

EFFECTS OF CONDITIONING EXPOSURE ON THE pH DISTRIBUTION NEAR ADHESIVE–WOOD BOND LINES

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Abstract. The pH distribution near the adhesive–wood bond line in black spruce (*Picea mariana*) and Douglas-fir (*Pseudotsuga menziesii*) bonded with various acidic and alkaline adhesives was investigated. For alkaline adhesives, exposure to moderate to high RH conditions and to accelerated aging treatments such as vacuum-pressure-dry or water soaking resulted in diffusion of hydroxyl ions (OH^-) away from the bond line and decreased alkalinity. A moderate increase of pH in the bond line was also observed for acidic adhesives, and under very wet conditions, hydrogen ions (H^+), also diffused away from the bond line. Spruce and Douglas-fir samples exposed to strongly acidic and alkaline buffered solutions for 3 mon did not show appreciable changes in chemical composition by wet chemical analysis. FTIR attenuated total reflectance spectra of samples bonded with an alkaline adhesive and exposed to either dry or wet conditions showed dissociation of carboxylic acid groups in hemicelluloses (decreased absorbance at 1735 cm^{-1}) to a distance of 150–300 μm from the center of adhesive bond lines. No effects on wood chemistry were observed

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around acidic adhesive bond lines. In summary, wood bonded with high-pH adhesives and exposed to wet service conditions rapidly reached moderate pH conditions in the bond line because of the high rate of OH^- diffusion in wood and the acidic buffering capacity of wood. This mitigated the effects of high pH in these alkaline adhesives. A similar but less effective process occurred with acidic adhesives.

Keywords: pH distribution, phenol formaldehyde, melamine formaldehyde, melamine-urea formaldehyde, adhesives, bond line, accelerated aging, chemical change, FTIR ATR.

INTRODUCTION

Thermosetting adhesives for bonding of wood composites are generally catalyzed by acidic or alkaline additives to accelerate the cure rate during hot pressing. As more extreme pH adhesives are formulated to improve bonding and increase cure rates, there is a concern that the highly acidic or alkaline conditions in the bond line might degrade the adhesive or the wood itself leading to early failure, especially in composites exposed to wet service conditions. Alternatively, overly conservative pH requirements in adhesive standards could limit the range of adhesive technology available to bonded wood product manufacturers or increase press time and processing costs.

Potential adverse effects of extreme pH adhesives could occur to the wood substrate, the bond line, and/or the interface of wood/adhesive depending on the resin pH and alkalinity or acidity, the pH and buffering capacity of the wood, chemistry of the wood, and exposure conditions. Regarding the last factor, high temperature and humidity could accelerate deleterious effects on the wood, but also speed up the migration of hydrogen ions (H^+) or hydroxyl ions (OH^-) from the bond line, thereby mitigating any adverse effect.

Some studies have documented that highly alkaline and acidic exposures affect the chemical composition of wood resulting in decreases in mechanical properties. Wood hemicelluloses are degraded and solubilized at alkaline conditions, and under extreme conditions, lignin may also be degraded. Zimmermann et al (2007) showed that 5-h exposure of spruce wood to 10% NaOH, 18% NaOH, or 24% KOH at room temperature resulted in slight reductions in

hemicellulose components and, in most cases, significant reductions in bending strength and stiffness. No lignin degradation was observed with these treatments.

Some research has identified effects of the acidity and alkalinity of adhesives on bond durability and on the wood substrate. Blomquist (1949) investigated the effects of alkalinity of a hot-press phenol formaldehyde (PF) adhesive on the durability of yellow birch and Douglas-fir plywood joints under different exposure conditions by adding different amounts of NaOH to the adhesive formulation (final film pH of cured adhesives = 10.0-11.5) before spread. Exposure at room conditions (27°C/65% RH) for 2 or 3 yr had no significant effect on the durability of any of the adhesive joints. However, based on the loss in the shear strength and the difference in the appearance of the wood failure, it was concluded that exposures at an elevated temperature/low humidity (70°C/20% RH) or at room temperature/high humidity (27°C/97% RH) resulted in damage to the birch wood bonded with the most alkaline hot-pressed PF formulations when tested wet. A similar but less severe effect was observed in the case of Douglas-fir wood. On the other hand, Santos et al (2003) examined the effects of pH (12.00, 12.25, 12.50, 12.75, 13.00, 13.25, and 13.50) on the performance of thermosetting adhesive formulations and found no adverse effect on the wood.

