Optimizing Manufacturing Conditions for Durable Composite Panels with Eastern White Cedar and Aspen Strands

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Abstract

This study aimed to optimize manufacturing conditions when utilizing eastern white cedar (*Thuja occidentalis* L.) to increase the durability of structural panels with aspen (*Populus tremuloides* Michx.) strands in terms of resistance to mold and decay. Panels of three layers using eastern white cedar strands in two face layers and aspen in a core layer were made under different species ratios, temperatures, and pressing conditions. The physical and mechanical properties as well as mold and decay resistances of the panels were tested according to standard methods. Panels with white cedar strands in surfaces and aspen strands in the core at a ratio of 25:50:25 and pressed at 240°C for 180 seconds had the best mechanical and physical properties. Aspen panels with white cedar strands in surfaces at a ratio of 15:70:15 had similar internal bond (IB) and thickness swelling values, lower water absorption (WA), and higher modulus of rupture (MOR) and modulus of elasticity (MOE) compared with pure-aspen control panels. When the white cedar strand proportion in the two surface layers was increased from 15 to 25 percent, IB strength and WA of panels decreased, whereas MOR and MOE increased. Panels with white cedar strands in surfaces at a ratio of 15:70:15 had little infection from molds on the two surface layers but a moderate infection rate on all four sides. In terms of mold and decay resistance, panels made with 25 percent white cedar strands in surfaces performed better than those with 15 percent.

One of the main end-uses of wood-based panels, such as oriented strand board (OSB), is the residential wall framing market. OSB panels are commonly made of nondurable wood species, such as aspen (*Populus tremuloides* Michx.) or southern yellow pine (*Pinus* spp.) strands, and are susceptible to mold and decay when they are subject to moisture. Building envelope failures resulting from mold, decay (fungal infection), or poor construction practices can have a negative impact on the image of wood as perceived by mainly the public but also the construction industry (TenWolde 1993). This may result in product substitution, which in turn can affect the overall competitiveness of the wood and wood composite industry.

Different wood species have varied levels of natural durability against mold and decay (fungal attack) and can be classified as resistant, moderately resistant, slightly resistant, and nonresistant species (Williams and Feist 1999). In North America, the wood species known to be resistant/very resistant are western red cedar (*Thuja plicata* Donn ex D. Don), yellow cedar (*Callitropsis nootkatensis* (D. Don) Örsted), and eastern white cedar (*Thuja occidentalis* L.), whereas the moderately resistant wood species are identified as Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), tamarack (*Larix laricina* (Du Roi) K. Koch), and western larch (*Larix occidentalis* Nutt.; Laks et al. 2008).

The natural durability of cedars (red, white, and Japanese (*Cryptomeria japonica* D. Don)) is mainly caused by the presence of antimicrobial compounds, notably thujone and thujaplicin, in the heartwood. The character and distribution of these compounds have been extensively studied (Rennerfelt 1948, Jin et al. 1988, Nault 1988). Utilization of natural durable cedars to make durable composite panels, such as medium-density fiberboard (Behr 1972), particle-

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board (Behr and Wittrup 1969), and flakeboard (Haataja and Laks 1995), that resist decay and termites has been studied for many years in North America. However, cedar wood contains a high volume of volatile compounds in its heartwood, and it is difficult to manufacture well-bonded strand board panels without blowing. To solve this problem, panels need to be pressed at a high temperature for 5 to 8 minutes, until most of the highly volatile compounds inside panels are evaporated. Extending pressing temperature and time, however, may cause panel surface burn and an unacceptably long manufacturing time frame.

Recently, a new type of three-layer strand board panel has been developed by a Canadian forest products research institute, FPInnovations–Wood Products Division. This panel is made of durable eastern white cedar strands in surface and bottom layers and nondurable aspen strands in the core layer, and it is highly resistant to mold and decay (Wan et al. 2007). The study of Wan et al. (2007) was aimed at developing durable strand board panels with eastern white cedar wood and its extracts mixed with nondurable aspen strands. The results showed that using white cedar strands in the face layers of a strand board panel was the most effective way to improve the resistance to mold and decay of panels constructed with aspen strands. However, the study did not show any effects of the temperature, pressing time, and mass distribution on the quality of these panels. The objective of the current research was to optimize manufacturing conditions for such durable structural panels made using strands of eastern white cedar and aspen.

Methods and Materials

Strand preparation

Freshly felled aspen and eastern white cedar logs were obtained from a local forest farm and debarked upon arrival. The logs were flaked into strands 127 mm long by a random width by 0.6 mm thick with a 32° knife sharpness angle and a 58° counter knife angle at room temperature. Immediately after flaking, all strands were dried to a moisture content (MC) of 3 to 4 percent based on ovendry weight before panel manufacturing.

