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Editors

Xiaoyan Zhou
Changtong Mei
Juwan Jin
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Effects of A New Caul System on Strength and Stability of Structural Flakeboard

Cheng Piao[1], Todd F. Shupe[2], Chung Y. Hse[3]

[1]Post-Doctoral Research Scientist, School of Renewable Natural Resources, Louisiana State University AgCenter, Baton Rouge, LA, USA. Email: chpiao@lsu.edu.

[2]Associate Professor, School of Renewable Natural Resources, Louisiana State University AgCenter, Baton Rouge, LA, USA. Email: tshupe@agcenter.lsu.edu.

[3]Principle Wood Scientist, USDA Forest Service Southern Research Station, Pineville, LA, USA. Email: chse@fs.fed.us

ABSTRACT

Pressing flakes or fibers at a high moisture content (MC) may generate substantial benefits for the manufacture of wood composites. Such technology could reduce furnish drying costs and the risk of fire hazard, improve panel mechanical and moisture soaking properties, and reduce emission of volatile organic compounds (VOCs) at drying of flakes and at hot pressing. However, high MC levels are restricted by the occurrence of blows and delamination in the conventional hot-pressing system. A perforated caul system may enlarge the area for the moisture to escape out of the board mat during pressing, and thus, make possible the high-moisture-content pressing. The objectives of this study were to evaluate the effects of platen hole number (PHN) and MC on the mechanical and dimensional properties of flakeboard. Three PHN levels (no holes, low PHN, high PHN) and 5 flake MC levels (2%, 8%, 13%, 17%, 20%) were selected as the treatments. No blows or delaminations were found after 7-minute press cycles with flake MC up to 17 percent. This study showed that the perforated caul had the function of releasing moisture and vapor pressure during hot pressing.

Keywords: perforated platens, caul, heat transfer, high moisture hot pressing, flakeboard, furnish drying

INTRODUCTION

In the process of consolidation of wood composites, moisture in a mat first changes to vapor under heat and pressure, and migrates to the cooler areas of the mat core, edges, and corners along with volatile extractives of wood furnish and nonreactive adhesive components (Kamke and Casey 1988a, b). The four edges and corners are the only areas for the moisture to escape from the mat during hot pressing. Thus, moisture, temperature and vapor pressure gradients are formed from face to core and from core to edges (Strickler 1959, Suchsland 1962, Maloney 1977). The mat edges are small compared with the total surface area of the board. Therefore, only a small amount of moisture escapes through the edges and corners, and most moisture is released through the panel faces upon opening of the hot press (Maloney 1977). Since excessive moisture may cause blows or delamination, the MC in a conventional process is rigorously controlled in a low range through drying.

MC and its distribution are important factors governing the properties of wood composites. We can reduce or eliminate the negative effects of moisture and take advantage of its positive effects. Several endeavors have been implemented to achieve this goal. One was to distribute higher moisture in the face layer than in the core layer to produce the "steam-shock" effect. Strickler (1959) showed that the heat transfer rate increases with increasing face layer MC but modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond (IB) strength decrease when the core MC is at 9 percent. Although the moisture in the face layer accelerates the heat transfer at the beginning of a pressing cycle, excessive moisture in the core will be detrimental to the mechanical properties of the final panel. Steam pressing is another effort in this direction. This technique, however, is not widely commercially accepted due to its high cost in investment and operations as well as poor product qualities (Spelter 1999).

To implement the high MC process, Palardy et al. (1989) made flakeboard at 25 percent MC and moderate temperature (99 °C or 210 °F) using diphenylmethane diisocyanate (MDI) adhesive. Their study showed that the experiment boards had a more uniform vertical density profile (VDP) than the control panels. The boards show better dimensional stability properties and higher modulus of elasticity but poorer modulus of rupture than those of control panels. The pressing time was around 10 minutes, which is longer than that of a conventional process. Because the temperature used was low, phenol-formaldehyde adhesive could not be used.

The solution to the problem of high moisture pressing is dependent on the releasing of excessive moisture in the middle of the hot pressing process. In a typical pressing cycle, the steam pressure is the highest in the middle of a mat and diminishes toward the edges, where the steam is released. The objective of this study was to evaluate the effects of a perforated caul system on the physical and mechanical properties of flakeboard.

