

Low-VOC Waterborne Coatings for Use in Industrial Maintenance Painting

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Increasingly demanding environmental regulations for industrial maintenance coatings have put pressure on manufacturers and users of both solventborne and waterborne coating systems. The lowering of volatile organic compound (VOC) levels to below 100 g/L is being considered for industrial maintenance coatings in many regions of the U.S. This article discusses the development of waterborne acrylic latex polymers for use in high performance, VOC-compliant coatings applied to steel and concrete structures. Formulation and coating properties of these polymers are described, with an emphasis on comparisons of performance to traditional, higher VOC waterborne and solventborne coatings.

INTRODUCTION

Environmental regulations have put increasing pressure on all members of the coatings industry to develop and use coatings that have lower impact on our environment. Raw material suppliers are constantly working to develop new resins and additives that allow paint manufacturers to produce coatings with favorable health, safety, and environmental profiles. In addition, painting contractors and end-users such as homeowners and facility owners are constantly asking for higher performing products. Those two desires are often difficult to bring together in a new product, especially when it comes to lowering volatile organic compound (VOC)

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levels. Waterborne latex coatings are one technology which provides an opportunity to reduce VOC levels relative to traditional solventborne technologies. However, technical challenges still exist, considering the low-VOC targets posed by many existing and proposed regulations. In particular, properties such as hardness, dirt pickup resistance, block and print resistance, and the ability to withstand freeze-thaw cycles, can be difficult to achieve. Using latex polymers with lower glass transition temperatures is an obvious route to coatings that require less coalescing solvents and have lower VOC demands, but this seemingly simple solution also leads to many of the problems already mentioned.

Industrial maintenance painting of steel and concrete structures is still done mainly with solventborne coating technologies. It is estimated that about 80% or more of the coatings used in these applications are solventborne, with epoxies, polyurethanes, and alkyds making up the bulk.¹ Only about 16% by volume of industrial painting relies on waterborne acrylic latex coatings, while architectural applications today overwhelmingly utilize latex-based coatings. However, the use of waterborne coatings for industrial maintenance has grown considerably since the 1970s, when they were virtually non-existent. Waterborne acrylics now find use in a variety of light and medium duty industrial applications. Overall, the phenomenal growth of waterborne acrylic has been driven by a number of factors, including compliance with VOC regulations, ease of clean-up, less hazardous waste disposal and its associated costs, lower risk of health hazards due to exposure to solvents, less concerns with flammability and the impact on insurance costs, their one-component ease of use, and, finally, their proven performance capabilities in real world settings.²

As with architectural coatings, industrial maintenance (IM) coatings are coming under increasingly stringent VOC regulations in many areas of the United States and around the globe. For example, in July 2006, the South Coast Air Quality Management District (SCAQMD) in California lowered VOC levels for industrial maintenance coatings to 100 g/L. Such regulatory pressures will continue to move IM coatings towards waterborne, high-solids solventborne, and other technologies that are able to comply with these strict limits. At the same time, end-users are unwilling to sacrifice coatings performance for these often high-performance coatings.

This article describes our efforts to find a solution to the issues of decreasing VOC limits and the continued desire for higher performing IM coatings. In particular, the development of a new waterborne acrylic binder for direct-to-metal (DTM) coatings will be discussed. The new binder provides both lower VOC levels (< 100 g/L)

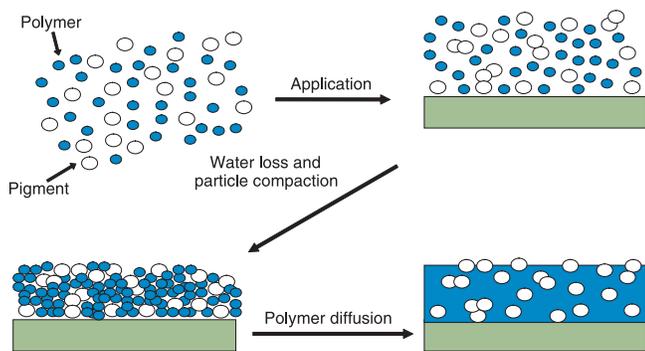
and higher performance (e.g., gloss, durability, and corrosion resistance) than currently available binders, and is based on novel technology which leads to improved pigment distribution in both the wet paint and dry film. This new approach to making latex paints involves the formation of composite particles through the controlled adsorption of latex particles onto the pigment surface. Evidence for the formation of the latex polymer-pigment composites is presented, as well as a description of how this new method for controlling film structure affects the properties and performance of industrial maintenance coatings.

EXPERIMENTAL

The binder based on the new technology that is the basis for this report will be designated as EXP-1. EXP-1 is a self-crosslinking acrylic copolymer with a minimum film formation temperature (MFFT) of 14 °C, weight solids of approximately 50-51%, and pH value of 8.5 to 9.0. In most instances, a comparison is made of EXP-1 to a commercially available, conventional waterborne acrylic emulsion polymer (COM-1) that is widely used in industrial maintenance finishes. COM-1 has a MFFT of 30 °C and weight solids of approximately 42%, and is typically formulated at VOC levels equal to or greater than 200 g/L. The term "conventional" is meant to imply a typical acrylic latex that is stabilized via carboxylic acid functionality. Commercially available paints (waterborne acrylic and solventborne alkyd) were also used as controls, and were obtained from their suppliers. The commercial waterborne acrylic coatings have VOC levels of approximately 200 g/L, and the alkyd is greater than 400 g/L. Acrylic polymers were formulated into gloss DTM coatings using exterior grades of titanium dioxide. All paints were prepared from dry powder pigments and extenders. Latex particles were coalesced using Texanol[®] solvent unless noted otherwise. EXP-1 was formulated at a VOC level of 100 g/L, and COM-1 at approximately 200 g/L. Unless noted, paints were applied with a drawdown bar to give 3 mils (75 µm) dry film thickness, and were allowed to cure at 25 °C and ~55% relative humidity for two weeks prior to testing.

