Forintek Canada Corp.
Western Division
2665 East Mall
Vancouver, British Columbia V6T 1W5

Specialty Plywood Products
A Way to Increase Value Recovery from Mountain Pine Beetle (MPB) – Attacked Lodgepole Pine

by

Brad Jianhe Wang
Composites Research Scientist
Composites Group

Prepared for

Forestry Innovation Investment

Recipient Agreement No.: FII-MDP-07-0028
Contract No.: 2007 - 5422

March 2007

Brad Wang
Project Leader

Gary Troughton
Reviewer

Jean Cook
Department Manager

Summary

Lodgepole pine (*Pinus contorta* Dougl.) has the best engineering wood properties in the interior BC spruce-pine-alpine fir (SPF) species mix. This report examines the potential to produce more veneer based engineered wood products (EWP) in BC using veneer from the mountain pine beetle (MPB) impacted resource.

In this study the utilization of Mountain Pine Beetle (MPB)-attacked lodgepole pine veneer for specialty plywood was benchmarked against control SPF veneer and Douglas-fir veneer. A comparison between two veneer stress grading methods was made in terms of grade outturn and within-grade veneer modulus of elasticity (MOE or E) variation. MPB veneer and Douglas-fir veneer were then segregated into designated E grades with the same E breakpoints on the mill production line and then randomly sampled for plywood manufacturing in the pilot plant. The manufacturing parameters and performance of pure grade MPB plywood, mixed grade MPB plywood, mixed grade Douglas-fir plywood and mixed grade Douglas-fir/MPB plywood were established and evaluated.

Tests on mill production veneer demonstrated that on average, the density and E of the MPB veneer were only slightly lower than those of Douglas-fir veneer and significantly higher than those of the control SPF veneer. Quantitatively, the density and E of the MPB veneer were approximately 7.0% and 8.7% higher than those of the control SPF veneer, respectively.

Mill production veneer data demonstrated that there was no significant difference in ultrasonic propagation time (UPT) between the MPB veneer and control SPF veneer. This indicates that the grade outturn of these two types of veneer will stay more or less the same if UPT-based stress grading is performed.

Compared to the UPT-based stress grading, E-based stress grading yielded an approximately 45.6% higher grade outturn for the MPB veneer tailored for engineered applications. With E-based veneer stress grading, the MPB veneer yielded about 20% more in grade outturn compared to the control SPF veneer. In addition, the MPB veneer can be effectively segregated into distinct E/density groups with a substantially reduced variation, which is beneficial for making consistent engineered wood products such as specialty plywood and laminated veneer lumber (LVL).

With the same E breakpoints, compared to Douglas-fir veneer, the MPB veneer yielded similar E values measured by average and standard deviation and a 9.4% higher in grade outturn of the middle three E grades.

Five-ply pure grade MPB plywood with non-bluestain veneer as outer plies yielded satisfactory appearance and superior parallel ply bending performance and gluebond quality. Compared to 5-ply pure grade MPB plywood, 5-ply mixed grade MPB plywood helped fully utilize low E grade veneer without noticeably diminishing both gluebond quality and bending performance. Note that for manufacturing 5-ply pure grade MPB plywood, the platen pressure should be adjusted in terms of veneer E grades - higher grades required higher pressures to bond. A constant platen pressure could be used to make mixed grade MPB plywood.

The MPB veneer was found to be interchangeable with Douglas-fir veneer in terms of bending stiffness and strength for making specialty plywood. The gluebond quality of 5-ply mixed grade MPB plywood was better than that of 5-ply mixed grade Douglas-fir plywood. However, the MPB plywood

demonstrated less dimensional stability. The 24-h water absorption and thickness swell of 5-ply mixed grade MPB plywood was about twice those of 5-ply mixed grade Douglas-fir plywood.

To improve the overall performance and possibly lower the cost of producing specialty plywood, a viable technical solution is to manufacture mixed Douglas-fir/MPB plywood or paper overlaid MPB plywood. Compared to 5-ply mixed grade MPB plywood, 5-ply mixed Douglas-fir/MPB plywood with Douglas-fir veneer as the two outer plies (top and bottom) yielded reduced water absorption and thickness swell and better appearance. Indications are that the low grade MPB veneer can be fully used as the inner plies for manufacturing higher performance plywood.

Successful use of veneer from MPB logs for high-end concrete forms has a potential to enable mills to offset the recovery loss from MPB veneer processing. This work could help the plywood industry open new niche markets for other engineered applications. Based on the results from this project, the feasibility of using the MPB veneer for other high-end products such as bridge decks, truck and trailer decks, container floors, upholstered furniture frames, wood pallets and cut-to-size panels requiring higher stiffness and strength may be technically feasible.

To increase value recovery for the MPB veneer, E-based veneer stress grading is strongly recommended.

Manufacturers can use the benchmarking results for the MPB veneer from this study to assess their potential to retain veneer for manufacturing specialty plywood products or sell veneer to LVL mills. Currently, some plywood mills are producing oiled (face) and edge sealed plywood concrete forms from visually graded Douglas-fir veneer. Since there is little or no relationship between veneer visual appearance and stiffness, some concrete forms made are low-end and have a large variability of bending stiffness. Compared to these concrete forms, MPB plywood forms made from stress-graded veneer could have a higher bending stiffness with more uniform engineering properties and thus be appropriate for longer span construction end uses and provide greater design flexibility for building engineers.

A market study, and if promising, mill trial to develop and fully quantify the business case for manufacturing specialty plywood products such as mixed Douglas-fir/MPB plywood and/or paper overlaid MPB plywood for increased bending performance, dimensional stability and better appearance is recommended.

Acknowledgements

Forintek Canada Corp. would like to thank its industry members, Natural Resources Canada (Canadian Forest Service), British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, Nova Scotia, New Brunswick, Newfoundland and Labrador, and the Yukon Territory, for their guidance and financial support for this research.

Forintek Canada Corp. acknowledges the assistance provided by the Province of British Columbia through the Forestry Innovation Investment Market Development Program.

The author would like to thank Dr. Jean Cook for her contributions to this report. The author also thanks the following mill personnel of Tolko Industries Ltd., Michael Sivucha, Ralph Dawson and Steve Wharton for their help during the course of this project.

Table of Contents

List of Tables

List of Figures

1 Introduction

BC is a major North American supplier of structural panels and engineered wood products. In 2004, BC shipments of plywood, veneer and OSB structural panels totaled $2.2 billion. BC shipments of engineered wood products totaled $100 million (BC Competition Council 2006). BC sales of plywood ($322 million) and veneer ($251 million) totaled $573 million in 2004 (RISI 2006). Lodgepole pine (*Pinus contorta* Dougl.) has the best engineering wood properties in the interior SPF species mix. This study explores the potential to produce more veneer based engineered wood products (EWP) in BC using veneer from the mountain pine beetle (MPB) impacted resource.

The study is limited to an exploration of the opportunity from a panel properties perspective. The business case for actually shifting production for more specialty veneer and EWPs would have to include many other considerations. Canadian softwood plywood (CSP) competes directly with OSB in structural panel markets. Veneer based EWP such as laminated veneer lumber (LVL), industrial decks, container flooring and concrete forms compete with other products and typically command higher prices than the same volume of structural panels. However, EWPs are usually more costly to produce and market. Individual EWP customers expect the manufacturer to provide engineering support as well as products. A shift to producing veneer for EWPs, or to manufacturing EWPs only improves competitiveness if margins are increased.

This report provides the technical knowledge needed for producers to estimate the potential manufacturing costs and benefits of shifting more production towards veneer based EWP manufacturing to offset the increasing costs BC interior plywood producers are now experiencing producing structural plywood panels from a dry, checked and stained MPB log supply.

