

## Innovative Water-based UV Resins for Exterior Applications

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### Introduction

Waterborne (WB) UV chemistry has shown significant growth in interior industrial wood markets because the technology provides excellent performance, low solvent emissions and increased production efficiency. These same advantages can be beneficial for factory applied exterior applications including window and door frames, siding and other millwork. These market segments conventionally utilize acrylic emulsions and polyurethane dispersions because they have excellent gloss and color retention and demonstrate superior durability. In this study, polyurethane-acrylic resins with UV functionality have been evaluated according to industry specifications.

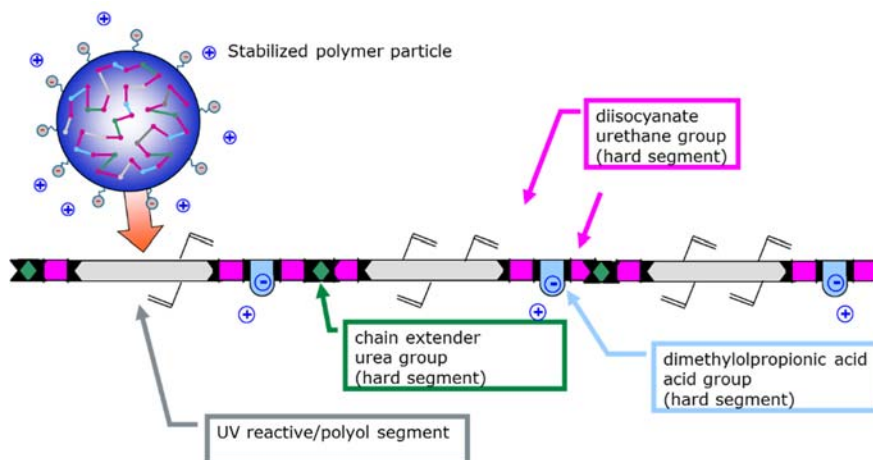
### Benefits of UV Coatings

UV coatings systems offer the end user the benefits of outstanding chemical and scratch resistance, excellent block resistance, very low VOCs and a small equipment footprint with less storage space required. These systems have properties that compare favorably with two component urethane systems without the complications of hazardous cross-linkers and pot life concerns. The overall system is cost effective because of increased production speeds and lower energy costs.<sup>1</sup>

### Benefits of WB UV Polyurethane Dispersions (PUDs)

WB UV coatings have many inherent advantages. While 100% solid UV oligomers are typically high in viscosity and must be diluted with reactive diluents, WB UV PUDs are low in viscosity and the viscosity can be adjusted with traditional WB rheology modifiers. WB UV PUDs have an initially high molecular weight and do not build molecular weight as they cure as dramatically as 100% solid UV coatings. Because they have little or no shrinkage as they cure, WB UV PUDs have excellent adhesion to many substrates. The gloss of these coatings is easily controlled with traditional matting agents. These polymers can be very hard but also extremely flexible making them ideal candidates for exterior wood coatings.

### Chemistry of WB UV PUDs



WB UV PUDs are made by incorporating UV functionality into the backbone of a PUD. A pre-polymer is

