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Laminated Decking and Flooring Products from MPB Infested Wood

by

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Executive Summary

British Columbia is currently facing the largest outbreak of mountain pine beetle on record. Harvesting of the affected trees has increased in an effort to try and keep up with the spread of the beetle attack. The harvested mountain pine beetle lumber contains blue-stained sapwood that has a detrimental effect on the value of the end product. The rapid increase in available blue-stained fiber has lead to a need for more value-added products in order to maximize return on the affected lumber.

This study was carried out to evaluate the dimensional stability, durability, and finishing of a veneer laminated MPB decking product. This laminated decking is composed of a thick 2x6 blue-stained substrate laminated to a thin 4mm Western Red Cedar and Douglas-Fir veneer. The adhesive chosen was a Type I catalyzed polyvinyl acetate (PVA) suitable for interior applications. This goal of this strategy was to capitalize on the proven strength properties of blue-stained Lodgepole Pine while achieving the appealing aesthetical properties of high-grade softwood veneers for higher margin products.

The dimensional stability of the laminated decking was assessed by exposing samples to 3 types of conditioning environments: Humid, Ambient, and Dry Low Humidity. The warping was measured in the form of cup, twist, bow, and crook to determine the overall stability of the product.

Durability performance of the PVA glue was evaluated using 3 testing procedures - a 1 cycle vacuum-pressure-dry method, a 1 cycle boil-dry method, and a 1 cycle dry testing method. The delamination of the glueline was quantified on the end-grain surface of the samples to determine the durability performance of the laminated decking.

The appearance of the final product was evaluated by first surfacing the veneer by either sanding or planing, then three different finish types were applied to coat the veneer. The result was a visually appealing product well suited for interior applications.

Results of the dimensional stability testing indicated that there was high stability, with minimal warping of the laminated decking after a 3-week conditioning period. No significant difference was found in dimensional stability of the samples laminated to the heartwood or sapwood surfaces of the MPB substrate.

Results of the durability testing indicated that the PVA adhesive is suitable for decking products intended for interior applications. The samples laminated to a Western Red Cedar veneer were found to have superior bonding strength to the Douglas-Fir, but all samples tested still had acceptable adhesion.

Recommendations for this study include further analysis of alternative adhesives that could yield higher bond durability under severe conditions. Utilizing a more durable adhesive has the potential to expand the use of this decking product into exterior applications.

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1 Objectives

The objectives of this study were:

- To evaluate the dimensional stability of veneer laminated mountain pine beetle decking subjected to a range of conditioning environments.
- To determine the durability of PVA glue when laminating Western Red Cedar and Douglas-Fir veneer to a MPB substrate.
- To assess the appearance performance of the Western Red Cedar and Douglas-Fir veneers with a range of finish types.

2 Introduction

The lumber produced from dry Mountain Pine Beetle (MPB) affected trees is acceptable for North American markets but the blue-stained wood associated with MPB has limited it in other markets such as Japan. Recent studies have shown that MPB blue-stained lumber is suitable for structural applications (Byrne, T 2004) but the absence of a strong market for the lumber has led to the requirement of value-added products to enhance the return on MBP fiber supply.

The laminated decking product was developed and designed for interior applications such as roofing, wall or flooring systems using a MPB substrate laminated with high-grade veneer such as Western Red Cedar or Douglas-Fir. The structural requirements of such applications are readily achievable using Lodgepole Pine as a building material as it has greater strength-to-volume properties than a solid Cedar or Douglas-Fir product. By combining the desirable building properties of Lodgepole Pine with the appealing aesthetics of high-grade veneers a stable product of high-value is attainable. This product would ideally meet the requirements of architects and builders while reducing the need for large volumes of costly species fiber.

In order to benchmark this product against solid wood products already available in the market it must meet or exceed these existing products in dimensional stability and durability. Evaluation of the catalyzed PVA glue lamination and dimensional stability was carried out to determine these parameters.

3 Materials and Methods

3.1 Sample Preparation

Decking samples consisted of a 4mm Douglas-Fir or Western Red Cedar veneer laminated to a 2” x 6” MPB substrate. Four types of samples were made, alternating the heartwood and sapwood surfaces on the substrate and the two species of overlay. This experiment required 25 - 10’ boards of each type for a total of 100 boards to be laminated.

