

Waterborne Polymers for Water Repellent Wood Coatings

by Charles R. Hegedus,
Frank R. Pepe, and
John J. Rabasco

Air Products and Chemicals, Inc.*

Waterborne polymer emulsions composed of vinyl acetate-ethylene (VAE), ethylene-vinyl chloride (EVC), and other vinyl acetate copolymers were evaluated as polymer systems in water repellent coatings for exterior wood applications. Data presented indicates that these polymer emulsions exhibit an excellent balance of performance properties, making them the polymer of choice in water repellent coating formulations requiring low volatile organic compound (VOC) content. The data further suggest that polymer morphology and other emulsion polymerization process parameters (e.g., surfactant package, functional comonomers, initiation system, and particle size) may play a role in achieving industry accepted performance.

INTRODUCTION AND BACKGROUND

There are over 30 million wood decks in the United States and the popularity of wood decking is growing due to its attractive features and its ability to add versatile living space.¹ These decks are exposed to a number of harsh exterior environmental conditions which can cause wood to degrade. Rain, sunlight, extreme temperatures, and temperature fluctuations cause wood to swell and shrink due to water absorption and release, as well as expand and contract from temperature fluctuations. These conditions induce high levels of stress and cyclic fatigue within the wood, causing the wood to develop checks, cracks, and raised grain, as well as degradation and discoloring of the wood surface. Other deleterious factors causing wood to degrade include mildew growth, fungus, and insect attack.^{2,3}

Because of these risks, lumber used to construct decks is usually pressure treated with a preservative, or the lumber used is a durable natural wood such as redwood or cedar. Exotic hardwoods such as teak, tigerwood, ipe, and cumaru, which also tend to be durable, are becoming popular as well. A number of different compounds have been used as wood preservative treatments, but ammoniacal copper quat (ACQ), creosote solutions, and copper azole have been the most common. Detailed descriptions of these materials and their performance is beyond the scope of this article but fur-

*7201 Hamilton Blvd., Allentown, PA 18195-1501.

ther details on these and other treatments can be found in references 2 and 3.

Another popular approach to protecting wood decking is to apply a finish coat, commonly referred to as water sealer, water repellent, exterior stain, and/or preservative. Although these terms all suggest specific traits and functions, they often are used interchangeably. In this article, we will refer to this generic class of coating as a water repellent coating which is intended to protect wood from harsh conditions experienced by wood decking and other exterior wood structures. In addition to providing an aesthetic quality, these finishes protect wood from environmental factors and thereby minimize problems of cracking, raised grain, wood degradation, insect attack, and mildew growth. These finishes normally are applied after the wood has been sold and the deck has been assembled; however, there are some water repellent products that are applied by the wood processor.

Commercially available water repellent coatings vary in performance, which will be discussed throughout this article, but most of them contain common generic ingredient types, all of which provide specific functions. Table 1 provides a listing of common ingredient types within water repellent coatings, general concentration ranges, and their intended function(s). Although all of these ingredients provide functions that contribute to the coating performance, two critical ingredients are the polymer and the hydrophobe. The polymer carries these ingredients to the substrate, forms a protective barrier, and it is the primary component in determining long-term performance by providing resistance to water, sunlight, chemicals, and other environmental factors. The hydrophobe, as the name

implies, causes the applied coating to be hydrophobic and repel water.

Water repellent coatings used for after-market applications can be characterized in a number of ways such as: solventborne versus waterborne; level of transparency; and penetrating versus film forming. Solventborne and waterborne products are simply defined relative to the type of volatile content within the coating. Solventborne versions typically are alkyl and/or oil (e.g., linseed oil) based. Waterborne versions are based on water reducible alkyds and/or acrylic latex polymer systems.

The relative transparency/opacity of the finish is another distinguishing feature. Common terminology of the various transparency levels is clear, toner, semi-transparent, and solid stains. Of course, these are somewhat self-explanatory and they are highly dependent upon the solids concentration, pigment concentration, and pigment type within the formulated product. Table 2 describes some distinguishing factors among these finishes. Generally speaking, the durability/weatherability of these finish types trends with the level of opacity:

(Less weatherable) Clear < Toner < Semi-transparent
< Solid color stain (More weatherable)

The reason for this trend is that one of the major contributors to degradation of both the coating and the wood is UV radiation. Increasing pigment concentration generally increases protection from UV. Therefore, coatings with higher pigment concentration tend to provide greater opacity and greater UV protection, and these coatings tend to be more weatherable and will last longer. However, it should be noted that greater

Table 1—Typical Ingredients in Water Repellent Coatings

Raw Material Type	Solventborne	Waterborne	Concentration Ranges	Intended Function(s)
Polymer/oil	Alkyd, linseed oil	WR alkyd Emulsified oils Acrylic latex	10–70%	Reduce water vapor transmission Dimensional stability Durability—wear, weathering
Solvent.....	Mineral spirits, etc.	Water Texanol Butyl cellosolv Butyl carbitol Glycols	Solvent-based 10–30% Waterborne 2–10%	Penetration into substrate Coalescence
Hydrophobe.....	Wax Silicone	Wax Silicone (emulsions)	10–30% 10–30%	Water beading Water exclusion
Additives	Surfactant Defoamer Mildewcide UV absorber Pigments, extenders	Surfactant Defoamer Mildewcide UV absorber Pigments, extenders	0–5% 0–5% 0–5% 0–5% 0–25%	Wetting, penetration Foam reduction Prevent decay Prevent graying, fading Screen UV light, graying, color, gloss control

WR = water reducible.

Table 2—General Description of Water Repellent Finish Types

Finish Type	Description	Pigment Type and Concentration Type
Clear	Clear to slight color; allows color and grain of wood to show through the coating; no or low pigmentation	None or slight concentrations of trans-iron oxides; 0–2 lb/100 gal
Toner	Slight coloration; allows grain to show through coating; low pigment concentration	Trans-iron oxides; 2–4 lb/100 gal
Semi-transparent	Strong color but not complete hiding; may alter color of wood; allows most of wood grain to show; low-moderate pigment concentration	Iron oxides, may contain other traditional pigments and extenders; 4–15 lb/100 gal
Solid color	Opaque, completely hiding wood color and obscuring wood grain, allowing only texture of wood to show; similar in formulation to typical exterior house paints but usually low in viscosity; high pigment and extender concentration	Typical paint pigments and extenders; >15 lb/100 gal

opacity also will hide more of the wood color and grain, and thereby hide the natural beauty of the wood.

The last water repellent coating classification noted above is film-forming versus penetrating finishes. Film-forming finishes form a thin layer over the surface to which they are applied. These finishes lie on and adhere to the wood, similar to a traditional paint.

