# IMPACT OF MOUNTAIN PINE BEETLE-ATTACKED LODGEPOLE PINE LOGS ON VENEER PROCESSING

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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* Dougl.) wood on green veneer processing, and determine if it makes economic sense to sort and process MPB logs separately from normal logs of white 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, 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 less 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 MC and processing characteristics, it is recommended that it be sorted in the log yard when its proportion reaches about 10% of the total logs procured.

***Keywords:*** Stain, clipping, conditioning, drying, lodgepole pine, moisture content, mountain pine beetle, peeling, plywood, recovery, sorting, SPF, veneer, visual grading.

## INTRODUCTION

Softwood plywood is a substantial part of the wood panel industry in British Columbia (BC), Canada. Lodgepole pine is the predominant softwood species, accounting for almost 24% of the province's total growing stock and one-half of the growing stock in the central/interior parts of the province (Byrne 2003). Traditionally, the normal white-wood mix, SPF (spruce-lodgepole pine-alpine fir), is not sorted prior to making standard sheathing-grade softwood plywood (CSA 0325 2007; CSA 0151 2004). Over the past few years, a large outbreak of mountain pine beetle (MPB) infestation has taken place in interior BC forests, which is expected to continue for several more years. According to the BC 2006–2011 Mountain Pine Beetle Action Plan (MPBAP 2007), the current beetle epidemic has killed approximately 500 $Mm^3$ of merchantable lodgepole pine timber, leading to an increased volume of dry and stained logs entering plywood and LVL manufacturing facilities. As a result, a crucial issue has arisen in western Canada concerning how to maximize the value recovery from MPB-attacked pine wood (Wang and Dai 2004; Wang and Dai 2005). Finding viable processing methods and commercial applications for this altered

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resource has provincial and national strategic importance.

Dry MPB wood can be thawed easier in the winter and dried faster than the normal wood, presenting 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 the MPB logs on green veneer processing, and 2) determine if it makes economic sense to sort and process the 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 the MPB wood to the 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.

## MATERIALS AND METHODS

### Pilot Plant Tests

A total of 60 logs (2.4 m long) consisting of 30 logs of typical MPB wood and 30 logs of control SPF were acquired from a cooperating plywood mill in BC. These MPB logs represented a typical log mix from green and red stages of beetle attack. In general, the green stage is defined as within 1 yr, and the red stage 1 – 2 yr after beetle attack. All the tests were performed at the FPInnovations - Forintek's composites pilot plant. To differentiate the logs before conditioning, the MPB logs were marked with numbers, and the control logs marked with letters. For peeling with a 38-cm mini-lathe, 20 logs each were cut into six 33-cm-long blocks, and marked in sequence for MPB and control tests, respectively. Figure 1 shows the cross-section of 33-cm-long MPB blocks. Meanwhile, a 5-cm-thick disk was cut from the middle part of each log for measurement of 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-long blocks for peeling with a 1.2-m lathe.

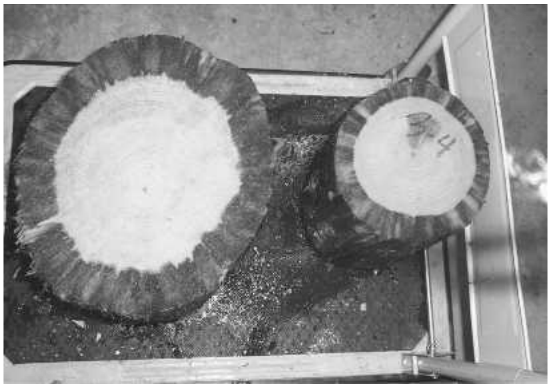

FIGURE 1. The cross-section of MPB logs.

***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 different levels of temperature were targeted: 21, 27, and 32°C. As shown in Fig 2, a log conditioning computer simulation program, Logcon®, was used to estimate the heating time needed in terms of different target log temperatures (Dai and Wang 2003). The ambient 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 different core temperature targets (cases 4, 5, 6, and 7) based on computer simulations. For each test, 6 blocks (replicates) each were cut from 3 MPB logs and 3 control SPF logs, respectively.