Some adhesives become more acidic during curing. The acid-induced gelling reactions can cause severe deterioration of the wood substance (Pizzi et al 1986). Wangaard (1946) reported that intermediate temperature curing PF adhesives with high amounts of acidic catalysts could cause wood deterioration and thus low joint

strength under high temperature and humidity accelerated exposures. In determining the effect of acidic catalysts on strength of PF resin-bonded plywood, Kline *et al.* (1947) found that hydrochloric, benzenesulfonic, nitric, and sulfuric acids had pronounced deteriorating action on the wood, especially when the pH values of birch veneers were reduced within a range of 2.1–2.4. Furthermore, birch veneers bonded with acidic adhesives had reduced flexural, impact, and shear properties. They concluded that the critical pH value below which optimum strengths were not achieved and deterioration on aging became appreciable was approximately 3.5. Gillespie and River (1975) reported that yellow birch and Douglas-fir plywood shear specimens stored for 4 yr at ambient room conditions (27°C/30% RH) lost little, if any, strength when bonded with nonacidic adhesives but showed appreciable strength loss when bonded with acidic adhesives, the latter being attributed to the degradation of the wood during the storage period. Raknes (1976, 1981) also reported that acidic PF adhesives started showing signs of failure after 10–15 yr probably because of acid damage to the wood.

Current wood adhesive standards vary in their specifications for allowable acidity or alkalinity, as determined for example by dry adhesive film pH by ASTM D 1583 (ASTM 2008). ASTM D 2559 (ASTM 2004) and Canadian Standards Association (CSA) standards O112.6 and O112.7 (CSA 1977a, 1977b) all set a lower limit for dry film pH of 2.5 for structural adhesives, whereas draft ISO standard ISO/DIS 20152.1 (ISO 2008) specifies pH of 3.0 or higher. Many structural adhesive standards, including ASTM D 2559 and CSA O112.6, place no upper limit on pH for alkaline adhesives, but CSA O112.7 and the draft ISO/DIS 20152.1 (2008) set an upper limit on dry film pH of 11.0. Standard CSA O112.9 (CSA 2004) was recently developed in Canada to evaluate adhesives for products for wet use or exterior exposure. As originally written, it specified the dry film pH to be not less than 3.0 and not greater than 11.0. A recent amendment by the relevant CSA committee reduced the lower limit to pH

2.5 and removed the upper pH restriction until or unless evidence of bond-line deterioration is shown. Increasingly, there is an interest to re-evaluate whether the pH restrictions or lack of them are warranted for such applications.

The pH of cured film tested according to ASTM D 1583 is expected to be different from the bond-line pH because NaOH penetrates into wood with adhesive penetration during the curing process, depending on wood MC and bonding pressure and adhesive viscosity. In situ pH may also be affected by the pH and buffering capacity of the wood. Posttreatment conditioning is also expected to affect the pH distribution around the bond line.

The objective of this study was to evaluate the pH environment and wood chemical changes in and around adhesive bond lines as affected by the original dry film pH of the adhesive and to compare these effects for different exposure conditions, including accelerated aging. This information will be used to help determine if there is a need to place stricter pH limitations on adhesives used in wood composites under wet service conditions.

MATERIALS AND METHODS

Commercial structural wood adhesives, representing a wide range in dry film pH properties, were acquired from adhesive manufacturers (Table 1). All of the adhesives investigated were measured for dry film pH according to CSA O112.6 for hot setting resins.

