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24 Month Evaluation of Novel UV Protection Systems

by

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Summary

A transparent coating with long-term performance could help wood maintain its share of residential markets against material substitution and potentially expand markets in recreational property and non-residential buildings. While transparent coatings can be made reasonably resistant to UV some UV likely penetrates to the wood and by necessity clear coatings are transparent to visible light. Visible light can also cause damage over the long term thus the underlying wood needs additional protection. Four novel UV protection systems were tested as pre-treatments on uncoated wood and under three coatings, a water-based film forming coating, a water-based acrylic varnish and a solvent based water repellent. Samples were exposed to natural weathering facing South at 45^{o} at a test site in Gulfport, Mississippi, in collaboration with the USDA Forest Products Laboratory. The test material was inspected every six months for discolouration, mold and stain, coating water repellency, flaking, erosion and cracking and substrate condition. After 24 months exposure, coatings over the combination of UV absorber and lignin stabilizer identified by Stephen Ayer were performing better than the same coatings applied over the combination recommended by Ciba and coatings over both pre-treatments were performing substantially better than controls with no pre-treatment. Projection of fitted curves beyond the data appears to indicate that pretreatment may double the life expectancy of the coating. There was no consistent effect of the synergists on either combination at this time.

Acknowledgements

The authors wish to thank the Canadian Forest Service for their support of this project. Stephen Ayer was the project leader and the originator of the concept of combining UVA, photostabilizer and synergist for protecting wood.

We also wish to acknowledge Sam Williams and Peter Sotos of the Forest Products Laboratory in Madison, Wisconsin for their guidance and support and for the use of their Mississippi test site.

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1 Objective

To develop an economically, technically and environmentally viable transparent coating that will provide long-term weather protection without masking the natural colour and texture of wood.

2 Introduction

Meeting demand for low-maintenance exterior transparent coatings could help the wood products industry defend existing markets against non-wood substitutes and exploit opportunities in new markets. Most commercially available transparent coatings contain UV absorbers and UV blockers that protect the coating from UV and greatly assist in protecting the underlying wood. However, these systems tend to ultimately fail due to degradation of the wood surface, causing breakdown of the coating-to-wood bond (Williams and Fiest 1999) and invasion by black-stain fungi using lignin breakdown products as a carbon source (Sharpe and Dickinson 1993). Film-forming coatings do not penetrate deeply into the wood and retain the UV absorbers in the film. Many “penetrating stains” show limited penetration and similar failure modes. If some UV does get through the coating, the wood has no protection. Furthermore, by necessity clear coatings are transparent to visible light. Visible light can also cause damage over the long term thus the underlying wood needs additional protection. This may be achieved using hindered amine light stabilizers, UV absorbers, free radical quenchers and energy sinks.

Most industry observers anticipate a change from copper-based preservatives to metal-free combinations of organics for residential treated wood products within the next one to five years. While the chromium in chromated copper arsenate (CCA) and the copper in Alkaline Copper quat (ACQ) and copper azole (CA) provide considerable protection against UV, the metal free formulations will need UV protection in the form of additives or coatings.

The work described in this report was designed to evaluate combinations of UV protectants applied to the wood surface prior to application of any coating. Stephen Ayer identified the potential of combining a UV absorber (UVA) with a compound that might act as a light stabilizer and also adding a synergist. He found that Ciba Specialty Chemical were recommending a combination of UVA and hindered amine light stabilizer (HALS) that might also benefit from one of his proposed synergists. The coatings chosen to go over these pre-treatments were selected based on the data obtained from the testing of commercial transparent coatings reported by Morris, McFarling and Groves (2004). The water-based film forming coating was selected as the best of those tested previously. The water-based varnish was selected as likely to fail earlier due to UV degradation of the wood surface. The solvent-based water repellent was selected to provide some protection against leaching in the absence of a coating containing UV absorbers.

Evaluation of this material after 12 months exposure (Morris and McFarling 2004) was too soon to distinguish any effects of the pre-treatments. This report covers evaluation after 24 months.

3 Staff

Stephen Ayer	Research Chemist, Durability and Protection
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4 Materials and Methods

4.1 Wood Sample Preparation

4.1.1 Source Lumber

Kiln-dried coastal Douglas fir, 24 pieces, 140 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. The moisture content was then checked and ranged from 15-19%. All boards were then planed on both faces and edges to 130 mm (width) x 18 mm (thickness). Fifteen samples were then cut to 0.45 m in length, and three samples were cut to 0.6 m in length.

