Light-Stabilized Coatings for Preservation of Wood-Plastic Composite Decking

by Robert Waldron and Brett Moyer†
Ciba Corporation*

Wood-plastic composite (WPC) materials have found extensive use in the construction of residential decks. Although recognized as a low maintenance product, WPC lumber is not immune to the effects of weathering. Sunlight and water exposure can lead to color change and physical degradation.[1,2]

Previous WPC preservation studies have evaluated the effectiveness of light stabilizers incorporated during the wood fiber/thermoplastic compounding process.[3,4] This study presents the results of accelerated exposure tests of WPC materials preserved by the application of a light-stabilized clearcoat.

DISCUSSION

Four light stabilizer (LS) options (including a no light stabilizer case and three different combinations of UV absorber and hindered amine free radical scavenger) were tested in each of three waterborne acrylic topcoats on each of two wood-plastic composite (WPC) substrates (one made with polyethylene and a second made with polypropylene).

Corresponding samples, as well as samples of each substrate without any topcoat, were prepared for both accelerated weathering in a xenon arc weatherometer (1000 hr, CAM 7) and for exterior exposure on a test rack.

The unprotected WPC samples exposed to accelerated weathering lightened significantly. The corresponding CIELAB ΔL^* values were in the range of 13 to 14. The samples protected with topcoats that lacked light-stabilizer additives fared better. The samples protected with light-stabilized topcoats showed the best color stability. The ΔL^* values corresponding to the best-performing topcoat resin/light stabilizer combination were in the range of 4 to 6.

Presented at FutureCoat! 2008, sponsored by FSCT, October 15-16, 2008, in Chicago, IL.
*Coating Effects Regional Technical Center Americas, 205 S. James St., Newport, DE 19804.
†Currently employed with Wacker Chemie.

The exterior exposure test is ongoing. One of the coatings failed within the first three months of exposure (although this same coating performed reasonably well under accelerated weathering test conditions). Through six months exposure the exterior weathering test results showed that across both WPC substrates, and 2 of 3 resin types, the application of a coating provides significant protection against color fade. Light stabilization yielded a further incremental benefit in one of the two successful coatings, but made little apparent difference in the other.

MATERIALS AND METHODS

Two types of commercial WPC decking material, each made with wood flour and each compounded with a different plastic, were procured for use in this study: (a) WPC-1: made with polyethylene plastic; and (b) WPC-2: made with polypropylene plastic.

Three different waterborne resin systems were used to prepare the topcoats:

(a) Resin A: a 100% acrylic emulsion polymer developed for low- to zero VOC exterior semi transparent wood stains
(b) Resin B: an all-acrylic emulsion polymer that features extensive crosslinking for sufficient hardness to withstand heavy foot traffic
(c) Resin C: a 100% acrylic binder with good adhesion and water-blocking properties.

Coatings were prepared from each of these binders by mixing the following constituents in order, with continuous stirring:

(a) Specified quantities of resin and water
(b) A pre-mixed solution of Dowanol DPnB and water
(c) Propylene glycol (where applicable)
(d) Defoamer and fungicide/mildewcide
(e) A pre-mixed solution of Acrysol™ RM-825 thickener and water (to adjust viscosity, target = 70 KU)

Four different light stabilization options were tested in each of the three waterborne acrylic topcoats:

(a) No light stabilizer (LS) additives
(b) LS Blend
(c) UV absorber 1 (UVA-1) plus hindered amine light stabilizer 1 (HALS-1)
(d) UV absorber 2 (UVA-2) plus HALS-1

The "LS Blend" is a liquid product consisting of 100% active material. It contains a benzotriazole UV absorber with a broad UV absorption spectrum, high thermal stability, and good photopermanence. It also contains a hindered amine free radical scavenger based on a substituted tetramethyl piperidine with an N-CH_3 (methyl) head group. This product can be used in waterborne coatings, but typically requires the use of a cosolvent for incorporation.

