IMPACT OF STEAM PRESSING VARIABLES ON THE DIM ENSIONAL STABILIZATION OF FLAKEBOARD

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ABSTRACT

The objective of this study was to determine if an unsealed steam-injection system affects flakeboard dimensional stability. Two steam pressures (690 and 1370 kPa) and two steam times (10 and 30 sec.) were investigated. Core temperatures in isocyanate-bonded, steam-injected pressed flakeboards were well above those recorded in conventionally pressed boards. Closing board pressures were considerably less than needed for conventionally pressed boards. Thickness swell of the steam-injected pressed flakeboard, following exposure to either relative humidity conditioning or a vacuum pressure soak treatment, was less than experienced in a conventional pressed board. Thickness swell, as well as linear expansion properties, improved as steam pressure and steam exposure time increased. The increase in board thickness during a 24-hour soak was similar in all specimens. Rapid moisture movement in the steam-injected press (SIP) boards is attributed to a reduction in the vertical density gradient and increased permeability as a result of the steam treatment. An analysis of variance test based on the board-to-board variance indicated no statistical difference in bending properties. Differences in shear propeties are attributed in part to changes in the vertical density gradient.

Marty efforts have been directed toward improving the hot pressing of wood composites because of its importance in the development of both productivity and board quality (10). A relatively new technology, steam-injection pressing (SIP), utilizes perforated platens to inject steam directly into the board and permits the transfer of heat into the core of a board much faster than in conventional pressing. Many studies on reduction of press time using SIP have been conducted (2, 11-15). The process is applicable to all composites using thermosetting resins but is especially applicable in the production of thick boards such as composite lumber.

In addition to reduced press time, an additional benefit of SIP is improvement of dimensional stability. Shen (13) and Thoman (14) reported improved dimensional stability of phenolic resin-bonded particleboard using a sealed SIP process. In recent work with a unique closed SIP system that permitted steaming under pressure during press closure, Geimer et al. (3,6) defined the basic response of flakeboard thickness swell (TS) and selected mechanical properties to changes in steam pressure and time. The results indicated that wood plasticization, lignin flow, and molecular changes, all contributed to the reduction of TS. Reductions in TS were dependent on both steam pressure and steam duration. The TS following a vacuum pressure soak (VPS) of SIP isocyanate-bonded boards treated with 10 seconds of 1,050 kPa steam was reduced to half that measured in conventionally pressed boards. A sixfold reduction of TS was obtained in SIP boards using 40 seconds of steam at 1,950 kpa. However, bending properties of the boards were adversely affected by the steam treatment. This was attributed largely to short press times and the reduction of vertical density profiles in the SIP boards.

A sealed SIP system, because of its peripheral edge seal, permits the attainment of high steam pressures. According to Hsu (8), an unsealed system that uses the mat to act as the seal can provide only a little stabilization effect. He reasoned that high pressure steam is needed to lower the softening level and increase the plasticization of wood components to reduce internal stress in the mat, consequently reducing TS. However, Hsu's work showed that steam pressures of 1,030 kPa are sufficient to improve dimensional stability of phenolic-bonded boards. Han et al. (7) showed that detectable hemicellulose degradation begins with steam pressures as low as 600 kPa (corresponding to saturated steam tem-

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TABLE 1A. — Steam-injection and press schedules.

Press schedule	Cumulative press time[a]	Steam-injection schedule
Hold at 200 mm for 2 sec.		
	2	
1st closure rate of 7 mm/sec. to 25 mm		
	27	
2nd closure rate of 2 mm/sec. to 13 mm		Steam flow of 350 kg/hr. begins at 25 mm (approximately 27 sec. cumulative time) for 4 sec.[b]
	(31)	
		Steam at pressure of (a) for (b)[c]
	33	
Hold at 13 mm for 180 sec.		
	(31 + (b))	
		Vent
	213	
Decompress at 50 to 150 kPa		
	214	
Hold at 150 kPa for 10 sec.		
	224	
Open rate of 6 mm/sec. to 200 mm		
	255	

[a] Cumulative times in parentheses apply only to steam-injection portion of schedule.
[b] Steam purge is the same for all schedules.
[c] The (a) and (b) in Table 1A refer, respectively, to steam pressure and steam time in Table 1B.

TABLE 1B. — Steam-injection variables.