***Veneer peeling.*** The mini-lathe was equipped with a smooth roller bar (6.5 cm dia) and used to peel 3.2-mm-thick veneer at a speed of 1.5 m/s with a core drop-size of 9.5 cm dia. To investigate the effect of lathe settings on veneer quality

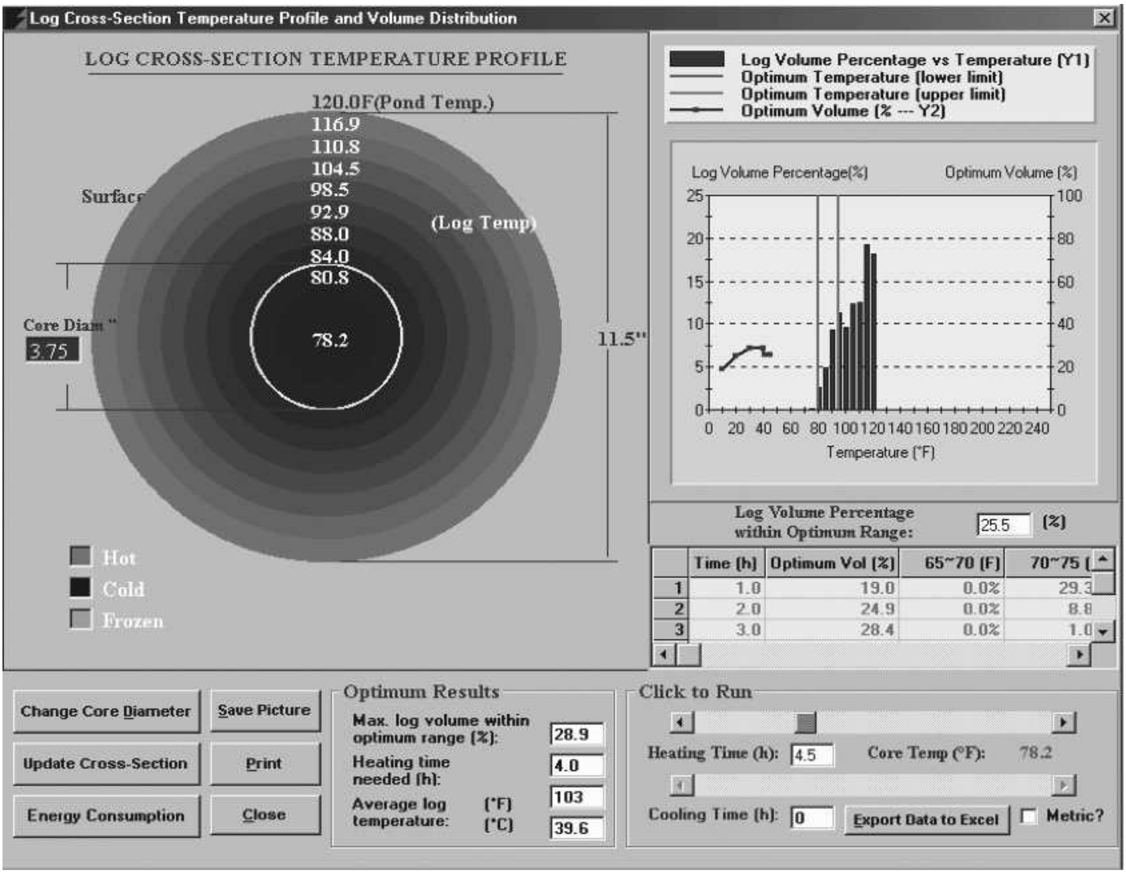


FIGURE 2. Estimating log heating time required with Logcon®.

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 | |
| 5 | 36 | 49 | 8.0 | |
| 6 | 32 | 66 | 4.5 | |
| 7 | 45 | 66 | 8.0 | |

Note: * for isothermal log conditioning

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

| Lathe settings | Pitch angle (PA) (degree) | Horizontal gap (HG) (cm) | Vertical gap (VG) (cm) | CR* at 29 cm diameter (%) | Conditioning cases |
|---|---|---|---|---|---|
| 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 and ** |
| 3 | 89.5 | 0.25 | 0.95 | 15.5 | 4, 5, 6, 7 and *** |
| 4 | 90.0 | 0.25 | 1.08 | 13.0 | 4 |
| 5 | 89.0 | 0.25 | 1.08 | 13.0 | 4 |

Note: * Compression ratio
** 57°C for 8 h
*** 66 C for 4 h then 21 C for 2 h

and ribbon continuity, as shown in Table 2, 5 lathe settings were tried to peel veneer for both MPB logs, and control SPF logs treated with different conditioning cases or varied conditioning temperature and time. To properly position the knife, roller bar, and block for peeling, these lathe settings were determined through the FPInnovations - Forintek's computer simulation program, VPeel®, as shown in Fig 3 (Dai and Wang