The UVA-1, UVA-2, and HALS-1 are products based on a newly developed encapsulation technology to render organic, water-insoluble UVA compatible with waterborne coating systems.[5,6] These novel dispersions exhibit long-term storage stability even after being added to the liquid paint without any sedimentation, and are designed for easy, stir-in incorporation into aqueous paints without the use of cosolvents or high-energy dispersion equipment.

The concentration of active ingredient in UVA-1 is 20% w/w. This is a red-shifted hydroxy-phenyl-s-triazine chromophore that provides strong protection in the UV-A range of the UV spectrum. It has high heat stability and excellent photopermanence.

The concentration of active ingredient in UVA-2 is also 20% w/w. Again, this is a hydroxy-phenyl-s-triazine chromophore with superior thermal stability and photopermanence. However, its peak absorbance occurs in the shorter wavelength range of the UV spectrum.

The concentration of active ingredient in HALS-1 is 30% w/w. This HALS is based on a substituted tetramethyl piperidine with an N–OR (aminoether) head group. Relative to the HALS contained in the LS Blend product, this variant has low basicity to minimize the potential for interaction with acidic media or catalyst residues in the paint.

One-quart batches of each coating were prepared without light-stabilizer additives. Each batch was divided into half-pint portions. These portions were used to prepare coating variants with the light-stabilizer additive loadings shown below:

(a) No LS additives
(b) 2% w/w UVA-1 and 1% w/w HALS-1
(c) 2% w/w UVA-2 and 1% w/w HALS-1

A second set of quart batches of each coating was prepared. Each batch was stabilized by the addition of 3% w/w LS Blend.

The light-stabilizer additive concentrations cited here are stated in terms of weight percent active component on binder solids.

The detailed clearcoat formulations for the Resin A, Resin B, and Resin C binder systems are shown in *Tables* 1, 2, and 3, respectively.

The accelerated weathering test matrix developed for this project is shown in *Table* 4. Thirteen sample types were specified for each WPC substrate (one sample with no coating + four light stabilizer variants for each of three coating types). Each sample consisted of a 6-

Table 1—Resin A Topcoat Formulation

	1 Quart Batch, g	Half-Pint Batch, g
Resin A	682.64	170.66
Water	80	20.00
Water	30.5	7.63
Dowanol DPnB (Dow Chemical)	10	2.50
Propylene glycol	16	4.00
Tego Foamex 805 (Degussa)	8	2.00
Polyphase 678 (Troy)	6	1.50
Water	19.01	4.75
Acrysol RM-825 (Rohm and Haas)	3.5	0.88
Total	**855.65**	**213.91**
% w/w solids	30.87	30.87
Solids	258.74	64.68
3% LS blend	7.8	
2% UVA-1		6.5
2% UVA-2		6.5
1% HALS-1		2.2

Table 2—Resin B Topcoat Formulation

	1 Quart Batch, g	Half-Pint Batch, g
Resin B	620.05	155.01
Water	100	25.00
Texanol (Eastman Chemical)	16.74	4.19
Water	40	10.00
Dowanol DPnB (Dow Chemical)	16.74	4.19
Tego Foamex 805 (Degussa)	8	2.00
Polyphase 678 (Troy)	6	1.50
Water	60.05	15.01
Acrysol RM-825 (Rohm and Haas)	1.5	0.38
Total	**869.08**	**217.27**
% w/w solids	32.11	32.11
Solids	274.08	68.52
3% LS blend	8.2	
2% UVA-1		6.9
2% UVA-2		6.9
1% HALS-1		2.3