MATERIALS AND METHODS

The experimental variables of this study included three levels of platen hole number (PHN) (no holes – PHN1, low number of holes – PHN2, and high number of holes – PHN3) and five levels of flake MC (2%, 8%, 12%, 17%, and 20%). For each PHN level, the holes were uniformly distributed throughout the aluminum platens, which were 0.32 cm (1/8 in) in thickness. Figure 1 illustrates one design of the platens.

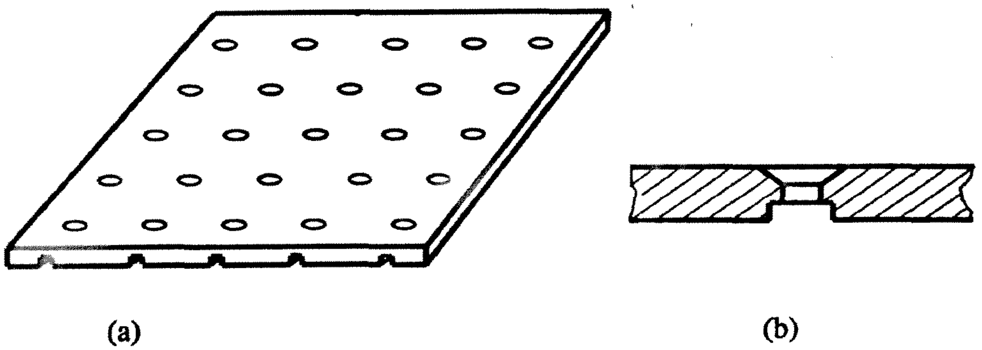

Figure 1. Schematic diagram of a perforated caul used in the manufacture of flakeboard: (a) a caul platen (b) dissection of a particular hole on the caul.

Material Preparation

Southern pine (*Pinus*, sp) flakes were obtained from a local OSB company in central Louisiana. The flakes were further hammer-milled into smaller flakes using a motor miller (Industrial Plus manufactured by Briggs & Stratton Corp., model 133412) at 8 percent MC. The particles were screened on a 6-cm mesh screen, and particles on the screen were then uniformly divided into five groups. Five moisture treatments were randomly applied to the five groups of particles with each group receiving one treatment. The group with a targeted MC of 2 percent was oven-dried. The other four groups of particles were conditioned according to the targeted MC of the group in a conditioning chamber. The resin used was phenol formaldehyde resin obtained from Borden Chemical Company. The solid content of the resin was 51 percent.

Flakeboard Manufacture and Testing

Panels were made with a resin content of 4.5 percent. Resin was applied to the particles in a drum blender by an air-atomizing nozzle. The targeted density of the boards was 0.65 g/cm^3. The target thickness of the boards was 12.7 mm. In the middle of the forming operation, thermal couple wires were buried in the geometric center of the randomly formed mats to measure the temperature changes of the mat core during hot pressing. After forming, one of the treatment platens (no holes, low PHN, high PHN) was randomly selected and put on the top of the formed mat as the upper platen. Two boards were made for each combination of the moisture content and PHN variables. For each board, the temperatures of the core were recorded immediately after the pressure reached the maximum and kept recording till the opening of the press.

The boards were tested for modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond (IB) strength, water absorption (WA), and thickness swelling (TS) according to the ASTM D1037-98.

RESULTS AND DISCUSSION

Heat Transfer and Vapor Release

Temperature changes of the board core with pressing time for the five MC and three PHN levels are presented in Figure 2. Each temperature-time line in the figure can be divided into three parts. The first part was the linear increase part of the temperature-time lines. The water in the board core started vaporizing at the end of this period, which lasted 1 to 2 minutes after press closure, depending on the mat MC. Vaporizing temperatures (VTs) of PHN1 were the highest at the five flake MC levels and all greater than those of other PHN levels. The VTs of boards pressed with PHN3 (i.e., the highest hole density) were the lowest and were almost equal to 100 °C for the five moisture levels. Since the vapor pressure is proportional to temperature, the vapor pressure inside the mat for PHN3 level was similar to that of ambient conditions.

One benefit of a high MC is the quick heat transfer from board face to core, or the "steam-shock" effect (Maloney 1977). To analyze the effects of an MC on heat transfer from board face to core, linear regression analyses were conducted for the data that represented the linear part of the temperature-time lines in Figure 2. The slopes (°C/second) of the regression lines were summarized in Table 1. As shown in the table, the holes on platens slowed the heat transfer from panel face to core at a flake MC below 13.7 percent and had little effects after this MC point. However, the heat transfer rates increased with the increase of mat moisture contents for all platen number levels. The average temperature rising rates were 3.04, 2.95, and 3.10 °C per second for PHN1, PHN2, and PHN3, respectively; for different MC levels, the average rates were 2.07, 2.80, 2.60, 3.37, and 4.31 °C per second for 2.1, 8.7, 13.7, 17.0, and 19.7 percent flake MC, respectively.