Penetrating finishes, as the name implies, absorb into the wood surface, saturate the surface fibers, and fill the surface pores, providing a surface that repels water and prevents water from absorbing into the wood. Very little, if any, of the coating resides directly above the wood surface. Penetrating coatings are preferred and

typically perform better in many exterior wood applications, including decking, for several reasons. First, film-forming coatings on the surface are more exposed and more susceptible to wear. Second, since film-forming coatings have a discrete continuous thickness on the wood surface, they are more prone to crack, chip, and peel. Third, when this type of coating system fails, it must be removed or stripped from the surface, which is labor intensive, time consuming, and costly. In contrast, penetrating finishes, since they mainly reside at or below the surface, are less prone to wear and they typically do not fail by cracking, chipping, or peeling. Plus, surface preparation prior to re-painting usually

Table 3—Generic Listing of Commercially Available Water Repellent Coatings

Product Designation	Finish Type	Polymer Chemistry	System Base	VOC (g/L)	Solids Wt%	Retail Selling Price U.S. \$/Gal
C-SB-1	Clear	BLEND: W/R Alkyd/wax	Solvent-based	300	7	10
C-SB-2	Clear	BLEND: Linseed oil/paraffin wax/resin	Solvent-based	600	29	11
C-SB-3	Clear	BLEND: Wax/surfactant	Solvent-based	600	30	10
C-WB-1	Clear	BLEND: Silicone oil/acrylic (SA, BA)/wax	Waterborne	250	8	13
C-WB-2	Clear	BLEND: W/R Alkyd/wax	Waterborne	350	16	10
T-SB-1	Toner		Solvent-based	550	38	19
T-WB-1	Toner	BLEND: W/R Alkyd/acrylic (BA)	Waterborne	250	18	12
T-WB-2	Toner	BLEND: W/R Alkyd/polyester isochloralate	Waterborne	250	21	17
T-WB-3	Toner	BLEND: W/R Alkyd/acrylic (2-EHA, SA)/polyisobutylene	Waterborne	250	33	20
T-WB-4	Toner	BLEND: Acrylic (MMA,BA)/Linseed oil	Waterborne	350	20	32
T-WB-5	Toner	BLEND: W/R Alkyd/acrylic (MMA,BA)/Linseed oil	Waterborne	550	40	18
T-WB-6	Toner	W/R Alkyd	Waterborne	300	11	20
T-WB-7	Toner		Waterborne	250	27	20

W/R = water repellent.

requires minimal washing of the deck with common commercial products designed for this purpose.

As mentioned above, there is a wide variability in the commercial coatings sold for wood decking application. Table 3 provides a listing of various commercial products (listed generically), along with generic polymer composition, volatile organic compound (VOC) level, solids content, and retail selling price.

The function of water repellent coatings is to provide long-term protection to exterior wood substrates that are subjected to environmental conditions. As such, the desired performance traits are ease of application and clean-up, water repellency, UV resistance, and re-coatability. These attributes can be assessed and described in a number of ways, which will be discussed later in this article. Another consideration is the VOC level of these coatings. Table 3 indicates a range of VOC for these products from 250 to 600 g/L. Of course, VOC regulations vary throughout the United States. The most stringent regulations typically are set by the South Coast Air Quality Management District (SCAQMD) within California. SCAQMD rule 1113 for Architectural Coatings currently has a VOC limit for waterproofing sealers at ≤ 250 g/L. This limit is scheduled to be reduced to ≤ 100 g/L effective July 1, 2006. Only five of the 13 commercial products listed on Table 3 have a

VOC of 250 g/L and none of the products has a VOC near 100 g/L. The reduction from 250 g/L to 100 g/L is a dramatic decrease. The limit of 100 g/L almost assuredly dictates the use of waterborne technology for this application.

Although polymer systems used in water repellent wood coating applications traditionally have been based on alkyd and/or acrylic chemistry, vinyl acetate and vinyl chloride based copolymers have been making strides in exterior applications.⁴ References 4, 5, and 6 describe basics of vinyl acetate and vinyl chloride copolymers used in coatings. Vinyl acetate copolymers also offer the promise of low-VOC formulations. Vinyl acetate can be copolymerized with ethylene to form polymers with a T_g far below room temperature. Vinyl acetate copolymers also can hydroplasticize. These attributes allow coatings with these polymers to have a relatively low minimum film-forming temperature with relatively low organic solvent content and VOCs.

The objective of this effort was to evaluate waterborne vinyl acetate and vinyl chloride-based copolymers, specifically vinyl acetate-ethylene (VAE) copolymers and ethylene-vinyl chloride (EVC), for use in water repellent coatings for exterior wood applications. Although the focus of this work has been on wood decking, in many cases similar characteristics and per-

Table 4—Waterborne Polymer Emulsions Evaluated

Emulsion Designation	Polymer Type ^a	pH	Avg. Part. Size (microns)	Stabilization	MFFT °C	T _g °C
VAE-1	VAE	4.5–5.5	0.50	Surfactant and colloid	0.0	4
VAE-2	VAE	5.0–6.0	0.17	Surfactant	0.0	5
VAE-3	VAE	5.0–6.5	0.17	Surfactant	0.0	0
VAE-4	VAE	6.0–8.0	0.40	Surfactant and colloid	2.0	6 and 45
VAE-5	VAE	4.0–5.0	0.23	Surfactant	2.0	12
VAE-6	VAE	4.0–6.0	0.20	Surfactant	0.0	–29
VAE-7	VAE	4.0–6.0	0.19	Surfactant	0.0	–30
VAE-8	VAE	4.0–6.0	1.06	Surfactant	0.0	–28
VAE-9	VAE	3.0–5.0		Surfactant and colloid	0.0	–39
VAE-10	VAE	4.0–6.0	0.24	Surfactant	0.0	–29
VAE-11	VAE	4.0–6.0	0.21	Surfactant	0.0	–30
VAE-12	VAE	4.0–6.0	0.24	Surfactant	0.0	–28
VAE-13	VAE	4.0–6.0	0.34	Surfactant	16.0	–8
VAE-14	VAE	4.0–6.0	0.32	Surfactant	14.0	–29
VAE-15	VAE	4.0–6.0	1.60	Surfactant	0.0	32
VAE-16	VAE	4.0–6.0	1.95	Surfactant	—	–5
VAE-17	VAE	4.0–6.0	0.27	Surfactant	0.0	–21
VAE-18	VAE	4.0–6.0	0.10	Surfactant	0.0	5
VA-1	VA	4.0–6.0	0.30	Surfactant and colloid	6.0	13
VA-2	VA	4.0–6.0	0.30	Colloid	3.0	0
SA-1	SA	7.5–8.5	0.10	Non-ionic	12.0	9
SA-2	SA	6.5–7.5	0.06	Surfactant	1.0	10
EVCI-1	EVCI	7.0–9.0	0.12	Surfactant	4.0	3
EVCI-2	EVCI	7.0–9.0	0.12	Surfactant	14.0	12
EVCI-3	EVCI	7.0–9.0	0.11	Surfactant	50.0	29
EVCI-4	EVCI	4.0–5.0	0.70	Surfactant	2.0	7

(a) VAE: vinyl acetate-ethylene copolymer; VA: vinyl acetate-acrylic copolymer; SA: styrene-acrylic copolymer; EVCI: ethylene-vinyl chloride copolymer.

formance are desired for other wood structures such as wood siding, sheds, fencing, and docks.