Film gloss was measured on coatings cast onto either phosphate-treated (Bonderite 1000) cold rolled steel panels (ACT Laboratories) or chromate-treated aluminum panels (Q-Panel). Film gloss was determined in accordance with ASTM D 523. The effect of weathering on film gloss was determined artificially using a QUV accelerated weathering cabinet set for UV-A exposure, and a cycle of 8 hours light followed by 4 hours condensation. Gloss retention upon exterior exposure was measured on chromate-treated aluminum panels exposed at an eastern Pennsylvania site. Dry hiding was estimated,

Figure 1—Film formation mechanism for a typical latex paint.



using ASTM D 2805, by calculating the contrast ratio from Y-reflectance measurements using a 45°/0° reflectometer (BYK-Gardner).

Corrosion resistance was evaluated by salt spray exposure (ASTM B117) on 4 in. by 12 in. hot rolled steel panels cleaned by abrasive blast to an SSPC-SP 5 (white metal) condition. Panels were scribed with a single vertical scribe of 50 mm in length positioned in the bottom half of the panel, and were rated for blistering, rusting, and undercutting.

Dirt pickup resistance (DPU) was measured by applying a slurry of brown iron oxide to the coating surface, allowing the slurry to dry for several hours, and then washing the pigment from the surface under running water and applying light pressure with a piece of clean cheesecloth. The Y-reflectance was measured before application of the slurry and after cleaning, and the ratio ($Y_{\text{final}}/Y_{\text{initial}}$) was reported as the dirt pickup resistance. DPU was measured on coatings dried for one week at 25°C and ~55% relative humidity, and on coatings exposed for one week to UV-A accelerated weathering.

The relative barrier properties of paints to electrolyte diffusion were determined by measuring the change in coating resistance (Rc) during exposure to a salt solution using electrochemical impedance spectroscopy.³ Electrochemical impedance spectra were measured on paint films applied to cold rolled steel using an EG+G Princeton Applied Research Model 273A potentiostat/galvanostat and a Schlumberger Model SI-13260 Impedance gain-phase analyzer along with platinum electrodes. Electrical contact with the paint film was maintained with a 5% aqueous NaCl solution. Coating resistance as a function of exposure time to the NaCl solution was obtained by fitting the raw impedance data to a simple model (Randles) circuit containing a parallel resistor (Rc) and capacitor (Cc).

The amount of latex adsorbed onto pigments was estimated using a centrifugation method. Paints were first

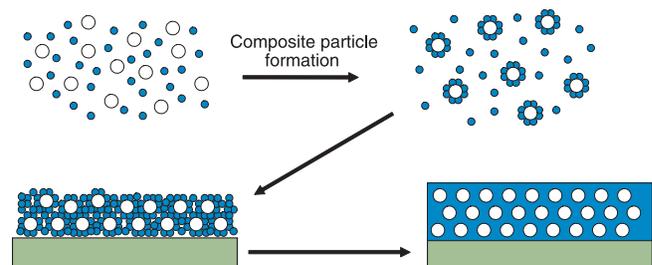
diluted in deionized water (1 paint/2.5 water) and centrifuged at 5000 rpm for 30 min. After centrifugation, a solids measurement of the supernatant was performed. The percentage of latex removed from the serum phase (after centrifugation) relative to the initial starting amount of latex (before centrifugation) was calculated. This percentage was taken as the amount of latex adsorbed onto the pigment. Additionally, the amount of latex adsorbed was calculated by performing a thermal gravimetric measurement on the sediment after centrifugation. Both measurements were in agreement.

Film morphologies of dried paints were determined using Field Emission Scanning Electron Microscopy (FE-SEM) and atomic force microscopy (AFM). For FE-SEM imaging studies, TiO₂/latex blends were diluted and dispersed onto silicon wafers, coated with Au/Pd (~10 nm) and imaged with a JEOL 6700 FE-SEM. Dry films for AFM measurements were prepared by casting paints onto Mylar to give a dry film thickness of approximately 25-50 μm. AFM images were collected using a Digital Instruments Nanoscope III Scanning Probe Microscope. The films were imaged by selecting small samples roughly 1/4 in. by 1/4 in. from the Mylar sheet. These samples were adhered to the sample holder with no additional sample preparation methods. The samples were imaged under ambient conditions. Three separate sections of the cast films were imaged to insure an accurate representation of the surface. The images were collected using conventional tapping mode techniques and employed a TESP tip. The height images demonstrate the topology of the sample surface, and surface roughness (Ra) was calculated from 20 by 20 micron images using digital software.

RESULTS AND DISCUSSION

The newly developed polymer (designated as EXP-1) was designed specifically for industrial maintenance applications. In addition to the ability to be formulated into primers, topcoats, and DTM finishes with

Figure 2—Formation of latex polymer-pigment composites and their effect on the film formation mechanism of latex paints.



