Long-Term Performance of Engineered Wood Flooring with Oriented Strand Board Substrate

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Abstract

Plywood is widely used as a substrate in engineered wood flooring (EWF) construction. While the Canadian EWF industry largely relies on Baltic birch plywood (BBP), the development of an alternative substrate is clearly desirable.

The objective of this study was to evaluate the long-term performance of EWF made with an oriented strand board (OSB) substrate designed to deliver a higher than normal internal bond. Three-layer OSB panels were made from a mixture of 90 percent aspen (*Populus tremuloides*) and 10 percent paper birch (*Betula papyrifera*). Three adhesive configurations were used in the manufacture of specialty OSB panels: 100 percent liquid phenol formaldehyde (PF) resin, a mixture of 60 percent liquid PF resin and 40 percent powder PF resin, and 100 percent polydiphenylmethane diisocyanate (pMDI) resin. The performance of these three specialty OSB products was studied. Five types of substrate were used in the manufacture of EWF: BBP, sheathing OSB, and the three specialty OSBs. A polyurethane adhesive was selected to bond the surface layers to the substrates. The result of this experimental study indicated no significant difference between the long-term performance of the OSB substrate made with pMDI resin and that of the BBP substrate.

The performance of engineered wood flooring (EWF) as a layered wood composite product is mostly determined by the mechanical properties of individual component layers. EWF generally consists of three component layers glued together: the surface layer or wear layer (usually hardwood); the core layer (substrate), which provides stability; and the backing layer. Even though the backing layer reduces EWF cupping (Blanchet et al. 2006), its presence is not obligatory (i.e., EWF with a plywood substrate). The material most commonly used as a substrate in high-quality EWF is plywood that is 5 to 11 mm thick. The Canadian EWF industry depends mainly on imported plywood from Russia and Finland (Baltic birch plywood [BBP]); however, the quality and supply of shipments from Russia are inconsistent, while the Finnish products are costly. Consequently, the development of an alternative substrate is needed.

The components of EWF are hygroscopic and they will absorb or desorb moisture in order to reach an equilibrium moisture content with the surrounding environment. Two key mechanisms are responsible for the moisture exchange process in EWF: surface diffusion and vapor diffusion. Because the top layer provides the only surface in contact with ambient air, moisture exchanges will occur through this surface. The mobility of water molecules adsorbed at the external and internal surfaces rises with increasing relative humidity (RH) and occurs from moist to drier areas. Moisture movement by vapor diffusion occurs from an area of higher vapor pressure to an area of lower vapor pressure. Vapor pressure increases as temperature and RH rise. Moisture exchanges across the EWF layers generate distortion and internal stresses.

Blanchet (2008a) conducted a study investigating the effect of the components on EWF hygromechanical behavior and comparing three wood composite panels used as substrates: Russian plywood, oriented strand board (OSB), and high-density fiberboard. The Russian plywood yielded the best result in terms of resistance to cupping deformation followed by OSB and high-density fiberboard.

Barbuta et al. (2010a) developed two OSB panels with high stiffness for use as substrate in EWF manufacturing.

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Three-layer OSB panels were manufactured from two types of strand feedstock: a mixture of 90 percent aspen (*Populus tremuloides*) and 10 percent paper birch (*Betula papyrifera*), and 100 percent ponderosa pine (*Pinus ponderosa*). In a second study, Barbuta et al. (2010b) assessed the performance of EWF manufactured with these two specialty OSB panels. These studies demonstrated genuine potential for OSB as a substrate for EWF. However, the authors suggested that the OSB substrate be manufactured to a higher internal bond (IB) standard to prevent substrate delamination. An efficient way to improve IB in OSB panels is to use a polydiphenylmethane diisocyanate (pMDI) resin (Roll 1997, Sumardi et al. 2008) or a mixture of powder and liquid phenol formaldehyde (PF) resin (Wang and Wan 2001).

The type of adhesive used to bond components is another factor to be considered in EWF design. The adhesives used in most operations include polyvinyl acetate (PVA) type 1, polyurethane, and emulsion polymer isocyanate (Blanchet 2008b). Blanchet et al. (2003b) investigated the effect of the adhesive type on the glueline shear strength lost over nine cycles of accelerated aging. The polyurethane adhesive was found to be the best adhesive to bond EWF layers. Barbuta et al. (2010b) used a PVA type 1 adhesive in their EWF prototypes and observed weak bonding between the surface layer and the high-density OSB panel substrate.