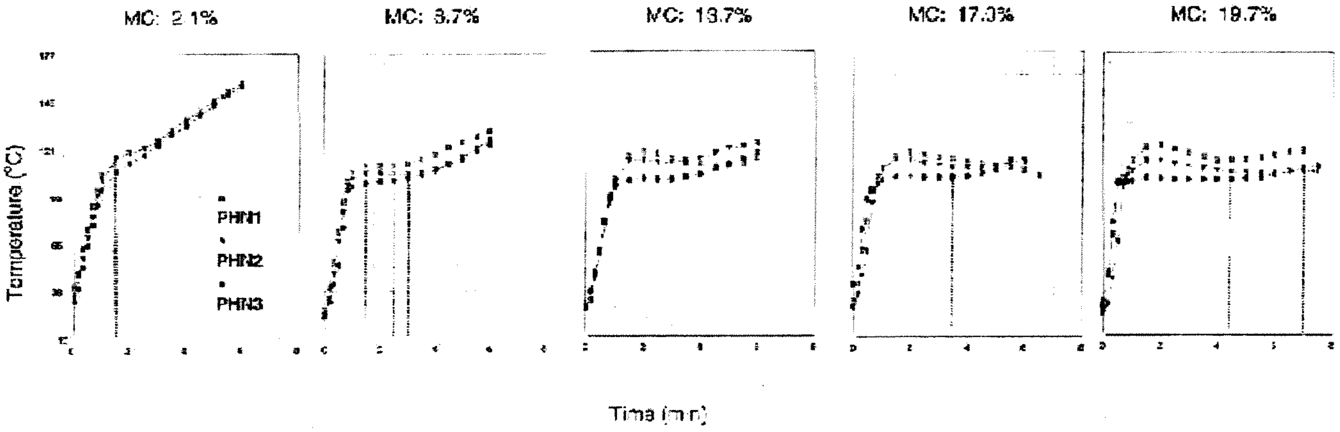

Figure 2. Core temperature increases with pressing time of flakeboard in a new caul system.

Table 1. Regression slope values (°C/second) of the linear parts in Temperature-Time lines of boards as affected by PHN and MC conditions.[a]

Targeted MC(%)	2.0	8.0	13.0	17.0	20.0
Actual MC(%)	2.1	8.7	13.7	17.0	19.7
PHN1[b] (0.430)	2.08 (0.066)	2.89 (0.105)	2.77 (0.038)	3.27 (0.066)	4.21
PHN2 (0.522)	2.08 (0.032)	2.85 (0.133)	2.48 (0.095)	3.15 (0.501)	4.19
PHN3 (0.297)	2.05 (0.054)	2.66 (0.275)	2.54 (0.142)	3.70 (0.145)	4.53

[a] Values in parentheses represent the standard error.

[b] PHN represents platen hole number; PHN1 - no holes, PHN2 - low hole number (holes/m^2), PHN3 - high hole number (holes/m^2).

The second part of the temperature time lines was from the time when vaporization began to the time when core temperature increased again. Moisture in the mat was vaporized in this period. This period lasted from seconds for 2.1% MC to more than two minutes for the 17% MC for both PHN2 and PHN3. It is noted that the second part never came to an end in the pressing cycle for PHN1 for the flake MC of 17% and 19.7%. The time used in this period increased with increasing MC and decreased with increasing PHN.

The rest of the temperature-time line is the third part. For the last two flake moisture levels the third part never came to the PHN1 (17% and 19.7%) because the press was opened before the temperature increased. The highest temperature reached at the end of pressing cycles decreased with increasing flake MCs.

After the boards were pressed, no blow or delamination was found with furnish MC up to 17 percent even though total mat MC was about 22 percent for the fifth group furnish. Although boards pressed with PHN1 did not fail, the bonding between flakes was weak. Boards with 19.7 percent moisture level were delaminated except for one board of PHN3.