VOC levels at or below 100 g/L, the binder EXP-1 also offers new levels of performance for waterborne acrylic coatings. The improved properties include higher gloss potential, better durability and corrosion resistance, better adhesion to metal substrates, and more efficient hiding. EXP-1 also undergoes self-crosslinking after film formation via an oxidative cure mechanism, and this leads to good solvent resistance and dirt pickup resistance, and aids with the durability. Many of the property enhancements are the result of a unique proprietary chemistry built into the polymer, which causes the latex particles to associate with pigment surfaces in the wet paint. The association leads to the adsorption of latex particles onto the surface of pigment particles and the formation of latex polymer-pigment composite particles. The nature of the composite particles, and how they affect the film formation process and the various coating properties, is discussed below.

In order to make a stable waterborne latex paint, it is usually the desire of a formulator to keep all colloidal particles in the system—whether latex polymer or pigment—separated in the wet state. Pigments are dispersed under high shear during the milling or grinding process, and stabilized with surfactants and low molecular weight polymeric dispersants. Establishment of a repulsive barrier between particles, either by electrostatic or steric means, prevents the pigment particles from agglomerating again once the shear is removed. In a similar manner, latex polymers are stabilized during the synthetic process by use of surface charge and steric hindrance, and remain as discrete colloidal particles for long periods of time. Conventional acrylic polymers typically receive their surface charge from neutralized carboxylic acid groups in the polymer backbone, as

well as from surfactant molecules adsorbed on the latex surface. The paint formulator takes the stable dispersions of pigment and latex polymer, and mixes them to produce a stable paint where all particles remain separated. The stability of the wet paint relies on the ability of those particles to resist coagulation over long periods of time.

It is also well known that the quality of pigment dispersion in the dry film has a strong effect on the appearance and barrier properties of the coating. Gloss, distinctness of image, color, hiding, and corrosion resistance are important properties for industrial coatings that are dependent on how well the pigment particles are dispersed throughout the dry film. Poor pigment dispersion in the wet state will obviously lead to a less than ideal distribution in the dry state. *Figure 1* shows the film formation process for a typical latex paint prepared from a conventionally stabilized latex polymer. The first image is the ideal state for a wet paint, where all pigment and polymer particles are well dispersed. After the paint is applied to the substrate and water begins to evaporate, the particles come closer together, and some agglomeration of the pigment particles is likely to occur. In the final film, the pigment is rarely distributed ideally throughout the film. Pigment agglomerates have formed during the drying process, and some pigment particles will be protruding from the paint surface. One method of maintaining good dispersion during the application and drying process would be to use higher levels of dispersants and surfactants. However, in many applications it is advantageous to keep the level of these additives as low as possible because they can negatively affect properties such as water and corrosion resistance. An alternative approach to

Figure 3—FE-SEM images (50,000x) of diluted blends of TiO_2 and latex particles. The left image is based on the conventionally stabilized acrylic polymer COM-1, while the right image is based on the adsorbing polymer EXP-1. The right image shows latex adsorbed onto the TiO_2 surface.

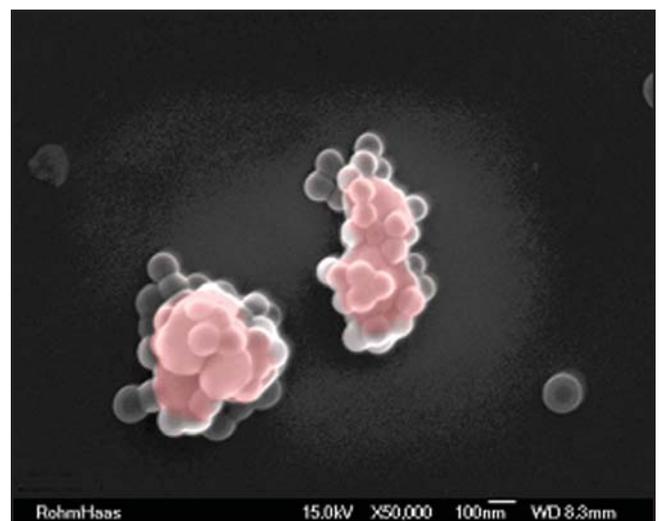
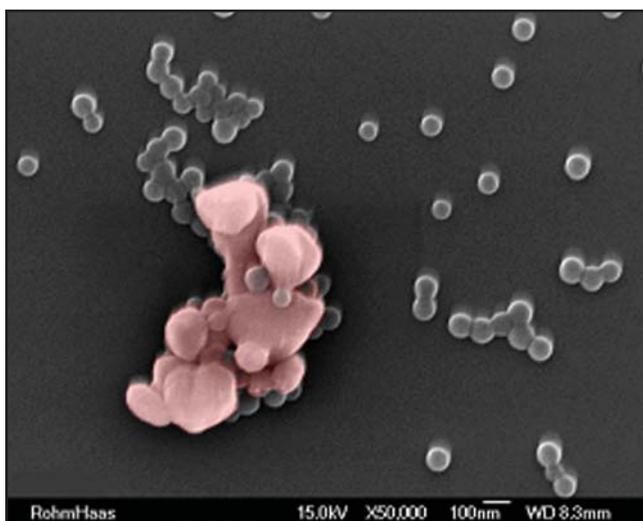


Table 1—Comparison of Polymers EXP-1 and COM-1 in an 18 PVC Gloss White DTM Formulation

