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Impact of mountain pine beetle-attacked lodgepole pine logs on veneer processing

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Mountain Pine Beetle Working Paper 2009-12

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Abstract

Pilot plant tests and mill trials were conducted to quantify the impact of using mountain pine beetle (MPB) -attacked lodgepole pine (*Pinus contorta* Douglas) wood on green veneer processing, and determine if it makes economic sense to sort and process MPB logs separately from normal logs of SPF (spruce–lodgepole pine–alpine fir) mix for plywood manufacturing. The results demonstrated that log dry-out, improper log conditioning, and veneer peeling contribute to the breakage of veneer ribbon, and in turn, to the loss of veneer recovery at the green end when processing MPB wood. Compared with the green SPF veneer controls, green MPB veneer has lower moisture content (MC) with smaller variation. The MPB veneer can be clipped narrower with an equivalent of 1% increase in recovery due to smaller width shrinkage, and be sorted more accurately requiring only two green sorts: heart and light-sap. The MPB veneer can also be dried faster with a reduction in drying time by about 25% for the heart veneer and 35% for the light-sap veneer. However, due to higher volume of narrower random sheets and increased waste from manual handling and composing, the net recovery of the MPB logs is about 8% lower than that of the control SPF logs. Furthermore, the color of the stained MPB veneer is lightened after drying, but it still causes interference with visual grading. Since MPB wood has unique moisture content and processing characteristics, it is recommended that it be sorted in the log yard as its proportion reaches about 10% of the total logs procured.

Keywords: Stain, bluestain, clipping, conditioning, drying, lodgepole pine, mountain pine beetle (MPB), moisture content, peeling, plywood, value recovery, veneer

Résumé

Essais en usine pilote et des essais en usine ont été réalisées afin de quantifier l'impact de l'utilisation du pin tordu latifolié (*Pinus contorta* Douglas) attaqué par le dendroctone du pin ponderosa (DPP) sur la production de placage de bois vert, et de déterminer si elle a un sens économique à trier et à transformer les billes DPP à partir de billes blanches normales de mélange SPF (épinette, pin tordu, le sapin subalpin) pour la fabrication de contreplaqué. Les résultats ont démontré que le séchage des billes, le conditionnement impropre des rondins, et le déroulage de placage contribuent à la rupture d'un ruban de placage, et, en retour, à la perte de rendement en placage à l'étape verte dans la production du bois DPP. En comparaison avec les contrôles placages verts SPF, placage vert DPP a une plus faible teneur en humidité (MC) avec une plus petite variation. Le placage DPP peut être fixé plus étroit avec un équivalent de 1% d'augmentation dans la récupération fait de leur petite retrait en largeur, en étant triés avec plus de précision ne nécessitant que deux catégories de bois: le duramen et la sève claire. Le placage DPP peut également être séché rapidement avec une réduction des temps de séchage d'environ 25% pour le placage de duramen et 35% pour le placage de la sève claire. Toutefois, en raison de l'accroissement du volume de feuilles étroites aléatoire et déchets est passé de la manutention manuelle et la composition, le recouvrement net de les billes DPP est d'environ 8% inférieur à celui des billes contrôles SPF. En outre, la couleur de la facette DPP coloré est allégé après séchage, mais elle provoque encore des interférences avec le classement visuel. Puisque le bois DPP est unique avec son teneur en humidité et les caractéristiques de traitement, il est recommandé qu'il soit trié dans le chantier de billes que sa proportion atteint environ 10% du total des billes obtenues.

Mot clés: Tache, bleuissement, coupure, le conditionnement, le séchage, le pin tordu, le dendroctone du pin ponderosa (DPP), la teneur en eau, de l'épluchage, le contreplaqué, récupération de la valeur, placage

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1 Introduction

Softwood plywood is a substantial part of the wood panel industry in British Columbia (BC), Canada. Lodgepole pine is the main softwood species, accounting for almost 24% of the province's total growing stock and half the growing stock in the central/interior parts of the province (Byrne 2003). Traditionally, the normal white-wood mix, spruce–lodgepole pine–alpine fir (SPF), is not sorted prior to making standard sheathing-grade softwood plywood (CSA 1988; CSA 2004). Over the past few years, the mountain pine beetle (MPB) has infested interior BC forests and is expected to continue for several more years. According to the BC 2006-2011 Mountain Pine Beetle Action Plan (BCMoFR 2007), the current beetle epidemic has killed approximately 500 million m^3 of merchantable lodgepole pine timber, leading to an increased volume of dry and stained logs entering plywood and laminated veneer lumber (LVL) manufacturing facilities. As a result, a crucial issue arises in western Canada concerning how to maximize the value recovery from beetle-attacked pine wood (Wang and Dai 2004; Wang and Dai 2005). Finding viable processing methods and commercial applications for this altered resource has provincial and national strategic importance.

Dry MPB-killed wood can be thawed easier in wintertime and dried faster than normal SPF wood, which present an opportunity to reduce costs by using different log conditioning, veneer peeling, and drying parameters.

The general objectives of this study were to: 1) quantify the impact of using MPB logs on green veneer processing, and 2) determine if it makes economic sense to sort and process MPB logs separately from normal logs of SPF mix for plywood manufacturing. Pilot plant tests and mill trials were conducted to determine the optimal manufacturing strategies for log conditioning, veneer peeling, and drying to recover the highest value from this altered resource. Specifically, the objectives for the pilot plant tests were to: 1) determine the MPB wood quality pertaining to veneer processing, 2) compare veneer quality of MPB wood to control SPF wood, and 3) determine the optimal conditioning parameters and lathe settings for MPB veneer. The objective of the mill trials was to validate pilot plant test results.

