Field Performance of Glued Laminated Timber (Glulam) Manufactured from Thin Treated Lamina

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Abstract

Glued Laminated Timber, commonly referred to as Glulam, is an important structural wood product, suitable for use in exterior applications provided it is protected against decay by building design, natural durability, or treatment. Bonding treated lamina made from refractory species is challenging because resurfacing after treatment can remove much of the treated zone and create a waste disposal challenge. It was hypothesized that use of roll-pressing rather than resurfacing could address this. When an adhesive modifier was used to prevent the adverse effects of wood preservatives on adhesive bonding, treated lamina that were replaned before gluing had similar shear strength to untreated planed lamina. However, the treated lamina that were roll-pressed before gluing had lower shear strength than the replaned lamina. The consequence of this weakening was evident in an above-ground field test where delamination was observed in several test units after 12 years of exposure. Decay resistance was evaluated in above-ground, ground contact, and ground proximity tests. The decay resistance of treated glulam was high with only low levels of decay reported in all tests, while untreated controls showed advanced decay or failure. Yellow cedar glulam, included as a reference in the ground proximity test, showed moderate decay after 10 years of exposure.

Glued laminated timber (glulam) uses sawn wood lamina bonded together in parallel with a durable moisture-resistant structural adhesive to create a larger structural member. Glulam members can be made to cover long spans and in curved shapes. Wood products, including glulam, used in exterior applications need to be protected against biodegradation. Untreated glulam is generally limited to applications that are fully protected by design (AWC 2018). Glulam may be manufactured from many wood species (APA 2020). Some, such as yellow cedar (*Callitropsis nootkatensis*), have naturally durable heartwood that can resist biodegradation (Wacker 2004). Other species that do not have naturally durable heartwood require the use of wood preservatives as described in AWPA U1 Commodity Specification F (AWPA 2020a). Wood preservatives may also be required for higher hazard or critical use applications where natural durability is insufficient (AWC 2018).

Glulam can be preserved by treating the lamina before gluing, or by treating the member after manufacture (Selbo 1957). A combination of both approaches has been used, for example, to make glulam utility poles from chromated copper arsenate (CCA) treated lamina followed by a creosote treatment of the finished pole (Bergman and Jermer 2010). Treating lamina prior to fabrication can lead to a better cross-sectional distribution of preservative within the member and can be used to make glulam members of any size or curvature (Tascioglu et al. 2003). However, surfacing the lamina prior to gluing creates a treated wood waste, and may expose untreated wood if preservative penetration is shallow. Bonding may also be affected by the preservative system. Treating manufactured glulam can protect cuts, cracks, and drillholes that would otherwise expose untreated wood that would be vulnerable to biodegradation and does not produce any treated wood waste. However, this approach is limited to glulam members

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that can fit into a retort, large glulam members may be difficult to penetrate, and the choice of preservative is limited to oilborne systems and ammoniacal copper zinc arsenate (Tascioglu et al. 2003).

Gluing preserved wood lamina has been studied by several groups and bonding issues have frequently been reported (Winandy and River 1986, Tascioglu et al. 2003, Gaspar et al. 2010, Lee et al. 2006, Yang et al. 2012). Studies on bonding alkaline copper quaternary (ACQ) and copper azole (CA) -treated southern pine bonded with a phenol–resorcinol–formaldehyde (PRF) found higher rates of delamination compared with untreated controls, particularly for ACQ (Lorenz and Frihart 2006). Gluing lamina treated with metal-based preservatives is affected by reactions between metal ions in the treated wood and the phenol–formaldehyde resin, which affected the resin curing rate (Vick and Christiansen 1993). Resorcinol adhesive systems have been found to bond CCA-treated lamina more effectively (Sellers and Miller 1997). Feng et al. (2008) noted that when glulam beams were bonded with a PRF resin, sodium borate–treated lamina produced a much higher rate of delamination than untreated lamina. The bonding problem was likely the result of chemical interactions between borate ions and the PRF resin molecules. This problem was overcome by adding a water soluble and strongly alkaline substance to the PRF as a resin modifier to prevent the adverse effects of borate interactions with the resin (Feng et al. 2008). Successful lamination of CA- and ACQ-treated beetle-killed lodgepole pine (*Pinus contorta* Dougl.) lamina with PRF resin and the alkaline modifier was reported (Feng and Knudson 2006). Lamination quality without the use of the modifier was not satisfactory.