Paint based on:	EXP-1	COM-1
Gloss (20°/60°)		
Initial . . . . .	.64/82	14/54
After 528 hr UV-A exposure . . . . .	.55/83	5/34
% Gloss Retention (20°/60°)		
After 528 hr UV-A exposure . . . . .	.86%/101%	36%/63%
Hiding - Contrast Ratio		
18.0 PVC . . . . .	.0988	0.977
15.8 PVC . . . . .	.0986	0.974
13.6 PVC . . . . .	.0982	0.969
Dirt pickup resistance ($Y_{final}/Y_{initial}$)		
1 week dry . . . . .	.089	0.91
1 week UV-A exposure . . . . .	.099	0.92
MEK double rubs		
1 week air dry . . . . .	.96	25
1 week UV-A exposure	> 500	25
Hardness		
Konig pendulum (sec) . . . . .	.11.2	16.8
Pencil . . . . .	.2B	4B

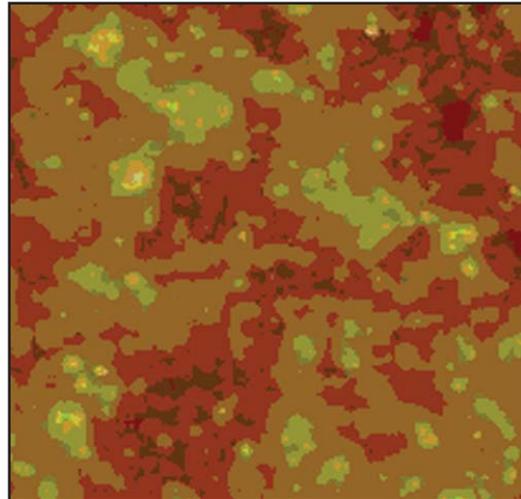
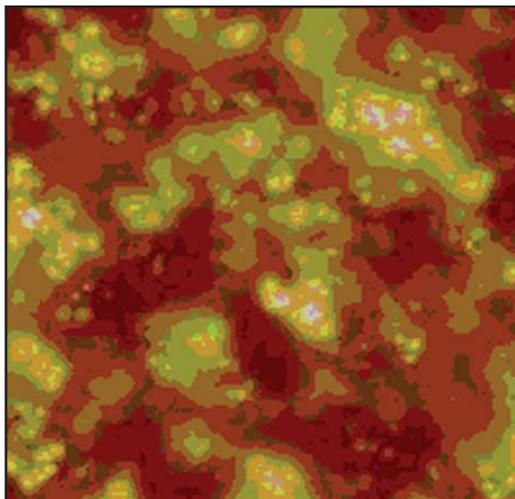
obtaining a uniform dispersion of pigment particles in dried paint films is to form latex polymer-pigment composites by adsorbing latex polymer particles onto the pigment surfaces in the wet state.

The process of forming latex polymer-pigment composite particles and their effect on the film formation process is shown in *Figure 2*. The process starts as in the conventional case, where the fully dispersed polymer and pigment are initially mixed to form a paint. However, in the case of a latex which adsorbs onto pigments, such as polymer EXP-1, the formation of com-

posite particles begins fairly rapidly. Depending on the nature of the pigment surface and the resin composition, latex particles associate with and form a layer surrounding the pigment particle. The adsorbed latex particles act to keep the pigment particles separate and prevent agglomeration in the wet state. In addition, after the film is applied and water begins to evaporate, the adsorbed binder acts as a spacer to maintain the pigment separation in the drying film. The result is a dry paint film where the pigment is more optimally dispersed.

Evidence of the formation of latex polymer-pigment composite particles is given in *Figure 3*, which shows images taken with FE-SEM of diluted latex-pigment blends using a conventionally stabilized acrylic polymer (COM-1) and the newly developed polymer EXP-1. The samples based on EXP-1 exhibit titanium dioxide (TiO₂) particles covered with latex particles that have associated with the pigment surface. The conventional polymer COM-1 displays little association with the TiO₂ surface. The amount of latex adsorbed onto the pigment surface can be quantified by a centrifugation method. When tested on a simple 18 PVC DTM formulation, using TiO₂ as the only pigment, results show that EXP-1 has approximately 40% of the latex adsorbed onto the pigment. The value can vary due to changes in formulation, such as grade of TiO₂, coalescent, rheology modifier, and other additives. Among the various factors which likely affect the amount of latex adsorbed is how well the TiO₂ is originally dispersed during the grinding process, i.e., the average particle size of TiO₂ in a particular millbase prior to composite particle formation. Based on simple geometrical considerations, the results of the centrifugation experiments imply near saturation of the available pig-

Figure 4—AFM height images of surfaces of 18 PVC coatings (TiO₂ pigment only) based on a conventional non-adsorbing latex polymer (left image), and an adsorbing latex polymer which forms polymer-pigment composites (right image).



ment surface area with adsorbed latex. Although the FE-SEM images suggest the TiO₂ surface in that experiment is not completely saturated, the apparent disparity may have resulted from the sample preparation, where the paints were diluted and sprayed before FE-SEM imaging to ensure individual composite particles were isolated.