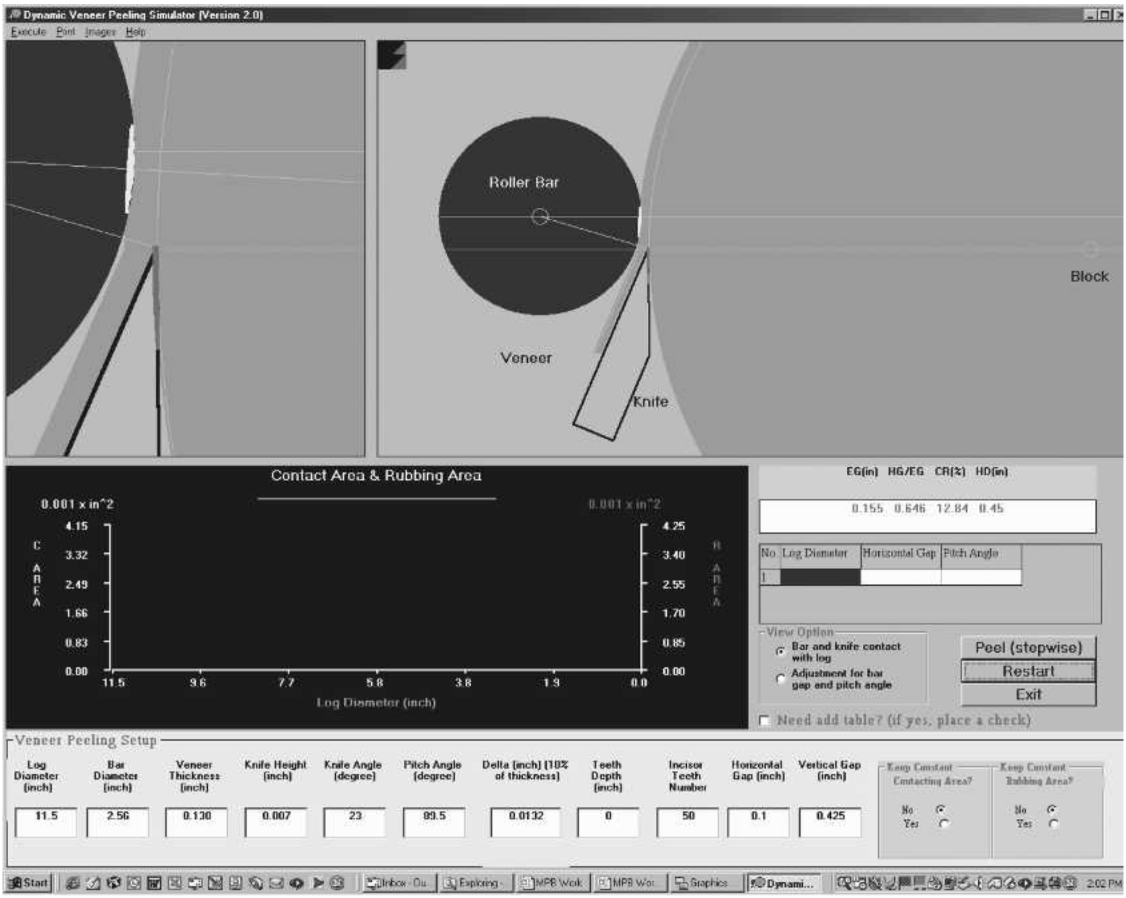


FIGURE 3. Determining lathe settings with VPeel®.

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 IR gun. Figure 4 shows the 38-cm veneer mini-lathe and veneer ribbon peeled from the MPB 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, as shown in Fig 5. Each of the remaining ten 2.4-m-long logs were cut into two 1.2-m-long logs, with a 5-cm-thick disk being removed from the middle part of the log to measure the average log MC. These logs were conditioned with 49–54°C pond temperature for 4.5 h 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 into 63.5-cm width and stacked in piles.

***Veneer property measurement.*** After each peel with the mini-lathe, the core drop diameter was measured. The veneer quality was evaluated in terms of veneer thickness variation and roughness. Meanwhile, veneer ribbon continuity was monitored to assess the percentage of full sheets, and in turn, veneer yield. Seven 33-cm-wide ve-