4.1.2 Surface Preparation

The samples were separated into 6 groups of three replicates and labelled (Group F, untreated controls were on 0.6 m samples). The surfaces of the samples were then sanded, wiped with a damp cloth to remove dust and pre-treated by brushing on 4 coats of the treatments listed in Table 1 with drying between coats. Two combinations of UVA and photostabilizer were tested. The combination of Tinuvin 1130 and Product A was identified by Forintek's Stephen Ayer, the combination of CGL 777 and CGL 1198 was recommended by Ciba Specialty Chemicals[1]. Two synergists were tested with the first combination and one synergist was tested with the second combination. The synergists identified by Stephen Ayer were expected to improve the performance of the UVA/Stabilizer combinations. All pre-treatment formulations were made up as solutions in 50/50 Ethanol/Methyl-isobutyl-ketone.

Table 1: Surface pre-treatments

Treatment	UVA	Stabilizer	Synergist
A	5% Tinuvin 1130	1% Product A	2% Product 1
B	5% Tinuvin 1130	1% Product A	-
C	5% Tinuvin 1130	1% Product A	2% Product 2
D	5% CGL 777	1% CGL 1198	2% Product 1
E	5% CGL 777	1% CGL 1198	-
F	-	-	-

The samples were then marked; with a pencil line being scribed every 150 mm, to aid in separating the different coatings.

[1] Note: certain synergistic combinations of UV protectants may be covered by patents not held by Forintek.

4.1.3 Coating Application

The coatings used in this study were as follows:

F1 water-based, 2-step, transparent film
F2 water-based acrylic varnish, transparent film
F3 solvent-based, water repellent

Coatings #F1-F3 were brush applied in the Vancouver laboratory, according to manufacturers instructions, in locations as shown in Figures 1 and 2 (0.45 m and 0.6 m samples). All the coatings were applied to the planed side, the two edges (one planed and one rough) and the bottom 75mm of the back. Between all coatings a 6 mm overlap was used. Incompatibility between the varnish and the water repellent resulted in poor overlap between these two coatings. There were 3 replicates prepared for each F1-F3 coating combination per pre-treatment.

F1	F2	F3	C
152 mm	152 mm	152 mm	152 mm

Figure 1: Coating locations on 0.6 m samples (C= unfinished)

F1	F2	F3
152 mm	152 mm	152 mm

Figure 2: Coating locations on 0.45 m samples

The remainder of the back (rough side) of all the samples was primed with two coats of an alkyd primer. The end-grain of the samples was also primed.

4.2 Natural Exposure Tests

Natural weathering tests were set up at the USDA test site, Gulfport Mississippi in a warm, humid climate, to evaluate the performance under the worst case conditions experienced in the U.SA and to accelerate conditions as experienced in Canada (Morris, McFarling and Groves 2004).

The samples were fastened onto South facing, 45^{o} platforms. The samples were attached using aluminium brackets and stainless steel screws. The brackets were screwed to the back of the samples.

The samples were installed on November 20th, 2002. All samples were photographed and mapped.

4.3 Weather Data Collection

Data loggers were set-up to record ambient temperature, relative humidity (RH) and coating surface temperature. Ambient temperature and RH were recorded inside a solar-shielded, vented enclosure. Surface temperatures were recorded with a white-surface mounted thermocouple. Data was recorded for the period of two years.

4.3.1 Sample Rating

Samples were visually assessed based on a rating system adopted from the USDA Forest Products Laboratory (FPL) which inspects for discolouration, mold/stain, coating water repellency, flaking, erosion and cracking and substrate condition (Table 2). Discolouration, mold/stain and coating evaluations were each based on ASTM methods 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. 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 a coating from an adjacent coating.

