Improved Coating Performance on Wood Treated with Carbon-Based Preservatives and an Ultraviolet/ Visible Light Protective Precoat

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Abstract

Transparent and semitransparent coatings applied to wood products often fail due to photochemical degradation and colonization by black stain fungi. Longer-lasting coatings are needed to enhance the competitiveness of wood products used in appearance applications. We hypothesized that shell treatment with carbon-based wood preservatives combined with a protective precoat containing organic ultraviolet (UV) absorbers and hindered amine light stabilizers would control black stain fungi and provide enhanced coating service life. After 3 years of field exposure at Maple Ridge, British Columbia, and Saucier, Mississippi, samples were evaluated for degree of black stain, coating degradation, and substrate damage. Heartwood substrate, preservative treatment, and use of protective precoats were associated with better stain resistance and enhanced coating performance. Use of preservative treatments and UV protective precoats is recommended to enhance the service life of high-quality transparent and semitransparent finishes. However, further work is needed to enhance the performance of transparent and semitransparent coatings to meet consumer demands for low maintenance.

Long-lasting coatings are needed to support the continued use of wood products in many exposed exterior applications. Clear coatings in exterior exposures must be extremely robust to protect against ultraviolet (UV) and visible light, water, and microorganisms. The absence of pigments reduces the ability of clear coatings to block UV and visible light. The coating itself as well as the underlying wood are vulnerable to photochemical reactions. Transparent coatings may use organic UV absorbers or nanoscale metal oxides to block UV radiation. UV absorbers have been used for decades (Rothstein 1967). Modern UV absorbers include hydroxyphenyl-s-triazines and 2-(2-hydroxyphenyl)-benzotriazoles (Schaller et al. 2008). Similarly, metal oxides have long been used in semitransparent coatings. More recently, nanoscale metal oxides in transparent coatings have been found to be effective in protecting wood from UV light (Liu et al. 2010, Blanchard and Blanchet 2011). Combinations of inorganic UV screeners and organic UV absorbers are also effective in reducing wood surface photodegradation (Forsthuber et al. 2013). In addition, light in the visible range close to the UV boundary can cause substantial damage (Kataoka et al. 2007); thus, semitransparent coatings must also protect against these wavelengths. Much of the damage done by photochemical reactions comes from free radical damage. Sequestering these radicals is another approach to mitigate photochemical reactions. Hindered amine light stabilizers (HALS) can protect wood and coatings using this approach (Hayoz et al. 2003, George et al. 2005). The combination of UV absorbers and HALS has been shown to be particularly effective in protecting wood (Kiguchi et al. 2001, Morris and McFarling 2006, Schaller and Rogez 2007, Forsthuber and Grüll 2010).

One obvious sign of failure in transparent and semitransparent coating systems is often the growth of black stain fungi. Although this type of discoloration has been termed ‘‘blue stain’’ by previous authors (e.g., Sharpe and Dickinson 1993), we use the term ‘‘black stain fungi’’ to more accurately reflect the discoloration and to differentiate these fungi from blue stain caused by *Ophiostoma* and related genera (Stirling et al. 2011).

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Black stain fungi, including *Aureobasidium, Hormonema,* and *Epicoccum* species, are highly melanized and consequently resistant to UV light (Butler and Day 1998). These fungi can damage coated wood by directly degrading some finishes, puncturing the finish with mechanical pressure, and degrading the wood on the wood–coating interface (Duncan 1963). *Aureobasidium pullulans* can cause minor losses to polysaccharides (Seifert 1964) and utilizes lignin photodegradation products as carbon sources (Sharpe and Dickinson 1993). This may explain why these fungi are able to dominate the wood–coating interface niche (Schoeman and Dickinson 1996). It also suggests that more effective protection from UV and visible light could help control these fungi.