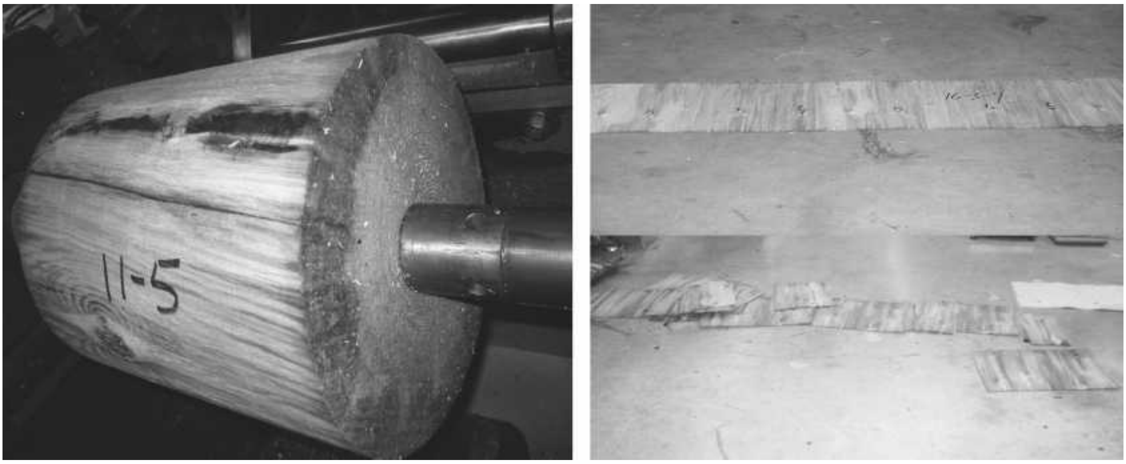


FIGURE 4. Peeling MPB blocks with a pilot plant 38-cm mini-lathe.

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

neer samples were cut from the ribbon, representative of sap (3 sheets) and heart (4 sheets) to measure veneer thickness (at 9 points), roughness grade, MC, and density. The roughness grade of each veneer sheet was assigned visually using a comparative roughness scale developed early at FPInnovations–Forintek, where 0 means the smoothest and 9 the roughest veneer.

***Veneer drying and width shrinkage.*** To investigate the effect of the MPB veneer on drying rate, a mini-dryer was used that has accurate control of drying temperature and 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. The drying conditions were set at 180°C and 1–2% RH, with an air velocity of 5–7 m/s.

To investigate the width shrinkage of the MPB veneer, a pilot-scale jet dryer was used. The drying temperature was set at 175°C. The drying time was 6.5 min for heartwood and 8.5 min for sapwood veneer.

## Mill Trials

The production trials were conducted at the same mill in two major subtests. A total of 550 logs (2.4-m-long, approximately 100 $m^3$) were used in each test to process plywood. Data were collected on- and off-line in terms of veneer quality, grades, recovery, and productivity. The species used in each test were: 1) 100% MPB logs, and 2) a typical SPF mix, with approximately 10% being MPB 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 6 h before peeling. The surface and core temperatures of about 70 blocks at the lathe were monitored using an IR gun.

For veneer peeling, the VG, HG profile, and PA profile were checked. The spin-out rate, and 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 preprogrammed 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 MC distribution for each sort was measured. For veneer drying, the final peak and average MC 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 48 h to further reduce the MC through dissipation and equalization.

For the MPB veneer, sixty 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 a one-zone longitudinal dryer and recovered to measure the dry veneer weight, width, and thickness. In doing so, the green veneer MC and veneer width-shrinkage were obtained.

## RESULTS AND DISCUSSION

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

## Pilot Plant Tests

***Wood properties.*** As shown in Table 3, log diameter was measured for both MPB logs and control SPF logs before round up. The average diameters of the MPB logs and control SPF logs were 29.5 and 26.1 cm, respectively. Compared with the control SPF logs, the diameter of the MPB logs was about 13% greater. The average stained depth for the MPB logs was 4.2 cm. The stained portion accounted for about 51.2% of total log volume, which indicates that nearly all of the sapwood portion of the MPB logs was stained.

Table 4 summarizes the wood density (at green conditions), oven-dry specific gravity (SG), and MC of sapwood and heartwood veneer of the MPB and control SPF logs. The results demonstrated that: 1) compared with the control sap-