Panel manufacturing

Four types of panels were manufactured for studying the effects of pressing conditions on panel properties of three-layer cedar/aspen strand board. Aspen strands were used in the core layer (50% of the panel strands based on ovendry wood weight), and white cedar strands were used in the two face layers (each layer contained 25% of the panel strands based on ovendry wood weight). Strand boards were made from these strands using various pressing temperatures and time schedules: (1) 200°C, pressed for 160 seconds; (2) 200°C, pressed for 180 seconds; (3) 240°C, pressed for 160 seconds; and (4) 240°C, pressed for 180 seconds.

Three types of panels were manufactured for studying the effect of the mass distribution ratio in wood strands of white cedar and aspen on the physical and mechanical properties of panels and on resistance to mold and decay: (1) aspen/aspen/aspen (25:50:25), (2) white cedar/aspen/white cedar (15:70:15), and (3) white cedar/aspen/white cedar (25:50:25).

Strands used for face layers were blended with a liquid phenol formaldehyde (PF) resin (3.4% solid content based on dry wood weight) in a drum-type laboratory blender. Then, 1.5 percent slack wax was added. Strands used to form the core layer were coated with a powdered PF resin (2.4% on a dry wood basis). After blending, the actual strand MC in the core layer was 3 to 4 percent based on ovendry weight, whereas the strand MC in the face layers was 7 to 8 percent based on ovendry weight. Unless specified otherwise, all panels were pressed at 220°C for 160 seconds. The detailed pressing conditions are described in Table 1. A Dieffenbacher press (34 by 34 in.) equipped with a PressMan control system was used. The final panel dimension was 610 by 610 by 11.1 mm (24 by 24 by 7/16 in.), and two replicate boards were made for each combination.

Panel quality and durability evaluation

After manufacturing, all panels were conditioned in a chamber at 20°C and 65 percent relative humidity (RH) for at least 3 weeks to reach equilibrium MC before testing. Internal bond (IB) strength, dry modulus of elasticity (MOE), dry modulus of rupture (MOR), 24-hour thickness swelling (TS), and 24-hour water absorption (WA) of these panels were tested according to Canadian Standards Association (CSA) Standard O437.1-93 (CSA 1993).

The mold resistance of panels was tested according to American Wood Protection Association (AWPA) Standard E24-06 (AWPA 2007). Ten replicates of testing specimens were used for each type of panel. Panel samples in the incubator were inspected for mold growth after 8 weeks. Mold growth on each panel sample was visually rated using a scale of 0 to 5, where 0 = no mold growth, 1 = trace of mold growth (less than 5% mold coverage), 2 = little mold growth (5% to less than 25% mold coverage), 3 = moderate mold growth (25% to less than 50% mold coverage), 4 = heavy mold growth (50% to less than 75% mold coverage), and 5 = very heavy mold growth (75% or greater mold coverage). Average scores, which measure the general severity of the mold infection on each panel, were obtained by averaging infection rates from all samples in a treatment.

The decay resistance of panels was tested according to AWPA Standard E10-09 (AWPA 2009). One white-rot fungus, *Irpex lacteus* (ATCC 11245), and one brown-rot fungus, *Gloeophylum trabeum* (ATCC 11539), were used in

Table 1.—Panel manufacturing parameters.

Panel dimension	11.1 mm (7/16 in.) by 610 mm (24 in.) by 610 mm (24 in.)
Panel construction	Three layers
Mass distribution ratio	25:50:25 or 15:70:15 in ovendry weight
Wood species	Aspen and eastern white cedar
Supports	Caul plate and screen at the bottom
Target MC	Face layer: 7%–8% on ovendry basis
	Core layer: 3%–4% on ovendry basis
Slack wax content	1.5% by weight
Resin content	Face layer: 3.4% liquid PF (liquid)
	Core layer: 2.4% powdered PF (solid)
Blender	3 ft (diameter) by 3 ft (depth) or 914 mm (diameter) by 914 mm (depth)
Blender rotation speed	11 rpm
Target ovendry density	624 kg/m^3 (39 lb/ft^3)
Press temperature	200°C, 220°C, or 240°C (surface of platen)
Total press time	160 or 180 s
Degas	30 s
No. of replicates	2

the test. The inoculated test specimens in soil bottles were incubated at 25°C for 16 weeks. At the end of the incubation period, samples were removed from the bottles, cleaned of any fungal mycelia attached, oven dried to a constant weight at 50°C, and weighed to determine weight loss. The average weight loss from six replicates of each type of panel served as an index of how much wood decay was caused by a particular fungus.

