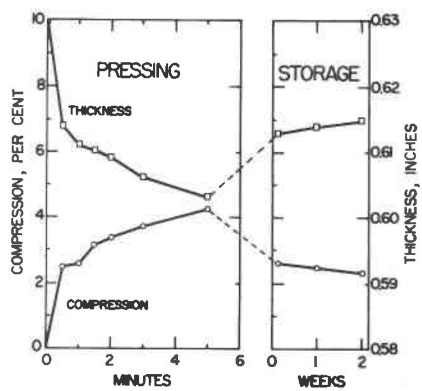


Table 4. Effect of Various Pressure Cycles on Average Thickness of Plywood From 5 Plies of 1/8-Inch Douglas Fir Veneer.

Pressure cycles	Soft-grained veneer						Hard-grained veneer	
	Exterior-phenolic glue		Interior-phenolic glue		Blood-resin glue		Blood-resin glue	
	Initial	Final[1]	Initial	Final[1]	Initial	Final[1]	Initial	Final[1]
	In.	In.	In.	In.	In.	In.	In.	In.
A-1, 2, 3	0.631	0.592	0.626	0.578	0.627	0.596	0.632	0.602
B-1, 2, 3	.632	.611	.633	.607	.627	.609	.643	.623
C-1, 2, 3	.631	.607	.630	.602	.624	.607	.636	.615
D-1, 2, 3	.631	.606	.628	.593	.626	.608	.641	.620
E-1, 2, 3	.626	.597	.629	.601	.628	.611	.648	.626
F-1, 2, 3	.632	.608	.628	.607	.630	.615	.642	.623
G	.627	.589	---	---	---	---	---	---

[1]Thickness after 14 days' reconditioning at 70 F, 65 per cent relative humidity.

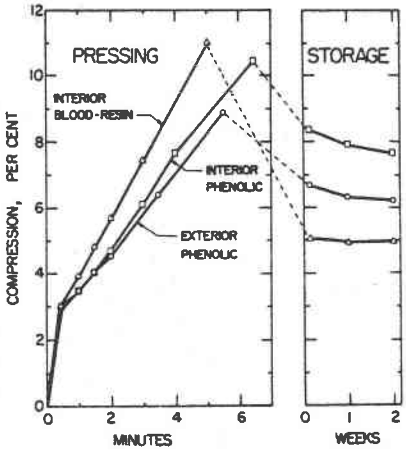


Figure 22. Average compression of soft-grain Douglas fir plywood bonded with three different glues and pressed at 175 psi.

be seen in Figure 23. Spring-back of panels containing blood-resin glue was rapid; most of it occurred within the first day after hot pressing. On the other hand, recovery of phenolic-bonded plywood was not so great, and tended to continue throughout the entire reconditioning period.

Results of special measurements of thickness performed upon group A-3 plywood (soft-grained veneer glued with exterior-phenolic resin at 175 psi) are presented in Figure 24. The hot-pressed panels continued to decrease in thickness during the 2 hours of hot stacking in an oven at 140 F, remained at the same thickness for the first 6 hours of reconditioning at 70 F and 65 per cent relative humidity, then gradually increased in thickness over the next 14 days.

Average loss in thickness after hot pressing was 0.004 inch. Using the formulas for coefficient of linear thermal expansion of wood (1), theoretical expansion under conditions of hot pressing the 5/8-inch plywood showed a value of 0.002 inch in the radial direction and 0.003 inch in the tangential direction. Rotary-peeled veneer would fall between these directions, thus explaining in part the decrease in thickness. Remainder of the decrease could have resulted from repeated pressure in measuring the thickness 5 times in 2 hours.

A practical application of information contained in Figure 24 would be to delay sanding of hot-pressed plywood for as long as possible so as to avoid sanding when panel thickness was at a minimum.

<u>Glue-bond tests</u>

Results of glue-bond tests are presented in Tables 5 through 9; in summary, results were excellent. Reducing pressure by various methods during hot pressing did not appear to affect integrity of bonds of either interior or exterior glue, as all plywood surpassed minimum requirements outlined in CS 45-60, or stipulated by the Douglas fir plywood industry.

Interior-type bonds. All interior plywood passed the 3-cycle CS 45-60 test at a value of 100 per cent. Specifications call for 95 per cent of all test specimens to pass the first cycle and 85 per cent, the third cycle.

Breaking load and percentage of wood failure resulting from the dry-shear test are presented in Table 5. There were no official requirements pertaining to results for this particular test procedure. In general, there appeared to be some reduction in wood failure when plywood manufactured under reduced pressures was compared to the control series pressed at 175 psi. Phenolic-glued plywood had a percentage of wood failure greater than that of plywood bonded with blood-resin glue. Reduction of pressure during hot pressing did not seem to affect the average breaking load of the shear specimens. In most instances, highest breaking loads occurred in plywood bonded with phenolic glue.

The wet-shear test (Table 6) followed the same pattern found for dry-shear tests. As expected, values for both breaking load and wood failure were lower than those in dry-shear tests.

