CWPA Proceedings, 2004, pp 157-173

FIELD PERFORMANCE OF TRANSPARENT COATINGS

K. Groves, S. McFarling and P. I. Morris
Forintek Canada Corp., 2665 East Mall, Vancouver, B. C. V6T 1W5

Summary

Development of a transparent coating with long-term performance should assist wood products to maintain market share in residential applications in the face of substitute materials and potentially expand markets in recreational property and non-residential applications. A range of commercially available products, reputed to be among the best in their class, were exposed for two years accelerated natural weathering facing south at 45° at test sites in Vancouver, BC and Gulfport, Mississippi, the latter in collaboration with the USDA Forest Products Laboratory. A range of pre-treatments were evaluated under these coatings including sanding, "mill glaze" treatment, chromated copper arsenate treatment and several zinc-containing formulations expected to provide some protection against UV and mold/stain. The test material was inspected every six months for discolouration, mold/stain, coating water repellency, flaking, erosion and cracking and substrate condition. Two variants of a water-based film forming coating stood out among the products tested after only one-year and showed little or no deterioration (with the right surface preparation) after two years exposure in Mississippi. With regard to the pre-treatments, sanding doubled the time to refinishing for the water-based film forming coating but had no effect on a solvent-based film forming coating. "mill glaze" treatment increased the refinishing interval, but was not as effective as sanding. Chromated copper arsenate pre-treatment doubled the life of the solvent based film forming coating but did not affect the water-based film forming coating. Zinc naphthenate pre-treatments negatively affected coating performance and zinc acetate provided no improvement in performance. The Mississippi test site provided a factor of acceleration of about 1.3 for film forming transparent coatings compared to the Vancouver test site. Based on this acceleration factor, the water based film-forming coating F5 over sanded wood would be anticipated to give a life of at least 4 years without refinishing in high-end applications under Canadian conditions. All the other products tested required refinishing after 1 year or less in Vancouver.

1 Introduction

The North American market for wood products on the exterior of buildings merits considerable effort to maintain. For example, over 96 million square metres of wood and wood panel products are used as exterior siding annually in Canada and the U.S (NAHB). Other products include windows, doors, shingles, fascia and trim boards. There are also opportunities to capitalize on the expanding market in recreational property and increase market share in non-residential buildings. Non-wood alternatives including concrete, metal and plastics are competing for the residential market and are entrenched in the non-residential market. These products often mimic wood's appearance and promise long-term durability with minimal maintenance. If wood is to retain and expand its market share, it must be able to offer similar low-maintenance performance. It must also be able to capitalize on its natural appearance.

Sun (UV and visible light), moisture and microorganisms act together to deteriorate unfinished surfaces of wood products used outdoors, creating a “weathered” appearance within a few weeks or months (Williams 1996). Options to prevent this include pressure treatment with copper-based waterborne preservatives, painting, staining and transparent coatings. The same three agents of deterioration also act on the surface coatings.

Waterborne wood preservatives containing copper and chromium reduce the rate of erosion, but eventually weather to a grey-green and do little to stop cracking due to wetting and drying. Water repellents can be added to these treatments but they adversely affect the ability of the preservative to penetrate the wood. If a dimensionally stable wood is used and the customer is willing to accept a grey-green colour, copper-based wood preservatives can offer a minimal maintenance solution lasting for decades. Developments in wood preservation are moving towards metal-free systems for above ground application, but additional protection against UV will be needed.

Paints can provide adequate performance over 5 to 15 years, the duration depending on the care taken with surface preparation and the paint quality. However, paint hides the natural colour and figure of the wood and does not provide a distinct look to separate wood from competing non-wood materials.

For many applications the customer desires a “natural” wood appearance. Penetrating stains can contain a range of levels of pigmentation that partially block the wood's natural colour and figure. These pigments typically include iron oxides with a range of yellow, through red to brown colours. The greater the level of pigmentation the less natural the look, but the better the UV protection and the longer the interval between re-finishing. The major advantage of these products is the ease of refinishing which is typically required after 1.5 to 5 years.

