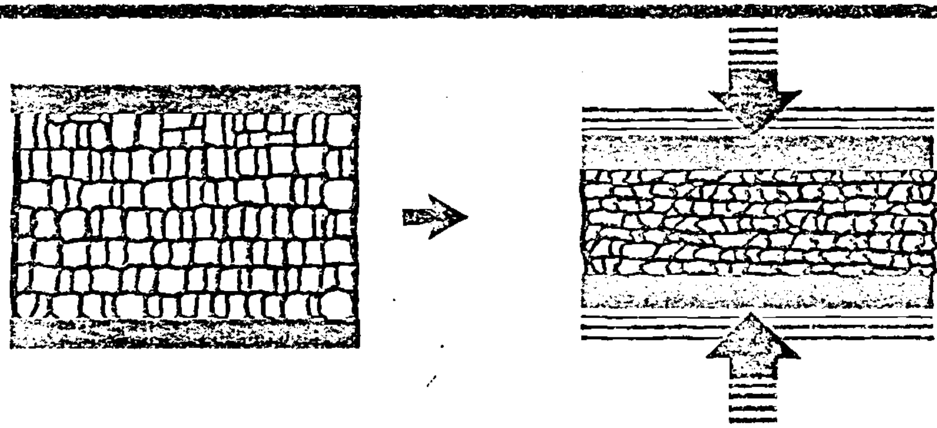
COMPRESSION LOSSES IN HOT PRESSED PLYWOOD



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Benefits

This report shows that reducing panel compression in the hot press by one percentage point, thus permitting a similar decrease in peel thickness, can save \$100,000 per year per 100 million 3/8" production.

The above savings can be realized by using a single properly-timed pressure reduction during the press cycle with no increase in press time. Significantly greater savings can be realized by using multiple pressure drops during the cycle.

Cost

Over two-thirds of the hot presses in use in APA mills are capable of a single drop pressure without modification. Mills with these dual-pressure presses can realize the above savings with no associated equipment cost and no loss of press production.

More refined methods of automatic pressure control are possible, but one approach would be to simply add timers and controllers for additional pressures. The figures below show that this basic approach costs \$5,000 or less. To this must be added the in-plant installation costs. If installation cannot be completed during scheduled downtime, a further production loss cost will be incurred. Still, return of investment should be realized within the first quarter of operation.

Modifications

The following brands account for 85% of the hot presses presently in use in APA mills. The cost figures, where shown, are an estimate of the cost of parts and engineering drawings only.

Williams-White

Presses manufactured before 1950 or after 1963 have dual-pressure capability; others are single-pressure. Cost to convert a single to dual, or a dual to triple: maximum \$3,500.

Columbia

About half these presses are capable of dual-pressure now. They are no longer manufactured, so contact another press supplier for a bid on modifications.

Fjellman

All presses manufactured in the last 20 years have dual-pressure capability. Parts to add two more pressures would cost \$3,000 - \$4,000 maximum.

Superior

All have dual-pressure capability. Two more pressures can be added for not more than \$5,000.

Siempelkamp

Nearly all are capable of two pressures. Additional pressures can be added for not more than \$2,000 per pressure.

George Sleet
Plywood Research Foundation

Compression Losses in Hot Pressed Plywood

Objectives

The objectives of this study were (1) to determine the magnitude of compression losses occurring during conditions typical of softwood plywood manufacture, (2) to determine the extent to which those losses could be avoided by reducing hot press pressure or recovered by wetting the panels after pressing, and (3) to determine where within the thickness of the plywood panels the compression losses occur.

