Comparative weathering tests of North American and European exterior wood finishes

François W. Kropf
Jürgen Sell
William C. Feist

Abstract

With the goal of comparing the performance of exterior paints on weather-exposed wood surfaces in the United States and western Europe, a number of commercially available coating systems were applied to various wood surfaces and exposed on test fences in the U.S. Midwest in Madison, Wis. (43° north), and in northern Switzerland near Zurich (47° north) for 5 years. This report summarizes the results of the performance and durability tests of the different coating systems.

The starting point for this study was an interest in comparatively evaluating different types and product formulations of North American and European finishes for exterior wood when they are applied to different commonly used siding materials for residential buildings. The basic differences in products and types of applications have been reported earlier by Sell and Feist (7,8). This present paper reports the results of 5 years of weather exposure of a number of commercially available finishes that were evaluated and compared on test fences at the USDA Forest Products Laboratory (FPL), Madison, Wis., and at the Swiss Federal Laboratory for Materials Testing and Research (EMPA), Dübendorf, Switzerland.

Literature review

The problem of weathering behavior of various surface coatings on wood has been dealt with by numerous authors over the last 10 to 15 years. Final conclusions and, therefore, useful recommendations were hard to develop because the formulations of the coating products have repeatedly changed over that period due to environmental considerations. The main change has been the reduction of organic volatile solvents in the formulas and, of course, the change to water-soluble products.

In the United States, comprehensive work has been done at the FPL (2). As in other European institutes, extensive weathering studies have been carried out at the EMPA Wood Department since 1962 (3,4). To assess the validity of various test results, a "round-robin" test was set up in 1981 between the Centre Technique du Bois (CTBA), Paris, France; the British Research Establishment (BRE), Princes Risborough Laboratory, Princes Risborough, United Kingdom; the Wilhelm Klauditz Institute (WKI), Braunschweig, Germany; and EMPA (6). After 5 years of weather exposure, the samples were compared. The results demonstrated that the climatic differences were not of great influence to the long-term behavior and durability of the various coatings, at least for the range tested. Other factors, such as color, coating thickness, and pigmentation were more decisive to the long-term behavior. At present, further such "round-robin" tests are being performed by several countries within the framework of European standardization.

To extend the testing range, another series was set up in 1984 by researchers at the FPL and EMPA to cover a wider range of climates and a greater variety of paint formulations. Preliminary information on U.S. and European practices was published earlier by Sell and Feist (7,8). Detailed results of the study reported here can be found elsewhere (3). This paper is intended to transmit the main results of interest to the English-speaking professional community.

The authors are, respectively, Research Engineer and Chief, Wood Section, Swiss Federal Laboratories for Materials Testing and Research, Uberlandstrasse 129, CH-8600 Dübendorf, Switzerland; and Research Chemist, USDA Forest Serv., Forest Products Lab., One Gifford Pinchot Dr., Madison, WI 53705. This paper was received for publication in February 1994.

Forest Prod. J. 44(10):33-41.

Materials and methods

Wood substrates

The wood substrates used in these studies were western redcedar *(Thuja plicata)* (WRC), Douglas-fir plywood *(Pseudotsuga menziesii)* (DFPLY), European beech *(Fagus sylvatica)* (EB), and European spruce *(Picea abies)* (ES). Specifications of the weathering test are summarized in Table 1.

It should be noted that the poor moisture resistance and dimensional stability of beech wood do not permit its use for weathered applications. It is, however, a practical substrate for the accelerated testing of quality surface coatings, as degradations appear more quickly than on other species.

Finishes

The stains and paints selected were products commonly used in the United States and Central Europe and covered a range from the semitransparent, low-build, penetrating stains to film-forming white paints. The specifications for the finishes used in this study

TABLE 1. — *Specifications of the weathering test.*

	FPL, Madison, Wis.[a]		EMPA, Dübendorf, Switzerland[b]
Specimen/species			
Material	Panels, 410 by 340 mm	Bevel siding, 410 by 340 mm	Single test boards, 100 by 300 mm
Thickness	16 mm	12 mm	20 mm
No. of replicates	Three replicates plus one reference for indoor storage	Three replicates plus one reference for indoor storage	Three replicates plus one reference for indoor storage
Edges	Not rounded	Not rounded	Not rounded
Substrate[c]	DFPLY, T-111 siding	WRC	ES, EB
Grain/texture	Roughsawn, grooved	Vertical-grain, defect-free, smooth-planed	Flat-grain, defect-free, smooth-planed
Wood MC at start (%)	12	12	12
Exposure conditions			
Avg. daytime temperature	−8.2°C (winter) 21.5°C (summer)	−8.2°C (winter) 21.5°C (summer)	2.5°C (winter) 24.5°C (summer)
Avg. yearly temperature	7.4°C	7.4°C	14.0°C
Avg. yearly rainfall	780 mm	780 mm	1050 mm
Duration of sunshine	2,100 hr./yr.	2,100 hr./yr.	1,700 hr./yr.
Orientation	Above ground, facing South, top edge covered	Above ground, facing South, top edge covered	Above ground, facing South, top edge covered
Inclination	90° and 45°	90° and 45°	45°

