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Improving Productivity, Recovery and Quality of Veneer Products with a New Pressing Method

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Summary

Hot pressing is a critical stage in plywood and laminated veneer lumber (LVL) manufacturing. In this study, a new hot pressing method was developed for plywood and LVL products, which integrated both pressure control and position control in one pressing cycle. The optimum pressing parameters and resulting benefits of this method were determined for panels made from stress graded Douglas-fir, white spruce and mountain pine beetle (MPB) veneer through laboratory tests and for white spruce-lodgepole pine-subalpine fir (SPF) veneer through full-size panel tests. The method was further successfully applied in a mill trial using an industrial multi-opening plywood press.

The results demonstrate that the new pressing method is suitable for manufacturing plywood and LVL products. Compared to conventional hot pressing methods with a constant pressure control, the new method expedites heat transfer and in turn reduces hot pressing time by 5-15%, depending on species, veneer moisture content (MC) and panel thickness. The thickness of final panel products can be more precisely controlled for reduced panel thickness loss. The mill trial results demonstrate that between-panel thickness variation can be reduced by as much as 30%. This enables thinner veneer to be peeled in the mill. As a result, material recovery can be increased by up to 4%. The new method is more forgiving of dry veneer MC variation, and is suitable for pressing relatively high MC veneer without causing blisters and blows. For plywood products, as long as the hydraulic ram pressure of the press is sufficient and the panel control thickness (or full hydraulic pressure time) is set correctly, the new method has no negative effects on plywood gluebond quality and bending performance.

To apply this method in the mill, an upgraded industrial multi-opening press is required with a compression control. It is conservatively estimated that with a 3% increase in productivity, an average plywood and LVL mill can realize about $300,000 in annual savings. On top of productivity increase, an estimate of 1-3% increase in material recovery means additional $150,000 to $450,000 annual savings. Therefore, by applying the new pressing method, the total annual savings can be greater than $500,000 for an average mill and $1,000,000 for a larger size plywood and LVL mill. Coupled with a higher hydraulic ram pressure and a position control in the press, a greater impact can be achieved from increased manufacturing productivity and material recovery.

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1 Introduction

Plywood and laminated veneer lumber (LVL) are the two main veneer-based wood composite products in North America. Currently, softwood plywood produces total about 1,721 thousand cubic meters of panels per year. However, the industry is facing strong competition from oriented strand board (OSB) for wall and roof sheathing and flooring. Compared to OSB, softwood plywood has lighter weight and better dimensional stability but production costs are relatively higher since it requires larger diameter logs and more labour intensity. As an engineered wood product, LVL has been widely used for such applications as I-beams, flanges and joists. To maintain competitiveness, the production costs of softwood plywood and LVL need to be further reduced.

Hot pressing is one of the most critical and expensive operations in plywood and LVL manufacturing. This is because the process significantly affects manufacturing productivity, material recovery, panel quality and performance, and involves high energy consumption and costly equipment investment. During the process, drastic changes in heat, moisture content (MC), deformation and glue curing take place simultaneously (Zavala and Humphery 1996). The productivity is mainly governed by the time needed for the innermost glueline to reach a target curing temperature (Wang 2001b; Wang and Dai 2005). Conventional plywood and LVL hot-pressing is easy to operate with a constant pressure control. However, it is extremely sensitive to the variations of species, veneer thickness, density and MC. Thus, a large variation of product thickness generally results (Wellons *et al.* 1983; Wang and Yu 2003). In order to cure the innermost glueline, the conventional pressing method requires long pressing times, especially for thicker plywood and LVL products. To meet the tolerance of final product thickness, veneer is generally peeled thicker, resulting in reduced material recovery (Wang 2001a). Further, during press unloading and opening, blisters and blows tend to occur. This type of defects in final panel products is often associated with increased customer claims, and loss of market share and profit.

Currently, the devastating mountain pine beetle (MPB) infestation in BC has changed the resource available to plywood producers (Wang and Dai 2004) and increased pressing complexity. MPB veneer is denser than the control veneer from typical white wood mix of white spruce-lodgepole pine-subalpine fir (SPF). Using the conventional hot pressing method, MPB plywood takes about 10% longer pressing time than control plywood (Wang *et al.* 2005). To effectively tackle this altered resource and increase the manufacturing productivity for both plywood and LVL products, it is important to develop more effective and less costly pressing methods.

A new plywood/LVL hot-pressing method was recently developed at Forintek. Preliminary pilot plant tests successfully integrated the pressure control and thickness control in one pressing cycle. A pressure control was performed at the first stage for faster heat and mass transfer followed by a position control while achieving adequate glue cure. The results indicated that pressing time was reduced by 5-15% depending on species, veneer MC and panel thickness. Blows were reduced and the thickness of final products was precisely controlled, which resulted in higher material recovery. In pilot plant tests, the new method had no negative effect on panel gluebond quality, bending stiffness and strength. This project was designed to demonstrate the feasibility of the new method through full-size panel tests and determine its economic benefits through a mill trial.

2 Objectives

This project aims to develop and implement a new hot pressing method for plywood and LVL manufacturing through pilot plant tests, full-size tests and a mill trial. The specific objectives of this project were to:

- further develop the new plywood and LVL hot pressing method through pilot plant tests;
- establish the optimum pressing parameters through full-size tests for use in the mill production; and
- quantify the economic benefits of the new hot pressing method through a mill trial.

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4 Materials and Methods

4.1 New plywood and LVL hot pressing method

The new plywood and LVL hot pressing method integrates a pressure control and a position control in one pressing cycle. It has two stages. In the first stage, a higher platen pressure is generally used to speed up heat transfer and in turn temperature rise (Wang and Yu 2003; Wang *et al.* 2006a), leading to a reduction of pressing time. Once the panel thickness reaches the target, the second stage automatically starts in the position control mode. During this stage, the temperature keeps rising for glue curing while the platen pressure automatically drops due to stress relaxation. Panel internal stress is also reduced, which may help develop adequate bonding strength and shorten decompression cycle. Panel permeabilities are not reduced, which helps release gas to avoid blisters and blows. Compared to the conventional pressing method with a constant pressure control, the new method is less sensitive to variations of species, veneer thickness, MC and density, leading to more uniform panel thickness.

4.2 Materials

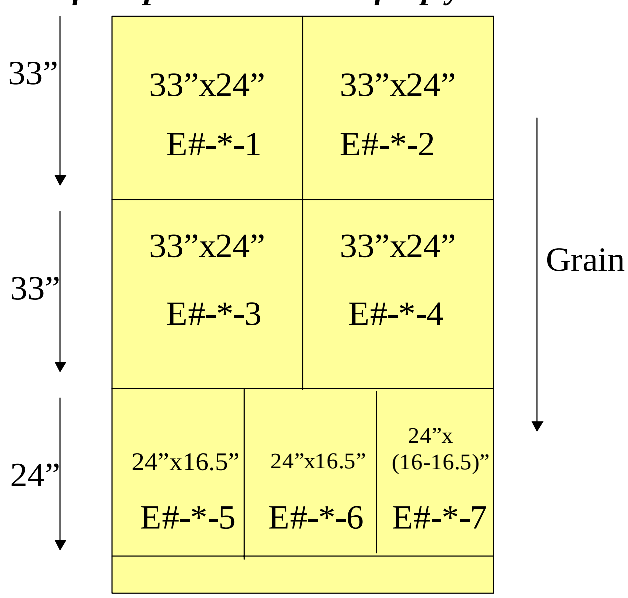
In one BC plywood mill, 2000 cubic meters of MPB logs were segregated for veneer production. These MPB logs were conditioned and peeled to nominal 1/8 -in thickness and MPB veneer was dried and tested by a production line Metriguard stress grader. As well, 1/8 -in thick Douglas-fir and spruce veneer were also peeled and tested with the same grader. The production data such as veneer density, thickness, MC, ultrasonic propagation time (UPT) and MOE were acquired for the MPB pine, spruce and Douglas-fir veneer. Furthermore, the dry MPB veneer, spruce veneer and Douglas-fir veneer were segregated into five E grades (E0, E1, E2, E3 and E4) with four E breakpoints. Table 1 shows the grade thresholds with three middle E grades. As shown in Figure 1, for three species, one lift each (about 200 4 x 8 -ft sheets per lift) was randomly sampled for three middle E grades (E1, E2 and E3) and delivered to Forintek's Composites Pilot Plant for plywood/LVL manufacturing. Based on the distribution of veneer density, UPT and MOE for each species, the characteristic values of veneer MOE, density for each E grade and actual grade outturn were determined.

Table 1: The E thresholds used and number of veneer sheets sampled

Species	E1 grade		E2 grade		E3 grade	
	Threshold (10^6 psi)	No. of sheets	Threshold (10^6 psi)	No. of sheets	Threshold (10^6 psi)	No. of sheets
Douglas-fir	1.85<E<=2.20	200	1.65<E<=1.85	200	1.35<E<=1.65	200
MPB	1.85<E<=2.20	200	1.65<E<=1.85	200	1.35<E<=1.65	200
Spruce	1.85<E<=2.20	200	1.65<E<=1.85	200	1.35<E<=1.65	200

At Forintek’s composites pilot plant, 33 x 24 -in and 24 x 16.5 -in veneer sub-sheets were cut from each 4 x 8 -ft sheet and marked in sequence as shown in Figure 2. In total, about 400 (33 x 24 -in) sheets and 300 (24 x 16.5 -in) sheets were generated from each E grade/species. Note that 33 x 24 -in sheets were used for 13-ply LVL and 5-ply plywood manufacturing, and 24 x 16.5 -in sheets were used for crossbands in 5-ply plywood. For each grade/species, veneer MC was checked and veneer thickness and weight were measured from 10 random sheets to calculate average veneer density. To reduce the material variation, the comparison study used the veneer sub-sheets cut from the same 4 x 8 -ft sheet and then followed the same lay-up sequence. For example, as shown in Figure 2, for manufacturing 13-ply LVL, the conventional method will use sub-sheets from E1-1-1 to E1-13-1 whereas the new method will use sub-sheets from E1-1-2 to E1-13-2.