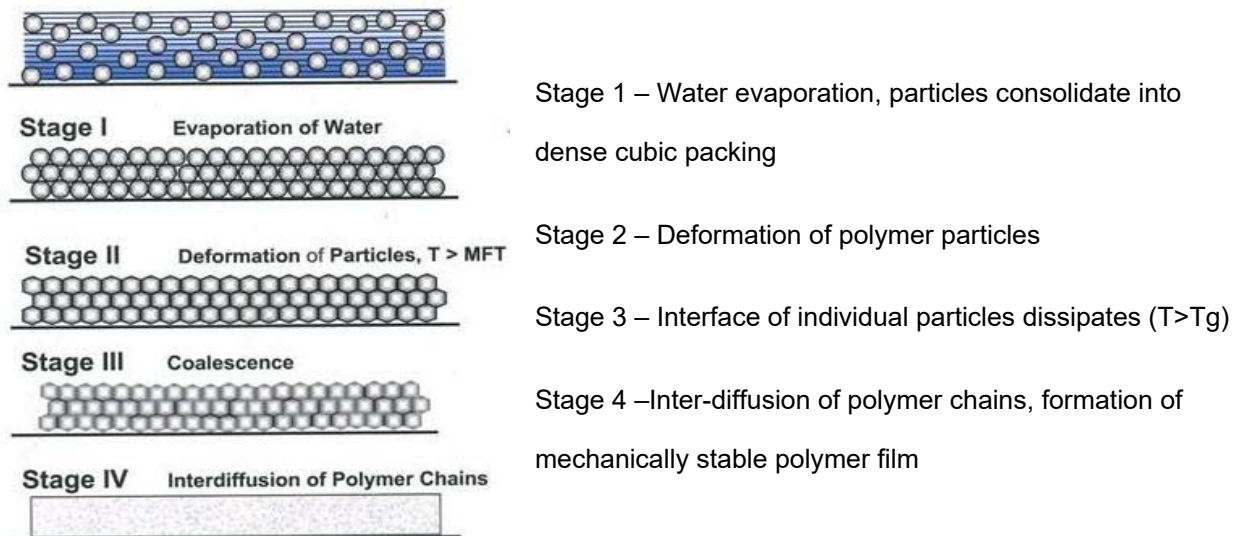
produced by reacting a polyol and a UV acrylate with a stoichiometric excess of an aliphatic isocyanate. Dimethylolpropionic acid, an anionic stabilizing agent, is used to build functionality into the polymer chain. An amine is used for neutralization. Then the pre-polymer is dispersed in water and chain extension is carried out building molecular weight. These UV PUDs can be either polyether, polyester and/or polycarbonate based. There is a large selection of UV acrylates available with varying backbones and functionalities. The choice and amount of the UV functional material used impacts the final crosslink density of the coating. There are also multiple processing options that effect the final polymer performance.

### Hybrid UV PUDs

Modifications to WB UV PUDs are made for various reasons. Acrylic dispersions can be added to improve exterior durability and lower costs. Surfactants can be added to improve shelf stability. Emulsified UV acrylates can be added to adjust drying properties. Because different types of WB UV resins can provide different performance parameters, technologies can be combined to optimize the properties needed.

### Film Formation

Unlike 100% solid UV coatings, WB UV coatings are stable dispersions of colloidal particles that must coalesce to form a continuous film before UV cure can take place. This process of film formation takes place in several stages beginning with water evaporation. The schematic below provides further details of this process:



### Traditional Exterior Wood Coatings

Environmentally friendly exterior wood coatings are traditionally made from waterborne acrylic dispersions and polyurethane dispersions. Both one component (1K) and two component (2K) coatings are used with the 2K coatings providing the best performance properties. WB acrylic dispersions have excellent UV stability and the weathering resistance is very good. These dispersions can have the disadvantage of poor flexibility.<sup>2</sup> Flexibility is necessary for an exterior wood coating because wood is a dimensionally unstable substrate. Flexibility can be improved by lowering the glass transition temperature of the acrylic



	H	I	J	K	L	M	N
HALS	0.84	0.84	0.84	0.84	0.84	0.84	0.84
PI - Alpha hydroxy ketone	1	1	1	1	1	1	1
PI - Acyl phosphine oxide	1	0	1	0	1	0	1
water	17	21.2	21.2	33.39	33.39	0.21	0.21

In Phase 1 all coatings were cured at 800 mJ/cm<sup>2</sup>. The coatings with only alpha hydroxy ketone photoinitiator were cured using a mercury lamp. Coatings with both alpha hydroxy ketone and acyl phosphine oxide photoinitiator were cured using both a mercury lamp and a gallium lamp.

### Test Methods

#### Hardness development –

Make a 150 micron draw down on a glass panel. Air dry for 10 minutes then force dry for 10 minutes at 50C. Measure Koenig hardness before cure. Measure Koenig hardness 1 hour and 3 days after cure.

#### Block Resistance –

Make a drawdown on a 3B-H Leneta chart using a 3 mil bird bar. Air dry for 10 minutes then force dry for 10 minutes at 50C. Cure. Cut off a 1" X 8.5" strip from the card perpendicular to the draw down direction. Cut this strip in half to give two 1"x 4.25" strips. Put the two pieces together with each coated surface touching (face to face). Make a duplicate. Place the samples on a glass plate and put a 1000 gram weight on top of the samples. Place in a 50C oven for one hour. Remove from the oven and rate the block resistance.