Biocides can also be used to control black stain fungi. To be effective, they must be active at the wood–coating interface where the fungi grow. Biocides impregnated deep into the wood will not be active, nor will biocides that are immobilized within the coating itself. Early work in this field found that water repellents as well as copper and chromium salts, pentachlorophenol, dichlofluanid, copper-8-quinolinolate, and copper naphthenate were effective in controlling black stain fungi on coated wood (Sell and Wälchli 1974, French 1977, Feist 1984). Several biocidal actives have since been found to be effective against black stain fungi on the wood–coating interface, including zinc borate, iodopropynyl butylcarbamate, propiconazole, thiabendazole, and 4,5-dichloro-2-octyl-4-isothiazolin-3-one (Schoeman and Lloyd 1999, Gobakken and Jenssen 2007, Stirling et al. 2011, Schauwecker et al. 2012). In addition, recent work has also found that wood treated with carbon-based (organic in the chemical sense) preservatives containing triazoles and/or quaternary ammonium compounds was associated with improved resistance to colonization by black stain fungi (Stirling and Morris 2013). Though preservatives can help control black stain fungi, none has yet been found to provide fully effective long-term protection.

We hypothesized that the combination of superficial shell treatment with carbon-based wood preservatives plus a protective precoat (PPC) containing UV absorbers and HALS would control black stain fungi and provide enhanced coatings service life.

Experimental Methods

Kiln-dried ponderosa pine (*Pinus ponderosa*) sapwood obtained from Kalesnikoff Lumber (Thrums, British Columbia) and kiln-dried white spruce (*Picea glauca*) obtained from Tolko (High Level, Alberta) was cut into 142 by 19 by 600-mm boards with eased edges and end sealed with three coats of epoxy resin (Intergard 740, International Marine Coatings). Boards from each species were randomly allocated to four preservative treatment groups of 24 boards each. One group remained untreated, whereas the other three were treated with one of three proprietary carbon-based preservative (CBP) formulations to typical retentions for aboveground exposure. CBP1 and CBP2 contained mixtures of tebuconazole and/or propiconazole and didecyldimethylammonium carbonate. Wood was pressure treated using a full-cell process with a 30-minute initial vacuum at 95 kPa, followed by a 2-hour press at 1,030 kPa and a 15-minute final vacuum at 95 kPa. Total uptake of biocidal actives for CBP1 was 1.2 kg/m^3 in spruce heartwood and 1.1 kg/m^3 for pine sapwood. Total uptake of biocidal actives for CBP2 was 1.2 kg/m^3 in spruce heartwood and 2.0 kg/m^3 in pine sapwood. CBP3 was a dip plus kiln-conditioning treatment that contained only triazoles with retentions of 0.20 kg/m^3 in pine sapwood and 0.19 kg/m^3 in spruce heartwood. All samples were air-dried for a minimum of 2 weeks to a moisture content of approximately 10 percent before application of PPCs or coatings.

Each board was lightly sanded with 80-grit sandpaper and divided into three equal sections approximately 200 mm in length. A UV/visible light PPC was prepared by dissolving a hydroxyphenyl benzotriazole-class UV absorber (Tinuvin 1130, 5% product basis; Ciba) and a HALS (Lignostab, 2.5% product basis; Ciba) in a solution of 36 percent 2-butoxyethanol in water. This solution was applied by brush with an average coverage of 76 g/m^2 to 12 of the boards from each preservative treatment group. After approximately 1 week, each board was then divided into three sections and finished by brush with one of three commercial water-based coatings. These included three coats in Step 1 and one coat in Step 2 for a two-step polyurethane-based semitransparent film-former (F1), three coats of a urethane/acrylic transparent film-former (F2), and two coats of a semitransparent penetrating stain containing natural oils (F3) with target spread rates of 490, 323, and 327 g/liter, respectively. Film thickness was not measured. Finishes were applied to different positions on the boards so that each finish was applied to both middle and end sections. A 6-mm overlap was made between each section, and one coat of alkyd primer was applied to the back side of each board. End-seal applied before treatment remained on the boards to protect the end-grain. Six of the boards from each group were fastened onto south-facing exposure racks at 45 degrees to the horizontal using aluminum brackets and stainless steel screws at FPInnovations' field test site at the University of British Columbia's Malcolm Knapp Research Forest at Maple Ridge in March 2010 and at the US Department of Agriculture (USDA) test site at the Harrison Experimental Forest near Saucier, Mississippi, in April 2010. Approximately 1 month elapsed between finishing and installation. The Maple Ridge site has a temperate, oceanic climate with mean monthly minimum and maximum temperatures of 1°C and 23°C, respectively, and 2,150 mm of annual precipitation (Morris et al. 2011). The Saucier test site has a warm, humid climate with mean monthly minimum and maximum temperatures of 12°C and 24°C, respectively, and 1,600 mm of annual precipitation (Hennon et al. 2007). These sites represent moderate (Maple Ridge) and aggressive (Saucier) North American exposure hazards.