Based on the mechanism in *Figure 2*, one of the expected benefits of the composite particles is higher initial gloss. Because each pigment particle has latex polymer adsorbed on its surface, the surface of the paint film is expected to be richer in polymer than with a non-adsorbing binder. The 20°/60° gloss of 18 PVC DTM coatings based on EXP-1 and COM-1 is seen in *Table 1*, showing a large benefit for EXP-1. Formulations are described in *Table 2*. It should also be noted that the high gloss is achieved without lowering the molecular weight of the polymer, which is a route often used to yield high initial gloss with an acrylic latex. However, lowering molecular weight has other detrimental effects, such as decreasing durability and solvent-resistance properties. Evidence for a smoother, polymer-rich surface resulting from the polymer-latex composites is found in atomic force microscopy (AFM) height images of the surfaces of dry paint films, as shown in *Figure 4* for 18 PVC paints based on adsorbing and non-adsorbing polymers. The AFM height images show more surface uniformity for the paint based on the adsorbing binder, which suggests a more uniform TiO₂ distribution. The light areas of the image correspond to high points on the film. Surface roughness values (Ra) calculated from the image data were 24 and 49 nm for the coatings based on adsorbing and non-adsorbing latex polymers, respectively. Smaller Ra values imply a smoother surface, and correspond to the higher gloss observed for EXP-1.

As noted above, the formation of polymer-pigment composites gives the paint formulator the ability to achieve high gloss with a high molecular weight polymer. The high molecular weight is also expected to have a positive impact on durability, as measured by gloss retention. Gloss retention results for 18 PVC gloss DTM formulations (*Table 2*) based on adsorbing polymer EXP-1 and non-adsorbing polymer COM-1 are shown in *Figure 5* and *Table 1*. The data is for paints exposed to accelerated UV-A weathering, and shows that EXP-1 has better durability compared to a commercially successful product. *Figure 6* shows similar durability data comparing EXP-1, formulated into an 18 PVC DTM coating, to some commercial waterborne acrylic and solventborne alkyd DTM coatings. Again, compared to coatings that are currently used for light and medium duty maintenance applications, EXP-1 is shown to provide excellent durability under accelerated weathering conditions. *Figure 7* demonstrates that the

Figure 5—Plot of 60° gloss values versus exposure time in UV-A accelerated weathering for 18 PVC paints based on adsorbing polymer EXP-1 and non-adsorbing polymer COM-1.

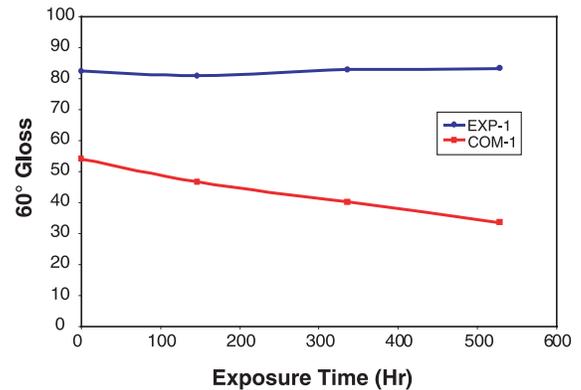


Figure 6—Plot of 60° gloss versus exposure time for UV-A accelerated weathering comparing an 18 PVC gloss white DTM formulation based on polymer EXP-1 to commercial gloss white DTM coatings.

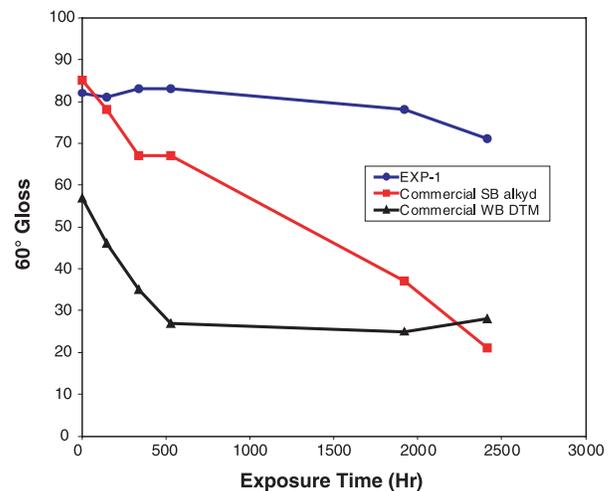


Figure 7—Plot of 60° gloss versus exposure time for exterior exposures comparing an 18 PVC gloss white DTM formulation based on polymer EXP-1 to commercial gloss white waterborne acrylic DTM coatings. Panels were exposed south vertical at an eastern Pennsylvania site.