Conclusions

1. Recent trends toward higher veneer moisture and higher press temperatures can result in compression losses as high as 11% during hot pressing of Douglas-fir plywood.
2. Compression loss is inversely proportional to veneer density. Southern pine and Douglas-fir, being of similar density, exhibit similar compression. Lower density species such as hemlock and true firs compress more readily.
3. Reducing press pressure at press closure or during the press cycle compensates in large part for the greater compression losses at higher temperatures and moisture contents.
4. In this work, panel durability (as measured by wood failure) was unaffected by reductions in pressure to 100 psi. Pressure reductions to 75 psi, however, significantly lowered wood failure levels.
5. Wetting of Douglas-fir plywood immediately after hot pressing causes about a 1% recovery in panel thickness, regardless of the amount of compression occurring.
6. Anatomical observations show that as compression losses increase above 5-7%, zones of compression failure in thin-walled fibers are scattered throughout the veneer, in addition to adhesive-saturated fibers compressed in the glueline.

Introduction

Justification

Log costs have increased so dramatically in the past ten years that veneer has increased from less than 50% to more than 60% of the cost of producing softwood plywood. As a result, process losses once considered too small for concern have become very important.

One such process loss is the compression of the veneers in the hot press. The hot pressing step causes densification of the veneers with a resulting loss of wood volume. If hot press compression could be reduced enough to permit a 1% decrease in dry veneer thickness, a plant with an annual production of 100 million square feet (3/8" basis) could realize a savings of $100,000 per year. This assumes veneer costs of $100/M 3/8".

Past Work

Variables influencing compression losses have been studied previously. Redfern and Fawthrop (1945) documented that Douglas-fir plywood lost an additional 10% of panel thickness (over normal compression) when press pressure was increased from 125 to 200 psi and veneer moisture content was increased from 1% to 9%. MacDonald (1951) confirmed the detrimental effects of long press time, high temperature, and high press pressure, and he designed equipment that would minimize compression by continuously reducing pressure during the press cycle.

Currier (1962, 1963) found that compression losses at 175 psi varied from 5% to 10% depending on species density, but he found that these losses could be nearly halved by reducing pressure in steps during the press cycle (step-pressing). He also showed that some of the compression is recovered as panels absorb moisture from the air.

Few plants implemented the changes recommended by these early studies, presumably not because of mechanical limitations, but because greater opportunities were available for saving wood.

Recent Changes

During the 20 years since these earlier studies, a number of changes have occurred in softwood plywood plants. Many mills now dry veneer to an average moisture content of 5-8% rather than 0-2% as in earlier days, to consume less energy during veneer drying, to minimize veneer shrinkage, and to improve adhesion. But the more moist veneer is more easily compressed. Hot press temperatures used today are 25 to 50°F higher than used in the 1960s (increasing compression) but the phenolic adhesives are faster curing, requiring about 3/4 the previous time (reducing compression). Some mills have found it necessary to increase hot press pressure from 175 to 200 psi in order to obtain intimate contact between the rough veneer surfaces obtained when peeling smaller, coarse-grained, second-growth logs. To compensate for these compression losses, a few mills now spray water on panels shortly after hot pressing. But earlier studies did not examine humidification, so it is impossible to know whether gains in thickness from wetting and humidification are in addition to, or in lieu of, gains from reduced pressure.

The above changes make it difficult for today's mill manager to use the earlier data to estimate accurately the potential savings from pressure reduction during hot pressing or from humidification. Therefore, this study was undertaken to measure separately the effects of pressure, temperature, and veneer moisture content on panel compression in the hot press. The question of whether some of this compression could be recovered by humidification after pressing was also examined.

Study Variables

Veneer Species

Veneer species used were Douglas-fir (*Pseudotsuga menziesii*), southern yellow pine (*Pinus spp.*), and hem-fir, a commercial mixture of western hemlock (*Tsuga heterophylla*) and true firs (*Abies spp.*).

All veneers were commercially peeled, 1/8" thick, C-D grade.

Drying/Moisture Content

All veneers were commercially dried except for a small amount of Douglas-fir which was obtained green and platen-dried in the laboratory to a moisture content (M.C.) of 5% at a platen temperature of 425°F and a contact pressure of 35 psi (Sandoe 1980).

All veneers were conditioned after drying either to a M.C. of 5.8 ± 0.5% at a temperature of 90°F and 30% relative humidity (R.H.), or to a M.C. of 1.0 ± 0.5% by storing them in a convection oven at 145°F for 24 hours. For simplicity, these moisture levels are referred to in the text as 6% and 1%.