Delamination by D-test (Table 7) indicated general superiority of interior-phenolic glue over blood-resin glue in withstanding deterioration resulting from numerous cycles of alternate soaking and drying. Plywood produced by reduced pressures usually exhibited a percentage of delamination greater than that produced by the control pressure of 175 psi; however, degree of delamination was not serious in any instance.

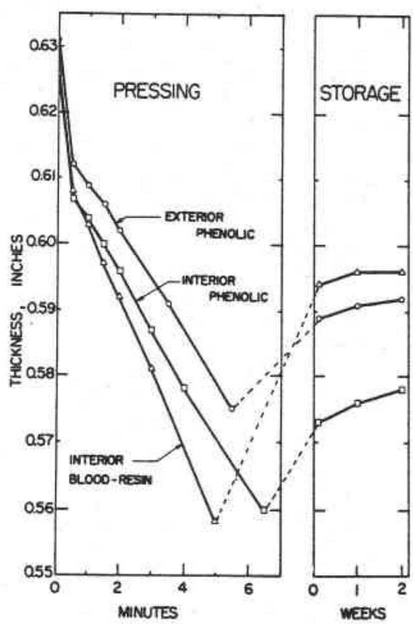


Figure 23. Average thickness of soft-grain Douglas fir plywood bonded with three different glues and pressed at 175 psi.

Table 5. Results of Dry-Shear Test on Plywood with Five Plies of 1/8-Inch Douglas Fir Veneer.

Pressure cycles	Soft-grained veneer				Hard-grained veneer	
	Interior-phenolic glue		Interior blood-resin glue		Interior blood-resin glue	
	Breaking load	Wood failure	Breaking load	Wood failure	Breaking load	Wood failure
	Psi[1]	Per cent[1]	Psi[1]	Per cent[1]	Psi[1]	Per cent[1]
A-1,2	298	90	243	59	247	66
B-1,2	295	73	244	50	241	42
C-1,2	290	72	245	25	251	56
D-1,2	276	82	250	43	278	60
E-1,2	289	75	228	40	266	56
F-1,2	278	83	249	38	277	49

[1] Based on average of 4 specimens from each of 10 plywood panels.

Table 6. Results of Wet-Shear Test (48-Hour Soak) on Plywood with Five Plies of 1/8-Inch Douglas Fir Veneer.

Pressure cycles	Soft-grained veneer				Hard-grained veneer	
	Interior-phenolic glue		Interior blood-resin glue		Interior blood-resin glue	
	Breaking load	Wood failure	Breaking load	Wood failure	Breaking load	Wood failure
	Psi[1]	Per cent[1]	Psi[1]	Per cent[1]	Psi[1]	Per cent[1]
A-1,2	236	80	204	33	171	45
B-1,2	238	70	204	33	168	12
C-1,2	235	57	199	13	178	31
D-1,2	231	70	193	26	194	27
E-1,2	225	76	176	23	177	12
F-1,2	206	79	205	28	192	16

[1] Based on average of 4 specimens from each of 10 plywood panels.

Table 7. Delamination by D-Test in Plywood with Five Plies of 1/8-Inch Douglas Fir Veneer.

Pressure cycles	Delamination after cycles indicated					
	Soft-grained veneer				Hard-grained veneer	
	Interior-phenolic glue		Interior blood-resin glue		Interior blood-resin glue	
	5 cycles	10 cycles	5 cycles	10 cycles	5 cycles	10 cycles
	Per cent[1]	Per cent[1]	Per cent[1]	Per cent[1]	Per cent[1]	Per cent[1]
A-1,2	0.0	0.0	0.0	0.7	0.1	1.7
B-1,2	0.0	0.1	0.2	1.4	0.7	2.3
C-1,2	0.0	0.6	0.4	4.6	0.3	1.0
D-1,2	0.0	0.0	0.2	1.6	0.0	0.3
E-1,2	0.0	0.0	1.4	5.3	0.4	2.6
F-1,2	0.0	0.1	2.1	7.9	0.0	3.1

[1]Based on average of 1 specimen from each of 10 plywood panels.

Table 8. Results of Tests by Delamination Machine on Plywood with Five Plies of 1/8-Inch Douglas Fir Veneer.

Pressure cycles	Delamination at end of test			
	Soft-grained veneer			Hard-grained veneer
	Exterior-phenolic glue	Interior-phenolic glue	Interior blood-resin glue	Interior blood-resin glue
	Per cent[1]	Per cent[2]	Per cent[2]	Per cent[2]
A-1,2,3	0.0	0.0	0.0	0.0
B-1,2,3	0.0	0.0	0.0	0.0
C-1,2,3	0.0	0.0	0.0	0.0
D-1,2,3	0.0	0.5	0.0	0.0
E-1,2,3	0.0	0.2	1.3	0.0
F-1,2,3	0.0	0.3	0.1	0.2
G	0.0	---	---	---

[1]Based on average of 1 specimen from each of 7 plywood panels.

[2]Based on average of 1 specimen from each of 10 plywood panels.