2 Materials and Methods

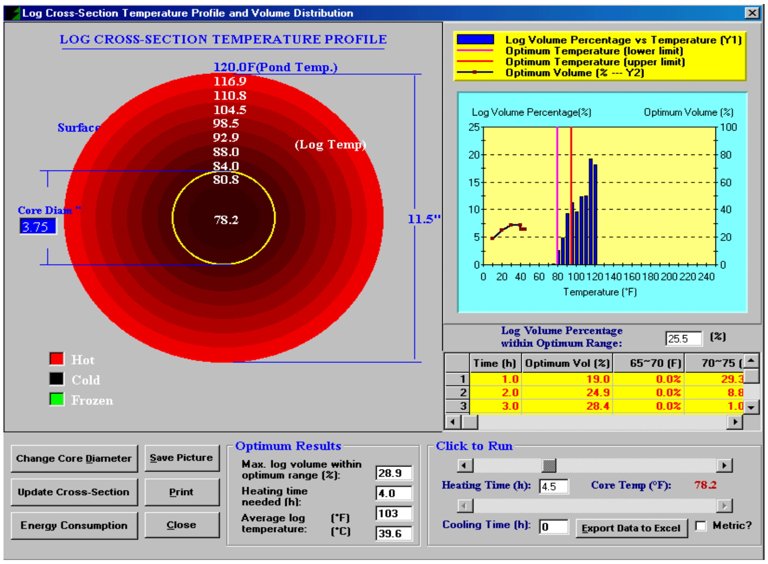
2.1 Pilot plant tests

Sixty 2.4 m logs (30 MPB and 30 control) were acquired from a plywood mill in BC. These beetle-killed logs represented a typical log mix from green and red stages of beetle attack. Green stage is generally defined as within 1 year and red stage 1 to 2 years after beetle attack. Tests were performed at the FPInnovations–Forintek's composites pilot plant. To differentiate the logs before conditioning, MPB logs were numbered 1 to 30 and control logs were marked with letters. For peeling with a 38-cm mini-lathe, 20 logs each were cut into six 33-cm blocks, and marked in sequence for MPB and control tests. Figure 1 shows the cross-section of 33-cm-long MPB blocks. Meanwhile, a 5-cm-thick disk was cut from the middle of each log to measure average moisture content (MC) and oven-dry specific gravity. The diameter of each log was measured. For each MPB log, the stained (infestation) depth was also measured. The remaining 10 logs each were cut into 1.2-m blocks for peeling with a 1.2-m lathe.

Figure 1. The cross-section of MPB logs

2.1.1 Log conditioning

To find the optimal conditioning temperature for veneer peeling, a first trial was conducted to heat blocks in two steps to achieve uniform temperature through the log cross-section. Three levels of temperature were targeted: 21, 27, and 32°C. As shown in Figure 2, a log conditioning computer simulation program, Logcon®, was used to estimate the heating time needed for each target log temperature (Dai and Wang 2003). The weather temperature was estimated at 18°C. A second trial was conducted with one-step heating. Table 1 summarizes the pond temperature and heating time required for achieving three levels of isothermal heating (cases 1, 2, and 3), and four core temperature targets (cases 4, 5, 6, and 7) based on computer simulation. For each test, six replicate blocks each were cut from three MPB and three control SPF logs.



Core Diam ": 3.75

Log Volume Percentage within Optimum Range: 25.5 (%)

	Time (h)	Optimum Vol (%)	65~70 (F)	70~75 (
1	1.0	19.0	0.0%	29.3
2	2.0	24.9	0.0%	8.8
3	3.0	28.4	0.0%	1.0

Max. log volume within optimum range (%): 28.9
Heating time needed (h): 4.0
Average log temperature: (°F) 103
(°C) 39.6

Heating Time (h): 4.5
Core Temp (°F): 78.2
Cooling Time (h): 0
☐ Metric?

Figure 2. Estimating log heating time required with Logcon®

Table 1. Parameters for pilot plant log conditioning

Case	Target log (core) temperature (°C)	Set pond temperature (°C)	Heating time (h)	Total time required (h)
1*	21	27	3.0	6
		21	3.0	
2*	27	32	6.0	9
		27	3.0	
3*	32	38	8.0	11
		32	3.0	
4	27	49	4.5	6
5	36	49	8.0	6
6	32	66	4.5	6
7	45	66	8.0	6

Note: * for isothermal log conditioning

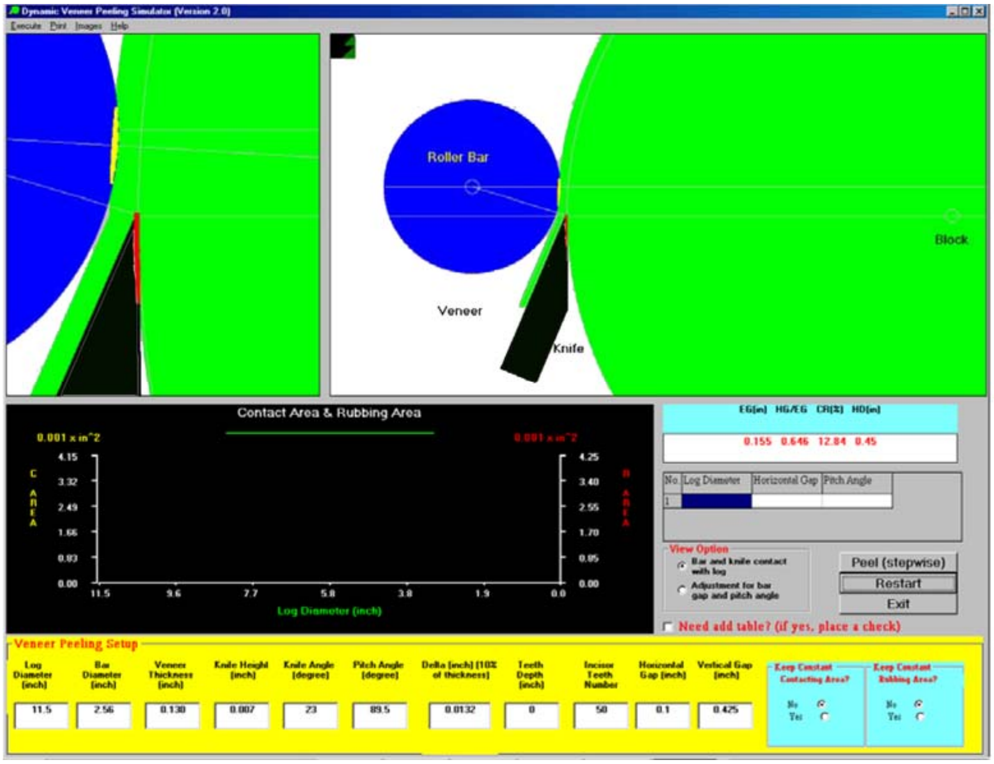
2.1.2 Veneer peeling

The mini-lathe was equipped with a smooth roller bar (6.5 cm diam) to peel 3.2-mm-thick veneer at 1.5 m/s with a core drop-size of 9.5 cm diam. To investigate the effect of lathe settings on veneer quality and ribbon continuity, as shown in Table 2, five lathe settings were tried to peel veneer for both MPB and control SPF logs treated with different conditioning cases or varied conditioning temperature and time. Lathe settings for the knife, roller bar, and block for peeling were determined through the FPInnovations–Forintek's computer simulation program, VPeel®, as shown in Figure 3 (Dai and Wang 2003). As shown in Table 2, for each given combination of pitch angle (PA), horizontal gap (HG), and vertical gap (VG), the VPeel® program can determine the compression ratio (CR) of the block from the bar at a given block diameter, such as 29.2 cm during peeling. Before peeling, the round-up diameter of each block was recorded. During peeling, the temperature of each block was monitored with an infrared gun. Figure 4 shows the 38-cm veneer mini-lathe and veneer ribbon peeled from the MPB logs.