1.1 The Opportunity

In the BC interior SPF (white spruce, lodgepole pine and subalpine fir) is the primary log supply for softwood plywood. Lower peeler log quality and recovery result from including MPB logs in the SPF supply (Wang and Dai 2004). These higher costs combined with increasing global OSB production capacity directed towards commodity sheathing markets is reducing the BC plywood sector's ability to continue to compete in structural panel markets.

The CSP industry does not generally sort SPF into species prior to making standard plywood panels (CSA O151-04). In the interior of BC the beetles act as a natural species sorter. Recent studies have reported that processing MPB logs for plywood in the SPF mix yields an overall 8% lower recovery than processing control SPF (Wang and Dai 2004). Compared to the typical SPF control veneer, veneer peeled from MPB logs is denser and stronger. Quantitatively, the MPB veneer is about 10% higher in average modulus of elasticity (MOE) compared to the control SPF veneer which results in about 20% more high-grade outturn. The MPB veneer panels not only have higher bending stiffness and strength but also have higher dry and wet gluebond performance (Wang *et al.* 2005).

Manufacturing EWPs from veneer requires sorting the veneer into stiffness classes to cost effectively meet specific requirements and optimize value recovery. This report presents specialty panel layup and manufacturing options for MPB attacked logs using the production of concrete forms to illustrate manufacturing strategies, cost effective layups and quantify panel attributes.

1.2 Potential Economic Benefits

The price gap between specialty plywood used for concrete forms and regular sheathing grade plywood is estimated at US$400-450 per thousand square feet for 5-ply 5/8" panels (Random Lengths 2005). This is equivalent to US$270 -305 or Can. $315 -360 per cubic meter. Assuming one plywood mill consumes 400,000 cubic meters of logs annually with about 50% and 42% overall recovery for normal wood and MPB wood, respectively (Wang and Dai 2004), the difference in high-grade outturn between the MPB veneer and control SPF veneer for specialty plywood manufacturing is about 20% (Wang *et al.* 2005). As a result, the potential added value recovery from producing plywood for concrete forms could be more than $1.0 million annually, less added costs, for the mill processing about 10% MPB logs.

1.3 Plywood Concrete Forms

Softwood plywood concrete forms are high-end engineered wood products (APA 2005; CertiWood 2005). They are internationally recognized value-added specialty products for general construction use CertiWood 2006). In Canada, plywood forms such as COFI FORM, and COFI FORM PLUS are certified and manufactured with specialty plywood having stricter limits on face and crossband species and thicknesses than standard construction of Douglas-fir plywood. COFI FORM panels are 10% to 30% stronger than standard Douglas-fir plywood depending on the conditions of use. Overlaid panels provide a smoother concrete surface and more re-uses than standard panels. At present, only Douglas-fir, the strongest common softwood species, is designated for the manufacture of high-end concrete forms for exterior use (CSA O151-04; CertiWood 2005). Plywood for concrete forms requires higher stiffness and strength and superior wet service performance to resist deformation for exterior applications than sheathing grades of plywood (http://www.canply.org/english/products/cofiform.htm).

This study was designed to investigate the potential for using the MPB resource to make plywood suitable for exterior applications such as concrete forms. It quantifies the grade outturn from veneer stress grading and documents the dry and wet gluebond performance of test plywood panels made at Forintek's Vancouver pilot plant made from mill production MPB and Douglas-fir veneer. Properties of the veneer used in the pilot plant were taken from known populations of mill production veneer from which the pilot plant test veneer was sampled. The premise is that if the bending modulus of elasticity (MOE) of pilot plant produced specialty panels from mill stress graded MPB veneer could match or surpass that of Douglas-fir plywood, it is at least technically feasible for MPB logs to be made into more specialty plywood products, like concrete forms. The pilot plant study was conducted so that the results could be scaled up to design a workable mill trial if the results were promising.

Acceptance of plywood that contains MPB pine veneer for use in EWPs would require supportable mill production data to present to standards authorities.

1.4 Overall Approach

Coupled with veneer visual grading, stress graded MPB veneer with/without bluestain and Douglas-fir veneer were segregated and used to manufacture various combinations of pilot plant panels. The MPB veneer and Douglas-fir veneer were sorted into five E grades based on veneer modulus of elasticity (MOE or E). 5-ply MPB and Douglas-fir plywood panels were manufactured using the three medium E grades: E1, E2 and E3. Recommended layup and manufacturing parameters for potential mill manufacturing layups were determined in terms of veneer stress grades, parallel ply bending MOE and modulus of rupture (MOR) and gluebond performance. The performance of MPB plywood in wet conditions was evaluated in terms of swell resistance and dimensional stability and compared to traditional Douglas-fir plywood. In this way the best performing lay ups could be selected for a future mill trial.

2 Objectives

The overall objective of this project is to investigate the technical feasibility and economic benefits of manufacturing specialty plywood products, showcased by high-end concrete forms, from MPB wood through pilot plant tests for higher value recovery. Specific objectives are:

- to benchmark the utilization of the MPB veneer;
- to establish optimum grading strategies for the MPB veneer to maximize grade outturns and value recovery; and
- to evaluate the overall performance of specialty MPB plywood made from stress graded veneer in dry and wet conditions.

3 Staff

Brad Jianhe Wang	Project Leader, Composites Research Scientist, Composites Group
Chunping Dai	Group Leader, Composites Group
Peter Ens	Senior Technologist, Composites Group
Axel Andersen	Senior Technologist, Composites Group
John Hoffman	Senior Technologist, Composites Group
Don Moffat	Technologist, Composites Group

4 Materials and Methods

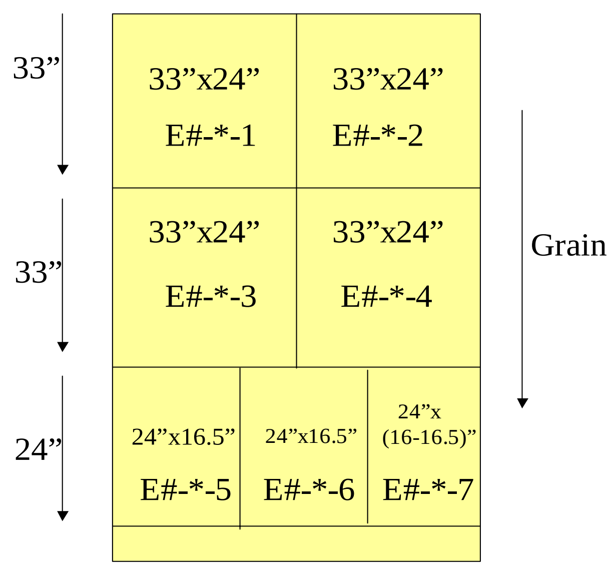
A cooperating BC plywood mill segregated 2000 cubic meters of MPB logs from the typical white wood mix (SPF) for veneer production. The MPB logs were conditioned and peeled to nominal 1/8 -in thickness. The MPB veneer was segregated into two sorts based on green moisture content (MC) and the control SPF mix veneer was segregated into three sorts: heavy sap, light sap and heart. The veneer was dried separately with typical veneer drying schedules. Subsequently, all dry veneer sheets were tested by the mill’s production line Metriguard Stress Grader (http://www.metriguard.com). At the same mill, 1/8 -in thick Douglas-fir veneer was also peeled, dried and tested with the grader. To form generic veneer stress grades, the dry MPB veneer and Douglas-fir veneer were segregated into five E grades (E0, E1, E2, E3 and E4) with four E breakpoints, as shown in Table 1. For the MPB and Douglas-fir veneer, two lifts each (about 200 4x 8 -ft sheets per lift) were randomly sampled from the three medium E grades (E1, E2 and E3) and delivered to Forintek’s Composites Pilot Plant for panel manufacturing (gluing, layup, pressing) and panel testing.