The consumer demand for “transparent” coatings can be seen in the degree to which these are commonly used in high-end shop fronts, recreational properties and landscape furniture in resort areas, despite the fact that failed examples of such uses can be seen everywhere. Failure of transparent coatings in North America occurs after 0.5 to 1.5 years depending on the climate and the degree of exposure to it.

This work owed a great deal to the experience gained in the Value Added project “Finishing Properties of Canadian Wood Species for Exterior Applications” (Groves and Gignac, 2002). That project investigated the impact of the wood substrate on the performance of a range of surface coatings from a copper containing preservative (Chromated copper arsenate) through water repellents, transparent coatings and stains to paints. Besides coating type, factors investigated in this project included, wood species, (those traditionally used in exterior applications and a range of other species less often used) heartwood only vs. heartwood and sapwood, planed vs. saw textured coating, vertical vs. flat grain and second growth vs. old growth of some species. Tests were set up in Quebec city, Vancouver and at the Mississippi test site of the USDA Forest Products Laboratory (FPL) in Madison, Wisconsin.

Key findings from that project included:

- Paints performed by far the best, followed by penetrating stains, transparent films and water repellents.
- Panels at 45° in Mississippi deteriorated twice as fast as panels at 90°.
- Panels at 90° in Mississippi deteriorated twice as fast as panels at 90° in Vancouver.
- Panels at 90° in Mississippi deteriorated six times as fast as panels at 90° in Quebec.

These results suggest one year's exposure at 45° in Mississippi can simulate twelve years exposure as siding in central Canadian markets. Windows and doors often have components at 45° or less thus the factor of acceleration may be less for these applications.

This project focussed on the transparent coatings, penetrating stains and film formers, and evaluated a much broader range of such coatings commercially available. The coatings selected were those that were generally believed by the industry or researchers to be among the best in their class. It also focussed on planed surfaces and examined methods of improving coating adhesion such as sanding and liquid treatment to remove "mill glaze". In addition three zinc-containing pre-treatments were tested because zinc was expected to provide some of the protection against UV and mold/stain given by copper, but without altering the colour of the wood. CCA-treated wood was used as a reference material since it is known that CCA treatment enhances the performance of coatings (Ross and Fiest, 1991; Fiest and Ross, 1995).

2 Materials and Methods

2.1 Natural Exposure Tests

Natural weathering of all coatings was tested at two sites (Table 1) to provide data for a worst case Canadian climate and a worst case US climate, accelerated with respect to Canadian conditions. At the two sites, 45-degree test fences were constructed for mounting samples with southern exposure. Samples were prepared and coated at Forintek for set-up on each of the outdoor test fences.

Table 1: Exterior test fence sites

Test Site	Climate	Test Fence Orientation
Vancouver, BC – Forintek Western lab	Moderate, coastal	45° south facing
Gulfport, Mississippi, USDA Site	Southern, warm, humid	45° south facing

2.1.1 Wood Sample Preparation

2.1.1.1 Source Lumber

Rough green coastal Douglas fir, 35 pieces, 115 mm x 32 mm x 2.42 m were obtained from a sawmill on Vancouver Island, British Columbia. The boards were sorted, selecting for heartwood only/vertical grain pieces. This was intended to minimize the potential for decay during the experiment and minimize variability in coating performance among replicates. The boards were then force air-dried to a moisture content ranging from 15-19%. All boards were then planed on one face and one edge to 110 mm (width) x 28 mm (thickness).

Thirty boards were then cross-cut to 1.52 m in length (siding), with the remaining boards cross-cut into 64, 305 mm long, short boards.

2.1.1.2 Surface Preparation

The 1.52 m siding was separated into 5 groups and labeled. The 305 mm short boards were separated into 8 groups and labeled. The surfaces of the siding/short boards samples were then pre-treated as in Table 2. Surface preparation of all boards, with the exception of the boards treated with chromated copper arsenate, was completed within 14 days of planning.