Table 3—Resin C Topcoat Formulation

	1 Quart Batch, g	Half-Pint Batch, g
Resin C	612.51	153.13
Water	100	25.00
Water	40	10.00
Dowanol DP-B (Dow Chemical)	10	2.50
Propylene glycol	16	4.00
Tego Foamex 805 (Degussa)	8	2.00
Polyphase 678 (Troy)	6	1.50
Water	70.81	17.70
Acrysol RM-825 (Rohm and Haas)	2.4	0.60
Ammonium hydroxide	1.2	0.30
Total	**866.92**	**216.73**
% w/w solids	31.79	31.79
Solids	270.38	67.60
3% LS blend	8.1	
2% UVA-1		6.8
2% UVA-2		6.8
1% HALS-1		2.3

Table 4—Accelerated Weathering Test Matrix

Substrate	Coating Variant	Light Stabilizers (LS) Variant
WPC-1	No Coating	—
	Resin A	No LS 3% w/w LS blend 2% w/w UVA-1 + 1% w/w HALS-1 2% w/w UVA-2 + 1% w/w HALS-1
	Resin B	No LS 3% w/w LS blend 2% w/w UVA-1 + 1% w/w HALS-1 2% w/w UVA-2 + 1% w/w HALS-1
	Resin C	No LS 3% w/w LS blend 2% w/w UVA-1 + 1% w/w HALS-1 2% w/w UVA-2 + 1% w/w HALS-1
WPC-2	No Coating	—
	Resin A	No LS 3% w/w LS blend 2% w/w UVA-1 + 1% w/w HALS-1 2% w/w UVA-2 + 1% w/w HALS-1
	Resin B	No LS 3% w/w LS blend 2% w/w UVA-1 + 1% w/w HALS-1 2% w/w UVA-2 + 1% w/w HALS-1
	Resin C	No LS 3% w/w LS blend 2% w/w UVA-1 + 1% w/w HALS-1 2% w/w UVA-2 + 1% w/w HALS-1

Table 5—Color Measurement Results for Samples Exposed to Accelerated Weathering

	WPC-1 ΔE*				WPC-2 ΔE*			
	No Coating	Resin A	Resin B	Resin C	No Coating	Resin A	Resin B	Resin C
No coating	14.3	..	..	—	13.4	—	—	—
No LS	—	8.8	9.2	7.3	—	11.3	11.3	9.9
3% LS blend		7.9	7.2	7.2	—	9.1	8.1	7.7
2% UVA-2, 1% HALS 1	—	6.9	6.5	5.4	—	8.3	6.4	6.8
2% UVA-1, 1% HALS-1	—	6.3	6.3	6.0	—	7.1	7.3	6.5

	WPC-1 ΔL*				WPC-2 ΔL*			
	No Coating	Resin A	Resin B	Resin C	No Coating	Resin A	Resin B	Resin C
No coating	14.3	—	—	—	13.4	—	—	—
No LS	—	8.6	9.1	6.7	—	11.2	11.2	9.6
3% LS blend	—	7.6	6.8	6.5		8.8	7.9	7.1
2% UVA-2, 1% HALS 1		6.1	5.8	4.6	—	8.0	6.0	6.1
2% UVA-1, 1% HALS-1	—	5.8	5.4	4.6	..	6.0	7.1	5.8

All LS concentrations stated as weight percent actives on binder solids.

in. length of WPC lumber trimmed with respect to width and thickness to fit the weatherometer sample holders. Coatings were applied to these panels using foam brushes with a spread rate target of 350 ft²/gal. This target was achieved by weighing the amount of coating applied to the known surface area of each panel.

An equivalent set of WPC panels was prepared for exterior weathering on an exposure rack in southeastern Pennsylvania. Each sample consisted of a 3-ft length of WPC lumber demarcated into 6-in. segments. The two 6-in. segments at the ends of each panel were not coated. The four 6-in. segments contained between the two ends were coated, each with a different light stabilizer (LS) variant in a given coating type. For each WPC substrate type, one 3-ft panel was prepared using the LS variants in the Resin A coating, a second was prepared using the LS variants in the Resin B coating, and a third was prepared using the LS variants in the Resin C coating. Thus, there were three panels per substrate, and six panels overall. As in the case of the 6-in. panels prepared for accelerated weathering, coatings were applied to the 3-ft panels using foam brushes with a spread rate target of 350 ft²/gal.

