Thick composites are technically feasible with steam-injection pressing

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Abstract

Large 4- by 8-foot flakeboards made in a pilot plant using a steam-injection method of pressing were compared to small 26- by 30-inch laboratory-made panels. Acceptable 1-1/2-inch-thick panels were made using isocyanate resin, although strength properties were somewhat reduced. The large, thick panels were pressed in 147 seconds; however, laboratory trials indicated that press time can be reduced to as little as 66 seconds. Problems were encountered with the bonding of phenolic resin and with air entrapment in the center of the panel. Comparison of laboratory panels fabricated with and without steam injection indicates that the steam-injection pressing system may reduce thickness swelling of southern hardwood flakeboards made with either isocyanate or phenolic resin.

Conventional pressing techniques are not practicable for manufacturing thick wood composites because of the long time required for curing the resin. One way to reduce press time is to accelerate the temperature rise in the composite. Steam-injection pressing purportedly accelerates heat transfer into the center of the board and drastically reduces press time (2). We studied the feasibility of steam-injection pressing for the manufacture of thick, 4- by 8-foot flakeboard panels using different resins.

Steam injection pressing is especially suitable for panels 1 to 2 inches thick. During this process, saturated steam is injected into a mat from both the top and bottom platens during press closure (Fig. 1). In general, the steam must produce a temperature of at least 105°C before the mat reaches its specified density level. Steam pressure increases after the mat reaches its final position, resulting in a rapid mat temperature increase and subsequent resin cure. Following the exhausting of steam and any final resin cure period, the panel can be removed from the press. Total press the, steam time, and steam pressure vary with panel thickness, density, particle types, and resin, and must be carefully controlled.

Until recently, laboratory studies of steam-injection pressing have used small presses (1). However, before steam-injection pressing can be implemented in industry, its applicability must be verified for conventional size (4- by 8-ft.) panels composed of a given furnish. In the study reported here, we made 4- by 8-foot flakeboards greater than 1 inch in thickness using a hardwood furnish. Hardwood was selected because of the mutual desire of the Forest Service and industry to utilize hardwoods in structural flakeboards.

To our knowledge, the first reports of steam pressing on large presses were published by Karl Walter of Siempelkamp Corp. in 1984 (5). Siempelkamp Corp., a West German press manufacturer working in cooperation with Weyerhaeuser Company, modified their 4- by 8-foot pilot plant press in Krefeld, West Germany, to include the capability to inject steam into the mat during press closure. Although Siempelkamp has concentrated on the fabrication of medium-density fiberboard and particleboard, we decided that their equipment would be suitable for the manufacture of flakeboard and more economical than enlarging the U.S. Forest Service capability. Thus, our study on fabrication of thick flakeboards using steam-injection pressing was undertaken with the support of the U.S. National Forest Products Association and the cooperation of Siempelkamp personnel.

Preliminary results of this venture were reported in the Proceedings of the Twentieth Annual Particleboard Symposium, Pullman, Wash. (3), with the exceptionof some of the performance data on both the large panels and similarly constructed small laboratory panels. The study reported here presents these data as well as conclusions on the technical feasibility of implementing the steam-pressing process in the industrial fabrication of thick flakeboards. Technical feasibility is based on comparable properties of panels made with and without steam-pressing techniques.

Panel construction

Our study was comprised of two parts: 1) manufacture of large, 4- by 8-foot panels in a pilot plant (Siempelkamp Cop, West Germany); and 2) manufacture of small panels in a laboratory setting (Forest Products Laboratory (FPL), Madison, Wis.).

Large panels

Twenty tons of southern red oak *(Quercus fakara)* and sweetguni *(Liquidambar styraciflua)* logs from central Louisiana were shipped to Maschinen-Fabrik Bezner in Ravensburg, West Germany, for processing. The logs were flaked into random width 0.020-inch-thick by 3-inch-long flakes (Fig. 2). The flakes were dried by Schenkmann and Piel in Leverkusen, rebagged, and shipped to Siempelkamp Corp. in Krefeld. The flakes were then screened to eliminate the fines by passing through a 0.079-inch screen. Oversized sweetgum flakes (those retained on a 0.79-in. screen) were reduced using a drum-type flake breaker and mixed back into the furnish.