The veneers were first calibrated for thickness using the wide-belt sander equipped with a 100-grit belt. One pass was made on one side to achieve a smooth surface of equal thickness for tight lamination. The substrate was J-Grade mountain pine beetle 2 x 6 dimensional lumber that was graded for absence of major defects and air dried to approximately 13%. Immediately prior to laminating, all of the substrate boards were surfaced on one face using the moulder to achieve a corresponding smooth surface to the sanded side of the veneer, of which both will compose the glue-line. The substrate boards were sorted into groups that contained the best heartwood or sapwood faces for laminating.

The veneers were laminated to the 10’ long substrate boards using 5% catalyzed 42-2150 PVA glue (Type 1) supplied by Nacan Products Ltd. and applied at a rate of 50-55 lb/1000ft^2. Samples were pressed in batches of eight for 15 minutes using a Kallesoe press with plates heated to 90^o C. Top pressure was applied at 130 psi specific pressure to obtain a small bead of squeeze-out around the perimeter of each glue-line.

After gluing the boards were hot stacked and allowed to cure for two days before overhanging veneer was removed using the two side cutterheads on the moulder. The boards were then sorted into groups to meet the requirements of the finish acceptance, durability, and dimensional stability tests.

3.2 Dimensional Stability

The dimensional stability testing required 6 replicates from each of the 4 board types for each of the 3 conditions for a total of 72 samples in addition to 6 control boards in each condition for a total of 90 boards. Control boards were produced in 5’ lengths using the MPB substrate that was not laminated with veneer. Initial measurements of moisture content, warping, and density were taken for each sample. Warping of each of the 90 boards was quantified using the CRDC flatness table (see Figure 1). Measurements for cup, twist, bow, and crook were recorded.

Six replicate samples from each of the 4 board types along with 6 control boards were placed in each conditioning environment for 3 weeks. The first group was placed in the Forintek humidity chamber (20^{o} C and 90%RH), the second was hung at the CRDC labs at ambient room temperature (10^{o} C and 62.8%RH), and the third group was stacked and stickered inside an oven set to 19.4^{o} C and 40.8%RH (see Figure 2, 3 and 4). At the end of the three-week conditioning period, the final density and warping measurements were taken on all samples and control boards using the CRDC flatness table.

Figure 1 - CRDC Flatness Table

Figure 2 -Dimensional Stability Decking Samples At Forintek Humidity Chamber

Figure 3- Dimensional Stability Samples Hung at Ambient Conditions

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Figure 4 –Dimensional Stability Samples at Oven Conditions

3.3 Durability

The durability testing for the laminated decking samples was composed of three different tests. Sample size for each method was 3 inches in length by nominal width. Four samples were taken from 5 of each board type (4) for a total of 80 samples per test. All samples were stickered or spaced so that end-grain was freely exposed to the testing conditions.

1. Modified ASTM 1101 used one cycle of vacuum-pressure, vacuum-pressure then dried for 21 hours at 71 ± 3^{o}C (see Figures 5 and 6). Evaluated glueline. (80 samples)
2. Modified ASTM 4317 - dried for a minimum of 24 hours at 71 ± 3^{o}C. Evaluated glueline. (80 samples)
3. Modified ASTM 4317 – 4 hours boil followed by 50 minutes in running cool water, 10 minutes of weeping then dried at 71 ± 3^{o}C for approximately 21 hours. Evaluate glueline. (80 samples)

After testing, delamination of the veneer/substrate at the 2 end-grain surfaces of the samples was evaluated using a 0.004-inch feeler gage to probe for delamination.

Figure 5 –Pressure Vessel Used in Vacuum-Pressure Testing

Figure 6 –Durability Samples in Drying Oven

3.4 Finish Acceptance

Finish acceptance samples were either Douglas-Fir, or Western Red Cedar and were nominal width and thickness by 12" long. Half of each species was either planed or sanded with 100-grit to achieve two different surface treatments. Three types of finishes were selected for the test: Watco's clear Danish oil with the recommended application rate of 13.1g/ft^2, Clear Minwax Satin Oil-based Polyurethane (6.81g/ft^2), and Clear Minwax Satin Water-based Polyurethane (7.10g/ft^2). While samples were being coated, they were placed on a balance to ensure the correct rate of application. All finishes were applied by brush to the manufacturers recommended rate and directions were followed carefully. All samples received two coats with a light 400 grit sanding between applications except for the Danish oil which did not require sanding.