10	Pieces fall apart with little or no effort upon shaking
9	Trace Tack
8	Pieces easily pulled apart but with very slight tack
7	Very slight to slight tack
6	Pieces are harder to pull apart but no sign of seal; slight tack
5	Moderate tack
4	Very tacky but no seal
3	5- 25% seal
2	Pieces are sealed 25-50%
1	50 to 75% seal
0	Pieces are 100% completely sealed

#### Water Resistance –

Make a draw down on a 3B-H Leneta Chart using a 3 mil bird bar. Air dry for 10 minutes then force dry for 10 minutes at 50C. Cure. Wait 24 hours. Place a small glass vial of water inverted on the surface of the coating over the black section of the Leneta card. Wait 24 hours. Remove the water and wipe the surface dry. Check for blushing and blistering. Rate the coating performance on a scale of 0 to 5 with 5 being no effect and 0 being complete destruction of the film.

### Cure Response –

The cure response is measured by comparing the FTIR absorbance peaks of the C=C bond (810 cm<sup>-1</sup>) and C=O bond (1730 cm<sup>-1</sup>) before and after cure. The C=C bond reacts during UV exposure; the C=O bond does not react.<sup>3</sup> Make a 3 mil drawdown on a 3B-H Leneta chart. Air dry for 10 minutes then force dry for 10 minutes at 50C. Using FTIR measure and record the IR absorbance at 810 cm<sup>-1</sup> and 1730 cm<sup>-1</sup>. Cure the charts and then re-measure and record the IR absorbance at 810 cm<sup>-1</sup> and 1730 cm<sup>-1</sup>. Calculate the percent cure:

Relative concentration of UV cured group (%) =

$$\frac{[A]_{810}^{UV} / [A]_{1730}^{UV}}{[A]_{810}^{\circ} / [A]_{1730}^{\circ}} \times 100$$

where [A]<sub>810</sub><sup>°</sup> is the IR absorbance at 810 cm<sup>-1</sup> before UV irradiation,

[A]<sub>1730</sub><sup>°</sup> the IR absorbance at 1730 cm<sup>-1</sup> before UV irradiation,

[A]<sub>810</sub><sup>UV</sup> the IR absorbance at 810 cm<sup>-1</sup> after UV irradiation,

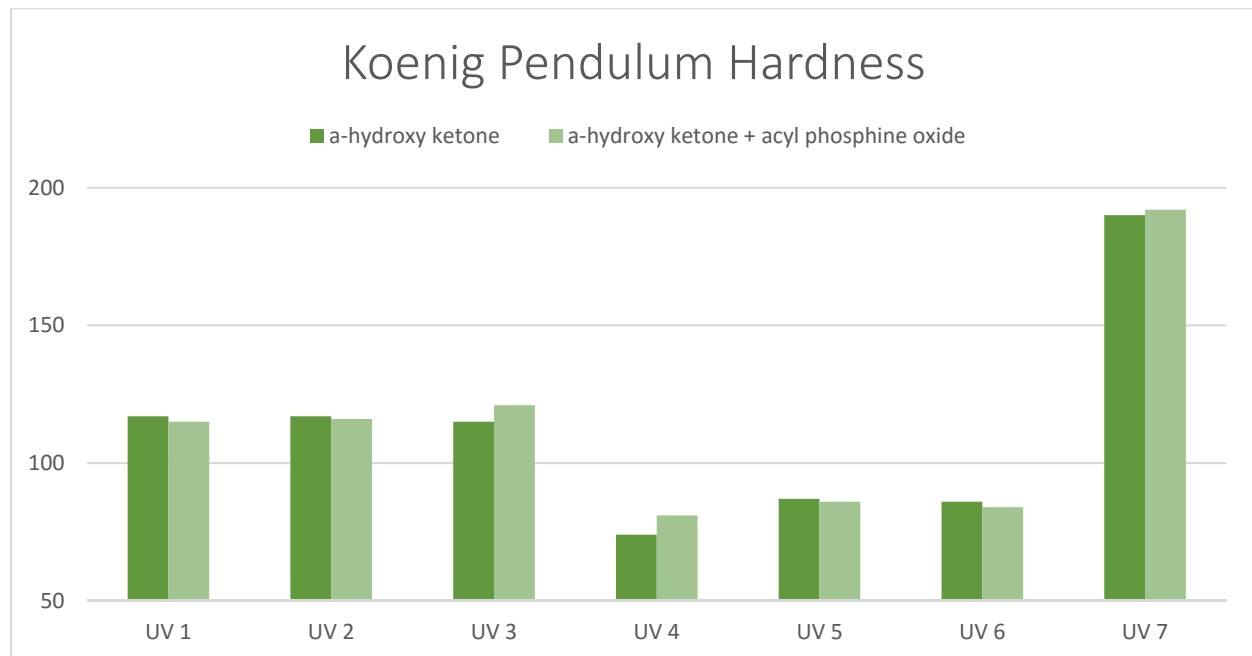
and [A]<sub>1730</sub><sup>UV</sup> the IR absorbance at 1730 cm<sup>-1</sup> after irradiation.<sup>3</sup>