Figure 1: Preparation of sample veneer sheets for plywood/LVL manufacturing



Note: # refers to 1, 2 or 3. *refers to 1 to 100. The E#-*-7 could be slightly narrow

Figure 2: Preparation of veneer sub-sheets for pilot plant manufacturing

4.3 Panel manufacturing and testing

At Forintek's composites pilot plant, a 36 x 36 -in computer controlled press was used for manufacturing 13-ply LVL billets and 5-ply 34 x 24 -in plywood panels. For each species, ten 34 x 24 -in veneer sheets from each E grade were randomly sampled for measuring thickness, density and MC. Control tests were conducted to compare the difference in pressing time and panel thickness between the conventional and new pressing method. During hot-pressing, one coupled thermocouple and gas pressure sensor was used to measure the real-time temperature and gas pressure at the innermost glueline. The target innermost glueline temperature was 105°C for LVL and 110°C for 5-ply plywood. Glue spread was 35 lb/1000 ft^2 per single glueline for LVL and 32 lb/1000 ft^2 per single glueline for plywood. Pressing temperature was 155°C. The average veneer MC of Douglas-fir and spruce veneer was about 3% whereas the veneer MC of MPB pine veneer was about 3.5%. During press unloading, the blows and blisters were carefully monitored. For each species/grade, 3 replicates were used.

For LVL products, as shown in Figure 3, four (4) flatwise and edgewise bending specimens each were cut from each billet. Five (5) blocks each were also cut for measuring shear strength parallel to grain and through-the-thickness. The tests were conducted according to the JAS, APA and ASTM standards (JAS 1993; APA 2000; ASTM D5456-05). In addition, two samples (5.5 x 5.5 -in) were cut for measuring thickness swell (TS) and water absorption (WA) after 24-h cold water soaking. The thickness of each billet was measured to calculate panel compression ratio (CR).

For plywood products, as shown in Figure 4, four (4) bending specimens were cut for measuring parallel ply MOE/MOR for each plywood panel; and two (2) 5.5 x 5.5 -in specimens were cut for measuring panel TS after 24 -h cold water soaking. Also twenty (20) lap-shear specimens were cut to measure shear strength and percent wood failure according to CSA O151-04 standard (CSA 2004). Among them, half were subject to vacuum-pressure cycle tests and the other half went through the boiling cycle tests. The thickness of each panel was measured to calculate the panel CR.

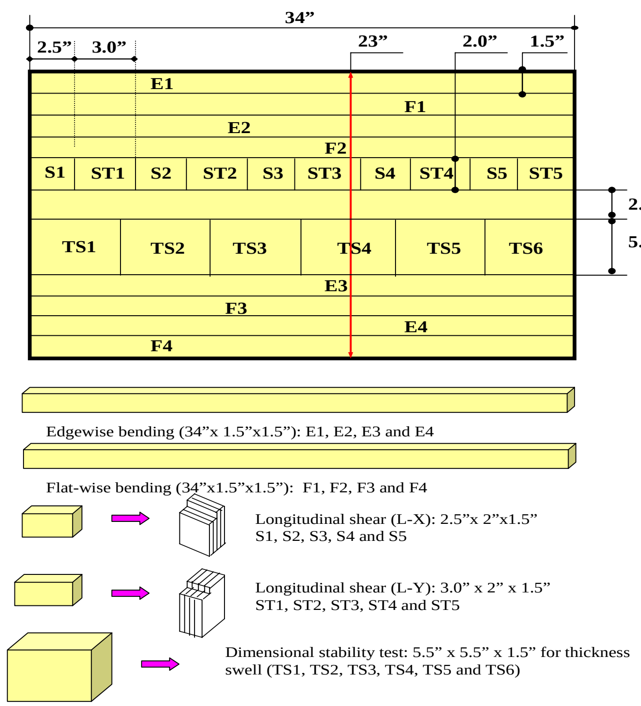


Figure 3: Cutting diagram for 13-ply LVL billets

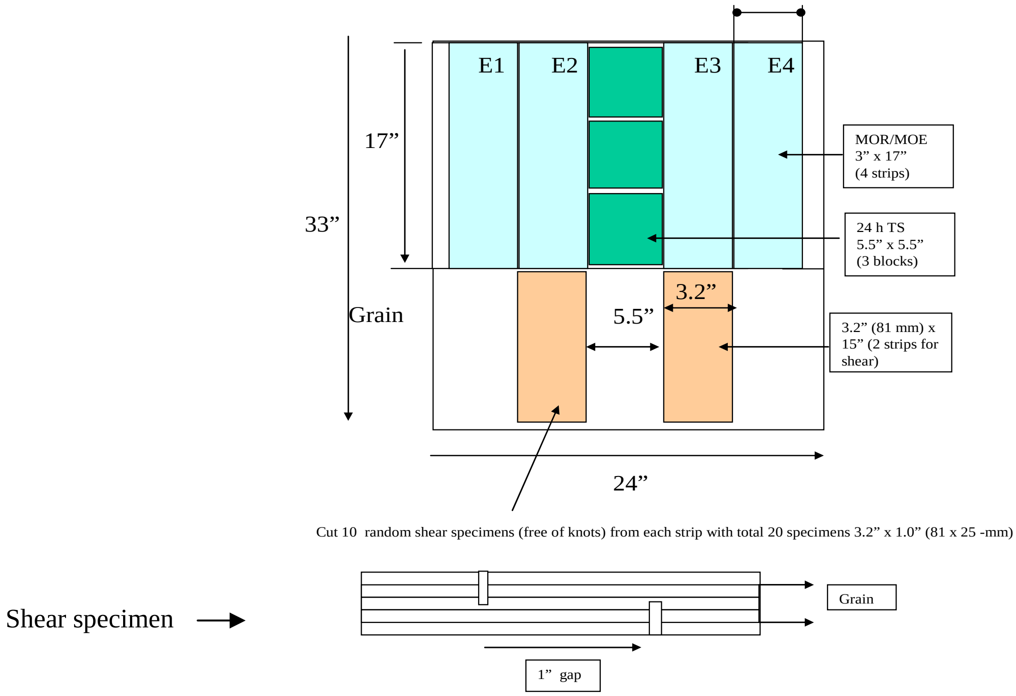


Figure 4: ***Cutting diagram for 5-ply plywood***

4.3.1 Experimental design for 13-ply LVL

The platen pressure for the conventional pressing (pressure control) and the new pressing (combined pressure/thickness control) methods are shown in the Table 2 for the three species. The target thickness was set at either 1.485 or 1.495 inches for the new method. For MPB LVL, the decompression cycle was 60 s for both methods. Three replicates were made. In total, for each species, 18 LVL billets (3 replicates x 3 E grades x 2 pressing methods) were made. To investigate the effect of MC and thickness control target on the pressing time required for the two pressing methods, 100 sheets (33 x 24 -in) of the MPB veneer from each E grade were put into a conditioning chamber for a week to achieve an average MC of 9%. Nine 13-ply MPB LVL billets each were made using the conventional pressure control method and new pressing method, respectively. For the conventional pressure control, the platen pressure used for pressing three E grades at 9% veneer MC was only 175 psi compared to an average pressure of 285 psi used for pressing 3.5% MC veneer.

Table 2: The pressing parameters used for 13-ply LVL manufacturing

13-ply LVL billet	Grade	Platen pressure (psi)		Target control thickness for the new method (inches)	Replicates
		Conventional	New		
Douglas-fir	E1	250	300	1.485	3
Douglas-fir	E2	225	275	1.485	3
Douglas-fir	E3	200	250	1.485	3
Spruce	E1	190	240	1.485	3
Spruce	E2	175	225	1.485	3
Spruce	E3	150	200	1.485	3
MPB (3.5% MC)	E1	300	350	1.485	3
MPB (3.5% MC)	E2	285	335	1.485	3
MPB (3.5% MC)	E3	270	320	1.485	3
MPB (5.5% MC)	E1	275	350	1.495	3
MPB (5.5% MC)	E2	250	300	1.495	3
MPB (5.5% MC)	E3	225	250	1.495	3
MPB (9% MC)	E1	175	250	1.495	3
MPB (9% MC)	E2	175	250	1.495	3
MPB (9% MC)	E3	175	250	1.495	3

Analyses were conducted to compare the difference in pressing time, material recovery and panel stiffness and strength between the two pressing methods. The productivity was evaluated based on the pressing time, the recovery was evaluated based on the panel CR and uniformity of the panel thickness. As a result, the feasibility of using the new pressing method to reduce veneer peeling thickness can be determined.

4.3.2 Experimental design for 5-ply MPB plywood

During 5-ply MPB plywood lay-up, veneer sub-sheets with little bluestain were put on the surface for cosmetic reason. Since the density of the MPB veneer decreases from high E1 grade to low E3 grade, different platen pressures need to be used for the conventional pressure control method. As shown in Table 3, for test 1 with an average MC of about 3.5%, the platen pressure used for the new pressing method was 50 psi higher than the conventional pressure control method. To investigate the effect of platen pressure and thickness control target on pressing time and final panel thickness, test 2 was conducted with different platen pressures and a higher panel thickness control target. Note that when test 2 was conducted, veneer picked up some MC with an average MC of 5.5%. As a result, a slight lower platen pressure was used for each E grade of the MPB veneer. In test 2, the platen pressure used for the new pressing method was 65 psi higher than the conventional pressure control method. To further investigate the MC tolerance of the new pressing method, test 3 was conducted. Before doing the tests, veneer sheets were conditioned in the chamber for 48 h to achieve an equilibrium MC of 9%.