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 4). 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 2: Evaluation methods

<table>
<tr><td colspan="2">Evaluation</td><td>Method</td></tr>
<tr><td colspan="2">Discolouration</td><td>Subjective visual assessment similar to ASTM D 3274-82</td></tr>
<tr><td colspan="2">Mold/stain</td><td>ASTM D 3274-82</td></tr>
<tr><td rowspan="4">Coating</td><td>Water Repellency</td><td>Subjective visual assessment</td></tr>
<tr><td>Flaking</td><td>ASTM D 772-47</td></tr>
<tr><td>Erosion</td><td>ASTM D 662-44</td></tr>
<tr><td>Cracking</td><td>ASTM D 661-44</td></tr>
<tr><td colspan="2">Substrate Condition</td><td>Subjective visual assessment</td></tr>
<tr><td colspan="2">General Rating</td><td>Overall appearance</td></tr>
</table>

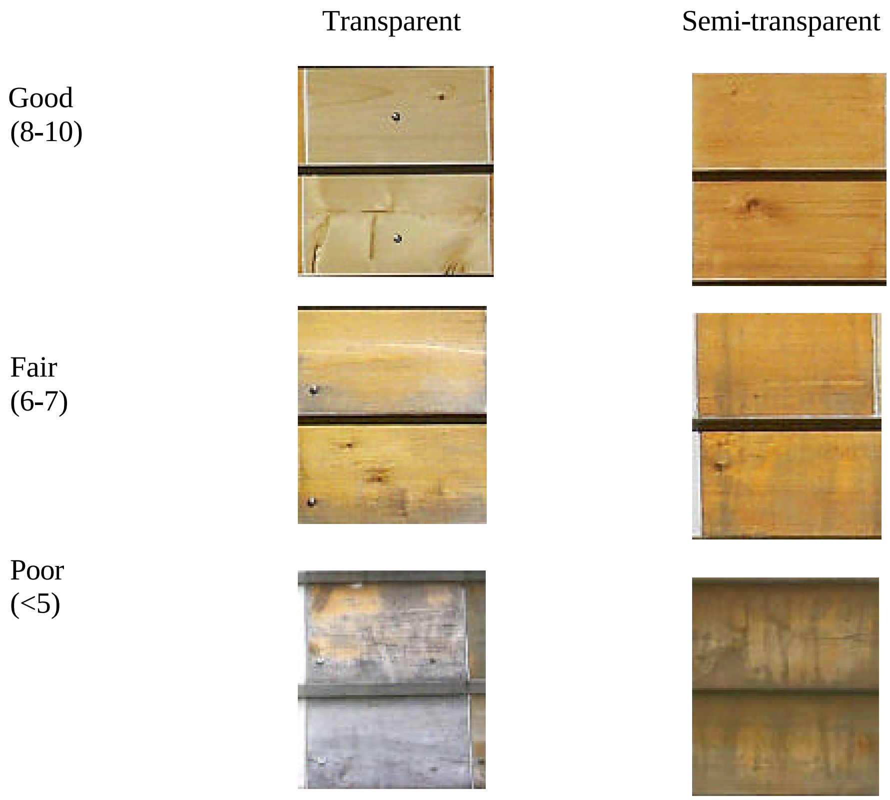

Figure 3: Sample rating examples

5 Results and Discussion

5.1 Exposure Test Results

Tables 4 and 5 show the average general ratings for pre-treatment/coating combinations on siding after 6, and 12 months exposure respectively. Within each table the data cells are shaded to show relative coating deterioration described as follows:

- (white) = 8 to 10 (little or no deterioration)
- (light grey) = 6 to 7 (noticeable deterioration)
- (dark grey) = 0 to 5 (refinishing required)

Figures 6, 7 and 8 show deterioration over time. Curves were fitted to the data using the curve-fitting program in Microsoft Excel with the intercept constrained to 10 the original rating at installation. The equations are presented in Table 4 and the R^2s are given on the Figures. An R^2 of 1.0 would be a perfect fit to the data.

After 24 months exposure, coatings F1 (fig 6) and F2 (Fig 7) over the combination of UV absorber and lignin stabilizer identified by Stephen Ayer and that recommended by Ciba were both performing better than controls with no pre-treatment under coatings F1 (Figure 6) and F2 (Figure 7). All the pretreatments reduced the rate of deterioration under coating F3 (Figure 8), the water repellent. The Ciba combinations also appeared to stabilize the material at a less deteriorated condition.

There was no consistent effect of either synergist. Synergist 2 did not appear to make a difference to the performance of Stephen Ayer’s combination. Synergist 1 appeared to have a negative effect on the Ciba combination under coating F1, no effect under coating F2 and a positive effect under coating F3. Synergist 1 appeared to have a positive effect on Stephen Ayer’s combination under coating F2 and but not under coating F1 or F3.