The color of each 6-in. panel, and of each 6-in. segment on each 3-ft panel, was measured using an X-Rite

Figure 1—Lightness deviation (ΔL*) of WPC-1 after 1000 hr Xe-WOM CAM 7 (no coating L* = 14.3).

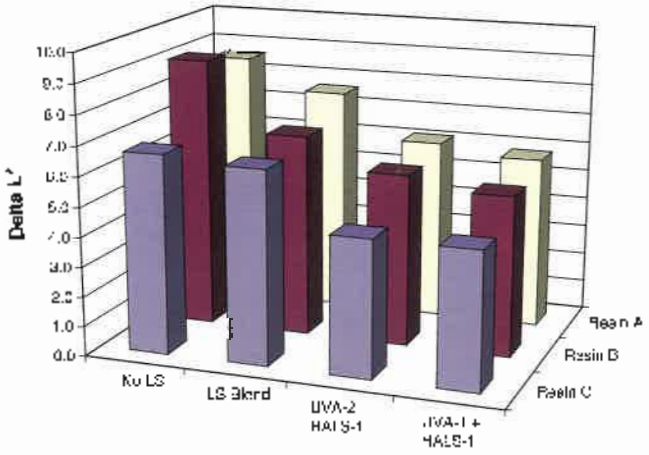


Figure 2—Lightness deviation (ΔL*) of WPC-2 after 1000 hr Xe-WOM CAM 7 (no coating L* = 13.4).

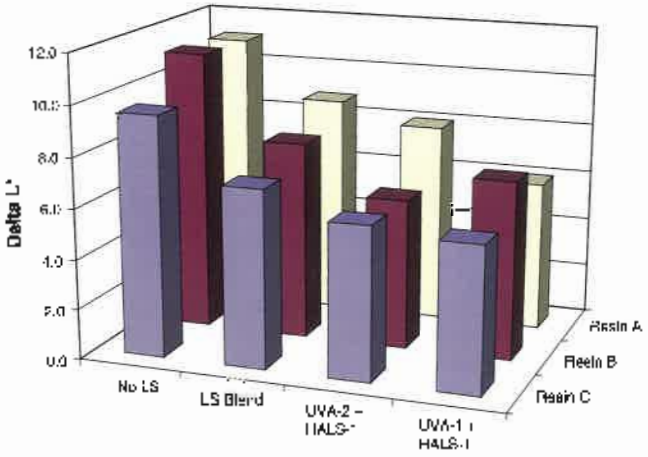


Table 6—Color Measurement Results for Samples Exposed to Three Months' Exterior Weathering

Exterior Weathering 3-Months Exposure	WPC-1, ΔE* Resin A	WPC-1, ΔE* Resin B	WPC-1, ΔE* Resin C	WPC-2, ΔE* Resin A	WPC-2, ΔE* Resin B	WPC-2, ΔE* Resin C
No coating	4.6	7.2	6.3	9.1	6.1	7.7
No LC	2.1	11.6	1.3	2.6	7.7	1.8
3% LS blend	2.1	13.3	3.4	1.6	4.2	1.3
2% UVA-1, 1% HALS-1	3.1	10.6	3.4	1.8	8.3	1.9
2% UVA-2, 1% HALS-1	1.5	11.8	1.5	3.4	8.1	2.4
No coating	6.5	6.6	7.0	8.5	9.4	7.6

Exterior Weathering 3-Months Exposure	WPC-1, ΔL* Resin A	WPC-1, ΔL* Resin B	WPC-1, ΔL* Resin C	WPC-2, ΔL* Resin A	WPC-2, ΔL* Resin B	WPC-2, ΔL* Resin C
No coating	4.2	7.0	6.1	9.1	5.9	7.6
No LS	2.0	10.3	1.0	2.4	6.3	0.6
3% LS blend	1.8	11.5	3.2	0.3	3.2	1.3
2% UVA-1, 1% HALS-1	2.6	10.1	3.1	1.6	5.6	1.8
2% UVA-2, 1% HALS-1	1.0	10.8	1.4	3.3	6.8	1.9
No coating	6.4	6.4	6.9	8.5	9.2	7.5

All LS concentrations stated in terms of weight percent actives on binder solids.