Schedule	Pressure (a)	Time (b)	Total
(sec./kPa)	(kPa)	- - - - - (sec.) - - - - -	
Conventional	0	0	0
10/690	690	6	10
10/1380	1380	6	10
30/690	690	26	30
30/1380	1380	26	30

peratures of 165°C) and increases with steam time and pressure. Exposure of wood flakes to 40 seconds of steam at 1,950 kpa (213°C) resulted in a 72, 54, and 50 percent hydrolysis of the respective arabinose, rhamnose, and galactose potions. Wolcott et al. (16), in discussions on the dependency of vertical density profiles to changes in the state of amorphous polymem, indicated that the glass transition temperature (TJ of lignin (which is greater than hemicelluloses) was reached in mats having a moisture content (MC) of 15 percent during a conventional pressing schedule using 190°C platen temperature. Geimer et al. (5) indicated that with the added moisture available during SIP, temperatures up to 100°C above the T_g of lignin were attainable using an unsealed system. Pressures of up to 1,500 kPa with associated temperatures of 200°C have been attained using an unsealed system. Therefore, it would seem that TS reductions dependent on exceeding the T_g of lignin could be attained.

Geimer (2) previously indicated the time dependency of steam stabilization and reported that short steam-injection times, which were sufficient to reduce total press times substantially, did not significantly improve dimensional stability of phenolic boards made with an unsealed steam-injection press. Geimer (5) later reported that reduction of a 24-hour soak TS in isocyanate-bonded boards made with an unsealed steam-injection press was proportional to the degree of steaming. Walter (15) also reported dimensional stability enhancement in boards made with commercial unsealed steam-injection presses. The advantages of using an unsealed system are readily apparent when the problems of sealing a large industrial press in a dirt-prone environment are considered. Therefore, it is of practical interest to explore the limits to which an unsealed system can affect dimensional stability.

OBJECTIVE

The purpose of this study was to determine the relative degree that steam pressure and steam time have on the dimensional stability of isocyanate-bonded wood composites pressed with an unsealed steam-injection system.

EXPERIMENTAL PROCEDURES

Twenty-five flakeboards were constructed. Variables included two steam times (10 and 30 sec.) and two steam pressures (690 and 1,370 kPa). Five replications were made for each combination of steam time and steam pressure. In addition, five control boards were made in a conventional manner without steam treatment.

FLAKE PRODUCTION

Air-dried, 5-cm-thick rough lumber of aspen *(Populus tremuloides* or *Populus grandidenta)* was used to make flakes. The 244-cm-long lumber was ripped to approximately 23 cm wide and saturated with water in a vacuum pressure tank. The wet lumber was then converted to 1.9-cm chips and further reduced to 0.76-mm-thick flakes in a ring flaker. The flakes were dried to an MC of approximately 4 percent in a steam-heated drum drier and screened on 0.16- and 0.08-cm mesh vibrating screens. Twenty-three percent of the total material passed through the 0.08-cm mesh and was eliminated. The two screen fractions were recombined and stored in polyethylene bags.

BOARD FABRICATION

All boards were fabricated to an oven-dry specific gravity target of 0.64 and target board thickness of 13.0 mm. The flakes were sprayed with 3 percent polymeric isocyanate binder (based on oven-dry wood) in a drum blender. Viscosity and specific gravity of the resin were 200 cps and 1.24 (25°C), respectively. The boards were hand formed in a 760- by 660-mm deckle box. The mat was formed on a 1.78-mm-thick screen caul, which had been sealed around the edges with latex to prevent the steam from escaping (4). Prior to pressing, a similar screen was placed on top of the mat. A thermocouple was installed halfway through the mat thickness in the center of the mat. Mat MC into the press was approximately 4 percent; press temperature was 190°C.