### QUV Resistance –

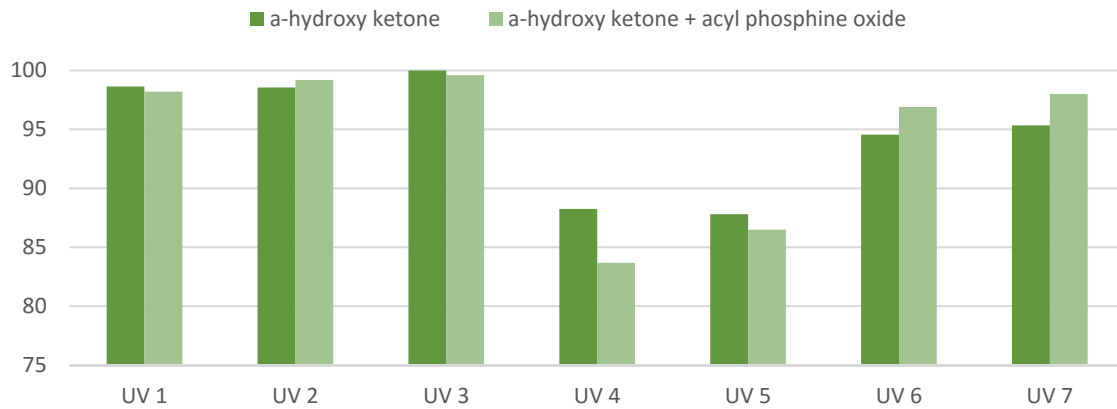
Make a 4 mil drawdown on a white ceramic tile. Air dry for 10 minutes then force dry for 10 minutes at 50C. Cure. Wait seven days before testing. Record the CIELab color data for each tile using a BYK Gardener color-guide sphere. Record the 60° gloss for each tile using a BYK Gardener micro-TRI-gloss meter. Place the tiles in the QUV cabinet with 340 UVA bulbs. Set the cabinet for 4 hours of UV light followed by 4 hours of condensation. Run these cycles for 4000 hours. Report color change (delta E) and gloss loss.

### Data

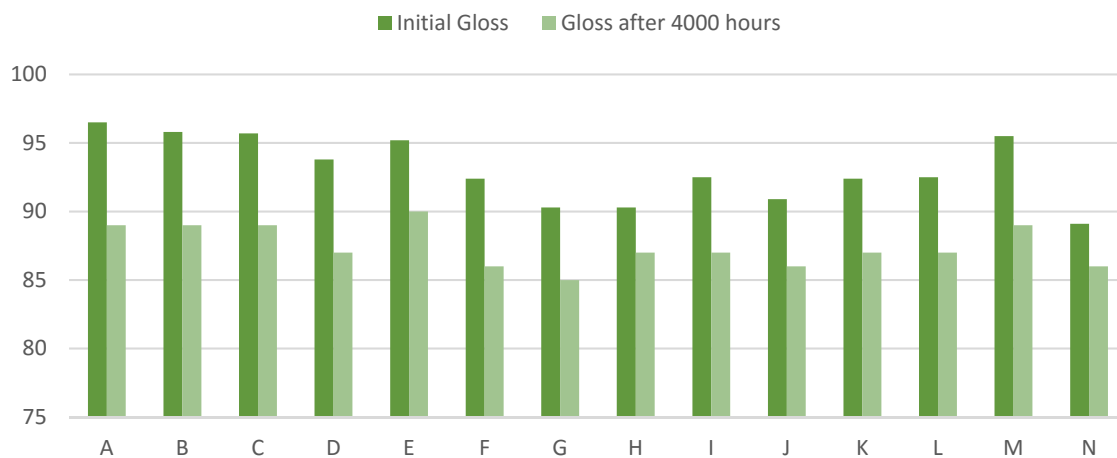
Block resistance and water resistance were excellent on all samples. The tests that showed differentiation were:



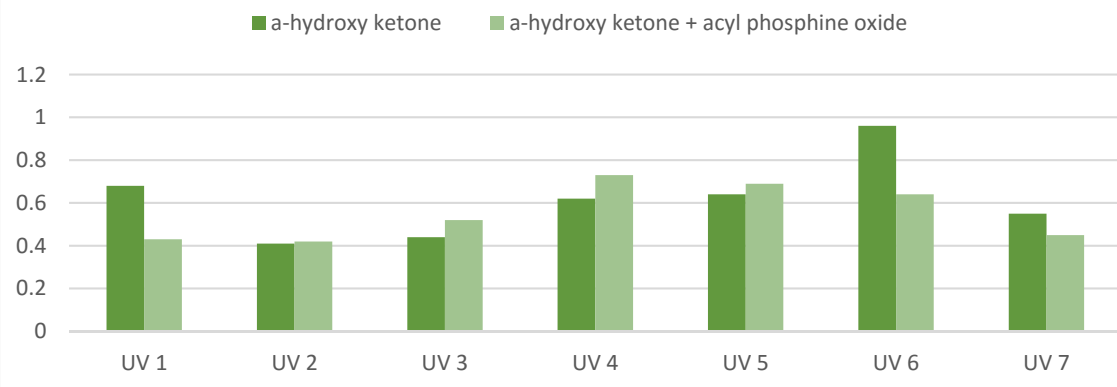
## Cure Response - % cure



## QUV - Gloss Retention



## QUV - Color Retention Delta E after 4000 hours



## Conclusions from Phase 1 Testing

- All samples showed excellent QUV results with minimal gloss and color changes after 4000 hours of exposure.
- The addition of acyl phosphine oxide photoinitiator did not impact the properties of the coatings. In Phase 2 testing, only alpha hydroxy ketone photoinitiator will be used.
- UV 3 was eliminated from the study due to production difficulty.
- UV 4, UV 5 and UV 6 was eliminated from the study due to low cure response and hardness.
- UV 1, UV 2 and UV 7 was included in Phase 2 testing.

## Project Plan – Phase 2

In Phase 2 coatings were evaluated according to the specifications outlined in the American Architectural Manufacturers Association AAMA 653-14 Voluntary Performance Requirements and Test Procedures for Organic Coatings on Wood and Cellulose Composite Substrates. This specification covers factory applied coatings intended for service in exterior environments.<sup>4</sup> QUV resistance was repeated on poplar substrate. Coatings were formulated using traditional defoamers, surface tension modifiers, wax emulsion and rheology modifiers. The weight solids of the coatings was controlled with water.

## Formulations

	O	P	Q
UV 1	312.5	0	0
UV 2	0	302.7	0
UV 7	0	0	392.5
UV Absorber	2	2	2
HALS	2	2	2
Surfactant	1.4	1.4	1.4
Wax	12.1	12.1	12.1
Defoamer	1.4	1.4	1.4
Photoinitiator	2.3	2.3	2.3
water	80.7	68.7	0.5
Rheology modifier	0.8	0.7	1