Effect of Ambient Conditions on Bond-Line Thickness and pH Distribution

Black spruce samples bonded with alkaline PF Resin-I were prepared to evaluate the effects of ambient conditions and conditioning time on the bond-line thickness and pH distribution around the bond line. The adhesive was applied (0.30 kg/m²) to surfaces of two 22-mm-thick planed spruce boards (600 × 87 mm), which were pressed together in an 850- × 850-mm laboratory press (platen temperature: 150–160°C; pressure: 1.03 MPa; press time: 30 min). Nominal 50- × 40-mm samples

Table 1. Structural wood adhesives evaluated and effect of vacuum-pressure-dry (VPD) and long-term exposure on pH in bond line.

Resin ID	Resin type	pH of cured film	Maximum bond-line pH after VPD		Maximum bond-line pH after long-term exposure for Douglas-fir assembly		
			B. Spruce	Douglas-fir	4 mon	8 mon	12 mon
Resin-I	PF	12.8	8.9	8.4	4.2	4.1	4.0
Resin-II	PF	12.8	7.0	—	5.2	4.9	3.9
Resin-III	PF	12.5	6.4	6.7	4.4	4.3	3.7
Resin-IV	PF	12.1	5.9	6.7	4.3	4.3	3.8
Resin-V	PRF	10.6	7.6	7.1	4.0	3.8	3.6
Resin-VI	MUF	3.0	4.1	—	3.8	3.7	3.5
Resin-VII	MUF	2.7	4.3	—	3.9	3.7	3.6
Resin-XI	MF	3.7	2.8	—	3.4	3.7	3.6
Resin-XII	MF	3.6	—	—	3.6	3.5	3.4

PF, phenol formaldehyde; PRF, phenol-resorcinol formaldehyde; MUF, melamine-urea formaldehyde; MF, melamine formaldehyde.

were held for different periods of time at ambient conditions (21°C/48-65% RH; 5-9% MC), moderate humidity conditions (30°C/80% RH; 12-13% MC), or high humidity exposure (50°C/80-94% RH; 16-17% MC).

The adhesive film thickness and penetration into wood in the spruce samples were estimated from the density profile of samples (50 × 40 × 44 mm) after conditioning to ambient room condition. The samples were placed in an X-ray densitometer (QMS density profiler, QDP-01X; Quintek Measurement Systems, Inc) with the bond line parallel to the direction of X-rays. The change in density along the thickness direction was recorded at 0.06-mm intervals.

At each test time interval, four to five replicate 10- × 10-mm samples were cut from the interior of the bonded samples and trimmed so microtome sections could be taken around the bond line. The samples were microtomed in the dry condition to avoid affecting the distribution of acid or alkali. Each sample was clamped in a microtome, and the sample holder was adjusted so the microtome blade was parallel to the bond line. Approximately 2-3 mm of wood on both sides of the adhesive-wood interface together with the bond line were microtomed layer by layer (30 µm in thickness for each microtome section). Four microtome sections were collected sequentially in preweighed 1.5-mL plastic vials, and an appropriate amount of cool newly boiled deionized water, equal to 15 times the calculated oven-dried sample weight, was added

to each vial. The vials were sealed and kept at ambient temperature for 3 da. The pH values were then measured using a PH17-SS ISFET sensor micropH probe coupled to an IQ150 pH meter (IQ Scientific Instruments, Inc).

pH Distribution in Conditioned Shear Block Specimens

To investigate the effects of accelerated aging protocols on the pH distribution, shear block specimens were prepared and conditioned according to CSA O112.9. After shear tests were complete (shear strength results were reported by Wang et al [2009a, 2009b]), the failed samples were evaluated for pH distribution as mentioned previously. High-grade black spruce [*Picea mariana* (Mill) BSP] (38 mm × 140 mm × 3.7 m) and Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*] (38 mm × 89 mm × 2.4 m) lumber samples were selected at a local sawmill. From these samples, billets were cut with the following dimensions: black spruce = 820 × 138 × 31 mm (length × width × thickness) and Douglas-fir = 820 (or 600) × 88 × 32 mm. The billets were planed on both surfaces to about 21-mm thickness, measured for weight and density, and stored at 21°C/65% RH to achieve about 12% EMC before use. The adhesives listed in Table 1 were applied at manufacturer recommended rates. An 815- × 915-mm platen hydraulic press was used to press the test assemblies following

the procedures recommended by adhesive manufacturers. Before shear block testing of samples from these assemblies, test specimens had been exposed to postbonding exposure conditions including:

- 1) Air-dried—The bonded block shear specimens were conditioned to constant weight at 21°C/65%RH.
- 2) Vacuum-pressure-dry (VPD)—The specimens were immersed in tap water in an impregnation tank, and a vacuum of -90 kPa was applied for 30 min followed by a pressure of 550 kPa for 120 min. After impregnation, excess water was wiped from the specimen surfaces, and the specimens were placed in an oven at 60°C and conditioned at 21°C/65%RH to constant weight.
- 3) Long-term exposure—Wet specimens that had been subjected to a vacuum-pressure treatment were double-sealed in plastic bags and placed in a chamber maintained at 50°C for 4, 8, or 12 mon. At each designated exposure time, the specimens were removed from the chamber, weighed, dried in an oven at 60°C, and conditioned as mentioned previously.

To evaluate the effects of other exposure conditions, some of the air-dried samples (black spruce bonded with Resin-I) were exposed to:

- 4) High humidity conditions—exposure at 33°C/90% RH for 30 da.
- 5) Wet conditions—vacuum treatment in water at -85 kPa for 30 min followed by soaking in water for 1 or 30 da.

After specimens were tested for block shear strength, they were oven-dried to determine MC of specimens at test. Before bond-line area pH measurements were made, all specimens were conditioned to about 6% MC.

Chemical Changes to Wood Exposed to Extreme pH Conditions

Black spruce and Douglas-fir samples were ground with a Wiley mill, and the fraction between 40 and

70 mesh was chosen and exposed to buffered solutions at pH 2.0, 3.0, 11.0, and 12.0 and deionized water for 3 mon and analyzed for cellulose, hemicelluloses, and lignin content according to Browning (1967) and Effland (1977). The microtomed samples from near the bond line of selected samples were analyzed directly by FTIR attenuated total reflectance (HYPERION FT-IR Microscope, Bruker Optics).

RESULTS AND DISCUSSION

Estimated Bond-Line Thickness by Density Profile

The presence of PF resin in the bond line increased the sample density in this region permitting an estimate of the bond-line thickness. Although there was some variability sample to sample, this technique indicated a bond-line thickness of 500-600 μm for the black spruce bonded with alkaline PF Resin-I. This was narrower than the zone of elevated pH levels near the bond line as determined by the pH of the microsections. In the example shown in Fig 1, the bond line was 500-600 μm thick according to the density profile, whereas the zone of increased pH was about 1200 μm wide, ie the penetration of alkali from the adhesive film into the adjacent wood was about 300 μm .

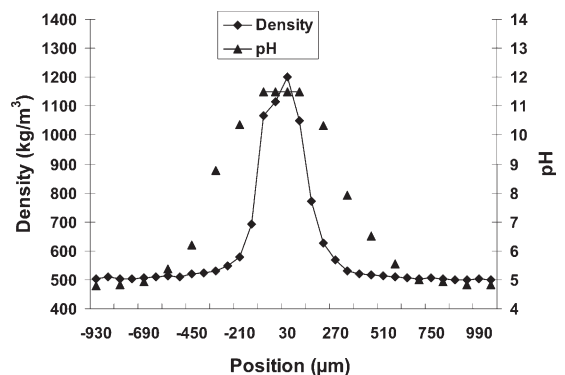


Figure 1. Comparison of bond line zone after hot pressing (black spruce and Resin-I) and conditioning at room temperature as characterized by density profile and pH distribution.