[a] Located at 43° north, 265 m above sea level.
[b] Located at 47° north, 450 m above sea level.
[c] DFPLY = Douglas-fir plywood; WRC = western redcedar; ES = European spruce; and EB = European beech.

TABLE 2. — *Specifications of the finish systems evaluated.*[a]

U.S. products	Non-volatile content (%)	Density (kg/l)	Density (lb./gal.)	Swiss (CH) products	Non-volatile content (%)	Density (kg/l)	Density (lb./gal.)
Semitransparent stains							
US-1 Medium brown				CH-7 Medium brown			
1st coat: Penetrating stain (s) 2nd coat: Penetrating stain (s) ('Madison formula' — linseed oil base)	76	0.94	7.84	1st coat: Penetrating stain (s) 2nd coat: Penetrating stain (s) 3rd coat: Penetrating stain (s)	26	0.87	7.26
US-2 Reddish brown				CH-8 Dark brown			
1st coat: Film-forming stain (w) 2nd coat: Film-forming stain (w)	25	1.04	8.72	1st coat: Film-forming stain (s) 2nd coat: Film-forming stain (s) 3rd coat: Film-forming stain (s)	53	0.96	8.03
Solid-color stains							
US-3 Cocoa brown							
1st coat: Solid-color stain (s) 2nd coat: Solid-color stain (s)	60	1.13	9.40				
US-4 Cocoa brown							
1st coat: Acrylic latex stain (w) 2nd coat: Acrylic latex stain (w)	45	1.24	10.36				
Opaque white stains							
US-5 White				CH-9 White			
1st coat: Alkyd primer (s)	78	1.36	11.40	1st coat: Alkyd primer (s)	66	1.42	11.90
2nd coat: Latex topcoat (w) 3rd coat: Latex topcoat(w)	53	1.44	12.02	2nd coat: Alkyd intermediate (s)	79	1.62	13.50
				3rd coat: Alkyd topcoat (s)	68	1.20	10.00
US-6 White				CH-10 White			
1st coat: Latex primer (w)	52	1.17	9.76	1st coat: Latex primer (w)	56	1.38	11.40
2nd coat: Latex topcoat (w) 3rd coat: Latex topcoat (w)	53	1.31	10.93	2nd coat: Latex topcoat (w) 3rd coat: Latex topcoat (w)	54	1.30	10.81

[a] (w) = waterborne; (s) = solvent borne.

TABLE 3. — *Paint application rates on European spruce (ES) and western redcedar (WRC). Six U.S. products and four Swiss (CH) products were tested. U.S. test site was the FPL, Madison, Wis., the Swiss test site was at the EMPA, Dubendorf.*

	U.S. products								CH products							
		ES samples at EMPA			WRC samples at FPL					ES samples at EMPA			WRC samples at FPL			
Type of finish	Coating	Wet weight of coating	Initial coating thickness	Spreading rate	Wet weight of coating	Initial coating thickness	Spreading rate	Ratio of coating weights: EMPA vs. FPL	Coating	Wet weight of coating	Initial coating thickness	Spreading rate	Wet weight of coating	Initial coating thickness	Spreading rate	Ratio of coating weights: EMPA vs. FPL
		(g/m^2)	(μ)	(ft.^{2}/gal.)	(g/m^2)	(μ)	(ft.^{2}/gal.)			(g/m^2)	(μ)	(ft.^{2}/gal.)	(g/m^2)	(μ)	(ft.^{2}/gal.)	
Semitrans-parent stains	US-1 (medium brown)								CH-7 (dark brown)							
	1 coat	54	7	710	63	8	560		2 coats	94	7	377	94		377	
	2 coats	104	28	370	121	25	300	1:1.2	3 coats	136	13	260	124		265	1:0.9
	US-2 (reddish brown)								CH-8 (medium brown)							
	1 coat	79	>7	540	79	33	505		2 coats	118	36	331	153	25	256	
	2 coats	133	15	320	145	58	280	1:1.1	3 coats	190	54	205	246	58	165	1:1.3
Solid-color stains	US-3 (olive grey)															
	1 coat	75	20	650	97	33	475									
	2 coats	142	50	350	191	51	240	1:1.3								
	US-4 (grey brown)															
	1 coat	96	>7	525	93	38	515									
	2 coats	196	22	260	180	58	250	1:0.9								
Opaque (white paints)	US-5 (white)								CH-9 (white)							
	2 coats	191	74	300	317	102	180		2 coats	244	60	254	357	127	173	
	3 coats	272	90	210	432	135	130	1:1.6	3 coats	348	95	160	530	152	105	1:1.5
	US-6 (white)								CH-10 (white)							
	2 coats	182	40	277	254	76	200		2 coats	255	80	214	261	84	209	
	3 coats	300	60	175	373	102	125	1:1.2	3 coats	326	110	165	372	114	130	1:1.1