Coating F1 with no pre-treatment dropped to a rating of 7 after 15 months. In contrast in previous tests this coating was still at a rating of 9 after 24 months on sanded Douglas fir (Morris, McFarling and Groves 2004) and there is no apparent reason for the reduction in performance. Projection of the fitted curves gives an estimate of close to 30 months to reach a rating of 7 with pre-treatments A, B, C and E. Similarly, coating F2 with no pre-treatment dropped to a rating of 7 after 20 months. In contrast in previous tests this coating dropped to a rating of 7 after only 6 months on sanded Douglas fir (Morris, McFarling and Groves 2004) and this difference in performance merits further investigation. Projection of the fitted curves gives an estimate of close to 40 months to reach a rating of 7 with pre-treatments A, D and E. In previous tests a commonly recommended solvent-based transparent film-forming coating dropped to a rating of 7 after only 8 months in Mississippi (Morris, McFarling and Groves 2004).

Morris, McFarling and Groves (2004) calculated an acceleration factor around 1.3 between Mississippi and Vancouver for film-forming transparent coatings. Groves, and Gignac (2002) calculated an acceleration factor of 2 for exposure at 45^o compared to 90^o and an acceleration factor of 6 for Mississippi compared to Quebec City for all types of coatings. Since they also calculated a factor of 2 between Vancouver and Mississippi for all coatings and we are now finding 1.3 for film-formers, these other factors clearly need to be recalculated specifically for film-forming transparent coatings. If the fitted curves are accurate and the original acceleration factors were indeed valid, coating F2 with pretreatment over Douglas fir heartwood might not require re-finishing for approximately 8 years at 90^o in Vancouver and 24 years at 90^o in Quebec. Further testing is required to confirm these estimates.

Table 3: 24-month data

Pre-Treatment	UVA	Stabilizer	Synergist	Average General Rating			
				F1	F2	F3	C
A	Tinuvin 1130	Product A	1	8	9	1	N/A
B	Tinuvin 1130	Product A	-	8	8	1	N/A
C	Tinuvin 1130	Product A	2	8	8	1	N/A
D	CGL 777	CGL 1198	1	6	9	4	N/A
E	CGL 777	CGL 1198	-	8	9	3	N/A
F	-	-	-	3	5	1	1