## Panel Preparation

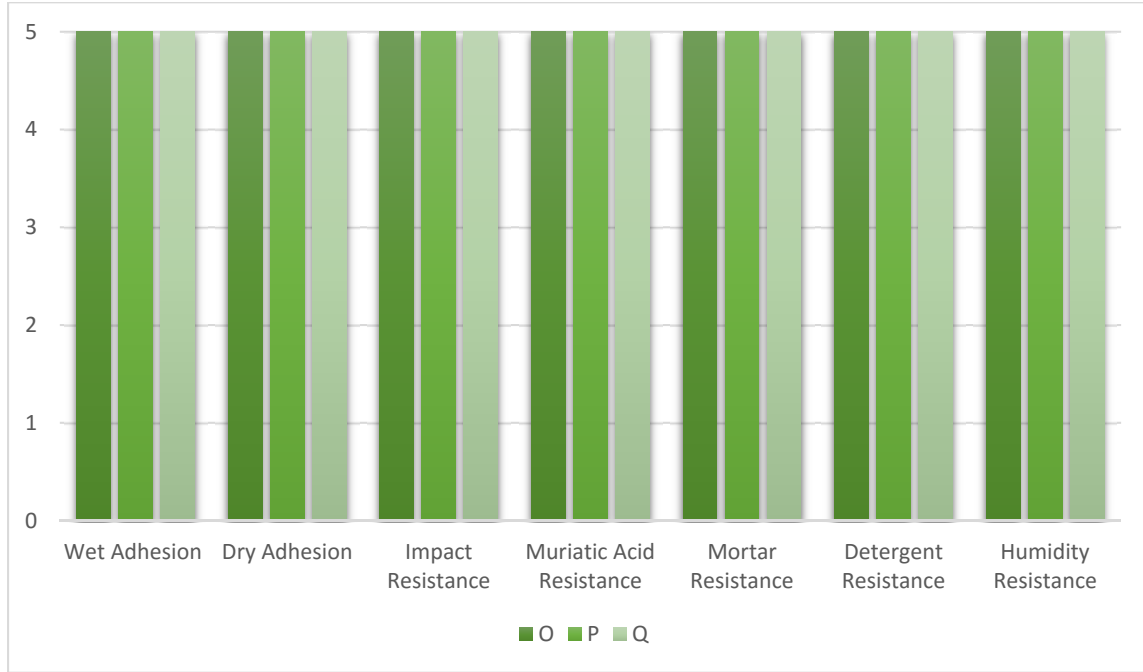
For AAMA testing:

Unless otherwise stated in the AAMA 653-14 specification, all panels were prepared by:

1. Spray approximately 4 wet mils of coating over a 4 X 6 inch unstained southern yellow pine panel.
2. Air dry for 10 minutes.
3. Force dry for 10 minutes at 50C.
4. Cure with a mercury lamp at 800 mJ/cm<sup>2</sup>.
5. Sand with a 3M Superfine Sanding Sponge.
6. Repeat steps 1 – 4.

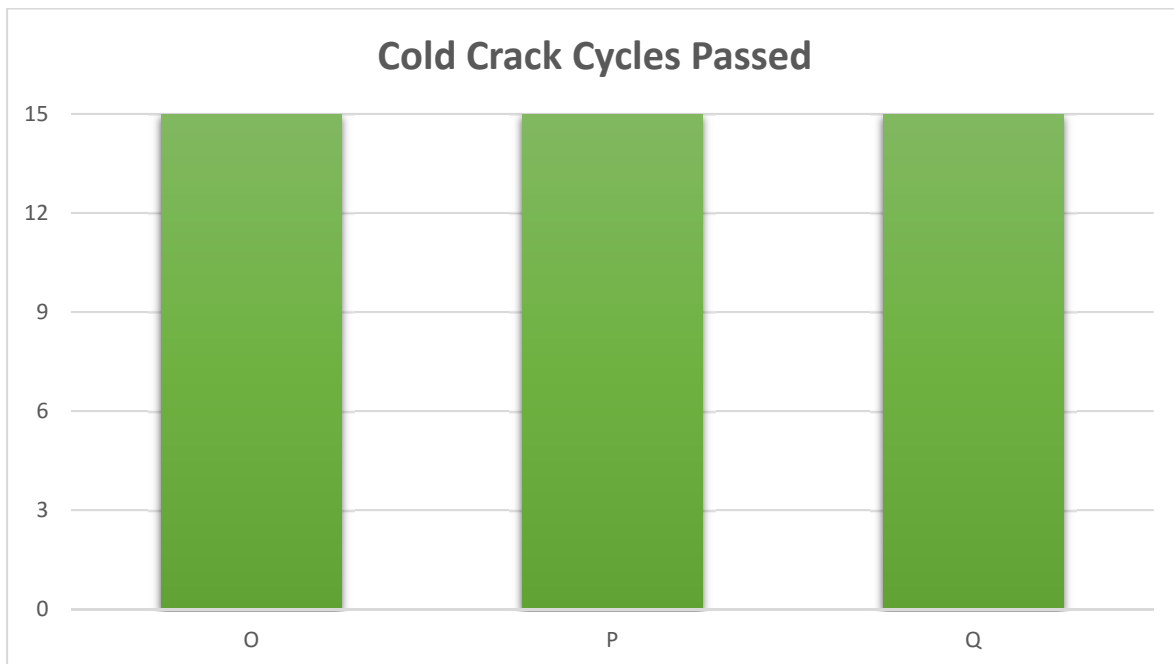
Unless otherwise stated in the AAMA 653-14 specification, all panels had the cut edges sealed with a 2K 100% solid urethane sealer. All sides of the panels were coated. All panels were aged for 7 days before testing was performed.