An additional challenge is the dimensional instability of the lamina. Preservative impregnation and subsequent drying have been found to affect surface roughness and reduce bond strength (Sellers and Miller 1997). Larch (*Larix* sp.) wood impregnated with alkyl ammonium compounds, ACQ or CA, did not have a significant impact on bonding with PRF, though a minimum 1-mm depth of surfacing after treatment was needed to meet bond quality performance criteria (Miyazaki et al. 1999). A follow-up study confirmed the need to plane to a depth of 1 mm after treatment and showed that incising with a 2.8-mm needle diameter further reduced shear strength (Miyazaki and Nakano 2003).

The use of primers or pretreatments may help to bond preservative-treated lamina. An hydroxy methylated resorcinol coupling agent applied as a dilute aqueous primer has been found to help bind CCA-treated southern pine lamina with a PRF adhesive (Vick 1995). Application of an hydroxymethyl resorcinol primer was found to reduce delamination for CA- and CCA-treated lamina but had minimal effect on ACQ-treated lamina (Lorenz and Frihart 2006).

Field tests and simulated field tests of softwood glulam treated either before or after manufacture found that the material treated before manufacture was more durable (Cookson 2013). This was attributed to improved protection of the end grain, which was where much of the decay was observed. Three-ply Norway spruce glulam treated with a copper-based preservative has been reported sound after 2 years of exposure in an above-ground horizontal configuration, while untreated controls showed early signs of decay (Kržišnik et al. 2020).

Most Canadian wood species are difficult to impregnate with wood preservatives, resulting in treated wood with a shell of treatment protecting an untreated interior (Cooper and Morris 2007). Such shell-treated wood requires special consideration when laminating. The most permeable species available may be selected, thinner lamina can be used to maximize the total treated area, and minimizing resurfacing after treatment can help to retain as much treated wood as possible.

Planing of the treated lamina prior to lamination was an essential step for achieving good gluing performance. Planing of the treated lamina represents an additional manufacturing process plus a disposal challenge for the treated shavings. It was hypothesized that the challenges in bonding lamina treated with copper-based waterborne preservatives without planing or sanding could be overcome using a posttreatment roll press to smooth the lamina surface without creating treated wood waste from planing or sanding (Knudson et al. 2008). The present work evaluates the impact of this process on block shear and delamination resistance. An expanded series of test materials are further evaluated for their field performance in above-ground, ground proximity, and ground contact exposures to provide a comprehensive understanding of the field performance of these materials.

Materials and Methods

Test material preparation

Two sets of test materials were made for this experiment: 5-ply glulams and 12-ply glulams. The five-ply glulams were made using 2.44-m- (8-ft-) long 19 by 89-mm (nominal 1 by 4-in.) kiln-dried lamina cut from red pine (*Pinus resinosa* Ait.) obtained from the Ottawa valley, Pacific silver fir (*Abies amabilis* Dougl. Forbes) obtained from Vancouver Island, and mountain pine beetle–killed lodgepole pine obtained from central British Columbia. There was particular interest in the beetle-killed lodgepole pine because the blue-stained sapwood is known to be more permeable (Woo et al. 2005). The lamina were either left untreated, or pressure-treated with ACQ type D or copper azole type B using a full cell pressure treatment cycle that included an initial 30-minute vacuum at –22 mm Hg, followed by 120 minutes at 1,035 kPa and a final 15-minute vacuum. Target retentions were 3.3 kg/m^3 for CA and 6.4 kg/m^3 for ACQ. All treatments were carried out at 20°C.