The purposes of this study were to improve the IB of OSB substrates and to evaluate the long-term performance of EWF prototypes made with these substrates. The performance of specialty OSB panels was compared with those of commercial OSB sheathing (OSB-SHE) and BBP.

Materials and Methods

OSB manufacturing

Three-layer OSB panels were made with a mixture of trembling aspen (90% by weight) and white birch (10%). The strands were provided by Produits Forestiers Arbec, located in Saint-Georges-de-Champlain, Quebec, Canada. For an assessment of strand dimensions and species ratio, 120 strands were randomly selected. The mean strand dimensions were 120 mm in length, 45 mm in width, and 0.7 mm in thickness. The aspen-to-birch ratio was about 9:1 per company specification.

Three types of OSB panels were manufactured using three different adhesive mixtures: 100 percent liquid PF resin (OSB-VA), a mixture of 40 percent powder PF resin and 60 percent liquid PF resin (OSB-VB), and finally 100 percent pMDI resin (OSB-VC). The resin contents used were 6.5 percent for the PF resins and 4.5 percent for the pMDI resin. A wax emulsion was applied at the rate of 1 percent. Strand blending was achieved using a rotating cascade-action laboratory blender. The resin and wax emulsion were atomized through separate spray nozzles, with the wax being applied to the strands before the resin. Following blending, the measured moisture contents (MCs) of the surface and core layer furnish ranged from 8 to 8.5 percent and 6 to 6.5 percent, respectively. In order to ensure these MCs, the strands for the OSB panels made with a mixture of powder and liquid PF resin were dried to a greater extent before the application of the wax and the resin. Mat formation and strand orientation were done by dropping the strands through a mesh with parallel plates. The weight-base ratio between the surface and core layers was 0.40:0.20:0.40. All panels were pressed to a thickness of 9.5 mm and a target density of 675 kg/m^3. The panel characteristics and constant parameters for making OSB panels are shown in Table 1. The manufacturing parameters were based on the work done by Barbuta et al. (2010a).

Panel testing

Prior to specimen preparation, all panels were conditioned at 20°C and 50 percent RH for 5 weeks, which are the standard EWF manufacturing conditions in North America. The mechanical properties of the OSB panels, namely modulus of elasticity (MOE) in the parallel direction, modulus of rupture (MOR) in the parallel direction, and IB strength were determined as per ASTM Standard D 1037-06a (ASTM International 2006). Linear expansion (LE) was determined in accordance with Canadian Standard Association (CSA) 0437.1-93 (CSA 1994). The grain direction of the surface layers determines the direction of physical and mechanical properties. These properties were measured before EWF manufacturing and after 15 weeks of accelerating aging.

Table 1.—OSB production parameters.

Production parameter	Value and description
Physical parameters	
Panel dimension (mm)	762 × 762 × 9.5
Three-layer panels	Ratio 0.40:0.20:0.40
Target density (kg/m^3)	675
Mat target moisture content (%)	
Surface layers	8
Core layer	6
Resin 1, OSB-VA	
Resin type	Phenol formaldehyde 100% liquid
Brand	Cascophen OSF-59 FLM
Solids content (%)	59
OSB resin content (%)	6.5
Resin 2, OSB-VB	
Resin type	Phenol formaldehyde mixture of 40% powder and 60% liquid
Brand	Cascophen OSF-59 FLM and ARBEC
OSB resin content (%)	6.5
Resin 3, OSB-VC	
Resin type	MDI
Brand	Huntsman Rubinate 1840
OSB resin content (%)	4.5
Wax emulsion (%)	
Solids content	100
Wax content (each layer)	1
Pressing parameters	
Press platen temperature (°C)	
OSB-VA	210
OSB-VB	210
OSB-VC	200
Resin curing time (s)	
OSB-VA	165
OSB-VB	165
OSB-VC	135

EWF manufacturing

The EWF constructions used in this study consisted of two-layer strips as shown in Figure 1. The test strips involved five different substrate panels: BBP, OSB-SHE, and three types of specialty OSB. A 3.5-mm-thick surface layer of sugar maple (*Acer saccharum*) was chosen for all constructions. The adhesive selected to bond the layers was a liquid polyurethane adhesive (PUR WELD 1052) provided by Henkel Company. In order to ensure constant substrate thickness and a proper gluing surface, all panels were sanded on both sides to a final thickness of 8.9 mm using a 100-120-150 grit sequence. In assembled strips, the grain of the maple layer was perpendicular to the grain of the substrate surface strands. Press time was 20 minutes at 200 psi. After the pressing operation, the EWF strips were reconditioned at 20°C and 50 percent RH for 3 weeks. Final sanding was done on the maple layer, resulting in a thickness of 12 mm. All strips were then milled to a tongue and groove profile.