To characterize the population distribution of veneer properties from which the test veneer was sampled, the mill supplied production data: veneer density, MC, UPT and MOE acquired from the mill’s Metriguard grader for the MPB veneer, control SPF veneer and Douglas-fir veneer, respectively. Based on the resulting population distributions of veneer density, UPT and MOE for each species, the values of veneer MOE and density for each E grade and actual production grade outturn were determined.

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

Veneer	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	400	1.65<E<=1.85	400	1.35<E<=1.65	400
MPB	1.85<E<=2.20	400	1.65<E<=1.85	400	1.35<E<=1.65	400

At Forintek's composite pilot plant the number of sample sheets with bluestain was counted to estimate its volume percentage for each MPB veneer E grade. Half of the randomly sampled veneer sheets from each E grade (200 sheets of 4 x 8 -ft) were further trimmed according to the cutting pattern shown in Figure 1. Each 4 x 8 -ft sheet was cut into four 33 x 24 -inch sub-sheets and three 24 x 16.5 -inch cross-bands. All sub-sheets and cross-bands were marked in sequence. In total, approximately 800 (33 x 24 -inch) sheets and 600 (24 x 16.5 -inch) sheets were generated from each E grade. Figure 2 shows some of the test sheets prepared for pilot plant panel manufacturing.



Note: # refers to 1, 2 or 3. *refers to 1 to 200. The E#-*-7 could be slightly narrow

Figure 1: Veneer cutting pattern for plywood manufacturing

For making appearance panels at the pilot plant, 50 (4x 8 -ft) non-stained MPB veneer sheets were selected from each of E1, E2 and E3 grades, respectively. Veneer sub-sheets were cut and marked based on Figure 1. In total, about 200 (33 x 24 -inch) and 150 (24 x 16.5 -inch) sub-sheets were generated from each E grade.

Figure 2: Preparation of the MPB and Douglas-fir veneer for plywood manufacturing

4.1 Benchmarking MPB veneer against Douglas-fir and SPF veneer

For the MPB veneer, the population distribution of veneer density, UPT and E was directly established from the mill data. However, for the control SPF veneer and Douglas-fir veneer, to construct the population distribution of veneer properties, the mill production data collected from different MC sorts were combined and the population figures constructed in proportion to their respective volume ratios. These were the population statistics used to compare the difference in veneer density, UPT and E among the MPB veneer, control SPF veneer and Douglas-fir veneer.

4.2 Optimum veneer stress grading strategies

At present, there are two methods of veneer stress grading, namely ultrasonic propagation time (UPT)-based grading and modulus of elasticity (MOE or E)-based stress grading (Dai and Wang 2000; Wang and Dai 2006). The former is largely affected by wood grain angle without taking veneer density into account. The latter measures veneer density and UPT simultaneously and then adjusts for moisture content (MC) and temperature. Currently, no information is available regarding the benefits of E-based grading over UPT-based grading for common softwood species.

In this study, stress grading methods are compared for the MPB veneer in terms of grade outturn and within-grade E variation.

4.3 Pilot plant panel manufacturing and testing

Three E grades of the MPB veneer and three E grades of Douglas-fir veneer were used to make 33 x 24 -inch 5-ply plywood panels**.** Different panel constructions or lay-ups were tested in terms of pure grade structure, grade mix and species mix to determine the optimum structure and pressing parameters for specialty plywood. Panel bending performance: parallel ply bending MOE and MOR and gluebond quality: shear strength and percent wood failure were evaluated. Panel quality and performance under wet conditions were characterized by swell resistance. All panel performance data were compared to the traditional Douglas-fir plywood values.

At the cooperating mill the following pressing parameters are typically employed:

- 5 ply SPF plywood: platen pressure: 200 psi; pressing time: 4.25 min
- 5 ply MPB plywood: platen pressure: 215 psi; pressing time: 4.75 min

The test panels made in the pilot plant were manufactured according to the plywood product standard for regular unsanded 5-ply Douglas-fir. Panel thickness should be controlled within $15.5^{+1.0}_{-0.5}$ mm (or $0.610^{+0.04}_{-0.02}$ inches). For each species, ten 33 x 24 -inch veneer sheets from each E grade were randomly sampled for measuring thickness, density and MC. A 36x 36 -inch computer controlled press was used for manufacturing 5-ply 33x 24 -inch pure MPB, pure Douglas-fir and mixed MPB/Douglas-fir plywood. The pressing process was tightly controlled with real-time temperature and gas pressure measurements. A plywood PF glue was used with a glue spread level of 32 lb/1000 ft^2 per single glueline. The innermost glueline temperature was carefully monitored during hot-pressing with a target temperature of 110°C.

Based on the specimen cutting pattern shown in Figure 3, plywood gluebond quality was determined in terms of shear strength and percent wood failure. Panels were tested for parallel-ply bending stiffness and strength and dimensional stability. Vacuum-pressure cycle and boiling cycle tests were done in accordance with CSA O151-04 to evaluate gluebond quality. Although the bending stiffness and strength are not required in the Canadian softwood plywood standard (CSA O151-04), for the research purposes of this study, these properties were assessed following the ASTM D 3043 standard test method with some modifications to specimen width and span-to-depth ratio. Modification was necessary due to the limitation of plywood panel sizes that can be made in the pilot plant. A conversion is generally required to estimate the apparent value of panel modulus of elasticity (MOE) for a specific span-depth ratio and load configuration (ASTM D 2915-94).

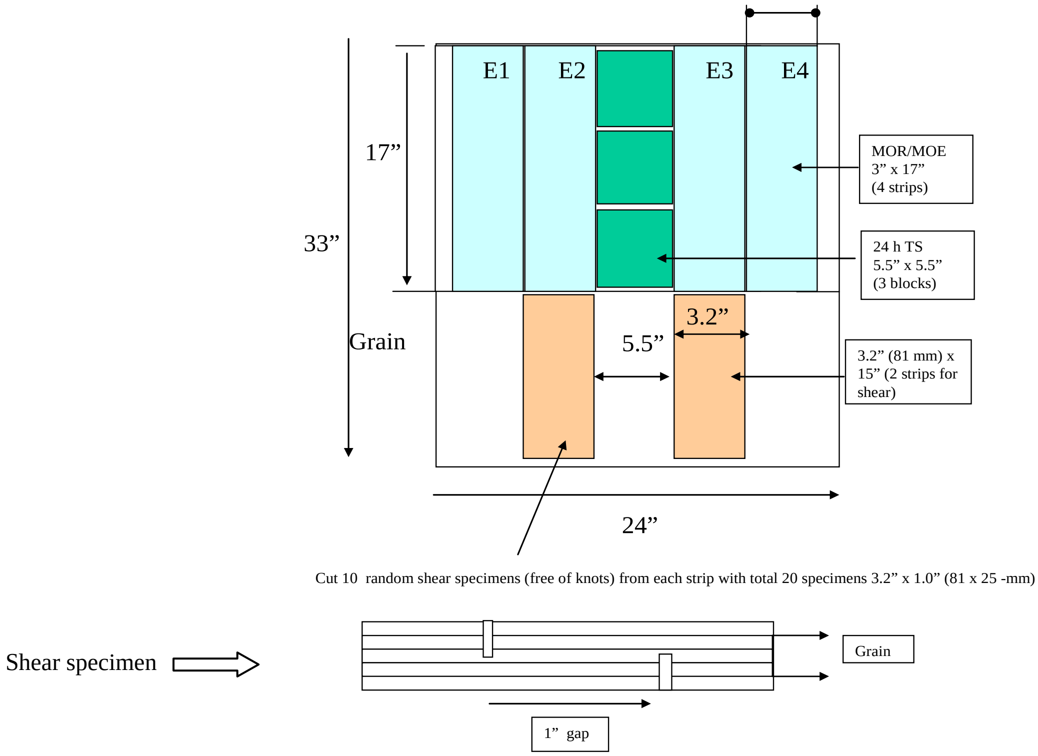


Figure 3: The cutting diagram for 5-ply plywood

4.3.1 Pilot plant manufacturing of 5-ply pure grade MPB plywood

For 5-ply MPB plywood, non-stained MPB veneer was placed in the parallel plies for appearance, namely, the surface ply, the innermost ply and the bottom ply. Bluestained MPB veneer was used for the two crossband layers. The average veneer MC was 3.5%. With the conventional pressing (constant pressure control) method, three 5-ply plywood panels were made from each E grade. In total, nine 5-ply plywood panels were made. Due to the significant difference in veneer density among the three E grades, a higher platen pressure was required for the higher E grade to achieve the panel thickness tolerance (CSA Standard O151-2005). As shown in Table 2, different platen pressures were used for different E grades for 5-ply MPB plywood pressing. The platen temperature was 155°C.