EXPERIMENTAL

The objective of this project was to assess the applicability of waterborne vinyl acetate and vinyl chloride-based copolymers for use in water repellent coatings. Considering polymer compositional and processing parameter latitude, there is a wide spectrum of potential properties that can be obtained with these copolymers. In order to thoroughly investigate this range of materials, this effort was completed in four phases, with each phase narrowing the field of attractive candidates while exploring more deeply the properties and performance that these materials might contribute. Table 4 lists the polymer emulsions and associated properties that were investigated during this study. The formulations evolved through each of the phases and will be described in the Results and Discussion section as they are presented. The test procedures followed are described below.

Water Repellency Efficiency (WRE)

Coatings were evaluated for WRE according to ASTM D 5401. The coatings were applied to Southern

Yellow Pine wood blocks by immersing the blocks in the coating for 30 seconds. Coatings were then placed on a Tedlar sheet and allowed to dry at 21 °C and 50% relative humidity for seven days. After drying, the coatings were immersed in deionized water for 30 minutes. Both coated and uncoated (bare, control) wood blocks were tested. WRE was calculated as:

WRE = 100((A-B) - (C-D))/(A-B) where

- A = weight of the uncoated specimen after water contact
- B = weight of the uncoated specimen before water contact
- C = weight of the coated specimen after water contact
- D = weight of the coated specimen before water contact

Five replicates of each coating were evaluated. It should be noted that higher numbers indicate better water repellency. Further details can be found in reference 7.

Water Spot Test

A water spot test was performed according to ASTM method D 1308. The coatings were applied to glass plates and allowed to dry at 21 °C and 50% relative hu-

midity for 24 hours prior to testing. A drop of deionized water was placed on the coating surface and covered with a watch glass. After one hour exposure, the coating was inspected for color/haze change, blistering, softening, and swelling. The following rating system was used to record the observed effect:

Ratings: dissolved/swell = 3; blisters = 1;
white/soft = 0.5; hazy = 0.25; no effect = 0

Weathering Evaluations

Coatings were evaluated for weather resistance using QUV-A and Weather-Ometer accelerated weathering chambers. They also were evaluated in exterior exposures. Coatings were applied liberally (two coats, wet on wet) to the front face of cedar siding planks using a nylon polyester bristle brush at room temperature. The applied coatings were evaluated visually for appearance during application and after drying. Coatings were dried at room temperature for seven days prior to exposure. The QUV-A exposure was conducted according to ASTM G 154 with the following parameters: QUV-A bulb with irradiance of 0.89 watts/sq m/nm at 340 nm; exposure cycle of 8 hr UV at 60°C black panel temperature; 0.25 hr water spray (no light); 3.75 hr of condensation at 50°C black panel temperature.

Xenon Arc Weather-Ometer was performed according to ASTM G 155—Appendix X3, cycle 1. The exposure cycle consisted of 102 minutes dry (no water spray) with black panel temperature of 63°C, xenon arc bulb of 0.35 watts/sq m at 340 nm, followed by a spray cycle of 18 minutes.

During the QUV-A and xenon arc accelerated exposure evaluations, specimens were removed on a weekly basis and evaluated for water beading, color change, and wood degradation according to the procedures and rating systems described below.

Exterior exposure of coated and uncoated wood specimens was conducted in Allentown, PA, for one year (September 2004–September 2005). The exposures were conducted on cedar siding planks as noted above, and also on ACQ pressure treated decking boards. Cedar specimens were exposed at a 45° angle facing south. The pressure treated boards were prepared by first weathering uncoated, as purchased, horizontally for six months. Coatings were then ap-

plied as described previously. The coated pressure treated decking boards were exposed horizontally. Specimens were examined every three months by evaluating water beading, color change, and wood degradation according to the methods described below. Four specimens of each coating on both substrates were exposed and the results are reported as an average of ratings for the four specimens.

Water Beading

In order to assess the water beading efficiency of the coatings throughout the exposures, a water beading test was performed according to ASTM D 2921. The test was performed by liberally spraying tap water on the wood surface using a standard hand pump sprayer. Water on the surface was evaluated for beading according to a relative scale of 0 (worst) to 5 (best), where a rating of 0 indicated complete wetting and penetrating of water into the wood and a rating of 5 represented water droplets of high contact angle on the wood surface. Water beading evaluations were performed prior to exposure and then weekly throughout the duration of the exposures in QUV-A and Weather-Ometer. They were performed on a three-month interval through the duration of the exterior exposures.

Table 5—Water Repellency Efficiency Results from Phase 1

Emulsion	Water Repellency Efficiency (%) ASTM D 5401
VAE-1	.49
VAE-2	.26
VAE-3	.38
VAE-4	.53
VAE-5	.34
VAE-6	.52
VAE-7	.52
VAE-8	.57
VAE-9	.32
VAE-10	.43
VAE-11	.27
VAE-12	.38
VAE-13	.32
VAE-14	.44
VAE-15	.60
VAE-16	.62
VAE-17	.51
VAE-18	.56
VA-1	.28
VA-2	.33
SA-1	.46
SA-2	.25
EVCI-1	.29
EVCI-2	.18
EVCI-3	.17
EVCI-4	.55

Appearance, Color Change, and Wood Degradation

Accelerated and exterior exposure specimens were evaluated using a relative visual comparison for color change and damage of both wood and coating. Note was taken of the integrity of the wood—most specifically to warping and/or cracking. Ratings ranged from 0

Table 6—Water Spot Test from Emulsions Evaluated in Phase 2

Emulsion	Water Spot Test (1 hr) ASTM D 1308
VAE-1	.0.25
VAE-3	.0.25
VAE-4	.1.00
VAC-5	.0.25
VAE-6	.3.00
VAE-7	.0.25
VAE-8	.3.00
VAE-10	.0.50
VAE-14	.3.00
VAE-15	.3.00
VAE-16	.0.50
VAE-17	.0.25
VAE-18	.0.50
VA-2	.0.25
SA-1	.0.00
EVCI-4	.1.00

Ratings: dissolved/swell. = 3; hlisters = 1; white/soft = 0.5; hard = 0.25; no effect = 0.

(extreme color change and/or damage) to 5 (no color change or damage). This assessment was performed prior to exposure and then weekly during the exposure in QUV-A and Weather-Ometer; they were performed every three months on the exterior exposure specimens.

RESULTS AND DISCUSSION

As mentioned previously, the objective of this work was to assess the potential for waterborne vinyl acetate and vinyl chloride-based polymers in water repellent coatings. The effort was performed in four phases, starting with a broad spectrum of emulsions in Phase 1. Each subsequent phase was designed to more specifically identify the most promising polymer systems and explore their properties and performance in wood coating applications.