EWF evaluation

In order to evaluate the long-term performance of the EWF, the strips were glued onto 610 by 1,220-mm cement boards (Permabase) with a one-part urethane adhesive (Bostik Best) used in commercial and residential housing installations. The edges were sealed with silicon to avoid moisture transfer. One assembly of 12 strips was made for each type of EWF.

The accelerated aging cycle chosen to assess EWF resistance to cupping deformation over time was a modification of EN 29142 standard (AFNOR 1993) and ASTM D 1183-96 standard (American Society for Testing and Materials 1996) and duplicated the one used by Blanchet (2008b). The test involved cycles of wet and dry conditions. The humid conditions were set at 20°C and 80 percent RH and the dry and warm conditions at 40°C and 20 percent RH. Total cycle time was 1 week (168 h) with alternating climatic conditions as shown in Figure 2. This cycle was repeated 15 times in order to increase hygroscopic exchanges and amplify wood shrinkage and expansion. Cupping deformation measurements over the surface layer were used as quantitative indicators of EWF performance. EWF deformation was measured with an electronic dial gauge at the beginning of the accelerated aging test and after each cycle, per a method described in detail in Blanchet et al. (2003a).

In addition, variations in substrate IB during the aging test were determined. Sets of 18 EWF strips were prepared for each type of substrate. These were sealed with an adhesive aluminum foil over the back and the edges. The strips were subjected to the same aging test used to measure resistance to distortion. After each aging cycle, IB tests were performed on nine specimens for each substrate. The IB of the EWF substrate was tested according to ASTM Standard D 1037-06a (ASTM International 2006). The IB specimens were tested with the maple surface glued to the substrate. The nine specimens consisted of three specimens from three different EWFs, taken from the center of the strips as shown in Figure 3.

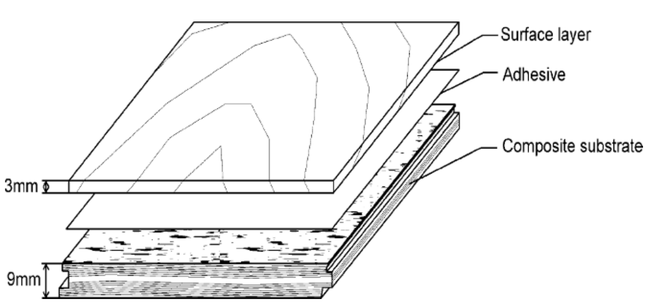

Figure 1.—Engineered wood flooring construction.

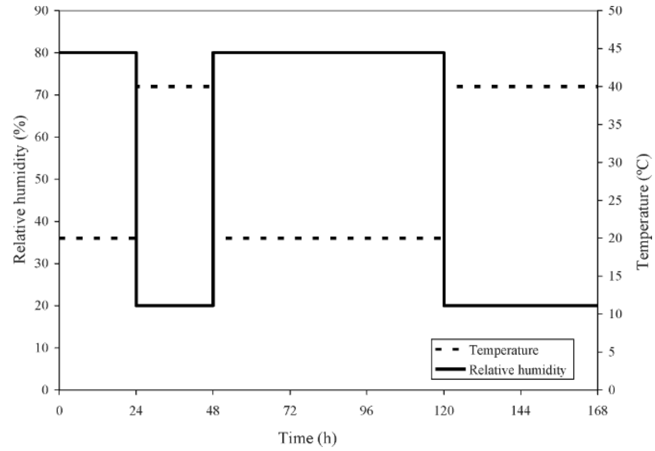

Figure 2.—Aging cycle used in this study.

Given that Barbuta et al. (2010b) had observed a tendency for OSB substrate delamination, the edges of the EWF strips were carefully inspected after each aging test. For the strips sealed with aluminum foil, these inspections took place each time an IB test was performed. They were carried out on the edge that had been sealed with aluminum foil on the two 50-mm trims (Fig. 3) resulting from IB specimen preparation.