Table 3: The pressing parameters used for 5-ply MPB plywood manufacturing

5-ply MPB plywood	Grade	Platen pressure (psi)		Target control thickness for the new method (inches)	Replicates
		Conventional	New		
Test 1 (3.5% veneer MC)	E1	285	335	0.585	3
	E2	250	300	0.585	3
	E3	235	285	0.585	3
Test 2 (5.5% veneer MC)	E1	250	315	0.600	3
	E2	235	300	0.600	3
	E3	220	285	0.600	3
Test 3 (9.0% veneer MC)	E1	175	250	0.600	3
	E2	175	250	0.600	3
	E3	175	250	0.600	3

During pressing, the temperature and gas pressure were monitored at the innermost glueline. During unloading, the blisters/blows were carefully monitored. For this pure grade panel construction, 3 replicates were used. In total, 18 (3 x 3 x 2) plywood panels were made.

4.4 Full-size plywood/LVL trials

A full-size panel (4 x 8 -ft) trial was conducted at Alberta Research Council (ARC). Three hundred 4 x 8 -ft and one hundred fifty 4 x 4 -ft SPF veneer sheets were acquired from one Alberta plywood mill and shipped to ARC. Of these 450 sheets, two hundred and fifty (250) 4 x 8 -ft and one hundred (100) 4 x 4 -ft were normal dry veneer sheets; and fifty (50) 4 x 8 -ft and fifty (50) 4 x 4 -ft were fresh redry veneer sheets. Two buckets of plywood glue were also acquired from the same mill. Glue spread was 32 lb/1000 ft^2 per single glueline (156 g/m^2) for plywood and 35 lb/1000 ft^2 per single glueline (171 g/m^2) for LVL. The ARC's 4 x 8 -ft PressMan® controlled press, as shown in Figure 5, was used in the trial. The press temperature was 155°C. Different platen pressures and controlling thickness were tested for the new pressing method. Before pressing, the thickness (4 -point) and weight of 120 veneer sheets were measured to calculate veneer density and thickness. For each matched panel pair, the weight of panel assemblies was made as close as possible. For LVL, the target innermost temperature was 105°C whereas for plywood, the target innermost temperature was 110°C. The time needed for the innermost glueline to reach the target temperature, total pressing time and maximum gas pressure were recorded. As well, the blows during press opening were monitored, and panel thickness and weight were measured. In total, 8 LVL and 14 plywood panels were made.

Figure 5: Full-size plywood/LVL manufacturing on ARC's 4'x 8' press

4.5 Mill trial

A trial was conducted at Federated Co-operatives Limited plywood mill. This mill has an annual capacity of 112 million square foot (on a 3/8 -in basis) processing 80% Douglas-fir and 20% SPF for plywood. The mill has one 40-opening hot press. To reduce compression losses from the hot press, the mill has purchased and installed a hot press compression control system from Clouston Hydraulics Inc., as shown in Figure 6. A Clouston hot press compression control is a device that allows for control of how much of the pressing cycle is dedicated to pressing the panels at a full hydraulic pressure, then it makes the hydraulic rams hold position for the duration of the pressing cycle. The main purpose of using this control is to reduce plywood panel over-compression, which means that same thickness of panels could be made with a thinner veneer peel.

Unlike the single-opening press equipped with a PressMan® control in the pilot plant and ARC, the thickness control target for the multi-opening press cannot be set directly. Instead, the full pressure time and total pressing cycle time can be programmed at the Clouston Human Machine Interface (HMI) located at the operator's station. The full pressure time is the amount of time to compress the plywood at full hydraulic pressure. As shown in Figure 7, the Clouston controller is interfaced with existing hot press PLC and hydraulic control systems. As the press closes, the HMI displays the increasing ram pressure until the press comes to full pressure. At this time, the controller is in "monitor only" mode. The press stays at the full pressure for a period of time set by the operator. When the timer has timed out, the Clouston controller stops compression of the panels and then maintains the bottom platen position. As the wood cells in the panels yield to the heat of the platens due to stress relaxation, it requires less pressure to maintain position. Throughout the remaining cycle time, ram pressure will decrease and platen position will not change. The panels will not be over-compressed and thus maximum panel thickness is maintained. When the press timer has finished its cycle, the press opens.

Since the Clouston controller offsets compression losses at the hot press by allowing only enough compression to achieve adequate gluebond performance then holding that position for the remainder of the pressing cycle, the panel thickness can be maximized. Maintaining platen position could give excellent panel gluebond because the wood fibers do not expand or contract from movement in the press platen. This could successfully deal with the over compression from veneers with higher MC or higher

MC variation. However, in the mill application of the Clouston controller, one big challenge is to determine the optimum full hydraulic pressure time to ensure adequate veneer-to-veneer contacts for gluebond development while minimizing the panel compression loss. When the same hydraulic pressure is used, if the full hydraulic pressure time is too short, the veneer-to-veneer contacts will not be adequate, resulting in a low percent wood failure or panel delamination (Wang *et al.* 2006a; Wang *et al.* 2006b).

Figure 6: The 40-opening plywood hot press with a Clouston compression control

Figure 7: The pressing station interfaced with PLC and a Clouston compression control

At the time of mill trial, 1/8 -inch Douglas-fir veneer was peeled for making 5-ply plywood. The veneer peel thickness target was 0.129 -inch. In this season, the mill used the following pressing parameters for 5-ply Douglas-fir plywood manufacturing: pressing time, 285 seconds; platen pressure, 190 psi; platen temperature, 285°F (or 140.5°C). Due to the limitation of the hydraulic ram pressure, the maximum platen pressure available was 210 psi, which is only 20 psi higher than that normally used in the mill for Douglas-fir plywood. Note that this pressure was also lower than that used in the pilot plant tests. Considering this limitation, a slightly long full hydraulic pressure time was used for the new pressing method. In this way, adequate veneer-to-veneer contact can be achieved for bonding development. As a result, for the new pressing method, the following pressing parameters were used: pressing time, 275 seconds; platen pressure, 210 psi; the time for full hydraulic pressure: 240 seconds; platen temperature, 285°F (or 140.5°C).

One load of 40 full size (4 x 8 -ft) 5-ply Douglas-fir plywood panels was pressed with the new pressing method. Right after pressing, one load of the same number of 5-ply Douglas-fir plywood panels were pressed as a control. As shown in Figure 8, the 40 trial panels were unloaded from the press. These panels were then trimmed and recovered for thickness measurements (Figure 9). Their sequence was recorded and marked from 1 (bottom platen) to 40 (top platen). After measuring 8-point panel thickness, 7 panels were sampled from each load with the following sequence number: 3, 7, 12, 18, 24, 31 and 37.

As shown in Figure 10, to help fine tune the new pressing schedule at a full hydraulic pressure of 210 psi for the mill application, 60 sheets of full-size dry Douglas-fir veneer were sampled to measure 8-point thickness with a micrometer. In the meantime, veneer MC of each sheet was measured with a hand-held capacitance MC meter to estimate the average and peak values.

Figure 8: Forty 5-ply Douglas-fir plywood panels unloaded from the press

Figure 9: Measurement of 5-ply Douglas-fir plywood thickness

Figure 10: Measurement of Douglas-fir dry veneer thickness

For each of the 14 panels sampled, one 2 -ft strip (4 x 2 -ft) was cut from one end of the panel and then shipped to Forintek for gluebond and bending tests. At Forintek, following the cut diagram in Figure 4, four bending samples (17 x 3 -in) were cut from each strip for measuring parallel ply bending MOE and MOR, and 20 shear specimens (or chips) in the dimension of 3.2 x 1.5 x 0.61 -in were cut from each strip for measuring shear strength and percent wood failure after a vacuum pressure treatment according to CSA O151-04 (CSA 2004).

5 Results and Discussion

5.1 Pilot Plant Comparison of LVL Physical and Mechanical Properties

5.1.1 Douglas-fir LVL

Table 4 summarizes the comparison results concerning pressing time, panel compression and swell behaviour of Douglas-fir LVL billets. On average, for 13-ply Douglas-fir LVL, compared to the conventional pressing method, the new pressing method reduced pressing time by 6.4%. As well, the new method reduced the panel thickness variation by about 45%. Table 5 summarizes the comparison results concerning flatwise bending, edgewise bending performance and shear strength. There was no significant difference between the two methods in terms of flatwise bending, edgewise bending and shear strength for billets made from the three E grades.

Table 4: Pressing time, panel compression and swell behavior of Douglas-fir LVL billets

Pressing method	Veneer E grade	Platen pressure	Pressing time	Panel thickness (inches)		Panel CR	Swelling	
							WA*	TS**
		(psi)	(min)	Average	Std.***	(%)	(%)	(%)
Old	E1	250	23.6	1.532	0.012	7.9	13.7	1.6
	E2	225	23.1	1.512	0.011	8.4	14.4	1.6
	E3	200	23.3	1.530	0.010	7.3	18.0	1.7
New	E1	300	22.0	1.527	0.005	8.2	13.7	1.5
	E2	275	22.5	1.525	0.004	7.6	15.2	1.5
	E3	250	21.0	1.518	0.009	8.1	17.6	1.6

Note: * representing 24-h water absorption;
** representing 24-h thickness swell; and
*** average within-panel thickness standard deviation.

Table 5: Mechanical properties of Douglas-fir LVL billets

Pressing method	Veneer E grade	Edgewise bending (psi)		Flatwise bending (psi)		Shear strength (psi)	
		MOE ($x10^6$)	MOR	MOE ($x10^6$)	MOR	Parallel	Per**
Conven-tional	E1	2.17 (0.058)*	11637 (809.2)	2.23 (0.057)	11077 (831.4)	948.0 (130.0)	1115.7 (94.2)
	E2	2.09 (0.096)	12728 (805.1)	2.16 (0.072)	11970 (1328.3)	1053.9 (110.0)	1077.9 (82.9)
	E3	1.67 (0.044)	8856 (628.7)	1.77 (0.081)	9217 (879.4)	832.5 (74.8)	1052.0 (79.4)
New	E1	2.16 (0.139)	12229 (1794.7)	2.20 (0.144)	12239 (1307.6)	889.7 (134.6)	1077.1 (139.1)
	E2	2.09 (0.067)	12808 (836.8)	2.13 (0.086)	13006 (2497.4)	949.6 (90.0)	1081.9 (96.1)
	E3	1.69 (0.042)	10342 (620.7)	1.69 (0.079)	9286 (911.5)	912.9 (117.3)	969.6 (99.6)

Note: * data in bracket indicates the standard deviation;
** indicating shear strength through-the-thickness.