Phase 1: Screening of Emulsions Using Water Repellency Efficiency

Phase 1 was a screening phase intended to assess a wide range of materials. In order to accomplish this, a variety of waterborne vinyl acetate and vinyl chloride-based polymer emulsions (Table 4) were evaluated in coatings applied to wood for their ability to resist water penetration. In this phase, the neat, as-received polymer emulsions were tested. Water Repellency Efficiency (WRE) is one of the critical properties recognized by wood coating experts for performance of water repellent coatings; therefore, WRE was one of the main criteria for evaluating the potential of emulsions to perform in this application. WRE results for this phase are listed in Table 5. WRE results varied over a wide range, from 17% (poor) to 62% (good). In comparison, many commercial water repellent coatings have WRE values above 60%. However, it must be recognized that formulating additives, such as hydrophobes (e.g., waxes, silicones) can dramatically improve WRE performance and these commercial products have been formulated and optimized specifically to perform well in this particular test. Neat polymer emulsions with WRE values greater than 40% in this phase were considered promising candidates as polymer systems in water repellent coatings. Generally, emulsions with a WRE less than 40% were deemed poor and were discontinued from the study.

Assessing these results compared to the polymer properties listed in Table 4, there are no clear, definitive correlations. However, there are indications of some general trends. Emulsions with non-ionic surfactants generally appear to perform better. This would seem reasonable considering that anionic based surfactants generally are more hydrophilic and could lead to water sensitivity. Also, it appears that lower minimum film-forming temperature (MFFT) is beneficial, which also seems logical due to better particle coalescence. Even if

Table 7—Formulation Evaluated in QUV-A During Phase 2

Ingredient	Supplier	Parts by Weight
Emulsion	Air Products and Chemicals	48
Water		Added to obtain 20% solids by weight
Texanol™	Eastman	2
Surfynol® TG	Air Products and Chemicals	1

these coatings penetrate into the wood substrate as opposed to film-form on the surface, particle coalescence will lead to improved coating integrity and better water repellency. Also, molecular weight and morphology of emulsion polymerized polymers are affected substantially by polymerization processing parameters—their properties also can vary dramatically. This also may play a role in the water repellency properties that are exhibited by these emulsion polymers. Furthermore, the inherent hydrophobicity of ethylene may lead to better performance for polymer systems which incorporate ethylene.

Phase 2: Further Screening of Emulsions Using Water Spot Test and QUV-A Exposure

In Phase 2, the emulsions that were deemed promising from Phase 1 were evaluated using the early water spot test and QUV-A exposure; again, on neat emulsions. Table 6 illustrates that early water spot test results range from 0 (excellent) to 3 (poor). Emulsions with water spot test results greater than 1.0 swelled or dis-

solved, indicating poor early water resistance. These emulsions were deemed not promising for the water repellent application and were discontinued from the study (i.e., VAE-6, VAE-8, VAE-14, and VAE-15).

QUV-A exposures of coated cedar specimens were performed by including the emulsions in a very basic coating formula containing co-solvent, surfactant, and water to dilute all the coatings to 20 wt% solids (a typical solids content for water repellent coating formulations). Table 7 lists the basic formula used for all emulsions. Table 8 illustrates the QUV-A weekly exposure evaluations and a cumulative total from these weekly assessments. The results in Table 8 have been sorted from best to worst, based on the cumulative total performance. Weekly appearance ratings of 0 or 1 indicate substantial coating failure and/or wood deterioration. Water beading values of 0 or 1 indicate complete wetting and possibly absorption of water into the wood substrate. In many cases it became obvious that performance was deteriorating over the exposure time and by week 5 several of the coating systems were performing poorly. The total assessment values range from 15 (poor) to 38 (good). Based on these results, coatings with a total assessment of less than 25 were considered poor candidates and were dropped from consideration upon moving into Phase 3 (i.e., VAE-3, VAE-5, VAE-6, and VA-2).

Phase 3: Screening of Toner Formulations Using WRE and QUV-A

Emulsions that remained in consideration at this point and were advanced into Phase 3 included: VAE-1,

Table 8—Wood/Coating Appearance and Water Beading Results through QUV-A Exposure in Phase 2

Emulsion	1 Week		2 Weeks		3 Weeks		4 Weeks		5 Weeks		Total
	App. ^a	Bead. ^b	App.	Bead.	App.	Bead.	App.	Bead.	App.	Bead.	
VAE-10	4	4	5	3	5	3	4	3	3	4	38
VAE-14	4	4	4	4	4	4	2	4	2	4	36
VAE-8	4	4	4	4	3	4	1	4	3	4	35
VAE-4	4	3	5	3	5	2	3	1	3	2	31
SA-1	4	4	4	2	4	2	4	3	3	1	31
VAE-1	4	3	4	3	4	2	4	1	3	2	30
VAE-7	4	4	3	4	3	4	1	4	1	2	30
VAE-15	5	3	4	3	3	3	1	4	1	3	30
EVCL-4	4	3	4	3	4	2	4	1	3	2	30
VAE-16	5	2	4	3	2	3	2	3	2	3	29
VAE-18	3	3	3	4	3	4	2	3	1	3	29
VAE-17	3	3	3	3	2	3	2	2	1	3	25
VAE-3	4	1	4	3	2	2	2	2	2	1	23
VA-2	4	2	3	2	3	2	3	1	3	0	23
VAE-6	5	2	3	3	2	2	1	2	0	2	22
VAE-5	4	1	4	1	2	0	1	0	2	0	15

(a) Appearance ratings: Ratings range from 0 (extreme color change and/or damage) to 5 (no color change or damage).

(b) Water beading ratings: Water sprayed onto the wood surface was evaluated for beading according to a relative scale from 0 (worst) to 4 (best); a rating of 0 indicated complete wetting and penetrating of water into the wood and a rating of 4 represented water droplets of high contact angle on the wood surface.