After the final finishes were allowed to cure for 24 hours each sample was evaluated considering factors such as colour uniformity, presence of blotchiness, general attractiveness and fitness for end use. A grade ranging from 1 to 5, with 5 being the highest, was given to each sample for each of the above criteria.

4 Results and Discussion

4.1 Dimensional Stability

Results of all 6 replicate samples at the 3 conditions are shown in Table 1 and depicted in Figure 7. Over the three-week conditioning period, bow saw the most considerable increase for the laminated samples at 0.78mm compared to 0.30mm initially. Crook also increased from 0.36mm to 0.43mm, and twist decreased from 0.57mm to 0.51mm after 3 weeks (see Figure 7).

Table 1- Laminated Decking Dimensional Stability Data Summary

		Initial Measurements				Final Measurements (3 Weeks)					
	Boards	**Avg Bow (mm)**	**Avg Twist (mm)**	**Avg Crook (mm)**	**Combined Avg Warp (mm)**	**Avg Bow (mm)**	**Avg Twist (mm)**	**Avg Crook (mm)**	**Combined Avg Warp (mm)**	**Change in Warp**	**% Change in Warp**
Ambient	DS(1-6)	0.17	0.36	0.18	0.23	0.36	0.59	0.48	0.48	0.24	103.0
	CS(1-6)	0.62	1.33	1.14	1.03	1.73	0.90	1.23	1.29	0.26	25.1
	DH(1-6)	0.32	0.22	0.31	0.28	0.25	0.55	0.17	0.33	0.04	15.2
	CH(1-6)	0.16	1.43	0.28	0.62	0.67	0.54	0.67	0.63	0.00	0.4
	Control(7-12)	0.24	0.74	0.67	0.55	0.82	0.65	0.72	0.73	**0.18**	**32.3**
	***Average**	**0.32**	**0.84**	**0.48**	**0.54**	**0.75**	**0.64**	**0.64**	**0.68**	**0.14**	**25.2**
Oven	DS(7-12)	0.59	0.00	0.28	0.29	0.88	0.80	0.12	0.60	0.31	105.8
	CS(7-12)	0.25	0.23	0.15	0.21	0.84	0.60	0.21	0.55	0.34	160.5
	DH(7-12)	0.17	0.11	0.11	0.13	0.75	0.07	0.07	0.29	0.16	124.7
	CH(7-12)	0.18	1.03	0.41	0.54	1.27	0.71	0.30	0.76	0.22	40.5
	Control(12-18)	0.60	0.93	0.28	0.60	0.35	0.40	0.74	0.49	**-0.11**	**-18.0**
	***Average**	**0.30**	**0.34**	**0.24**	**0.29**	**0.93**	**0.54**	**0.18**	**0.55**	**0.26**	**87.7**
Humid	DS(13-18)	0.53	0.42	0.15	0.37	0.39	0.26	0.13	0.26	-0.11	-29.1
	CS(13-18)	0.30	0.28	0.72	0.43	0.83	0.02	1.00	0.62	0.18	41.6
	DH(13-18)	0.15	1.12	0.38	0.55	0.88	0.49	0.29	0.56	0.01	1.0
	CH(13-18)	0.16	0.34	0.17	0.22	0.55	0.56	0.42	0.51	0.29	133.5
	Control(1-6)	0.30	0.76	0.61	0.56	0.93	0.14	0.75	0.60	**0.04**	**8.1**
	***Average**	**0.28**	**0.54**	**0.35**	**0.39**	**0.66**	**0.34**	**0.46**	**0.49**	**0.09**	**23.7**

*Average is calculated with laminated boards only (not control).