Results and Discussion

Effect of pressing conditions

Panels made under various pressing temperatures and times possessed dramatically different physical and mechanical properties. Panels with face layers made of white cedar strands and the core layer made of aspen strands at a ratio of 25:50:25 and pressed at 200°C for 160 seconds had an IB strength of 0.582 MPa, TS of 26.7 percent, WA of 39.6 percent, MOR of 31.92 MPa, and MOE of 3,547 MPa (Table 2). When the pressing time was increased from 160 to 180 seconds at 200°C, panel IB strength and MOE increased, and panel TS, WA, and MOR decreased. When the pressing temperature was increased from 200°C to 240°C with a pressing time of 160 seconds, panel IB strength, MOR, and MOE increased, and panel TS and WA decreased sharply. At a pressing temperature of 240°C and a pressing time of 180 seconds, panel IB strength, MOR, and MOE were significantly increased, and panel TS and WA were significantly reduced, as compared with the other pressing conditions. These data show that aspen panels with white cedar strands in the face layers at a ratio of 25:50:25 and pressed at 240°C for 180 seconds had the best mechanical and physical properties.

The results of mold testing on white cedar strand-faced aspen panels made under various pressing conditions are presented in Table 3. After an 8-week incubation period at 25°C and 100 percent RH, little mold growth was found on the smooth surface (top surface), and almost no mold growth was found on the rough surface (bottom surface), of all tested panel samples. A fair amount of molds infected the sides of panels pressed at 200°C for 160 seconds, followed by panels pressed at 240°C for 180 seconds and those pressed at 200°C for 180 seconds. The panels pressed at 240°C for 160 seconds were the least infected by mold, with an infection rate of 0.3. Panels pressed at 200°C had a white-yellowish color, whereas those pressed at 240°C were yellow-brownish (darker than those pressed at 200°C).

The weight losses of the white cedar strand-faced panels made under various pressing conditions are presented in Table 4. After a 16-week decay process, panels pressed at 200°C for 160 or 180 seconds and those pressed at 240°C for 160 seconds were the most resistant to decay. The decay resistance of panels pressed at 240°C for 180 seconds was decreased in terms of both white-rot and brown-rot. The reduction in decay resistance in this type of panel might be

Table 2.—Mechanical and physical properties of panels made from white cedar and aspen strands under different pressing conditions.

Panel type	Pressing temp. (°C)	Pressing time (s)	Density (kg/m^3)	IB (MPa)[a]	TS (%)[b]	WA (%)[b]	Dry MOR (MPa)[b]	Dry MOE (MPa)[b]
White cedar/aspen/white cedar (25:50:25)	200	160	659	0.582	26.7	39.6	31.92	3,547
	200	180	657	0.775	23.4	35.8	30.72	3,638
	240	160	652	0.700	17.6	28.8	32.07	3,756
	240	180	675	1.073	14.4	24.7	39.67	4,069

[a] Average of five to eight specimens per panel.
[b] Average of two specimens per panel.

Table 3.—Mold growth on panels made from white cedar and aspen strands under various pressing conditions.

Panel type	Pressing temp. (°C)	Pressing time (s)	Mold growth scale (0–5)[a]			
			Smooth face	Screen face	Sides	Overall
White cedar/aspen/white cedar (25:50:25)	200	160	0.6 (0.52)	0	1.8 (1.4)	0.8 (0.71)
	200	180	0.2 (0.42)	0	0.9 (1.2)	0.4 (0.61)
	240	160	0.3 (0.48)	0	0.6 (0.84)	0.3 (0.42)
	240	180	0.4 (0.52)	0.1 (0.32)	1.1 (1.1)	0.5 (0.41)

[a] Values are the mean (SD) of 10 replicates. Scale: 0 = no mold growth; 1 = trace of mold growth (<5% mold coverage); 2 = little mold growth (5% to <25% mold coverage); 3 = moderate mold growth (25% to <50% mold coverage); 4 = heavy mold growth (50% to <75% mold coverage); and 5 = very heavy mold growth (75% or greater mold coverage).

Table 4.—Weight loss of panels made from white cedar and aspen strands under various pressing conditions.

Panel type	Pressing temp. (°C)	Pressing time (s)	Weight loss (%)[a]	
			White-rot fungus (*I. lacteus*)	Brown-rot fungus (*G. trabeum*)
White cedar/aspen/white cedar (25:50:25)	200	160	18.82 (16.17)	3.67 (0.66)
	200	180	17.63 (12.07)	3.31 (1.45)
	240	160	16.99 (21.81)	3.93 (0.51)
	240	180	43.73 (4.72)	11.46 (12.81)

[a] Values are mean (SD) of six replicates.

Table 5.—Mechanical and physical properties of panels made at various ratios of white cedar and aspen strands.