Press Time/Press Temperature

All panels were pressed at one of the following combinations:

5.8 min. @ 270°F
5.2 min. @ 290°F
4.6 min. @ 310°F
4.2 min. @ 330°F

Press Pressure

Seven pressure schedules were examined. Three were a steady pressure for the total press cycle, three included a single pressure reduction during the cycle, and one used three such pressure reductions:

Steady	200 or 175 or 150 psi
Single-step	200/125 or 200/100 or 200/75 psi
Triple-step	200/150/125/100 psi

For step-pressures, the portion of total press time at each incremental pressure is shown in Table 2, page 10.

Post-Treatment

Immediately after hot pressing, each panel was cut in half. One half was placed while hot in an insulated box for 24 hours to simulate a mill hot stack, then stickered for conditioning to approximately 10% M.C. (70°F, 60% R.H.). The other half was dipped in water (70°F) for 20 seconds to simulate a mill humidification step, then placed in a separate hot stack for 24 hours prior to being conditioned to 10% M.C. This water dip added an average of 5% moisture to the panels.

Study Constants

Panel construction, adhesive, spread level, prepress conditions, and assembly time were held constant for all panels:

Panel Construction:	5/8" x 2' x 2', 5 plies 1/8" veneer		
Adhesive:	Monsanto PF 3098 with wheat and alder bark flours		
Spread Level:	65-67 lbs per 1000 sq ft double glueline		
Prepress Conditions:	5 min. @ 150 psi, ambient temperature		
Assembly time:	Open:	None	
	Closed:	Before prepress	5 min.
		Prepress	5 min.
		After prepress	10 min.
		Total	20 min.

Four replicate panels were pressed for each combination of variables shown in Tables 1, 2 and 3: a total of 124 panels were glued in the study.

Procedure

Thickness Measurements

Panel thickness measurements were made in different ways, depending on when the measurements were made. All thickness gauges were standardized to both metal and wood plates whose thicknesses were uniform and known within 0.0005".

Before Hot Pressing — The thicknesses of uncured panels before and after prepressing were made while the panels were in the prepress at a pressure of one psi. A dial gauge (sensitivity = 0.0001") was used, calibrated to record the distance between the plates of the prepress.

The intent was to use these measurements in determining what part of total panel compression occurred during prepressing. But if the veneer was not uniform in thickness, or if the veneer was wavy, daylight could be seen between portions of the panel and the press plates at one psi, giving erroneously high thickness readings for panels entering the prepress.

All panels *leaving* the prepress were flat, so a similar bias did not exist in subsequent measurements at the hot press. For that reason, the thickness leaving the prepress was used as the base for comparing all future measurements.

During Hot Pressing — The thickness of panels being cured in the hot press was measured continuously by a pair of linear variable differential transducers (sensitivity = 0.0001") mounted on opposite corners of the hot press and calibrated to record on a strip chart the average distance between the plates of the hot press.

After Hot Pressing — The thickness of cured panels was measured on the midline along the length of each half panel (see "Post Treatment" above) at various times after hot pressing. Measurements were made with a Trienco non-contact thickness gauge, a laser-based instrument with repeatability better than 0.001".

Measurements were taken 2 minutes, 60 minutes, one day, 7 days and 60 days after hot pressing.

Panel Bond Quality

Glueline quality was checked after panels had been conditioned for 60 days or more. Each half panel was cut and tested according to Product Standard PS 1-74 (Anon 1974) to produce 5 plywood shear specimens which were vacuum-pressure-soaked, sheared while wet and wood failure estimated from the dried specimens.

Anatomical Observations

Microscopic examinations of gluelines and end-surfaces of veneers of various panels were made with a Zeiss stereomicroscope, a Leitz incident fluorescence microscope, and an AMR 1000A scanning electron microscope. Specimens were sawn from a panel and the surface to be examined was cut cleanly with a razor blade. No other wetting, softening or sectioning procedure was used except for preparation of some surfaces and sections for photomicrography to illustrate the observations.