Figure 3—WPC-1 panels exposed to accelerated weathering.

Unprotected

Resin C Topcoat
2% w/w UVA-1
1% w/w HALS-1

Figure 4—WPC-2 panels exposed to accelerated weathering.

Unprotected

Resin C Topcoat
2% w/w UVA-1
1% w/w HALS-1

Table 7—Color Measurement Results for Samples Exposed to Three Months' Exterior Weathering

Exterior Weathering 3 Months Exposure	WPC-1, ΔE* Resin A	WPC-1, ΔE* Resin B	WPC-1, ΔE* Resin C	WPC-2, ΔE* Resin A	WPC-2, ΔE* Resin B	WPC-2, ΔE* Resin C
No coating	5.3	9.3	7.6	9.3	8.7	6.6
No LC	7.3	15.2	3.8	6.4	10.8	5.4
3% LS blend	4.5	15.1	5.6	4.4	11.7	5.8
2% UVA-1, 1% HALS-1	4.6	13.4	4.5	4.0	11.6	4.9
2% UVA-2, 1% HALS-1	4.4	13.8	3.8	7.3	10.7	5.4
No coating	10.0	8.5	9.7	7.7	8.7	7.5

Exterior Weathering 3 Months Exposure	WPC-1, ΔL* Resin A	WPC-1, ΔL* Resin B	WPC-1, ΔL* Resin C	WPC-2, ΔL* Resin A	WPC-2, ΔL* Resin B	WPC-2, ΔL* Resin C
No coating	4.0	9.0	7.0	9.2	8.6	6.4
No LS	7.2	14.4	3.7	6.4	10.1	5.3
3% LS blend	4.3	14.1	5.3	4.1	10.5	5.6
2% UVA-1, 1% HALS-1	4.4	13.0	4.3	3.6	9.5	4.7
2% UVA-2, 1% HALS-1	4.3	13.0	3.6	7.2	9.7	5.2
No coating	9.9	8.2	9.6	7.6	8.6	7.2

All LS concentrations stated in terms of weight percent actives on binder solids.

Figure 5—Lightness deviation (ΔL*) of WPC-1, Resin A samples exposed to exterior weathering.

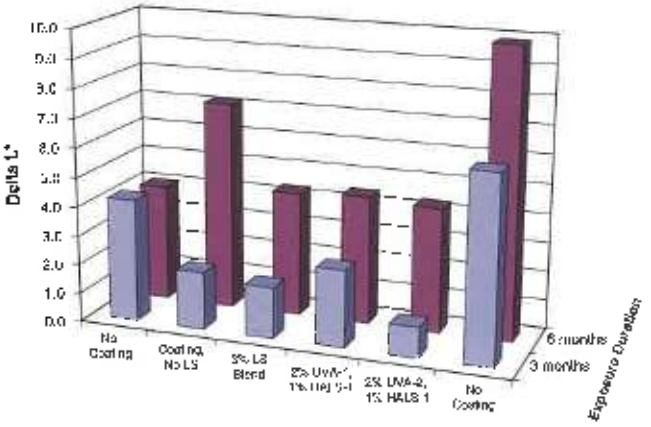
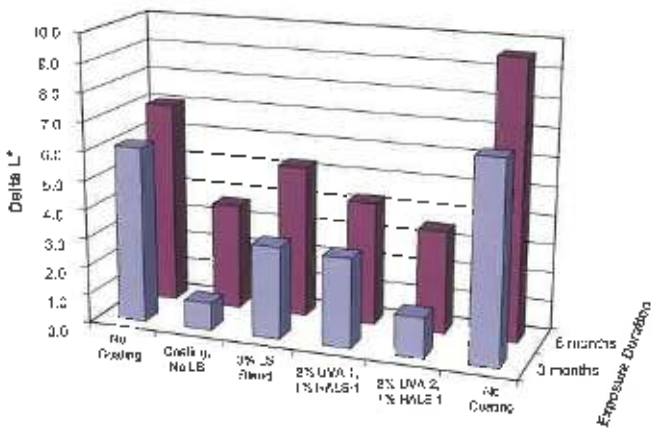