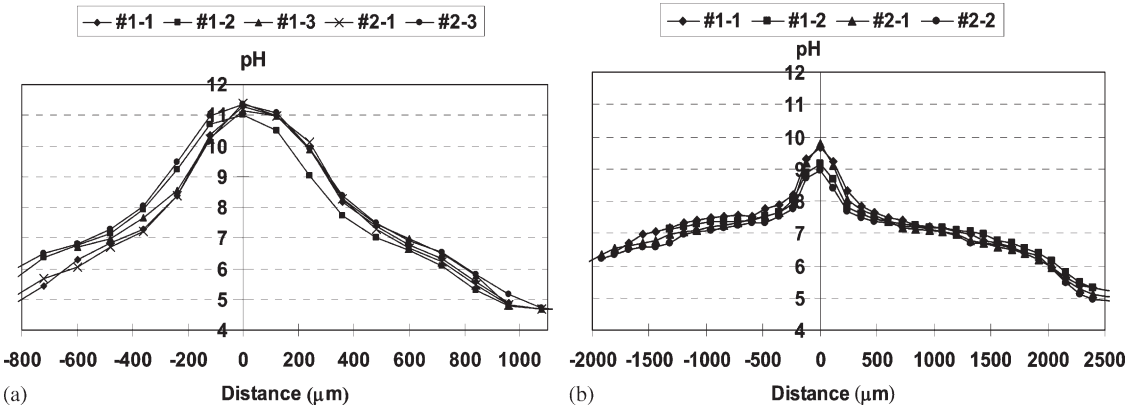


Figure 2. Reproducibility of pH measurements of microtome samples: (a) 5 replicate samples after 1 wk at 30°C/80% RH and (b) 4 replicate samples after 14 wk at 30°C/80% RH.

This results from the diffusion of the alkaline catalyst from the adhesive layer into the adjacent wood during adhesive application and hot pressing.

Effect of Conditioning on pH Distribution Around the Bond Line

Alkaline adhesives. By pH measurement of microtome sections cut from dry samples, the effects of conditioning on pH distribution could be reliably determined. Examples of consistency of pH measurements for replicate samples are shown in Fig 2 for samples exposed for different times at 30°C/80% RH. For all of the alkaline resins tested, the maximum pH in the bond line after hot pressing was lower than that of the pure dry resin. The air-dry sample bonded with adhesive Resin-I (Fig 3) had an in situ film pH of about 11.5 compared with a dry adhesive film pH of 12.8. This is likely because of the migration of alkali as noted previously and the buffering effect of the wood that partially neutralizes the alkaline resin. Samples held under dry conditions (48-65% RH, about 7% wood MC) after pressing had no significant change in the pH profile or of the maximum bond-line pH (Fig 3) after 2 mon.

When samples were maintained at 50°C/80-94% RH (wood MC about 16%), there was a very rapid change in pH distribution (Fig 3).

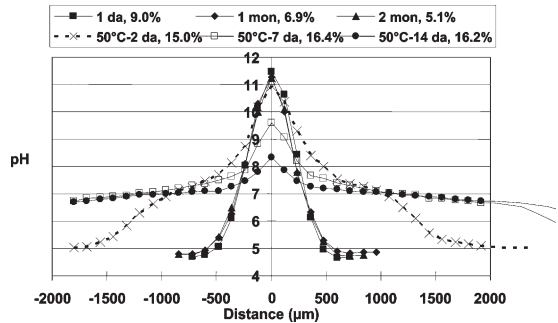


Figure 3. pH distribution around the bond line of alkaline PF resin (Resin-I) bonded black spruce specimens exposed to ambient low humidity conditions for up to 2 mon and high RH (80-94% RH) at 50°C for up to 14 da. Values in the legend are wood MCs at the time of test.

After 2 da, the zone of increased pH had increased to about 1500 μm on each side of the bond line and the peak pH at the center of the bond line had dropped from 11.5 to 10.9. After 1 and 2 wk, the maximum pH had dropped significantly to 9.5 and 8.3, respectively, and the alkali had diffused beyond the zone measured and more than 2 mm to either side of the bond line.