Table 9—General Toner Formulation Evaluated During Phase 3

Ingredient	Supplier	Parts by Weight
Emulsion	Air Products and Chemicals	48
Water		Added to obtain 20% solids by weight
Michelube® 743 wax emulsion	Michelman	1.5
Dow Corning® 2-9034 silicone emulsion	Dow	1.0
Surfynol® TG surfactant	Air Products and Chemicals	1.0
Finovin® 5050 (HALS/UVA)	Ciba	1.5
Polyphase® P-20T	Troy Chemical	2.5
Trans-oxide yellow 243	Hilton-Davis	1.2

VAE-4, VAE-7, VAE-10, VAE-16, VAE-17, VAE-18, SA-1, and EVCI-4. However, VAE-7 and VAE-17 are relatively similar in composition and basic emulsion properties, so therefore VAE-7 also was discontinued. To further the study and refine the formulations, the emulsions still considered promising were evaluated in a simplistic toner formulation containing wax emulsion, silicone emulsion, surfactant, hindered amine light stabilizer (HALS), UV absorber (UVA), biocide with co-solvent, and trans-iron oxide pigment dispersion (the general formula is presented in Table 9). WRE values for these toner formulations and some commercial water repellent coatings (noted in Table 3) are presented in Table 10. WRE values for the toner formulated emulsions range from 44% to 65%. It is interesting to note that about only half of the emulsions improve in WRE in the toner formulation compared to the coinciding unformulated emulsions as reported in Phase 1 (Table 5). As might be expected, the cause for improvements may be explained by incorporation of the wax and silicone hydrophobes in the toner formulations. The cause for reduction in WRE values with some toner formulations is not clear but may be due to some incompatibility between ingredients, especially between polymer emulsion and hydrophobe. Although incompatibility was not clearly observed in the toner formulations, there may be some subtle incompatibilities that exist and are even more prevalent after application and drying of the coating. Nonetheless, as noted, several toner formulations had promising WRE results (i.e., VAE-1, VAE-10, VAE-17, VAE-18, and EVCI-4).

Table 10 also lists WRE results for commercial water repellent coatings and these results range from 11 to 95%. Generally, these WRE values are higher than those obtained for the toner formulated emulsions in this study. However, it must be noted that the toner formulation evaluated is a general formulation and not specifically optimized for any of the emulsions. It is highly suspected that noticeable improvements in WRE can be obtained by selecting additives and concentra-

tions with specific consideration of the emulsion products in this study. In addition, and as will become evident, WRE is only an indication of potential performance in water repellent coating applications. True performance is indicated by actual exterior exposures, which were performed in Phase 4 of this study and are reported and discussed below.

QUV-A exposures for the toner formulations on cedar planks also were performed in Phase 3 and these results are reported in Table 11, on a weekly basis and a cumulative total. Also included are results from three commercial products. Performance of some coatings decreased slightly over the exposure period, but in many cases performance remained relatively constant. These QUV-A results, in comparison to those of the unformulated emulsions (Table 8), indicate an improvement in performance, which would be expected from incorporating formulating additives. Figure 1 illustrates a comparison of QUV-A total ratings at five weeks for clear (Phase 2) versus toner (Phase 3) formulations. Again, in most cases performance of toner formulations improved over that of clear formulations with the same emulsion.

Table 10—Water Repellency Efficiency Results on Toner Formulations and Commercial Products from Phase 3

Toner	Water Repellency Efficiency (%) ASTM D 5401
VAE-1	.62
VAE-4	.44
VAE-10	.59
VAE-16	Not tested
VAE-17	.57
VAE-18	.50
SA-1	.45
EVCI-4	.65
C-SB-1	.52
C-SB-2	.87
C-SB-3	.85
C-WB-2	.11
T-SB-1	.88
I-WB-1	.80
T-WB-2	.85
T-WB-3	.95
T-WB-4	.62
T-WB-5	.72
T-WB-6	.82

Table 11—Wood/Coating Appearance and Water Beading Results through QUV-A Exposure of Toner Formulations and Selected Commercial Products in Phase 3

Toner	1 Week		2 Weeks		3 Weeks		4 Weeks		5 Weeks		Total
	App. ^a	Bead. ^b	App.	Bead.	App.	Bead.	App.	Bead.	App.	Bead.	
VAE-17	4	3	4	4	5	4	4	3	5	4	40
VAE-16	4	3	4	4	4	4	4	4	4	4	39
EVCL-4	4	5	3	4	4	4	4	3	4	4	39
VAE-1	3	5	4	4	5	4	4	2	4	3	38
VAE-4	3	4	3	4	4	4	4	3	4	4	37
VAE-10	3	3	3	4	4	4	4	4	4	4	37
T-SB-1	4	4	4	4	4	4	4	3	4	2	37
VAE-18	3	3	3	4	4	4	4	3	4	4	36
I-WB-6	4	4	3	2	4	2	4	1	4	1	29
SA-1	3	3	3	2	4	3	4	1	4	1	28
T-WB-4	4	2	3	1	3	0	3	0	3	0	19

(a) Appearance rating: Ratings range from 0 (extreme color change and/or damage) to 5 (no color change or damage).

(b) Water beading ratings: Water sprayed onto the wood surface was evaluated for beading according to a relative scale from 0 (worst) to 5 (best); a rating of 0 indicated complete wetting and penetration of water into the wood and a rating of 5 represented water droplets of high contact angle on the wood surface.

QUV-A total performance values for the formulated emulsions ranged from 28 to 40, while the commercial products were 19, 29, and 37, respectively. It should be noted that a perfect rating over this period would be 50. In comparison, the emulsion toner formulations performed comparably well versus the commercial products and in some cases even outperformed those products, which also are toners. Even so, it must be re-emphasized that these toner formulations were not optimized as are the commercial products. Although somewhat preliminary, these results certainly are an indication that some of these emulsions can perform well in water repellent coating formulations and applications, offering performance equal or superior to commercial products.

Assessing WRE and QUV-A performance in Phase 3, VAE-1 had the lowest WRE result (44%) and SA-1 had poor WRE (45%) and QUV-A performance (28); therefore, these two emulsions were discontinued from the study. VAE-16 had relatively good performance in QUV-A in Phase 3. However, this emulsion has a relatively large average particle size (two microns) and it is believed that a larger particle size will prohibit penetration of the coating into the wood.⁶ As mentioned in the Introduction, penetrating coatings normally perform better and are preferred over film-forming coatings that reside on the wood substrate. Therefore, VAE-16 was eliminated from consideration as well. Considering the remaining VAE emulsions (i.e., VAE-1, VAE-10, VAE-17, and VAE-18), VAE-10 is similar in a number of respects to VAE-17. In order to minimize the number of emulsions evaluated in the final phase of the effort, VAE-10 was eliminated for this reason. Therefore, emulsions which performed well, and were reasonably different while having a relatively small particle size, were further evaluated in Phase 4. Those emulsions were: VAE-1, VAE-17, VAE-18, and EVCL-4.

Phase 4: Final Evaluations in QUV-A, Weather-Ometer, and Exterior Exposures

The final assessment of the preferred emulsions in this effort was an extended evaluation of weathering performance. While not optimized, the toner formulations were refined slightly from Phase 3 to improve compatibility. These formulations are presented in Table 12. Several exposure studies were performed on these formulations, as well as a number of commercial water repellent coatings. These evaluations were performed by exposures of coated cedar planks in QUV-A and Xenon Arc Weather-Ometer, as well as exterior exposure of cedar planks (south 45°) and pre-weathered ACQ decking boards (horizontal) in Allentown, PA, from September 2004 to September 2005. Weekly appearance and water beading ratings for the accelerated ex-

Figure 1—Comparison of QUV-A performance over five weeks of clear (Phase 2) versus toner (Phase 3) formulations.