Large (4- by 8-foot) panels were made with both isocyanate and phenolic resins. The isocymate resin (PBA 1042) was supplied by Imperical Chemical Industry (ICI) in Holland. This resin is equivalent to the Rubicon ME 178 isocyanate used in laboratory trials. The isocyanate resin was sprayed without dilution at a 3 percent ovendry (OD) wood basis in a rotary drum continuous-feed blender, using air atomization. The phenolic resin used for both the pilot plant study and the laboratory study was obtained from Borden Corporation. However, although the pilot plant phenolic resin was patterned af-

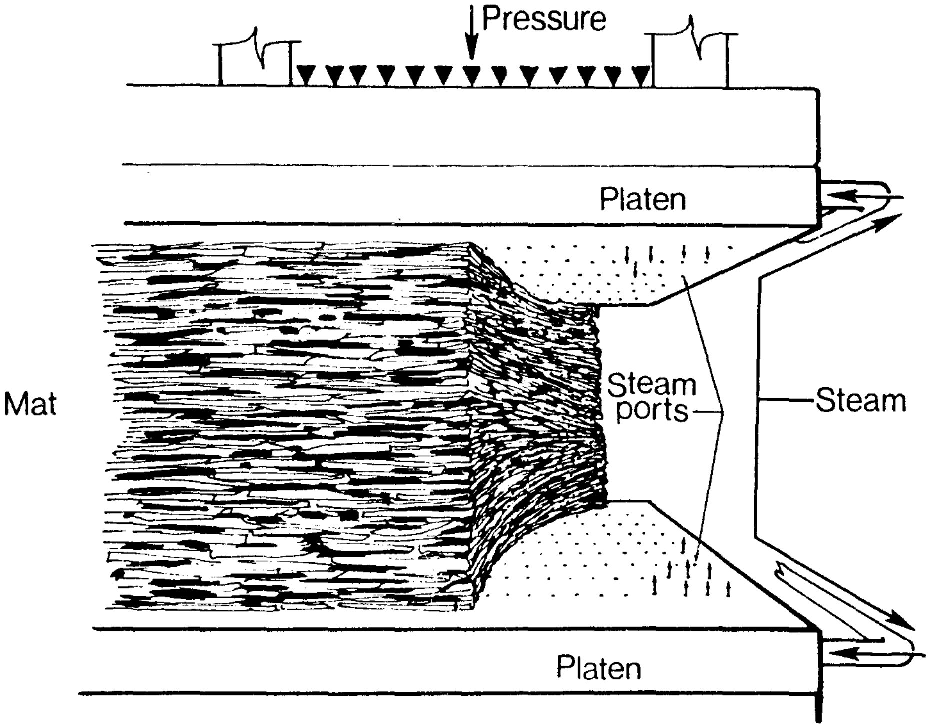

Figure 1. - Saturated steam is injected into the mat through top and bottom perforated platens during press closure.