PRESSING AND STEAM INJECTION

Geimer (2) reported that to be effective in reducing press time, steam should be introduced prior to compressing the mat to a specific gravity of 0.42 to 0.45. He found that this mat specific gravity permitted relatively easy penetration of steam around the wood flakes. In later work, Geimer et al. (3,6) also found this

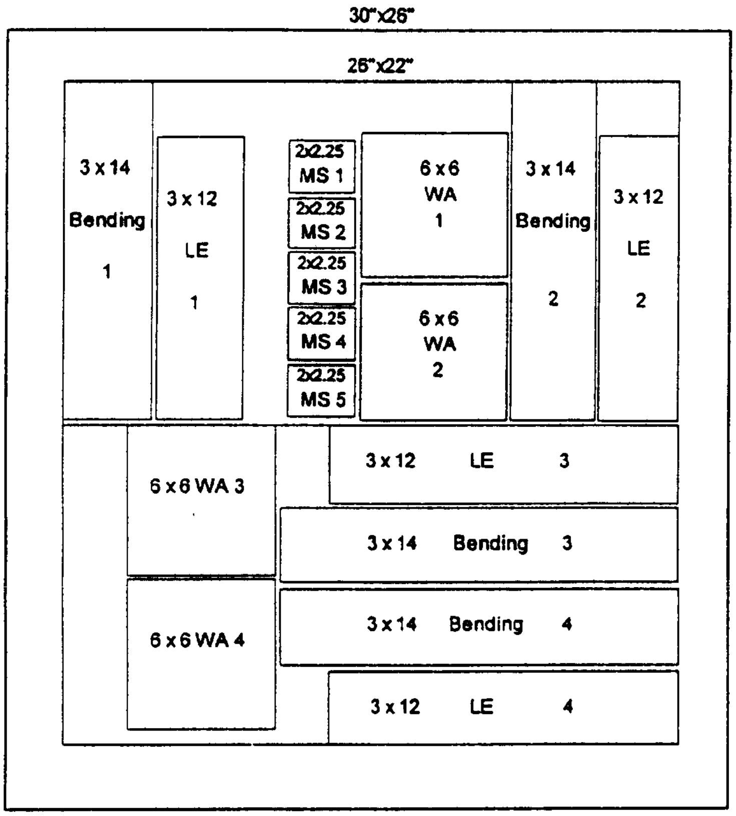

Figure 1. — Diagram of cut-out specimens from panels. All dimensions are in inches; 1 in. = 2.54 cm. Five Minnesota shear (MS), four static bending (Bending), four linear expansion (LE), and four 24-hour TS (WA) specimens were obtained from each panel.

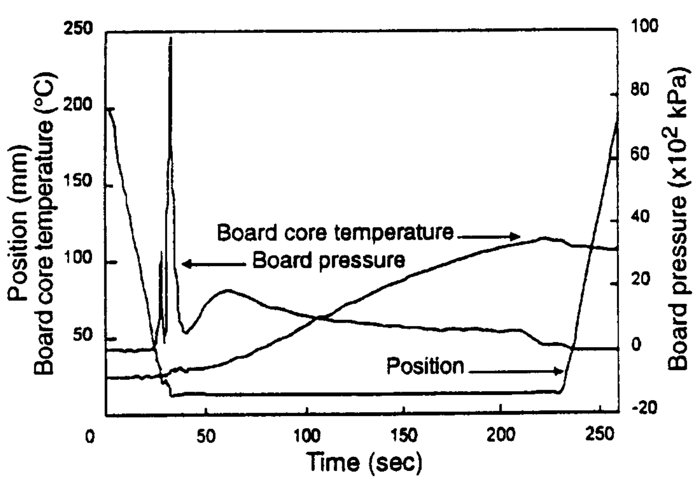

Figure 2. — Board thickness, board temperature, and compaction pressure for the conventionally pressed board.

procedure to be the most effective for reducing TS when the steaming was continued until the press had reached target thickness. **Table 1A** gives the press schedule used in this study for the steam-injected and conventional control boards. Steam was first introduced at a mat thickness of 25 mm, corresponding to a mat specific gravity of 0.33, while the press was closing at a rate of 2 mm/second. Following 4 seconds of steaming, at a rate of 350 kg/hr., steam control was switched to manifold pressure control. This allowed 2 seconds for the manifold pressure to stabilize at target stem pressure prior to the press reaching target thickness. Steam duration and pressures are given in **Table 1B.** The type of SIP schedule is indicated by time and pressure (sec./kPa) for four combinations: 10/690, 10/1380, 30/690, and 30/1380. Steam manifold pressure was returned to atmospheric pressure immediately following the steam period. Press dwell time, the time between reaching target thickness and the beginning of decompression, was 180 seconds for all SIP boards. Platen tempemture was held at 190°C for all boards, including those pressed conventionally.