5.1.2 Spruce LVL

Table 6 summarizes the comparison results concerning pressing time, panel compression and swell behavior of 13-ply spruce LVL billets. On average, for 13-ply spruce LVL, compared to the conventional pressing method, the new pressing method reduced pressing time by 5.7%. As well, it was found that with the conventional pressing method, the optimum platen pressure is veneer E grade dependent. By comparison, with the new pressing method, a higher platen pressure was normally used which is not as sensitive as the target control thickness programmed into the pressing schedule. As a result, it is much easier to control the final panel thickness with the new pressing method. It is estimated that the panel thickness variation can be reduced by as much as 73% for this spruce LVL. Table 7 summarizes the comparison results pertaining to flatwise bending, edgewise bending performance and shear strength. There was no significant difference between the two methods in terms of flatwise bending, edgewise bending and shear strength for billets made from the three E grades.

Table 6: Pressing time, panel compression and swell behavior of spruce LVL billets

Pressing method	Veneer E grade	Platen pressure	Pressing time	Panel thickness (inches)		Panel CR	Swelling	
							WA*	TS**
		(psi)	(min)	Average	Std.	(%)	(%)	(%)
Conven-tional	E1	190	24.4	1.513	0.039	10.5	39.8	5.3
	E2	175	23.2	1.543	0.025	8.7	35.8	4.3
	E3	150	21.6	1.552	0.032	6.7	24.7	2.0
New	E1	240	22.6	1.510	0.008	10.7	36.0	5.1
	E2	225	21.3	1.537	0.004	9.1	25.3	3.1
	E3	200	21.6	1.531	0.014	8.0	24.2	2.3

Note: * representing 24-h water absorption;
** representing 24-h thickness swell.

Table 7: Mechanical properties of spruce LVL billets

Pressing method	Veneer E grade	Edgewise bending (psi)		Flatwise bending (psi)		Shear strength (psi)	
		MOE ($x10^6$)	MOR	MOE ($x10^6$)	MOR	Parallel	Per**
Conven-tional	E1	2.10 (0.070)*	10639 (826.0)	2.12 (0.070)	10326 (1299.0)	787.6 (112.8)	932.1 (50.1)
	E2	1.89 (0.072)	10158 (1065.4)	1.89 (0.079)	10023 (1260.0)	720.8 (102.8)	877.4 (66.1)
	E3	1.56 (0.070)	8028 (1131.2)	1.63 (0.080)	8620 (1281.6)	762.7 (145.3)	871.5 (113.3)
New	E1	2.18 (0.053)	11682 (694.4)	2.25 (0.123)	11620 (1627.4)	761.8 (91.3)	937.1 (50.0)
	E2	1.87 (0.051)	9381 (665.8)	1.94 (0.056)	9399 (1237.0)	643.5 (71.6)	859.2 (100.1)
	E3	1.65 (0.042)	8882 (530.0)	1.60 (0.111)	7968 (1118.0)	705.4 (89.7)	1036.2 (78.4)

Note: * data in bracket indicates the standard deviation;
** indicating shear strength through-the-thickness.

5.1.3 MPB LVL

5.1.3.1 LVL made from 3.5% MC MPB veneer

Table 8 summarizes the comparison results concerning pressing time, panel compression and swell behavior of 13-ply MPB pine LVL billets made from 3.5% MC veneer. On average, the pressing time was 21.8 min for the conventional pressing method and 20.7 min for the new pressing method. As a result, compared to the conventional pressing method, the new pressing method can reduce pressing time by 5.0%. In the meantime, the new method resulted in more uniform panel thickness. It was estimated that the new method reduced the panel thickness variation by about 66%. Table 9 summarizes the comparison results concerning flatwise bending, edgewise bending performance and shear strength. Again, there was no significant difference between the two methods in terms of flatwise bending, edgewise bending and shear strength for billets made from the three E grades.

Table 8: Pressing time, panel compression and swell behavior of MPB LVL billets made with 3.5% veneer MC

Pressing method	Veneer E grade	Platen pressure	Pressing time	Panel thickness (inches)		Panel CR	Swelling	
							WA*	TS**
		(psi)	(min)	Average	Std.	(%)	(%)	(%)
Conven-tional	E1	300	22.7	1.456	0.035	10.4	48.9	8.7
	E2	285	21.7	1.477	0.010	11.9	38.6	7.2
	E3	270	20.9	1.479	0.032	12.5	38.0	5.0
New	E1	350	20.9	1.489	0.009	8.4	53.8	8.6
	E2	335	20.8	1.491	0.008	11.1	35.3	5.9
	E3	320	20.3	1.491	0.009	11.8	46.6	6.0

Note: * representing 24-h water absorption; ** representing 24-h thickness swell.

Table 9: Mechanical properties of MPB LVL billets made with 3.5% veneer MC

Pressing method	Veneer E grade	Edgewise bending (psi)		Flatwise bending (psi)		Shear strength (psi)	
		MOE ($x10^6$)	MOR	MOE ($x10^6$)	MOR	Parallel	Per**
Conven-tional	E1***	2.38 (0.072)*	11074 (1391)	2.24 (0.534)	10715 (3059)	808.0 (141.5)	1152.3 (156.0)
	E2****	2.03 (0.084)	10548 (913.9)	2.06 (0.103)	9446 (1097.3)	857.7 (136.7)	1088.6 (104.7)
	E3	1.89 (0.095)	9343 (978.3)	1.86 (0.138)	9618 (914.9)	739.0 (103.9)	1039.8 (101.0)
New	E1	2.36 (0.051)	11611 (1032)	2.39 (0.089)	11171 (2273)	732.8 (70.1)	1015.3 (139.7)
	E2	2.04 (0.097)	10262 (562.0)	2.06 (0.092)	10005 (533.7)	796.5 (128.1)	1038.4 (104.7)
	E3	1.90 (0.086)	9346 (693.6)	1.90 (0.136)	9798 (1252.3)	782.8 (98.8)	1078.5 (101.0)

Note: * data in bracket indicates the standard deviation; ** indicating shear strength through-the-thickness; *** 2 out of 12 bending samples were delaminated; **** 1 out of 12 bending samples was delaminated.

5.1.3.2 LVL made from 5.5% MC MPB veneer

Note that for MPB LVL made with 5.5% MC veneer, a slightly lower platen pressure was used for the conventional pressure control pressing. For the new pressing method, the target control thickness was adjusted up to 1.495 -in from 1.485 -in. Table 10 summarizes the comparison results concerning pressing time, panel compression and swell behavior of 13-ply MPB pine LVL billets. On average, the pressing time was 23.4 min for the conventional pressing method and 21.9 min for the new pressing method. As a result, compared to the conventional pressing method, the new pressing method can reduce pressing time by 6.4%. As well, the new method resulted in more uniform panel thickness. It was estimated that the new method reduced the panel thickness variation by about 34%. Table 9 summarizes the comparison results concerning flatwise bending, edgewise bending performance and shear strength. Due to the higher panel density, the E1 grade LVL made with the conventional pressing method had a higher flatwise and edgewise bending performance than that made with the new pressing method. In general, if the panel density was close such as E2 and E3 grade LVL, there was no significant difference between the two methods in terms of flatwise bending, edgewise bending and shear strength for billets made from the three E grades.

Table 10: Pressing time, panel compression and swell behaviour of MPB LVL billets made with 5.5% veneer MC

Pressing method	Veneer E grade	Platen pressure	Pressing time	Panel thickness (inches)		Panel CR	Swelling	
							WA*	TS**
		(psi)	(min)	Average	Std.	(%)	(%)	(%)
Conven-tional	E1	275	23.0	1.440***	0.014	11.4	26.7	5.3
	E2	250	23.6	1.458	0.019	13.0	44.8	8.5
	E3	225	23.5	1.474****	0.023	12.8	48.7	6.7
New	E1	350	22.6	1.515	0.014	6.8	22.5	3.6
	E2	325	22.2	1.509	0.013	10.0	47.2	7.2
	E3	300	20.9	1.512	0.010	10.5	35.9	4.5

Note: * representing 24-h water absorption; ** representing 24-h thickness swell;
*** one panel thickness was only 1.41”; **** one panel thickness was only 1.40”.

Table 11: Mechanical properties of MPB LVL billets made with 5.5% veneer MC

Pressing method	Veneer E grade	Panel density	Edgewise bending (psi)		Flatwise bending (psi)		Shear (psi)	
			MOE (x10^6)	MOR	MOE (x10^6)	MOR	Parallel	Perp.**
Conven-tional	E1	0.603	2.44 (0.104)*	12686 (587.7)	2.56 (0.130)	12927 (1323)	929	1139
	E2	0.557	2.04 (0.060)	11192 (345.9)	2.13 (0.138)	10675 (1132)	908	1070
	E3	0.522	1.77 (0.054)	8805 (829.6)	1.80 (0.105)	8093 (1430)	818	935
New	E1	0.555	2.21 (0.107)	11443 (826.0)	2.32 (0.21)	11269 (1396)	941	1006
	E2	0.536	2.03 (0.070)	10393 (904.6)	2.12 (0.177)	9828 (1284)	816	1031
	E3	0.503	1.82 (0.042)	9418 (868.0)	1.80 (0.071)	9477 (1301)	795	924

Note: * data in bracket indicates the standard deviation;
** indicating shear strength through-the-thickness.