Samples were rated for mold and stain growth (ASTM D3274; American Society for Testing and Materials [ASTM] 1988b); coating degradation, which was the minimum rating of cracking, flaking, and erosion (ASTM D661, D772, and D662; ASTM 1986, 1988a, 1993b); and substrate condition (similar to ASTM D660; ASTM 1993a). An overall rating was calculated as the minimum value of the mold/stain, coating degradation, and substrate condition ratings. All measures were on an ordinal scale from 1 to 10, where 1 = complete failure and 10 = no change from the unweathered condition (Feist 1988a). Samples were rated every 6 to 12 months for up to 36 months. Analysis of variance was used to determine the variance in ratings attributed to wood type, treatment, and precoat. Time was specified as a covariate.

Results and Discussion

Individual ratings for substrate, stain, and coating degradation were highly correlated (Table 1). As a result of the moderately high correlations and relatedness of the dependent variables, each was analyzed independently by analysis of variance (Tables 2 and 3). Average overall ratings for F1 and F2, which were calculated as the minimum rating of substrate, stain, and coating degradation, are shown in Figures 1 through 4. A rating of 7 was considered to be sufficient degradation to be noticeable and warrant refinishing (Morris and McFarling 2006).

The semitransparent penetrating stain (F3) failed so rapidly that the frequency of inspections was inadequate to determine any potential benefits of wood type, preservative treatment, or PPC. Ratings of F3 are not included in this article. The semitransparent film-former (F1) performed better than the transparent film-former (F2). This may be attributable to the protective effects of the pigments in F1 (Feist 1988b), although other uncontrolled differences between these coatings, such as dry film thickness, may have had an impact.

At Maple Ridge, average overall ratings of less than 7 for untreated controls were reached after 20 months for F1 and after 14 months for F2, whereas at Saucier, average overall ratings of less than 7 were reached after 13 to 24 months for F1 and after 7 months for F2. In general, samples degraded more rapidly at Saucier than at Maple Ridge. This is consistent with Saucier's more aggressive climate. High UV exposure and frequent wetting and drying stress the coatings, whereas the more consistent warm temperatures and high humidity support the growth of black stain fungi. Overall, the relative performance and modes of failure for each treatment group were similar between sites. This is consistent with the results of earlier work comparing coating performance between sites in Wisconsin and Switzerland (Knopf et al. 1994).

Spruce heartwood generally had higher substrate, stain, coating degradation, and overall ratings than equivalent pine sapwood samples. White spruce heartwood is not naturally durable (Clausen 2010), but it does contain fewer nutrients than sapwood to support the growth of black stain fungi. Whether the better performance of spruce heartwood was caused by less abundant nutrients for growth of black stain fungi or by other factors is not known. The better performance of the heartwood samples agrees with the results of Sandberg (2008), who reported more cracking and surface-discoloring fungal growth on painted Scots pine sapwood samples than on heartwood samples after field exposure.

Table 1.—Correlations between dependent variables.

Ratings	Correlation (*R*)
Substrate and stain	0.74
Stain and coating degradation	0.68
Substrate and coating degradation	0.85

Treatment was a significant factor for all dependent variables except stain and overall ratings at Saucier. In general, preservative treatment was associated with higher overall ratings, as previously reported (Stirling and Morris 2013). The improved performance of coatings on treated wood observed in the present study is consistent with previous work that found improved performance on wood treated with chromated copper arsenate (Ross and Feist 1993) and copper amine preservatives (Nejad and Cooper 2011). The absence of copper from treatments in the present work suggests that it is the biocidal effects of the preservatives, rather than the photoprotective effects of copper, that contribute to enhanced performance.