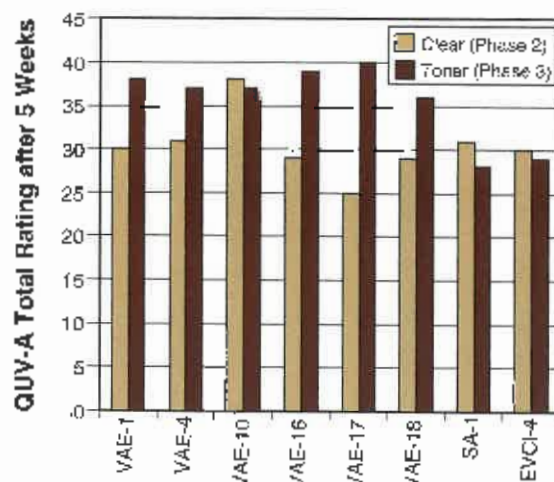


Figure 2—Cedar plank specimens after five weeks exposure in QUV-A.



Table 12—Toner Formulations Evaluated in Phase 4

	Toner Formulations (pph)			
	VAE-1	VAE-17	VAE-18	EVCL-4
Water	61.68	56.55	57.40	58.64
Emulsion	30.36	34.93	34.08	33.40
Michem® 723 ^a	1.56	3.12	3.12	1.56
Dow Corning® 2-9034 ^b	1.00	—	—	1.00
Surfynal® TG ^c	1.00	1.00	1.00	1.00
Trans-oxide yellow ^d	1.00	1.00	1.00	1.00
Trans-oxide red ^e	0.40	0.40	0.40	0.40
Tinuvin® 5050 ^f	0.50	0.50	0.50	0.50
Polyphase® P-20T ^g	2.50	2.50	2.50	2.50
Totals	100.00	100.00	100.00	100.00
W/L% solids	20	20	20	20
Vol% solids	17	19	19	17
VOC (g/L)	119	111	111	121

(a) Michem

(b) Dow

(c) Air Products and Chemicals, Inc.

(d) Hiltor-Davis

(e) Hiltor-Davis

(f) Ciba

(g) Troy Chemical

Figure 3—Cedar plank specimens after five weeks exposure in QUV-A with water spray to evaluate water beading.



posures and three month results for the exterior exposures are presented in Tables 13–16. The tabulated results have been sorted from best to worst based on the total performance rating.

The results for the Phase 4 QUV-A performance for the formulated and commercial products are presented in Table 13. These exposures were extended from the five week duration followed in previous phases to six weeks due to improved performance. The ratings indicate that performance in QUV-A generally degrades around weeks 5 and 6. Nonetheless, performance even at week 6 is still fairly good for many coatings, especially with appearance ratings of 4 and some water beading. The total performance ratings for the four formulated emulsions ranged from 45 to 47, while the eight commercial products evaluated had performance ratings from 21 to 48. Only one of the commercial products, T-WB-3, had a higher rating than the formulated emulsions. Many commercial products displayed QUV-A performance much worse than the formulated emulsions. Figure 2 illustrates the appearance of T-SB-1 and C-SB-3 compared to the VAE-17 formulated toner after five weeks of exposure. Note that the strip on the left side of each specimen was not exposed to UV. This photo clearly illustrates the severe fading of C-SB-3 on the exposed area. The results in Table 13 indicate this fading occurred during weeks 1–3. However, C-SB-3 is a clear finish and, as discussed in the Introduction, clear finishes typically do not perform as well as finishes with more pigmentation, such as toners. The photo also illustrates that T-SB-1 and the VAE-17 toner have very good appearance with minimal color change (appearance ratings of 4 as reflected in Table 13).

Figure 3 is a photograph of the same specimens as in Figure 2, but taken after water spray on the surface for water beading evaluation. The specimens have a different color appearance due to the photograph being taken at a different time and with different exposure settings. Nonetheless, the attractive appearance of the T-SB-1 and VAE-17 specimens is still obvious. It also is apparent that specimens coated with T-SB-1 and C-SB-3 had poor water beading and, in fact, water had absorbed into the wood. In contrast, the specimen with the VAE-17 toner exhibited good water beading. Therefore, these QUV-A exposure results continue to confirm the excellent performance of the four emulsions under evaluation.

Results for the Xenon Arc Weather-Ometer exposures are presented in Table 14. As the results illustrate, performance for many of the coatings (both appearance and water beading) noticeably declined between weeks 4 and 5 and therefore the exposure was concluded at five weeks. Total performance ratings for the four emulsions ranged from 25 to 34, with the best performer being EVCL-4. In comparison, performance of the com-

Table 13—Wood/Coating Appearance and Water Beading Results through QUV-A Exposure of Toner Formulations and Selected Commercial Products on Cedar Planks in Phase 4

QUV-A Cedar Planks	1 Week		2 Weeks		3 Weeks		4 Weeks		5 Weeks		6 Weeks		Total
	App. ^a	Bead ^b	App.	Bead	App.	Bead	App.	Bead	App.	Bead	App.	Bead	
T-WB-3.....	5	5	5	4	5	3	5	3	4	3	4	2	48
VAE-18.....	5	4	5	4	5	3	5	3	4	3	4	2	47
VAE-17.....	5	3	5	4	5	3	5	3	4	3	4	2	46
EVCL-4.....	5	4	5	4	5	3	5	3	4	2	4	2	46
VAE-1.....	5	4	5	4	5	3	5	3	4	1	4	2	45
T-WB-7.....	4	5	4	5	3	4	3	4	2	4	2	4	44
T-SB-1.....	4	4	4	4	4	3	4	2	4	2	4	2	41
I-WB-6.....	5	4	5	2	5	1	5	2	4	2	4	1	40
T-WB-5.....	5	3	5	1	3	2	3	2	3	1	3	0	31
C-WB-2.....	4	5	3	4	2	2	2	2	1	2	1	2	30
T-WB-4.....	5	3	5	3	3	0	3	0	3	0	3	0	28
C-SB-3.....	3	3	2	3	1	2	1	1	1	2	1	1	21

(a) Appearance ratings: Ratings ranged from 0 (extreme color change and/or damage) to 5 (no color change or damage).

(b) Water beading ratings: Water sprayed onto the wood surface was evaluated for beading according to a relative scale from 0 (worst) to 5 (best); a rating of 0 indicated complete wetting and penetrating of water into the wood and a rating of 5 represented water droplets of high contact angle on the wood surface.

mercial products ranged from 4 to 35. Several observations are clear. Failures of coatings occurred more rapidly in the Weather-Ometer than in the QUV-A exposures. Although there is not a direct correlation of performance between these two exposures, there are trends. Better performers in QUV-A generally are also better performers in Weather-Ometer. Poorer performers in QUV-A are clearly poorer performers in Weather-Ometer. There was a significant distinction of the bottom four performers, which are all commercial products, in Weather-Ometer versus the remaining coatings. In comparison, the experimental emulsions fared well, especially EVCL-4 versus the commercial products in the Weather-Ometer exposure, continuing to indicate the contribution these products can make in this application.