Table 2: The manufacturing parameters of 5-ply MPB plywood from pure E grade

MPB veneer E grade	Glue spread (lb/1000ft^2)	Platen pressure (psi)	Target innermost glueline temperature (°C)	Replicates
E1	32	285	110	3
E2	32	250	110	3
E3	32	235	110	3

4.3.2 Pilot plant manufacturing of 5-ply mixed grade MPB and mixed grade Douglas-fir plywood

4.3.2.1 Five-ply mixed grade MPB plywood

As shown in Table 3, six different constructions of mixed E grade MPB plywood were manufactured. The following manufacturing parameters were used: platen pressure: 250 psi; glue spread level: 32 lb/1000 ft^2 per single glueline; platen temperature: 155°C; and target innermost glueline temperature: 110°C. Three replicates were used to make a total of eighteen 5-ply mixed grade MPB plywood panels. To simulate appearance grades, veneer sub-sheets with little bluestain were placed on the two surface layers (top and bottom).

Table 3: The lay-up of 5-ply mixed grade MPB plywood

5-ply MPB plywood layup	1st (0°)	2nd (90°)	3rd (0°)	4th (90°)	5th (0°)
1	E1	E2	E1	E2	E1
2	E1	E2	E2	E2	E1
3	E1	E2	E3	E2	E1
4	E1	E3	E1	E3	E1
5	E1	E3	E2	E3	E1
6	E1	E3	E3	E3	E1

4.3.2.2 Five-ply mixed grade Douglas-fir plywood

As shown in Table 4, similar to mixed E grade MPB plywood, mixed E grade Douglas-fir plywood was also manufactured with one additional pure E1 grade panel construction. The following manufacturing parameters were used: platen pressure: 235 psi; glue spread level: 32 lb/1000 ft^2 per single glueline; platen temperature: 155°C; and target innermost glueline temperature: 110°C. Three replicates were used to make a total of twenty-one 5-ply mixed E grade Douglas-fir plywood panels.

Table 4: The lay-up of 5-ply mixed grade Douglas-fir plywood

5-ply Douglas-fir plywood layup	1st (0°)	2nd (90°)	3rd (0°)	4th (90°)	5th (0°)
1	E1	E2	E1	E2	E1
2	E1	E2	E2	E2	E1
3	E1	E2	E3	E2	E1
4	E1	E3	E1	E3	E1
5	E1	E3	E2	E3	E1
6	E1	E3	E3	E3	E1
Additional	E1	E1	E1	E1	E1

Before pressing, the thickness of each veneer sheet was measured. The weight of each panel layup before gluing, after gluing and after pressing was measured, respectively. The thickness of each plywood panel was also measured at 9 points to calculate the actual panel compression ratio (CR).

4.3.3 Pilot plant manufacturing of 5-ply mixed grade Douglas-fir/MPB plywood

As shown in Table 5, mixed E grade Douglas-fir/MPB plywood was manufactured with three different panel constructions. The following manufacturing parameters were used: platen pressure: 235 psi; glue spread level: 32 lb/1000 ft^2 per single glueline; platen temperature: 155°C; and target innermost glueline temperature: 110°C. Three replicates were used to make a total of nine 5-ply plywood panels.

Table 5: The lay-up of 5-ply mixed grade Douglas-fir/MPB plywood

Mixed species plywood layup	Fir -1st (0°)	MPB-2nd (90°)	MPB-3rd (0°)	MPB-4th (90°)	Fir-5th (0°)
1	E1	E1	E1	E1	E1
2	E1	E2	E2	E2	E1
3	E1	E3	E3	E3	E1

5 Results and Discussion

5.1 Benchmarking potential utilization of the MPB veneer

Table 6 lists the average value and standard deviation of UPT, density and E for the MPB veneer, control SPF veneer and Douglas-fir veneer. The average UPT value was more or less the same for all three "species". As expected, Douglas-fir had the highest oven-dry density (SG), followed by MPB and SPF. With the combining effect of UPT and density, Douglas-fir had the highest veneer E, followed by MPB and control SPF. The average density and average E of the MPB veneer were only slightly smaller than those of Douglas-fir veneer with the former being smaller in variation. The average density and average E of the MPB veneer were significantly larger than those of the control SPF veneer with the former being smaller in variation.

After deleting the zero readings from the mill machine grader for the MPB veneer, the current results were very close to those obtained in the previous study (Wang *et al.* 2005).

Table 6: Comparison of veneer properties between MPB, control SPF and Douglas-fir

Veneer	No. of sheets	Veneer UPT (µs)		Veneer density (g/cm^3)		Veneer E (10^6 psi)	
		Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
MPB	5272	430.0	26.5	0.434	0.040	1.818	0.258
Control SPF	3583	436.0	25.2	0.405	0.055	1.673	0.272
Douglas-fir	1363	432.9	25.6	0.446	0.056	1.822	0.316
Previous MPB*	3801	429.4 (413.7)*		0.431(0.424)*		1.813 (1.810)*	

*Note: * data in bracket contains the zero readings from the machine (Wang et al. 2005).*

Figure 4 compares the population distribution of veneer UPT for the control SPF veneer and MPB veneer. The shape of distribution was similar between the control veneer and MPB veneer. There was no statistical difference in UPT between these two veneer types. This indicates that the grade outturn of these two veneer types will be similar if UPT-based veneer stress grading is performed on the production line.

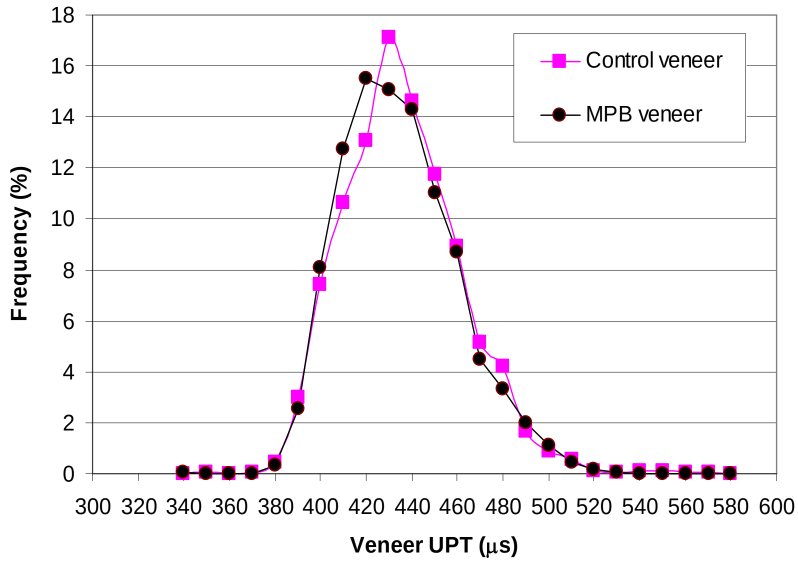


Figure 4: Comparison of UPT distribution between the control SPF veneer and MPB veneer

Figure 5 compares the population distribution for density of the control SPF veneer and MPB veneer. Statistically, there was a significant difference in veneer mean density between the control and MPB veneer at the 0.05 level. On average, the MPB veneer is about 7% denser than the control veneer.