Treated and untreated lamina were roll-pressed to a thickness of 18.0 mm (5.3% compression) at ambient temperature (20°C) to smooth the surface prior to gluing. A PRF resin (Cascophen LT-75C) and a paraformaldehyde catalyst (Cascomet FM-282C) were used to bond the lamina. Immediately prior to lamination, the glue mix preparation was carried out by mixing the LT-75C with sodium hydroxide as a PRF resin modifier at a 2:100 ratio (m/m) followed by combining the resulting solution with the FM-282C catalyst in a 5:1 ratio (m/m). An adhesive spread of 0.39 kg/m^2 (80 lb/1,000 ft^2) with a single side application was used. The beams were immediately clamped and heated at 35°C for approximately 16 hours.

The 12-ply glulams were made from 2.44-m- (8-ft-) long 19 by 140-mm (nominal 1 by 6-in.) Pacific silver fir obtained from coastal British Columbia and lodgepole pine obtained from central British Columbia. The lodgepole pine came from trees affected by the mountain pine beetle

(*Dendroctonus ponderosae*) and contained high proportions of blue-stained sapwood, which is known to be highly treatable (Woo et al. 2005). Yellow cedar (*Callitropsis nootkatensis* (D. Don) Oerst) obtained from coastal British Columbia was also included as a reference on account of its naturally durable heartwood (Morris et al. 2011). Each board was measured for Modulus of Elasticity (MOE) using a flat-wise, long-span method following ASTM D4761-05 section 12-17 (ASTM International 2005). Moisture content was measured for each board using a Wagner electromagnetic moisture meter. Average moisture contents were found to range from 9.0 to 16.2 percent. Boards with the lowest MOE or large defects were removed because they would not be considered suitable for glulam stock. Boards were sorted into treated and control groups with an equal distribution of MOE (data not shown). The materials allocated to the treated group were pressure-impregnated with ACQ-D by a commercial treater. After treatment, the boards were air-dried for 3 weeks followed by kiln drying for 24 hours to a temperature <60°C to reach a moisture content below 10 percent.

The treated lamina were roll-pressed through a gap of 18.5 mm (2.6% compression). Additional lamina were replaned to 18.5-mm thickness instead of being roll-pressed to be used as a comparison for block shear and delamination tests. Lamina were finger-jointed and 12-ply glulams were manufactured by a commercial producer. A PRF resin (Cascophen LT 5210J) with a catalyst (FM6210S) at a ratio of 2.5:1 was used. The resin was modified with resin modifier at 2 percent (m/m) to improve bonding with the preservative-treated wood. The glue loading rate was 0.49 kg/m^2 (100 lb/1,000 ft^2). The assemblies were clamped and cured overnight under indoor ambient conditions.

Block shear and delamination testing

The 12-ply glulam specimens were evaluated in a block shear test as described in Section 9.2 of CSA O177-06 (CSA Group 2006). Each of the 11 glue lines in each specimen were tested. The specimens were tested dry with shear load recorded and wood failure tabulated. Shear strength data were compared between untreated planed, treated planed, and treated roll-pressed groups for lodgepole pine and Pacific silver fir using multiple *t*-tests and the Bonferroni correction.

A three-cycle vacuum-pressure and drying cycle delamination test was conducted following methods described in Section 9.3.1 of CSA O177-06 (CSA Group 2006). The specimens were exposed to three consecutive cycles consisting of 8 hours of vacuum-pressure followed by 72 hours of drying at 27 ± 3°C. Glue line delamination was measured after the third cycle when the specimens reached their original moisture content.

Durability field tests

The specimens that were put into field tests are listed in Table 1. Some treatment groups have fewer specimens than desired on account of limited material availability. Three different field exposures were used to evaluate the performance of these materials under a range of exposure conditions.