MOR and MOE

Average values and standard deviations of the physical and mechanical properties of tested flakeboard specimens are summarized in Table 2. Most boards at 19.7 percent flake MC were delaminated, and the data for these boards was not available. The vertical density profiles (VDPs) of different MC and PHN levels are shown in Figure 3.

Moisture had significant effects on flexural properties. Figure 4 shows that both MOR and MOE reached the highest when the flake MC was about 9 percent. It is evident that the flexural properties of boards at 2.1 percent flake MC were inferior to those of boards at other MC levels except MOR at 19.7 percent level. Both MOR and MOE decreased with an increase in MC after the 9 percent flake MC. Both MOR and MOE of PHN3 were lower than the other two PHN levels. However, PHN1 and PHN2 lost more strength than PHN3 as the MC increased from 8.7 to 17.0 percent.

Table 2. Physical and mechanical properties of flakeboard pressed by a new caul system at 5 flake moisture content levels.

FMC[a]	PT	SG	MOR (MPa)	MOE (MPa)	IB (MPa)	TS[c] (%)	WA (%)	NTS[d] (%)
	PHN1[b]	0.66 (0.012)	16.8 (0.73)	2895 (30.5)	0.496 (0.030)	30.78 (2.15)	94.12 (1.67)	14.90 (0.77;
	PHN2	0.67 (0.007)	16.7 (1.33)	2817 (146.0)	0.541 (0.028)	30.29 (1.28)	95.55 (3.33)	14.43 (0.67)
	PHN3	0.65 (0.014)	15.3 (0.99)	2867 (83.8)	0.545 (0.027)	32.43 (2.25)	95.48 (3.92)	13.67 (2.62)
8.7	PHN1	0.63 (0.008)	23.3 (0.52)	3827 (15.9)	0.563 (0.023)	31.49 (1.46)	79.97 (2.20)	17.31 (2.53)
	PHN2	0.68 (0.016)	23.7 (1.63)	3858 (115.6)	0.625 (0.016)	32.00 (3.	81.14 (3.38)	14.82 (2.89)
	PHN3	0.65 (0.016)	20.8 (0.81)	3335 (84.6)	0.580 (0.022)	32.14 (1.	86.71 (1.88)	16.42 (1.52)
	PHN1	0.67 (0.01	45)	3731 (152.2)	0.295 (0.013)	42.10 (2.29)	84.51 (1.08)	26.34 (3.64)
	PHN2	0.69 (0.01	72)	3629 (204.0)	0.333 (0.016)	36.65 (1.20)	86.98 (1.61)	21.23 (0.29)
	PHN3	0.68 (0.01	21)	3198 (162.9)	0.386 (0.015)	35.69 (2.73)	90.74 (2.34)	19.52 (1.23)
0	PHN1	0.65 (0.014)	17.9 (1.81)	3543 (166.6)	0.124 (0.008)	41.21 61)	92.72 (3.54)	24.56 (3.41)
	PHN2	0.67 (0.009)	18.3 (1.15)	3437 (186.4)	0.144 (0.008)	35.59 49)	91.49 (2.72)	18.58 (2.28)
	PHN3	0.67 (0.003)	16.5 (1.21)	3357 (95.2)	0.159 (0.009)	40.36 (91)	91.80 (2.18)	22.08 (2.20)
.7	PHN1	B[e]	B	B	B	B	B	B
	PHN2	0.66 (0.009)	15.1 (0.51)	3602 (62.1)	B	B	B	B
	PHN3	0.68 (0.009)	17.3 (0.46)	3609 (47.0)	0.096 (0.015)	B	B	B

FMC - flake moisture content, PT - platen type, SG - specific gravity, IB - internal bond, TS - thickness swelling, WA - water absorption, NTS - non-recoverable thickness swelling, values in parentheses represent standard error.

PHN represents platen hole number: PHN1 - no holes, PHN2 - low hole number (holes/m^2), PHN3 - high hole number (holes/

TS and WA were measured after 48-hour soaking.

NTS was measured after 216-hour soaking.

Some boards in this group blew; property values are unavailable.