Figure 6—Lightness deviation (ΔL*) of WPC-1, Resin C samples exposed to exterior weathering.



SP68 spectrophotometer (D_{65} illuminant, 10° observer) according to DIN 6174 before exposure. The color of each 6-in. panel was measured in the same way after exposure.

The 6-in. panels prepared for accelerated exposure testing were weathered for 1000 hr in a xenon arc weatherometer using the Xe-WOM CAM 7 cycle according to DIN EN ISO 11341 A. This cycle consists of:

(a) 102 min of light (0.35 W/m² @ 340 nm) with a black panel temperature of (60±2)°C and a relative humidity of (50±5)% at the end of the dry period
(b) 18 min of light and spray with a black panel temperature of (40±2)°C and a relative humidity of (95±3)%

RESULTS

The color stability results for the WPC panels exposed to accelerated weathering are shown in *Table* 5. The uncoated WPC-1 and WPC-2 samples lightened (or faded) considerably. The measured CIELAB ΔL* values were 14.3 and 13.4, respectively. The samples protected with topcoats that lacked light-stabilizer additives fared better. The samples protected with Resin C topcoats containing 2% w/w UVA-1 and 1% w/w HALS-1 showed the best color stability, with ΔL* = 4.6 for the WPC-1 sample and ΔL* = 5.8 for the WPC-2 sample.

The ΔL* data for the WPC-1 and WPC-2 panels exposed in the xenon arc weatherometer are plotted in *Figures* 1 and 2, respectively. *Figure* 3 is a photograph of two weathered WPC-1 panels. The one on the left is the unprotected sample. The one on the right was protected with the Resin C topcoat containing UVA-1 and HALS-1.

Figure 7—Lightness deviation (ΔL*) of WPC-2, Resin A samples exposed to exterior weathering.

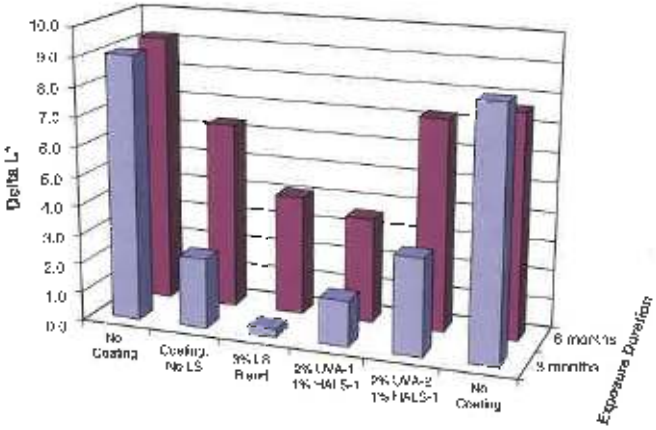


Figure 8—Lightness deviation (ΔL*) of WPC-2, Resin C samples exposed to exterior weathering.