Table 2. Lathe settings used for the pilot plant mini-lathe peeling

Lathe settings	Pitch angle (PA)	Horizontal gap (HG)	Vertical gap (VG)	CR* at 29 cm diameter	Conditioning cases
	(degree)	(cm)	(cm)	(%)	
1	89.5	0.25	1.20	10.5	1, 2, 3, 4
2	89.5	0.25	1.08	13.0	4, 5, 6, 7
					57°C for 8 h
3	89.5	0.25	0.95	15.5	4, 5, 6, 7
					66°C for 4h then 21°C for 2 h
4	90.0	0.25	1.08	13.0	4
5	89.0				4

Note: * Compression ratio



EG(in)	HG/EG	CR(%)	HD(in)
0.155	0.646	12.84	0.45

No.	Log Diameter	Horizontal Gap	Pitch Angle
1			

View Option
● Bar and knife contact with log
○ Adjustment for bar gap and pitch angle

☐ Need add table? (if yes, place a check)

Veneer Peeling Setup

Log Diameter (inch)	Bar Diameter (inch)	Veneer Thickness (inch)	Knife Height (inch)	Knife Angle (degree)	Pitch Angle (degree)	Delta (inch) (10% of thickness)	Teeth Depth (inch)	Incisor Teeth Number	Horizontal Gap (inch)	Vertical Gap (inch)
11.5	2.56	0.130	0.007	23	89.5	0.0132	0	50	0.1	0.425

Keep Constant Contacting Area? No ● Yes ○

Keep Constant Rubbing Area? No ● Yes ○

Figure 3. Determining lathe settings with VPeel®

Figure 4. The 38-cm veneer mini-lathe (left) and veneer ribbon (right) peeled from beetle-killed logs

To validate the conditioning and peeling parameters obtained from the mini-lathe tests, a scale-up test was performed using a 1.2-m lathe in the pilot plant (Figure 5). Each of the remaining ten 2.4-m logs was cut into two 1.2-m logs and a 5-cm-thick disk was trimmed from its middle to measure the average log moisture content. These logs were conditioned with 49 - 54°C pond temperature for 4.5h and peeled with the optimal parameters identified from the peeling tests (Table 2). Four MPB blocks and three control SPF blocks were used. After peeling, veneer sheets were clipped every 63.5 cm and stacked in piles.

Figure 5. Pilot plant scale-up peeling test with a 1.2 m lathe

2.1.3 Veneer property measurement

After each peel with the mini-lathe, the core drop diameter was measured. Veneer quality was evaluated for thickness variation and roughness. Veneer ribbon continuity was monitored to assess the percentage of full sheets, and in turn, veneer yield. Seven 33-cm-wide veneer samples were cut from the ribbon, representative of sap (three sheets) and heart (four sheets) to measure veneer thickness (at nine points), roughness grade, moisture content, and density. The roughness grade of each veneer sheet was assigned visually using a comparative roughness scale developed early at FPInnovations–Forintek, ranging from 0–9 in increasing roughness.

2.1.4 Veneer drying and width shrinkage

To investigate the effect of the MPB veneer on drying rate, a mini-dryer was used which has accurate control of drying temperature and relative humidity (RH) (Dai et al. 2003). Three 33 x 33-cm sapwood and heartwood veneer sheets each were randomly sampled from the MPB veneer and control SPF veneer, respectively. During drying, the weight and temperature of each sheet were continuously monitored. Drying conditions were set at 180°C and 1–2% RH, with an air velocity of 5–7 m/s.

Width shrinkage of the MPB veneer was investigated using a pilot-scale jet dryer. The drying temperature was set at 175°C. The drying time was 6.5 min for heartwood veneer and 8.5 min for sapwood veneer.

2.2 Mill trials

Production trials were conducted at the same mill in two major sub-tests. A total of 550 logs (2.4 m long, approximately 100 m^3) were used in each sub-test to process plywood. Data were collected on production line for grades, recovery and productivity and off production line for veneer quality. The species used in each sub-test were: 1) 100% beetle-killed logs, and 2) a typical SPF mix, with approximately 10% being beetle-killed logs.

For log conditioning, the inlet and outlet water temperature, conditioning time, and block diameter distribution were recorded. The water pond temperature was 60°C and the logs were conditioned for approximately 6h before peeling. The surface and core temperatures of about 70 blocks at the lathe were monitored using an infrared gun.

For veneer peeling, the VG, HG profile, and PA profile were checked. The spin-out rate, numbers of full sheets and random sheets were recorded. Lathe settings used for veneer peeling were: roller bar diameter: 95 mm; VG: 16.6 mm; and knife height: 0.5 mm. The PA and HG were pre-programmed to change during peeling.

For veneer clipping, the width of green veneer was measured for different green sorts. For green veneer sorting, the volume breakdown was recorded. The green veneer moisture content distribution for each sort was measured. For veneer drying, the final peak and average moisture content of dry veneer sheets were checked. The drying temperature and drying speed (drying time), as well as volume ratios of veneer sheets in three categories: dry, rotation, and redry, were recorded from the dryer control screen. The veneer sheets classified as the rotation category generally require hot stacking for 48h to further reduce the moisture content through dissipation and equalization.

For the MPB veneer, 60 2.4 x 1.2 m full-size sheets were randomly selected from two sorts: heart and light-sap. For the control SPF veneer, sixty 2.4 x 1.2 m full-size sheets were randomly selected from three sorts: heart, light-sap, and sap. For each green veneer sheet, the weight, width, and three-point thickness (left, middle, and right) were measured. Each sort of veneer was then put through the one-zone longitudinal dryer and recovered to measure the dry veneer weight, width, and thickness. In doing so, the green veneer moisture content and veneer width-shrinkage were obtained.

3 Results and Discussion

The results are summarized based on wood and veneer properties and are presented under pilot plant tests and mill trials.

3.1 Pilot plant tests

3.1.1 Wood properties

Table 3 shows log diameter for beetle-killed and control SPF logs before roundup; averages were 29.5 and 26.1 cm, respectively. The average stained depth for beetle-killed logs was 4.2 cm. The stained portion accounted for about 51.2% of total log volume, which indicates that nearly all the sapwood portion of the MPB logs was stained.

