Photodegradation of wood affects paint adhesion

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Abstract

Short-term outdoor exposure of southern pine, Douglas-fir, yellow-poplar, Engelmann spruce, and western redcedar prior to finishing affected adhesion of primers. Freshly planed and unpainted panels were exposed outdoors, oriented vertically facing south, for 4 or 8 weeks during the summer near Madison, Wis. The panels were then painted with an alkyd or acrylic latex primer and tested in shear to determine paint adhesion. Results were compared to data from panels not exposed before painting. The change in shear strength was dependent on type of primer, exposure time before painting, and wood species. Panels painted with acrylic latex primer failed primarily at the wood-paint interface, and shear strength decreased with time of exposure. Although panels painted with alkyd primer had no general failure trend for the specimens exposed for 0 or 4 weeks, specimens exposed for 8 weeks before painting failed primarily at the wood-paint interface. The adhesive strength decreased with exposure time for the two lower density species, but increased for the three higher density species. The results from the low density species agreed with previous results using western redcedar. The results from the high density species were unexpected and additional studies are planned.

One of the most serious modes of paint failure on wood is blistering and peeling. This mode usually involves a failure at the wood-paint interface; it can result in damage to the substrate and difficult and costly refinishing. One cause of interface failure is a degraded wood surface caused by weathering prior to initial priming with paint (2-4,9, 10,12,16). These previous studies showed in a qualitative way that long-term weathering of wood prior to painting reduces subsequent paint performance. It was previously reported that paint adhesion to western redcedar decreased up to 50 percent if the wood was exposed outdoors for 16 weeks prior to painting (17).

The objective of the work reported here was to evaluate paint adhesion in several species exposed for 4 or 8 weeks during the summer. This exposure was typical of the degradation that newly installed wood siding might undergo prior to painting. Adhesion was determined by a shear test similar to that used for testing wood-adhesive bonds, and test results were compared with the results for western redcedar from a previous study (17). The same primers were used in both studies. The decrease in paint adhesion to weathered wood reported here is correlated with paint performance on wood panels that are currently being exposed outdoors. The ultimate objective of this research is to relate initial paint adhesion to long-term finish performance.

Experimental methods

Freshly planed vertical-grained panels 410 by 100 by 10 mm (longitudinal by radial by tangential) were exposed outdoors, oriented vertically facing south, for 4 or 8 weeks during the summer of 1987 near Madison, Wis. The species were southern pine (*Pinus* sp.), Douglas-fir (*Pseudotsuga menziesii*), yellow-poplar (*Liriodendron tulipifera*), Engelmann spruce (*Picea engelmannii*), and western redcedar (*Thuja plicata*). For each exposure time, three replicate panels and three end-matched control panels were

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cut from three different large boards. The control panels were kept from exposure to sunlight in a darkened room (27°C, 65 percent relative humidity (RH)). When not outdoors, all specimens were stored in the darkened room.

Following weathering, the wood panels were lightly washed with distilled water, air-dried, and painted by brush with two coats of primer. One half of the panel was painted with an alkyd primer (Sherwin-Williams A-100 primer) and the other half with an acrylic latex primer (Du Pont Lucite, Wood Primer). After curing for 3 months, freshly planed hard maple (*Acer saccharum*) panels were glued to the painted surface of the exposed wood using an emulsion polymer-isocyanate (EPI) adhesive (Ashland Isoset WD2-A312 with 10 percent Isoset CX-11 catalyst). The EPI adhesive contained no organic solvents that might interfere with the paint. The resulting panels were cured in a press (517 kPa (75 psi)) at room temperature for 36 hours. Block-shear specimens were then cut from each assembled primed-wood/maple specimen after the adhesive cured.

Expanded cross sections of the block-shear specimens (Fig. 1) show three interfaces: wood-primer, primer-EPI, and EPI-maple. Because hard maple is a stronger wood than the five test species, the failure was biased toward the weaker wood-paint interface or the wood substrate. The block-shear specimen was a further modified version of specimens as defined in ASTM D 905 (1) and modified by Strickler (14). Block-shear specimens were equilibrated to 12 percent equilibrium moisture content (EMC) and tested using a constant-displacement load rate of 0.38 mm/min. Load and deflection data were acquired during each shear test. All comparisons are based on the stress at specimen failure.