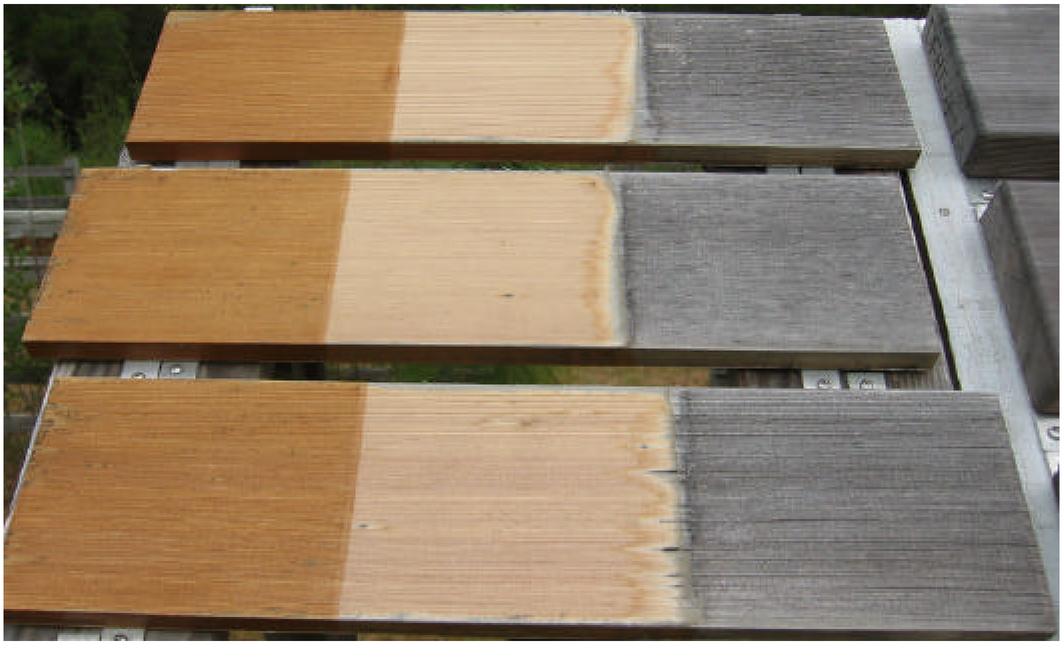

Figure 4 Pre-Treatment A Samples after 24 months exposure

Figure 5 Samples with no Pre-Treatment after 24 months exposure

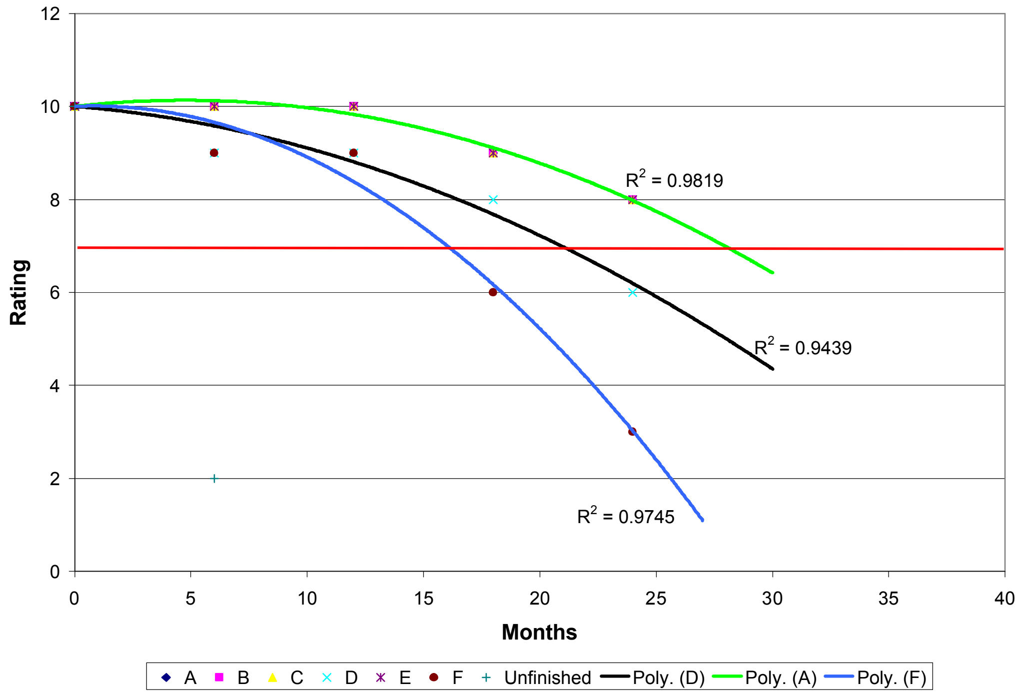

Figure 6 Coating F1 – Progress of deterioration over 24 months

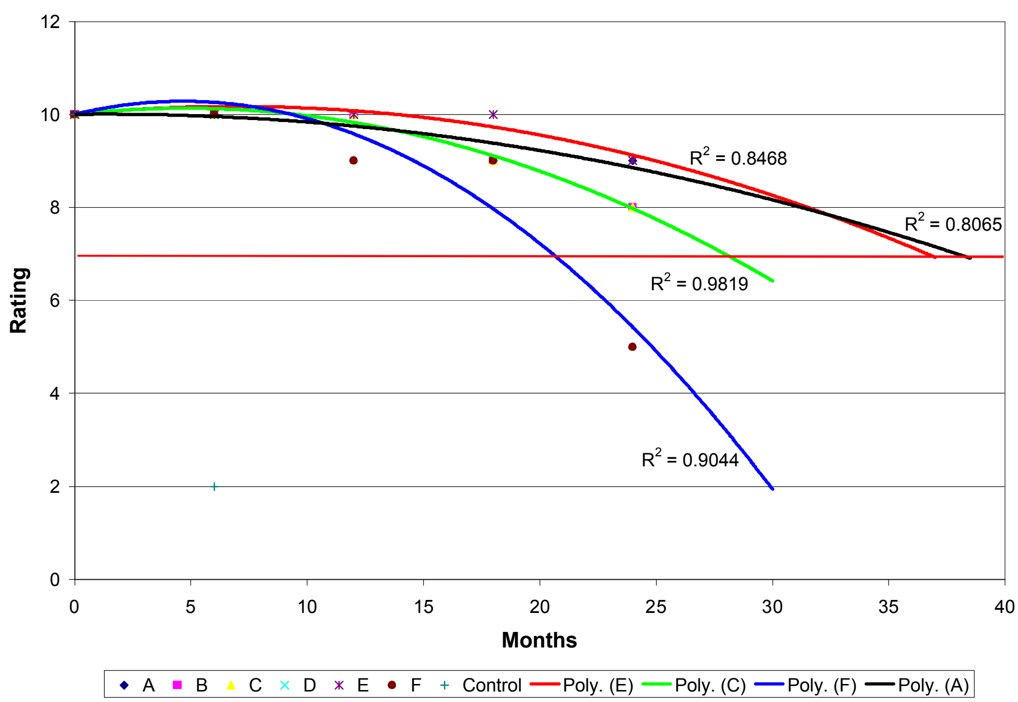

Figure 7 Coating F2 – Progress of deterioration over 24 months

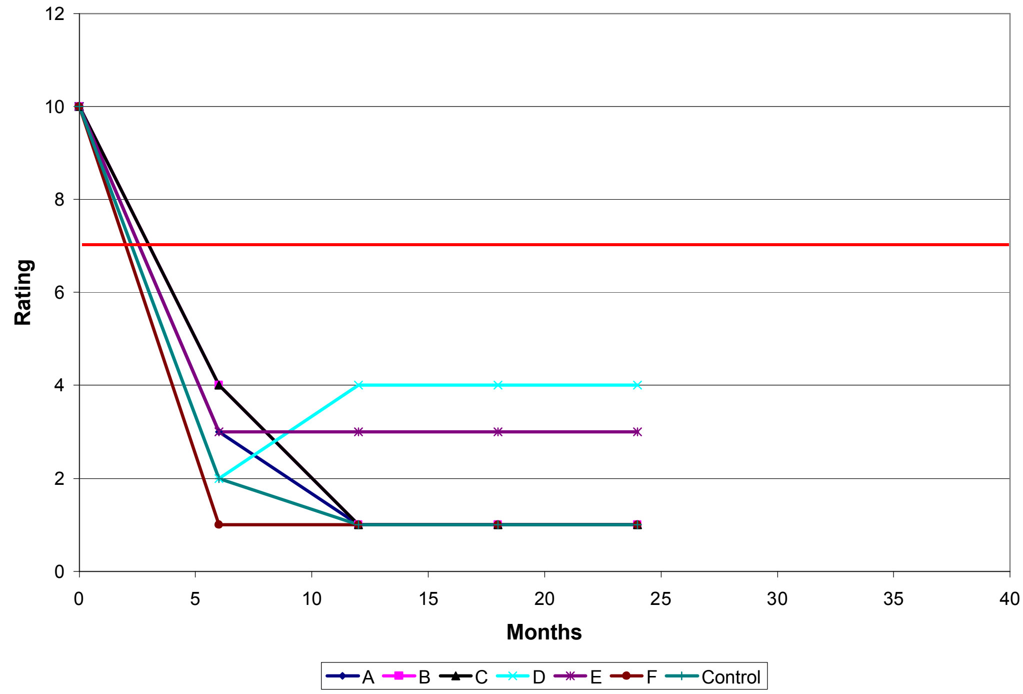

Figure 8 Coating F3 – Progress of deterioration over 24 months

Table 4: Equations fitted to data for coatings F1 and F2

Pre-Treatment	Equation	
	F1	F2
A	$Y = 10 - 0.0058x^2 + 0.0554x$	$Y = 10 - 0.0022x^2 + 0.0059x$
B	$Y = 10 - 0.0058x^2 + 0.0554x$	$Y = 10 - 0.0058x^2 + 0.0554x$
C	$Y = 10 - 0.0058x^2 + 0.0554x$	$Y = 10 - 0.0058x^2 + 0.0554x$
D	$Y = 10 - 0.0049x^2 - 0.0403x$	$Y = 10 - 0.0036x^2 + 0.0495x$
E	$Y = 10 - 0.0058x^2 + 0.0554x$	$Y = 10 - 0.0036x^2 + 0.0495x$
F	$Y = 10 - 0.013x^2 + 0.021x$	$Y = 10 - 0.013x^2 + 0.121x$