Test Results and Discussion

Product Standard PS 1-74 requires unsanded and touch-sanded panels to be within ± 1/32" of stated nominal thickness, so the minimum allowable thickness for 5/8" panels is .594". But the average thickness of panels glued here with 6% M.C. veneer was .640 ± .005" entering the hot press; these panels were unacceptably thin if compression losses exceeded 7%.

Tables 1, 2 and 3 show all compression losses measured in the study at times up to 60 days after pressing. But since most mill thickness checks are made within one to three days after pressing, the discussions below will reference only the one-day data from the tables.

NOTE: The compression loss percentages shown here may seem high, because of the base thickness used to calculate losses (see Summary, page 8). However, the figures do accurately reflect compression response to changes in press conditions.

Influence of Variables

Veneer Species — The effect of species on hot press compression was not examined in detail, but Douglas-fir was compared to southern pine to show that species of similar density have similar compression losses. The following excerpt from Tables 2 and 3 covers 6% M.C. veneer only:

Press Time, Temperature	Pressure, psi	Compression Loss, %	
		Douglas-fir	So. Pine
5.8 min. at 270°	200/150/125/100	5.2	6.8
4.2 min. at 330°	200	12.3	11.4

Similarly, Douglas-fir was compared to hemlock/true fir to show that lower-density species compress more under identical conditions. Again, from Tables 2 and 3, 6% M.C. veneer only:

Press Time, Temperature	Pressure, psi	Compression Loss, %	
		Douglas-fir	Hem-Fir
5.8 min. at 270°	200/150/125/100	5.2	10.3
4.2 min. at 330°	200	12.3	13.9

Drying Method — Green Douglas-fir veneer loses about 4% of its thickness during conventional drying. But an earlier study (Sandoe 1980) showed that platen drying results in an 8% thickness loss. It was felt that this higher thickness loss during drying might be offset by lower compression during hot pressing, since the veneers had been "precompressed." But panels glued here showed that platen-dried veneer was not significantly different in hot press compression from veneer dried conventionally (from Tables 2 and 3):

Press Time, Temperature	Pressure, psi	Douglas-fir, 6% M.C. Compression Loss, %	
		Conventional	Platen
5.8 min. at 270°	200	8.7	9.2
5.8 min. at 270°	175	8.3	8.1
5.8 min. at 270°	150	7.4	6.6

Veneer Moisture Content — The following excerpt from Tables 1 and 2 isolates the effects of veneer moisture content on compression loss:

Press Time, Temperature	Douglas-fir, 200 psi Compression Loss, %	
	1% M.C.	6% M.C.
5.8 min. at 270°	5.8	8.7
5.2 min. at 290°	6.2	9.3
4.6 min. at 310°	7.6	9.4
4.2 min. at 330°	8.1	12.3

Note that compression losses at 6% M.C. are two to four percentage points higher than at 1% M.C. Due to their higher moisture, the 6% M.C. panels were slightly thicker (.640 ± .005") going into the hot press than the 1% M.C. panels (.630 ± .006"). But this small difference in initial thickness (1.5%) was more than offset by subsequent compression losses. Thus, veneer thickness savings realized by drying to a higher initial M.C. are nullified at the hot press, if temperature and/or pressure are not reduced.

Press Temperature — Even though press *time* was reduced as press temperature was increased, panels pressed at 330° still showed significantly more compression than those pressed at 270°:

Pressure, psi	Douglas-fir, 6% M.C. Compression Loss, % 5.8 min. @ 270°	4.2 min. @ 330°
Steady 200	8.7	12.3
200/125	8.5	8.6
200/100	8.2	8.6
200/75	6.3*	8.2*
200/150/125/100	5.2	7.5

*Suspected poor bonds. See Summary.

Compression losses can be reduced by lowering press temperatures, but a production loss is incurred due to the longer press time.

Press Pressure — The effect of press pressure and the interaction between press pressure and press time were examined in detail. All charts below are for Douglas-fir at 6% M.C., from Table 2.