TABLE 3. *Pilot plant comparison of log diameter between the MPB and control SPF 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. *Pilot plant comparison of wood density and MC between the MPB and control SPF logs.*

| | | Sapwood MC(%) | | Heartwood MC (%) | | Wood density (kg/m$^3$) | | Oven-dry specific gravity (SG) | |
|---|---|---|---|---|---|---|---|---|---|
| Log category | Number of logs | Mean | Std. | Mean | Std. | Mean | Std. | Mean | Std. |
| MPB | 30 | 47.7 | 14.8 | 29.2 | 4.5 | 570 | 32 | 0.429 | 0.034 |
| Control SPF | 30 | 106.8 | 30.0 | 43.6 | 13.9 | 605 | 57 | 0.368 | 0.019 |

wood veneer, the MPB sapwood veneer had a significantly lower MC with a smaller variation due to log dry-out. The average MC of sapwood was only 47.7% for the MPB logs compared with 106.8% for the control SPF logs; 2) the MC of the MPB heartwood veneer was also lower than that of the control SPF heartwood veneer with a smaller MC variation; 3) the MC of the MPB sapwood veneer was very close to that of the control heartwood veneer; and 4) the oven-dry SG of the MPB logs was significantly greater than that of the control SPF logs, which is because lodgepole pine has the largest SG among the SPF species mix.

***Log conditioning and veneer peeling.*** For MPB logs, as shown in Fig 4, cracks appeared in the block after round up. After peeling, the breakage of the sap veneer ribbon occurred regardless of how the blocks were conditioned. In practice, this discontinuity will cause difficulty in handling, sorting, and drying, as well as increase in random-width veneer and a reduction in veneer recovery. If there were no serious cracks, veneer ribbons peeled from MPB 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 MC for sapwood and heartwood. For lathe-setting 1, as shown in tests 1, 2, and 3 (Table 5), log isothermal conditioning at below 32°C was not effective because the ribbon of the MPB sapwood veneer was fully or severely broken. Meanwhile, the variation of green veneer thickness was above the specification limit generally set at 0.127 mm for both sapwood and heartwood veneer. Further, as shown in the test 4 (Table 5), conditioning blocks at 49°C for 4.5 h improved the ribbon continuity slightly. The reasons for the ribbon breakage were probably due to: 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 MPB blocks.

To increase the wood plasticity, it is advisable to use higher conditioning temperature and longer conditioning time. 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. The results showed that conditioning at 49°C for 4.5 h with a target core temperature of 27°C satisfactorily improved the ribbon continuity with the least veneer thickness variation. However, conditioning at $\geq$ 49°C for a longer time did not show any further improvement in ribbon continuity. On the contrary, veneer became rougher with a larger thickness variation.

To investigate the effect of the VG on veneer quality and ribbon continuity, the 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. The results showed that compared with the lathe-setting 2, the ribbon continuity was worsened, probably due to the larger CR. 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 at 21°C for 2 h brought sapwood MC up to 68%, but veneer quality and ribbon continuity were not noticeably improved. As a result, conditioning blocks at 49°C for 4.5 h was encouraging. By just heating up the sap portion of MPB

TABLE 5. *Pilot plant results of veneer quality and ribbon continuity.*

| Test no. | Lathe setting | Conditioning | Block | Roughness grade* | Green veneer MC Heart (%) | Green veneer MC Sap (%) | Green veneer thickness (mm) Heart Mean | Heart Std. | Sap Mean | Sap Std. | Ribbon continuity |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |

Note: * 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.

blocks to about 38°C, the greater 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). The results showed that compared with lathe-setting 2, both lathe-settings 4 (pitch angle = 90°) and 5 (pitch angle = 89°) did not show any improvement in the ribbon continuity, and lathe-setting 5 was better than lathe-setting 4. In addition, lathe-setting 5 resulted in a smaller thickness variation in the sapwood veneer. Therefore, it is recommended that for peeling MPB logs, the pitch angle be 89.5°–89°.

Based on the mini-lathe peeling tests with 33-cm blocks, the breakage of veneer ribbon was found to be the main issue for peeling MPB logs with their dry-out and cracks. Improper peeling also caused increased breakage. From the peeling perspective, a conditioning schedule with 49°C water temperature and 4.5 h soaking time improved the ribbon continuity. Compared with the shorter blocks used in the laboratory, longer blocks would have slightly slower heat conduction to the center of the blocks. Therefore, in the subsequent tests with 1.2-m blocks and the mill trial with 2.4-m blocks, a schedule of 49–57°C pond temperature with a target core temperature of about 27°C was applied 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% CR (at a diameter of approximately 29 cm), was recommended for peeling the MPB 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.

***Green veneer MC characteristics.*** Based on the MC measurement results from the 33- x 33-cm sheets proportionally sampled from all ribbons peeled under various peeling conditions (Table 5), the green veneer MC distribution was established for both MPB veneer and control SPF veneer. As shown in Fig 6, the green MC of the

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

| | | Green veneer thickness (mm) | | | | |
|---|---|---|---|---|---|---|
| | | Heart | | Sap | | |
| Log category | Block no. | Mean | Std. | Mean | Std. | Roughness grade* |
| 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.