**Data**



All properties were rated on a scale of 0 – 5 with 0 being complete film destruction and 5 being no effect on the film.

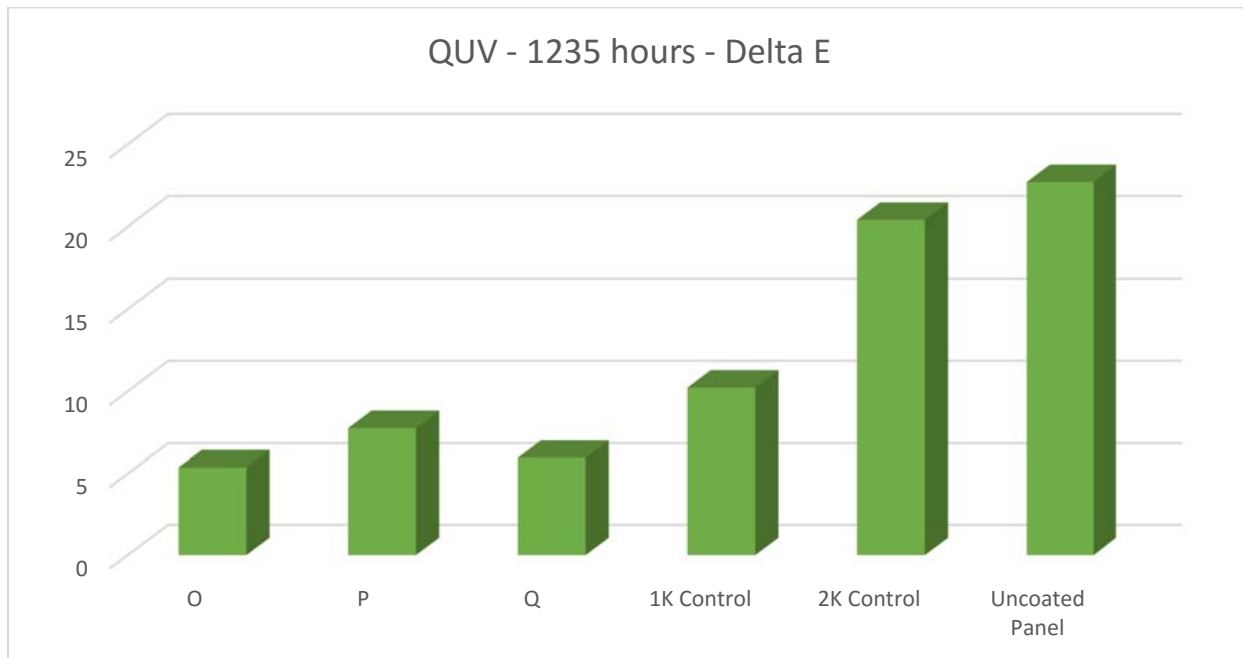
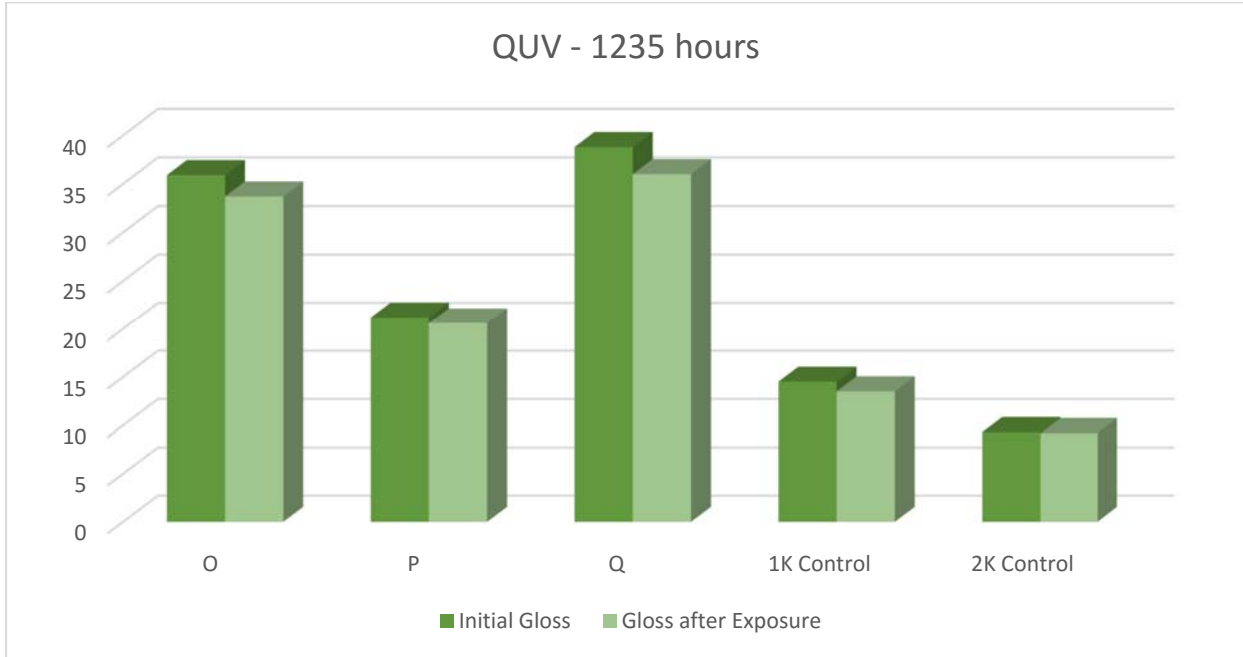
Fifteen cycles of a cyclic humidity chamber/freezer test was performed.