Boards were pressed in the conventional fashion using the same closing time (33 sec.) and time at target thickness (180 sec.) as used for the SIP boards. All the press activity, including steam injection and data acquisition, were computer controlled and monitored.

TESTING

Figure 1 is a diagram of the panel cut-up. Five Mimesota shear (MS), four static bending, four linear expansion, and four 24-hour TS (WA) specimens were obtained from each panel. Minnesota shear and static bending specimens were conditioned in a 27°C, 65 percent relative humidity (RH) room and tested according to procedures in ASTM D 1037-92 (1). Weight, thickness, and length of each linear expansion specimen were measured after each successive exposure to ovendry, 65 percent RH, 90 percent RH. VPS, and a final ovendry condition in accordance with D 1037-92 (1) procedures. The vacuum-pressure test specimens were placed in a pressure cylinder and submerged in cold tap water. A vacuum of 63.5 cm of mercury was drawn and maintained for 30 minutes, followed immediately with application of 400 to 434 kPa of pressure for 30 minutes. The 24-hour TS and water absorption tests were performed in accordance with D 1037-72 (1) procedures.

RESULTS AND DISCUSSION

BOARD TEMPERATURE AND PRESSURE

Board core temperature and compaction pressure varied inboards made using different press schedules. **Figure 2** shows board core temperature, thickness. and pressure changes during the pressing of a conventional board. Core temperature began to increase after 50 seconds and reached 100°C in about 170 seconds.

Peak temperatures of 114°C were reached in 221 seconds. **Figure 3** shows changes in pressing variables for a SIP (30/1380) board. Six seconds of steam injected prior to compressing the mat to a target density (0.64) reduced the closing pressure. Mat temperature in all SIP boards was elevated above 100°C before target thickness was attained.

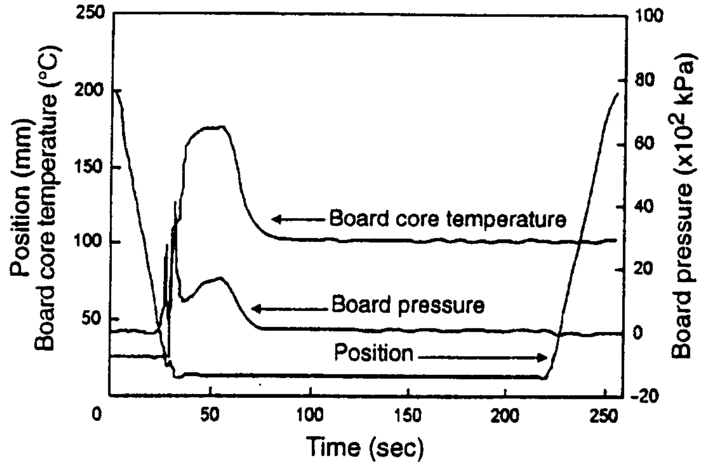

Figure 3. — Board position, temperature, and pressure for the 30/1380 SIP boards.

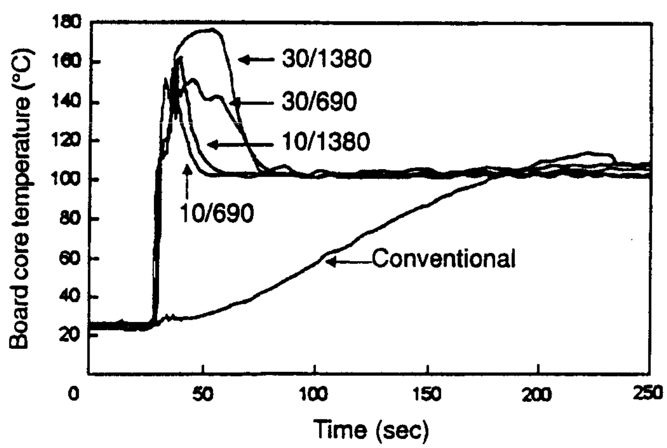

Figure 4. — Comparison of board center core temperatures for all press schedules.