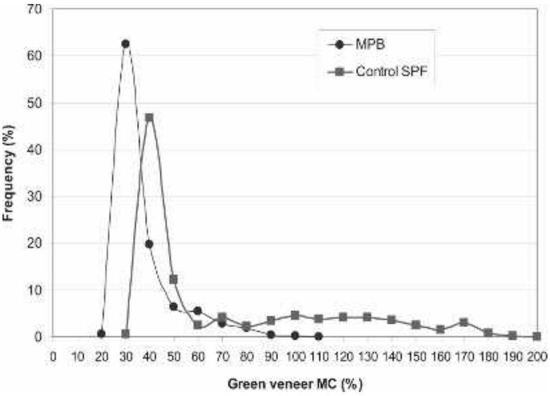


FIGURE 6. Pilot plant comparison of green MC distribution between the MPB and control SPF veneer.

MPB veneer ranged 20–110% with a majority being around 30%. There was no distinct peak for the sapwood veneer. In contrast, the green MC of the control SPF veneer ranged 30–200%. Since the control SPF veneer displays a larger MC variation, improvement of green veneer MC sorting is deemed to be essential to achieve more uniform veneer drying and better drying quality.

***Veneer drying characteristics.*** Figure 7 shows the comparison of drying curves between MPB sapwood veneer (2 sheets, A and B) and control sapwood veneer (2 sheets, A and B) obtained from the mini-dryer. The results demonstrated that the MC of MPB sapwood sheets was very consistent and lower compared with that of con-

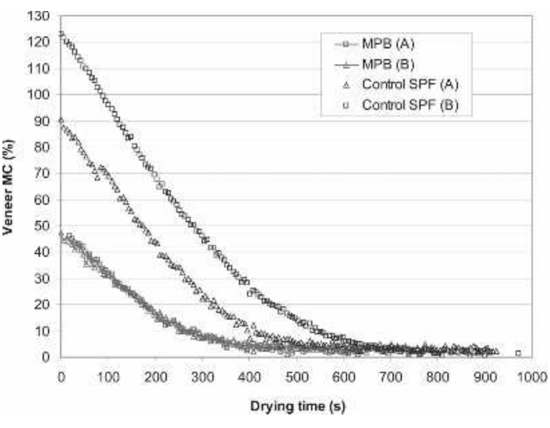


FIGURE 7. Pilot plant comparison of sapwood drying curves between the MPB and control SPF veneer.

trol sheets. This implies that drying time can be reduced for the MPB sap veneer. Based on the drying curves, to dry veneer to a target MC of 3%, the average drying time for the control sap veneer was about 11.5 min (690 s), whereas the average drying time for the MPB sap veneer was only 7.5 min (450 s), a reduction in drying time of about 35%.

Figure 8 shows the comparison of drying curves between the MPB heartwood and control heartwood veneer. The results demonstrated that the MC of the MPB heartwood sheets were also very consistent and lower compared with those of the control SPF heartwood sheets. The implication is that drying time can also be reduced for the MPB heartwood veneer at an estimated 25%. By comparison, the drying time of the MPB sapwood veneer was close to that for the control SPF heartwood 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 with the control SPF veneer. Since the mill volume ratio of MPB logs

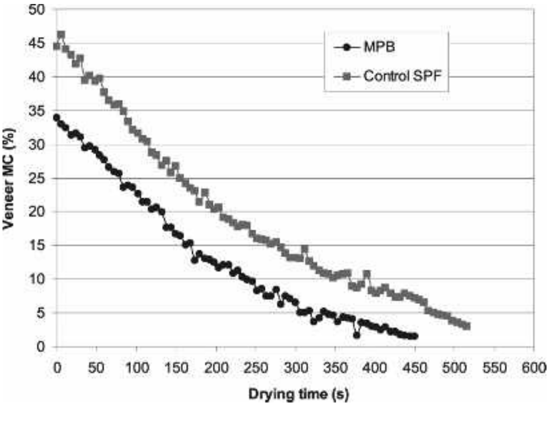


FIGURE 8. Pilot plant comparison of heartwood drying curves between the MPB and control SPF veneer.

procured was 10%, the overall increase in drying production was about 2.8%. Because a 1% productivity increase can translate into an 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 MC 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 $p = 0.05$ level; and 3) on average, the difference in width shrinkage between sapwood and heartwood veneer was only 0.3% for the MPB wood compared with 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 into a recovery increase by about 1%. Since the mill volume ratio of MPB logs was about 10%, the annual profit from veneer clipping was about $30,000 (1% increase in recovery means $300,000).