For QUV testing:

Panels for the QUV testing were prepared in the same way as the AAMA panels except the substrate was 2 X 4 inch poplar panels. QUV cycles were performed as in Phase 1. A commercially available 1K and 2K control and an uncoated panel were included for reference.



## Discussion

The three experimental samples passed the testing as outlined by AAMA 653-14. This is a good indication that these coatings will perform well in an exterior environment. The cold crack cycle test and the humidity test are extreme environments for wood and wood coatings. Wood swells during periods of high humidity and it shrinks during periods of low humidity. This instability puts extreme stress on the coating. Coatings that do not have the flexibility needed to move with the substrate can show whitening or cracking when exposed to this punishing environment.

QUV testing is on-going. The Phase 1 testing over white ceramic substrate was completed to determine the yellowing properties and gloss retention of the coatings. The Phase 2 QUV testing will determine the ability of the coatings to protect against the degradation of the wood substrate. The commercial controls show substantial discoloration after only 209 hours of UV exposure. This indicates that these coatings are intended to be applied over a pigmented basecoat that will protect the wood from UV degradation. The use of clear UV curable coatings can be applied directly to a wood substrate without a basecoat present.

## Conclusions

Water-based UV coatings have become the industry standard for interior industrial wood applications. The excellent hardness, flexibility and chemical resistance of these coatings make them good candidates for exterior industrial wood applications. The coatings show excellent humidity and cold crack resistance. They have very good gloss retention and are non-yellowing when exposed to UVA radiation. This technology can help to increase productivity and comply with VOC restrictions. Future work will focus on exterior exposures in south Florida, Arizona and North Carolina according to AAMA 653-14 specifications.

## References

- 1) Laurie, M., Katie Gaynor, "Performance Capability of Waterborne UV Curable Emulsions for Wood Substrates", *Coatings Tech*, September 2007.
- 2) Juren Lippemeier, Stefan Sommer, Arno Nennemann, "Water-borne UV Coatings for Exterior Wood Application", RadTech Europe Conference Proceedings 2009.
- 3) Y.-J. Park et al. / *Journal of Adhesion Science and Technology* 22 (2008) 1401–1423
- 4) [www.aamanet.org](http://www.aamanet.org)