Blending Vinyl Acetate-Ethylene and Acrylic Latexes to Achieve Targeted Performance Properties

by Wenjun Wu, Keith R. Olesen, Albert R. Miner II, and Jeff A. Schneider
The Dow Chemical Company*

Vinyl acetate-ethylene (VAE) and acrylic (A/A) latexes are two important classes of dispersion polymers for architectural coatings, each offering distinct performance benefits. Low- or zero-VOC capable VAE and A/A dispersions have become especially desirable, due to their ability to meet increasingly demanding environmental regulations. Latex blending is a useful strategy that provides ultimate formulation flexibility to achieve a broad range of performance and price targets.

In this article, blends of a VAE latex with various acrylic latexes are investigated. The VAE/acrylic latex blends are tested in a 26% PVC semi-gloss formulation. Application properties such as scrub resistance, wet adhesion, and block resistance are examined as a function of blend ratio and particle size of the acrylic latexes.

INTRODUCTION

Paint and coatings play an important role in preserving, protecting, and beautifying the objects to which they are applied. Architectural paints are used to decorate and extend the service life of the interior and exterior surfaces of residential and commercial buildings.

The U.S. paint and coatings industry is large and mature. In the year 2000, the architectural market represented about 50% of the total coatings volume sold in the United States at 644 million gallons. Vinyl acrylic (V/A) latexes dominate the U.S. architectural coatings

Presented at the Federation of Societies for Coatings Technology's 2007 FutureCoat! Conference, October 3-5, 2007, in Toronto, Ont., Canada.
*410 Gregson Dr., Cary, NC 27511.

market segment, representing 62% of the latex sold and utilized in 70% of paint produced. V/A latexes have achieved this position due to their favorable cost/performance balance.

Changes in the marketplace, resulting from increased government regulation regarding volatile organic compounds (VOC) used in paint manufacture, raw material shortages and margin pressures, have caused many coatings manufacturers to reevaluate their formulating approach in an effort to maintain their profitability and market share. As a result, many coatings manufacturers are evaluating vinyl acetate-ethylene (VAE) latexes as possible replacements for V/A.

The performance requirements of a coating differ depending on whether it is used in interior or exterior application. *Table* 1 lists the typical performance criteria along with a qualitative comparison of acrylic (A/A), V/A, and VAE polymers. From the performance comparison it is clear that VAE offers several advantages in interior paint formulations over conventional V/A. These advantages are of particular significance given the trend to lower VOC paint formulations and the need to drive coatings to lower formulated cost while maintaining performance. It is also clear that several performance deficiencies exist for the typical V/A and VAE binders, most notably wet adhesion and block resistance for interior application.

Wet adhesion refers to the ability of a latex paint to adhere to a substrate under wet conditions. Wet adhesion is a critical property not only for exterior paints but also for some interior applications such as in kitchens and bathrooms. Poor wet adhesion can lead to blistering, peeling, flaking, and chipping when the coating is exposed to periods of precipitation and temperature/humidity cycles.

Wet adhesion can be imparted to a polymer through the incorporation of a wet adhesion monomer (WAM) into the polymer backbone.[1-3] This is routinely practiced with acrylic chemistry but is less common for V/A and VAE binders due to the expense of the wet adhesion monomers. Blending V/A and VAE binders with wet adhesion containing acrylic latex offers a more cost effective alternative to achieve wet adhesion. For example, Boyce has disclosed in U.S. patent 5,208,285 that good wet adhesion can be achieved at low cost when a minor proportion of a small particle size acrylic latex containing ureido wet adhesion functionality is blended with vinyl acetate-butyl acrylate copolymer.[4] Hybrid polymer compositions combining VAE with emulsified epoxy resin and isophoronediamine hardening agent have also demonstrated improved wet adhesion.[5-6]

Block resistance is the tendency of painted surfaces to stick together (or block) when brought into contact, as is experienced with the closing of windows and doors. A coating with good block resistance will retain its film integrity upon reopening of the windows or doors. Poor anti-blocking properties cause the two contacting films to stick, resulting in tearing or peeling of the paints upon separation.