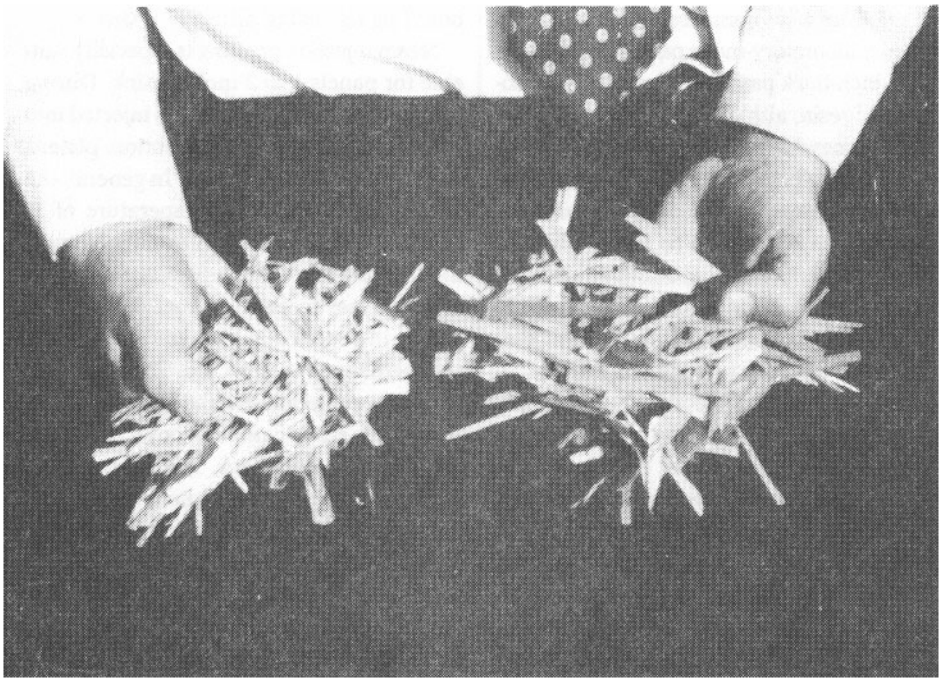

Figure 2. - Flakes for large-scale panel fabrication. Left: red oak flakes; Right: sweetgum flakes.

ter the resin made in the United States, it was obtained from Borden's laboratory in Great Britain. The pilot plant resin had a slightly higher solid content, somewhat lower pH, and considerably higher viscosity than the laboratory resin because of differences in equipment, batch size, and handling. The pilot plant resin had an original viscosity of 2,700 cP and had to be diluted to 38 percent solids to pass through the spray equipment. As a result, the mat furnish had a high moisture content (MC), between 11 and 12 percent, instead of the desired MC between 5 and 8 percent.

After resin application, the mats were formed in two passes, alternating direction under one forming head. The mats were weighed and then pressed to a thickness based on the target panel density calculated on an OD weight basis. In general, two types of computer-controlled press schedules, designated A and B, were followed. Steam must be introduced before the mat is pressed to a specific gravity (SG) of approximately 0.45. The steam is then halted until final position is reached (schedule A] or continuously applied (schedule B). Schedules A and B for 1-1/2-inch 0.721 SG panels are shown in Figure 3. Both schedules incorporate a push-through stage, described by Taylor and Reid (4), wherein steam is introduced into the lower platen and exhausted to the atmosphere through the top platen. Preliminary trials indicated this step was necessary in order to prevent air from being trapped in the center of the larger panels. Following the final steaming period, the steam manifolds were shut off, permitting the trapped steam to bleed into the panel. Excess steam was bled off from both platens during the exhaust period. The exhaust period was shorter for the type B schedule. Press variables such as total time, steam time, and steam pressure varied with target panel thickness and SG. Total press time was 81 seconds for the 1/2-inch-thick panels and ranged from 107 to 147 seconds for the 1-1/2-inch-thick panels.