TABLE 4. — *Paint application rates on European beech (EB) and Douglas-fir plywood (DFPLY). Six U.S. products and four Swiss (CH) products were tested. U.S. test site was the FPL, Madison, Wis., the Swiss test site was at the EMPA, Dubendorf.*

	U.S. products							CH products						
		ES samples at EMPA			DFPLY samples at FPL[a]		Ratio of coating weights: EMPA vs. FPL		EB samples at EMPA			DFPLY samples at FPL[a]		Ratio of coating weights: EMPA vs. FPL
Type of finish	Coating	Wet weight of coating	Initial coating thickness	Spreading rate	Wet weight of coating	Spreading rate		Coating	Wet weight of coating	Initial coating thickness	Spreading rate	Wet weight of coating	Spreading rate	
		(g/m^2)	(µ)	($ft.^2/gal.$)	(g/m^2)	($ft.^2/gal.$)			(g/m^2)	(µ)	($ft.^2/gal.$)	(g/m^2)	($ft.^2/gal.$)	
Semitrans-parent stains	US-1 (medium brown)							CH-7 (dark brown)						
	1 coat	75		510	210	175		2 coats	121	8	293	340	104	
	2 coats	121	<3	320	336	100	1:2.8	3 coats	155	13	230	45	87	1:2.9
	US-2 (reddish brown)							CH-8 (medium brown)						
	1 coat	104	<3	410	237	170		2-coats	120	25	326	332	118	
	2 coats	167	11	260	439	91	1:2.7	3 coats	191	50	205	427	100	1:2.2
Solid-color stains	US-3 (olive grey)													
	1 coat	79	<10	620	247	185								
	2 coats	137	<15	350	360	120	1:2.6							
	US-4 (grey brown)													
	1 coat	86	<3	590	261	180								
	2 coats	170	<15	300	430	105	1:2.5							
Opaque (white paints)	US-5 (white)							CH-9 (white)						
	2 coats	210	~35	272	450	127		2 coats	264	50	235	576	107	
	3 coats	336	80	160	617	93	1:1.8	3 coats	371	<60	155	790	68	1:2.1
	US-6 (white)							CH-10 (white)						
	2 coats	171	26	295	424	120		2 coats	248	67	220	456	120	
	3 coats	289	30	185	595	85	1:2.1	3 coats	323	75	167	594	86	1:1.8

[a] Coating thickness could not be determined on roughsawn plywood.

are summarized in Table 2. The necessary quantity of finishes was exchanged between the two laboratories and applied on four replicates for each system. A total of 10 formulations was applied on a first set of samples according to the manufacturer's instructions (1 or 2 coats) and on a second set with an additional finishing coat (2 or 3 coats, respectively). The samples (three replicates) were installed on the test fences at approximately the same time in August 1984 in Madison and Dübendorf and had been exposed for over 5 years when data for this report were gathered.

The consumption of liquid finish on the flat grain surfaces was measured during sample preparation for both weathering sites (Tables 3 and 4). Coating thicknesses were measured microscopically on cross sections of the unweathered samples. The numbers reported are the rounded averages of 10 measurements.

Periodic photographic recordings were taken under natural light conditions. A selected set of samples (one of each) was also photographed periodically at EMPA under reproducible studio conditions. The comparison of performance at the two sites was made on the basis of the photographs (3).

Periodic visual evaluations were performed at both exposure sites according to American Society for Testing and Materials (ASTM) standards (1). A compilation of the resulting "overall ratings" at the end of the weathering period of 5 years is given in Table 5.