Given the low glass transition temperature (T_g) of VAE copolymers, they are generally not expected to have exceptional block resistance. Several recent publications reporting good block resistance involve either latex blends or VAE/polyurethane hybrid compositions.[7-9] The component latex responsible for anti blocking properties is either a vinyl acetate homopolymer[7] or acrylic latex containing a sterically hindered alkoxylated silane monomer.[8]

Table 1—Performance Comparison of Acrylic (A/A), Vinyl Acrylic (V/A), and Vinyl Acetate-Ethylene (VAE) Latexes

Application			Performance Assessment		
Interior	Exterior	Test Method	A/A	V/A	VAE
Odor		ASTM D 1296	--[a]	-	+
Color acceptance			o	o	o
Package stability			o	o	o
Freeze-thaw stability		ASTM D 2243	o	o	-
Microorganism resistance		ASTM D 3273	o	o	o
Associative thickener response			+	o	-
Touch-up uniformity		ASTM D 3928	o	o	+
Low temperature coalescence		ASTM D 3793		o	++
Gloss		ASTM D 523	o	+	+
Hiding power		ASTM D 2805	o	o	o
Wet adhesion			++	--	-
Burnish resistance		ASTM D 6736	o	o	o
Scrub durability		ASTM D 2486	-	+	++
Block resistance		ASTM D 4946	+	-	-
Cleansability			o	-	-
	Adhesion to chalking surfaces	ASTM D 3450, D 4828	+	-	
	Dirt pick-up resistance	ASTM D 3719	o	--	--
	Blister resistance	ASTM D 4585	+		--
	Alkali resistance		+	--	-
	Exposure resistance	ASTM D 1006		-	-

[a] o is equal, - is superior, + is significantly superior, - is inferior, and -- is significantly inferior.

Table 2—VAE and Acrylic Latexes for the Blend Study

Latex	T_g (°C)	Mv (µm)	WAM
VAE	11	0.380	0
Acrylic A	20	0.150	2.5X
Acrylic B	39	0.075	2.5X
Acrylic C	0	0.090	2.5X
Acrylic D	0	0.133	2.5X
Acrylic E	0	0.138	1X

For both wet adhesion and block resistance, latex blending has proven to be a useful strategy to deliver balanced performance properties. It also provides greater flexibility for achieving a broad range of performance and cost targets. With increasingly lower VOC requirements, latex blending will continue to be an area of high interest.[10] Extensive research in the past decade has involved the combinations of bimodal hard and soft latexes.[10-20] The hard polymer is defined by its high glass transition temperature ($T_g > 20°C$). For coalescent free film formation, the blend systems usually include a predominant amount of soft polymer and a minor amount of hard polymer particles. In non-reactive blends, it is believed that non film-forming hard polymers act like filler particles to reinforce the bulk films.[11] Additionally, small modifying particles are preferred for maximum packing efficiency because they can fill the interstitial space between the large particles. As a result, the coalesced blend films contain less void volume.[11-12,16-17] Improved block resistance and dirt pick-up properties have been reported for various latex blends containing a small particle size, non-film-forming modifier.[21-24]

Unfortunately, the small particle size modifier is rather a special grade than a general purpose product. Preparation of ultrafine particle size requires a large amount of water-soluble raw materials like emulsifiers or functional monomers for colloidal stability. These hydrophilic materials increase water sensitivity of the resulting latex and the final blend. High viscosity due to ultra-fine particle size makes it a challenge to produce high-solids content. More importantly, the hard constituent polymer as the sole binder has limited utility in low-VOC coatings. Versatility is always a desirable characteristic for any latex as it allows coatings manufacturers to inventory fewer raw materials.