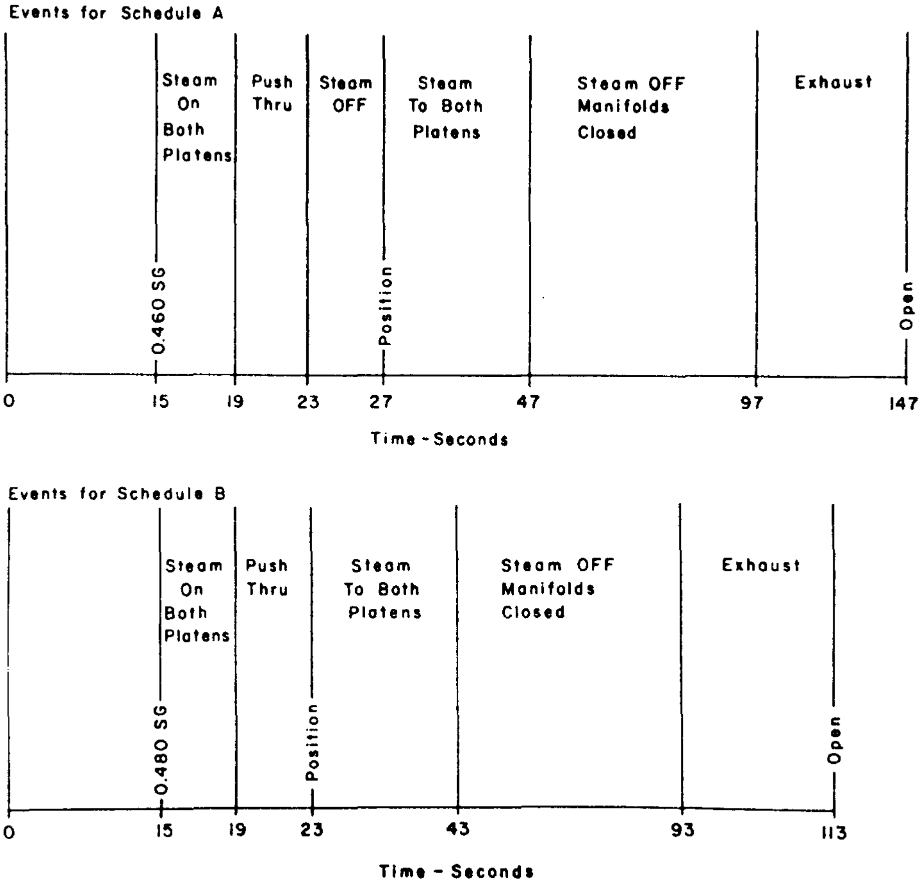

Figure 3. - Press schedules for 1-1/8-inch 0.72 specific gravity oak/gum isocyanate panels.

The pilot plant scheduling called first for the production of phenolic-bonded panels, followed by isocyanate-bonded panels. During the first stages of fabrication, several problems related to press and forming resulted in poor resin bonding in the phenolic-bonded panels. For example, as mentioned previously, the mat MC was excessive. Another set of phenolic-bonded panels was therefore produced later. For these panels, a mixture of 25 percent oak and 75 percent sweetgum was dried to 2 percent MC after blending with 6 percent phenolic resin.

Small laboratory panels

The press schedules for the large panels were based on guidelines established by prior laboratory tests (3). As expected, the large panel press schedules finalized during the pilot plant trial differed from the original laboratory panel schedules. Therefore, a series of small (26- by 30-in.) panels were made at the FPL after completing the tests at the pilot plant in Germany. A total of 54 panels were fabricated - 36 with isocyanate resin and 18 with phenolic resin. Variables included omission of the steam push-through phase, use of A and B press schedules, decreased press times, and use of conventional press schedules. This final sequence of panel fabrications yielded data for comparing large and small panels, evaluating the use of phenolic resin in steam-injection pressing, and comparing conventional and steam-injection pressing.

Panel properties

Interruption of steaming in the initial closing portions of the press cycle allows the mat a chance to "reseal" itself and promotes higher internal pressures. Early studies conducted prior to the large-scale trials had indicated that high internal pressure with accompanying higher temperature is important in curing the phenolic resin. Interruption of steaming made little difference in the large panels and did not appreciably promote cure in the small laboratory panels bonded with isocyanate. Consequently, the data for similar types of isocyanate-bonded panels have been combined for both large (Table 1) and small (Table 2) panels. Contrary to our expectation, the difference between the A and B press schedules had little effect on phenolic-bonded laboratory panels made following the large-scale test (Table 3). Very little difference in internal bond (IB), bending, and dimensional stability properties was observed in gum/oak panels. Although the initial IB values may be considered acceptable, the curing and bonding phenomenon of phenolic resin appears to depend heavily on a time-related interaction between both moisture and temperature.