Table 3. Pilot plant comparison of log diameter between the MPB and control logs

Log category	Number of logs	Log diameter (cm)		Average stained depth (cm)	Average stained volume (%)	Average diameter of heartwood (cm)	Sapwood volume (%)
		Mean	Std.				
MPB	30	29.5	3.0	4.2	51.2%	21.1	51.2%
Control SPF	30	26.1	3.8	N/A*	N/A	18.5	50.0%

Note: * N/A refers to not applicable

Table 4 summarizes the wood density (at green conditions), oven-dry specific gravity (SG), and moisture content of sapwood and heartwood veneer of the beetle-killed and control SPF logs. The results demonstrated that: 1) the beetle-killed sapwood veneer had significantly lower moisture content than the control, with a smaller variation due to log dry-out. The average moisture content of sapwood is only 47.7% for the beetle-killed logs compared to 106.8% (on oven-dry basis) for the control SPF logs; 2) the moisture content of the beetle-killed heartwood veneer is also lower than that of the control SPF heartwood veneer with a smaller variation in moisture content; 3) the moisture content of the beetle-killed sapwood veneer is very close to that of the control heartwood veneer; and 4) the oven-dry SG of the beetle-killed logs is significantly greater than that of the control SPF logs, which is because lodgepole pine has the largest SG among the SPF species mix.

Table 4. Pilot plant comparison of wood density and moisture content between MPB and control logs

Log category	Number of logs	Sapwood MC (%)		Heartwood MC (%)		Wood density (g/cm^3)		Specific gravity (SG)	
		Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
MPB	30	47.7	14.8	29.2	4.5	0.570	0.032	0.429	0.034
Control SPF	30	106.8	30.0	43.6	13.9	0.605	0.057	0.368	0.019

3.1.2 Log conditioning and veneer peeling

For beetle-killed logs, as shown in Figure 4, cracks appeared in the block after round-up. After peeling, sap veneer ribbon broke regardless of how blocks were conditioned. In practice, this discontinuity will cause difficulty in handling, sorting, and drying, increasing the random-width veneer and reducing veneer recovery. Without serious cracks, veneer ribbons peeled from beetle-killed blocks would be generally continuous from sap to heart if parameters of conditioning and peeling were appropriate. In contrast, veneer ribbons peeled from control SPF blocks generally did not break.

Table 5 summarizes the testing results in terms of veneer roughness grade and ribbon continuity, as well as green veneer thickness and moisture content for sapwood and heartwood. For lathe-setting 1, as shown in tests 1, 2, and 3, log isothermal conditioning below 32°C was not effective because the ribbon of the beetle-killed sapwood veneer was fully or severely broken. Variation of green veneer thickness exceeded the specification limit generally set at 0.127 mm for both sapwood and heartwood veneer. Further, as shown in test 4, conditioning blocks at 49°C for 4.5h improved ribbon continuity slightly. Ribbon likely broke because of: 1) lack of wood plasticity with improper conditioning of blocks, and 2) cleavage of veneer ahead of knife with a larger VG. Based on the above peeling results, the isothermal conditioning was abandoned for the beetle-killed blocks.

Table 5. Pilot plant results of veneer quality and ribbon continuity

Test no.	Lathe setting	Condi-tioning	Block	Roughness grade*	Green veneer MC		Green veneer thickness (mm)				Ribbon continuity
					Heart	Sap	Heart		Sap		
					(%)	(%)	Mean	Std.	Mean	Std.	
1	1	Case 1	MPB	3.5	28	38	3.463	0.120	3.408	0.125	Fully broken
			Control	3.2	51	135	3.364	0.091	3.435	0.159	
2		Case 2	MPB	3.5	26	43	3.428	0.116	3.342	0.106	Fully broken
			Control	3.1	62	131	3.398	0.100	3.312	0.135	
3		Case 3	MPB	2.9	26	39	3.462	0.142	3.402	0.139	Fully broken
			Control	2.7	46	122	3.417	0.102	3.345	0.125	
4		Case 4	MPB	3.2	28	31	3.434	0.101	3.416	0.158	Broken
			Control	2.7	63	140	3.416	0.085	3.321	0.113	
5	2	Case 4	MPB	2.8	32	40	3.405	0.063	3.335	0.110	Good ribbon
			Control	2.9	91	90	3.389	0.065	3.258	0.091	
6		Case 5	MPB	2.9	29	46	3.377	0.093	3.360	0.122	Broken at intervals
			Control	2.7	59	89	3.359	0.098	3.236	0.105	
7		Case 6	MPB	3.3	29	36	3.374	0.134	3.378	0.168	Slightly broken
			Control	2.9	57	92	3.374	0.103	3.261	0.138	
8		Case 7	MPB	3.1	28	45	3.390	0.086	3.323	0.152	Slightly broken at intervals
			Control	3.1	42	93	3.369	0.093	3.293	0.119	
9	3	Case 4	MPB	2.7	29	53	3.335	0.091	3.308	0.128	Broken at intervals
			Control	3.2	40	97	3.330	0.075	3.299	0.094	
10		Case 5	MPB	2.8	38	63	3.400	0.090	3.298	0.133	Fully broken
			Control	2.9	74	92	3.372	0.095	3.254	0.114	
11		Case 6	MPB	3.2	38	65	3.372	0.067	3.296	0.067	Fully broken
			Control	3.5	36	62	3.421	0.117	3.327	0.099	
12		Case 7	MPB	2.4	31	67	3.258	0.068	3.151	0.112	Broken at intervals
			Control	3.0	73	103	3.283	0.110	3.176	0.118	
13	2	**	MPB	3.4	28	47	3.412	0.104	3.306	0.131	Broken at intervals
			Control	3.2	45	97	3.434	0.119	3.311	0.114	
14	3	***	MPB	3.0	30	68	3.364	0.074	3.218	0.071	Fully broken
			Control	3.3	73	88	3.449	0.109	3.308	0.124	
15	4	Case 4	MPB	2.8	31	51	3.341	0.090	3.155	0.175	Broken at intervals
			Control	2.6	90	103	3.307	0.075	3.091	0.164	
16	5	Case 4	MPB	2.5	32	51	3.368	0.082	3.311	0.104	Slightly broken at intervals
			Control	2.3	120	117	3.332	0.066	3.172	0.100	Fully broken

* Roughness grade: 0 - smoothest; 9 - roughest. ** conditioning at 57 °C for 8 h; *** conditioning at 66 °C for 4 h, then at 21 °C for 2 h.

Higher conditioning temperature and longer conditioning time help increase wood plasticity. To reduce the knife cleavage, the lathe-setting 2 with a reduced VG was used. As shown in tests 5, 6, 7, 8, and 13 (Table 5), different combinations of temperature and time were tried to improve veneer ribbon continuity. Conditioning at 49°C for 4.5h with a target core temperature of 27°C suitably improved the ribbon continuity with the least veneer thickness variation, but conditioning at ≥49°C for a longer time made veneer rougher and its thickness varied more.