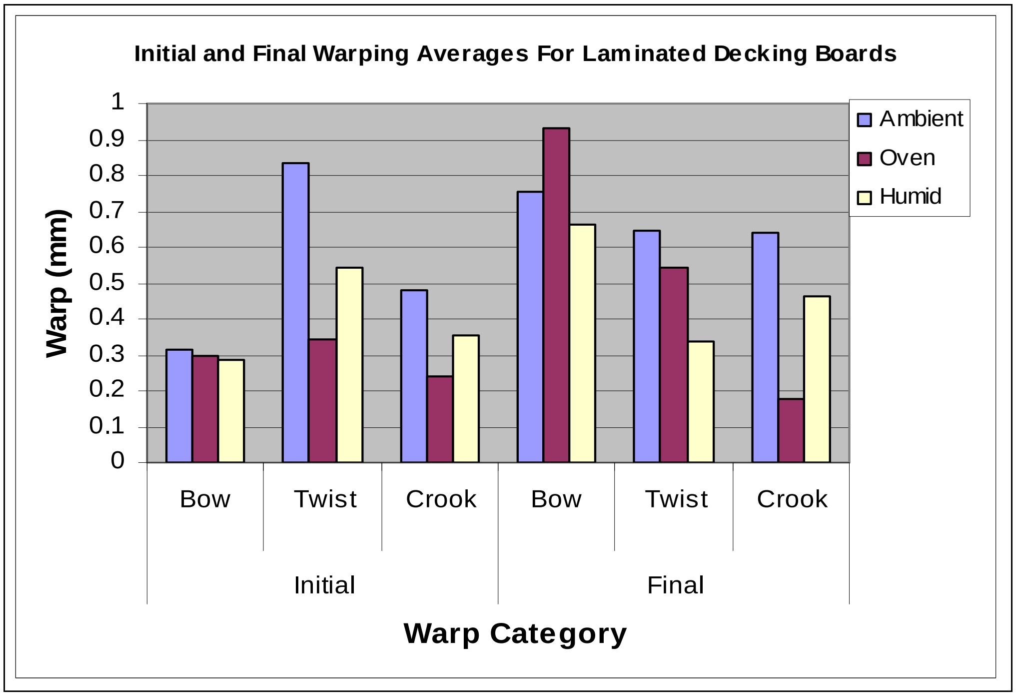

Figure 7 - Initial and Final Warping of Dimensional Stability Boards

Average combined warping was calculated for each sample to give an indication of the overall warping characteristic of the samples.

Cupping on all of the samples as well as the control boards was negligible during both the initial and final warp measurements. After 3 weeks, the laminated decking samples at ambient conditions (10^{o} C and 62.8%RH) resulted in a slight increase in warping of 25% from 0.54mm to 0.68mm (see Table 1). The increase in warping of the control boards at the ambient conditions was 32.3% from 0.55mm to 0.73mm, which is not significantly different to the warping of the laminated samples.

At oven conditions (19.4^{o} C and 40.8%RH) there was an increase of 88% from 0.29mm to 0.55mm in warping on the laminated boards, while the control boards had a decrease in warping of 18% from 0.60mm to 0.49mm (see Table 1). It should be noted that the increase of 88% is still not excessive warping as the final combined average warping was still less than 1mm.

At humid conditions (20^{o} C and 90%RH) the laminated boards had an increase in warping of 24% from 0.39mm to 0.49mm, while the control boards only increased 8.1% but from 0.56mm to 0.60mm as shown in Table 1. Although the change in warping was lesser for the control boards, the final warping of the control was still greater than the laminated boards at 0.60mm. Figure 8 shows the average warping of each board type in the various conditions.