5.1.3.3 LVL made from 9.0% MC MPB veneer

Note that for LVL billets made from 9.0% MC MPB veneer, a low platen pressure of 175 psi was used for pressing all three E grades with the conventional pressure control method. For the new pressing method, the platen pressure was kept the same at 250 psi for the three E grades, and the target control thickness was maintained at 1.495 -in. Table 12 summarizes the comparison results concerning pressing time, panel compression and swell behavior of 13-ply MPB LVL billets. On average, the pressing time was 24.7 min for the conventional pressing method and 23.1 min for the new pressing method. As a result, compared to the conventional pressing method, the new pressing method reduced the pressing time by 6.5%. For the 13-ply MPB LVL, no blows occurred during the pressing for both methods. However, compared to the new pressing method, the conventional pressing method resulted in a larger within-panel and between-panel thickness variation. Quantitatively, as far as the average within-panel thickness standard deviation is concerned, the new pressing method reduced about 14% of thickness variation.

Table 13 summarizes the comparison results concerning flatwise bending, edgewise bending performance and shear strength. In general, there was no significant difference between the two methods in terms of flatwise bending, edgewise bending and shear strength for billets made from the three E grades.

Table 12: Pressing time, panel compression and swell behavior of MPB LVL billets made with 9% veneer MC

Pressing method	Veneer E grade	Platen pressure	Pressing time	Panel thickness (inches)		Panel CR	Swelling	
							WA*	TS**
		(psi)	(min)	Average	Std.	(%)	(%)	(%)
Conven-tional	E1	175	25.4	1.523	0.015	7.8	25.8	3.2
	E2	175	25.0	1.488***	0.022	11.3	45.8	6.1
	E3	175	23.8	1.513	0.022	10.5	37.7	4.3
New	E1	250	23.4	1.523	0.015	7.8	29.8	4.1
	E2	250	23.6	1.504	0.017	10.3	40.5	5.5
	E3	250	22.4	1.507	0.019	10.8	35.2	4.9

Note: * representing 24-h water absorption;
** representing 24-h thickness swell;
***one panel thickness was only 1.43"

Table 13: Mechanical properties of MPB LVL billets made with 9% veneer MC

Pressing method	Veneer E grade	Panel density	Edgewise bending (psi)		Flatwise bending (psi)		Shear	
		(g/cm^3)	MOE (x10^6)	MOR	MOE (x10^6)	MOR	Parallel	Perp.**
Conven-tional	E1	0.566	2.29 (0.076)*	12233 (540.6)	2.32 (0.115)	11074 (549)	848	954
	E2	0.535	1.94 (0.052)	10395 (623.0)	2.00 (0.120)	10109 (1216)	792	1024
	E3	0.517	1.63 (0.086)	8883 (511.2)	1.70 (0.062)	8766 (900)	796	961
New	E1	0.569	2.26 (0.026)	11893 (723.8)	2.33 (0.045)	12427 (595.0)	853	1084
	E2	0.530	1.94 (0.025)	10468 (255.9)	2.05 (0.08)	9983 (1020)	851	1074
	E3	0.523	1.60 (0.051)	8053 (630.5)	1.71 (0.114)	8896 (1072)	867	1005

Note: *data in bracket indicates the standard deviation;
** indicating shear strength through-the-thickness.

5.2 Pilot Plant Comparison of Physical and Mechanical Properties for 5-ply MPB Plywood

5.2.1 Plywood made from 3.5% MC MPB veneer

Table 14 summarizes the comparison results concerning pressing time, panel compression and swell behavior of 5-ply MPB plywood made from veneers with an average MC of 3.5%. Table 15 summarizes the comparison results concerning parallel ply bending performance and shear strength. For 5-ply plywood, the thickness tolerance for regular unsanded panels was -0.5 mm and + 1.0 mm (0.605 -0.665 -in). On average, the pressing time for the conventional pressing method was 5.8 min compared to 4.9 min for the new pressing method. As a result, the new pressing method can reduce pressing time by 15.5%. As well, the new method resulted in more uniform panel thickness. It was estimated that the new method reduced the panel thickness variation by about 55%.

Table 15 summarizes the comparison results concerning parallel ply bending and gluebond performance. In general, there was no significant difference between the two methods in terms of parallel ply bending performance and shear strength made from the three E grades. On average, the percent wood failure was 91% with the conventional pressing method and 87% with the new pressing method. All plywood panels made with the two methods passed the CSA standard requirement of 80 percent or greater wood failure.

Table 14: Pressing time, panel compression and swell behavior of 5-ply MPB plywood made with 3.5% veneer MC

Pressing method	Veneer E grade	Platen pressure	Pressing time	Panel thickness (inches)		Panel CR	Swelling		Target thickness set
							WA*	TS**	
		(psi)	(min)	Average	Std.	(%)	(%)	(%)	(inches)
Conven-tional	E1	285	5.9	0.574	0.022	8.2	47.4	9.5	
	E2	250	5.8	0.583	0.013	9.6	49.2	7.3	
	E3	235	5.6	0.596	0.011	8.3	49.6	6.2	
New	E1	335	5.0	0.595	0.005	4.8	44.9	7.8	0.585
	E2	300	4.7	0.600	0.008	7.0	43.1	5.7	0.585
	E3	285	4.9	0.594	0.007	8.6	53.6	6.8	0.585

Note: * representing 24-h water absorption;
** representing 24-h thickness swell.

Table 15: Mechanical properties of 5-ply MPB plywood made with 3.5% veneer MC

Pressing method	Veneer E grade	Bending (psi)		Lap shear (vacuum)	
		MOE (x10^6)	MOR	Strength (psi)	Wood failure (%)
Conven-tional	E1	1.39 (0.138)	9237 (2194.6)	167.3 (46.9)	89.0 (14.7)
	E2	1.22 (0.084)	8949 (1461.4)	162.8 (7.5)	93.4 (7.5)
	E3	1.13 (0.073)	8330 (937.0)	169.2 (35.1)	91.5 (8.0)
New	E1	1.35 (0.080)	9865 (2437.9)	184.3 (41.1)	85.1 (11.7)
	E2	1.21 (0.089)	8719 (1945.4)	154.2 (53.0)	88.1 (12.4)
	E3	1.07 (0.074)	8444 (1201.8)	174.3 (50.2)	87.0 (10.7)

5.2.2 Plywood made from 5.5% MC MPB veneer

Note that for 5-ply MPB plywood made from an average veneer MC of 5.5%, a lower platen pressure was used to achieve the target panel thickness. Table 16 summarizes the comparison results concerning pressing time, panel compression and swell behavior of 5-ply MPB plywood. On average, the pressing time for the conventional pressing method was 5.5 min compared to 5.0 min for the new pressing method. As a result, the new pressing method reduced the pressing time by 9.5% for manufacturing 5-ply MPB plywood. As well, the new method resulted in more uniform panel thickness. The average within-panel standard variation was 0.0113 -in for the conventional pressing method and 0.0047 -in for the new pressing method. As a result, the new method reduced the panel thickness variation by about 59%.

Table 17 summarizes the comparison results concerning parallel ply bending performance and shear strength. In general, there was no significant difference between the two methods in terms of parallel ply bending performance and shear strength made from the three E grades. On average, the percent wood failure was 88.4% for the conventional pressing method and 88.3% for the new pressing method. All plywood panels made with the two methods passed the CAS standard requirement of 80 percent or greater wood failure.

Table 16: Pressing time, panel compression and swell behavior of 5-ply MPB plywood made with 5.5% veneer MC

Pressing method	Veneer E grade	Platen pressure	Pressing time	Panel thickness (inches)		Panel CR	Swelling		Target thickness set
							WA*	TS**	
		(psi)	(min)	Average	Std.	(%)	(%)	(%)	(inches)
Conven-tional	E1	250	5.6	0.585	0.005	6.4	42.1	6.8	
	E2	235	5.5	0.565	0.018	12.4	51.3	8.0	
	E3	220	5.5	0.589	0.011	9.4	45.3	5.9	
New	E1	315	4.9	0.605	0.004	4.7	45.9	6.0	0.600
	E2	300	4.7	0.601	0.004	7.0	58.0	5.9	0.600
	E3	285	5.4	0.607	0.006	6.6	54.7	5.6	0.600

Note: * representing 24-h water absorption. ** representing 24-h thickness swell.

Table 17: Mechanical properties of 5-ply MPB plywood made with 5.5% veneer MC

Pressing method	Veneer E grade	Bending (psi)		Lap shear (vacuum)	
		MOE (x10^6)	MOR	Strength (psi)	Wood failure (%)
Conven-tional	E1	1.49 (0.100)	10574 (2324)	162.3 (37.8)	86.2 (11.4)
	E2	1.41 (0.064)	9308 (1555)	141.1 (34.0)	94.8 (8.1)
	E3	1.13 (0.097)	8416 (1734)	158.8 (51.2)	84.1 (11.2)
New	E1	1.44 (0.129)	10577 (2341)	165.4 (42.6)	84.5 (14.2)
	E2	1.29 (0.099)	8485 (2255)	141.1 (48.0)	91.9 (9.9)
	E3	1.15 (0.156)	7120 (1998)	158.3 (35.3)	88.6 (12.0)

5.2.3 Plywood made from 9.0% MC MPB veneer

Note that for 5-ply MPB plywood made from an average veneer MC of 9.0%, a lower platen pressure at 175 psi was used to achieve the target panel thickness. Table 18 summarizes the comparison results concerning pressing time, panel compression and swell behavior of 5-ply MPB pine plywood. On average, the pressing time for the conventional pressing method was 5.7 min compared to 5.3 min for the new pressing method. Hence, the new pressing method reduced pressing time by 7.0%. As well, the new method resulted in more uniform panel thickness. The average within-panel standard variation was 0.0127 -in for the conventional pressing method and 0.007 -in for the new pressing method. Thus, the new method reduced the panel thickness variation by about 45%. However, at this high veneer MC, all plywood panels made with the two pressing methods had localized blows or delamination. Note that there were no blows with 13-ply MPB LVL made from 9% MC veneer. It seems that for pressing 5-ply MPB plywood, the platen pressure used at 250 psi with the new pressing method might have been too high which caused blows or panel delamination.

Table 19 summarizes the comparison results concerning parallel ply bending performance and shear strength. All 5-ply MPB plywood panels made with the two methods did not pass the CSA standard requirement of 80 percent or greater wood failure.