A modified post and rail test featuring an angled component inset into a vertical member (gamma joint) was used to evaluate decay resistance above-ground (Fig. 1).

Table 1.—Description of specimens used in field testing.

Species	Preservative	No. of plies	No. of test specimens: Above ground	Ground contact	Ground proximity
Pacific silver fir	ACQ-D	5	10	6	
	CA-B	5	10	6	
	Untreated	5	6	2	
Lodgepole pine	ACQ-D	5	10	5	
	CA-B	5	10	6	
	Untreated	5	6	2	
Red pine	ACQ-D	5	10	6	
	CA-B	5	10	6	
	Untreated	5	6	2	
Pacific silver fir	ACQ-D	12			5
	Untreated	12			8
Lodgepole pine	ACQ-D	12			6
	Untreated	12			9
Yellow cedar	Untreated	12			9

The test units and exposures were similar to those described in AWPA E32-18 (AWPA 2020b). The test units were bolted to test racks approximately 1 m above ground and installed at the Maple Ridge test site in September 2008.

The angled piece of the gamma joint was removed from each test unit to facilitate inspection. Each unit was inspected for decay every 2 years and given ratings based on the methods described in AWPA E32. This included ratings for the top and bottom of the vertical member, the vertical face of the interior joint, and the inside and exposed ends of the angle piece. The presence of fruit bodies of wood-rotting fungi anywhere on the test unit resulted in a maximum rating of 7. The minimum decay rating for each

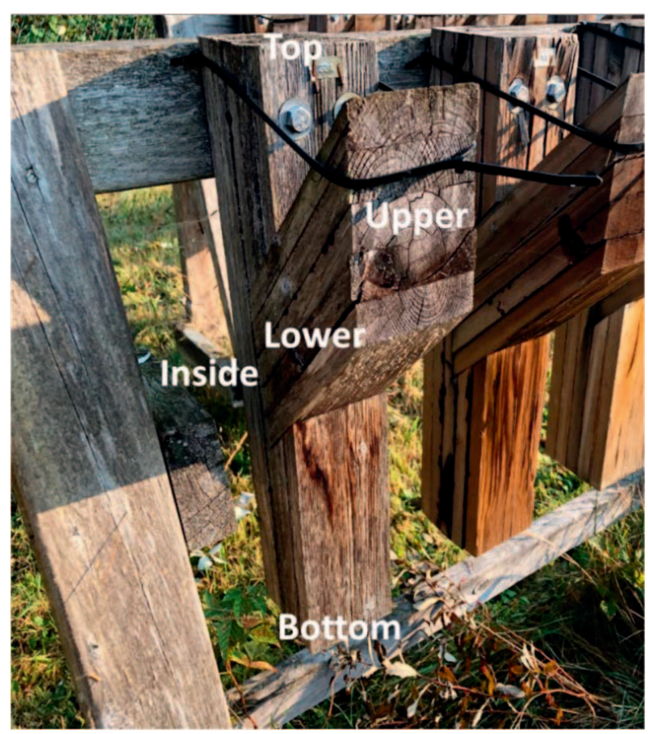

Figure 1.—Above ground (gamma joint) decay test of treated glulam after 12 years of exposure in Maple Ridge, British Columbia.

unit was based on the lowest rating made on any part of the test unit. Delamination of the lower part of the vertical member was observed in some samples and noted.

Six 660-mm-long test specimens were cut for each treatment group, except ACQ-treated lodgepole pine, which had five specimens, and untreated glulams, which were prepared in duplicate. End cuts from treated groups were coated with two coats of copper naphthenate (2% Cu) in mineral spirits. Test specimens were divided into four groups of similar composition and installed in four quadrants at the Maple Ridge test site in April 2010. Sample installation was based on AWPA E7 (AWPA 2020c). Glulams exposed in ground contact (Fig. 2) were removed and inspected annually for decay and given a decay rating based on the methods described in AWPA E7.