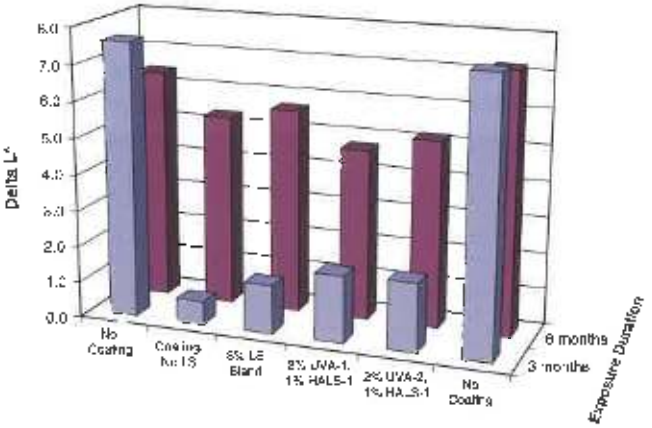


Figure 9—WPC-1 panels after three months' exterior exposure. Top—Resin C; Center—Resin B; Bottom—Resin A. L to R: no coating→coating, no LS →LS Blend→UVA-1/HALS-1→UVA-2/HALS-1 →no coating.

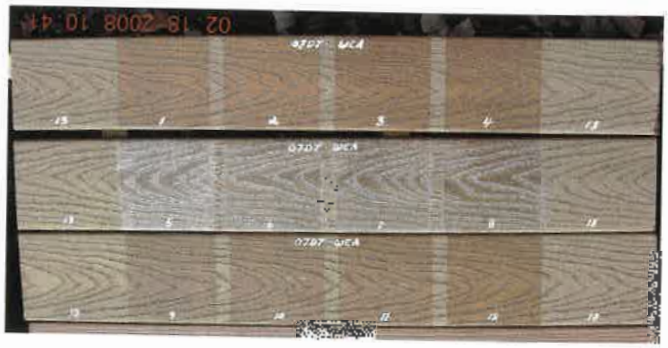
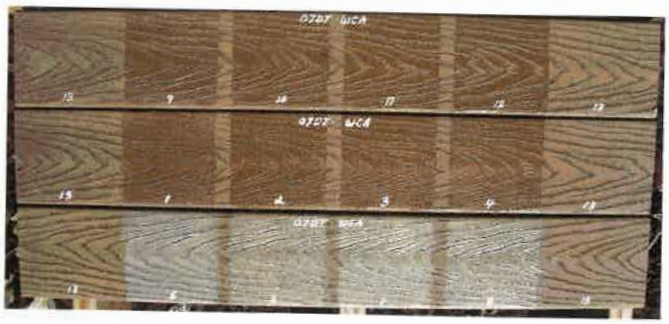


Figure 10—WPC-1 panels after eight months' exterior exposure. Top—Resin A; Center –Resin C; Bottom—Resin B. L to R: no coating→coating, no LS–>LS Blend →UVA-1/HALS-1→UVA-2/HALS-1 →no coating.



Likewise, *Figure* 4 is a photograph of two weathered WPC-2 panels. Again, the one on the left is the unprotected sample and the one on the right was protected with the Resin C topcoat containing UVA-1 and HALS-1.

Color stability data for the WPC panels exposed outdoors are shown in *Tables* 6 and 7. The data in *Table* 6 were measured after three months' exposure, while the data in *Table* 7 were measured after six months' exposure. Resin B coating failure was observed on both WPC substrates within the first three months of exterior exposure. This problem involved extensive cracking, and was somewhat worse on WPC-1 than on WPC-2. The Resin B coating continued to deteriorate during the second three-month exposure interval. Much better durability was obtained with the Resin A and Resin C coatings.

Exterior exposure color fade results for the WPC-1 panels coated with Resins A and C are plotted in *Figures* 5 and 6, respectively. These figures show that:

(a) Coated sections faded less than uncoated sections, regardless of resin type.
(b) Light stabilizers further improved the color stability of sections protected with Resin A coating. (No one light stabilizer package performed significantly better than any other in this respect.)
(c) The color stability of sections protected with Resin C coating was not improved by the addition of light stabilizers.