The push-through steam period of 4 seconds used in fabrication of the large panels proved marginally low because delamination spots caused by air pockets appeared in eight of the thicker panels. Spots were more prevalent with the B schedule, in which closure time from initial steam injection to final board thickness targets was 4 seconds shorter than in the A schedule. The problem with air entrapment has never been encountered with laboratory panels, presumably due to the relatively short distance between the panel center and panel edge. A set of three gum/oak laboratory panels made using a push-through period possessed mechanical and dimensional stability properties very similar to panels made without the push-through period. Consequently, all other laboratory panels were pressed without the push-through period (Table 2)

Isocyanate-bonded panels

In general, the large, higher density, 1-1/2-inch-thick panels had acceptable IB properties and good bending moduli of rupture (MOR) and elasticity (MOE) values. However, their mechanical properties were lower than those of similarly constructed laboratory panels. To eliminate a large variability in sample SG, the average IB and bending properties for the laboratory panels (Tables 2 and 3) were adjusted to the target SG of either 0.72 or 0.67. Mechanical property data for the large panels (Table 1), on the other hand, are shown as unadjusted values. The most notable difference between the properties of the large full-scale panels and laboratory panels was a threefold reduction in IB in the large panels. Adjustment for SG would not have appreciably affected this difference.

Scheduling problems caused an interruption of 2 weeks during large panel fabrication. The final panels were fabricated using an alternate isocyanate. For some unexplained reason, maximum panel temperatures attained were higher than those encountered in the main trial (160°C versus 140°C). Mechanical properties of these panels, shown in Table 1 under the heading Alternate Isocyanate, were much higher than those attained in the main trial. Bending properties were superior to those of comparable laboratory-made panels, and the IB values were influenced by the species mixture. The IB strength of large gum/oak panels was two-thirds that of the laboratory panels, whereas the IB strength of large all-gum panels was greater than that of the laboratory panels.

A set of three isocyanate-bonded gum/oak panels was made in the laboratory to determine the effect of reduced resin content. There was a 17 percent reduction in IB strength for gum/oak panels made with 2 percent isocyanate compared to panels made with 3 percent isocyanate. Bending properties were reduced approximately 5 percent (Table 2). The thickness swelling values were slightly higher, whereas linear expansion values remained approximately the same.

Another set of isocyanate-bonded gum/oak laboratory panels was made to determine the effect of reduced press time (Table 2). The total press time was reduced successively from 148 to 66 seconds with no reduction in mechanical or dimensional stability.

Laboratory isocyanate-bonded oak panels conventionally pressed for 545 to 550 seconds had higher IB and bending properties than panels pressed with steam injection (Table 2). Surprisingly, however, the dimensional stability of the steam-injected panels was noticeably better than that of panels pressed conventionally. This is the first time that we have found major improvement in dimensional stability that could be attributed to this type of steam-injection process. This phenomenon may be species dependent. None of the variables studied, including species and density, had an appreciable effect on altering dimensional stability of the steam-injected panels [Table 1).

Phenolic-bonded panels

In total, 13 large phenolic-bonded panels were constructed. Only one set of three panels had any appreciable IB strength (Table 1). These panels were made after drying the blended furnish to approximately 2 percent MC. The properties of these panels compared favorably to those of the isocyanate-bonded panels. The properties of the phenolic-bonded laboratory panels were superior to those of the large panels. However, the difference between the phenolic-bonded laboratory and the phenolic-bonded large panels was much less than the difference between isocyanate-bonded laboratory and the isocyanate-bonded large panels. The IB strengths of the laboratory panels ranged from 69 to 93 psi (Table 3), compared to 60 psi for the large panels (Table 1). In this study, no great difference was noted between those panels made with either A or B pressing schedule.