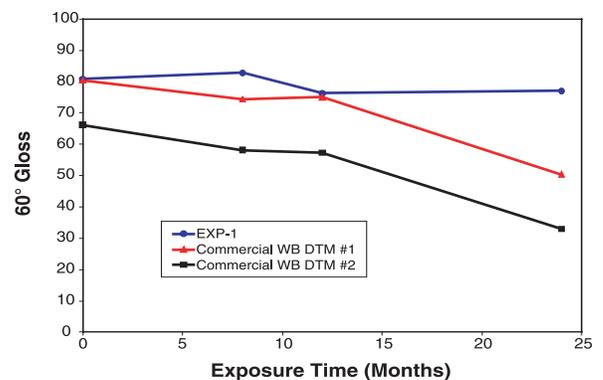


Table 2—Gloss White DTM Formulations Based on Polymers EXP-1 and COM-1

Paint Based On:	EXP-1		COM-1	
	Lb	Gal	Lb	Gal
Grind				
Water	.55.00	6.59	55.00	6.59
Tamol 2001	.8.75	0.99	8.75	0.99
Surfynol CT-111	.2.00	0.25	2.00	0.25
Tego Foamex 8050	.0.25	0.03	0.25	0.03
Ammonia (28%)	.2.00	0.27	2.00	0.27
Ti-Pure R-706	.210.00	6.29	210.00	6.29
Grind Sub-total	.278.00	14.41	278.00	14.41
Let Down				
Polymer	517.00	59.72	618.00	72.19
Water	130.00	15.57	14.00	1.68
Ammonia (15%)	2.00	0.25	7.00	0.89
Tego Foamex 1488	1.00	0.12	1.00	0.12
<i>Add grind from above</i>				
Texanol	20.60	2.60	51.30	6.47
Dowanol DPM	14.00	1.76	14.00	1.76
Sodium Nitrite (15%)	9.00	0.99	9.00	0.99
Water	35.00	4.19	9.50	1.14
Acrysol RM-8W	3.00	0.35	3.00	0.35
Totals	1009.60	99.97	1004.80	100.00
PVC:	18		18	
Volume Solids:	36.2%		35.8%	
Weight Solids	47.5%		47.2%	
VOC (g/L):	100		180	

performance in actual exterior weathering is also very good compared to commercially available coatings. The data in Figure 7 compares EXP-1 to two commercial waterborne acrylic DTM coatings after 24 months of south vertical exposure at an eastern Pennsylvania site. After two years of exposure, the paint based on EXP-1 retained approximately 95% of the initial gloss, compared to 63% and 50% for the two commercial DTM coatings, respectively.

The weathering data suggests that the film structure resulting from adsorbing binders such as EXP-1 is a major cause of the improved durability. Certainly, the bulk monomer composition of EXP-1 and COM-1 are different, and could account for some differences in durability. In particular, EXP-1 contains functionality that leads to crosslinking via an oxidative cure mechanism, which is known to contribute to improved durability. It is also likely that the excellent durability of EXP-1 is aided by the high polymer molecular weight. However, other studies have indicated that the benefit in durability is observed for an adsorbing binder versus a non-adsorbing binder even when the bulk monomer composition and molecular weight is nearly identical.⁴ In addition, adsorbing polymers which do not contain the self-crosslinking functionality also demonstrate improved durability. This suggests it is not only the effect of high molecular weight and the self-crosslinking mechanism which leads to good durability for EXP-1.

One suggestion as to how the presence of polymer-pigment composites during film formation could affect durability is depicted in Figure 8. The improved pigment dispersion in the dry film—in particular, better spacing of TiO₂—is the proposed reason for increased durability. Titanium dioxide plays two roles in the durability of a coating film when exposed to the elements. It is well known that the TiO₂ acts as a catalyst for the photodegradation of polymer that is in contact with the pigment. In particular, in the presence of water, oxygen, and UV light, TiO₂ catalyzes the formation of radical species, which then react with the polymer and lead to breakdown of the polymer backbone. However, TiO₂ also protects the polymer underneath it in the film from photodegradation because it absorbs UV light and converts it to harmless energy (i.e., heat), thus preventing the UV light from interacting directly with the polymer backbone. When the TiO₂ is better dispersed throughout the dry coating film, as depicted in Figure 8, it is more efficient at blocking the UV light from the underlying polymer, and thus leads to improved durability.⁵

Direct evidence for improved pigment (TiO₂) dispersion in the dry film comes from FE-SEM studies of cross-sections of cured coatings based on both adsorbing and non-adsorbing polymers. Figure 9 shows an FE-SEM image of a dried film consisting of two layers. The bottom layer is a coating based on an adsorbing latex polymer, and the top layer is a coating based on a conventional, non-adsorbing polymer. Both paint formulations are identical except for the polymer, and are 18 PVC gloss white DTM coatings containing TiO₂ as the only pigment. The white spots are pigment particles, and black represents the binder. The TiO₂ dispersion is clearly more uniform in the dry film of the adsorbing latex polymer, which is able to form polymer-pigment composites. The more even spacing suggests that the scattering of light by TiO₂ should be more efficient

Figure 8—Representation of the interaction of UV light with coatings formed from adsorbing (left) and non-adsorbing (right) latex polymers; in particular, for coatings pigmented with titanium dioxide. The formation of polymer-pigment composites by the adsorbing polymer leads to improved TiO₂ dispersion in the dry film, which results in improved protection of the underlying polymer from UV light.

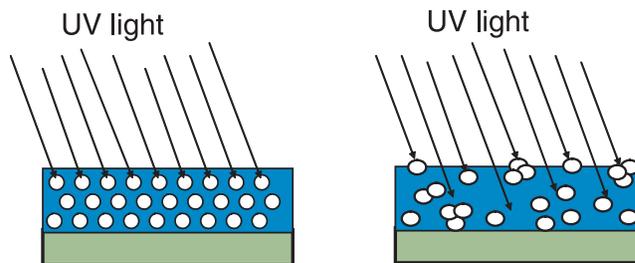
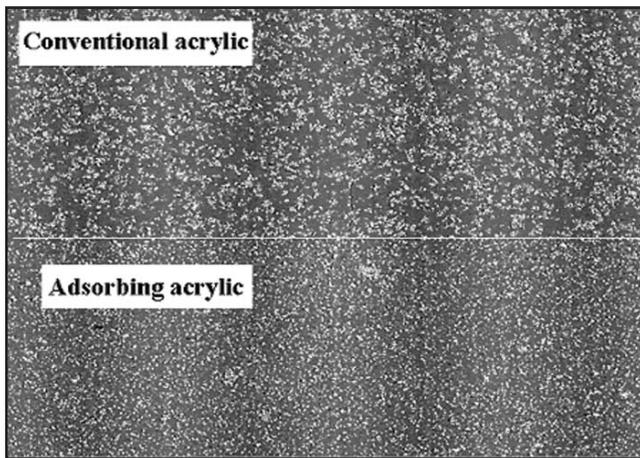