Specimens of 390-mm length were cut from the 12-ply glulam beams. End cuts were sealed with two coats of 2 percent copper naphthenate in mineral spirits. Two bolt holes were drilled through all layers of each sample. A stainless-steel bolt was dropped into one hole and a galvanized steel bolt into the other. The bolts were not secured in place and did not extend beneath the glulam but sat flat with the bottom of the samples. Test specimens were placed atop concrete blocks and abutted against concrete blocks on each end to create a moisture trap around the specimen ends. Test samples were installed at the Maple Ridge test site in April 2010 (Fig. 3). Materials were inspected for decay in 2015 and in 2020. Both ends of the glulam pieces, as well as the top and bottom faces, were inspected and given ratings for decay based on AWPA E7. The ends were distinguished by their proximity to either the galvanized or stainless-steel bolt (Fig. 3).

Test site

Test materials were exposed within the University of British Columbia's Malcolm Knapp Research Forest in Maple Ridge, British Columbia. The site is a gently sloping grassy field that has been used for durability testing since 2001. The site has mean daily maximum and minimum temperatures of 6.8°C and 1.8°C in January, and 23.8°C and 12.8°C in July. It receives a mean annual precipitation of

Figure 2.—Ground proximity test unit showing galvanized (left) and stainless-steel (right) bolts after 10 years of exposure in Maple Ridge, British Columbia.

Figure 3.—Treated 5-ply glulam samples from one quadrant in the ground contact test after 10 years of exposure in Maple Ridge, British Columbia.

2,150 mm. Based on climate data from 1970 to 2000, it has a Scheffer Index of 63, placing it in the moderate decay hazard zone (Morris and Wang 2008). The soil is a sandy silt loam to a depth of 0.3 m with a pH around 5.1 and approximately 18 percent organic matter. Below this is a layer of fine- to coarse-grained sand with some gravel and silt.

Results and Discussion

Block shear and delamination testing

The 12-ply glulam beams made from ACQ-treated lamina that were replaned before gluing had similar shear strength to the 12-ply glulam beams made from untreated planed lamina (Table 2). Treated lamina that were roll-pressed before gluing had significantly lower shear strength than the replaned lamina ($P < 0.05$). The shear strength of bonded treated lamina that were replaned after treating was not significantly different than that of bonded untreated lamina ($P < 0.05$). The average wood failure rate was >98 percent for all treatment groups. In the 3-cycle delamination tests according to CSA 0177-06 standard, as seen in Table 2, glulam beams made from roll-pressed lamina of ACQ-treated Pacific silver fir or ACQ-treated beetle-killed lodgepole pine gave higher average delamination rates (2.5% and 1.9%, respectively) and larger standard deviations than the glulam beams made from the corresponding replaned lamina (0.2 and 0.8%, respectively). The delamination tests of these glulam beams were probably indicative of their suitability for use in outdoor environment. Delamination rate exceeding 1% would indicate unsuitability of outdoor application (Henrique de Almeida et al. 2014). The field test outcomes after 12 years of outdoor exposure were in agreement with the results of block shear tests and delamination tests.

Durability field tests

Gamma joints.—After 12 years of exposure, untreated gamma joints had failed or were severely decayed (Table 3). The treated gamma joints showed signs of early decay with average decay ratings ranging from 9.2 to 9.8. Decay was

Table 2.—Block shear and delamination results for 12-ply glulam beams.