Table 18: Pressing time, panel compression and swell behavior of 5-ply MPB plywood made with 9.0% veneer MC

Pressing method	Veneer E grade	Platen pressure	Pressing time	Panel thickness (inches)		Panel CR	Swelling		Target thickness set
							WA*	TS**	
		(psi)	(min)	Average	Std.	(%)	(%)	(%)	(inches)
Conven-tional	E1	175	5.6	0.602	0.015	5.9	29.6	5.0	***
	E2	175	5.8	0.594	0.016	7.9	51.3	6.5	***
	E3	175	5.8	0.588	0.007	9.5	56.4	6.4	***
New	E1	250	5.5	0.611	0.005	4.5	36.3	5.4	0.600 ***
	E2	250	5.2	0.595	0.008	7.8	47.5	6.5	0.600 ***
	E3	250	5.2	0.603	0.008	7.2	49.1	6.5	0.600 ***

Note: * representing 24-h water absorption;
** representing 24-h thickness swell;
*** delamination occurred in the panels.

Table 19: Mechanical properties of 5-ply MPB plywood made with 9.0% veneer MC

Pressing method	Veneer E grade	Bending (psi)		Lap shear (vacuum)	
		MOE ($x10^6$)	MOR	Strength (psi)	Wood failure (%)
Conven-tional	E1	9977	1.36	157.3	48.5
	E2	8815	1.22	143.3	79.3
	E3	7804	1.05	147.3	73.8
New	E1	7620	1.27	117.0	45.5
	E2	8137	1.17	142.7	72.8
	E3	6879	0.96	128.2	55.5

5.3 Comparison for full-size plywood/LVL trials

As shown in Table 20, the manufacturing parameters and responses of gas pressure were recorded for the 5-ply full-size (4 x 8 -ft) SPF plywood made from redry veneer and normal dry veneer and 13-ply full-size (4 x 8 -ft) SPF LVL made from normal dry veneer. The times needed for the innermost glueline to reach a target temperature of 105°C for LVL and 110°C for plywood were recorded. The manufacturing parameters included glue spread level, platen pressure, target control thickness for the new pressing method and pressing time. The total pressing time and maximum gas pressure were also recorded for each panel. The locations of maximum gas pressure were also identified from the three sensors embedded inside the panel during hot pressing. The blows during press opening were carefully monitored, and panel thickness and weight were measured. The results concerning panel thickness, density, panel gluebond quality are summarized in Table 21.

Based on Tables 20 and 21, it was found that pressing redry veneer for 5-ply plywood caused blows for both the new pressing method and the conventional pressing method due to the higher veneer MC. With the new pressing method, the final panel thickness was controllable through programming the target control thickness. For 5-ply SPF plywood, the average pressing time was 5.2 min for the conventional pressing method and 4.9 min for the new pressing method. For 13-ply SPF LVL, the average pressing time was 23.7 min for the conventional pressing method and 21.9 min for the new pressing method. As a result, compared to the conventional pressing method, the new pressing method yielded a reduction in pressing time by 5.7% for 5-ply plywood and 7.6% for 13-ply SPF LVL. As well, the new pressing method yielded a smaller between-panel thickness variation, which was more noticeable with the 13-ply LVL. Furthermore, there was no significant difference in gluebond performance between the conventional pressing and new pressing methods for both SPF plywood and LVL. Note that the relatively low wood failure in the plywood and LVL panels were mainly caused by glue skips caused by rough veneer peeled from the mill. For 13-ply LVL, with the conventional pressing method, one out of four panels had blows whereas no blows occurred in the panels made using the new pressing method. The results indicate that the new pressing method was more forgiving to veneer MC and thick and thin veneer, leading to more uniform thickness for the final panel products and a higher material recovery. LVL/plywood mills could peel veneer slightly thinner than normal for the panel manufacturing.

Note that when pressing the normal dry veneer, some panel delamination occurred after pressing. The main reason was that the dry veneer obtained from the mill was very rough with a significant thickness variation. According to measurements from 120 veneer sheets, the average dry veneer thickness was 0.129 -inch with a standard deviation of 0.010 -inch. This variation was almost two times the target 0.005 -inch. Due to this larger thickness variation, glue-skips occurred regularly after applying glue, leading to panel delamination and a low percent wood failure. In the mill, curtain coating was used instead of roller coating to deal with the veneer thickness variation.

Table 20: The manufacturing parameters, pressing time of full-size plywood and LVL panel trials

Pressing method	Panel no.	Glue spread per single glueline	Platen pressure	Target control thickness	Pressing time	Maximum gas pressure
		(lb/1000ft^2)	(psi)	(inches)	(min)	(psi)
New	PH1	35	200	0.590	5.0	4.5 (core)
	PH3	35	200	0.590	5.3	3.5 (surface)
	PH5	35	185	0.595	5.2	13.0 (core)
Conven-tional	PH2	35	185		5.5	9.0 (core/surface)
	PH4	35	185		5.7	3.5 (core)
	PH6	35	170		5.4	17.5 (middle corner)
New	P1	35	200	0.590	5.0	17.5 (middle corner)
	P3	32	235	0.590	4.8	7.5 (core)
	P5	32	185	0.600	4.8	9.5 (middle corner)
	P7	35	235	0.590	5.0	15.0 (surface)
Conven-tional	P2	35	185		5.1	13.0 (surface)
	P4	32	175		4.9	12.0 (middle corner)
	P6	32	185		5.2	16.0 (middle corner)
	P8	35	185		5.4	6.5 (core/surface)
New	L1	32	235	1.485	21.6	3.5 (middle corner)
	L3	35	235	1.485	21.2	10.0 (surface)
	L5	35	235	1.485	22.8	21.0 (surface)
	L7	35	235	1.485	21.8	10.0 (surface)
Conven-tional	L2	32	185		22.4	19.5 (core)
	L4	35	185		23.7	13.0 (surface)
	L6	35	185		25.0	5.0 (surface)
	L8	35	185		23.7	17.5 (surface)

Table 21: Panel thickness, density and quality

Pressing method	Panel no.	Panel density (g/cm³)	Panel quality	Panel thickness (inches)	Shear strength (psi)	Wood failure (%)
New	PH1	0.486	Blow	0.602 (0.015)	N/A	N/A
	PH3	0.479	Good	0.595 (0.011)		
	PH5	0.473	Blow	0.607 (0.011)		
Conven-tional	PH2	0.505	Blow	0.581 (0.011)	N/A	N/A
	PH4	0.481	Blow	0.610 (0.012)		
	PH6	0.475	Blow	0.601 (0.009)		
New	P1	0.446	Blow	0.591 (0.009)	136.2 (19.4)	89
	P3	0.444	Good	0.591 (0.011)	118.2 (12.9)	78
	P5	0.431	Good	0.601 (0.011)	133.0 (22.8)	80
	P7	0.415	Good	0.594 (0.011)	99.5 (13.7)	69
Conven-tional	P2	0.459	Blow	0.581 (0.010)	115.0 (13.5)	77
	P4	0.484	Good	0.591 (0.009)	118.2 (7.8)	85
	P6	0.447	Good	0.583 (0.012)	130.0 (28.3)	76
	P8	0.433	Good	0.592 (0.013)	110.7 (23.9)	93
New	L1	0.487	Good	1.516 (0.007)	1015 (128)	84
	L3	0.477	Delam	1.507 (0.008)	958 (135)	71
	L5	0.459	Good	1.509 (0.009)	1035 (110)	87
	L7	0.449	Good	1.510 (0.007)	935 (125)	67
Conven-tional	L2	0.492	Good	1.489 (0.022)	1065 (140)	88
	L4	0.499	Delam	1.517 (0.012)	945 (154)	67
	L6	0.473	Blow/Delam	1.515 (0.015)	965 (160)	55
	L8	0.454	Good	1.498 (0.019)	1026 (105)	47

As shown in Table 22, for 5-ply plywood made from the new pressing method, the average panel thickness was 0.596 -inch with an average within-panel standard deviation of 0.0075 -inch. The between-panel thickness standard deviation was 0.0039 -inch, which was about 25% lower than 0.0051 -inch with the conventional pressing method. Based on CSA Canadian Softwood Plywood Standard (CSA O151-04), for regular unsanded plywood panels up to 0.807 -inch, the thickness tolerances are from –0.02 to +0.04 -inch. With the new pressing method, the thickness tolerance for 5-ply plywood could be established from –0.012 to +0.012 -inch. For 13-ply LVL, the average panel thickness was 1.494 -inch with an average within-panel standard deviation of 0.011 -inch. The between-panel thickness standard deviation was 0.0074 -inch, which was almost 50% lower than 0.0135 -inch from the conventional pressing method. According to PRL-501 Performance Standard for APA EWS LVL, the thickness tolerances for 1.5 -inch LVL are from –0.06 to +0.06 -inch. With the new pressing method, the thickness tolerances for 13-ply LVL could be established from –0.022 to +0.022 -inch. The results indicate that the new pressing method had tighter panel thickness control and higher material recovery. LVL and plywood mills could peel veneer slightly thinner than the normal, for example to adjust dry veneer target from 0.129 -inch down to 0.124 -inch. Therefore, material recovery can be increased by up to 4.0%. Since there is a good control of panel thickness, material loss from panel sanding could also be minimized when making overlaid plywood.

Table 22: Comparison of thickness variation between panels

All panels		13-ply LVL		5-ply plywood	
Pressing method		New	Conventional	New	Conventional
Panel thickness (inches)	Average	1.494	1.511	0.596	0.621
	Std. Dev. (between-panel)	0.0074	0.0135	0.0039	0.0051

Similar to the results obtained from the pilot plant tests, the results from full-size panel tests confirmed that the new pressing method was more forgiving to final veneer MC and thickness and would have more uniform thickness for the final panel products. The pressing time from the new pressing method could be reduced by 5 -10%. When pressing SPF veneer, the optimum pressing parameters were 235 psi for platen pressure and 0.590 -in for target control thickness when pressing 5-ply plywood and 1.485 -in for target control thickness when pressing 13-ply LVL.