The phenolic-bonded laboratory gum/oak panels made at the reduced time of 298 seconds maintained IB strength and dimensional stability properties. However, bending properties were reduced by approximately 10 percent.

Contrary to our expectations and to the results obtained with isocyanate resin, the conventionally pressed phenolic-bonded laboratory panels were not superior in mechanical properties to the steam-injected laboratory panels. However, steam injection had a favorable effect on dimensional stability of the phenolic-bonded as well as the isocyanate-bonded laboratory panels. Thickness swell of the conventionally pressed panels was 1.5 to 2.5 times that of the steam-injected panels.

Except for much lower IB properties, the phenolic-bonded laboratory panels were almost comparable to the isocyanate-bonded panels. The low strength retention values may be related to the low IB values. In fact, many IB samples were too poor to test after exposure to the vacuum-pressure-soak-ovendry aging cycle. Because of the sensitivity of phenolic resin to moisture during the curing process, it appears that some major resin formulation change is necessary to adapt this adhesive to the steam-injection

TABLE 1. — *Large (4 by 8 ft.) panels.*

													Dimensional stability^{d}							
Fabrication					Initial strength								Thickness swell			Linear expansion			Water absorption	
					Internal bond		Bending			Strength retention										
Press schedule	Press time	Target thickness	Variables^{a}	Number of panels	SG	Stress	SG	MOR	MOE	IB^{b}	MOR^{c}	MOE^{c}	30-90% RH	48-hr. soak	OD-VPS	30-90% RH	48-hr. soak	OD-VPS	30-90% RH	48-hr. soak
	(sec.)	(in.)				(psi)		(psi)	(Kpsi)						(%)					
ICI-isocyanate^{e} (gum)																				
A-B	147-113	1.5	--	4	0.701	60	0.699	3,980	642	23	50	48	5.5	25	34.3	0.20	0.30	0.38	7.7	42
A-B	107-113	1.5	0.673 SG	4	0.657	43	0.667	3,360	586	21	46	52	5.5	30	35.1	0.19	0.14	0.41	8.1	57
A	81	0.5	--	2	0.717	56	0.687	4,760	672	53	46	66	9.1	51	40.9	0.20	0.29	0.42	8.4	77
ICI-isocyanate^{e} (gum/oak)																				
A-B	147-113	1.5	--	5	0.707	61	0.704	4,140	610	24	58	49	5.2	17	30.9	0.20	0.05	0.41	7.5	31
A	107	1.5	0.673 SG	3	0.655	45	0.652	3,080	525	18	53	55	5.3	21	29.0	0.18	0.11	0.45	7.6	48
A	81	0.5	--	3	0.668	47	0.687	3,870	588	32	45	65	6.7	30	32.5	0.18	0.31	0.40	8.2	58
ICI-isocyanate^{e} (oak)																				
A	147	1.5	--	3	0.726	83	0.721	4,470	685	25	65	44	5.0	14	27.3	0.22	0.05	0.41	7.1	22
A	81	0.5	--	3	0.676	68	0.662	3,600	544	25	57	66	5.9	21	25.9	0.19	0.18	0.41	7.8	42
Alternate isocyanate (gum)																				
B		1.5	--	2	0.726	124	0.723	5,370	700	12	71	60	5.2	13	26.3	0.22	0.06	0.47	7.6	22
A-B	137-143	1.5	0.673 SG	2	0.671	107	0.650	4,340	576	18	--	--	5.3	14	24.7	0.20	0.08	0.52	7.9	26
Alternate isocyanate (gum/oak)																				
B	143	1.5	--	2	0.725	130	0.719	5,450	674	17	71	59	4.9	11	22.5	0.25	0.12	0.50	7.4	20
Phenolic^{d} (gum/oak)																				
A	133	0.5	25% oak and 75% gum	3	0.710	60	0.703	3,990	617	22	40	66	8.7	35	31.6	0.18	0.21	0.50	9.7	97

Note: IB = internal bond; MOE = modulus of elasticity; MOR = modulus of rupture; OD = ovendry; RH = relative humidity; SG = specific gravity; VPS = vacuum pressure soak.