5.2 Test Site Weather Conditions

Table 5: Test Site weather conditions

Weather Conditions		Mississippi
Normal annual ambient temperature °C		19.9
Normal annual rainfall (mm)		1593
Days with measurable rainfall		N/A
On-Site Measurements (2 ½ hr intervals)	Average RH (%)	85
	Maximum surface temperature (°C)	49
	Frequency of 100% RH (%)	49

6 Conclusions

- Pretreatment with the combination of UV absorber and lignin stabilizer identified by Stephen Ayer and by Ciba showed substantial improvement in the performance of two water-based transparent coatings.
- Projection of fitted curves beyond the data appears to indicate that pre-treatment may double the life expectancy of the coating.
- There was no consistent effect of the two potential synergists.

7 Recommendations

Further testing is warranted to explore synergism between lignin stabilizers, UV absorbers and other potential synergists.

A laboratory Weather-Ometer test will be set up to determine which UV protectants best combine to transfer, dilute and convert UV energy to less destructive forms. A damp chamber test will be set up determine the response of black stain fungi to UV protectants.

8 References

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Appendix

Detailed Ratings for discolouration, mold/stain, coating water repellency, flaking, erosion and cracking and substrate condition after 6, 12 and 24 months.

Table App - 1: Six-month data: Substrate

Pre-Treatment	Average Rating			
	F1	F2	F3	C
A	10	10	9	-
B	10	10	9	-
C	10	10	10	-
D	10	10	10	-
E	10	10	10	-
F	10	10	10	7

Table App - 2: Six-month data: Water Repellency

Pre-Treatment	Average Rating			
	F1	F2	F3	C
A	10	10	8	-
B	10	10	10	-
C	10	10	5	-
D	9	10	10	-
E	10	10	10	-
F	10	10	10	1

Table App - 3: Six-month data: Surface Discolouration

Pre-Treatment	Average Rating			
	F1	F2	F3	C
A	10	10	3	-
B	10	10	4	-
C	10	10	4	-
D	9	10	2	-
E	10	10	3	-
F	10	10	1	2

Table App - 4: Six-month data: Surface Mold/Stain

Pre-Treatment	Average Rating			
	F1	F2	F3	C
A	10	10	3	-
B	10	10	4	-
C	10	10	4	-
D	9	10	2	-
E	10	10	3	-
F	10	10	1	2

Table App - 5: Six-month data: Coating Flaking

Pre-Treatment	Average Rating			
	F1	F2	F3	C
A	10	10	N/A	-
B	10	10	N/A	-
C	10	10	N/A	-
D	9	10	N/A	-
E	10	10	N/A	-
F	10	10	N/A	N/A

N/A: Not applicable. Non-film forming stains do not fail by flaking. Controls have no surface coating.

Table App - 6: Six-month data: Coating Erosion

Pre-Treatment	Average Rating			
	F1	F2	F3	C
A	N/A	N/A	4	-
B	N/A	N/A	4	-
C	N/A	N/A	4	-
D	N/A	N/A	4	-
E	N/A	N/A	3	-
F	N/A	N/A	1	N/A

N/A: Not applicable. Erosion is not a major failure mode of film forming coatings. Controls have no surface coating.

Table App - 7: Six-month data: Coating Cracking

Pre-Treatment	Average Rating			
	F1	**F2**	**F3**	**C**
A	10	10	N/A	-
B	10	10	N/A	-
C	10	10	N/A	-
D	9	10	N/A	-
E	10	10	N/A	-
F	10	10	N/A	N/A

N/A: Not applicable. Non-film forming stains do not fail by cracking. Controls have no surface coating.