Results

Results at EMPA

Semitransparent stains. — Two of the tested stain systems were frequently used low-build solvent-borne penetrating systems. The first product was a frequently used product of European origin (CH-7), and the other was from the United States, the so-called "Madison formula" (US-1). The two others were film-forming, but still semitransparent formulations, one solvent-borne (CH-8) and the other waterborne (US-2).

Regarding the latter two products of this group, the solvent-borne film-forming system (CH-8) performed substantially better than the matching waterborne formulation (US-2), admittedly with a 45 percent higher application rate (Tables 3 and 4). The semitransparent latex system with an extra coating started to peel much faster than the sample with only two coatings, and was practically gone after 24 months. The reason for this reverse behavior of the thicker coating is probably the result of lesser and, thus, insufficient adhesion to hold the thicker film following the degradation of the wood surface by ultraviolet light.

On all EB samples, the stains were almost entirely weathered off after 48 months, except

TABLE 5. — *Performance evaluation of the coating systems after 5 years of exposure. Scale ranges from 10 to 1 where 10 = perfect condition and 1 = complete failure, according to ASTM rules (6).*[a]

Type of coating		No. of coats	DFPLY	EB	Differences between the ratings	WRC	ES	Differences between the ratings	Partial sums of ratings	Total sum of ratings	Overall rank of system
Semitransparent stains	US-1	1	2.0	1.0	- -[b]	1.0	1.0	±0	5.0	20.5	8
		2	7.0	1.0		3.0	4.5	+1.5	15.5		
	CH-7	2	3.0	1.0	- -	1.0	2.0	+1.0	7.0	19.5	9
		3	5.0	1.0		3.0	3.5	+0.5	12.5		
	US-2	1	2.0	1.0	- -	1.0	1.0	±0	5.0	16.0	10
		2	7.0	1.0		2.0	1.0	-1.0	11.0		
	CH-8	2	3.0	1.0	- -	3.0	2.5	-0.5	9.5	28.5	7
		3	5.0	1.0		7.0	6.0	-1.0	19.0		
Solid-color stains	US-3	1	6.8	3.0	- -	4.5	6.0	+1.5	20.3	47.8	5
		2	6.5	4.0	- -	8.5	8.5	±0	27.5		
	US-4	1	6.5	1.0	- -	1.5	1.0	-0.5	10.0	38.0	6
		2	8.0	4.5	- -	8.0	7.5	-0.5	28.0		
Opaque (white paints)	US-5	2	6.3	4.5	-1.8	8.3	10.0	+1.7	29.1	63.8	2
		3	7.0	8.7	+1.7	9.0	10.0	-1.0	34.7		
	CH-9	2	6.8	5.5	-1.3	8.8	10.0	+1.2	31.1	62.7	4
		3	6.3	6.0	-0.3	8.8	9.5	+0.7	31.6		
	US-6	2	8.3	3.0	-5.3	8.3	8.0	-0.3	27.6	63.7	3
		3	8.8	8.5	-0.3	8.8	10.0	+1.2	36.2		
	CH-10	2	7.5	6.3	-1.2	8.8	9.5	+0.7	32.1	65.8	1
		3	8.0	6.7	-1.3	9.0	10.0	+1.0	33.7		

[a] DFPLY = Douglas-fir plywood; EB = European beech; WRC = Western redcedar; and ES = European spruce.
[b] - - = comparison not meaningful.

the 3-coat film-forming system (CH-8). For ES, the standard 2-coat systems also showed substantial signs of degradation, but the 3-coat samples still performed quite satisfactorily. This is consistent with experience that the durability of wood finishes increases in general with the film thickness for as long as no film-cracktng takes place.

It is quite apparent that once erosion had worn out the thin film (maximum 25µ down to the wood surface at any one spot of an exposed surface, total washout was a rather fast process. This was shown by all four stain finishes in the 2-coat version at the end of the 5 years. By then, samples with an additional coating were still performing quite satisfactorily, but showed obvious signs of erosion as well. In any practical application, such surfaces would need refinishing quite soon.

The damage mechanism of film-forming systems was demonstrated in an obvious manner by the 3-coat film-forming stain (CH-8) applied on EB. Except for some chalking, the film remained intact, but as soon as the first cracks occurred, water seeped in and could not escape rapidly enough. Swelling occurred and mildew developed underneath the coating, which then produced rapid degradation.

The pronounced darkening with time of the product (US-1) seems to have taken place equally on FPL and EMPA test fences. After the breakdown of PCP, the linseed oil base of this formula is a food source for mildew, and the observed darkening is probably the combined result of the growth of mildew, the appearance of weathered wood, and the darkening of the linseed oil itself.