5.4 Mill trial results

5.4.1 Dry Douglas-fir veneer thickness and MC

As shown in Figure 11, the thickness of 60 Douglas-fir dry veneer sheets was plotted with error bars indicating a within-panel variation (± one standard deviation). The average dry veneer thickness was 3.338 mm (0.131 -in), which is higher than the target peel thickness (0.129 -in). The average within-sheet veneer thickness variation (standard deviation) was 0.0058 -in and the between-sheet veneer thickness variation was 0.0040 -in. The within-sheet veneer thickness variation was found to be larger than the normal target of 0.005 -in, which could be one of the main causes of lowered gluebond performance or panel delamination.

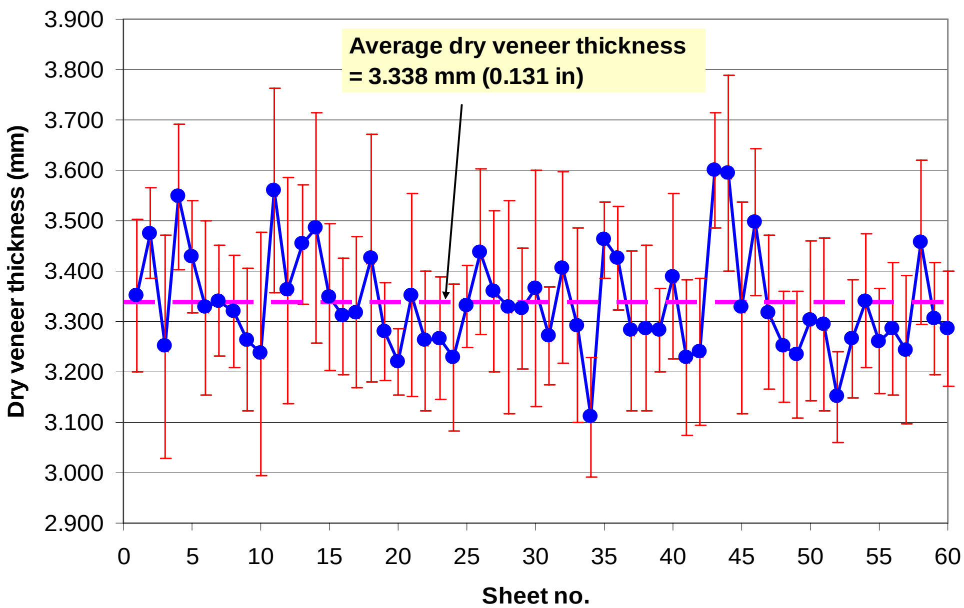


Figure 11: Variation of Douglas-fir dry veneer thickness

To examine the main cause of a larger within-sheet thickness variation, as shown in Figure 12, the average thickness of dry Douglas-fir veneer at 8 locations was plotted. It was found that the veneer was about 4.7% thicker at the two ends than the other six locations. The reason for this could arise from the lower pressure of the backup roll during veneer peeling. To increase the uniformity of veneer thickness or reduce the veneer peel thickness, it is recommended that the backup roll should be adjusted with a higher pressure.

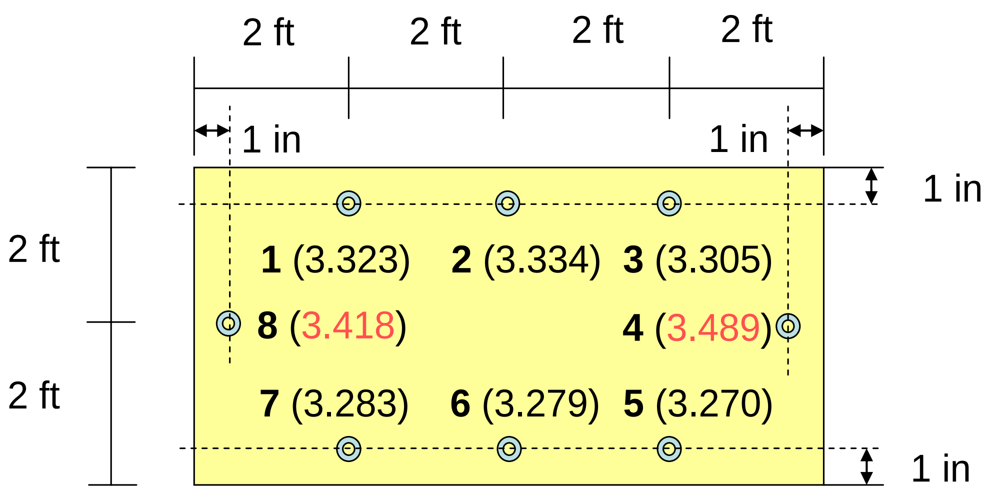


Figure 12: Variation of within-sheet Douglas-fir dry veneer thickness

As shown in Figure 13, the average MC and peak MC were plotted for 60 dry Douglas-fir veneer sheets. The average and peak MCs were 1.9% and 4.2% with standard deviations of 1.7% and 3.0%, respectively.

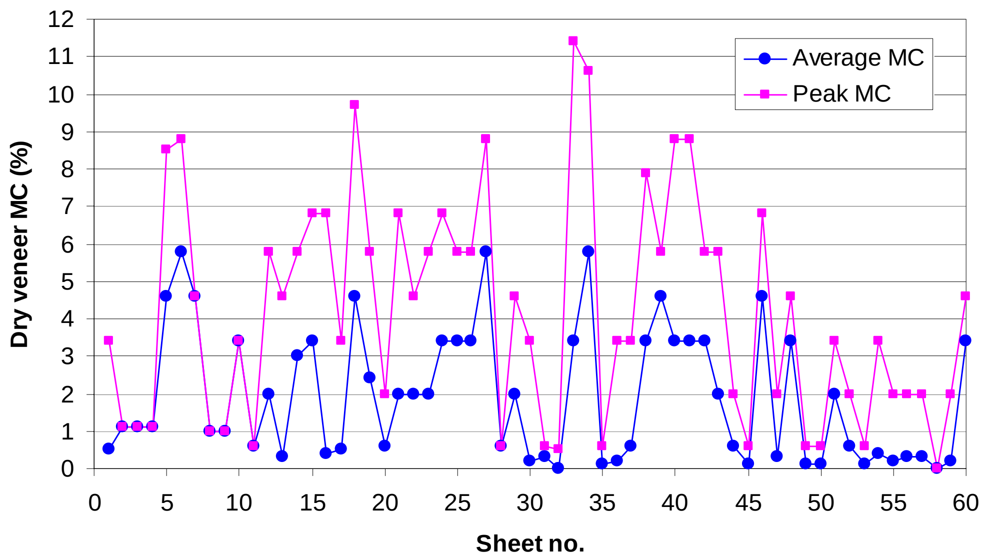


Figure 13: Variation of dry Douglas-fir veneer MC

5.4.2 Panel thickness of 5-ply Douglas-fir plywood

For the nominal thickness of 15.50 mm (or 0.610 -inch) of 5-ply Douglas-fir plywood, the average panel thickness was 15.83 mm (or 0.623 -inch) for the control panels and 15.65 mm (or 0.616 -inch) for the trial panels. Note that the thickness tolerance for 5-ply plywood is from 15.0 mm (0.590 -inch) to 16.5 mm (0.650 -inch) (CSA O151-04 2004). As shown in Figure 14, on average, the control panels were about 1.1% thicker than the trial panels, which is mainly due to the slightly higher platen pressure used in the trial. Both control panels and trial panels met the thickness requirements specified in the standard. The within-panel thickness variation was 0.20 mm (or 0.0078 -inch) for both the control and trial panels. Note also that the thickness of the trial panels increased from the bottom platen to the top platen, which was mainly due to the slight pressure difference between the bottom and top platens with the former being higher.

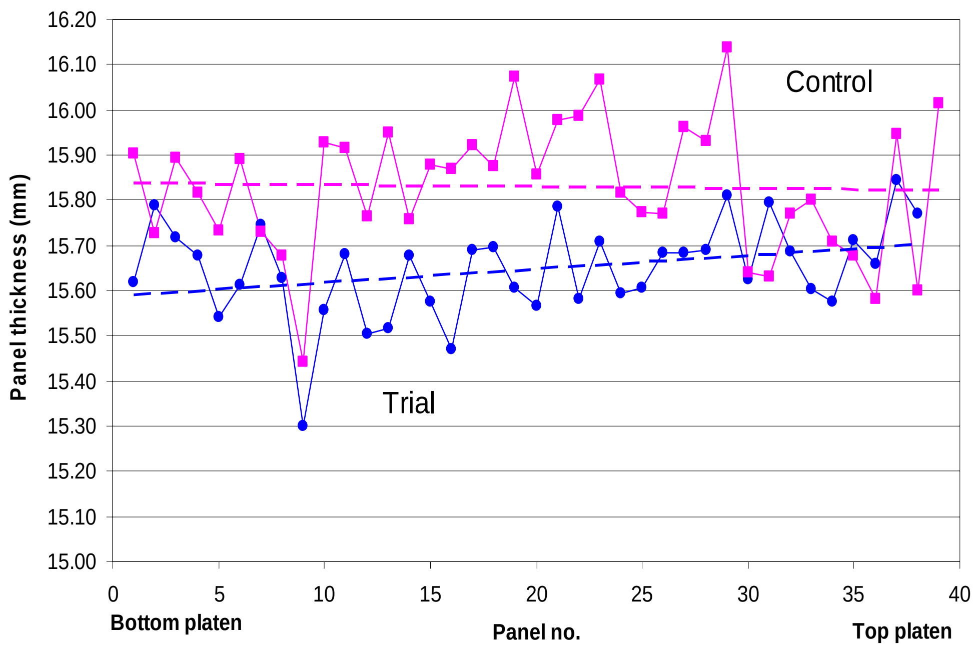


Figure 14: Variation of panel thickness of 5-ply Douglas-fir plywood

As shown in Figure 15, the trial panels had much smaller between-panel thickness variation than the control panels. The thickness standard deviation was 0.149 mm (0.0059 -inch) for the control panels compared to 0.106 mm (0.0042 -inch) for the trial panels. As a result, with the new pressing method, the reduction in between-panel thickness variation was about 30%, which is about 5% larger than that obtained from the single opening full-size panel tests at ARC.