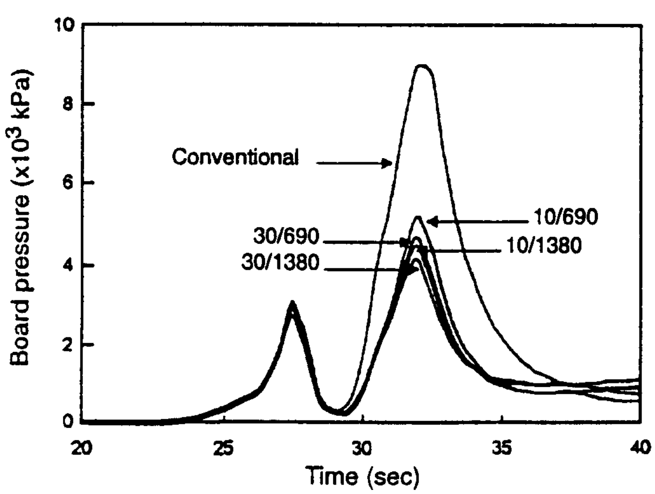

Figure 5. — Comparison of board pressures for all press schedules.

Peak core temperatures were directly dependent on steam time and pressure, ranging from 152°C to 175°C, as shown in Figure 4. Differences between these limits and the tempemture of saturated steam corresponding to target steam pressures (170°C at 690 kPa and 198°C at 1,380 kPa) are attributed to limited steam duration, condensation cooling, and escape of the steam through the edges of the mat. After steaming, the platens were vented, which reduced the core temperatures to a level between 100°C and 110°C.

Board pressures are shown for all boards in **Figure 5.** The first increase in pressure began at 24 seconds when the mat was at a specific gravity of 0.18. Pressure decreased when steam was injected at a mat specific gravity of 0.33 and the press closure slowed to 2 mm/second. Pressure began to increase again as the mat specific gravity reached 0.40 and the press continued to close. Peak pressure was reached at or near the time the press reached target thickness. This condition may shift somewhat, depending on the sensitivity of the control program to prevent or reduce overshoot. Maximum board pressure, between 4.1 and 5.2 MPa, reached in the steam-injection boards was considerably less than the 8.9 MPa needed for conventional pressing. Theoretically, higher press hydraulic pressure (which is used to compute board pressure) is needed to counteract increased steam pressure. However, the maximum board pressure reached during high steam pressure schedules was less than that reached during low steam pressure schedules, indicating the increased plasticization of the mat with high pressures. Length of steam time should not have affected maximum board pressure, because the same amount of steam was introduced into the mat prior to the press reaching final position.

Board thickness and MC

Immediately after removal from the press, five thickness measurements were taken on each board one in the center and one at each comer. **Table 2** gives average out-of-press board thickness. The control boards, pressed in a conventional manner, averaged 0.59 mm over the 13-mm target thickness. All steam boards were thinner than the target thick-

TABLE 2. — Effect of pressing variables on thickness swell and linear expansion at conditioned RH and VPS exposure.[a]

	Out-of-press		Specimen		Thickness swell[e]					Linear expansion[g]			
Schedule	Thickness	Moisture content[b]	Thickness[c]	Specific gravity[d]	Ovendry[f]	65% RH	90% RH	VPS	VPS-ovendry	65% RH	90% RH	VPS	VPS-ovendry
(sec./kPa)	(mm)	(%)	(mm)		(%)								
Conventional	13.59	3.9	14.55	0.596	12.1 A	17.3 A	28.7 A	34.6 A	27.8 A	0.24	0.36 A	0.46 A	-0.12 A
10/690	12.90	4.0	13.32	0.645	3.1 B	7.4 B	14.8 B	18.9 B	16.8 B	0.23	0.33 AB	0.42 AB	-0.14 AB
10/1380	12.73	4.1	13.20	0.665	2.5 BC	6.5 BC	13.2 BC	16.1 BC	13.3 C	0.24	0.33 AB	0.42 AB	-0.17 BC
30/690	12.53	4.2	12.92	0.663	0.6 BC	4.2 CD	10.6 CD	13.8 CD	11.2 C	0.23	0.31 BC	0.39 BC	-0.18 CD
30/1380	12.44	7.7	12.78	0.662	-0.2 C	3.1 D	8.8 D	11.3 D	7.2 D	0.22	0.29 C	0.36 C	-0.22 D

[a] Values followed by the same capital letter are not significantly different (Tukey's test).
[b] Ovendry weight basis.
[c] Thickness at 23°C and 65 percent RH.
[d] Ovendry weight, 23°C and 65 percent RH dimension.
[e] Thickness swell based on increase in thickness > 12.4 mm.
[f] Thickness swell (relative to 12.4 mm) at ovendry condition prior to RH and VPS exposures.
[g] Linear expansion based on increase in length from ovendry conditions.

ness. We assume that the steam boards did not shrink away from the platen and that the error between target and actual minimum thickness was due to calibration error, which was constant for all boards. Out-of-press thickness was reduced with longer steam times and higher steam pressures, denoting a direct relation between internal stress reduction and steam treatment. The results agree with those of Johnson et al. (9).