Even under moderately humid and ambient temperature conditions, the environment around the bond line of the alkaline adhesive changed rapidly. With exposure of bonded samples to 30°C/80% RH, the MC of the wood increased to 12-13%, and the depth of alkaline migration from

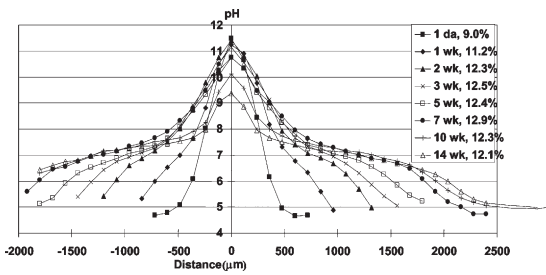


Figure 4. Average of 4-5 pH distribution around the bond line of alkaline PF resin (Resin-I) bonded black spruce specimens exposed to moderate humidity conditions (80% RH) at 30°C conditions for up to 14 wk. Values in the legend are wood MCs at the time of test.

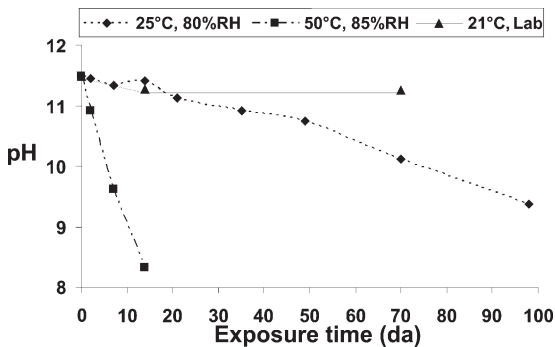


Figure 5. Effect of exposure time and conditions on the maximum pH at the center of the bond line—Black spruce Resin-I.

the bond line into the wood increased with the exposure time (Fig 4). After 5 wk, the zone of elevated pH had increased to about 3.5 mm and after 14 wk to about 5 mm compared with about 1 mm initially. The peak pH level at the center of the bond line decreased with exposure time for both temperature and humidity conditions (Fig 5); after 5 wk, the average peak pH was 10.75 and after 14 wk, 9.4, compared with a dry film pH of 12.8 and a peak film pH soon after treatment of about 11.5.

Accelerated aging procedures applied as part of CSA O112.9 evaluation of block shear specimens also affected the pH environment around the bond line. The sample soaked in water for 1 da had a similarly high pH as the air-dry sample at the center of the bond line, but the wood pH values were elevated to about 1300 μm

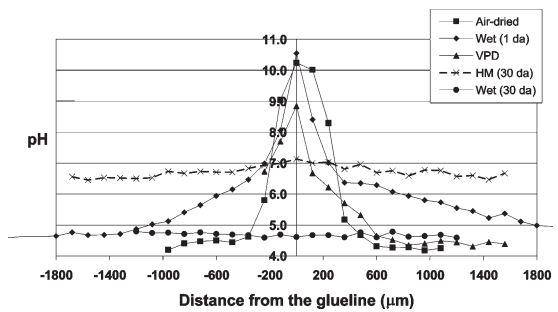


Figure 6. pH distribution around the bond line in black spruce shear block specimens (Resin-I) after different postbonding conditioning. Exposure conditions: air-dried, vacuum-pressure-dry (VPD), high humidity (HM, 30 da), and wet (1 and 30 da).

on either side of the bond line compared with the background wood pH of about 4.7, indicating significant diffusion of OH^- away from the bond line (Fig 6). After 30 da soaking, all alkalinity had dissipated and the pH in the bond-line zone was similar to the normal wood pH. For samples exposed to 33°C/90% RH for 30 da, the pH distribution was relatively flat at about pH 7 over the distances measured, indicating the redistribution of the OH^- ions but retaining a slightly more alkaline condition across the measurement zone compared with the normal wood. The VPD treatment also affected the pH distribution, having a lower pH at the centerline and a distribution of increased alkalinity to about 600 μm from the center of the bond line (Fig 6).