To measure the effect of pressure alone on compression, panels were glued at one of three steady pressures for the full press time.

Press Time, Temperature	Compression Loss, % Steady 200 psi	Steady 175 psi	Steady 150 psi
5.8 min. at 270°	8.7	8.3	7.4
4.2 min. at 330°	12.3	10.4	8.2

Pressing at a steady 150 psi produced a significant saving in panel compression, but this low pressure might not provide the necessary intimate contact between veneers when rough stock is encountered. A series of panels were pressed with high initial pressure (200 psi) to provide this intimate contact, followed by a reduction in pressure for the remainder of the cycle. For the panels represented below, this reduction in pressure occurred halfway through the press cycle:

Press Time, Temperature	Compression Loss, % Step 200/125	Step 200/100	Step 200/75
5.8 min. at 270°	8.5	8.2	6.3*
4.2 min. at 330°	8.6	8.6	8.2*

*Suspected poor bonds. See Summary.

Little difference was noted between the press cycles above, apparently because most of the compression had occurred before the pressure was reduced. To check this, the following panels were pressed at 200/125 psi with the pressure reduction occurring either very early in the cycle, or at about quarter-cycle, or at mid-cycle (actual times at pressures are shown in Table 2). Lowering the pressure early in the cycle was most effective in controlling compression:

Press Time, Temperature	Compression Loss, % 200/125 Early	200/125 Quarter/Cycle	200/125 Mid-Cycle
5.8 min. at 270°	7.2	8.3	8.5
4.2 min. at 330°	7.5	8.0	8.6

The final pressure schedule evaluated here involved initial pressure of 200 psi to provide intimate veneer contact, followed by reductions to 150, 125 and 100 psi during the cycle. Use of this schedule gave compression losses even lower than pressing at a steady 150 psi:

Press Time, Temperature	Compression Loss, % Steady 150 psi	Step 200/150/125/100
5.8 min. at 270°	7.4	5.2
4.2 min. at 330°	8.2	7.5

Post-Treatment — As mentioned earlier, panels were cut in half when they left the hot press, and one half of each panel was dipped in water for 20 seconds. Two minutes after the water dip, these wetter pieces were 0.5 to 1.5% thicker than the corresponding dry pieces. This difference was retained even after the wetted panels were conditioned to essentially the same moisture content as the dry panels ($M.C._{dry} = 9.8 \pm 0.3\%$; $M.C._{wetted} = 10.6 \pm 0.3\%$). Thus, the thickness recovery from wetting was from springback and not simply swelling due to an increase in moisture content.

Of special significance is the fact that the approximately 1% thickness recovery from wetting the panels occurred no matter whether the compression was 4% or 11%. Thus, the benefit from wetting can be gained *in addition to* the benefit from pressure or temperature reduction. Wetting the panels caused no significant change in durability, as measured by wood failure.

Summary

For many years, an industry "rule of thumb" has been that hot pressing causes a 5% compression loss. With that in mind, the losses measured here may seem high: only the "mildest" conditions here produced losses that low. But while the industry has historically calculated losses based on dry veneer thickness, they were calculated here with panel thickness entering the hot press as a base. Thus, the base thickness here was greater: it was the sum of dry veneer thickness, glueline thickness, and probably some slight swelling of the veneers caused by the wet glue. Note, however, that no part of the losses shown is due to prepressing: initial measurements were taken *after* prepressing.

The recent industry trend toward using higher moisture content veneers has reduced drying costs, minimized veneer shrinkage, and improved veneer gluability. But this higher M.C. veneer is more compressible, so changes must be made at the hot press or the compression losses will offset the above gains.

Compression can be lessened by using lower press temperatures or by lowering press pressure. But lower press temperatures require longer press *times* to insure adhesive cure, and this introduces a press production loss. Thus, the most logical alternative for reducing compression is lowering press pressure.