Figure 9—FE-SEM image of a cross-section of a dried film formed by casting one paint (based on a non-adsorbing latex polymer) on top of a second paint (based on an adsorbing polymer). Both paint formulations were identical except for the polymer, and were 18 PVC gloss white DTM coatings containing TiO_2 as the only pigment.



with adsorbing latex polymers such as EXP-1. Hiding measurements using contrast ratio agree with the better spacing shown by the FE-SEM images. Table 1 gives contrast ratios measured for gloss white DTM formulations based on EXP-1 and COM-1 at three different PVC levels. The contrast ratio for EXP-1 at the lowest PVC (13.6%) is still higher than the value for COM-1 at the highest PVC (18%). The difference in these PVC levels corresponds to approximately 60 lb of TiO_2 per 100 gal of paint for the formulation evaluated. At the least, the results suggest that EXP-1 and other latex polymers which are able to form polymer-pigment composites offer the possibility to reduce TiO_2 loadings while maintaining adequate hiding. This benefit could lead to raw material cost savings for the paint manufacturer.

The barrier properties of a paint film are also expected to rely on the quality of pigment dispersion. In particular, previous work has shown that corrosion resistance is affected by the level of pigment dispersion in the wet paint.⁶ Electrochemical impedance spectroscopy (EIS) shows that better barrier properties are exhibited by paints prepared from latex polymers which adsorb onto pigment surfaces. Figure 10 shows a plot of the calculated coating resistance (R_c) of paints based on adsorbing and non-adsorbing polymers as a function of exposure time to sodium chloride solution. Paints were 18 PVC gloss white DTM formulations using TiO_2 as the only pigment. The resistance (R_c) of the coating based on the non-adsorbing polymer dropped by approximately two orders of magnitude after about 20 min of exposure. On the other hand, the resistance of the coating based on the adsorbing binder remained high and unchanged. The results indicate adsorbing

polymers, and the formation of polymer-pigment composites, lead to films that are more resistant to the penetration of electrolytes. The results are also consistent with the observation of improved pigment dispersion in the dry film, as this model would suggest that fewer pigment-pigment interfaces should exist, because each pigment surface is covered by adsorbed latex particles. The pigment-pigment interfaces would provide pathways through the film for water and other species (i.e., electrolytes).

The EIS data and model described above also correlates well with corrosion resistance as measured by salt fog exposure (ASTM B 117).⁴ Figure 11 shows the appearance of steel panels, coated with 18 PVC DTM coatings based on either EXP-1 or COM-1, after 35 days of salt fog exposure. The coating based on EXP-1 offers significantly better corrosion protection, especially considering that the formulations contain only TiO_2 and no inhibitive pigments. The performance of the coating based on COM-1 is not unexpected for a single coat of waterborne acrylic gloss DTM on blasted hot rolled steel. Although COM-1 is used successfully in industrial painting when applied in systems (e.g., primer/top-coat), this result shows the great potential for binders based on the newer technology.

One of the main features of the new polymer EXP-1 is its ability to generate polymer-pigment composite particles via adsorption onto pigment surfaces. Another feature built into the polymer is the ability to self-crosslink after film formation via an oxidative cure mechanism.⁷ The crosslinking is also accelerated under exposure to UV light, which aids in generation of free radicals. As mentioned, it is thought that the self-

Figure 10—Plot of coating resistance (R_c) versus exposure time for 18 PVC DTM coatings based on adsorbing and non-adsorbing latex polymers. Data was derived from EIS measurements on films exposed to 5% NaCl solution.