Exterior exposure color fade results for the WPC-2 boards coated with Resins A and C are plotted in *Figures* 7 and 8, respectively. These figures show that:

(a) Coated sections faded less than uncoated sections, regardless of resin type.
(b) The conventional light stabilizer blend and the combination of novel light stabilizers UVA-1 and HALS-1 both further improved the color stability of sections protected with Resin A coating.
(c) The combination of UVA-1 and HALS-1 light stabilizers slightly improved the color stability of sections protected with the Resin C coating.

Photographs of the WPC-1 boards taken after three months and eight months of exterior exposure are shown in *Figures* 9 and 10, respectively. Photographs of the WPC-2 boards taken after three months and eight

Figure 11—WPC-2 panels after three months' exterior exposure. Top—Resin C; Center—Resin B; Bottom—Resin A. L to R: no coating →coating, no LS→LS Blend→UVA-1/HALS-1→UVA-2/HALS-1 >no coating.

Figure 12—WPC-2 panels after eight months' exterior exposure. Top—Resin A; Center—Resin C; Bottom—Resin B. L to R: no coating→coating, no LS→LS Blend→UVA-1/HALS-1 >UVA-2/HALS-1→no coating.

months of exterior exposure are shown in *Figures* 11 and 12, respectively. (No photos were taken at the six-month exposure interval.)

The exterior weathering test results show that across both WPC types, and two of three resin types (Resins A and C), the application of a coating provides significant protection against color fade. Addition of light stabilizers to the Resin A coating gives some further incremental benefit. So far, little benefit is evident from adding light stabilizers to the Resin C coating.

After six months of exterior exposure, the uncoated sections of the WPC boards still showed less color fade than was measured on corresponding WPC samples exposed to 1000 hr of accelerated weathering:

(a) WPC-1: $\Delta L^* < 10$ after six months' exterior exposure versus $\Delta L^* = 14.3$ after 1000 hr WOM exposure
(b) WPC-2: $\Delta L^* \leq 9$ after six months' exterior exposure versus $\Delta L^* = 13.4$ after 1000 hr WOM exposure

CONCLUSION

For good long-term performance of WPC, the key is to protect against the effects of light (UV and visible) and water. The results of this study indicate that clear topcoats based on all-acrylic emulsion polymers fortified with light stabilizers can significantly improve the color stability of WPC decking materials. CT

References

(1) Clemons, C., "Wood-Plastic Composites in the United States—The Interfacing of Two Industries," *Forest Products Journal*, 52, 6, 10-18 (2002).
(2) Matuana, L.M., Kamdem, D.P., and Zhang, J., "Photoaging and Stabilization of Rigid PVC/Wood-Fiber Composites," *J. Applied Polym. Sci.*, 80, 1943-1950 (2001).
(3) Muasher, M. and Sain, M., "The Efficacy of Photostabilizers on the Color Change of Wood Filled Plastic Composites," *Polym. Degrad. Stab.*, 91, 1156-1165 (2006).
(4) Stark, N.M. and Matuana, L.M, "Influence of Photostabilizers on Wood Flour—HDPE Composites Exposed to Xenon-Arc Radiation With and Without Water Spray," *Polym. Degrad. Stab.*, 91, 3048-3056 (2006).
(5) Peter, W., Schellenberg, C., Rogez, D., Schaller, C., and Kalscheur, G., "New Concepts for Improved Durability of Waterborne Wood Coatings," Coating Wood and Wood Composites, FSCT ACSeries, Charlotte, NC, 2005.
(6) Peter, W., Schaller, C., Schellenberg, C., and Rogez, D., "A New Concept of Aqueous Additive Preparations for Waterborne Coatings," Waterborne and High Solids Coatings Conference, Brussels, Belgium, 2006.