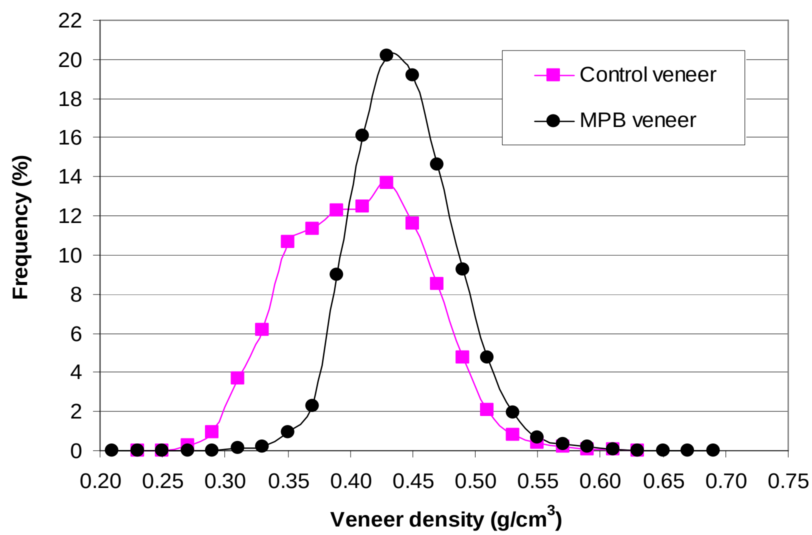


Figure 5: Comparison of density distribution between the control SPF veneer and MPB veneer

Figure 6 compares the population distribution of veneer E of the control SPF veneer and MPB veneer. There was a significant difference in veneer E between the control and MPB veneer at the 0.05 level. On average, the MPB veneer is about 8.7% higher in E than the control SPF veneer. Due to this difference, the grade outturn for manufacturing high grade structural LVL (or other EWPs) of the MPB veneer was about 20% higher than that of the control SPF veneer. This result is consistent with that from the earlier study (Wang *et al.* 2005).

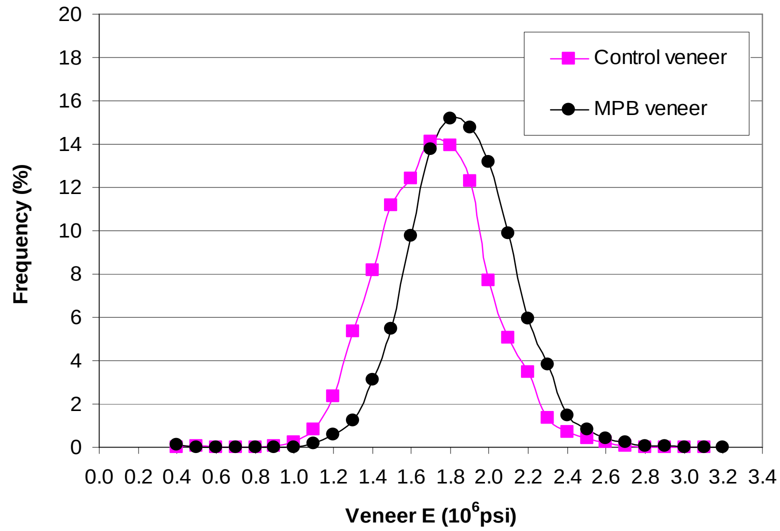


Figure 6: Comparison of E distribution between the control SPF veneer and MPB veneer

In summary, the stiffness (E) of the population MPB veneer was only slightly lower than that of the population Douglas-fir veneer. Douglas-fir had the largest variation in both veneer density and E. Because of the large range of veneer E from the populations, veneer stress grading would be an effective way to segregate veneer into more uniform stiffness groups.

5.2 Grading strategies for the MPB veneer

5.2.1 Comparison of UPT-based and E-based stress grading

Based on the population distribution of veneer E, density and UPT, the differences in grade outturns and veneer E variation between UPT-based and E-based were identified for the MPB veneer. Based on the data obtained, both the MPB veneer and control veneer had a higher percentage of zero UPT readings than zero E readings; and the MPB veneer had a smaller percentage of zero E readings (1.9%) than the control SPF veneer (5.6%).

Table 7 summarizes the results of the comparison between the UPT-based and E-based stress grading for the MPB veneer in terms of grading thresholds (breakpoints), grade outturn, veneer density and E. Stress grading resulted in smaller within-grade variation in both veneer density and MOE, and higher grades had higher densities. For both grading methods the resulting veneer stress grades, namely G1/E1, G2/E2 and G3/E3, were targeted to match the common grades of structural engineered products such as laminated veneer lumber (LVL). Currently, there are three common LVL grades, namely, 2.0E, 1.8E and 1.5E. Comparatively, the E-based grading resulted in a much smaller variation in veneer density and E within each grade and a much higher grade outturn. When the grading is based on these three product grades, the veneer grade outturn from E-based grading has been demonstrated to be about 34.4% and 11.2% higher than that from UPT-based grading for the G1/E1 and G2/E2 grades, respectively (Wang and Dai 2006). As a result, the E-based veneer stress grading is strongly recommended for the segregation of the MPB veneer for higher value recovery.

Table 7: Comparison of between UPT-based and E-based veneer stress grading

MPB veneer	Stress grades	Grading thresholds	Grade outturn (%)	Veneer density (g/cm^3)		Veneer E (10^6 psi)	
		UPT (μs) or E (10^6 psi)		Average	Std. Dev.	Average	Std. Dev.
UPT-based*	G1	UPT<=395	6.6	0.444	0.036	2.07	0.19
	G2	395<UPT<=415	28.7	0.434	0.036	1.87	0.16
	G3	UPT>415	64.7	0.417	0.035	1.52	0.20
E-based*	E1	E>=1.85	41.0	0.451	0.029	2.02	0.14
	E2	1.58 <=E<1.85	39.9	0.413	0.023	1.71	0.08
	E3	E<1.58	19.1	0.385	0.027	1.44	0.11

Note: *G1, G2 and G3 grades from UPT-based grading and E1, E2 and E3 grades from E-based grading are targeted for the same engineered wood products with 2.0, 1.8 and 1.5 million psi stiffness requirements.

5.2.2 Comparison of grade outturn and properties of veneer E grade

After excluding sheets with zero E readings, the veneer E and density as well as grade outturn (with the four E breakpoints defined in Table 1) were compared. Figure 7 shows the veneer density by veneer grade. In general, as indicated by the error bar (± one standard deviation), Douglas-fir veneer had a larger variation in density for all five E grades. There was a descending trend in veneer density from top E0 grade to E1, E2 grades and to E3 grade. However, for the lowest E4 grade, the average density of the MPB veneer was slightly higher than that of Douglas-fir veneer.