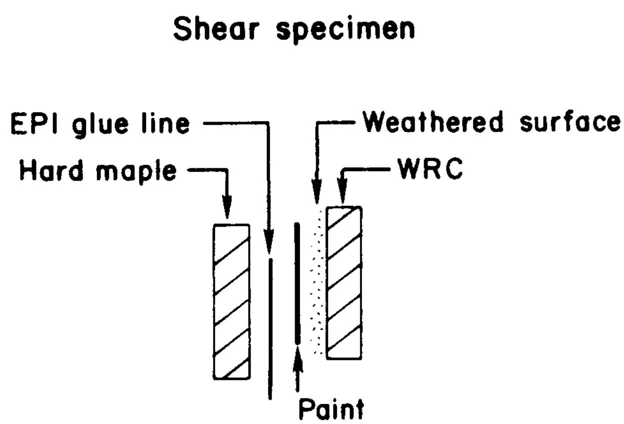

Figure 1. – Expanded drawing of block-shear specimen showing interfaces between the western redcedar (WRC) substrate and the maple panel.

An attempt was made to correlate the strength data with the type of specimen failure. For example, those specimens that failed primarily at the maple-EPI-paint interfaces were removed from the data-set prior to analysis. The analysis of the resulting modified data set did not decrease the coefficient of variation. Therefore, the results reported here include all the data regardless of the type of failure. The means listed in Table 1 are based on all 27 observations for each experimental condition.

Results and discussion

The mean adhesive strengths and standard deviations for both acrylic latex and alkyd primers are listed in Table 1. Analyses of variance (ANOVA) were done to test the null hypothesis of equal means for the groups that had been weathered 0, 4, and 8 weeks. The ANOVA was done for each species, primer, and exposure time combination because of significant interactions of these variables. The exposure times were blocked on boards (a third of each board was assigned to each time), and within-board variability was therefore used to look for differences between the times. The ANOVA results are reported in Table 2 as p values. The p value is the probability that if the null hypothesis were true (that is, the groups had equal means), one would observe as large or a larger difference in means than was observed in this experiment. The p values less than 0.05 were chosen as the cut-off for a statistically significant difference in means. If a statistically significant ($p < 0.05$) difference in means occurred, then Tukey's multiple comparisons of the means were done to determine which of the three means was different from the others (5). In Table 2, the lines under the means indicate no signif-

TABLE 1. – *Mean adhesive strengths and standard deviations for wood painted with acrylic latex and alkyd primers at various times after exposure.*

Primer and species	0 weeks			4 weeks			8 weeks		
	Adhesive strength		SD[a]	Adhesive strength		SD[a]	Adhesive strength		SD[a]
	(psi)	-------- (kPa) --------		(psi)	-------- (kPa) --------		(psi)	-------- (kPa) --------	
Acrylic latex primer									
Southern pine	581	4,011	1,071	331	2,288	1,128	345	2,383	1,491
Douglas-fir	735	5,070	795	624	4,305	664	558	3,849	586
Yellow-poplar	739	5,095	981	646	4,459	715	630	4,346	1,054
Engelmann spruce	757	5,220	917	603	4,171	854	545	3,761	845
Western redcedar[b]	685	4,728	581	720	4,968	913	559	3,859	789
Western redcedar[c]	800			710			560		
Alkyd primer									
Southern pine	790	5,448	1,251	873	6,020	1,264	868	5,985	1,355
Douglas-fir	712	4,910	1,192	815	5,619	995	862	5,944	749
Yellow-poplar	735	5,071	1,165	918	6,334	1,054	808	5,571	1,357
Engelmann spruce	820	5,660	1,490	767	5,292	796	696	4,799	1,398
Western redcedar[b]	845	5,831	1,231	860	5,932	927	553	3,817	946
Western redcedar[c]	690			675			530		

[a] Standard deviations from means.
[b] Results from study with western redcedar reported here.
[c] Results from previous study with western redcedar (17).