Data analysis

An analysis of variance (ANOVA) was performed on the variables studied using the Statistical Analysis System (SAS) 9.1 software. The ANOVA test was conducted to compare the long-term performance of the various EWF constructions and the variations in substrate parameters over the aging cycles. The significance of the differences between the averages was determined using the Waller–Duncan multiple comparison test at a 95 percent probability level.

Results and Discussion

Substrate properties

The physical and mechanical properties of the panels used as substrate are provided in Table 2. All OSB panels

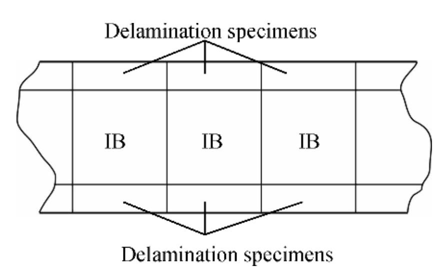

Figure 3.—Cutting pattern for IB and delamination specimens.

Table 2.—Physical and mechanical properties of EWF substrates.[a]

Type of substrate	Density (kg/m^3)	MOE (MPa)	MOR (MPa)	IB (MPa)	LE parallel (%)	LE perpendicular (%)
OSB-VA	670 (49)	7,296 A (745)	46.6 C (9.0)	0.517 D (0.09)	0.12 B (0.04)	0.46 A (0.07)
OSB-VB	710 (24)	7,500 A (747)	57.3 B (6.6)	0.704 CD (0.08)	0.17 AB (0.05)	0.41 AB (0.05)
OSB-VC	700 (32)	7,592 A (634)	60.3 BA (8.8)	0.984 B (0.15)	0.13 B (0.04)	0.34 BC (0.05)
SHE	725 (46)	4,988 B (934)	35.7 D (10.1)	0.743 C (0.08)	0.14 B (0.04)	0.30 CD (0.05)
BBP	690 (20)	7,567 A (504)	66.6 A (4.1)	1.919 A (0.36)	0.20 A (0.05)	0.25 D (0.04)
OSB standard requirements[b]	NA	5,500	29.0	0.345	0.35	0.50
BBP standard requirements[c]	678	11,395	NA	NA	NA	NA

[a] Means within a column followed by the same letter are not significantly different at the 5% probability level using the Waller–Duncan test. Numbers in parentheses are standard deviations. NA = not applicable.
[b] Minimal requirements of Canadian CSA 0437.0 Standard (CSA 1994) for OSB panels class O-2.
[c] Minimal requirements of *Handbook of Finnish Plywood* (Anonymous 2002).

involved in the test yielded results well above the minimum values required by Canadian Standard CSA 0437-93 (CSA 1994) for O-2 panels. The results obtained for MOE in the parallel direction showed no significant difference between the plywood (BBP) and the specialty OSBs (VA, VB, and VC). It was noted that the parallel MOE values obtained for BBP were lower than indicated in the *Handbook of Finnish Plywood* (Anonymous 2002). Even though the MOR is not a required property for the EWF substrate (Barbuta et al. 2010a), it was measured at the same time with the MOE and it is presented in Table 2. The parallel bending properties of O-2 OSB-SHE proved significantly lower than those of all other panels.

In terms of IB, the Waller–Duncan comparison test showed that the BBP yielded the highest values, and the OSB panels made with pMDI resin represented a significant improvement over those made with the PF resins. No significant difference was observed between IB values for OSB panels made with a combined powder/liquid PF resin and with 100 percent liquid PF resin. The IB measured in the sheathing grade OSB was an unexpected 0.743 MPa, i.e., 2.1 times the minimum required by CSA Standard 0437-93 (0.345 MPa; CSA 1994).

For all panels and in both parallel and perpendicular directions, LE was lower than the maximum values allowed by CSA 0437-93 (CSA 1994). For all OSB panels, LE perpendicular was clearly higher than LE parallel. LE (or shrinkage) in both directions depends on the ratio between surface and the core layer. In our case, the high quantity of strands in the surface layers resulted in a low level of parallel LE. As expected, LE differences in the parallel and perpendicular directions were minimal in the case of BBP because this type of plywood is made up of seven thin cross-banded veneers.