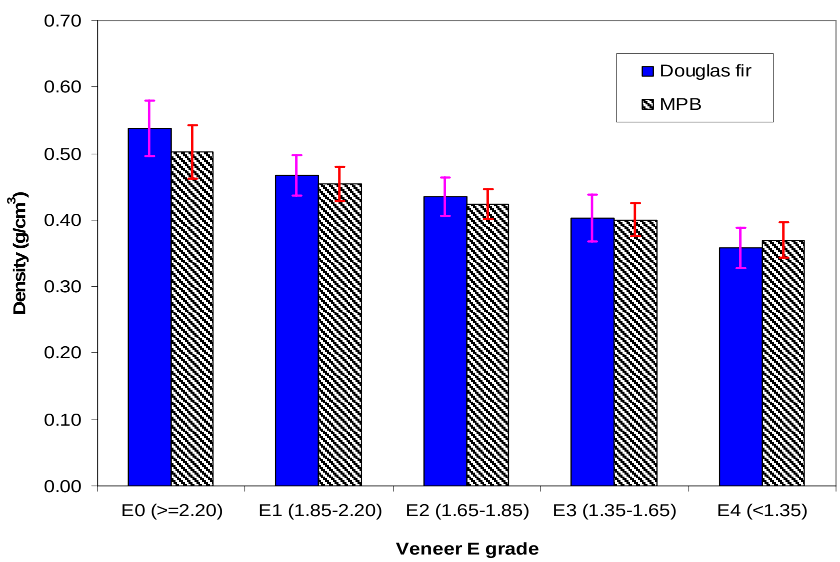


Figure 7: Comparison of density between MPB and Douglas-fir veneer E grades

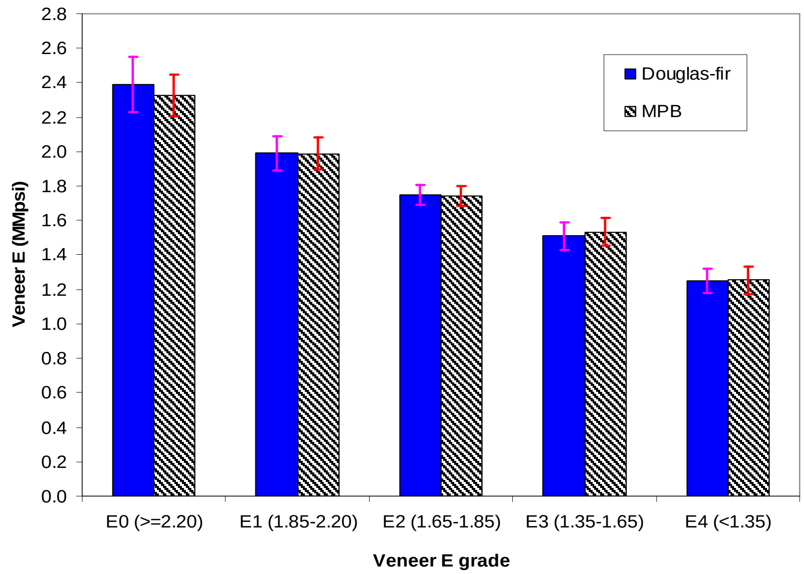


Figure 8: Comparison of E of five grades between the MPB and Douglas-fir veneer

Figure 8 shows veneer E for the five E grades. In general, for the top E0 grade, the average veneer E and its variation, as indicated by the error bar (± one standard deviation), were higher with Douglas-fir veneer than the MPB veneer. However, for each of the remaining E1, E2, E3 and E4 grades, the average veneer E and its variation were similar.

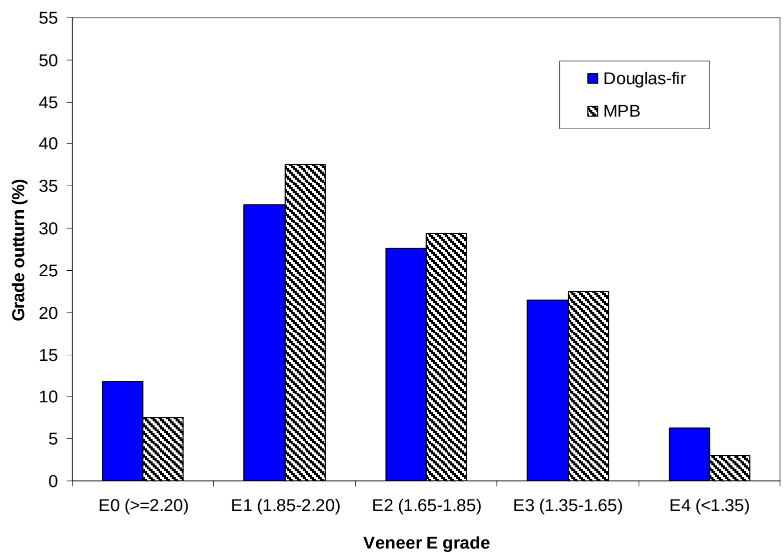


Figure 9: Comparison of grade outturn between the MPB veneer and Douglas-fir veneer

Figure 9 compares the grade outturn (volume ratio) of the MPB veneer and Douglas-fir veneer. For the top E0 grade and the lowest E4 grade, the MPB veneer had a lower grade outturn than the Douglas-fir veneer. However, the MPB veneer had a higher E1, E2 and E3 grade outturn than Douglas-fir veneer. There was a descending trend in grade outturn from E1 to E3 for both the MPB and Douglas-fir veneer.

5.3 Performance of 5-ply pure grade MPB plywood

Table 8 summarizes the results of physical property tests on the 5-ply pure grade MPB plywood. Different platen pressures were used to achieve the target thickness of the 5-ply MPB plywood panels made from different E grades. The resulting average panel compression ratio (CR) ranged from 5.1 to 7.6%. The 24-h plywood thickness swell ranged from 4.7% to 5.6%.

Table 8: Pressing time, panel compression and swell behavior of 5-ply MPB plywood

MPB E grade	Platen pressure	Pressing time	Panel thickness (inches)		Panel CR	Swelling	
						WA*	TS**
	(psi)	(min)	Average	Std.	(%)	(%)	(%)
E1	285	5.5	0.593	0.007	5.1	32.8	5.6
E2	250	5.4	0.596	0.006	7.6	41.1	5.5
E3	235	5.5	0.607	0.006	6.6	36.2	4.7
Average	250	5.5	0.600	0.006	6.4	36.7	5.3

Note: * WA refers to 24-h water absorption; and
** TS refers to 24-h thickness swell.

Parallel ply bending MOE and MOR values were specimen size and testing configuration dependent. This work only focused on their relative comparison. For absolute comparison, a size conversion is needed. Table 9 summarizes the results of mechanical properties and gluebond quality of the 5-ply pure grade MPB plywood. Parallel-ply bending performance demonstrated a descending trend in bending MOE from E1 to E3 grade. However, this trend was not observed for panel MOR. Panel gluebond quality passed the percent wood failure CSA O151-04 standard requirement of 80%.

Table 9: Mechanical properties of 5-ply pure grade MPB plywood

MPB E grade	Bending (psi)		Lap shear (vacuum pressure cycle)		Gluebond quality
	MOE* ($x10^6$)	MOR**	Strength (psi)	Wood failure (%)	
E1	1.41 (0.126)	10472 (2085)	185.8 (35.9)	89.7 (11.1)	Pass
E2	1.23 (0.097)	8173 (2357)	152.2 (51.3)	82.7 (15.1)	Pass
E3	1.11 (0.109)	9199 (1384)	212.5 (39.3)	80.7 (16.0)	Pass
Average	1.25	9281	183.5	84.4	

Note: * MOE refers to parallel ply bending modulus of elasticity;
** MOR refers to parallel ply modulus of rupture.

5.4 Performance of 5-ply mixed grade plywood

Compared to pure grade plywood construction, mixed grade plywood construction has the potential to make use of low grade veneer for high value recovery. A constant platen pressure can be used to manufacture panels with different grade mixes. In this study, 5-ply mixed grade MPB panels and 5-ply mixed grade Douglas-fir panels were manufactured and compared.