Pressing at a steady 150 psi resulted in significantly less compression than pressing at 200 psi, and glue bonds were not affected (see Wood Failure test results in Tables 1, 2 and 3). But this steady lower pressure might not provide intimate contact when veneers are rough. Step-pressing, or lowering the pressure during the cycle, will provide initial intimate contact and still avoid the large losses associated with continued high pressure.

Step-pressing at 200/125 or 200/100 or 200/75 psi produced less compression the lower the secondary pressure. But while panels pressed at 200/75 psi showed very low compression, wood failure results on these panels were significantly lower (close to the 80% minimum required for C-D panels with exterior glue). Use of 75 psi even in step-pressing is not recommended.

The effect of time at pressure, or where in a step-pressing cycle pressure should be reduced, was examined. It was found that lowering pressure early in the cycle was more effective in controlling compression than lowering pressure at mid- or quarter-cycle. No effect on bond quality was noted.

Based on the above observations, one multiple step-pressure schedule (200/150/125/100 psi) was devised and evaluated. Even though the initial pressure in this cycle was 200 psi (to consolidate rough veneers), it produced compression losses even lower than the steady 150 psi cycle. Panel glue bonds were excellent, and no production loss was incurred since no press time was added.

Panel humidification after hot pressing resulted in recovery of some of the compression loss, and this humidification did not affect glueline quality. This recovery was a fairly constant 1% of initial panel thickness, and seemed independent of total compression.

Anatomical Observations

One of the objectives of this study was to determine where within the panel compression occurred. While *location* of compression is beyond the control of the manufacturer, some knowledge of where it occurs might help in controlling total compression.

At panel compressions less than 5%, the major zone of compression was at or near the glueline (see Figure 1). These thin-walled earlywood fibers were saturated with adhesive and subsequently bonded in place when the adhesive cured. However, when thick-walled latewood fibers were adjacent to the glueline, little or no compression occurred in these fibers even though heated and plasticized by the adhesive.

At panel compressions over 7%, additional bands of thin-walled fibers were compressed in earlywood zones of growth rings. The compressed fibers appeared both near the glueline (Figure 2), or well removed from the glueline (Figure 3).

While one would expect serious compression at panel surfaces where the veneer touched the hot platen, no consistent zone of compressed fibers was noted there even at large compression losses.

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TABLE 1. Effect of Hot Press Variables on Thickness Loss of 5/8-inch Plywood Panels Made From Douglas-fir Veneer[a] at 1 Percent Moisture Content.

Hot press conditions			Thickness loss of dry panels and of wetted panels (in parenthesis) after hot pressing[b]						
Temperature (°F)	Pressure (psi)	Time (min)	0 min	2 min	60 min	1 day	7 days	60 days	Wood failure
			(%)						
270	200	5.8	9.4	5.4 (5.5)	5.5 (5.4)	5.8 (5.4)	5.2 (5.4)	3.8 (2.8)	88 91
290	200	5.2	9.0	5.9 (5.9)	6.1 (5.8)	6.2 (5.9)	5.9 (5.4)	4.8 (3.9)	92 93
310	200	4.6	9.4	7.1 (6.7)	7.2 (6.5)	7.6 (7.0)	7.0 (6.4)	6.2 (5.5)	96 98
330	200	4.2	10.6	7.8 (7.0)	7.8 (6.7)	8.1 (6.9)	7.6 (6.6)	6.6 (5.7)	98 96

[a] All veneer commercially dried in a conventional veneer dryer and conditioned to 1% MC.

[b] Values at 0 minutes were recorded at the end of the press cycle while panels were under 200 psi. Each value is an average for four panels with a 95% confidence limit of ~ ± 0.4%.

TABLE 2. Effect of Hot Press Variables on Thickness Loss of 5/8-inch Plywood Panels Made From Douglas-fir Veneer[a] at 6 Percent Moisture Content.