To investigate the effect of the VG on veneer quality and ribbon continuity, lathe-setting 3 was used with a further reduced VG. As shown in tests 9, 10, 11, and 12 (Table 5), the same conditioning parameters were employed as used by the lathe-setting 2. Compared to lathe-setting 2, ribbon continuity worsened, probably due to the larger compression ratio. Furthermore, as shown in test 14 (Table 5), by conditioning blocks at 66°C for 4 h, and then placing blocks in a pond with water temperature at 21°C for 2h brought sapwood moisture content up to 68%, but veneer quality and ribbon continuity were not noticeably improved. As a result, conditioning blocks at 49°C for 4.5h was encouraging. By just heating the sap portion of MPB blocks to about 38°C, the higher plasticity of wood improved the ribbon continuity.

As shown in tests 15 and 16 (Table 5), the effect of PA on veneer quality and ribbon continuity was studied with the optimal conditioning (49°C for 4.5 h). Lathe-settings 4 (pitch angle = 90°) and 5 (pitch angle = 89°) showed less ribbon continuity than lathe-setting 2; lathe-setting 5 was better than lathe-setting 4 and had less thickness variation in the sapwood veneer. Therefore, the recommended pitch angle for peeling beetle-killed logs is 89.5°–89°.

The mini-lathe peeling tests with 33 cm blocks indicated that breakage of veneer ribbon was the main issue for peeling beetle-killed logs from their dry-out and cracks. Improper peeling also caused increased breakage. From the peeling perspective, soaking blocks in 49°C water for 4.5h improved the ribbon continuity. Longer blocks conducted less heat to their centre; subsequent tests with 1.2-m blocks and mill trial with 2.4-m blocks used a schedule of 49–57°C pond temperature with a target core temperature of about 27°C to increase wood plasticity. Among the lathe settings tested with the mini-lathe, lathe-setting 2, namely, PA = 89.5°, HG = 2.5 mm, and VG = 10.8 mm with 13% compression ratio (at a diameter of approximately 29 cm), was recommended for peeling the beetle-killed logs to achieve smoother veneer, better ribbon continuity, and less thickness variation.

For the scale-up peeling tests in the pilot plant, lathe-setting 2 was used to peel veneer. Table 6 shows the results of green veneer thickness and roughness grade from the scale-up peeling tests with the 1.2-m lathe. In general, with the lathe setting recommended, the ribbon continuity was good without running through natural cracks, and both the MPB veneer and control SPF veneer exhibited acceptable roughness and thickness variation.

Table 6. Green veneer thickness and roughness from the pilot plant scale-up peeling tests

Log category	Block no.	Green veneer thickness (mm)				Roughness grade*
		Heart		Sap		
		Mean	Std.	Mean	Std.	
MPB	1	3.312	0.122	3.117	0.134	2.4
	2	3.372	0.127	3.282	0.138	2.7
	3	3.355	0.106	3.221	0.137	2.9
	4	3.403	0.103	3.303	0.128	2.6
Control SPF	1	3.302	0.051	3.268	0.127	3.7
	2	3.346	0.081	3.267	0.090	2.4
	3	3.416	0.112	3.404	0.086	2.6

Note: * Roughness grade: 0 = smoothest; 9 = roughest.

3.1.3 Green veneer moisture content characteristics

Green veneer moisture content distribution was established based on measurements from the 33 x 33-cm sheets proportionally sampled from all ribbons peeled under various peeling conditions (Table 5), for both MPB and control SPF veneer. Green moisture content of MPB veneer ranged from 20 to 110% with most around 30% (Figure 6). There was no distinct peak for the sapwood veneer. In contrast, the green moisture content of the control SPF veneer ranged from 30 to 200%. Given the control SPF veneer's moisture content varies more, improving green veneer moisture content sorting is essential to achieve more uniform veneer drying and better drying quality.

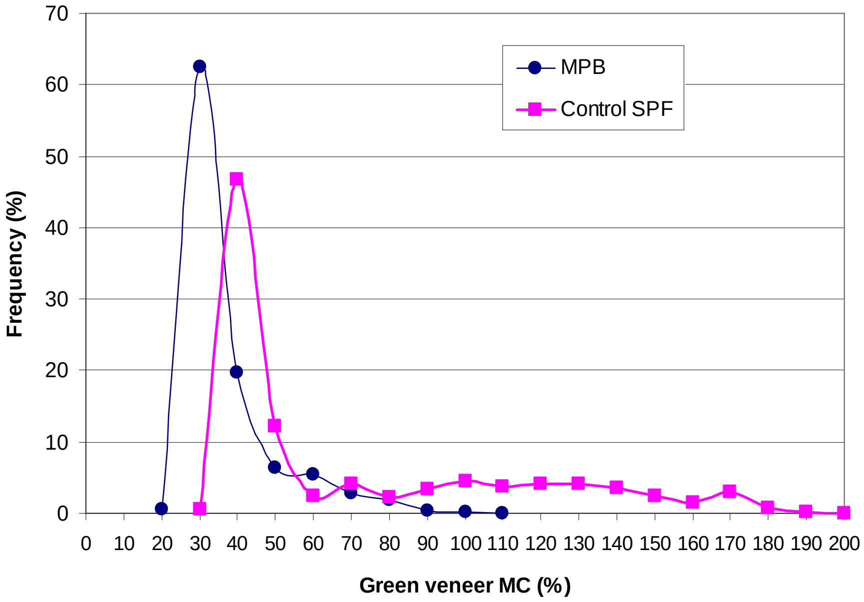


Figure 6. Pilot plant comparison of green moisture content distribution between MPB and control veneer

3.1.4 Veneer drying characteristics

Moisture content of beetle-killed sapwood sheets were more consistent and lower than those of control sheets (Figure 7), implying that drying time can be reduced for the MPB sap veneer. The average time to dry veneer to a target moisture content of 3% was about 11.5 min (690 s) for the control sap veneer, but only 7.5 min (450 s) for the MPB sap veneer, a reduction of about 35%.

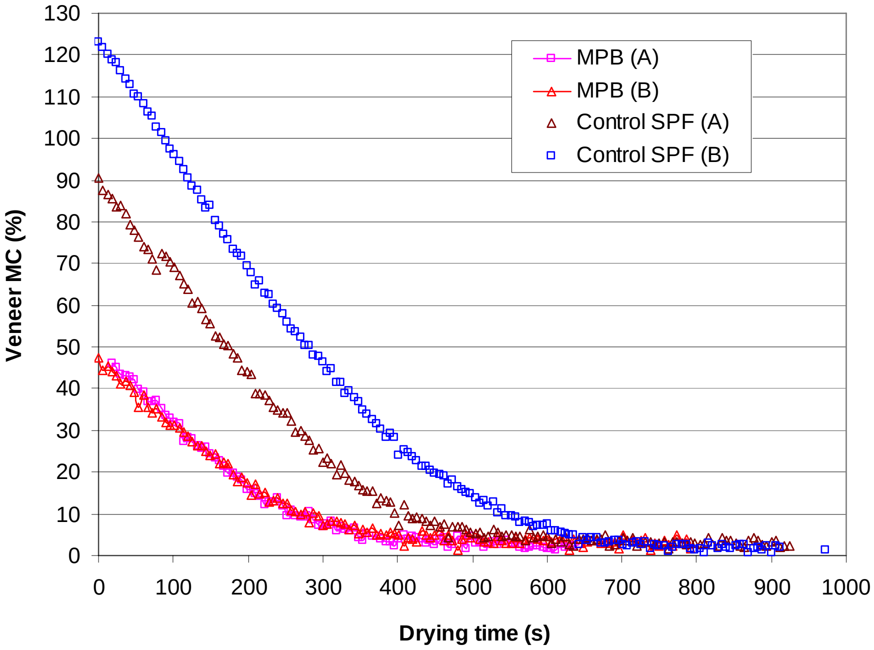


Figure 7. Pilot plant comparison of sapwood drying curves between MPB and control veneer