Species	Treatment	Block shear test			3-cycle delamination test	
		N	Shear strength (MPa)	Wood failure (%)	*N*	Delamination (%)
Pacific silver fir	ACQ, roll-pressed	174	5.66 (2.10)	99 (4.8)	88	2.5 (4.9)
	ACQ, replaned	146	9.63 (2.22)	99 (2.4)	77	0.2 (0.8)
	Untreated, planed	350	9.21 (2.16)	99 (3.7)	176	1.3 (3.1)
Lodgepole pine	ACQ, roll-pressed	262	8.56 (2.23)	99 (3.8)	132	1.9 (4.5)
	ACQ, replaned	88	11.46 (3.16)	99 (4.3)	44	0.8 (3.6)
	Untreated, planed	389	11.10 (2.60)	98 (5.7)	198	0.6 (2.5)
Yellow cedar	Untreated, planed	344	12.37 (3.27)	99 (5.0)	176	0.9 (2.6)

Table 3.—Average decay ratings of treated glulam exposed in an above-ground (gamma joint) test for 12 years in Maple Ridge, British Columbia. Standard deviations are shown in parentheses.

Treatment	Species	Total number	Total delamination failures	Top	Bottom	Inside	Angle lower	Angle upper	Average minimum decay rating
CA-B	LPP	10	1	9.5 (0.8)	10 (0)	9.7 (0.7)	9.9 (0.3)	10 (0)	9.4 (1.0)
	PSF	10	1	9.6 (0.7)	9.9 (0.3)	9.9 (0.3)	9.7 (0.5)	10 (0)	9.5 (0.7)
	RP	10	0	9.7 (0.5)	10.0 (0)	10.0 (0)	9.9 (0.3)	10 (0)	9.6 (0.5)
ACQ-D	LPP	10	4	9.3 (0.7)	9.9 (0.3)	9.6 (0.5)	9.4 (0.8)	10 (0)	9.2 (0.8)
	PSF	10	4	9.6 (0.7)	10 (0)	10 (0)	10 (0)	10 (0)	9.8 (0.4)
	RP	10	1	9.6 (0.7)	10 (0)	9.8 (0.4)	9.9 (0.3)	10 (0)	9.4 (0.7)
Untreated	LPP	6	1	6.2 (1.3)	9.2 (0.8)	7.0 (0.7)	7.4 (1.1)	9.4 (0.9)	6.2 (1.3)
	PSF	6	1	3.8 (2.9)	8.3 (0.6)	3.4 (3.3)	2.8 (3.8)	6.3 (5.5)	2.2 (3.2)
	RP	6	0	2.3 (2.7)	7.3 (0.6)	3.6 (3.5)	3.4 (3.3)	4.5 (5.0)	2.3 (2.7)

most often found on the top of the vertical member, the inside face, and on the lower angle.

Twelve specimens failed as a result of delamination during inspection or in previous years. All species and all treatments had at least one delamination failure. Failures occurred in a similar manner in all specimens, always occurring near the lamination closest to the bottom of the interior joint of the vertical member. This would have been the most stressed bond line because of the weight of the angle piece and the water trapping. Observation of the delamination showed a high percentage of wood failure near the bond line (Fig. 4), suggesting that the wood near the bond line may have been weakened by the pressing of the lamina prior to gluing. There were also signs to indicate that the roll-pressing of the lamina prior to gluing did not achieve sufficiently flat surfaces to allow complete intimate contact between lamina along the bond line. These data suggest that this method may not be an appropriate way to manufacture treated glulam, or that tighter controls on the temperature and moisture content of the wood and the force applied to the wood would need to be defined to minimize or eliminate crushing of the cell walls but also ensure adequate

Figure 4.—An example of delamination failure in one of the gamma joint test units. The lighter colored sections indicate wood failure.

smoothness on lamina surfaces, and these would need to be implemented into the process. This contrasts with other work that has shown that lamina treated with copper-based preservatives can be effectively bonded with replaning or resurfacing following treatment (Lee et al. 2006, Podgorski and Legrand 2006, Gaspar et al. 2010, Yang et al. 2012, Dias et al. 2020).