Table 2: Surface pre-treatments

Pre-Treatment	Applied to Surface	
	1.52 m Siding	305 mm Short Boards
None – "mill glaze" noted on surface[1]	Yes	Yes
Sanded – lightly with 100 grit paper and coated within 72 hrs	Yes	Yes
"mill glaze" treatment (MGT) – applied and allowed to dry for 24 hrs	Yes	Yes
Zinc naphthenate [4%] – (ZN-4) – sanded then 1 coat applied – allowed to dry 120 hrs before coating	Yes	Yes
Chromated Copper Arsenate (CCA) – see schedule below	Yes	Yes
Zinc naphthenate [8%] – (ZN-8) - sanded then 1 coat applied – allowed to dry 120 hrs before coating	No	Yes
Zinc acetate [4%] – (ZA-4) – 1 coat applied then samples wrapped @ 120°C for 16hrs then dried	No	Yes

[1] For the purpose of this study "mill glaze" is defined as reduced permeability developing during planning.

The following treating schedule was used for the CCA preservative system:

- 30 min vacuum 635mm Hg
- Fill retort under vacuum with 1.7% CCA treating solution
- 5 minutes to full pressure
- 240 minutes at full pressure - 1035 kPa
- 10 min pressure relief to atmospheric
- Empty retort
- 15 minute final vacuum 635 mm Hg

The CCA samples were then wrapped and stored at 22°C for 2 weeks to allow fixation to occur. Following fixation the samples were force air-dried to a moisture content of 19%.

The 1.52 m siding was then marked; with a pencil line being scribed every 152 mm, to aid in separating the different coatings.

2.1.2 Coating Combinations

The coating combinations selected in this study are as follows:

F1 water-based acrylic varnish, transparent film[1]
F2 solvent-based, 2-step, transparent film
F3 solvent-based, transparent film1 (two coats of first part of F2)
F4 water-based, 2-step, transparent film
F5 water-based, 2-step, semi-transparent film (a more pigmented version of F4)
F6 solvent-based Teflon penetrating semi-transparent stain1
F7 water dilutable oil-based, penetrating semi-transparent stain #1
F8 water dilutable oil-based, penetrating semi-transparent stain #21
F9 solvent-based, penetrating transparent stain

[1] Indicates two identical coats applied

2.1.3 Coating Application

2.1.3.1 Siding

Coatings #F1-F9 were brush applied to the siding (1.52 m siding samples) in the Vancouver laboratory, according to manufacturers' instructions. The locations are shown in Figure 1. All the coatings were applied to the planed side and the two edges (one planed and one rough). Coating combinations F1, F3, F5, F7, and F9 were applied first, using painter's tape to prevent over brushing, the coatings were allowed to dry for 72 hours. The remaining coating combinations, F2, F4, F6, and F8 were then applied, again using painter's tape to prevent over brushing, and allowed to dry. Between all coatings a 6 mm overlap was used. For the 45-degree test fences at both test sites, there were 3 replicates prepared for each F1-F9 coating combination per pre-treatment.

Figure 1: Example of siding immediately after installation, CCA-treated. F1 to F9 and control from left to right.)

The back (rough side) of all the siding was primed with one coat of an alkyd primer. The end-grain (ends) of the siding was also primed.

2.1.3.2 Short Boards

Only coatings #F2, F5, F7 and F9 were applied to the short boards (Figure 2). These were also brush applied in the Vancouver laboratory, according to manufacturers instructions. The coatings were applied to all 6 sides. For the 45-degree test fences at both test sites, there was 1 replicate prepared for each F1-F9 coating combination per pre-treatment.

Figure 2: Short boards

2.1.4 Installation of Samples

At both test sites, the siding and short board samples were fastened onto South facing, 45° platforms (Figure 3). The samples were attached using aluminium brackets and stainless steel screws. The brackets were screwed to the back of the samples.

The Vancouver samples were installed on October 29th, 2001 and the Mississippi samples on November 7th, 2001. All samples were photographed and mapped.