This article explores the blends of a VAE latex with various acrylic latexes in a semi-gloss paint formulation. The acrylic latexes chosen for this study have varying particle size, T_g, and wet adhesion monomer content. Influences of these acrylic design parameters as well as blend ratio on the properties of VAE/acrylic blends are discussed. Wet adhesion, block resistance, and scrub durability are the three primary performance properties of interest.

EXPERIMENTAL

VAE and Acrylic Latex Blends

The latexes used in the blending study are presented in *Table* 2. The VAE latex is a commercially available product from The Dow Chemical Company. It has a glass transition temperature of 11 °C and a volume averaged particle size of 0.38 µm. The acrylic latexes included in this study have varying hardness, particle size, and WAM levels. Acrylic A is a commercial product known for its excellent wet adhesion and block resistance. Acrylic B is also a commercial product designed for blending with vinyl acrylics to boost wet adhesion and block resistance. Acrylics C and D have identical monomer compositions while Acrylic E differs only slightly. The measured midpoint T_g of these three polymers is around 0 °C.

The blends were prepared by mixing predetermined amounts of VAE and acrylic latexes. The blend ratios are expressed as weight fractions. For example, the 80/20 blends contain 80 wt% VAE and 20 wt% acrylic latexes.

Paint Formulations

The component VAE and acrylic latexes and their blends were evaluated in a semi-gloss paint formula-

Table 3—Semi-Gloss Formulation

Ingredient	Pounds	Gallons
Grind		
Water	231.1	27.70
CELLOSIZE™ HEC ER 4400	5.0	0.40
Propylene Glycol	10.0	1.20
Colloid 226-35	7.0	0.70
KTPP	1.5	0.10
TRITON™ CF-10 surfactant	2.5	0.30
Rhodaline 643	1.0	0.10
Ammonium hydroxide, 28%	1.0	0.10
TiPure R-706	225.0	6.80
Polygloss 90	25.0	1.20
Letdown		
Acrylic polymer, 50% IS	425.0	48.02
Water	97.0	11.63
RM 2020	10.0	1.14
Rhodoline 643	1.5	0.21
Ammonium hydroxide, 28%	2.0	0.26
Totals	1044.6	99.86
Weight solids, %	45.8	
Volume solids, %	30.3	
PVC, %	26.2	
VOC, g/L	37	

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tion (26% PVC and 30% volume solids). The formulation given in *Table* 3 contained no coalescent solvent and the VOC content was 37 g/L due to the amount of propylene glycol used.

Wet Adhesion

The wet adhesion test measures the adhesion of a coating under wet conditions to an aged alkyd substrate. The gloss alkyd panels were prepared by casting a 7-mil film of Glidden Glid-Guard 4554 gloss alkyd paint onto a Leneta scrub chart and allowing it to cure for three to six weeks at constant temperature and constant humidity (CT/CH: 77°F and 50% relative humidity).

The test and control paints were drawn down in parallel on the same alkyd panel with a 7-mil Dow bar. After the panels were dried for 4 or 24 hr at CT/CH, the films were crosshatched through to the gloss alkyd substrate layer. The test panels were then soaked in water for 30 min. Size and density of blisters were noted. Before scrubbing, 20 mL of 50% Lava soap solution and 5 mL of water were added to the paint panels on the scrub machine. The reported results include the number of cycles at which initial failures were observed and the percent film remaining after 2000 cycles.

Block Resistance

The test paints were prepared on the Leneta 3B opacity charts using a 3-mil bird drawdown bar. The films for room temperature (RT) block were dried in the constant temperature and humidity environmental chamber for one day. Two square strips of 2.54 X 2.54 cm were placed together with paint film against paint film under 454 gram weight with the load transferred to the laminate using a 2.54-cm diameter rubber stopper. After 24 hr, the strips were separated and evaluated according to the ASTM D 4946 ratings. The test was run in triplicate and the average value was reported. For the elevated temperature (ET) block test, the paint strips after one day drying at CT/CH were placed in a 120°F oven under 1000 gram weight for 30 min. The films were allowed to cool for 30 min before the ratings of film separation were given. Room and elevated temperature block were rated on the scale of 0 to 10, 10 being the best.