[a] All boards made to 0.721 SG except as noted.

[b] Strength retention following a VPS followed by OD and subsequent conditioning at 60 percent RH (VPS-OD-60).

[c] Strength retention following a 48-hour water soak (tested wet).

[d] 30 to 90 percent RH at room temperature; 48-hour water soak at room temperature; OD followed by VPS (OD-VPS).

[e] 3 percent Imperial Chemical Industry (ICI) isocyanate; 6 percent Borden phenolic; resin solids based on OD wood weight.

TABLE 2. — *Laboratory (26- by 30-in.) panels bonded with isocyanate resin.*[a]

Fabrication					Initial strength			Strength retention			Dimensional stability								
						Bending					Thickness swell				Linear expansion		Water absorption		
Press schedule	Press time	Target thickness	Variables[b]	Number of panels	Internal bond	MOR	MOE	IB[c]	MOR[d]	MOE[d]	30-90% RH	48-hr. soak	OD-VPS	OD-VPS-OD	30-90% RH	OD-VPS	30-90% RH	0-90% RH	48-hr. soak
	(sec.)	(in.)			------ (psi) ------		(Kpsi)	------------------------------						(%)		------------------------------			
Gum																			
A	150	1.5	--	2	115	4,580	693	26	70	50	6.8	13.1	23.4	6.8	0.19	0.46	9.1	14.2	39
CONV	545	0.5	--	2	232	5,980	843	--	32	38	12.2	23.6	30.4	19.2	0.20	0.44	11.0	14.7	41
Gum/oak																			
A-B	148	1.5	--	6	197	5,175	653	18	67	59	5.9	11.8	16.6	6.6	0.16	0.35	8.9	13.8	40
A	148	1.5	Push-thru phase	3	219	5,000	638	19	63	62	5.7	12.5	16.9	7.2	0.17	0.36	8.9	13.6	39
A	66-98	1.5	Minimum time	4	194	5,100	663	20	76	57	6.1	10.7	17.7	7.2	0.18	0.38	8.9	13.7	34
A	148	1.5	2% isocyanate	3	163	4,960	616	15	56	59	6.1	16.5	19.1	7.7	0.14	0.33	8.9	13.7	45
A-B	108	1.5	0.673 SG	7	173	4,100	572	22	72	61	6.0	11.1	16.2	6.6	0.16	0.30	8.9	13.7	40
A	82	0.5	--	3	203	4,730	598	23	59	58	7.4	19.2	19.8	8.3	0.15	0.38	9.7	14.6	71
CONV	550	0.5	--	2	200	5,320	794	--	31	38	11.6	20.8	26.5	24.5	0.19	0.43	10.1	14.9	38
Oak																			
A	150	1.5	--	3	170	5,290	683	18	65	78	5.7	9.9	16.9	5.7	0.14	0.13	8.5	13.0	34
CONV	550	0.5	--	1	216	4,840	764	11	64	33	12.3	26.0	28.4	14.4	0.18	0.41	11.2	15.0	54

Note: CONV = conventional pressing; IB = internal bond; MOR = modulus of rupture; MOE = modulus of elasticity; OD = ovendry; RH = relative humidity; SG = specific gravity; VPS = vacuum pressure soak.

[a] 3 percent Rubicon MF178 isocyanate, resin solids based on OD wood weight (except where noted).

[b] All boards made to 0.721 SG unless otherwise noted.

[c] Strength retention following a VPS followed by OD and subsequent conditioning at 60 percent RH (VPS-OD-60).

[d] Strength retention following a 48-hour water soak (tested wet).