Table App - 8: 12-month data: Substrate

Pre-Treatment	Average Rating			
	F1	**F2**	**F3**	**C**
A	10	10	9	-
B	10	10	9	-
C	10	10	10	-
D	9	10	10	-
E	10	10	10	-
F	10	10	7	7

Table App - 9: 12-month data: Water Repellency

Pre-Treatment	Average Rating			
	F1	**F2**	**F3**	**C**
A	10	10	1	-
B	10	10	1	-
C	10	10	1	-
D	10	10	7	-
E	10	10	6	-
F	10	10	1	1

Table App - 10: 12-month data: Surface Discolouration

Pre-Treatment	Average Rating			
	F1	**F2**	**F3**	**C**
A	10	10	1	-
B	10	10	1	-
C	10	10	1	-
D	9	10	4	-
E	10	10	3	-
F	9	9	1	1

Table App - 11 12-month data: Surface Mold/Stain

Pre-Treatment	Average Rating			
	F1	**F2**	**F3**	**C**
A	10	10	1	-
B	10	10	1	-
C	10	10	1	-
D	9	10	3	-
E	10	10	3	-
F	9	9	1	1

Table App - 12: 12-month data: Coating Flaking

Pre-Treatment	Average Rating			
	F1	**F2**	**F3**	**C**
A	10	10	N/A	-
B	10	10	N/A	-
C	10	10	N/A	-
D	10	10	N/A	-
E	10	10	N/A	-
F	10	10	N/A	N/A

N/A: Not applicable. Non-film forming stains do not fail by flaking. Controls have no surface coating.

Table App - 13: 12-month data: Coating Erosion

Pre-Treatment	Average Rating			
	F1	F2	F3	C
A	N/A	N/A	1	-
B	N/A	N/A	1	-
C	N/A	N/A	1	-
D	N/A	N/A	4	-
E	N/A	9	4	-
F	N/A	N/A	1	N/A

N/A: Not applicable. Erosion is not a major failure mode of film forming coatings. Controls have no surface coating.

Table App - 14: 12-month data: Coating Cracking

Pre-Treatment	Average Rating			
	F1	F2	F3	C
A	10	10	N/A	-
B	10	10	N/A	-
C	10	10	N/A	-
D	10	10	N/A	-
E	10	10	N/A	-
F	9	9	N/A	N/A

N/A: Not applicable. Non-film forming stains do not fail by cracking. Controls have no surface coating.

Table App - 15: 24-month data: Substrate

Pre-Treatment	Average Rating			
	F1	F2	F3	C
A	9	10	6	-
B	10	10	7	-
C	9	10	6	-
D	10	10	8	-
E	10	10	7	-
F	7	9	5	4

Table App - 16: 24-month data: Water Repellency

Pre-Treatment	Average Rating			
	F1	F2	F3	C
A	10	10	1	-
B	10	10	1	-
C	9	10	1	-
D	9	10	4	-
E	10	10	4	-
F	3	7	1	1

Table App - 17: 24-month data: Surface Discolouration

Pre-Treatment	Average Rating			
	F1	F2	F3	C
A	8	9	1	-
B	8	8	1	-
C	7	8	1	-
D	6	9	4	-
E	8	9	3	-
F	3	5	1	1

Table App - 18 24-month data: Surface Mold/Stain

Pre-Treatment	Average Rating			
	F1	F2	F3	C
A	8	9	1	-
B	8	8	1	-
C	7	9	1	-
D	7	9	3	-
E	8	9	2	-
F	4	8	1	1

Table App - 19: 24-month data: Coating Flaking

Pre-Treatment	Average Rating			
	F1	**F2**	**F3**	**C**
A	9	9	N/A	-
B	10	9	N/A	-
C	8	9	N/A	-
D	9	9	N/A	-
E	9	10	N/A	-
F	6	8	N/A	N/A

N/A: Not applicable. Non-film forming stains do not fail by flaking. Controls have no surface coating.

Table App - 20: 24-month data: Coating Erosion

Pre-Treatment	Average Rating			
	F1	**F2**	**F3**	**C**
A	N/A	N/A	1	-
B	N/A	N/A	1	-
C	N/A	N/A	1	-
D	N/A	N/A	1	-
E	N/A	N/A	1	-
F	N/A	N/A	1	N/A

N/A: Not applicable. Erosion is not a major failure mode of film forming coatings. Controls have no surface coating.

Table App - 21: 24-month data: Coating Cracking

Pre-Treatment	Average Rating			
	F1	**F2**	**F3**	**C**
A	8	9	N/A	-
B	8	9	N/A	-
C	7	8	N/A	-
D	7	9	N/A	-
E	8	9	N/A	-
F	3	8	N/A	N/A

N/A: Not applicable. Non-film forming stains do not fail by cracking. Controls have no surface coating.