TABLE 2. – *Results of Tukey's multiple comparison test of mean adhesive strengths of wood-primer bonds.*[a]

		Alkyd primer				Acrylic latex primer			
			Adhesive strength				Adhesive strength		
Species	Density	*p*	0 weeks	4 weeks	8 weeks	*p*	0 weeks	4 weeks	8 weeks
	(cm^3)			(kPa)				(kPa)	
Southern pine	0.50	0.4495	5,448	6,020	5,985	0.0647	4,011	2,288	2,383
Douglas-fir	0.45	0.0756	4,910	5,619	5,944	0.0177	5,070	4,305	3,849
Yellow-poplar	0.42	0.0614	5,071	6,334	5.571	0.1115	5.095	4,459	4,346
Engelmann spruce	0.33	0.4319	5,660	5,292	4,799	0.0145	5,220	4,171	3,761
Western redcedar	0.31	0.0209	5.831	5,932	3,817	0.0038	4,738	4,968	3,859

[a]The lines under the means indicate the values are not significantly different at the $p = 0.05$ level.

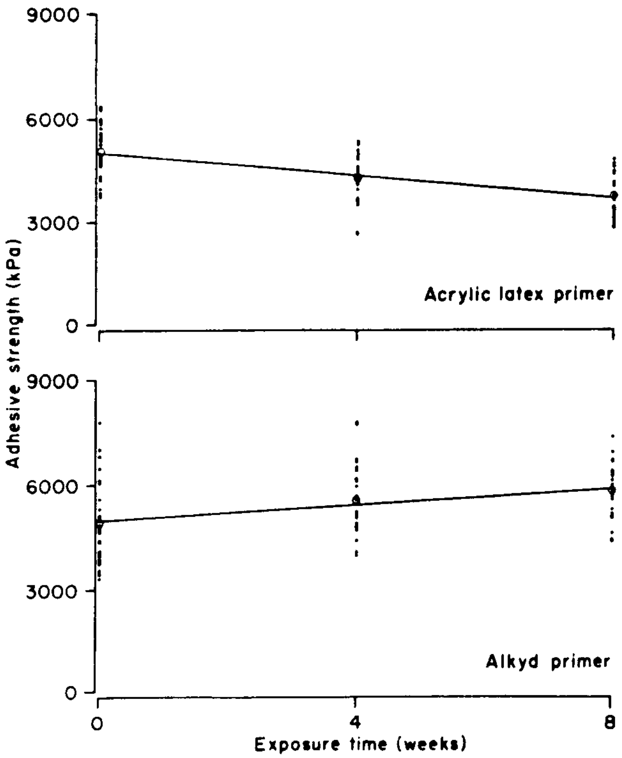

Figure 2. – Adhesive shear strength of Douglas-fir painted with acrylic latex or alkyd primer as a function of exposure time. Mean values are circles.

icant difference between the values at the 0.05 level of probability.

Acrylic latex primer

Although all species finished with acrylic latex primer had decreased mean adhesion values for specimens exposed for 8 weeks, the decrease was only statistically significant ($p < 0.05$) for Douglas-fir, Engelmann spruce, and western redcedar. The decrease in adhesive strength was nearly significant ($p = 0.0647$) for southern pine painted with acrylic latex primer. The decrease in the primer bond to yellow-poplar (the only hardwood included in the study) was unique, though not statistically significant. The erosion rate of wood surfaces is species dependent and is mainly a function of density (7,11). Most softwoods have distinct differences in cell anatomy for the early and late growing seasons. The density of latewood is greater than earlywood. The results with yellow-poplar probably reflect a slower weathering rate for this hardwood species. Many hardwoods have a different erosion pattern. In diffuse porous hardwoods, such as yellow-poplar, the anatomy of cells produced early in the growing season is much the same as that of cells produced later. All cells on the surface of yellow-poplar weather at much the same rate, whereas the earlywood erosion of softwoods is much faster than the latewood erosion.

Alkyd primer

The mean adhesive strengths for the five species finished with alkyd primer show inconsistent trends. For western redcedar, the results were similar to those found for acrylic latex primer and to the results reported earlier for this species (17). No significant difference occurred for the other four species at the 5 percent confidence level. However, contrary to our expectations, mean adhesion values for Douglas-fir, southern pine, and yellow-poplar increased after 4 weeks of weathering. Short-term weathering of these species seems to have improved paint adhesion of the alkyd primer. The increases for Douglas-fir and yellow-poplar were nearly significant ($p = 0.0756$ and $p = 0.0614$, respectively). Douglas-fir, southern pine, and yellow-poplar are denser woods than Engelmann spruce and western redcedar. The denser the wood, the more resistant to weathering (7,11). Further work is planned to explain this apparent difference among species. The results for lower density wood painted with alkyd primer were similar to those found for acrylic latex primer on all the species.