Figure 3: Vancouver south-facing 45° platform

2.1.5 Sample Rating

Samples were visually assessed based on a rating system adopted from the Forest Products Laboratory (FPL) that inspects for discolouration, mold/stain, coatingwater repellency, flaking, erosion and cracking and substrate condition (Table 3). Discolouration, mold/stain and coating evaluations were each based on ASTM methods [3,4,5,6] and were rated on a scale from 1 (complete failure) – 10 (perfect). In addition, the substrate was also rated (using the same scale) for signs of surface checking, warping and defects (i.e. knots becoming visible). Coating water repellency was rated on a scale from 1 (no water repellency) – 10 (complete water repellency). An overall general rating was assigned as the average rating of the evaluation group. Care was taken to discount deterioration, particularly mold/stain progressing into the coating under examination from an adjacent coating. Also ignored were resin blisters because the resins were not set by kiln drying and coating cracking at square edges. Future tests will use kiln-dried material with rounded edges. Where ratings increased with time, suggesting reversal of deterioration, the data were not altered in any way. It is known that with subjective ratings of surface appearance, variations in ratings of one or two are possible due to changes in lighting, wood moisture content or operator perception. For this reason conclusions are drawn on the pattern of deterioration with time, not at any single point in time.

A performance rating of 10 indicates no change from the original unweathered condition; 5 indicates that refinishing would normally be done by the homeowner but without extensive preparation; and 1 represents a total failure (Figure 5). According to FPL, the time required for the coating to reach a level of 5 serves as a convenient measure of durability. However, the target market for this work has higher standards than the average homeowner and it can be virtually impossible to eradicate black stain fungi once they are established, therefore a rating of 7 was used as the threshold for the purpose of this work.

Table 3: Evaluation methods

Evaluation		Method
Discolouration		Subjective visual assessment similar to ASTM D 3274-82
Mold/stain		ASTM D 3274-82
Coating	Water Repellency	Subjective visual assessment
	Flaking	ASTM D 772-47
	Erosion	ASTM D 662-44
	Cracking	ASTM D 661-44
Substrate Condition		Subjective visual assessment
General Rating		Overall appearance