Solid-color stains. — Both products of this type were U.S. products (US-3, US-4, Table 2), because such formulations are rarely used in outdoor applications in Europe. Both products were still somewhat transparent in the standard 1-coat application, but were practically opaque in the 2-coat application.

After 5 years, the waterborne (US-3) 2-coat version was practically washed off and no longer offered protection to the wood surface, whereas the corresponding solvent-borne product (US-4) still performed satisfactorily. When applied with an additional coat, both products performed practically the same in this time period. On ES, the coating was still in fairly good condition (average rating of 8, where 10 = perfect condition and 1 = complete failure), but on EB it was in need of refinishing (rating = 4).

Opaque white paints. — Four paint coating systems were evaluated, and the average coating weights were comparable for all four systems (Tables 3 and 4). On ES, 182 to 255 g/m^2 was used for the 2-coat applications, and 272 to 348 g/m^2 for the 3-coast systems (corresponding to a spread rate of 210 to 268 ft.^{2}/gal.). US-6 and CH-10 were wholly waterborne acrylic products, whereas US-5 consisted of an oilborne primer with acrylic topcoats. CH-9 was a purely solvent-borne system based on oil-modified alkyd resin.

After 4 years of weathering, the EB panels showed noticeable differences in the regular coatings, but also on the panels with an extra coating. Between years 4 and 5, a noticeable degradation of both U.S. products was observed — the 2-coat samples degraded to a point where repainting would be urgent. The CH formulations seemed to have resisted better — possibly due to their higher resin content — but also started to show obvious signs of erosion in the 2-coat version.

These visual observations and the ratings of Table 5 suggest the following conclusion. On the EB panels, the two Swiss paint systems (CH-9 and CH-10) performed somewhat better than the two U.S. products for the 2-coat system, whereas for the 3-coat system, the U.S. products performed better. Differences in the wet coating weights can explain the differences to some extent. It is suspected that the significantly higher resin content of both Swiss formulations is responsible for the different film-forming behavior and moisture-excluding efficiency of these products.

Evaluation of the ES panels was not easy, as all were still in surprisingly good condition. Linking observations to the corresponding EB panels, it seemed that latex topcoats are more subject to erosion and are more rapidly settled by fungi. The loss of gloss, which appeared as chalking, was also greater for latex topcoats than for oil-modified alkyd-based paints. On the other hand, the alkyd coatings showed a rather strong tendency for yellowing.

The same degradation mechanism found in the film-forming stains has been observed on the solvent-borne alkyd resin system (CH-9). The coating provides a rather water- and vapor-proof film, whereas latex coatings of equal thickness have a substantially lower moisture diffusion resistance. Thus, the alkyd paint gives an excellent protection to the wood surface as long as the film remains intact, but as soon as it starts to crack, deterioration of the entire surface is quite rapid. Unless remedial action is then taken quickly, the protective effectiveness is soon lost. Latex topcoats degrade more gradually over time, therefore, rehabilitation can be delayed for longer without damage becoming too apparent and severe.

For all four products tested, the 3-coat samples provided a better surface appearance than the 2-coat panels. This is obviously due to the relatively high coating thickness, but certainly a color effect of the white paint adds a substantial component by moderating the temperature influences and, thus, reducing the stresses on substrate and paint film.

Results at FPL

Comparison between WRC and DFPLY. — There were several differences in finish durability found between WRC and DFPLY. The vertical grain orientation of the DFPLY panels suffered less from erosion than the horizontal grain of the WRC boards. In general, the DFPLY panels were in a noticeably better state of conservation than the WRC boards (or for that matter the ES boards) evaluated at EMPA (Table 5).

A partial explanation can be found when comparing the original paint spread rates (in ft.^{2}/gal.) as given in the following table of average spread rates (abstracted from Tables 3 and 4).

	WRC	DFPLY	ES
First coats ($ft.^2$/gal.) —	462	179	503
Difference in percent	260	100	280
All coats ($ft.^2$/gal.) —	493	253	538
Difference in percent	195	100	213

The much lower spread rates on DFPLY mean that the coating weights on DFPLY were consistently at least double the weight as on the other species, due to the much greater uptake by the roughsawn veneer surfaces during the application of the first coat. Thus, the texture or surface roughness of the wood had a much greater effect on the better finish durability and state of conservation of the plywood panels than did the wood species involved. This is reflected in the greater values found for the percent difference in the WRC and ES from the DFPLY. This confirms the general experience that roughsawn surfaces weather differently than surfaced wood.