5.4.1 Five-ply MPB plywood

Table 10 summarizes the results of tests on the physical properties of 5-ply mixed grade MPB panels. A constant platen pressure of 250 psi was used for mixed grade MPB panel manufacturing. The resulting average panel compression ratio (CR) varied from 4.7 to 11.3%. The 24-h plywood thickness swell varied from 3.8% to 7.2%.

Table 10: Pressing time, panel compression and swell behavior of 5-ply mixed grade MPB plywood

Plywood layup*	Platen pressure	Pressing time	Panel thickness (inches)		Panel CR	Swelling	
						WA**	TS***
	(psi)	(min)	Average	Std.	(%)	(%)	(%)
1	250	5.5	0.603	0.004	4.7	24.0	3.8
2	250	5.6	0.585	0.005	8.2	45.2	6.7
3	250	5.4	0.602	0.005	5.6	37.8	4.9
4	250	5.8	0.593	0.009	6.6	30.8	4.9
5	250	5.7	0.577	0.005	9.7	40.7	6.2
6	250	5.4	0.568	0.006	11.3	53.7	7.2
Average	250	5.6	0.588	0.006	7.7	38.7	5.6

Note: * see Table 3;
** WA refers to 24-h water absorption; and *** TS refers to 24-h thickness swell.

Table 11 summarizes the results of tests for mechanical properties of 5-ply mixed grade MPB panels. Mixed grade panel construction resulted in more uniform parallel bending MOE and MOR. Panels from the No. 1 panel layup did not meet the standard requirement of 80 percent wood failure, indicating insufficient bonding. This is probably due to the low compression of the panels. In this case, due to the variation of veneer surface roughness, veneer-to-veneer contact was not adequate for bonding development. Panel layup (No. 4) also did not meet the CSA O151-04 requirement for the same reason.

Table 11: Mechanical properties of 5-ply mixed grade MPB plywood

Plywood layup***	Bending (psi)		Lap shear (vacuum-pressure cycle)*		Lap shear (boiling cycle)*		Gluebond quality
	MOE (x10^6)	MOR	Strength (psi)	Wood failure (%)	Strength (psi)	Wood failure (%)	
1	1.30 (0.10)	10269(1450)	197.5 (38.8)	77.9 (16.9)	148.6 (43.3)	82.3 (17.1)	Fail/Pass
2	1.40 (0.11)	11533(2172)	157.0 (33.3)	92.9 (5.3)	133.3 (46.0)	86.1 (25.0)	Pass/Pass
3	1.26 (0.10)	10785(1240)	202.2 (44.9)	87.2 (11.9)	168.8 (39.8)	81.1 (18.0)	Pass/Pass
4**	1.41 (0.05)	10900 (920)	199.7 (39.7)	83.6 (16.5)	169.0 (40.9)	77.3 (21.6)	Pass/Fail
5	1.30 (0.11)	9654 (1300)	159.6 (46.2)	90.0 (10.5)	130.4 (40.0)	85.9 (12.1)	Pass/Pass
6	1.15 (0.10)	8348 (1874)	174.4 (26.7)	93.6 (7.6)	151.5 (19.6)	91.7(6.6)	Pass/Pass
Average	1.30	10248	181.7	87.5	150.3	84.1	

Note: * 12 lap-shear specimens were cut from each panel (replicates) for vacuum pressure tests and 12 lap-shear specimens were cut from each panel (replicates) for boiling tests;
** percent wood failure from vacuum-pressure cycle tests met the standard requirements but that from boiling cycle tests did not meet; and
*** See Table 3.

5.4.2 Five-ply Douglas-fir plywood

Table 12 summarizes the results of tests on the physical properties of 5-ply mixed grade Douglas-fir panels. Note that a constant platen pressure of 235 psi was used for the mixed grade Douglas-fir panels. The resulting average panel compression ratio (CR) ranged from 5.0 to 7.7%. The 24-h plywood thickness swell ranged from 2.3% to 3.5% with an average value of 2.6%.

Table 12: Pressing time, panel compression and swell behavior of 5-ply mixed grade Douglas-fir plywood

Plywood layup*	Platen pressure	Pressing time	Panel thickness (inches)		Panel CR	Swelling	
						WA**	TS***
	(psi)	(min)	Average	Std.	(%)	(%)	(%)
1	235	5.5	0.602	0.005	5.5	18.0	2.3
2	235	5.5	0.597	0.007	6.3	20.2	2.3
3	235	5.4	0.604	0.005	6.1	21.0	2.5
4	235	5.7	0.611	0.012	5.0	20.0	2.8
5	235	5.6	0.604	0.005	7.0	21.0	2.4
6	235	5.4	0.588	0.007	7.7	20.0	2.3
Additional	235	5.5	0.594	0.005	7.2	22.5	3.5
Average	235	5.5	0.600	0.007	6.4	20.4	2.6

Note: * See Table 4; ** WA refers to 24-h water absorption; and *** TS refers to 24-h thickness swell.

Table 13 summarizes the results of the mechanical property tests of 5-ply mixed grade Douglas-fir panels. Mixed grade construction resulted in more uniform parallel bending panel MOE and MOR. The shear strength was higher but the gluebond quality was not satisfactory. Panels from No. 1, 3, 4 and 5 panel layups did not meet the standard requirement of 80 percent wood failure. This is probably due to the low compression in which veneer-to-veneer contact was not adequate from the variation of veneer surface roughness.

Table 13: Mechanical properties of 5-ply mixed grade Douglas-fir plywood

Plywood layup*	Bending (psi)		Lap shear (vacuum-pressure cycle)**		Gluebond quality
	MOE ($x10^6$)	MOR	Strength (psi)	Wood failure (%)	
1	1.47 (0.093)	11412 (1548)	213.1 (45.2)	61.1 (39.2)	Fail
2	1.40 (0.063)	11210 (1008)	200.7 (53.2)	83.8 (10.4)	Pass
3	1.39 (0.086)	10804 (1207)	213.2 (59.0)	63.7 (35.1)	Fail
4	1.42 (0.171)	10222 (2785)	197.5 (69.9)	67.1 (31.0)	Fail
5	1.29 (0.125)	8279 (1991)	185.2 (33.9)	91.6 (16.0)	Pass
6	1.44 (0.076)	11003 (600)	183.7 (51.7)	87.5 (6.9)	Pass
Additional	1.44 (0.111)	11254 (1698)	177.1 (41.3)	85.2 (10.2)	Pass
Average	1.40	10488	198.9	75.8	

Note: * See Table 4.
** 12 lap-shear specimens were cut from each panel (replicates).

5.4.3 Comparison between mixed grade MPB plywood and Douglas-fir plywood

Five-ply mixed-grade MPB layups and Douglas-fir plywood had similar bending stiffness and strength. MPB plywood showed poorer dimensional stability as measured by the 24-h water absorption and thickness swell tests. With a 250 psi platen pressure, the average panel compression ratio (CR) of mixed grade MPB plywood was 7.7%. In contrast, with a 235 psi platen pressure, the average panel CR of Douglas-fir plywood was 6.4%. Mixed grade MPB plywood showed better gluebond quality than mixed grade Douglas-fir plywood probably due to the higher compression.

5.5 Physical and mechanical properties of 5-ply mixed grade Douglas-fir/MPB plywood

Table 14 summarizes the results of tests for physical properties of 5-ply mixed grade Douglas-fir/MPB plywood. A platen pressure of 235 psi was used for these mixed species and grade constructions. The resulting average panel CR ranged from 8.1 to 8.5%. On average, the 24-h plywood water absorption and thickness swell was 34.4% and 5.0%, respectively. These values are between the pure MPB plywood and pure Douglas-fir plywood. This indicates that the dimensional stability of MPB plywood could be improved by a species mix with Douglas-fir veneer as outer plies and MPB veneer as inner plies. Further tests need to be conducted to verify this observation.