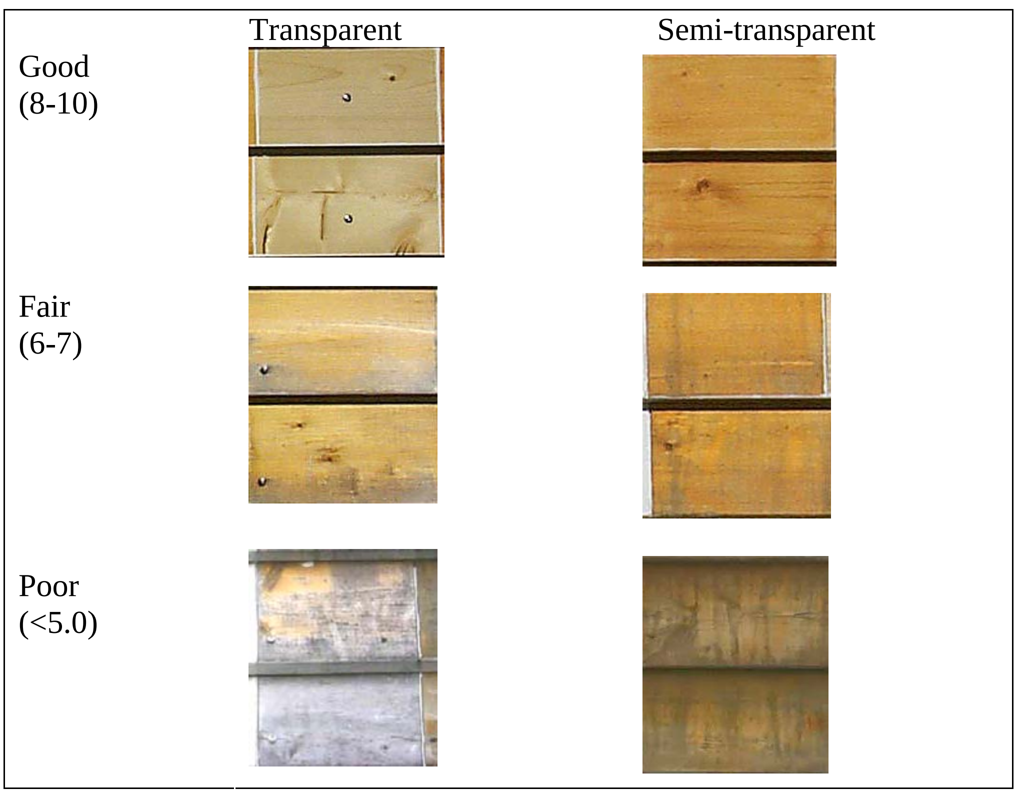

Figure 4: Sample rating examples

3 Results

3.1 Exposure Test Results

Tables 4, 6, 8, and 10 show the average general ratings for pre-treatment/coating combinations on siding after 6, 12, 18, and 24 months exposure respectively. Tables 5, 7, 9 and 11 show the data for the short boards. Within each table the data cells are shaded to show relative coating deterioration which is described as follows:

= 8 to 10 (little or no deterioration)

= 6 to 7 (noticeable deterioration)

= 0 to 5 (refinishing required

3.1.1 Siding

After six months exposure, samples with no treatment or coating had already dropped to average general ratings of 2 or 3 in Vancouver and 4 or 5 in Mississippi (Table 4). The varnish F1 was starting to deteriorate with ratings of 6 to 9 in both Vancouver and Mississippi. The film forming coatings, F2 to F5, were generally still rating 10 in Vancouver and 8 to 10 in Mississippi with the exception of the MGT and Zinc naphthenate pre-treatment. The penetrating stains, F6 to F9 were all rated 7 or less at both test sites, except over CCA treated wood. In Vancouver, F6 to F9 were all showing noticeable deterioration, over sanded or MGT-treated material. However, they generally had even lower ratings, requiring refinishing, over material with no pre-treatment or Zinc naphthenate treatment. In Mississippi there was a more complex pattern of deterioration difficult to interpret. All the coatings over CCA treated wood, with the exception of the varnish, had ratings of 8 to 10.

After twelve months exposure, two of the film forming coatings, F4 and F5, already stood out from the rest at both test sites (Table 6). The other film forming coatings F2 and F3 were showing similar ratings to the varnish and the penetrating stains, F6 to F9. All the coatings besides the varnish, F1, were still rating between 8 and 10 over CCA treated wood.

The trends at 12 months continued through 18 months (Table 8), and after 24 months only coatings F4 and F5 over sanded siding were in the range of 8 to 10 with little or no deterioration at both test sites (Table 10). With the exception of coatings over CCA treated wood, all the other coatings had ratings of 6 or less.

3.1.2 Short boards

The short boards with identical treatments to the siding sections all had virtually the same ratings as the siding and this continued through to the 24-month inspection. This showed that there was no adverse effect of putting all test coatings on the same piece of siding and thus validated the siding test method.

After 6 months exposure the (sanded) zinc naphthenate pre-treatments on the film forming coatings, F2 and F5, were generally showing signs of lower ratings than the sanded samples or the samples with no pre treatment (Table 5). There was less differential with the penetrating stains, F7 and F8. The (unsanded) zinc acetate was showing no effect compared to the samples with no pretreatment.

After 12 months, the zinc naphthenate pre-treatments were showing no beneficial effect on the penetrating stains, F7 and F8 compared to sanded samples, and a substantial negative effect on the best performing film forming coating, F5 (Table 7). No solvent controls were run so it is not possible to determine whether the negative effect was due to the zinc naphthenate or due to residual solvent. There was no beneficial effect of the zinc acetate pre-treatment compared to samples with no pretreatment with F7 and F8 but a less negative effect with F5.

After 18 and 24 months (Tables 9 and 11) there was no substantial difference between the samples with and without zinc acetate pre-treatment.