Moisture content of the MPB heartwood sheets was also more consistent and lower than that of the control SPF heartwood sheets (Figure 8). Accordingly, drying time can likely be reduced for the MPB heartwood veneer by about 25%. By comparison, the drying time of the MPB sapwood veneer was close to that for the control SPF heartwood veneer.

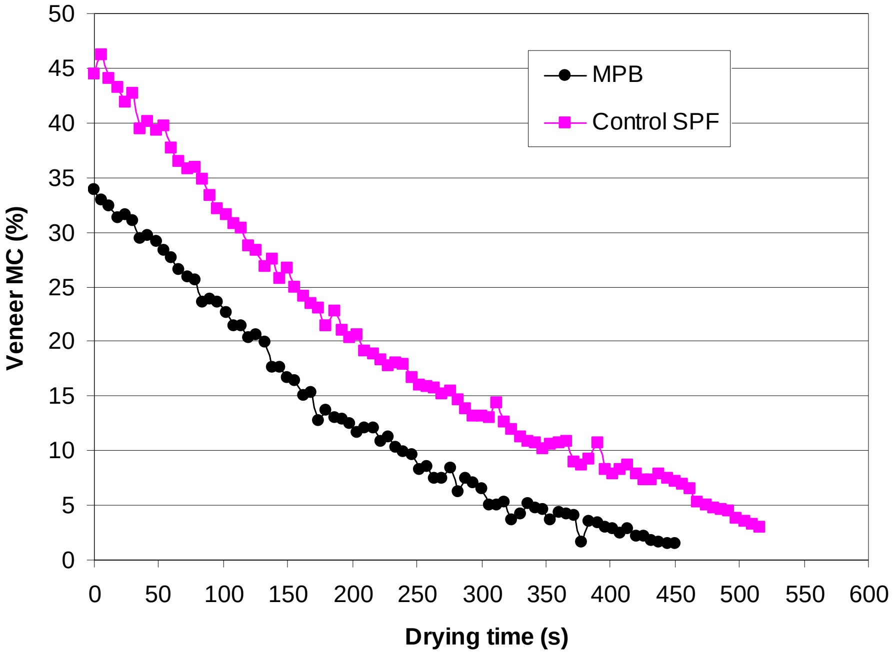


Figure 8. Pilot plant comparison of heartwood drying curves between MPB and control veneer

Overall, for the MPB veneer, the drying productivity can be increased by about 35% for sapwood veneer and about 25% for heartwood veneer, and more consistent drying schedules can be applied. In general, the MPB veneer can be sorted into about 70% heart and 30% light-sap/sap (Wharton 2004). Therefore, the drying productivity of the MPB veneer can be increased by about 27.5% compared to the control SPF veneer. As the volume ratio of beetle-killed logs procured was 10% in the mill, the overall increase in drying production was about 2.8%. Given that increasing productivity by a single percent can translate to annual profit of about $150,000 per mill, the benefit from MPB veneer drying is estimated at $412,500.

Table 7 shows the results of veneer width (tangential) shrinkage after drying from green to an average moisture content of approximately 3% with the pilot-scale dryer. It was found that: 1) the MPB veneer shrank less than the control SPF veneer; 2) the difference in width shrinkage between the control SPF veneer and the MPB veneer was 1.4% for sapwood and 0.7% for heartwood, which was statistically significant at $p = 0.05$; and 3) on average, the difference in width shrinkage between sapwood and heartwood veneer was only 0.3% for the MPB wood compared to 1.0% for the control SPF wood. These results suggested that the MPB sapwood veneer can be clipped about 20 mm narrower than the control SPF sapwood veneer, and the MPB heartwood veneer can be clipped about 10 mm narrower than the control SPF heartwood veneer. This could translate to a recovery increase by about 1%. Since the volume ratio of MPB logs was about 10% in the mill, the annual profit from veneer clipping was about $30,000 (1% increase in recovery means $300,000).

Table 7. Pilot plant comparison of width shrinkage between the MPB and control veneer

Veneer MC and shrinkage		Control SPF veneer		MPB veneer	
		Sapwood	Heartwood	Sapwood	Heartwood
Green veneer MC (%)	Mean	119.6	40.3	51.2	32.9
	Std.	35.8	11.9	12.7	3.7
Veneer width shrinkage (%)	Mean	6.7	5.7	5.3	5.0
	Std.	0.3	0.4	0.3	0.2
Difference in shrinkage (%)		1.0		0.3	

In summary, processing MPB veneer separately could save approximately $442,500 annually from 0.1% increase in veneer recovery through clipping, and 2.8% increase in drying productivity if the MPB logs account for 10% of total logs procured in the mill (Wang and Dai 2004; Wang and Dai 2005). But, because processing MPB logs generates more random veneer and waste from veneer handling and composing than SPF logs, plywood mills need to evaluate their potential net benefit based on the real volume ratio of the MPB logs procured.

3.2 Mill Trials

3.2.1 Log conditioning

Energy loss kept the actual block surface temperature lower than the pond temperature. The block surface temperature was averaged at 41°C with a range of 18–49°C. The average core temperature was 26°C, which was very close to the optimal target core temperature of 27°C obtained through the pilot plant tests. However, the core temperature between blocks varied -1–46°C, which was also normal in log conditioning without diameter sorting.

3.2.2 Veneer peeling

In general, the ribbon of the MPB veneer produced during the mill trials was continuous due to the close-to-optimal block conditioning. Peeling speed was 7.6 m/s, which was considered to be too fast since the head ribbon of veneer was flipped and rolled up, leading to waste in veneer clipping. The HG and PA were checked at the following four carriage positions: 273, 230, 152, and 42 mm. The measured gap openings were 2.6, 2.4, 2.2, and 1.5 mm, respectively. Using the VPeel® computer program, the actual compression ratio between the roller bar and block was determined as: 14.5, 16.1, 18.1, and 11.4%, respectively.