In commercial production applications, it is normal to compensate for minor changes in fabrication or press variables that affect board springback, with an adjustment in target press position. Keeping the target press position constant in this study allowed us to directly compare the effect of steam-injection variables on each SIP board and compare the SIP boards with conventionally pressed boards. In the same manner, total press times were scheduled intentionally long for the SIP boards to make direct comparisons with the conventional boards and assure maximum resin cure and eliminate problems with steam blows. We can attribute differences in board properties directly to steam pressure and time, because the platens were vented immediately following steam secession.

The MC of the boards, calculated from board weight measured immediately afterpressing, is presented in **Table 2.** Conventional boards lost relatively little weight during pressing. The 180-second hold at target thickness was long enough to permit the MC in all the steam boards except 30/1380 to return to the 4 percent press entry level. The 30/1380 SIP board, made with the longest steam time and highest steam pressure, had a press exit MC of almost double that of the others, yet was the thinnest due to reduction in internal stresses.

TABLE 3. — Effect of pressing variables on water absorption at conditioned RH and VPS exposure.[a]

	Water absorption[b]		
Schedule	65% RH	90% RH	VPS
(sec./kPa)	(%)		
Conventional	8.4 A	17.2 A	129 A
10/690	8.3 AB	15.9 B	105 B
10/1380	8.1 BC	15.6 C	100 C
30/690	8.2 BC	15.5 C	98 CD
30/1380	8.1 C	15.3 D	96 D

[a] Values followed by the same capital letter are not significantly different (Tukey's test).
[b] Water absorption based on increased weight from ovendry condition.

DIMENSIONAL STABILITY

The TS of the SIP (76.2 by 304.8 mm) dimensional stability specimens conditioned to equilibrium MC at various relative humidity conditions and exposed to a VPS treatment was less than that measured for the conventional pressed specimens **(Table 2).** The TS for the specimens was calculated as a percentage of 12.4 mm, which approximates the actual press closure, as indicated by the thinnest SIP boards. In this study, where a rather large difference in out-of-press thickness was attributed to the variables under consideration, it becomes necessary to calculate TS from a common base rather than from ovendry or other equilibrium exposure thickness. Note that a large portion of the conventional board TS occurred as out-of-press TS. The ideal press schedule would maintain those conditions that provide comparable resin cure and adjust the press target thickness for each steam condition, so that ail boards had equal out-of-press thickness. The number of necessary exploratory trials to determine these schedules and the interactions of the variables creating changes in internal board characteristics, such as the vertical density gradient, prohibited this approach.

The effectiveness of the SIP treatment increased with steam time and steam pressure. Boards made with 30 seconds of low pressure steam experienced less TS than did boards made with 10 seconds of high pressure steam. Analysis of these data showed that in most cases board-to-board variation exceeded within-board variation. An analysis of variance (ANOVA) based on board-to-board variation attributed significant variation, at least at the 0.05 level, to the pressing treatments. The relative difference caused by press treatments, as indicated by Tukey's test, is shown following the average values in **Table 2.** This analysis indicated that, in most cases, TS was statistically influenced by both steam time and steam pressure. Comparing TS measured at VPS to that after equilibrating to an ovendry condition following the VPS treatment (VPS-ovendry) indicates that a large portion of the TS was nonrecoverable.

Linear expansion values for those specimens exposed to controlled relative humidity and VPS treatments are given in **Table 2.** Data indicate that SIP also reduced linear expansion. This is more noticeable at the higher-equilibrated MC conditions. Contrary to previous work (3,6), the SIP treatment did show a slight tendency to reduce water absorption **(Table 3).** Statistical analysis confirmed this difference. The negative linear expansion values measured at ovendry conditions following VPS treatment were not unusual, considering the large nonrecoverable TS in these specimens.