Table 4: Siding - six-month data

Test Site	Pre-Treatment	Average General Rating									
		Control	F1	F2	F3	F4	F5	F6	F7	F8	F9
Vancouver	None	2	9	10	10	10	10	5	5	5	4
	Sanded	3	7	10	10	10	10	7	7	7	9
	MGT	3	6	10	10	10	10	6	6	6	9
	ZN-4	4	4	10	10	10	7	4	4	4	6
	CCA	10	6	10	10	10	10	10	10	10	9
Mississippi	None	5	8	8	8	10	10	5	7	7	4
	Sanded	5	6	8	8	10	10	5	6	6	5
	MGT	4	7	7	7	10	10	3	5	8	4
	ZN-4	6	3	6	6	8	8	4	5	5	4
	CCA	9	8	10	10	10	10	8	9	9	8

Table 5: Short boards - six-month data

Test Site	Pre-Treatment	Average General Rating			
		F2	F5	F7	F9
Vancouver	None	10	10	8	7
	Sanded	10	10	8	8
	MGT	10	10	8	9
	ZN-4	8	10	8	8
	ZN-8	10	8	7	9
	ZA-4	10	10	9	9
	CCA	10	10	9	10
Mississippi	None	8	10	6	4
	Sanded	8	10	8	7
	MGT	7	10	8	8
	ZN-4	7	9	6	4
	ZN-8	6	7	6	4
	ZA-4	7	9	5	6
	CCA	9	10	9	9

Table 6: Siding - twelve-month data

Test Site	Pre-Treatment	Average General Rating									
		Control	F1	F2	F3	F4	F5	F6	F7	F8	F9
Vancouver	None	1	4	4	5	9	9	3	5	3	3
	Sanded	2	4	4	6	9	10	3	6	7	7
	MGT	2	3	4	6	10	10	3	4	5	9
	ZN-4	3	3	7	5	4	6	3	4	3	4
	CCA	7	7	10	10	10	10	8	8	8	9
Mississippi	None	2	3	4	2	9	10	3	4	4	2
	Sanded	2	3	4	5	9	10	3	3	3	2
	MGT	1	2	4	4	9	9	2	4	4	4
	ZN-4	2	3	4	4	3	4	3	3	4	3
	CCA	7	5	9	5	10	10	7	8	9	7

Table 7: Short boards - twelve-month data

Test Site	Pre-Treatment	Average General Rating			
		F2	F5	F7	F9
Vancouver	None	3	8	4	2
	Sanded	7	9	5	6
	MGT	4	10	4	7
	ZN-4	6	6	4	7
	ZN-8	7	4	4	7
	ZA-4	4	8	6	6
	CCA	10	10	9	9
Mississippi	None	3	10	3	3
	Sanded	3	9	4	3
	MGT	3	9	4	3
	ZN-4	4	5	4	3
	ZN-8	4	4	4	3
	ZA-4	4	8	4	4
	CCA	9	10	9	4

Table 1: Siding – twenty four-month data

Test Site	Pre-Treatment	Average General Rating									
		Control	F1	F2	F3	F4	F5	F6	F7	F8	F9
Vancouver	None	1	2	3	3	7	7	1	2	4	1
	Sanded	1	2	3	3	9	10	1	3	6	5
	MGT	1	2	3	3	9	10	2	3	5	3
	ZN-4	1	2	3	4	3	4	1	2	2	2
	CCA	4	4	10	10	10	10	5	5	7	5
Mississippi	None	1	1	2	1	3	4	1	2	3	1
	Sanded	1	1	2	1	8	9	1	1	3	1
	MGT	1	1	2	2	6	7	1	2	4	2
	CCA	4	3	5	3	7	9	4	5	6	4

Table 9: Short boards – twenty four-month data

Test Site	Pre-Treatment	Average General Rating			
		F2	F5	F7	F9
Vancouver	None	3	6	2	2
	Sanded	6	9	3	3
	MGT	3	8	3	2
	ZN-4	2	4	2	2
	ZN-8	2	2	2	3
	ZA-4	2	7	2	2
	CCA	8	9	5	6
Mississippi	None	1	5	2	1
	Sanded	2	7	1	2
	MGT	2	6	2	2
	ZN-4	2	2	1	2
	ZN-8	2	2	1	1
	ZA-4	3	6	2	2
	CCA	6	9	5	4

3.1.3 Test Site Weather Conditions

Weather conditions for the two sites are shown in Table 12. Notable differences between the two sites include the ambient temperature, rainfall and frequency of 100% relative humidity. The recorded average RH and surface temperature were similar for both test sites.