Ground contact.—After 10 years of exposure, advanced decay was observed in the untreated controls (Table 4). Pacific silver fir had the most advanced decay, likely due to the low natural durability of its heartwood (Morris et al. 2014). Early stages of decay were observed in all treated groups with average decay ratings ranging from 8.7 to 9.3. It is clear from looking at the average decay ratings, that the untreated controls are highly vulnerable to decay and that both ACQ and CA treatments greatly slow this process (Fig. 5). More time is needed to define the service life, with respect to decay, of the treated glulam in this exposure.

The average decay ratings obtained on these treated 5-ply glulam specimens were slightly lower than data from treated nominal 2 by 4 stakes reported by Morris et al. (2017). In that study, Pacific silver fir stakes treated to similar retentions had average decay ratings of 9.1 for ACQ-D, 9.9 for CA-B, and 0.8 for untreated.

The CAN/CSA-O80 standard (CSA Group 2015) allows the use of lodgepole pine, red pine, and Pacific silver fir to be treated with CA-B or ACQ-D for preservative treatment of laminations before gluing. For ground contact applications (UC4.1) specified retentions are 3.3 kg/m^3 for CA-B and 6.4 kg/m^3 for ACQ-D. The present data show that material treated substantially below this standard was largely sound after 10 years of field exposure. AWPA U1 (AWPA 2020a) currently allows Pacific silver fir treated with ACQ type A, ACQ type C, and CA type C to be used in laminations prior to gluing. These data on closely related preservative systems suggest that they would also be effective treatments.

Ground proximity.—After 10 years of exposure, the majority of untreated lodgepole pine and Pacific silver fir 12-ply glulam specimens had failed as a result of decay or exhibited advanced decay (Table 5, Fig. 6). The yellow cedar reference exhibited moderate decay with an average minimum rating of 7.6. Glulam made from lodgepole pine or Pacific silver fir lamina treated with ACQ exhibited early stages of decay. The greatest extent of decay was observed on the sample ends and on the bottom surface that was in contact with the concrete block. At 5 years it was hypothesized that lower extent of decay on the galvanized bolt side of the untreated controls may have been due to the protective effective against decay of the zinc leaching from the galvanic coating. At 10 years the average decay ratings on each end were very similar, suggesting that any protective effect from the zinc was short-lived, and that this would not make up for the absence of a primary treatment. Such an effect may also be less important in wood treated with a preservative that contains mobile copper because this would also provide protection to the bolt hole (Morris et al. 2004).

Table 4.—Average decay ratings of treated glulam exposed in ground contact for 10 years in Maple Ridge, British Columbia. Standard deviations are shown in parentheses.

Species	Treatment	Average retention (kg/m^3)	Average penetration (mm)	Average decay rating
Lodgepole pine	ACQ-D	5.0	11 (7)	8.8 (0.4)
	CA-B	2.6	13 (7)	8.8 (0.4)
	None	—	—	5.0 (1.4)
Pacific silver fir	ACQ-D	4.5	17 (5)	8.8 (0.4)
	CA-B	2.0	13 (7)	9.3 (0.5)
	None	—	—	2.0 (2.8)
Red pine	ACQ-D	4.5	18 (3)	8.7 (0.5)
	CA-B	2.3	16 (5)	9.3 (0.5)
	None	—	—	4.0 (0)

Conclusion

Roll-pressing treated lamina was associated with a reduction in shear strength. In an above-ground field test this was associated with failure due to delamination in several specimens regardless of species or treatment. Further work is needed to identify ways of bonding shell-treated species without resurfacing. Glulam treated with ACQ or CA had little decay after 10 to 12 years of exposure,