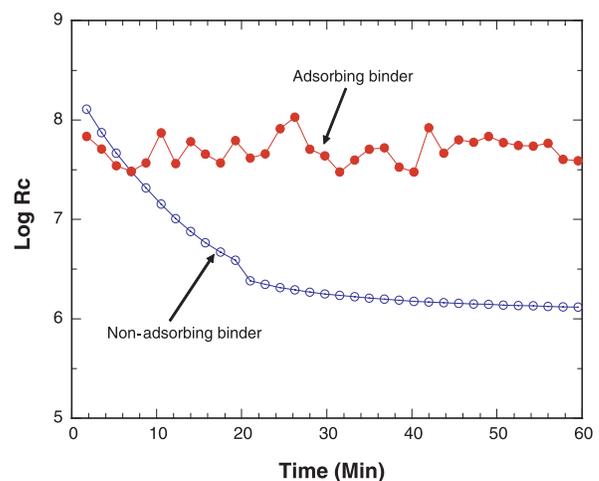
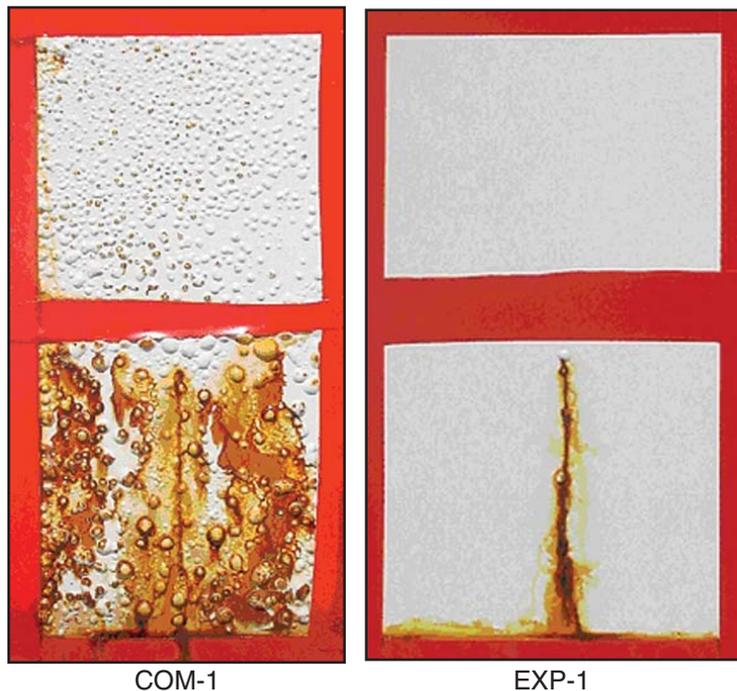


Figure 11—Steel panels after 35 days exposure to salt fog (ASTM B 117). Abrasive blasted hot rolled steel panels were coated with 3 mils DFT of 18 PVC gloss white DTM formulations, based on either EXP-1 or COM-1.



crosslinking mechanism, which results in an increase in polymer molecular weight after film formation, is at least partially responsible for the excellent durability of EXP-1. Crosslinking also results in improvements for some other important properties, including dirt pickup resistance and solvent resistance. In particular, acceptable dirt pickup resistance can be difficult to achieve in low-VOC coatings, because the polymers are typically softer than their higher VOC analogs. The oxidative crosslinking allows coatings based on EXP-1 to have

good dirt pickup resistance while also providing low VOC levels. *Table 1* shows results of dirt pickup resistance tests comparing EXP-1 and COM-1 (which has a higher MFFT than EXP-1) in a gloss white DTM formulation. Initially, EXP-1 exhibits slightly lower dirt pickup resistance; however, upon curing the film under UV-A exposure, it shows improved performance to the point where it is now better than the harder binder COM-1.

Crosslinking is also expected to yield good solvent resistance properties. *Table 1* shows that EXP-1 provides better solvent resistance than COM-1 after air-drying for one week, as measured by MEK double rubs required to break through the film to the substrate. In addition, on exposure to UV light, EXP-1 shows a significant increase in MEK double rubs while COM-1 remains at the same level. When drying under normal ambient conditions, the full benefits of crosslinking can usually be expected within a two to four week time period. Accelerating the oxidative cure with metal driers is also possible. *Table 3* shows results of MEK double rub tests for 18 PVC DTM formulations based on EXP-1, either with or without a metal drier package.

The metal drier package consisted of both cobalt and calcium driers (at approximately 0.075% active metal on polymer solids) and linoleic acid (at 2% on polymer solids). Without the drier package, solvent resistance builds steadily over a four week drying time to give greater than 300 double rubs for a 3 mil paint film. However, with the metal drier package, a considerable boost in performance is observed, with greater than 500 double rubs achieved in only two weeks. The use of metal driers is expected to be particularly useful in interior painting applications, where the accelerating effect of UV light will not aid crosslinking. *Table 3* shows that EXP-1 (with or without driers) also provides excellent solvent resistance after short exposures to UV light in both accelerated weathering and exterior exposure.

Table 3—Solvent Resistance (MEK Double Rubs) of DTM Coatings Based on Polymer EXP-1, Either With or Without Metal Drier Package

	Without Metal Drier Package	With Metal Drier Package
MEK double rubs		
<i>Air dry</i>		
1 week	96	184
2 weeks	148	>500
3 weeks	222	>500
4 weeks	339	>500
<i>UV-A exposure (after 1 week air dry)</i>		
24 hr	>500	>500
<i>Outdoor exposure (after 1 week air dry)</i>		
1 week	>500	>500

CONCLUSIONS

In this article, we have described the development of a new waterborne acrylic latex polymer (EXP-1) designed for both low-VOC and high performing industrial maintenance coatings. The improved performance of EXP-1 relative to currently available binders and commercial coatings is based on the use of a novel technology which enhances the pigment distribution in both the wet paint and dry film. The formation of latex polymer-pigment composite particles in the wet state leads to better pigment dispersion in the dry film, and

results in significantly improved gloss, durability, hiding, and corrosion resistance. In addition, self-crosslinking via an oxidative cure mechanism leads to improvements in dirt pickup and solvent resistance, and also contributes towards the excellent durability. Direct evidence for the formation of polymer-pigment composites and improved pigment dispersion in the dry film comes from centrifugation and microscopy (FE-SEM, AFM) techniques, and correlates with the observed properties. The technology exploited in this work represents a new method for controlling the wet paint and dry film structure of waterborne acrylic latex coatings, and the demonstrated benefits suggest potentially broad utility and value in both industrial and architectural coating applications.

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