Table 10: Test site weather conditions

Weather Conditions		Vancouver	Mississippi
Normal annual ambient temperature		9.9	19.9
Normal annual rainfall (mm)		1234	1593
Days with measurable rainfall		168	N/A
On-Site Measurements (2 ½ hr intervals)	average RH (%)	72	85
	maximum surface temperature (C)	44	49
	frequency of 100% RH (%)	6	49

4 Discussion

4.1 Performance of coatings

Two water-based film forming coatings, F4 and F5, variants on the same formulation, clearly stood out from the pack in terms of overall performance over two years exposure. A curve fitted, using Microsoft Excel, to a plot of average general rating against time at the Mississippi test site predicted just under three years for F5 on sanded wood to reach a rating of 7, requiring refinishing for high-end applications (Figure 6). At the same site F2 over sanded wood reached a rating of 7 after a little over 6 months. The degree of acceleration of the Mississippi site over the Vancouver site can be judged by comparing the curves for the siding without pre-treatment for F2 and F5. Coatings F2 and F5 reached ratings of 7 after 7 and 18 months respectively in Mississippi (Figure 6) and 9 and 25 months respectively in Vancouver (Figure 7). This suggests an acceleration factor around 1.3 for these film forming transparent coatings rather than the factor of 2, averaged over all types of coatings, found in previous work (Groves and Gignac, 2002). This would suggest a refinishing interval for high-end applications under Canadian conditions of at least 4 years for the best performing transparent coating, F5 over sanded wood. All the other coatings tested had dropped to a rating of 7 or lower, requiring refinishing, after 1 year or less in Vancouver.

4.2 Effect of pre-treatments

Pre treating with sanding or "mill glaze" treatment provided improvements in time to refinishing for all coatings besides F2 and F3. To estimate the degree of service life extension on selected coatings, average general ratings at the Mississippi site were plotted against time (Figure 6). A rating of 7 was used as the threshold for refinishing. The water-based film forming coating F5 showed approximately double the service life from sanding while the solvent based film forming coating F2 showed no effect. A similar plot for CCA treated siding showed this pre-treatment doubled the life of F2 and F5 compared to wood with no pre-treatment. The performance of F5 over CCA treated wood was almost identical to that over sanded wood.