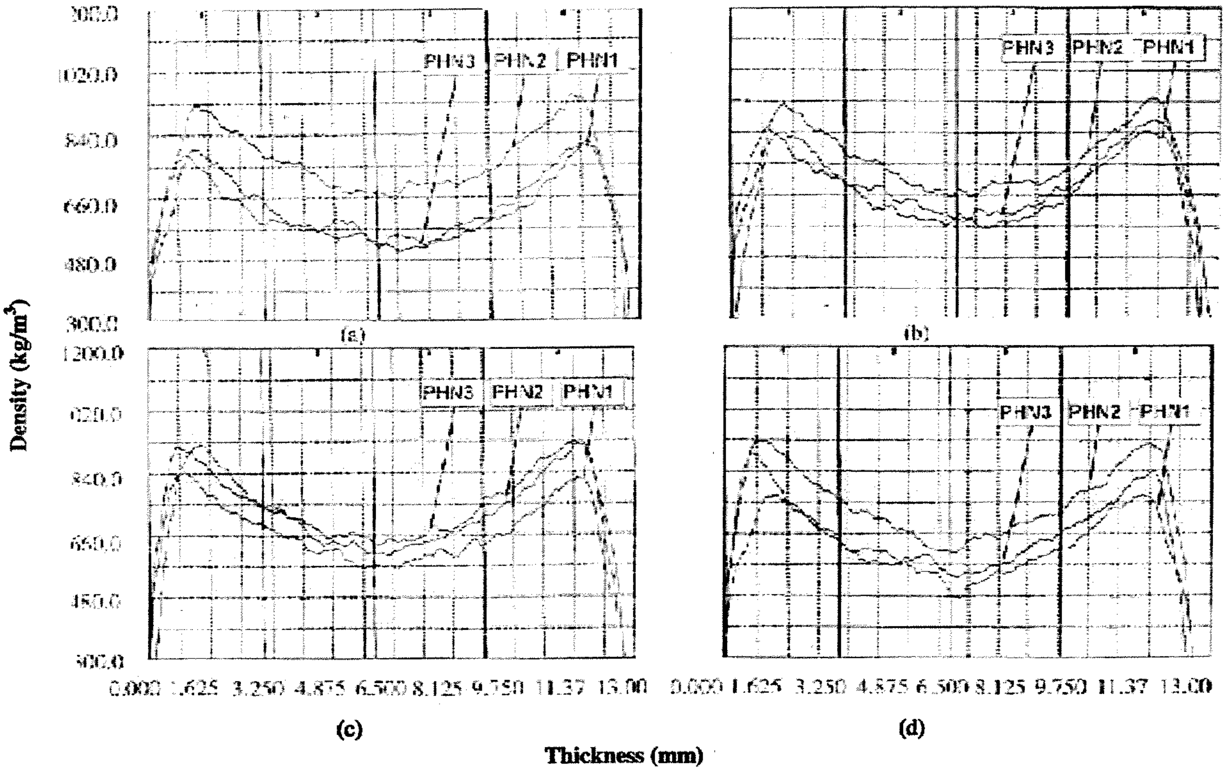

Figure 3. Vertical density profiles of flakeboard pressed at 5 levels of flake moisture contents and 3 platen hole numbers (PHN): (a) 2.1 percent of MC (b) 8.9 percent of MC (c) 13.7 percent of MC (d) 17.0 percent of MC. PHN1 – no holes, PHN2 – less holes, PHN3 – more holes.

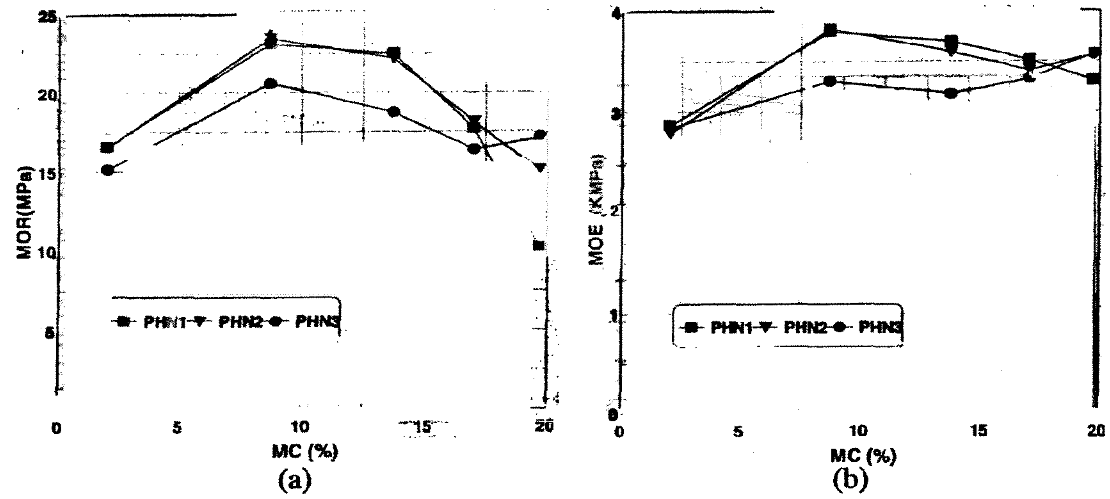

Figure 4. Effects of perforated hole number and moisture content on modulus of rupture (a) and modulus of elasticity (b) of southern pine flakeboard.