Long-term performance of EWF constructions

Figure 4 presents average EWF cupping deformation in relation to substrate type and aging cycles. An ANOVA was conducted on maximum cupping deformation after 15 cycles of accelerated aging. The Waller–Duncan multiple comparison test highlighted three different groups (Table 3) at the 0.05 probability level. The BBP substrate yielded the lowest level of cupping deformation after aging. However, the cupping deformation measured with the OSB-VC substrate was not significantly different from that of the BBP substrate (Group C). A statistically significant difference emerged between the performance of this group (C) and that of the other substrates (OSB-VA, OSB-VB, and

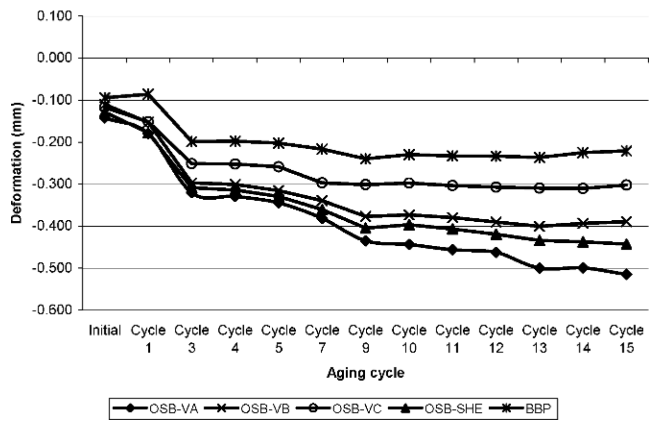

Figure 4.—Cupping deformation in relation to aging cycles and substrate type.

OSB-SHE). Given that the MOEs of the BBP and OSB-VC substrates were not statistically different either (Table 2), it is reasonable to conclude that the good long-term performance of the OSB-VC substrate is due to its improved IB. In contrast, the OSB-VA substrate, with the lowest IB value (0.517 MPa [Table 2]), showed the highest cupping deformation level. These observations are in agreement with the results obtained by Barbuta et al. (2010a). Substrates with higher IB values display better resistance to the stress and fatigue generated by the aging cycles (Chow et al. 1986).

Figure 5 illustrates the variations of IB values for the different EWF substrates during the aging cycles. It appeared that the number of aging cycles did not result in reduced IBs. It is important to note that the IB specimens had been taken from the center of the EWF strips, where internal stresses due to the moisture and temperature cycles are not high enough to affect IB strength. The IB variations

Table 3.—Average cupping deformation values in relation to substrate type after 15 weeks of accelerated aging.

Substrate type	Avg. cupping (mm)	Group[a]	
OSB-VA	0.381	A	
OSB-SHE	0.319	A	B
OSB-VB	0.230	B	
OSB-VC	0.199	C	
BBP	0.161	C	

[a] According to the Waller–Duncan test, the means with the same letter are not significantly different at the 5 percent probability level.

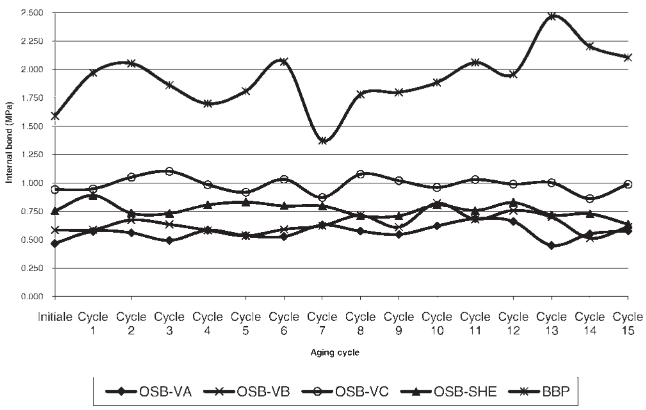

Figure 5.—IB variation in relation to aging cycles and substrate type.

observed over the accelerated aging test were due to variability across the panel from which the specimens had been cut out. It is worth noting that the BBP substrate was found to have a higher IB than the other substrates, although IB is not a property used to evaluate plywood products.

Substrate delamination

The EWF constructions evaluated in this study are unbalanced wood laminates. Moisture movement through the structures generates tensile/compression and shear stresses, the magnitude of which depends primarily on the physical and mechanical properties of each layer and on the composite structure. Interlaminar normal stress and shear stress play a significant role in the failure of wood composites, particularly near the free edges of the structure, where they may generate delamination. Observation of the substrates after the aging test revealed such delamination. Four random EWF strips were selected for each construction type. To facilitate examination of the 60-cm sides of the EWF strips, the underlying cement panel was cut beneath the joint between the two strips. The two EWF strips could then be separated, and the 60-cm sides examined. Table 4 indicates the number and total lengths of the delaminations on each side of each EWF strip. Accelerated aging generated severe delamination in the OSB-VA, OSB-SHE, and OSB-VB substrates. Delamination has a direct and negative effect on cupping deformation and explains the poor long-term performance of the OSB-VA, OSB-SHE, and OSB-VB substrates. Figure 6 illustrates a typical edge delamination such as that observed in an OSB-SHE substrate. By contrast, the number and the total lengths of delaminations observed in the OSB-VC and BBP substrates were minor.