The TS swell and water absorption data obtained from the 24-hour soak tests are given in **Table 4.** Again, total TS of the conventionally pressed boards was greater than the SIP boards when calculated using 12.4 mm as a base. Data show that the change in actual thickness of the conventional board from 65 percent RH (the thickness condition usually used as a reference) to that following a 24-hour soak, was approximately the same as that of the SIP boards. Examination of the conventionally pressed specimens showed pronounced edge swelling but little TS 25.4 mm in from the edge, the area designated for measurement. This, together with relatively low water absorption values, indicated that water had a difficult time penetrating the high density faces of the conventionally pressed boards **(Fig. 6).** This condition was noted previously (3,6) and is attributed to high density face layers and a surface glaze present on the conventional boards. Extended soaking of the conventional boards under ambient pressure will eventually equalize TS across the surface at a value greater than measured in the steam-treated boards. The TS of the SIP boards appeared to be uniform throughout the panel and may indicate increased permeability as a result of the steam treatment.

The 24-hour TS values for all SIP boards **(Table 4)** were actually greater than TS measured in the respective VPS (ovendry basis) specimens **(Table 2).** This peculiarity was also recognized previously (3,6). We attribute this to the longer period in those boards soaked at ambient pressures in which adjacent flakes are exposed to high stress concentrations.

TABLE 4. — Effect of pressing variables on thickness swell and water absorption 24-hour water soak.[a]

Schedule	Thickness[b]	Specific gravity[c]	Water absorption 24-hr. soak[d]	Thickness swell[e] 65% RH	Thickness swell[e] 24-hr. soak
(sec./kPa)	(mm)		(%)	(%)	(%)
Conventional	14.38	0.587	27.4 A	16.0 A	30.4 A
10/690	13.30	0.647	37.2 AB	7.3 B	21.1 B
10/1380	13.16	0.645	45.4 B	6.1 BC	20.9 B
30/690	12.88	0.654	49.0 B	3.9 CD	19.5 B
30/1380	12.77	0.655	49.5 B	3.0 D	17.3 B

[a] Values followed by the same capital letter are not significantly different (Tukey's test).
[b] Measured at 65 percent RH.
[c] Ovendry weight, 23°C and 65 percent RH dimension.
[d] Water absorption based on increased weight from 65 percent RH condition.
[e] Thickness swell based on increase in thickness > 12.4 mm.

TABLE 5 — Effect of pressing variables on physical and mechanical properties.[a]

Schedule	Bending: Specific gravity[b]	Bending: MOR[c]	Bending: MOE[c]	Minnesota shear: Specific gravity[b]	Minnesota shear: Shear[c]
(sec./kPa)		(MPa)	(MPa)		(kPa)
Conventional	0.577	21.8	2930	0.592	4120 AB
10/690	0.623	22.6	2680	0.661	3970 A
10/1380	0.625	20.2	2630	0.655	4950 C
30/690	0.636	21.2	2710	0.675	4710 BC
30/1380	0.638	19.3	2660	0.675	4790 C

[a] Values followed by the same capital letter are not significantly different (Tukey's test).
[b] Ovendry weight, 23°C and 65 percent RH dimension.
[c] Values adjusted to 0.640 specific gravity (SG):

$$MOR_a = MOR_m + 73.3 \times (0.640 - SG)$$
$$MOE_a = MOE_m + 6{,}201 \times (0.640 - SG)$$
$$Shear_a = Shear_m + 14{,}130 \times (0.640 - SG)$$

where:
MOR_a = adjusted MOR; MOR_m = measured MOR;
MOE_a = adjusted MOE; MOE_m = measured MOE;
$Shear_a$ = adjusted Shear; $Shear_m$ = measured Shear.

Mechanical strength

To compare bending and shear properties of the SIP boards with the conventionally pressed boards, we adjusted all values to a board specific gravity of 0.640 **(Table 5).** The values were adjusted for specific gravity using linear regression multipliers attained from the combined data for all boards. **Figure 7** shows the relationship between modulus of rupture (MOR) and specific gravity. Equations for adjusted bending MOR, bending modulus of elasticity (MOE), and shear values are given in **Table 5.** We caution that differences in specific gravity between SIP and conventionally pressed boards were significant and a direct result of the variables in question. An ANOVA test based on the board-to-board variance indicated no statistical difference in the adjusted MOR (r = 0.0796) and MOE (r = 0.1347) properties of all board types. Statistical analysis did show that shear properties were significantly dependent (r = 0.0002) on pressing treatment. Tukey's test showed a separation that indicates the vertical density gradient was important in determining shear properties.