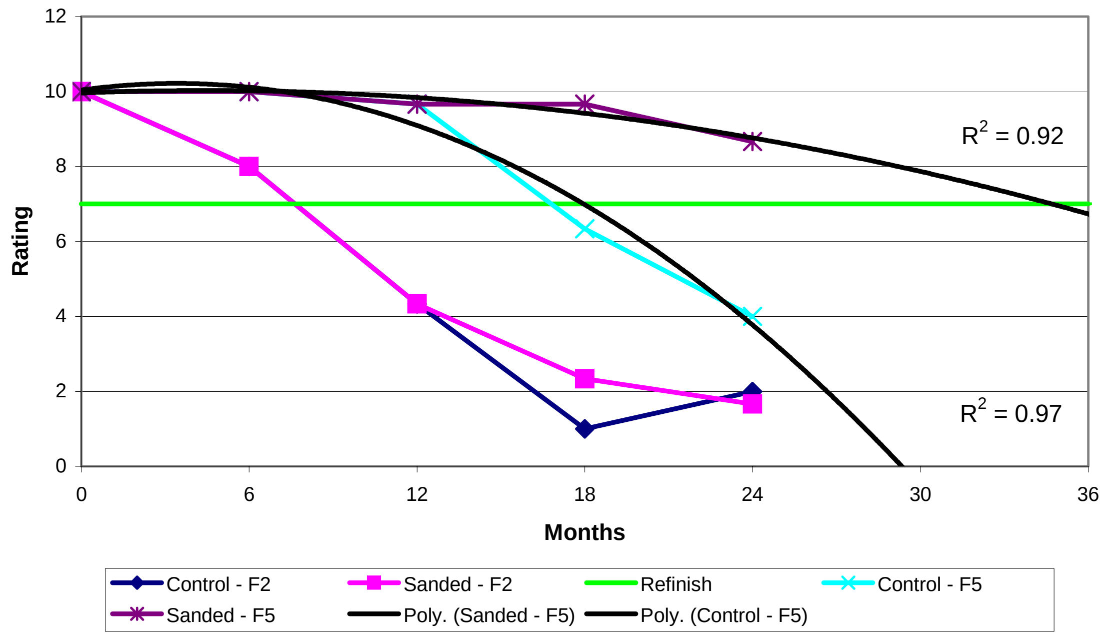

Figure 5: Change in average general rating over time for selected coatings with and without sanding in Mississippi.

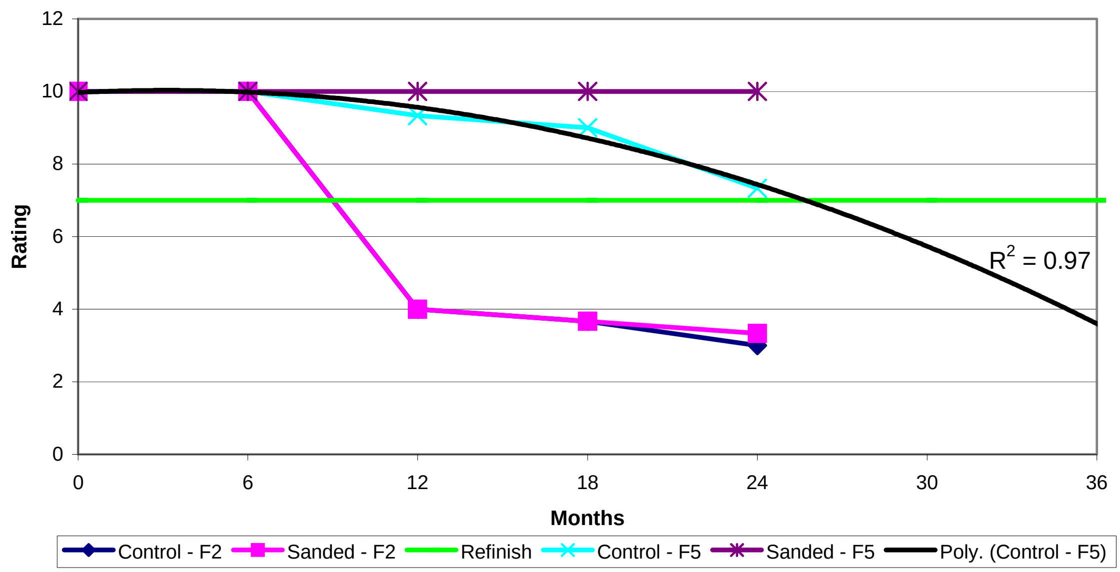

Figure 6: Change in average general rating over time for selected coatings with and without sanding in Vancouver.

5 Conclusions

- Two variants of a water-based film forming coating stood out among the transparent coatings tested.
- Sanding doubled the time to refinishing for this water-based film forming coating but had no effect on one solvent based film forming coating.
- “Mill glaze” pre-treatment increased the refinishing interval, but was not as effective as sanding.
- Zinc naphthenate pre-treatments negatively affected coating performance and zinc acetate provided no improvement in performance.
- Chromated copper arsenate pre-treatment doubled the life of the solvent-based film forming coating and the water-based film forming coating.
- The Mississippi test site provided a factor of acceleration of about 1.3 for film forming transparent coatings compared to the Vancouver test site.
- Coating F5 over sanded wood would be anticipated to give a life of at least 4 years, on a planed surface, without refinishing in high-end applications under Canadian conditions. All the other coatings tested required refinishing after 1 year or less in Vancouver.

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