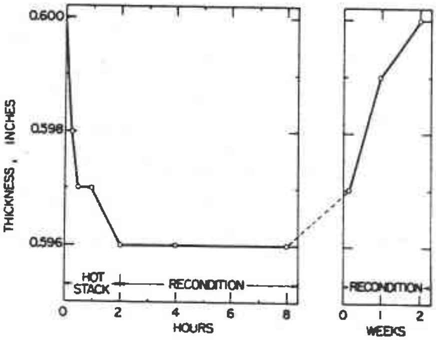


Figure 24. Average thickness during hot-stacking and reconditioning of soft-grain Douglas fir plywood bonded with exterior-phenolic glue (pressure-cycle group A-3, Table 1).

After 10 cycles, only 2 groups had delamination exceeding 5 per cent; this occurred with soft-grained veneer glued by blood-resin with compression controlled to 5 and 3 per cent.

Results of tests by delamination machine are given in Table 8. The slight degree of delamination developing occurred in plywood pressed with compression controlled at either 5 or 3 per cent, and also in the 3-stage pressure cycle.

Exterior-type bonds. Table 9 contains results of tests required by CS 45-60, and Table 8 has results from delamination-machine tests of exterior-phenolic-bonded plywood.

Table 9. Results of Exterior-Type Shear Test According to Commercial Standard 45-60 on Plywood with Five Plies of 1/8-Inch Douglas Fir Veneer.[1]

Pressure cycles	Two-cycle boil test: Exterior-phenolic glue		Cold-soaking test: Exterior-phenolic glue	
	Breaking load	Wood failure	Breaking load	Wood failure
	Psi[1]	Per cent	Psi	Per cent
A-3	185	92	205	92
B-3	169	92	190	93
C-3	200	93	218	92
D-3	191	95	192	93
E-3	208	92	230	93
F-3	180	94	196	94
G	192	97	194	95

[1]Based on average of 4 specimens from each of 7 plywood panels.

The quality-control program for Douglas fir plywood prescribes that wood failure must meet a minimum average of 85 per cent when tested after the 2-cycle boil test, or when results of both the cold-soaking and boil tests are combined. As may be noted in Table 9, all plywood easily met these requirements regardless of pressing conditions. Additional evidence of excellent bonding is shown in the results of the delamination-machine tests (Table 8), where no delamination was indicated in any plywood bonded with exterior-phenolic glue.

COMMENTS

Before listing conclusions that may be drawn from the research reported here, a few words of caution appear to be appropriate. All data resulted from closely controlled manufacture of plywood in a laboratory under conditions somewhat different from those usually found in a commercial plywood plant.

Another factor of importance, and one worthy of further research, is effect of size of panel upon compression during hot pressing. Research in the laboratory was completed with plywood one foot square; this size is vastly different from commercial panels 4 by 8 feet, or larger, in size. In all probability, adjustments will have to be made to the data for small-scale panels to make the information effective for large-sized plywood.

This is not to say results from laboratory-size panels are only theoretical in nature, for they present a goal attainable in production if management analyzes the problem and takes corrective steps to eliminate or modify current practices leading to over-compression and large variation in thickness of veneer and plywood. To be effective, control must extend from peeling the veneer to sanding the panel, and must include all operations having a potential effect upon thickness of veneer or panel.

CONCLUSIONS

1. Significant reduction in permanent compression resulted when plywood hot-pressed by 5 different pressing cycles involving lowered pressures was compared to plywood produced under normal pressure of 175 psi. Reduction in compression ranged from 26 to 57 per cent, and averaged 39 per cent of that in plywood pressed at 175 psi.

2. Permanent compression of plywood bonded with blood-resin glue consistently was less than that of plywood bonded with either exterior- or interior-phenolic glue. This was due in part to greater recovery, or spring-back, of plywood bonded with blood-resin.

3. In comparing soft- and hard-grained Douglas fir veneer hot-pressed under identical conditions, hard-grained veneer compressed less than soft-grained veneer during hot pressing, but retained more of the compression during the recovery period.

4. Based upon thickness of panels after hot pressing and reconditioning, reduced pressure cycles during hot pressing offer increased chance of producing 5/8-inch, unsanded, sheathing-grade plywood from 5 plies of 1/8-inch veneer within tolerances of CS 45-60 for thickness.

5. Hot-pressed plywood, because of thermal expansion, will continue to lose in thickness after removal from the hot press. Once the plywood is cooled and starts to regain moisture, recovery in thickness will commence. Sanding should be delayed to take full advantage of regained thickness of the plywood.

6. Based upon standard and other procedures for testing glue bonding, reduction of pressure during hot pressing did not appear to affect integrity of glue bonds. Plywood bonded with either interior or exterior glues easily surpassed minimal requirements of CS 45-60 and of the Douglas fir plywood industry.

7. As shown by the D-test, bonds with interior-phenolic glues were superior to those with blood-resin glue in withstanding delamination caused by repeated cycles of soaking and drying.

8. Controlled reduction of pressure during hot pressing of Douglas fir plywood offers the industry an opportunity for substantial potential savings of veneer by eliminating excessive compression of wood.

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