Conclusions

Core temperature in isocyanate-bonded SIP flakeboard reached between 152°C and 172°C, depending on the steam pressure used and the length of steam exposure. This is well above the 114°C peak temperature recorded in conventionally pressed boards. Closing board pressures were reduced from 8.9 MPa in the conventionally pressed boards to less than 5.2 kpa in the SIP boards. The large differences in the heat and mass transfer affected the out-of-press springback and resulted in thinner SIP boards.

The TS of SIP flakeboard, following exposures to relative humidity conditioning and a VPS treatment, was less than experienced in a conventional pressed board. The TS decreased with increasing

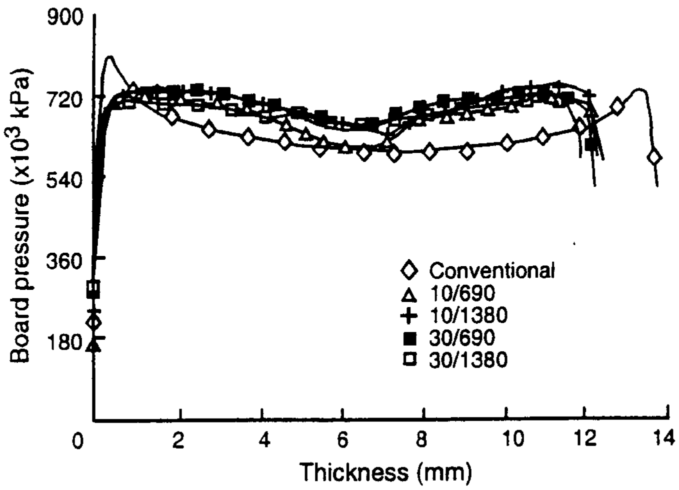

Figure 6. — Vertical density profiles for all board types.

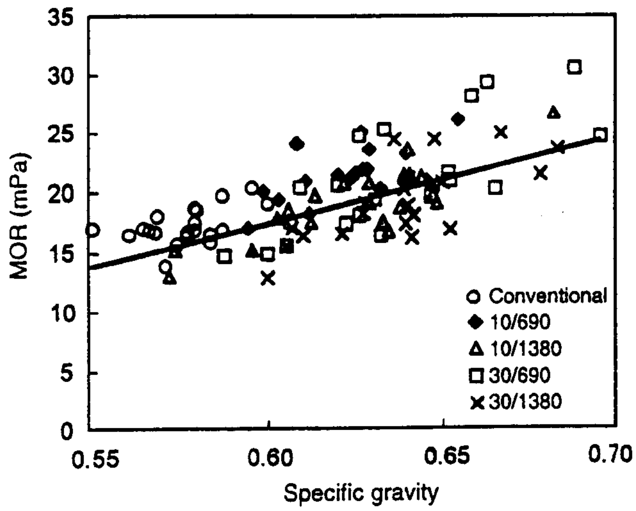

Figure 7. — Effect of board specific gravity on bending modulus of rupture (MOR).

steam time and pressure. The 34.6 percent TS measured for a VPS conventional board was reduced to less than 11 percent in boards exposed to 30 seconds of 1,380 kPa steam during pressing. Actual change in thickness from a 65 percent RH exposure to that following a 24-hour soak at ambient pressure was similar in all boards. Reduced water movement, through the high density faces, limits TS in the conventionally pressed board. High water absorption in the SIP 24-hour-soaked boards is attributed to the reduced density gradient and increased permeability resulting from the steam treatment. The TS of the SIP specimens exposed to a 24-hour soak test was greater than that of SIP specimens exposed to a VPS treatment. This anomaly is attributed to differences in internal stresses caused by the two tests and points out the need to evaluate the suitability of present tests in defining long-term exposure applications for composites.

Linear expansion properties also improved with steam treatment. No significant differences in bending properties resulted from the pressing treatments. However, differences in shear properties were attributed to changes in the vertical density gradient.

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