The PPCs were also effective in extending the serviceability of the coatings. This is consistent with work by Schaller and Rogez (2007), who reported improved coating performance and resistance to black stain associated with pretreatments using solutions containing a 2-hydroxyphenyl-s-triazine type UV absorber and HALS after 18 months of similar exposure in Pfeffingen, Switzerland. The combination of UV absorber and HALS has been shown to reduce the rate of lignin loss and minimize the accumulation of degradation products on the wood surface (Schauwecker et al. 2012). This may directly explain the improved substrate ratings observed. Improved substrate stability would likely have contributed to enhanced coating performance and reduced black stain colonization by maintaining film integrity.

The statistically significant correlation between the wood type × treatment interaction and the substrate, stain, coatings degradation, and overall ratings may be explained by higher concentrations of biocidal actives on the surface of the more impermeable spruce heartwood. Although

*Table 2.—Statistical significance (*P* value) of independent variables from analysis of variance for the semitransparent film-former (F1).*

Source[a]	Maple Ridge				Saucier			
	Substrate	Stain	Coating degradation	Overall	Substrate	Stain	Coating degradation	Overall
Corrected model	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Intercept	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Time	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Wood	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Treatment	<0.05	<0.05	<0.05	<0.05	<0.05	0.496	<0.05	0.313
PPC	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Wood × treatment	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Wood × PPC	0.084	0.723	<0.05	0.830	0.382	<0.05	0.832	<0.05
Treatment × PPC	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Wood × treatment × PPC	0.344	0.595	<0.05	0.211	<0.05	0.212	<0.05	0.455
R^2	0.64	0.71	0.52	0.66	0.76	0.72	0.73	0.74

[a] PPC = protective precoat.

Table 3.—Statistical significance (P value) of independent variables from analysis of variance for the transparent film-former (F2).

Source[a]	Maple Ridge				Saucier			
	Substrate	Stain	Coating degradation	Overall	Substrate	Stain	Coating degradation	Overall
Corrected model	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Intercept	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Time	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Wood	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Treatment	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
PPC	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Wood × treatment	0.389	0.256	<0.05	<0.05	0.628	<0.05	0.514	<0.05
Wood × PPC	0.698	<0.05	<0.05	<0.05	0.840	<0.05	0.550	<0.05
Treatment × PPC	<0.05	<0.05	0.281	<0.05	0.064	<0.05	0.289	<0.05
Wood × treatment × PPC	0.148	<0.05	<0.05	<0.05	0.662	0.101	0.408	0.082
R^2	0.65	0.81	0.57	0.80	0.74	0.77	0.39	0.77

[a] PPC = protective precoat.

surface concentrations were not measured, the refractory nature of spruce heartwood would have led to concentrations higher near its surface than near the surface of pine sapwood, which would have been largely through treated. It follows that this low-nutrient/high-biocide surface would be more resistant to black stain than the high-nutrient/lower-biocide pine sapwood surface.

The statistically significant correlation between the treatment × precoat interaction and the substrate, stain, coatings degradation, and overall ratings could potentially be explained in two ways: The PPC could protect the biocidal actives from photodegradation, or the biocides could protect the PPC from biodegradation. The nature of this potential cross-protection should be examined in future work.