Much of the difficulty in evaluating the shear strength values resulted from the large variability in the data (Table 1). The standard deviations of the means are large, particularly for the alkyd primer. The distribution of the wood-paint shear strength values, as a function of weathering time, for Douglas-fir painted with alkyd and acrylic latex primers (Fig. 2) are typical of the other species. The variability seems large even for shear tests on wood. This variability was attributed to the different failure modes for the specimens.

Examination of the specimens after testing revealed that for many of the specimens finished with alkyd primer, the failure surface was not limited to the wood-paint interface. Several Douglas-fir specimens are shown in Figure 3. The two halves of each block-shear specimen are shown: the Douglas-fir half is on the left and the maple half on the right. The different amounts of primer still bonded to the Douglas-fir half can easily be seen, particularly on the 4-week specimens painted with alkyd primer. The spec-

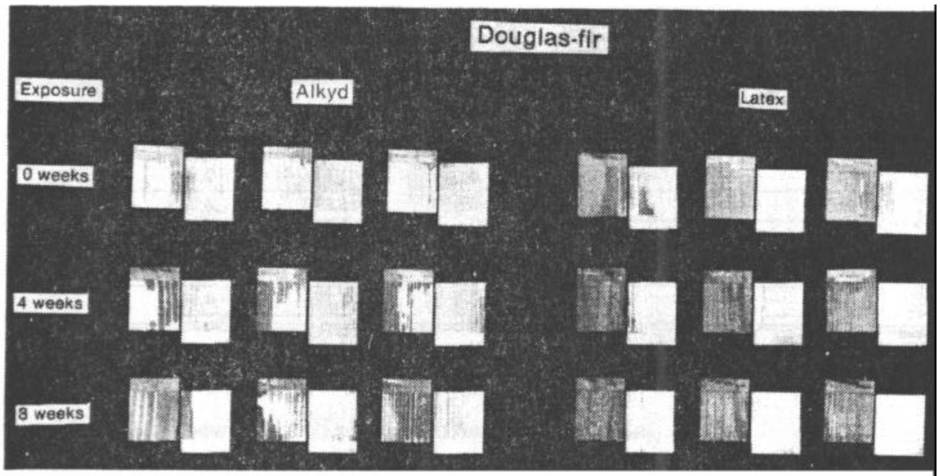

Figure 3. – Examples of Douglas-fir block-shear specimens after testing. For each set of panels, the left panel is the substrate and the right panel is the maple that was glued to the paint surface.

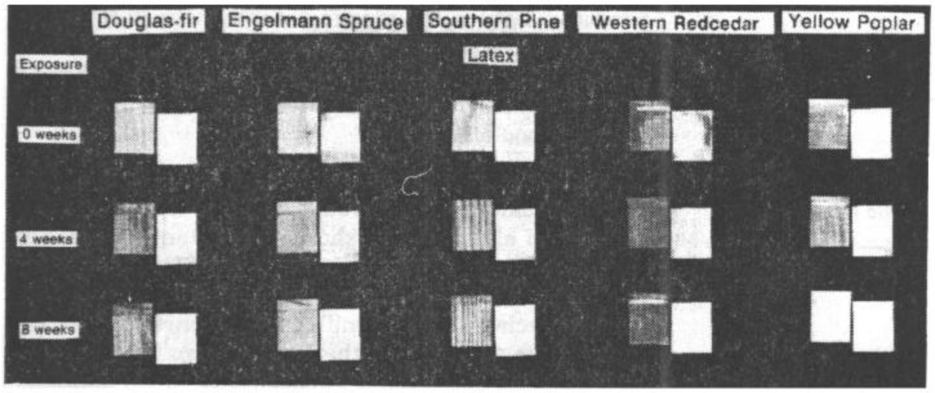

Figure 4. – Examples of block-shear specimens for all five species finished with acrylic latex primer.