Hot press conditions			Thickness loss of dry panels and of wetted panels (in parenthesis) after hot pressing[b]						
Temperature (°F)	Pressure[c] (psi)	Time[c] (min)	0 min	2 min	60 min	1 day	7 days	60 days	Wood failure
			(%)						
270	200	5.8	12.6	8.7 (8.0)	9.1 (8.0)	8.7 (7.3)	8.6 (7.4)	8.4 (6.9)	91 90
270	175	5.8	11.1	8.0 (7.6)	8.6 (7.6)	8.3 (7.2)	8.1 (7.2)	7.7 (6.3)	98 89
270	150	5.8	10.2	7.6 (7.1)	7.8 (6.9)	7.4 (6.4)	7.3 (5.9)	7.0 (5.7)	94 95
270	200/125	0.8/5.0	9.8	7.5 (7.2)	7.7 (7.0)	7.2 (6.3)	7.2 (6.2)	6.5 (5.7)	93 94
270	200/125	1.5/4.3	10.4	8.6 (7.7)	8.9 (7.5)	8.3 (6.9)	8.3 (6.9)	7.7 (6.6)	96 91
270	200/125	2.9/2.9	10.7	8.6 (7.6)	8.6 (8.0)	8.5 (7.6)	8.2 (7.3)	7.8 (6.8)	85 93
270	200/100	2.9/2.9	10.0	8.2 (7.5)	8.5 (7.0)	8.2 (6.7)	7.9 (6.8)	7.6 (6.3)	95 89
270	200/75	2.9/2.9	10.0	6.8 (6.1)	6.9 (5.7)	6.3 (5.2)	6.3 (5.2)	5.9 (4.2)	86 81
270	200/150/125/100	1.4/1.5/1.4/1.5	7.7	5.5 (4.9)	5.8 (4.9)	5.2 (4.1)	5.1 (4.2)	4.8 (3.8)	95 99
290	200	5.2	12.7	9.9 (8.9)	10.4 (9.0)	9.3 (7.9)	9.4 (8.1)	9.2 (7.3)	95 98
310	200	4.6	13.3	10.1 (9.2)	10.6 (9.2)	9.4 (8.7)	9.5 (8.7)	9.4 (8.2)	95 97
330	200	4.2	16.1	11.5 (10.1)	11.8 (10.1)	12.3 (10.2)	11.6 (10.0)	10.7 (9.7)	96 96
330	175	4.2	13.4	9.0 (7.9)	10.1 (7.7)	10.4 (7.9)	8.7 (7.7)	8.1 (6.8)	98 100
330	150	4.2	11.8	7.9 (7.8)	8.0 (7.6)	8.2 (8.0)	8.0 (7.5)	7.2 (6.9)	97 96
330	200/125	0.5/3.7	9.7	6.7 (7.0)	6.9 (7.0)	7.5 (7.4)	7.2 (7.0)	7.2 (6.2)	95 98
330	200/125	1.2/3.0	10.4	7.2 (6.5)	7.5 (6.5)	8.0 (6.8)	7.6 (6.4)	7.1 (6.0)	96 94
330	200/125	2.0/2.2	10.6	8.0 (7.1)	8.2 (7.1)	8.6 (7.3)	8.4 (7.2)	8.3 (7.0)	89 98
330	200/100	2.0/2.2	10.5	8.1 (7.6)	8.3 (7.7)	8.6 (8.2)	8.5 (7.9)	7.9 (6.4)	86 88
330	200/75	2.0/2.2	10.3	7.8 (7.2)	7.9 (7.1)	8.2 (7.7)	7.4 (7.2)	7.0 (6.4)	81 79
330	200/150/125/100	1.0/1.1/1.0/1.1	9.9	7.0 (7.1)	7.3 (6.6)	7.5 (6.5)	7.0 (6.2)	6.6 (6.0)	95 96

[a] All veneer commercially dried in a conventional veneer dryer and conditioned to 6% EMC.

[b] Values at 0 minutes were recorded at the end of the press cycle while panels were under full pressure. Each value is an average for four panels with a 95% confidence limit of ~ ± 0.4%.

[c] Changes during the press cycle are indicated by a diagonal line separating initial pressure and time from subsequent pressures and times.