Table 8 summarizes the results of green and dry veneer thickness, volume breakdown of each green veneer sort, and volume ratio of random veneer for both MPB veneer and control SPF veneer. Thickness variation of both green and dry veneer was slightly greater than the specification limit (0.127 mm). In the pilot plant tests, the optimal compression ratio was 13.0% at a carriage position of 29.2 cm (Table 2). The compression ratio used by the mill lathe during peeling seemed to be slightly higher, which would explain why the veneer ribbon in the mill was tighter, easier to roll up, and larger in thickness variation. To reduce veneer thickness variation, the current PA and HG profiles in the mill must be adjusted. Due to the low veneer moisture content, there were 69.6% of heart sort but only 6.8% of heavy-sap sort for the MPB veneer for the current mill settings. In contrast, there were only 46.5% of heart sort but 32.7% of heavy-sap sort for the control SPF veneer. In addition, the volume ratio of random veneer (or composer stock) was 17.9% for the MPB logs, which was about 2% greater than the control SPF logs. Furthermore, the average width of random veneer was 47.0 cm for the MPB veneer, which was considerably narrower than 76.2 cm for the control SPF veneer. This indicates that the MPB veneer requires more manual handling and is more labour intensive.

Table 8. Mill trial results on green and dry veneer thickness and recovery

Log category	Green veneer sort	Green veneer thickness		Dry veneer thickness		Volume ratio	Volume ratio of random veneer	Average width of random veneer
		Mean	Std.	Mean	Std.			
		(mm)		(mm)		(%)	(%)	(mm)
MPB	Heart	3.591	0.187	3.251	0.152	69.6	17.9	470
	Light sap/sap	3.548	0.176	3.125	0.128	23.6 / 6.8		
Control SPF	Heart	3.595	0.212	3.163	0.152	46.8	15.9	762
	Light sap	3.481	0.202	3.109	0.164	20.5		
	Sap	3.463	0.178	3.281	0.138	32.7		

Based on the data collected from the lathe in this mill (Wharton 2004), the average diameter was 29.7 cm for beetle-killed logs and 26.1 cm for control SPF logs. The results were consistent from those obtained from the laboratory measurement (Table 3). Due to the dry-out and cracks, peeling beetle-killed logs would generate more random veneer. Based on the mill tally from the peeling lathe, the spin-out rate was 1.6% for beetle-killed logs and 1.2% for control SPF logs. This was another source of loss in recovery with the beetle-killed logs.

3.2.3 Veneer clipping, sorting, and drying

Table 9 summarizes the results of veneer drying settings and drying output collected from the dryer control software for different sorts of the MPB veneer and control SPF veneer. All dryers were a one-zone longitudinal type. The final average moisture content was about 3% for the usable dry veneer. The dryers ran well with all sorts. After drying, the blue stain in the MPB veneer was lightened, but still interfered with visual grading. This was an additional issue when utilizing beetle-killed logs because operators had to override the visual scanner to extract the maximum grade possible. The MPB's low moisture content and volume ratio of sap veneer meant the sap veneer could be combined with the light-sap veneer. Thus, only two green sorts were generated: heart and light-sap/sap. The reduction in drying time was about 29% for the MPB heart veneer and 36% for the MPB light-sap/sap veneer compared to the SPF veneer. Drying time for the light-sap/sap veneer was reduced by as much as in the laboratory drying test. Heart veneer dried faster in the mill than the laboratory (25%) mainly due to the sorting accuracy of the control SPF heart veneer. The mill should be able to estimate the exact improvement in productivity by calculating the volume breakdown of the species mix and the sorting accuracy.

Table 9. Veneer drying results from mill trials

Log category	Green veneer sort	Veneer drying settings		Dryer output (volume ratio)		
		Temperature	Time	Dry veneer	Stacking	Redry
		(°C)	(min)	(%)	(%)	(%)
MPB	Heart	177	5.7	71.6	26.0	2.4
	Light sap/sap	178	9.1	77.6	21.0	1.4
Control SPF	Heart	170	8.0	75.6	17.4	7.0
	Light sap	178	11.5	76.8	18.6	4.6
	Sap	171	16.8	77.4	11.9	10.7

Table 10 summarizes the results of green veneer moisture content, green veneer clipping width, dry veneer width, and width shrinkage. Notably: 1) Moisture content of MPB heart veneer was the lowest with the smallest variation, and moisture content of MPB light-sap veneer was very close to that of the control SPF heart veneer. 2) Width shrinkage of the MPB veneer was less than that of the control SPF veneer. The average difference was about 0.7%. 3) Width shrinkage for both MPB heart sort and light-sap sort were consistent with those obtained through the pilot plant tests (Table 7), as was the width shrinkage of the heart sort for the control SPF veneer. 4) For the control SPF veneer, the difference in shrinkage between the heart sort and sap sort was only 0.3% compared to 1.0% obtained from the pilot plant tests, possibly because of the species mixture and the less accurate sorting for the control SPF veneer. 5) The control SPF light-sap sort shrank less than the control SPF heart sort, which may be due to significant moisture content overlapping between these two sorts, as shown in Figure 9.

Table 10. Green veneer moisture content, clipping width and width shrinkage from mill trials

Log category	Green veneer sort	Green veneer MC		Green veneer clipping width		Dry veneer width		Width shrinkage	
		Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
		(%)		(mm)		(mm)		(%)	
MPB	Heart	33.2	3.1	1339	5.6	1271	6.9	5.0	0.4
	Light sap/sap	45.9	8.5	1340	5.8	1267	6.9	5.4	0.5
Control SPF	Heart	47.4	9.6	1338	7.6	1260	8.6	5.8	0.5
	Light sap	51.1	12.7	1345	15.5	1271	10.2	5.6	0.4
	Sap	105.4	28.8	1359	4.3	1278	7.6	6.1	0.4