In summary, the pilot plant tests suggest that processing the MPB veneer separately could result in approximately $442,500 annual savings 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 by the mill (Wang and Dai 2004; Wang and Dai 2005). However, compared with the control SPF logs, processing the MPB logs will generate more random veneer and waste from veneer handling and composing. As a result, plywood mills need to conduct overall evaluation of the net benefit based on the true volume ratio of the MPB logs procured.

TABLE 7. *Pilot plant comparison of width shrinkage between the MPB and control SPF 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 | |

## Mill Trials

***Log conditioning.*** Due to the energy loss, the actual block surface temperature was 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.

***Veneer peeling.*** In general, the ribbon of the MPB veneer produced during the mill trials was continuous because of the close-to-optimal block conditioning. The peeling speed was 7.6 m/s, which was considered to be too fast since the head ribbon of veneer 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 CR 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. The results demonstrated that the 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 CR was 13.0% at a carriage position of 29.2 cm (Table 2). Therefore, the CR used by the mill lathe during peeling seemed to be slightly higher. This could be the main reason why the veneer ribbon in the mill was tighter, easier to roll up, and greater in thickness variation. To reduce veneer thickness variation, the current PA and HG profiles in the mill need to be adjusted. Due to the low veneer MC, there was 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 re-

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

| Log category | Green veneer sort | Green veneer thickness Mean (mm) | Green veneer thickness Std. (mm) | Dry veneer thickness Mean (mm) | Dry veneer thickness Std. (mm) | Volume ratio (%) | Volume ratio of random veneer (%) | Average width of random veneer (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 | | |

quires more manual handling and therefore is more labor intensive.

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

***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 MC was about 3% for the usable dry veneer. The dryers ran well with all sorts. After drying, the bluestain in the MPB veneer was lightened, but it still caused interference with visual grading. This was an additional issue when utilizing MPB logs, since operators had to override the visual scanner to extract the maximum grade possible. Because the MC of the MPB veneer was low with a low volume ratio of sap veneer, the sap veneer could be combined with the light-sap veneer. Thus, only two green sorts were generated: heart and light-sap/sap. Compared with the control SPF veneer, the drying time of the MPB veneer was much shorter. On average, the reduction in drying time was about 29% for the MPB heart veneer and 36% for the MPB light-sap/sap veneer. For the light-sap/sap veneer, the reduction in drying time was consistent with that obtained through the laboratory drying test. For the heart veneer, the reduction in drying time was slightly higher in the mill compared with 25% obtained in the laboratory. The reason is mainly from the sorting accuracy of the control SPF heart veneer. The mill should be able to estimate the exact improvement in productivity by taking into account the volume breakdown of the species mix and the sorting accuracy.

Table 10 summarizes the results of green veneer MC, green veneer clipping width, dry veneer width, and width shrinkage. The results demonstrated that: 1) the MC of the MPB heart veneer was the lowest with the smallest variation, and the MC of the MPB light-sap veneer was very close to that of the control SPF heart veneer; 2) overall, the width shrinkage of the MPB veneer was less than that of the control SPF veneer, with an average difference of about 0.7%; 3) the data of 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 with 1.0% obtained from the pilot plant tests; the reasons could be due to the species mixture and the less accurate sorting for the control SPF veneer; and 5) the control SPF light-sap sort shrank less than the control SPF heart sort, which may be due to significant MC overlapping between these two sorts, as shown in Fig 9.

Figure 10 shows the MC distribution of the heart sort and light-sap sort for the MPB veneer. It

TABLE 9. *Veneer drying results from mill trials.*

| | | Veneer drying settings | | Dryer output (volume ratio) | | |
|---|---|---|---|---|---|---|
| Log category | Green veneer sort | Temperature (°C) | Time (min) | Dry veneer (%) | Stacking (%) | Redry (%) |
| 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. *Green veneer MC, clipping width and width shrinkage from mill trials.*

| | | Green veneer MC | | Green veneer clipping width | | Dry veneer width | | Width shrinkage | |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. | Mean | Std. | Mean | Std. | Mean | Std. |
| Log category | Green veneer sort | (%) | | (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 |

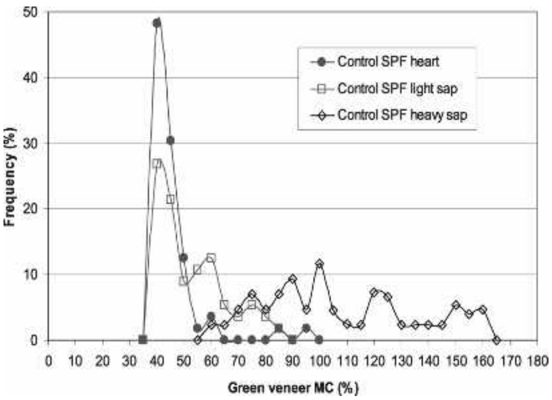


FIGURE 9. Green veneer sorting accuracy in the mill for the control SPF veneer.