The visual observations and the ratings of Table 5 also suggest that for the stains, the appearance of the WRC panels at FPL is practically the same as for the ES samples at EMPA. The DFPLY panels show a stronger erosion effect, but cracking is less severe in the EMPA panels. A comparison to the EB samples in EMPA is not appropriate, as all the EB samples had, 12 months earlier, already reached a minimum overall rating of 1.

After 5 years of weathering, all panels coated with opaque white paints were all still in better condition than the stained panels, and it was difficult to differentiate the results on either WRC or DFPLY substrates. On DFPLY, the product US-6 (a latex paint) did very well, whereas in Switzerland it did poorly on EB and in the 2-coat version on ES. The other three white paint systems still showed only small differences. These results indicate that the interaction between paint system and substrate is a relevant factor and of substantial influence for the overall performance.

This test series has shown the value of an extra coat beyond the manufacturer's recommendation. In the case of roughsawn surfaces, this extra quantity of paint is applied "unwillingly," but still contributes substantially to the improvement of the weathering performance.

Comparison of exposures at 45° *and* 90°. — In Madison, identical panels were exposed in a vertical position (90°) and at 45° inclination, all facing south. In an attempt to quantify the acceleration rate of a 45°-exposure, the surface appearance ratio (SAR) was defined as:

$$\text{SAR} = \text{time required to reach a specific performance rating } \frac{\text{at } 90^\circ}{\text{at } 45^\circ}$$

TABLE 6. — *Performance ratios from exposure at 90° vs. 45° for western redcedar (WRC) and Douglas-fir plywood (DFPLY).*

Type of coating	No. of coats	WRC	DFPLY	Average SAR[a]	
Semitransparent stains					
US-1	1	2.0	1.7	1.9	(1.6)
	2	>1.3	>1.0	1.2	
CH-7	2	1.3	1.3	1.3	
	3	2.5	1.3	1.9	
US-2	1	1.5	1.7	1.6	(1.4)
	2	1.5	>1.0	1.3	
CH-8	2	>1.3	1.3	1.3	
	3	>1.0	1.3	1.2	
Solid-color stains					
US-3	1	1.3	>1.0	1.2	(1.2)
	2	>1.3	>1.0	1.2	
US-4	1	1.3	>1.0	1.2	
	2	>1.0	1.3	1.2	
Opaque (white paints)					
US-5	2	>1.3	2.0	1.7	(1.4)
	3	>1.3	>1.3	1.3	
CH-9	2	1.3	1.0	1.2	
	3	2.0	1.0	1.5	
US-6	2	>1.3	>1.0	1.2	
	3	>1.3	>1.0	1.2	
CH-10	2	2.5	1.0	1.8	
	3	1.3	1.0	1.2	
Average SAR		1.5	1.2		

[a] SAR = surface appearance ratio.

The following performance ratings were used to determine times for each finish system:

Finish	Rating
1-coat stains	6 to 8
2-coat stains	7 to 9
2-coat paints	6 to 9
3-coat paints	8 to 9

The SARs determined by this procedure at the FPL are summarized in Table 6. The SAR varies from 1.0 to 2.0 depending on the type of finish used and reflects the different degradation mechanisms for the various finishes and the change in mechanism with different amounts of finish. The practical importance of the question of the acceleration factor in weathering, when the samples are exposed at a 45°-angle versus a 90°-angle, justifies the use of the SARs to provide an answer.

The last column of Table 6 gives the averages of the SAR ratings in each category of finishes. The 45°-inclination seems to have the greatest effect on penetrating stains, for which an average SAR of 1.6 was recorded. This can be explained by the stronger influence of erosion on thin stain films, which is clearly greater on inclined surfaces than on vertical ones.

All the average SAR numbers obtained in this test series in Madison are well in the range of the acceleration factor of 1.5 determined in the 1970s with a different method at EMPA for entirely different wood finishes (5). For all practical purposes — and for most customary wood finishes — we therefore conclude that an acceleration factor of 1.5 must be taken into consideration when the samples are exposed at a 45°-angle.

Discussion

Differences between the two test sites

The geographic and climatic data of the two sites are given in Table 1. The finish/substrate combinations were evaluated separately in 1- and 2-coat, and 2- and 3-coat versions. Considering that all ratings were done independently by two different evaluators, the concordance is quite good, as is demonstrated by the small differences between the ratings (Table 5). This is interpreted in the sense that the different features of the two test sites — mainly elevation and latitude — are of lesser relevance for exposure tests as one would be inclined to assume. Differences are observed in concordance with the weather features of each site, but the long-term results are quite comparable. This confirms an earlier finding of a similar round-robin test among four European test sites with quite different climatic conditions (6). Provided that weathering tests are carried out in equivalent climatic zones — in the present case, northern continental temperate climate — the results of natural weathering are consistently quite similar.