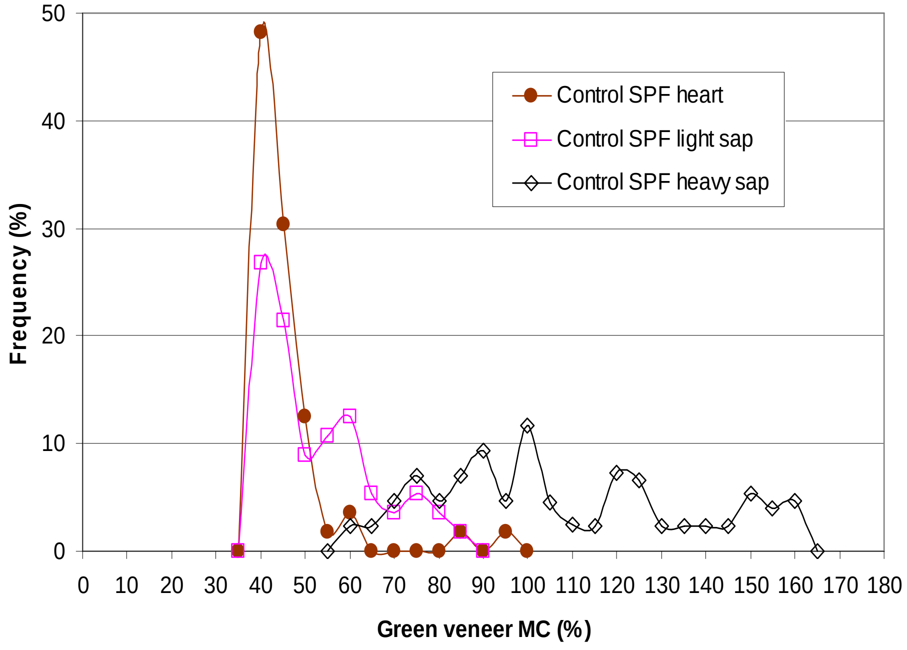


Figure 9. Green veneer sorting accuracy in the mill for the control SPF veneer

Figure 10 shows the moisture content distribution of the heart sort and light-sap sort for the MPB veneer. Overall, MPB veneer sorting was more accurate than that of the control SPF veneer, though there was some overlap.

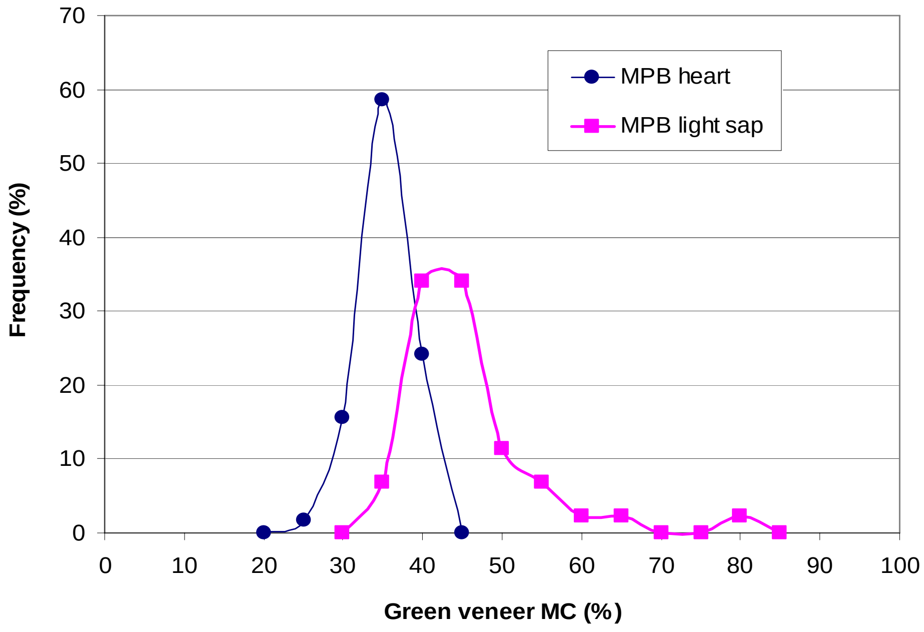


Figure 10. Green veneer sorting accuracy in the mill for the MPB veneer

3.2.4 Veneer recovery

Table 11 summarizes the veneer recovery data at log yard, green end, dry end, and overall after composer for the MPB logs and control SPF logs (mill shift average). The results demonstrated that: 1) Due to the MPB logs' larger diameter, only about 4.5% of them were sorted for saw logs (Wharton 2004), so their recovery at the log yard was higher compared to the control SPF logs. 2) At the green end, the recovery of the MPB logs was about 6% lower than that of the control SPF logs. 3) The overall veneer recovery after composer with the MPB logs was only 42.4%, which was about 8% lower than the control SPF logs. From log yard to composer, the total value loss in recovery from processing 10% volume of the MPB logs in this mill was approximately $240,000 (1% loss in recovery means $300,000). In addition, some inherent costs might result due to more manual handling and composing of random veneer. However, as demonstrated, processing this amount of the MPB logs could also save approximately $442,500 annually from 0.1% increase in recovery from veneer clipping, and 2.8% increase in productivity from veneer drying. As a result, there could be some net profit when processing 10% volume of MPB logs in the mill.

Table 11. Veneer recovery results from mill trials

Veneer recovery	MPB logs		Control SPF logs	
	m^2 of veneer on 9.5 mm basis per m^3 log	Recovery (%)	m^2 of veneer on 9.5 mm basis per m^3 log	Recovery (%)
Log yard		95.5		86.0
Green end	53.1	50.6	59.3	56.5
Dry end	50.1	47.7	N/A	N/A
Overall after composer	44.5	42.4	N/A	>= 50

Note: * N/A refers to not available

4 Summary and Conclusions

The log dry-out, improper log conditioning, and veneer peeling contributed to the loss of veneer recovery at the green end of plywood manufacturing when processing beetle-killed wood. Conditioning the beetle-killed logs at 49–57°C pond temperature with a target core temperature of approximately 27°C helped reduce ribbon breakage, and in turn reduce the volume ratio of random veneer. Lathe settings also affected veneer quality and recovery: a compression ratio of approximately 13% helped produce high-quality veneer and reduce the breakage of the veneer ribbon.

Compared to the control SPF green veneer, MPB green veneer had lower moisture content and smaller moisture content variation. In general, the MPB veneer can be clipped narrower with an equivalent of 1% increase in recovery because of smaller width shrinkage, and be sorted more accurately requiring only two green sorts: heart and light-sap. In particular, the MPB light-sap sort was comparable to the control SPF heart sort. The MPB veneer can also be dried faster: about 25% faster for the heart sort and 35% for the light-sap sort. Despite about 1% increase in recovery from veneer clipping and 27.5% increase in productivity from veneer drying, recovery of beetle-killed logs was about 8% lower than that of the control SPF logs due to higher percentage of narrower random sheets and waste from peeling, and increased manual handling and composing. Blue stain in the MPB veneer lightened after drying but still interfered with visual grading.

Because beetle-killed logs differ drastically from other species in their moisture content and subsequent processing characteristics, we recommend sorting species in the log yard. Such sorting exploits the faster drying speed, reduces the amount of over-dried veneer, and offers significant savings from increased recovery and productivity as the proportion reaches about 10% of the total logs procured. A new visual grading recipe should also be developed for the existing camera-based vision systems and implemented to handle the MPB veneer on the production line. As a follow-up study, the effect of beetle-killed logs on downstream plywood manufacturing such as gluing, lay-up, and hot pressing will be examined and quantified. Implementing the above recommendations and adopting the optimized veneer processing strategies can maximize value recovery from this altered MPB resource.

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