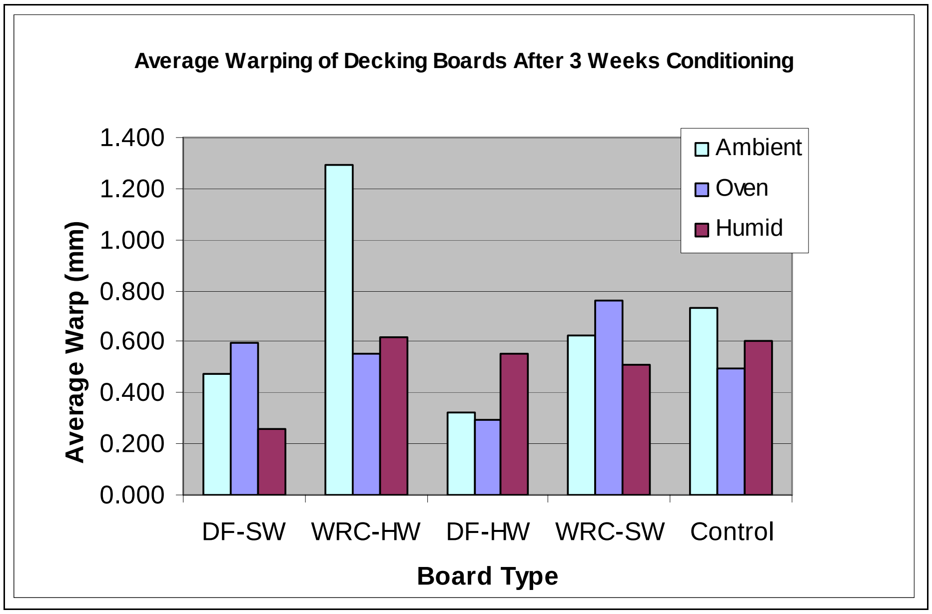

Figure 8 - Average Final Warp of Laminated Decking Samples After 3 Weeks

The average final warping of the sapwood boards was 0.63mm, an increase in 0.20mm from an initial warp of 0.43mm. The average final warping of the heartwood boards was 0.51mm, increased by 0.12mm from 0.39mm. There was no significant difference in the dimensional stability performance of the decking samples laminated to the sapwood or heartwood face of the MPB substrate. The laminated decking boards exhibited no significant difference in warping compared to the control boards (see Table 2). The overall dimensional stability of the decking samples performed very well having extremely minimal twist, bow, and crook as well as negligible cupping.

Table 2 –Dimensional Stability T-test for Significance of Difference in Means

	Sapwood Laminated	Heartwood Laminated	Sapwood Laminated	Control Boards	Heartwood Laminated	Control Boards
Mean Final Warp	0.63mm	0.51mm	0.63mm	0.61mm	0.51mm	0.61mm
Variance	0.31	0.26	0.31	0.33	0.26	0.33
Sample Size (n)	36	36	36	18	36	18
t Stat	**0.95**		**0.14**		**-0.63**	
t Critical two-tail	**1.99**		**2.01**		**2.01**	
	Not Significant		**Not Significant**		**Not Significant**	

4.2 Durability

Summerized results for each of the 3 durability tests conducted are shown in Table 3. To give an indication of severity of delamination, the number of samples with delamination greater than 10% were tallied and shown in Table 4. A further summary of results of heartwood or sapwood (with either Western Red Cedar or Douglas-Fir) and Western Red Cedar and Douglas-Fir (laminated to either sapwood or heartwood) were calculated and shown in Table 5.

Table 3- Delamination Data Expressed as Percent of Glueline

Average Delamination (%)						
	Cedar SW	D-Fir SW	Cedar HW	D-Fir HW	Total	Avg (%)
VP-VP	1.2	6.9	0.6	9.1	17.8	**4.5**
Oven Dry	0.3	0.0	0.0	0.5	0.8	**0.2**
Boil Dry	0.4	0.2	0.5	2.9	4.0	**1.0**
Total	1.9	7.1	1.1	12.4		
Average (%)	0.6	2.4	0.4	4.1		

Table 4 - Delamination of Decking Samples Over 10%

Boards Over 10% Delamination					
	Cedar SW	D-Fir SW	Cedar HW	D-Fir HW	Total
VP-VP	0.0	5.0	0.0	6.0	11.0
Oven Dry	0.0	0.0	0.0	0.0	0.0
Boil Dry	0.0	0.0	0.0	3.0	3.0
Total	0.0	5.0	0.0	9.0	
Average	0.0	1.7	0.0	3.0	

Table 5 –T-test for Difference In Mean Delamination of Laminated Decking Samples

	Sapwood Laminated	Heartwood Laminated	WRC Laminated	D-FIR Laminated
Mean Delamination (%)	1.51	2.26	0.51	3.26
Variance	13.56	54.03	3.00	61.04
Sample Size (n)	120	120	120	120
t Stat	-1.00		-3.77	
t Critical two-tail	1.97		1.97	
	Not Significant		**Significant**	

The decking samples laminated using a PVA adhesive with Western Red Cedar veneer had a lower level of delamination than samples laminated with Douglas-Fir veneer with average delamination of 0.5% and 3.3% respectively. A statistical analysis of the data using a t-test of two samples assuming equal variances was conducted (see Table 3); it was found that the mean delamination of Douglas-Fir (3.3%) was significantly greater than that of the Western Red Cedar (0.5%). The Western Red Cedar samples did not have any samples with delamination higher than 10%, while the Douglas-Fir samples contained 14 samples out of 120 with delamination exceeding 10% (see Table 5). It should be noted that the delamination was measured with a 0.004 inch feeler gauge and does not necessarily indicate severe separation between the veneer and substrate, as well the testing conditions that the samples were subjected to were severe.