TABLE 3. Effect of Hot Press Variables on Thickness Loss of 5/8-inch Plywood Panels Made From Various Species of Veneer at at 6 Percent Moisture Content.

Hot press conditions			Thickness loss of dry panels and of wetted panels (in parenthesis) after hot pressing[a]						Wood failure
Temperature (°F)	Pressure[b] (psi)	Time[b] (min)	0 min	2 min	60 min	1 day	7 days	60 days	
			(%)						
Southern pine									
270	200/150/125/100	1.4/1.5/1.4/1.5	8.0	6.4 (5.4)	6.4 (5.4)	6.8 (5.5)	6.5 (5.6)	6.2 (4.7)	95 93
330	200	4.2	15.2	10.8 (9.8)	10.1 (9.9)	11.4 (9.7)	10.7 (9.4)	9.6 (8.8)	96 94
Hemlock-true fir									
270	200/150/125/100	1.4/1.5/1.4/1.5	13.2	10.1 (8.1)	10.0 (8.0)	10.3 (8.2)	9.9 (8.3)	9.5 (7.7)	93 91
330	200	4.2	23.6	13.1 (12.2)	13.2 (11.6)	13.9 (12.2)	12.5 (11.4)	12.0 (10.8)	95 99
Douglas-fir, platen-dried[c]									
270	200	5.8	13.6	8.3 (8.6)	8.5 (8.5)	9.2 (8.4)	8.7 (8.1)	8.5 (7.9)	91 95
270	175	5.8	11.6	7.0 (7.1)	7.1 (7.0)	8.1 (7.3)	7.4 (7.1)	7.2 (6.7)	98 100
270	150	5.8	8.7	5.8 (5.8)	5.7 (5.9)	6.6 (5.9)	6.0 (5.7)	6.2 (5.5)	99 99

[a] Values at 0 minutes were recorded at the end of the press cycle while panels were under full pressure. Each value is an average for four panels with a 95% confidence limit of ~ ± 0.4%.

[b] Changes during the press cycle are indicated by a diagonal line separating initial pressure and time at that pressure from the subsequent pressures and times.

[c] Veneers were platen-dried at 425°F with a contact pressure of 35 psi; all other veneers were dried commercially in a conventional veneer dryer. All veneers were conditioned to 6% EMC after drying.

FIGURE 1. Light photomicrograph of plywood showing compressed fibers in the glueline.

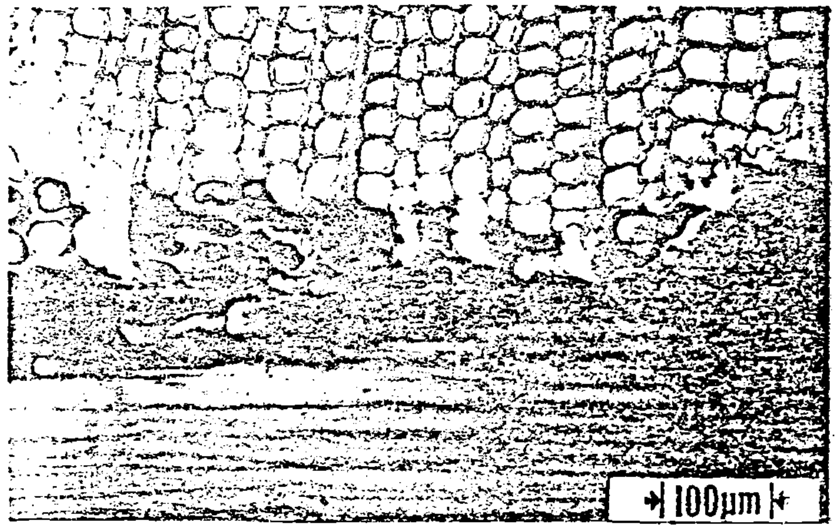

FIGURE 2. Scanning electron micrograph of plywood with zone of compressed fibers near glueline (G).

FIGURE 3. Scanning electron micrograph of plywood with zone of compressed fibers remote from glueline (G).