Panel type	Density (kg/m^3)	IB (MPa)[a]	TS (%)[b]	WA (%)[b]	Dry MOR (MPa)[b]	Dry MOE (MPa)[b]
White cedar/aspen/white cedar (15:70:15)	663	0.649	20.6	37.1	30.46	3,644
White cedar/aspen/white cedar (25:50:25)	660	0.509	20.8	34.9	31.95	3,718
Aspen/aspen/aspen (25:50:25)	640	0.618	20.2	39.2	24.89	3,272

[a] Average of five to eight specimens per panel.
[b] Average of two specimens per panel.

Table 6.—Mold growth on various panels made in various ratios of white cedar and aspen strands.

Panel type	Mold growth scale (0–5)[a]			
	Smooth face	Screen face	Sides	Overall
White cedar/aspen/white cedar (15:70:15)	0.2 (0.42)	0	1.2 (0.92)	0.5 (0.46)
White cedar/aspen/white cedar (25:50:25)	0.1 (0.33)	0	1.0 (0.94)	0.4 (0.48)
Aspen/aspen/aspen (25:50:25)	4.1 (0.74)	3.3 (0.48)	4.1 (0.57)	3.8 (0.13)

[a] Values are the mean (SD) of 10 replicates. Scale: 0 = no mold growth; 1 = trace of mold growth (<5% mold coverage); 2 = little mold growth (5% to <25% mold coverage); 3 = moderate mold growth (25% to <50% mold coverage); 4 = heavy mold growth (50% to <75% mold coverage); and 5 = very heavy mold growth (75% or greater mold coverage).

Table 7.—Weight loss of various panels made at various ratios of white cedar and aspen strands.

Panel type	Pressing temp. (°C)	Pressing time (s)	Weight loss (%)[a]	
			White-rot fungus (*I. lacteus*)	Brown-rot fungus (*G. trabeum*)
White cedar/aspen/white cedar (15:70:15)	220	160	51.07 (8.96)	24.99 (31.24)
White cedar/aspen/white cedar (25:50:25)	220	160	32.08 (22.58)	4.02 (0.39)
Aspen/aspen/aspen (25:50:25)	220	160	79.33 (3.38)	74.09 (1.75)

[a] Values are mean (SD) of six replicates.

caused by the evaporation and/or degradation of volatile antifungal compounds present in white cedar strands during pressing. Based on this result, we recommend that when manufacturing strand board panels with white cedar strands, the pressing temperatures should be controlled between 200°C and 240°C. If the panel is pressed at 200°C, the pressing time should be set to 180 seconds, but if the panel is pressed at 240°C, the pressing time should be set to 160 seconds.

Effect of mass distribution

The test results on the mechanical and physical properties of three types of panels with different strand ratios are shown in Table 5. Compared with the pure-aspen control panels, panels made with white cedar strands in the face layers at a ratio of 15:70:15 had similar IB and TS, lower WA, and higher MOR and MOE. When the proportion of white cedar strands in the face layers was increased from 15 to 25 percent, the panel IB and WA decreased, and the MOR and MOE increased.

The mold growth on samples of this series of panels is shown in Table 6. Samples of control aspen panels were seriously infected by molds, with an infection rate of 3.8, which indicated that panels made from 100% aspen were susceptible to mold growth. Panels with white cedar strands in the face layers at a ratio of 15:70:15 had little or no infection from molds on both surfaces, but these panels did have an increased infection rate on the four edges. The average overall infection rate of this type of panel was 0.5. When the proportion of white cedar strands in the face layers was increased from 15 to 25 percent, the average mold infection rate on the panel faces was still 0.1. However, the infection rate on the panel edges decreased from 1.2 to 1.0, and the overall rate was 0.4. These data indicate that having white cedar strands in the surfaces helped these aspen panels to be upgraded from mold susceptible to mold resistant. When the proportion of white cedar strands was increased in the face layers, the mold infection rate in the panel sides decreased.

The weight losses of this series of panels caused by decay (fungi) are shown in Table 7. Aspen panels made of 25 percent white cedar strands in the face layers were decay resistant, especially decay from brown-rot. Samples from this type of panel had 32.08 percent weight loss caused by white-rot and a 4.02 percent weight loss caused by brown-rot. When the proportion of white cedar strands was decreased from 25 to 15 percent in the face layers, the panel decay resistance also decreased. The weight losses of panels with 15 percent white cedar strands in the face layers were 51.07 and 24.99 percent caused by the white-rot and brown-rot fungi, respectively. Based on this result, we do not recommend reducing white cedar strands from the surface layers of the panel to less than 25 percent because of the effect on resistance to mold and decay.

Conclusions

The three-layer panels made of eastern white cedar strands in the face layers and aspen strands in the core layer at different ratios were resistant to mold and decay. Aspen panels with white cedar strands in surfaces at a ratio of 25:50:25 and pressed at 240°C for 180 seconds had the best mechanical and physical properties, whereas those panels pressed at 240°C for 160 seconds had the best mold and decay resistance when compared with panels manufactured in other conditions.

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