Scrub Resistance

Relative scrub resistance was evaluated using the Gardner Straight Line Washability and Wear Abrasion Machine. The coatings were applied at a wet film thickness of 7 mils over Leneta black plastic charts and allowed to cure for seven days at 77°F and 50% relative humidity. The nylon bristle brushes were conditioned by running 400 cycles before the test began. A standardized abrasive scrub media (#SC-2 from the Leneta Company) was used. The test included the addition of 7 mL of scrub media and 5 mL of water at the beginning and after every 400 cycles.

The test paints were drawn down and scrubbed side by side with Acrylic E sample as the control. Both the test and control paints were evaluated over a metal shim. The test was conducted in triplicate and the number of cycles to failure was recorded. The results were reported as percentage of scrub cycles of the control paint.

RESULTS AND DISCUSSIONS

Wet Adhesion

The VAE latex contains no wet adhesion monomer. The corresponding paint film developed blisters and eventually lost adhesion to the gloss alkyd substrate during the 30-min soak in water. The test paints based on 100% acrylic latexes included in this study all exhibited excellent wet adhesion. The films dried for 4 hr retained their integrity and adhesion after 2000 cycles. It is worth noting that Acrylic E sample also had 100% film remaining even though it contains significantly less wet adhesion monomer. This result demonstrates that creative polymer design can afford adequate wet adhesion at low cost.

When the VAE latex is modified with 20 wt% of the acrylic polymers, the blend compositions yield differentiated wet adhesion performance. *Figure* 1 presents the 4-hr wet adhesion results of the 80/20 blends in the test paints. Acrylic A imparts reasonably good wet adhesion to the VAE blend, showing 88% paint film remained after 2000 cycles. Acrylics B and C, having smaller particle size, both pass the test without adhesion failures. Acrylic D has the same monomer compo-

Figure 1—Four-hour wet adhesion of 80/20 blends.

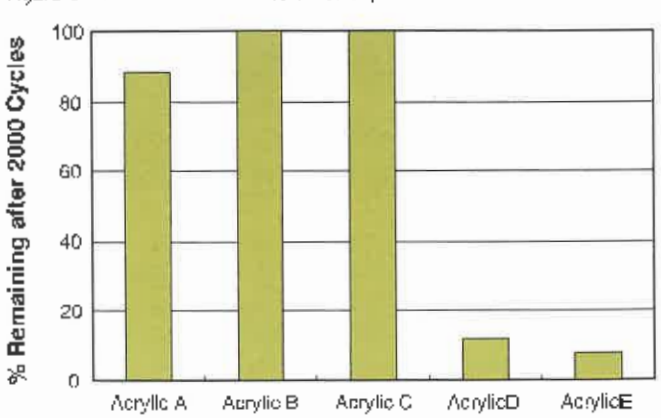
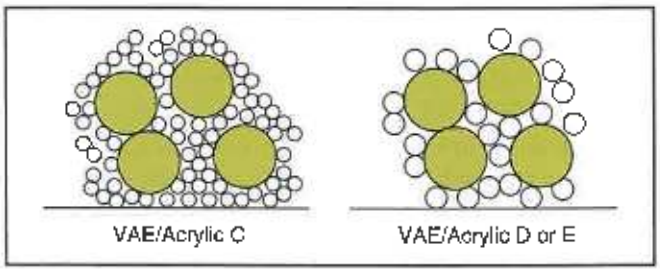


Figure 2—Schematic illustration of particle numbers in 80/20 blends.