Differences between the various wood substrates

The WRC and ES panels were used to compare the U.S. and European finishes. The results of the roughsawn, grooved DFPLY are reported separately because the rough surface texture and multiple veneer cracks of the plywood sheet change the substrate behavior and paint application is quite different from solid wood surfaces. The EB samples also showed degradation features at a much earlier test stage and therefore, cannot be included in a direct comparison.

WRC and ES. — The small difference between ratings (Table 5, col. 8) shows that the performance of the coatings on WRC at the FPL and ES at EMPA match surprisingly well for all products tested. Thus, it seems reasonable to say that the behavior of these two wood species under weather exposure is quite comparable. The different grain orientation — horizontal in Madison and vertical in EMPA — apparently did not lead to substantial differences in paint performance.

DFPLY panels. — Due to the roughsawn texture and higher paint absorption during application, the coating weights for all products were 2 to 4 times greater than on other species. Erosion significantly reduced the coating thickness, but the DFPLY panels still seemed to be in better condition and refinishing is not as urgent as for their counterparts on WRC.

EB. — As was expected, the finishes on EB panels degraded much more rapidly than on the other wood species. This permitted an early prediction of long-term trends. This was quite valuable for assessing the white paints where only the EB panels showed relevant differences after 4 years. On the other wood species even 5 years of exposure were insufficient to differentiate the products clearly, particularly between solvent-borne and latex systems (Table 5, col. 5). As was found earlier, the main reason for the more intense weathering effects on EB is the combination of its low dimensional stability and high capillary sorption capacity for liquid water, which leads to intense mechanical stresses on the coating.

Differences between the various coating products

The sum of the ratings was taken to obtain a ranking of the products (Table 5, col. 7/8 for the 1- to 2-coat version and col. 9/10 for the 2- to 3-coat version). Then, the overall sum of the ratings was compiled and an overall ranking was established: ranks 1 to 4: opaque white paints (4 products); ranks 5 and 6: solid-color stains (2 products); rank 7: film-forming semitransparent stain (1 product); and ranks 8 to 10: semitransparent penetrating stains (3 products). For each of these ranking orders, differences remain within their own category.

Thus, there are differences in weathering behavior within each group of products, but the groups do not overlap. This result clearly confirms the knowledge of many years that: 1) the overall durability of an exterior wood finish improves primarily by an increase in pigmentation (and to some extent by the pigment/volume concentration); 2) the second major factor for finish durability is the film thickness of the finish (9); and 3) the color effect of a white paint is an important moderating factor in reducing the stresses on substrate and paint film.

With one exception (US-2), all coatings with a supplementary topcoat performed better than the samples treated according to standard recommendations. This is a strong indication that, in most cases, it does pay off to give an extra coating to the surfaces directly exposed to harsh weather conditions. On the other hand, the total (wet) coating weight applied is not an absolute indication of weather resistance. It is even questionable if the 'dry weight' applied is a measure for this, as particle size of pigments and their penetration into the wood substrate are other important factors affecting the weather resistance of a protective coating.

Concerning film thickness, there is no question that within the same group of finishes with similar chemical formulations, durability can be improved by applying more finish and, therefore, achieving a higher coating thickness. But this only holds true as long as film thickness is being eroded, but no film cracking occurs, as was demonstrated by the conventional white solvent-borne system (CH-9), which did quite well for a long time on all substrates. Except for some stronger yellowing, it kept its gloss longer than any of the other products, but as soon as the first cracks appeared the subsequent degradation was very rapid.

Overall evaluation

These comparison field-testing experiments confirmed earlier findings and relationships between coating durability and major exposure parameters and also provided useful additional information.

Geographic location, angle of exposure

Despite substantial climatic differences between the two locations, the results of the long-term weather exposure were surprisingly similar. This is an important result with respect to future similar weathering tests. The differences between vertical (90°) and inclined (45°) exposure of the samples were also very noticeable. The time needed until similar damage appears on vertical samples is 1.5 to 2.0 times greater than on inclined surfaces. This applies for the intensity of cracking and surface erosion, as well as for blue-stain infestation when the coating contains no fungicide.