Acidic adhesives. For melamine formaldehyde (MF) Resin-XII, the air-dried sample had a bimodal pH distribution (Fig 7), with the lowest pH values at 100-250 μm on either side of the adhesive centerline, suggesting some H^+ migration from the adhesive film during pressing. The minimum pH of about 3.2 was lower than the dry film pH of 3.6, which was probably attributed to more acidic materials produced because of reactions between some components of the MF resin and the hardener components. The sample exposed to high humidity for 30 da had a similar pH distribution as the air-dry sample, suggesting that under these conditions, H^+ did not diffuse significantly

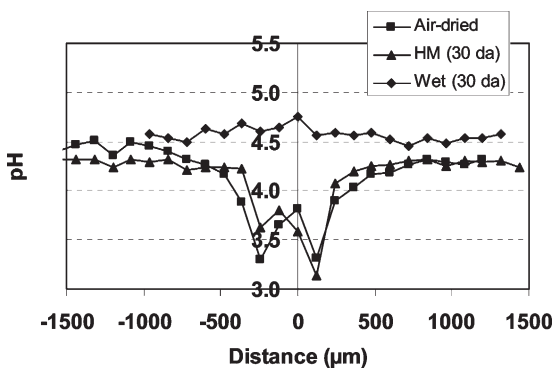


Figure 7. pH distribution around the bond line of black spruce shear block specimens (Adhesive XII) bonded after different postbonding conditioning. Exposure conditions: air-dried, high humidity (HM, 30 da), and wet (30 da).

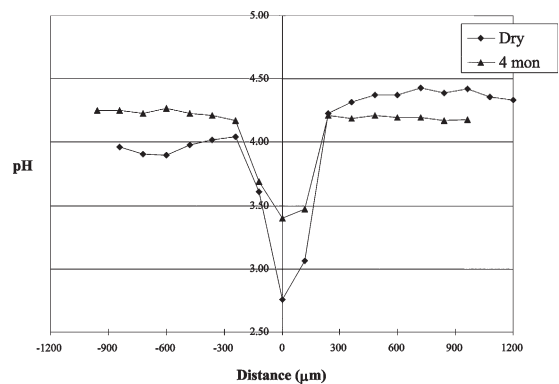


Figure 8. Effect of long-term exposure at high MC on pH profile (Douglas-fir shear block specimens Adhesive XI).

from the bond line. However, saturation and soaking in water for 30 da removed all of the acidity associated with the acidic adhesive from the bond-line area (Fig 7). Acidic MF adhesive XI did not have a bimodal distribution. The pH at the center of the bond line was also lower than its dry film pH. Long-term exposure under wet conditions for 4 mon resulted in less acidic conditions in the bond line but little spreading of the zone of high acidity away from the bond line (Fig 8).

Effect of vacuum-pressure-dry and long-term exposure on pH near bond lines of different adhesives. The bond-line pH of tested shear block samples made with a number of acidic and alkaline adhesives subjected to VPD conditioning treatments before testing are shown in Table 1. The response to conditioning varied somewhat from resin to resin and between black spruce and Douglas-fir, probably indicative of differences in alkalinity and acidity of the adhesives and wood species. However, in all cases, the conditions in the bond line were much less extreme than indicated by the dry adhesive film pH. For Douglas-fir block shear samples subjected to long-term exposure, at all exposure times, the pH in the bond lines were similar to that of Douglas-fir wood (Table 1), confirming that after 4 mon under these conditions, both the acid and the alkali are dissipated

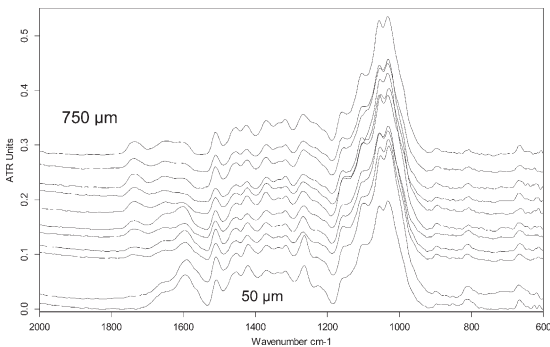
and the wood is not susceptible to extreme pH degradation.