sition (i.e., T_g and WAM concentration) as Acrylic C—the only difference being particle size. A large portion of the VAE/Acrylic D film did not survive the test. This particle size effect confirms the important influence of size ratio on film morphology and adhesion of bimodal latex blends.[10,16,17]

The driving force for film formation is inversely proportional to particle size.[18] The films formed from small particles have lower void fraction because of higher packing efficiency. Since Acrylics C and D have identical monomer compositions, it is reasonable to assume that the two polymers have the same density. For any given weight fraction, there are approximately three times more particle C in the blend (*Figure* 2). The smaller the particle size the larger the surface area, therefore, resulting in an increased interaction with their surroundings. When the wet adhesion functionalities are distributed over a large surface area, their efficiency is also enhanced. As illustrated in *Figure* 2, when the particle size of the modifier latex decreases, it becomes easier to fill the void space created by the larger latex particles. A greater proportion of the acrylic modifier is in contact with the substrate, leading to increased wet adhesion efficiency.

Compared to Acrylic D, sample E provides even less enhancement of wet adhesion. Besides the particle size effect, there are 2.5 times less WAM in Acrylic E and the 80/20 blend. The inferior wet adhesion results of Acrylics D and E suggest that particle size and concentration of wet adhesion monomer are the two determining factors. The glass transition temperature of the acrylic modifier is less important to wet adhesion performance of the blends.

The paint films may not have developed full strength in four hours. The 24-hr wet adhesion test is therefore more commonly accepted by the coatings industry. Based on this standard, all the 80/20 blends after drying for 24 hr demonstrate adequate wet adhesion property (100% film remaining). Longer drying time reduces the void content in the film to improve overall film integrity and strength. It also promotes uniform distribution of wet adhesion promoters in the film and film-substrate interface by allowing polymer chains to rearrange and to diffuse across the inter particle boundaries. Therefore, 20% acrylic in the VAE/acrylic blends is sufficient to impart satisfactory wet adhesion.

The effect of acrylic concentration is studied with VAE/Acrylic E combinations since Acrylic E provides the weakest wet adhesion efficiency. The blends with higher acrylic content (50% and 75%) show no failures in the more stringent 4-hr wet adhesion test. As acrylic weight fraction increases, fewer VAE particles are dispersed in the blend system to disrupt the interaction of acrylic polymer with the alkyd substrate. The concentration of adhesion-promoting groups per unit area increases. This study illustrates that wet adhesion can be improved by increasing the WAM concentration in the acrylic latex and/or the amount of acrylic component in the blend.

Block Resistance

The minimum film formation temperatures (MFFT) of the pure VAE and acrylic latexes are listed in *Table* 4. The glass transition temperature determines the MFFT and the physical characteristics of the film formed by the polymer. The MFFT is usually lower than T_g and the differential is dependent on the degree of polymer plasticization by water. The gap between T_g and MFFT is the greatest for the VAE latex presumably due to a high percentage of hydrophilic vinyl acetate monomer present. The coatings based on the two high T_g acrylic latexes, A and B, display visible cracks at ambient application temperature. The VAE and the other three acrylic latexes form coherent films in the coalescent-free paint formulation, consistent with their low MFFT values.

Table 4 also includes the one-day room temperature (RT) and elevated temperature (ET) block ratings of corresponding paints. Acrylic A and B paints receive the highest ratings for block resistance, confirming the contribution of bulk property as dictated by polymer T_g. Increasing the binder T_g results in improved hardness

Table 4—MFFT of Pure VAE and Acrylic Latexes and Coatings Block Resistance

	Latex		26 PVC Paints	
Polymer	T_g (°C)	MFFT (°C)	1 day RT Block	1 day ET Block
VAE	11	3.7	4	0
Acrylic A	20	19	9	9
Acrylic B	39	36	10	9
Acrylic C	0	<0	8	3
Acrylic D	0	<0	6	0
Acrylic E	0	<0	8	6

Rating of 0 is complete fusing; rating of 10 is non-blocking.

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