The 12-month exposure results on cedar planks are presented in Table 15. Again, there is a clear reduction in performance for many of the coatings towards the end of the exposure period, between 9 and 12 months, and this was the reason for suspending the exposure. The formulated toners had total ratings of: 27.5 for VAE-1 and VAE-17, 19 for VAE-18, and 17.5 for EVCL-4. The commercial products ranged from 4.5 to 29.5 in performance, with four of the products having a rating of 10 or less. Again, there is not a definitive correlation between these exposure results and those from QUV-A and Weather-Ometer, except that generally better performers fair well in all three exposures and poorer performers are clearly consistently poor. Again, performance of the toners formulated from the waterborne polymers fared well versus that of the commercial

Table 14—Wood/Coating Appearance and Water Beading Results through Xenon Arc Weather-Ometer Exposure of Toner Formulations and Selected Commercial Products on Cedar Planks in Phase 4

Weather-Ometer Cedar Planks	1 Week		2 Weeks		3 Weeks		4 Weeks		5 Weeks		Total
	App. ^a	Bead ^b	App.	Bead	App.	Bead	App.	Bead	App.	Bead	
T-SB-1.....	3	5	3	5	3	5	3	5	3	2	37
EVCL-4.....	5	5	4	4	3	4	3	3	1	3	35
I-WB-6.....	5	5	5	5	4	4	3	2	2	0	35
T-WB-3.....	4	5	4	4	3	4	3	3	3	1	34
T-WB-7.....	3	5	2	5	2	5	2	5	1	3	33
VAE-1.....	5	3	4	3	3	3	3	0	1	0	25
VAE-17.....	5	2	4	2	3	3	3	2	1	0	25
VAE-18.....	5	2	4	3	3	3	3	0	1	0	24
C-WB-2.....	1	5	0	4	0	2	0	1	0	0	13
T-WB-5.....	3	1	1	1	1	0	1	0	1	0	9
T-WB-4.....	2	1	2	0	1	0	1	0	1	0	8
C-SB-3.....	1	1	0	1	0	1	0	0	0	0	4

(a) Appearance ratings: Ratings ranged from 0 (extreme color change and/or damage) to 5 (no color change or damage).

(b) Water beading ratings: Water sprayed onto the wood surface was evaluated for beading according to a relative scale from 0 (worst) to 5 (best); a rating of 0 indicated complete wetting and penetrating of water into the wood and a rating of 5 represented water droplets of high contact angle on the wood surface.

Table 15—Wood/Coating Appearance and Water Beading Results through Exterior Exposures at Allentown, PA, September 2004–September 2005 Exposure of Toner Formulations and Selected Commercial Products on Cedar Planks in Phase 4

Test Fence (45°S) Cedar Planks	3 Months		6 Months		9 Months		12 Months		Total
	App. ^a	Bead ^b	App.	Bead	App.	Bead	App.	Bead	
T-SB-1.....	5	3.5	4	3	4	5	2	3	29.5
T-WB-3.....	4	4.5	3	4	3	5	2	3	28.5
T-WB-6.....	5	4.5	4	2	4	5	3	1	28.5
VAE-1.....	5	4.5	3	5	3	4	3	0	27.5
VAE-17.....	5	4.5	3	5	3	4	3	0	27.5
T-WB-7.....	2	4.5	1	4	0	5	0	4	20.5
VAE-18.....	5	3	3	1	3	1	3	0	19
EVCL-4.....	4	4.5	2	3	2	1	1	0	17.5
C-SB-3.....	1	3	0	3	0	3	0	0	10
C-WB-2.....	1	3	0	3	0	3	0	0	10
T-WB-5.....	2	1	1	0	1	0	0	0	5
T-WB-4.....	2.5	1	1	0	0	0	0	0	4.5

(a) Appearance rating: Ratings ranged from 0 (extreme color change and/or damage) to 5 (no color change or damage).

(b) Water beading rating: Water sprayed onto the wood surface was evaluated for beading according to a relative scale from 0 (worst) to 5 (best); a rating of 0 indicated complete wetting and penetration of water into the wood and a rating of 5 represented water droplets of high contact angle on the wood surface.

products, performing as well as many of the commercial products and even far superior to others. Figures 4–6 illustrate representative coated cedar specimens.

The final evaluation was a 12-month exposure on weathered ACQ pressure treated boards and those results are presented in Table 16. Some of the coatings, especially T-WB-3, EVCL-4, and VAE-1, performed very well through the end of the 12-month exposure period. The formulated toners had total ratings of: 33 for EVCL-4, 32 for VAE-1, 24 for VAE-18, and 23.5 for VAE-17.

The commercial products ranged from 7.5 to 35.5.

The poorer performers continue to be C-SB-3, C-WB-2, T-WB-4, and T-WB-5. Again, the polymer emulsions perform favorably versus the commercial products. Figures 7 and 8 illustrate representative coated pressure treated wood specimens.

Phase 4 results clearly indicate several observations. First, the commercial water repellent coatings have a very wide range of performance, with some only lasting a short duration in all of the exposures, while others

Table 16—Wood/Coating Appearance and Water Beading Results through Exterior Exposures at Allentown, PA, September 2004–September 2005 Exposure of Toner Formulations and Selected Commercial Products on ACQ Pressure Treated Decking Board Planks in Phase 4

Test Fence P/T ACQ Decking Boards (Horizontal)	3 Months		6 Months		9 Months		12 Months		Total
	App. ^a	Bead ^b	App.	Bead	App.	Bead	App.	Bead	
T-WB-3.....	4	4.5	5	5	5	3	4	5	35.5
EVCL-4.....	4	5	4	5	4	3	4	4	33
VAE-1.....	4	5	4	5	4	3	4	3	32
T-WB-6.....	4	5	5	4	5	5	4	0	32
VAE-18.....	4	3	4	1	4	1	4	3	24
T-WB-7.....	2	5	1	5	2	4	0	5	24
VAE-17.....	4	3.5	4	3	3	1	4	1	23.5
T-SB-1.....	2	2.5	1	4	1	5	1	5	21.5
C-SB-3.....	1	5	0	3	0	3	1	3	18
C-WB-2.....	1	3	0	3	0	3	0	0	14
T-WB-4.....	2	1.5	2	0	2	0	2	0	9.5
T-WB-5.....	2	1.5	1	0	1	1	1	0	7.5

(a) Appearance rating: Ratings ranged from 0 (extreme color change and/or damage) to 5 (no color change or damage).

(b) Water beading rating: Water sprayed onto the wood surface was evaluated for beading according to a relative scale from 0 (worst) to 5 (best); a rating of 0 indicated complete wetting and penetration of water into the wood and a rating of 5 represented water droplets of high contact angle on the wood surface.

Figure 4—Cedar planks prior to exterior exposure.