Internal Bond Strength

IB values of boards at different PHN and MC levels are shown in Table 2. As expected, high moisture deepened the VDP curves for platens without holes; while there was little difference in VDP for PHN3 in the four MC levels. IB strength of the boards increased with the number of holes on the platens. To compare the difference in IB values among three PHNs at each MC level, pair-wise comparisons were made and the resulting p-values of t-tests are listed in Table 3. At 2.1 percent MC level, PHN had no effects on the bonding properties of flakeboard. Since some moisture was released out of board mat once it was vaporized during hot pressing, the "wash-in" and "wash-out" effects were reduced at high MC levels. When the flake MC was 13.7 percent, IB strength increased by 12.9 percent and 30.8 percent as the PHN increased from 1 to 2 and from 1 to 3, respectively. The same percentages of increase were found when the flake MC was 17 percent.

Table 3. p-values of two-tail t-tests of internal bond strength among three platen hole number (PHN) levels of flakeboard pressed at five levels of moisture content.

Flake MC (%)	PHN1 to PHN2	PHN1 to PHN3	PHN2 to PHN3
2.1	0.146	0.126	0.915
8.7	0.036**	0.593	0.106
13.7	0.094	0.000**	0.031**
17.0	0.762	0.008**	0.061
19.7[a]	------	------	------

** Values are significant at the 5 percent significant level.

[a] Boards in this group blew; most property values are unavailable.

Water Absorption and Thickness Swelling

Thickness swelling and water absorption after 48-hour soaking and non-recoverable thickness swelling after 216-hour soaking are presented in Table 2. Flake moisture content had significant effects on thickness swelling (TS), water absorption (WA), and non-recoverable TS (NTS). Both TS and NTS increased as MC increased from 8.7 percent to 13.7 percent.

PHN had no effects on TS and WA, but had significant effects on NTS. NTSs were significantly reduced when the boards were pressed with perforated platens (Table 4).

The linear relationship between water absorption and thickness swelling was found by Lehamnn (1978). A similar relationship between WA and TS was found in this study. The slope values of this linear relationship are presented in Table 4. Slope values increased as the flake MC increased from 2.1 to 13.7 percent. This indicates that boards pressed at a high flake MC swelled more after soaking unit percentage of water than the boards pressed at a low flake MC. PHN had no effect on the slope values.

Table 4. Regression slope values of relationship between water absorption and thickness swelling as affected by PHN and MC conditions.[a]

Target MC (%)	2	8	13	17
Actual MC (%)	2.1	8.7	13.7	17.0
PHN1[b]	0.16 (0.01)	0.26 (0.04)	0.36 (0.06)	0.36 (0.05)
PHN2	0.13 (0.02)	0.23 (0.06)	0.31 (0.02)	0.28 (0.03)
PHN3	0.17 (0.02)	0.27 (0.04)	0.26 (0.03)	0.33 (0.03)

[a] Values in parentheses are standard error.

[b] PHN represents platen hole number: PHN1 - no holes, PHN2 - low hole number (holes/m^2), PHN3 - high hole number (holes/m^2).

CONCLUSIONS

A new caul system was developed to address the problem of pressing flakeboard at high flake MC and high temperature using phenol formaldehyde resin. This study showed that the perforated caul had the function of releasing moisture and vapor from the mat during hot pressing. In the current platen design, boards can be pressed without blows up to 17 percent flake MC. Based on the results obtained in this study, the following conclusions were made: (1) the perforated caul changed the heat and mass transfer properties of board mat during hot pressing, (2) flexural and bonding properties were negatively correlated with increasing flake MC when the flake MC was greater than 8.7 percent, (3) IB strength of boards pressed at moderate to high flake MC was significantly improved with increasing PHN levels, and (4) dimensional stability in thickness was negatively correlated with flake MC and improved with increasing PHN levels.

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