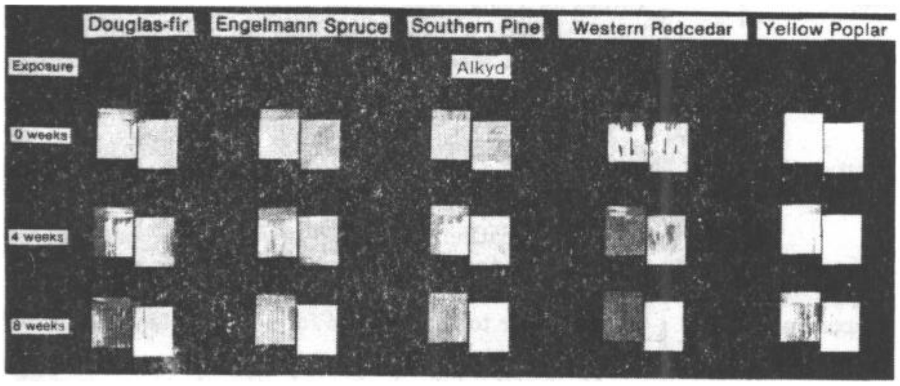

Figure 5. – Examples of block-shear specimens for all five species finished with alkyd primer.

imens that were not exposed failed primarily at the adhesive bond between the maple and the top of the painted specimen, whereas the B-week specimens failed primarily at the earlywood-paint interface. The 4-week specimens showed some of both types of failure. The results with Douglas-fir are representative of all five species painted with alkyd primer. Several specimens from all five species are shown in Figures 4 and 5 for comparison.

Differences in paint adhesion to earlywood and latewood on specimens painted with alkyd primer are also apparent in Figures 3 to 5. This difference was also observed in the previous study (17), and it is attributed to the more severe degradation of earlywood compared with latewood (7). The traditional view of better paint adhesion to earlywood is appropriate only for unweathered softwoods. Even a short period of weathering before painting results in enough earlywood degradation to cause preferential paint failure on this part of the substrate. The differential failure of the alkyd primer on earlywood or latewood and the uniform failure of the acrylic latex primer may be explained by the difference in the interface formed by these different primers with the weathered wood surface.

The micelles of polymer resins in latex paints are too large to penetrate the wood microstructure (cell wall), and the cured paint film adheres only to the surface (13,15). Adhesion is determined by the physical and chemical nature of this surface. Any differences between the depth of degradation for earlywood and latewood should not affect adhesion of the latex paint.

The molecular size of the modified oils used in alkyd primers may be small enough for some penetration into the wood microstructure (13,15). The weathering of wood causes chemical changes at the surface and to a depth of about 75 µm (6,8), and mechanically weakens the wood to this depth. Because of its higher density, latewood has less subsurface degradation than earlywood. The paint possibly forms a stronger bond in the less weathered latewood. In addition, the loss in strength that occurs during the early stages of weathering may be offset by increased penetration of the alkyd vehicle. This increased penetration may give increased mechanical bonding to the latewood and offset the strength loss in the earlywood. The slight increase in adhesive strength noted with the 4-week data supports this. The acrylic polymer is apparently not able to penetrate the wood to any greater extent following weathering and the adhesive strength decreases as a simple function of weathering time.

Conclusions

For a southern Wisconsin climate, adhesion of acrylic latex primers to wood was significantly reduced after the wood substrate had weathered for 4 to 8 weeks before painting. We anticipate a greater effect in warmer and especially sunnier climates. This reduction in adhesion will probably be reflected in reduced paint performance. Long-term exposure studies are underway. The same drop in adhesion was observed for low density species, such as western redcedar or Engelmann spruce, finished with alkyd primer. For higher density species, such as southern pine, Douglas-fir, and yellow-poplar, a short period of weathering appears to have improved adhesive strength with alkyd primer. We strongly recommend that any unprotected low density species not be allowed to weather for more than 4 weeks before the wood is protected with some finish that will prevent photodegradation and water damage. The time for other species may be extended slightly beyond 4 weeks if the wood is to be painted with an alkyd primer. This recommendation is based on weather conditions in southern Wisconsin.

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