Another important variable that was investigated was the difference in adhesion to the sapwood and heartwood surface of the MPB substrate. The mean delamination of samples laminated to the sapwood side was 1.5% while the heartwood side had a mean delamination of 2.3%. A T-test of two samples assuming equal variances was conducted and showed that there was no significant difference in delamination when laminating to the sapwood or heartwood surface of the substrate.

Overall, Western Red Cedar and Douglas-Fir veneer both performed well having relatively low levels of delamination after harsh durability testing and the PVA laminates samples performed adequately for interior product applications.

4.3 Finish Acceptance

Colour uniformity, blotchiness, attractiveness, and suitability for end-use was evaluated on the coated finish acceptance samples. Samples were assigned a grade ranging from 1-5, with 5 being very good; 4 good; 3 acceptable; 2 poor; and 1 not acceptable. All finishes were applied at their manufacturers specified rates.

The Watco® danish oil finish was applied by brush then wiped dry with a cloth after allowing the finish to penetrate for several minutes. After one coat the Danish oil performed extremely well on the Western Red Cedar and Douglas-Fir for both planed and sanded surfaces. It had excellent colour uniformity (5) and no noticeable blotchiness (5). The finish did not raise the fibers on the surface of the veneer, leaving it with a smooth finish. After one coating all boards had an attractive finish, and a second coat would not have been required. A light second coat that was applied had a negative effect on the appearance of the planed boards due to some noticeable blotchiness (3). The sanded boards did not have any blotchiness after the second coat. The Danish oil samples were left with a subtle finish that accented the natural look of the wood well, and achieved a high-quality finish after only one application.

The samples finished with satin oil-based polyurethane had strong colour uniformity (5) and some noticeable blotchiness (4) after the first coat. The surface was textured and not smooth to the touch with some noticeable lifting of the veneer fibers. After a light 400-grit sanding and a second application of the coating the samples improved greatly from the first coat. The finish was smooth with a slightly higher sheen than the Danish oil or water-based polyurethane, and received a 5 in all categories. No significant differences were noticed in the appearance of the sanded or planed boards. The only drawback to the oil-based polyurethane coating was the possibility that the slight sheen might render it undesirable in some applications.

The satin water-based polyurethane performed very similarly to the oil-based polyurethane. After one application the finish had noticeable blotchiness (3) and a rough texture. A light 400-grit sanding and a second application were done and the finish improved significantly from the first coat. All of the samples (planed and sanded) had a smooth, attractive satin finish, and received a grade of 5 in each category.

Figure 9 – Finish Acceptance Samples After One Coat

5 Conclusions

- The results of this study showed that the laminated decking is an extremely dimensionally stable product. After exposure to three different conditions, all of the decking samples exhibited very low combined average warp, the highest being 1.29mm for Douglas-Fir laminated to sapwood at ambient conditions. There was no advantage in dimensional stability found when laminating to the sapwood or heartwood surface of the substrate as both types of boards showed minimal warping after 3 weeks.

- The species of veneer affected the durability of the PVA glue veneer to the MPB substrate. Both Western Red Cedar and Douglas-Fir veneers performed very well in bond-durability testing, but Western Red Cedar proved to be somewhat more durable.

- The sapwood or heartwood orientation of the gluing surface on the MPB substrate did not have a significant effect on the integrity of the PVA glue-bond. Both the sapwood and heartwood laminated samples performed equally.

- The appearance of protective finishes applied was not affected by the surfacing treatment (either planed and sanded) of the veneers. The three finishes tested created an attractive look for the decking product when applied following the manufacturers recommended application instructions. The intended end-use of the product will be the deciding factor in determining what type of finish to be used on the laminated decking product.

6 Recommendations

- Based on the results of this study, further investigation into different types of adhesives could lead to increased durability of the laminated decking.

- It is recommended to evaluate the durability and dimensional stability of an exterior laminated decking product that utilizes an exterior grade adhesive such as PRF or polyurethane glue.

7 References

1. American Society for Testing and Materials (ASTM 2002. Volumes 04.10 Wood and 15.06 Adhesives.

2. Byrne, A. 2004. Implications of the propertied of post-mountain pine beetle wood for its utilization. Forintek Canada Corp. report to Canadian Forest Services. Vancouver, B.C.

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