[e] 30 to 90 percent RH at room temperature; 0 to 90 percent = OD to 90 percent RH at room temperature; 48-hour water soak at room temperature.

TABLE 3. — *Laboratory (26- by 30-in.) panels bonded with phenolic resin.*[a]

Fabrication					Initial strength			Strength retention			Dimensional stability								
						Bending					Thickness swell				Linear expansion		Water absorption		
Press schedule	Press time	Target thickness	Variables[b]	Number of panels	Internal bond	MOR	MOE	IB[c]	MOR[d]	MOE[d]	30-90% RH	48-hr. soak	OD-VPS	OD-VPS-OD	30-90% RH	OD-VPS	30-90% RH	0-90% RH	48-hr. soak
	(sec.)	(in.)			------ (psi) ------		(Kpsi)	------------------------------						(%)		------------------------------			
Gum																			
A	418	1.5	--	3	93	4,450	642	13	50	58	7.5	30.3	23.2	12.4	0.19	0.42	10.1	15.1	82
A	418	1.5	0.673 SG	3	88	3,470	527	27	58	64	6.5	19.1	19.1	7.9	0.18	0.39	10.1	15.1	78
CONV	530	0.5	--	1	82	4,210	505	--	40	40	19.2	50.5	39.6	24.1	0.22	0.46	12.3	17.5	73
Gum/oak																			
A	418	1.5	--	2	70	4,070	639	--	57	61	6.2	22.5	24.1	11.1	0.16	0.37	9.7	14.6	69
B	418	1.5	--	3	69	3,950	617	--	56	51	7.0	24.3	22.6	10.4	0.15	0.40	10.0	15.0	76
A	134	0.5	--	3	80	4,370	652	--	48	53	9.3	27.3	20.9	13.2	0.16	0.32	11.3	16.4	81
A	298	1.5	Minimum time	3	69	3,650	586	--	55	58	6.6	25.9	21.1	10.4	0.19	0.38	9.8	14.6	76

Note: CONV = conventional pressing; IB = internal bond; MOR = modulus of rupture; MOE = modulus of elasticity; OD = ovendry; RH = relative humidity; SG = specific gravity; VPS = vacuum pressure soak.

[a] 6 percent Borden (WS 337-122), resin solids based on OD wood weight (except where noted).

[b] All boards made to 0.721 SG unless otherwise noted.

[c] Strength retention following a VPS followed by OD and subsequent conditioning at 60 percent RH (VPS-OD-60).

[d] Strength retention following a 48-hour water soak (tested wet).

[e] 30 to 90 percent RH at room temperature; 0 to 90 percent = OD to 90 percent RH at room temperature; 48-hour water soak at room temperature.

processing of southern hardwoods.

Summary

Laboratory and pilot plant trials indicate that thick flakeboard panels can be made using a steam-injection pressing method. Flakeboard panels constructed of southern red oak, sweetgum, and a mixture of these species were successfully pressed using an isocyanate resin. Plant trials indicate that with proper selection of resin and control of pressing conditions, the properties of large-scale isocyanate-bonded panels can approach those of laboratory-made panels. Mechanical and dimensional stability properties were only slightly reduced when isocyanate levels were reduced from 3 to 2 percent. Laboratory trials indicate that the press time of 147 seconds used in the pilot plant to manufacture 1-1/2-inch-thick panels may be reduced to as little as 66 seconds without sacrificing panel quality. Moreover, results of dimensional stability tests indicate that the steam-injection process could be beneficial in reducing thickness swelling in panels made from the southern hardwoods.

Exploratory research indicates that the curing and bonding of phenolic resins is heavily dependent on a time-related interaction between both moisture and temperature. Although a few large-scale phenolic-bonded panels were manufactured with acceptable properties, both pilot plant and laboratory experiences indicate that improvements in the resin formulation and press schedules are necessary before phenolic resin can be used commercially with the steam-injection system.

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