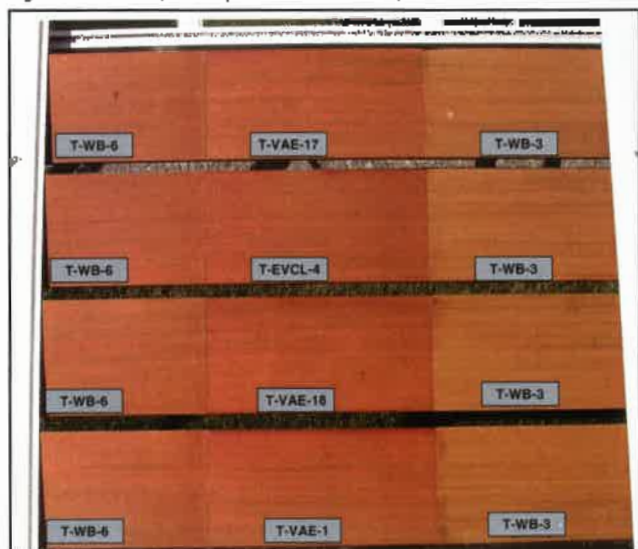
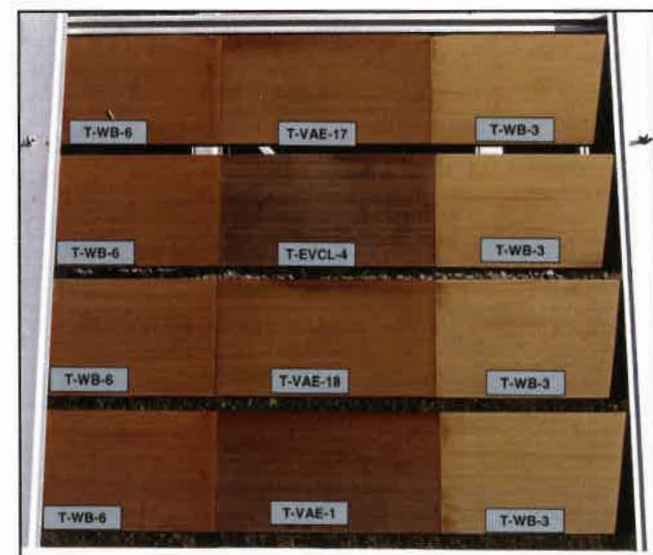


Figure 5—Cedar planks after 12-month exposure at 45°S in Allentown, PA.



perform well after extended periods, including one year of exterior exposure. Second, the toners formulated with the waterborne vinyl acetate and vinyl chloride-based polymers performed very well in all of the exposures, especially considering these formulations were not optimized. These formulated toners equaled and, in some cases, dramatically outperformed the commercial products. Third, it must be emphasized that the VOC of these formulations is approximately 110 g/L versus VOC levels of 250 to 600 g/L for the commercial coatings. The organic solvent in these formulations is necessary to dissolve and incorporate the biocide. Subsequent studies have definitively demonstrated that effective biocide can be incorporated without the use of

Figure 6—Cedar planks after 23-month exposure at 45°S in Allentown, PA.

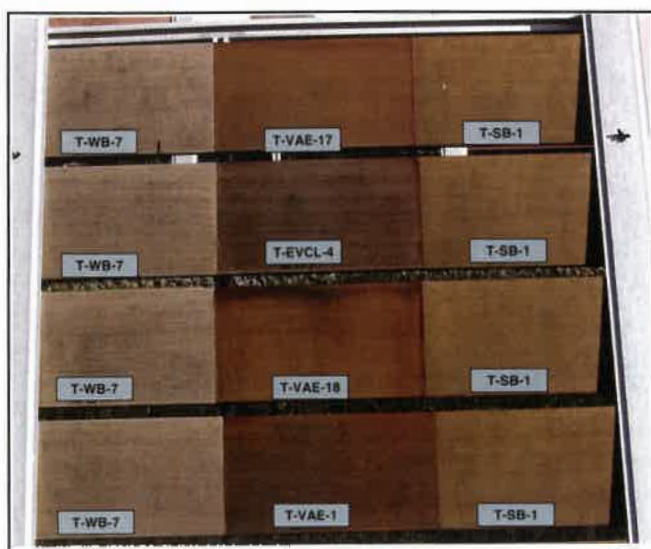


Figure 7—ACQ pressure treated decking boards after 12-month exposure at horizontal in Allentown, PA.

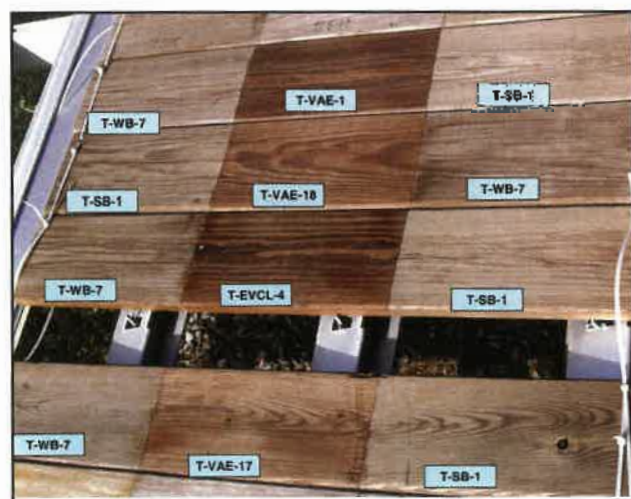


solvent and therefore coatings with VOC levels of < 100 g/L can be formulated easily, thus offering dramatic VOC reductions over current products and meeting the SCAQMD proposed limits of 100 g/L while still providing excellent performance.

SUMMARY AND CONCLUSION

Extensive testing of waterborne VAE, EVCL, and other vinyl acetate-based polymer emulsions show that these polymer systems are very effective materials for formulating low-VOC (< 100 g/L) water repellent coatings for exterior wood applications. The high level of perform-

Figure 8—ACQ pressure treated decking boards after 12 months' exposure at horizontal in Allentown, PA.



ance displayed by these materials is rather surprising given the basic, un-optimized formulations evaluated in these studies. The performance of the top polymer emulsions presented in this article matches or exceeds the performance of fully optimized water repellent coatings used in the marketplace today. It is expected that the performance of coatings containing these emulsions can be improved even further by formulation with other coating ingredients specifically selected for coatings containing these emulsions.

The best emulsion polymers were chosen based on an overall balance of properties, including water beading, color appearance, and wood integrity. However, it is possible that other materials evaluated in this study could be considered top candidates if only one or two specific properties are desired. Depending on the particular properties to be optimized for a specific formulation, many candidate materials can be considered. For example, a particular polymer emulsion may offer optimal water beading while another selection would offer optimal weathering. Overall, the balance of per-

formance may be best with a trade off between several of these desirable properties when selecting among the variety of VAE and EVCL resins available.

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