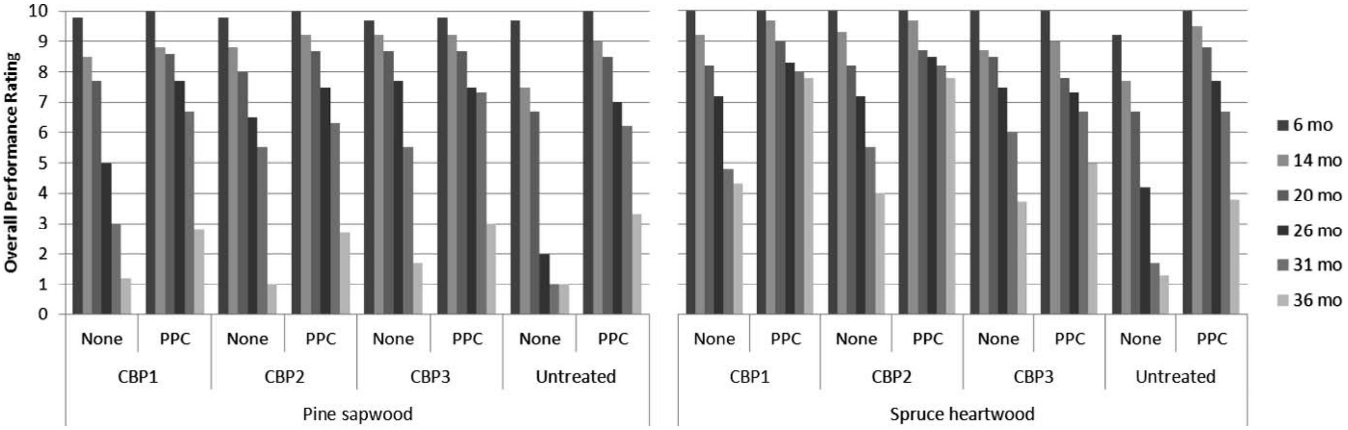

Figure 1.—Overall performance ratings of the semitransparent film-former (F1) at Maple Ridge. PPC = protective precoat; CBP = carbon-based preservative.

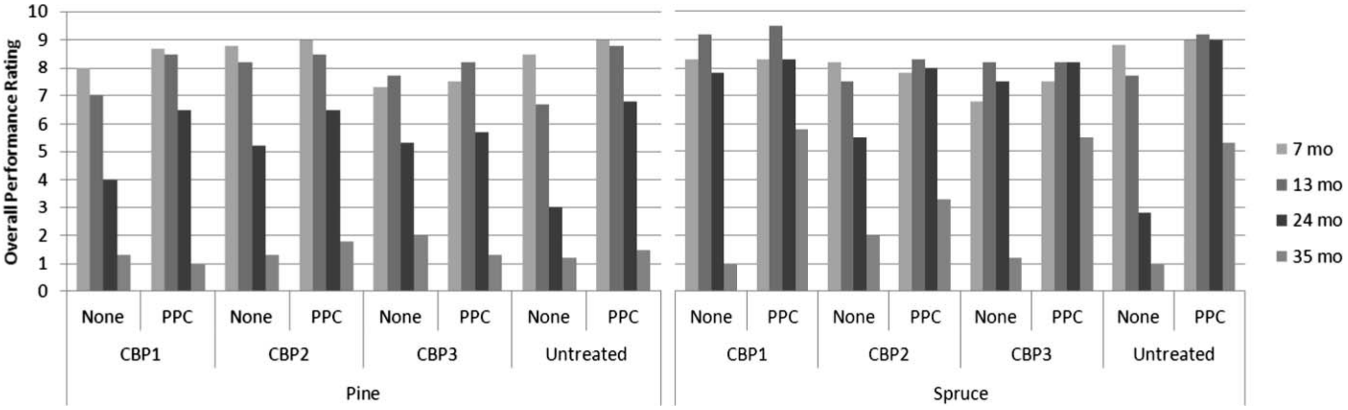

Figure 2.—Overall performance ratings of the semitransparent film-former (F1) at Saucier. PPC = protective precoat; CBP = carbon-based preservative.