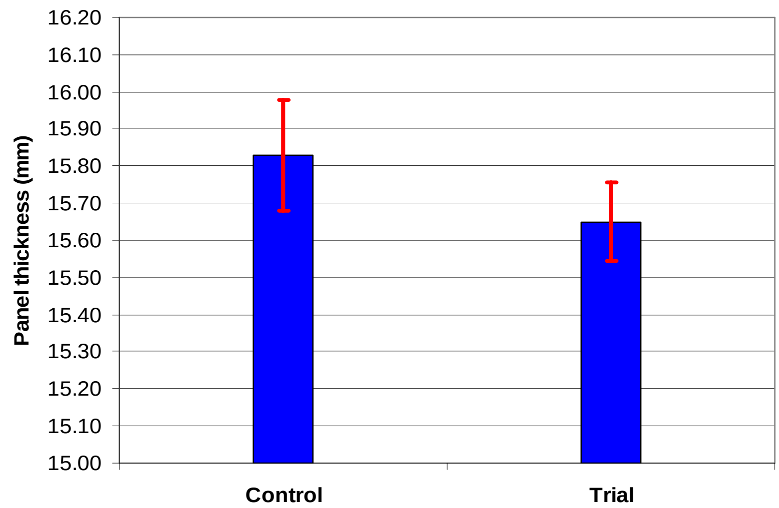


Figure 15: Comparison of thickness uniformity of panels

5.4.3 Panel gluebond quality and bending performance

Table 23 summarizes the panel density, parallel ply bending performance and gluebond quality. For both control and trial panels, one out of seven panels had an average wood failure below 80 percent. This was mainly due to the severe veneer surface roughness. Among 20 shear specimens, 7 and 6 shear specimens were extremely rough for the control panel no. 24 and trial panel no. 18, respectively. Although the average shear strength and percent wood failure from the control panels were slightly higher than those from the trial panels, overall, there was no significant difference in bending MOE and MOR, shear strength and percent wood failure between the control and trial loads.

Table 23: Plywood density, parallel ply bending performance and gluebond quality

Method	Panel no.	Panel density (g/cm^3)	Bending (psi)		Lap shear (vacuum)		Panel quality*
			MOR	MOE (10^6)	Strength (psi)	Wood failure (%)	
Control	3	0.546	6880	1.39	191.8 (34.5)	87.4 (14.4)	Pass
	7	0.527	7199	1.41	215.5 (38.2)	82.4 (9.0)	Pass
	12	0.517	9196	1.31	209.3 (52.5)	89.7 (10.1)	Pass
	18	0.538	9586	1.30	187.3 (57.5)	83.7 (11.9)	Pass
	24	0.520	9962	1.22	118.8 (9.0)	70.4 (17.1)	Fail**
	31	0.476	10530	1.29	165.3 (56.3)	93.4 (6.2)	Pass
	37	0.516	12535	1.52	185.8 (60.0)	83.0 (6.5)	Pass
	Average	0.520	9412	1.35	181.9	84.3	
Trial	3	0.514	11015	1.30	192.8 (47.5)	85.0 (11.2)	Pass
	7	0.522	7806	1.35	185.5 (58.1)	81.3 (9.7)	Pass
	12	0.505	12225	1.33	149.8 (30.8)	80.3 (13.5)	Pass
	18	0.553	8843	1.10	155.3 (32.8)	75.6 (19.1)	Fail**
	24	0.541	11730	1.44	202.6 (54.2)	85.8 (8.2)	Pass
	31	0.504	6464	1.10	154.5 (42.4)	87.4 (9.7)	Pass
	37	0.534	8005	1.24	189.0 (58.9)	82.7 (7.3)	Pass
	Average	0.525	9441	1.26	175.6	82.6	

Note: * panel quality was determined based on the minimum requirement of 80 percent wood failure;
** due to veneer surface roughness.

In summary, compared to the control panels, the trial panels yielded about 3.5% reduction in pressing time and 30% reduction in between-panel thickness variation. The resulting panels had similar bending performance and gluebond quality. With the current press at Federated Coop, since 5-ply spruce plywood generally uses a low platen pressure at 180 psi for the conventional pressing, the reduction of pressing time with the new pressing method could be more significant since a difference of 30 psi pressure can be applied. This mill is encouraged to conduct the mill trial for the spruce plywood. Further reduction in pressing time could be realized through the upgrading of the mill plywood press with a higher full hydraulic pressure. With the new pressing method, the time for keeping the full hydraulic pressure should be optimally determined through the measurement of dry veneer thickness and resulting panel thickness. In this case study, the final panel thickness (0.616 -in) from the new pressing method was still larger than the target (0.610 -in). If the full hydraulic pressure is maintained at 210 psi, the full pressure time should be set a minimum of 240 seconds. Indeed, as long as the full hydraulic pressure and time are set correctly, compared to the conventional pressing method, the new pressing method with compression control can help increase the productivity and material recovery without lowering plywood gluebond quality.

5.5 Economic impact

Based on the results from pilot plant tests, full-size tests and mill trials, the new pressing method can compensate the variations in veneer thickness and significantly improve the panel thickness uniformity. If the veneer-to-veneer contact is adequate, maintaining platen position yields good panel glue bonds because the wood fibbers do not expand or contract from movement in the press platen. The Clouston compression control system can be adapted to the present press configuration for a tighter panel thickness control. Compared to the conventional pressing method, the new pressing method can use a higher full hydraulic pressure to speed up the heat transfer without over-compressing the panels. As a result, the new pressing method can reduce pressing time by 5-15% depending on species, panel thickness and veneer MC. In the meantime, the thickness of final plywood/LVL panels can be controlled more precisely through the programming of the pressing schedules, which provides a possibility for the mill to peel thinner veneer and reduce the target panel thickness based on the panel thickness tolerance specified in the standard. The new method can also deal with high MC veneer better with less chance of blows.

For this plywood mill (100 million square feet annual capacity on a 3/8 -inch basis) equipped with one 40-opening press, it is conservatively estimated that with a 3% increase in productivity, the mill can gain about $300,000 profit annually. With the Clouston compression control, veneer peel thickness can be reduced by 0.002 -0.006 inches. As a result, the compression loss can be cut by 1.5% - 4.5% compared to single stage pressing. If the compression loss is reduced by 1-3% (at veneer costs of $125 per thousand square feet on a 3/8 -inch basis), this mill can save from $150,000 to $450,000 annually. Additional benefits could arise from reduced rate of blows and panel delamination as well as precise control of panel thickness for value-added applications. Therefore, the total annual savings will be $450,000 for this mill. For other plywood mills which have a higher annual capacity up to 250 million square feet (on a 3/8 -inch basis), the savings will be much greater.

6 Conclusions

A new hot pressing method was developed for plywood and LVL products, which integrated both pressure control and position control in one pressing cycle. The new pressing method was validated through laboratory tests, full-scale panel tests and a mill trial. The results demonstrate that with the new pressing method, the pressing time can be reduced with a faster heat transfer and a shorter decompression cycle. The manufacturing productivity can be improved by 5% to 15% depending on the species, panel thickness and veneer MC. The thickness of final panel products can be more precisely controlled through programming the pressing cycle. Particularly, the between-panel thickness variation was significantly reduced by as much as 30% in the mill trial.

The implication is that thinner veneer could be peeled, panel thickness loss can be reduced and less sanding of the products is required in the mill. As a result, the material recovery can be increased by up to 4%. The new pressing method has higher tolerance to dry veneer MC variation for panel manufacture. As long as the pressing parameters are set correctly, the new pressing method has no negative effect on panel gluebond and bending performance. Once the industrial multi-opening press is upgraded with additional features such as a Clouston compression control, the new pressing method can be implemented in the plywood and LVL mills to reduce veneer peeling thickness and panel thickness loss. Coupled with a higher hydraulic ram pressure and position control in the press, a greater impact could be achieved for increased manufacturing productivity and material recovery.

It is conservatively estimated that with a 3% increase in productivity, an average plywood and LVL mill can realize about $300,000 in annual savings. On top of productivity increase, an estimate of 1-3% increase in material recovery means $150,000 to $450,000 annual savings. Therefore, the total annual savings will be greater than $500,000 for an average mill.

7 Recommendations

This work has successfully showcased the new hot-pressing method to the plywood and LVL industry. With a faster heat transfer, the pressing time can be significantly reduced. With a tight control of final product thickness, material recovery can be increased, and value-added veneer products can be manufactured for broader applications and increased market shares. For plywood mills, it is recommended that while upgrading the existing multi-opening press for compression control, the capacity of hydraulic ram pressure could also be increased to maximize the reduction of pressing time.

To successfully implement the new pressing method in the mill and ensure that panels made can pass the standard gluebond quality requirements, the optimum pressing schedules, such as the full hydraulic pressure, the time for full hydraulic pressure and total pressing time, should be established based on species, dry veneer thickness, MC and target panel thickness tolerance. If failing to do so, a slightly low wood failure could result for plywood products from inadequate veneer-to-veneer bonding contacts.

To reduce the veneer peel thickness with the new pressing method, it is recommended that the lathe settings be optimized to improve the veneer thickness uniformity. Specifically, in this mill, the backup roll should be adjusted with a higher pressure to reduce the within-sheet thickness variation.

The current plywood presses are generally built with low ram pressures. They do not pose problems of using the new pressing method with softer species such as white spruce. The new pressing method can take the advantage of the highest possible pressure difference to maximum the pressing time reduction.

Compared to plywood, LVL generally requires a much longer pressing time. The LVL press generally has fewer openings (only from 1 to 5) and a higher hydraulic ram pressure. As a result, the new pressing method can be easily implemented in the LVL mills for reducing pressing time and panel thickness variation. As a further step, a LVL mill trial of the new pressing method should be conducted.

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