Table 14: Pressing time, panel compression and swell behavior of 5-ply mixed grade Douglas-fir/MPB plywood

Plywood layup	Platen pressure	Pressing time	Panel thickness (inches)		Panel CR	Swelling	
						WA*	TS**
	(psi)	(min)	Average	Std.	(%)	(%)	(%)
1	235	5.4	0.588	0.003	8.1	28.7	4.2
2	235	5.5	0.583	0.010	8.2	35.4	5.4
3	235	5.2	0.581	0.009	8.5	39.2	5.5
Average	235	5.4	0.584	0.007	8.3	34.4	5.0

Note: *WA refers to 24-h water absorption; ** TS refers to 24-h thickness swell.

Table 15: Mechanical properties of 5-ply mixed grade Douglas-fir/MPB plywood

Plywood layup	Bending (psi)		Lap shear (vacuum pressure cycle)		Gluebond quality
	MOE ($x10^6$)	MOR	Strength (psi)	Wood failure (%)	
1	1.685 (0.109)	13628 (1264)	162.8 (51.5)	89.9 (9.3)	Pass
2	1.462 (0.091)	9279 (2471)	161.9 (53.4)	91.2 (10.5)	Pass
3	1.452 (0.118)	12255(1047)	133.7 (35.7)	88.9 (13.7)	Pass
Average	1.53	11721	152.8	90.0	

Table 15 summarizes the results of mechanical properties tests of 5-ply mixed Douglas-fir/MPB plywood. Mixed species plywood construction resulted in higher bending MOE and MOR. Both shear strength and gluebond quality were excellent. Compared to No. 2 layup, No. 3 layup yielded a similar parallel-ply bending MOE but a higher MOR. This indicates that: 1) the MPB E2 and E3 grade veneer are interchangeable as inner plies; and 2) the low grade veneer can be effectively used as the inner plies without diminishing panel MOE and MOR.

6 Conclusions

Tests on mill production veneer demonstrated that on average, the density and modulus of elasticity (MOE or E) of the MPB veneer were only slightly lower than those of Douglas-fir veneer and significantly higher than those of the control SPF veneer. Quantitatively, the density and E of the MPB veneer were approximately 7.0% and 8.7% higher than those of the control SPF veneer, respectively.

Mill production veneer data demonstrated that there was no significant difference in ultrasonic propagation time (UPT) between the MPB veneer and control SPF veneer. This indicates that the grade outturn of these two types of veneer will stay more or less the same if the UPT-based stress grading is performed.

Compared to the UPT-based stress grading, E-based stress grading yielded an approximately 45.6% higher grade outturn for the MPB veneer tailored for engineered applications. With E-based veneer stress grading, the MPB veneer yielded about 20% more in grade outturn compared to the control SPF veneer. In addition, the MPB veneer can be effectively segregated into distinct E/density groups with a substantially reduced within-group variation, which is beneficial for making consistent engineered wood products such as specialty plywood and laminated veneer lumber (LVL).

With the same E breakpoints, compared to Douglas-fir veneer, the MPB veneer yielded similar E values measured by average and standard deviation and a 9.4% higher in grade outturn of the middle three E grades.

Five-ply pure grade MPB plywood with non-bluestain veneer as outer plies yielded satisfactory appearance and superior parallel ply bending performance and gluebond quality. Compared to 5-ply pure grade MPB plywood, 5-ply mixed grade MPB plywood helped fully utilize low E grade veneer without noticeably diminishing both bending and gluebond performance. Note that for manufacturing 5-ply pure grade MPB plywood, the platen pressure was required to be adjusted with veneer E grades - higher grades required higher pressures to bond. A constant platen pressure could be used to make mixed grade MPB plywood.

The MPB veneer was found to be interchangeable with Douglas-fir veneer in terms of bending strength for making specialty plywood. The gluebond quality of 5-ply mixed grade MPB plywood was better than that of 5-ply mixed grade Douglas-fir plywood. However, the MPB plywood demonstrated less dimensional stability. The 24-h water absorption and thickness swell of 5-ply mixed grade MPB plywood was about twice those of 5-ply mixed grade Douglas-fir plywood.

To improve the overall performance and possibly lower the cost of producing specialty plywood, a viable technical solution is to manufacture mixed Douglas-fir/MPB plywood or paper overlaid MPB plywood. Compared to 5-ply mixed grade MPB plywood, 5-ply mixed Douglas-fir/MPB plywood with Douglas-fir veneer as the two outer plies (top and bottom) yielded reduced water absorption and thickness swell and better appearance. Indications are that the low grade MPB veneer can be fully used as the inner plies for manufacturing higher stiffness plywood.

Successful use of veneer from MPB logs for high-end concrete forms has a potential to enable mills to offset the recovery loss from MPB veneer processing. This work could help the plywood industry open new niche markets for other engineered applications. Based on the results from this project, the feasibility of using MPB logs for other high-end products such as bridge decks, truck and trailer decks, container floors, upholstered furniture frames, wood pallets and cut-to-size panels requiring higher stiffness and strength may be technically feasible.

7 Recommendations

To increase value recovery for the MPB veneer, E-based veneer stress grading is strongly recommended.

Manufacturers can use the benchmarking results for the MPB veneer from this study to assess their potential to retain veneer for manufacturing specialty plywood products or sell veneer to LVL mills.

Currently, some plywood mills are producing oiled (face) and edge sealed plywood concrete forms from visually graded Douglas-fir veneer. Since there is little or no relationship between veneer visual appearance and stiffness, some concrete forms made are low-end and have large variations in panel stiffness and strength. Compared to these concrete forms, MPB plywood forms made from stress-graded veneer could have a higher stiffness with more uniform engineering properties and thus be appropriate for longer span construction end uses and provide greater design flexibility for building engineers.

A market study, and if promising, mill trial to develop and fully quantify the business case for manufacturing specialty plywood products such as mixed Douglas-fir/MPB plywood and/or paper overlaid MPB plywood for increased panel bending performance, dimensional stability and better appearance is recommended.

8 References

APA (The Engineered Wood Association). 2005. HDO/MDO plywood product guide.

ASTM D 3043 - 95. 1997. Standard Methods of Testing Structural Panels in Flexure. Vol 04.10.

ASTM D 2915 - 94. 1997. Standard Practice for Evaluating Allowable Properties for Grades of Structural Lumber. Vol 04.10.

BC Competition Council, Wood Products Industry Advisory Committee. 2006, Report to the Council. 122pp.

CSA O151-04. 2004. Canadian softwood plywood. Canadian Standards Association. 20pp.

CertiWood (formerly Canadian Plywood Association). 2005. Plywood handbook. 27pp.

CertiWood (formerly Canadian Plywood Association). 2006. COFI FORM: Plywood Concrete Formwork. http://www.canply.org/english/products/cofiform.htm.

Dai, C. and B. J. Wang. 2000. Veneer grading strategy for plywood/LVL products. Forintek Canada Corp. Report-1967. 39 pp.

Random Lengths. 2006. Panel Price Guide. Random Lengths Publications.

RISI. 2006. Annual Historical Data, North American Wood Panels.

Wang, B. and C. Dai. 2004. Maximizing value recovery from Mountain Pine Beetle-killed Pine for veneer products. CFS Mountain Pine Beetle Initiative Reports. 35pp.

Wang, B., C. Dai and S. Wharton. 2005. Optimization of gluing, lay-up and pressing for Mountain Pine Beetle (MPB) plywood. CFS Mountain Pine Beetle Initiative Reports. 58pp.

Wang, B. J. and C. Dai. 2006. Veneer grading strategies for LVL production. The 2nd international symposium on veneer processing and products. Vancouver. B. C. pp 263-275.