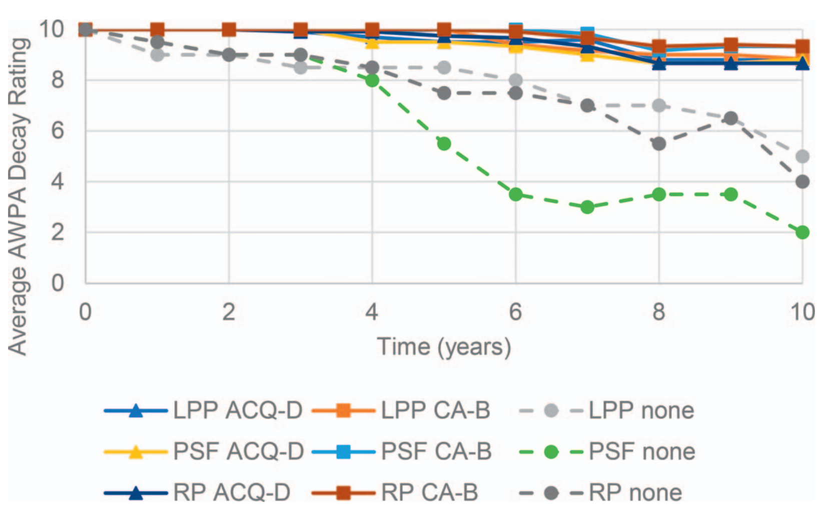

Figure 5.—Average decay ratings of lodgepole pine (LPP), Pacific silver fir (PSF), and red pine (RP) treated and untreated glulam over 10 years of exposure in a ground contact test in Maple Ridge, British Columbia.

Table 5.—Average decay ratings of treated glulam exposed in ground proximity for 10 years in Maple Ridge, British Columbia. Standard deviations are shown in parentheses.

Species	Treatment	No.	Galvanized end	Stainless end	Bottom	Top	Average minimum decay rating
LPP	ACQ-D	6	9.7 (0.8)	9.6 (0.8)	9.6 (0.8)	10.0 (0)	9.5 (0.8)
	None	9	3.8 (3.3)	3.3 (2.8)	3.3 (2.8)	5.9 (4.5)	3.3 (2.8)
PSF	ACQ-D	5	10.0 (0)	10.0 (0)	9.9 (0.2)	10.0 (0)	9.9 (0.2)
	None	8	1.3 (2.4)	0.5 (1.4)	0.5 (1.4)	2.8 (4.1)	0.5 (1.4)
YC	None	9	8.6 (1.2)	8.0 (0.9)	7.8 (0.7)	10.0 (0)	7.6 (0.7)

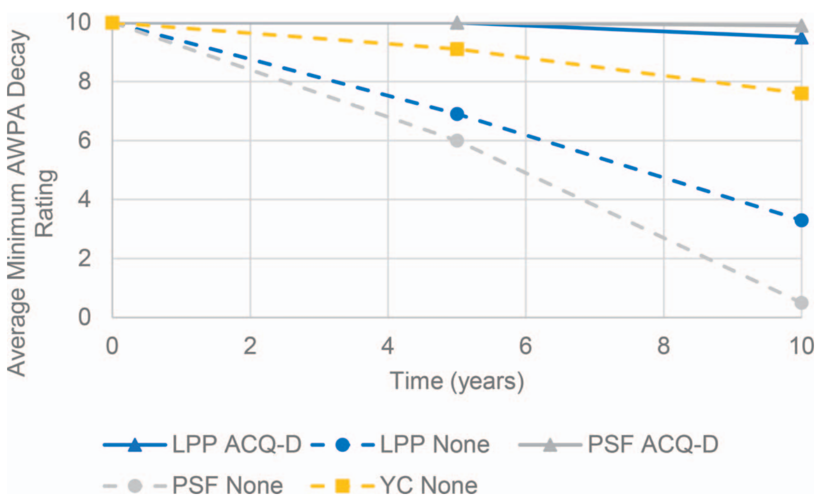

Figure 6.—Average decay ratings of untreated yellow cedar (YC) and treated and untreated lodgepole pine (LPP) and Pacific silver fir (PSF) glulam over 10 years of exposure in a ground proximity test Maple Ridge, British Columbia.

while untreated controls showed advanced decay or had failed. In the ground proximity test, a moderate level of decay was observed in the yellow cedar glulam reference.

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