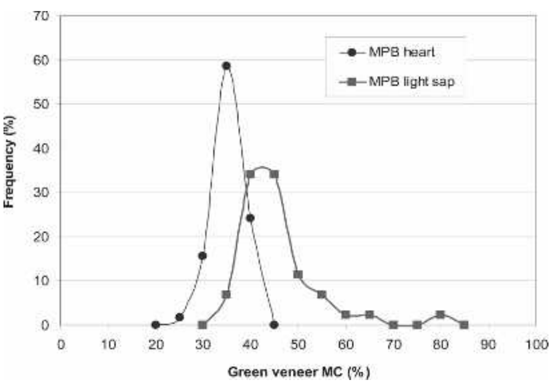


FIGURE 10. Green veneer sorting accuracy in the mill for the MPB veneer.

demonstrated that overall, the sorting of the MPB veneer was more accurate than that of the control SPF veneer, but there was still some overlapping between these two sorts.

***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 larger diameter with the MPB logs, only about 4.5% of the MPB logs were sorted for saw logs (Wharton 2004); hence, the recovery of the MPB logs at the log yard was higher compared with 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; and 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 from more manual handling and composing of random veneer. However, as demonstrated, processing these volumes of MPB logs could also generate approximately $442,500 annual savings 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.

## 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 MPB wood. Conditioning the MPB 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. Also,

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

lathe settings affected veneer quality and recovery; a setting with a CR of approximately 13% helped produce quality veneer and reduce the breakage of the veneer ribbon.

Compared with the control SPF green veneer, the MPB green veneer had lower MC and smaller MC variation. In general, the MPB veneer can be clipped narrower with an equivalent of 1% increase in recovery because of less 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 with a reduction in drying time by about 25% for the heart sort and about 35% for the light-sap sort. Despite about 1% increase in recovery from veneer clipping and 27.5% increase in productivity from veneer drying, the recovery of the MPB 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. The color of bluestain in the MPB veneer was lightened after drying, but it still caused interference with visual grading.

Since MPB logs are drastically different from other species in terms of MC and subsequent processing characteristics, it is recommended that the species be sorted in the log yard. Such sorting helps take advantage of the faster drying speed and reduces the amount of over-dried veneer, and is warranted from 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 to this work, the effect of the MPB logs on downstream plywood manufacturing such as gluing, lay-up, and hot pressing needs to be examined and quantified. By implementing the above recommendations and adopting the optimized veneer processing strategies, the value recovery from this altered MPB resource can be maximized.

## ACKNOWLEDGMENTS

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## REFERENCES

BYRNE T (2003) Properties of lumber with beetle-transmitted bluestain. Wood Protection Bulletin. Forintek Canada Corp. July 2003.

CSA O325 (2007) Test methods for construction sheathing. Canadian Standards Association.

CSA O151 (2004) Canadian softwood plywood. Canadian Standards Association.

DAI C, WANG BJ (2003) Innovative veneer processing technologies. Forintek Canada Corp. Report 3250. 34 pp.

———, ———, Groves K, Xu H (2003) Optimization of veneer drying processes. Forintek Canada Corp. Report -2020. 40 pp.

MPBAP (2007) The Mountain Pine Beetle Action Plan (2006-2011). The Government of British Columbia. http://www.for.gov.bc.ca/hfp/mountain_pine_beetle/.

Wang BJ, Dai C (2004) Maximizing value recovery from mountain pine beetle-attacked pine for veneer products. Natural Resources Canada Pacific Forestry Centre, Victoria, BC. Mountain Pine Beetle Initiative Report. 33 pp.

———, ——— (2005) Maximizing value recovery from mountain pine beetle-killed pine for veneer products. Mountain Pine Beetle Initiative (MPBI) working paper 2005-9. Canadian Forest Service, Natural Resources Canada.

Wharton S (2004) Recovery study #1 for mountain pine beetle-killed pine. Unpublished mill study. Armstrong Plywood Division, Tolko Industries Inc., BC