Wood characteristics

Due to EB's known poor dimensional stability, high capillary sorption capacity, and great sensitivity to blue-stain fungi infestation, EB is routinely used at EMPA to obtain faster results during weathering tests. Accordingly, the products applied on EB degraded fastest; the speed-up factor being at least 1.5 to 2 times for semitransparent and opaque stains. WRC and ES showed little difference in long-term behavior.

Coating characteristics

A durable protection of the wood surface from visible light and ultraviolet radiation can only be achieved with opaque pigmented formulations; moisture protection efficiency mainly depends on coating thickness. These two factors are the essential elements of the longevity of the wood/coating system. This was demonstrated by the substantially better performance (by a time factor of 2 or more) of the opaque film-forming coatings, when compared with the semitransparent stains, and even more so with the non-film-forming penetrating stains. On the other hand, the total (wet) weight applied is not an absolute indication of weather resistance. It is even questionable if the "dry weight" applied is a measure for this, as particle size of pigments and their penetration into the wood substrate are other important factors affecting the weather resistance of a protective coating. Still, there is a strong indication that in most cases it does pay to give an extra coating to the surfaces directly exposed to harsh weather conditions, as it improves performance beyond expectation.

The influence of the resin used in the formulation, in particular the differences between the solvent-based alkyd and the water-dispersed acrylic products (latex paints), was difficult to interpret. For comparable coating thicknesses, however, the acrylic products did offer a somewhat better long-term performance than the alkyd paints.

After 5 years of exposure, the products with a comparatively higher resin content but otherwise similar characteristics, demonstrated a somewhat better performance than those with a lower resin content. This was partially due to a thicker film formation and thus, better protection from moisture.

Ranking of coating systems

Using the rating values reported in Table 5, the following overall performance ranking of the coating systems tested has been obtained — from best to worst durability: l) waterborne film-forming systems (white); 2) solvent-borne or mixed systems (white); 3) solid-color stains (opaque); 4) film-forming semitransparent stains; 5) solvent-borne penetrating stains; and 6) water-borne penetrating stains.

This evaluation considers the technical performance of the coating system only and does not account for financial implications, such as the lesser price of a penetrating stain compared to a film-forming paint, ease of renovation, or aesthetic considerations, etc. Thus, the selection of an adequate product depends on the weighting of numerous factors and must still be considered for each case individually.

Literature cited

1. Feist, W.C. 1987. Weathering performance of finished yellow-poplar siding. Forest Prod. J. 37(3):15-22.
2. Gorman, T.M. and W.C. Feist. 1989. Chronicle of 65 years of wood finishing research at the Forest Products Laboratory. USDA Forest Serv. General Tech. Rept. FPL-GTR-60. USDA Forest Serv., Forest Products Lab., Madison, Wis. 81 pp.
3. Kropf, F.W., J. Sell, and W.C. Feist. 1993. Vergleichender Bewitterungsversuch mit nordamerikanischen und europäischen Holzaussenanstrichen. (Comparative weathering test of North American and European wood finishes). EMPA-Bericht No. 115/27, Dübendorf, Switzerland. 72 pp.
4. Kühne, H., M. Hochweber, and J. Sell. 1968. Freiland-Bewitterungsversuche an Aussenanstrichen für Holz — Versuchszeitraum 1962/1967. (Exterior weathering tests for wood finishes — testing period 1962/1967). EMPA-Bericht No. 182, Dübendorf, Switzerland. 78 pp.
5. __________, U. Leukens, J. Sell, , and O. Wälchli. 1972. Freiland-Bewitterungsversuche an Holz und Aussenanstrichen für Holz. Ergebnisse der 2. Versuchsperiode 1968-1971. (Exterior weathering tests for wood and wood finishes. Results of the 2nd test period 1968-1971). EMPA-Bericht No. 198, Dübendorf, Switzerland. 51 pp.
6. Roux, M.-L., E. Wozniak, E.R. Miller, P. Böttcher, F. Kropf, and J. Sell. 1988. Natural weathering of various surface coatings on five species at four European sites. Holz als Roh- und Werkstoff 46:165-170.
7. Sell, J. and W.C. Feist. 1985: Unterschiede der Oberflächenbehandlung von Holzaussenbauteilen in den U.S. und Westeuropa. Holz-Zentralblatt 111(40/41):617.
8. _________ and _________. 1986: U.S. and European finishes for weather-exposed wood — a comparison. Forest Prod. J. 36(4):37-41.
9. Feist, W.C. and D.N-S. Hon. Chemistry of weathering and protection. *In*: The Chemistry of Solid Wood, R. Rowell, ed. Amer. Chem. Soc. Washington, D.C. 1984:401-451.