Effect of pH Conditions on Wood Chemistry

Black spruce and Douglas-fir wood dust exposed to acidic or alkaline buffered solutions for 3 mon did not show appreciable or statistically significant changes in the recovery of cellulose, hemicelluloses, or lignin (Table 2). For the wood samples bonded with alkaline Resin-I and maintained at room conditions, FTIR analyses (Fig 9) indicated a decrease of the peak at about 1735 cm^{-1} associated with carboxyl-stretching vibration in carboxylic acid in the hemicelluloses fraction to a distance of 150–300 μm from the center of alkaline bond lines. There was a corresponding increase in the peak at about 1600 cm^{-1} associated with carbonyl stretching vibration in carboxylate salt (Pandey 1999; Zhang and Kamdem 2000; Pandey and Pitman 2003). This change was also observed in the samples bonded with alkaline adhesives and exposed to various postbonding conditioning, indicative of the dissociation of these weak acidic groups at high pH and formation of sodium salts. However, this pH response does not suggest any deterioration of the hemicelluloses. No change in the hemicelluloses fraction was observed by FTIR analysis in wood samples bonded with acidic resins.

Table 2. Chemical components of black spruce and Douglas-fir wood meal after soaking in buffered solutions for 3 mon—2 replicate samples, averages in bold.

Sample	Percent lignin		Percent cellulose		Percent hemicelluloses	
	Spruce	Douglas-fir	Spruce	Douglas-fir	Spruce	Douglas-fir
Control	26.4	29.6	54.4	48.2	—	—
	25.9	29.0	53.2	47.6	—	—
	26.15	29.3	53.8	47.9	20.0	22.9
DW ^a —3 mon	26.9	29.3	54.3	47.1	—	—
	27.0	29.1	53.2	46.1	—	—
	26.95	29.2	53.75	46.6	19.3	24.3
pH 2—3 mon	26.7	29.5	54.73	46.8	—	—
	25.8	29.4	51.86	45.6	—	—
	26.3	29.4	53.30	46.2	20.4	24.4
pH 3—3 mon	26.4	29.5	54.5	45.7	—	—
	26.2	29.3	54.2	45.6	—	—
	26.3	29.4	54.3	45.6	19.4	25.0
pH 11—3 mon	26.5	28.3	53.3	46.6	—	—
	25.9	28.7	55.8	48.5	—	—
	26.2	28.5	54.6	47.6	19.2	24.0
pH 12—3 mon	25.7	28.4	54.0	47.5	—	—
	26.1	27.0	54.2	47.2	—	—
	25.9	27.7	54.1	47.4	20.0	24.9

^a Deionized water.Figure 9. FTIR-ATR partial spectrum for black spruce specimens bonded with Resin-I and exposed to 21°C and low RH (6-7% EMC). From the bottom to top, spectra are for sections 50, 100, 150, 200, 250, 300, 350, 400, 450, 500, and 750 μm from the center of the bond line. Note changes at about 1735 cm^{-1} .

CONCLUSIONS

Wood samples bonded with alkaline adhesives and exposed to moderate humidity conditions at room temperature or to high humidity conditions at elevated temperatures resulted in diffusion of OH^- away from the bond line and decreased alkalinity in the bond line. Similarly, accelerated conditioning treatments such as VPD or wet exposure conditions resulted in a

decrease in alkalinity near the bond line. Under similar conditions, acidic adhesives showed a slight increase in the bond line pH and limited increases in acidity away from the bond line, indicating that H^+ diffuses away slowly under most exposure conditions evaluated.

Wet chemical analysis of wood samples exposed to high and low pH buffered solutions did not show significant differences in chemical constituents. Microtome sections at different distances from alkaline bond lines in black spruce and Douglas-fir were characterized by FTIR attenuated total reflectance. The absorption spectra showed changes indicating hemicellulose carboxylic acid conversion to carboxylate under the alkaline conditions to a distance of 150-300 μm from the center of the bond line. This effect was evident in samples exposed to both dry and wet exposure conditions. Although wood is inherently less able to mitigate the effects of high acidity, no effects on wood chemistry by the acidic adhesives evaluated in this study were observed.

Several factors that mitigated the effects of high pH in alkaline adhesives, including acidic buffering capacity of wood and high rate of

OH⁻ diffusion in wood, suggest that wood bonded with these adhesives and exposed to wet service conditions would rapidly reach moderate pH conditions in the bond line resulting in minimal damage to the wood adhesive joint.

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