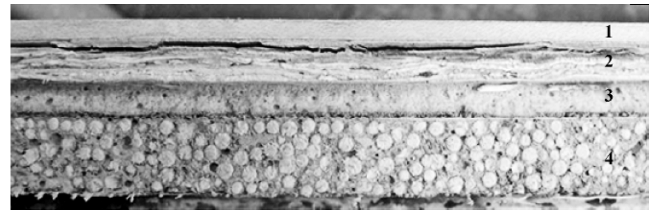

Figure 6.—Typical substrate delamination observed in EWF manufactured with sheathing grade OSB. From top to bottom: surface layer (1), delaminated OSB substrate (2), installation adhesive (3), and Permabase cement panel (4).

Table 5.—Number of specimens (of 18) showing delaminations in relation to aging cycles.

Aging cycle	OSB-VA	OSB-VB	OSB-VC	OSB-SHE	BBP
15	13	5	0	17	0
14	8	6	1	15	0
13	8	8	1	13	0
12	7	5	0	14	0
11	3	1	0	8	0
10	5	3	0	10	0
9	2	0	0	6	0
8	2	2	0	4	0
7	4	1	0	3	0
6	1	0	0	1	0
1–5	0	0	0	0	0
Initial	0	0	0	0	0

Table 5 shows the number of the specimens resulting from IB preparation (18 each time) that were affected by delaminations. As in the preceding case, the BBP and OSB-VC substrates yielded the lowest delamination level, while pronounced delamination occurred in the OSB-VA, OSB-VB, and OSB-SHE substrates. No delamination was observed before the sixth cycle. Once the first delaminations were generated, their number increased with successive aging cycles. Substrate delaminations were generally located near the surface layer (Fig. 6), which indicates a high degree of internal stress in the vicinity of the top layer on free edges. The experimental results of this study show that the IB of the substrate plays an important role in the delamination process and indirectly affects the long-term performance of EWF.

Table 4.—Number and total length (per 60 cm) of edge delaminations after 15 weeks of accelerated aging.

	OSB-VA		OSB-VB		OSB-VC		OSB-SHE		BBP	
Edge	No.	Total length	No.	Total length	No.	Total length	No.	Total length	No.	Total length
1	6	52	3	48	0	0	3	16	0	0
2	4	40	5	31	0	0	8	27	0	0
3	5	24	4	20	1	2	5	24	0	0
4	7	47	3	12	1	3	4	56	1	3
5	1	58	3	47	5	3	6	20	1	6
6	7	41	4	7	0	0	4	15	0	0
7	4	54	4	32	0	0	6	27	2	9
8	4	57	2	2	1	1	3	51	0	0

Conclusions

The objective of this study was to evaluate the long-term performance of EWF products incorporating an OSB substrate of different grades. Five panels, including three OSB prototypes (OSB-VA, OSB-VB, and OSB-VC), one commercial OSB (OSB-SHE), and one commercial plywood (BBP) were used to manufacture EWF specimens that were tested for cupping deformation and edge delamination following 15 aging cycles designed to generate fatigue in the assemblies. Before incorporation into EWF constructions, all panels used as substrate were tested for physical and mechanical properties. The experimental results showed that the BBP yielded the best IB and MOR values, while the pMDI resin significantly increased IB in the OSB panels.

The performance of all EWF constructions decreased with increasing numbers of accelerated aging cycles. EWF manufactured with BBP and OSB-VC yielded the best performance with cupping deformation of 0.161 and 0.199 mm, respectively. A low level of edge delamination was observed with these substrates after 15 aging cycles. The OSB-VA and OSB-SHE substrates led to the highest cupping deformation (0.381 and 0.319 mm). The accelerated aging treatment generated severe edge delamination in commercial OSB and the laboratory-made OSB using PF resin. The OSB-VC substrate, a specialty OSB using 100 percent pMDI resin, confirmed the work of Sumardi et al. (2008) and Roll (1997) and proved to be the best alternative to BBP in the manufacture of EWF products meeting industry requirements.

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