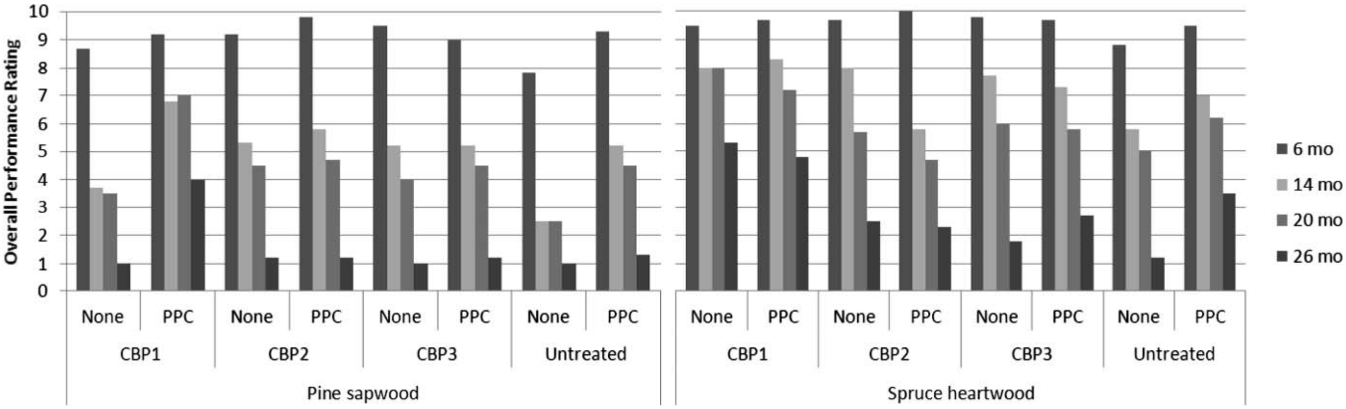

Figure 3.—Overall performance ratings of the transparent film-former (F2) at Maple Ridge. PPC = protective precoat; CBP = carbon-based preservative.

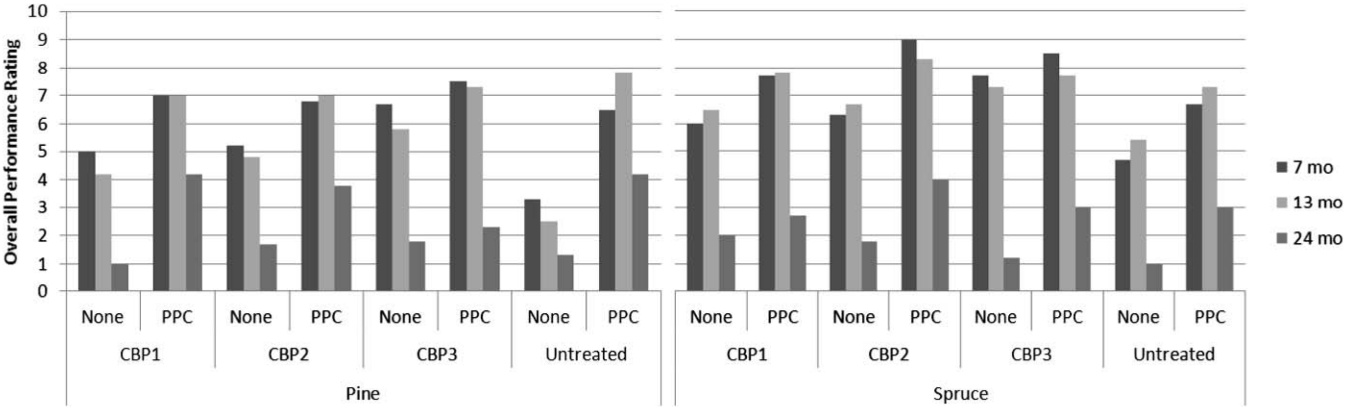

Figure 4.—Overall performance ratings of the transparent film-former (F2) at Saucier. PPC = protective precoat; CBP = carbon-based preservative.

The present work confirms the efficacy of UV absorbers/HALS applied in a PPC and of CBP treatment. Moreover, it indicates that the combination of preservative treatment and a PPC provides the best performance. Although the performance gains associated with these approaches may justify their commercial use, they provide only modest gains in coating performance. Even the best-performing treatments would still require refinishing after 3 years of exposure at Saucier under the conditions of the present study. Other approaches are needed to enhance the performance of transparent and semitransparent coatings to meet consumer expectations for low maintenance. A parallel study found that plasma pretreatments enhanced coating performance and reduced black stain (Blanchard and Stirling 2013). The degree of improvement was similar to that found with the PPCs. Further gains in performance may be achieved by combining these approaches. However, to obtain the low maintenance performance sought, greater photostabilization of the wood substrate may be necessary (Evans 2009). Recent work has found that treatment with phenol formaldehyde resin and HALS stabilized the wood surface as much as chromic acid (Evans et al. 2013). Such substrate treatments, combined with effective black stain control and high-quality coatings, may lead to much greater performance.

Conclusions

Coating performance on a low-nutrient substrate with no natural durability (spruce heartwood) was better than on a high-nutrient substrate (pine sapwood). Treatment with CBPs and the use of UV/visible light PPCs were associated with improved coating performance.

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