ALBERDINGK BOLEY

Waterborne UV Curable Resins for Industrial Wood Applications

Coatings Trends and Technologies

Rosemont, IL

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Outline

Interior Industrial Wood Coatings

Types of Solvent-based (SB) Coatings used in Interior Industrial Wood Applications

Advantages/Disadvantages of SB Coatings

Water-based (WB) Coatings used in Interior Industrial Wood Applications

Experimental – WB UV for Interior Wood

Conclusions

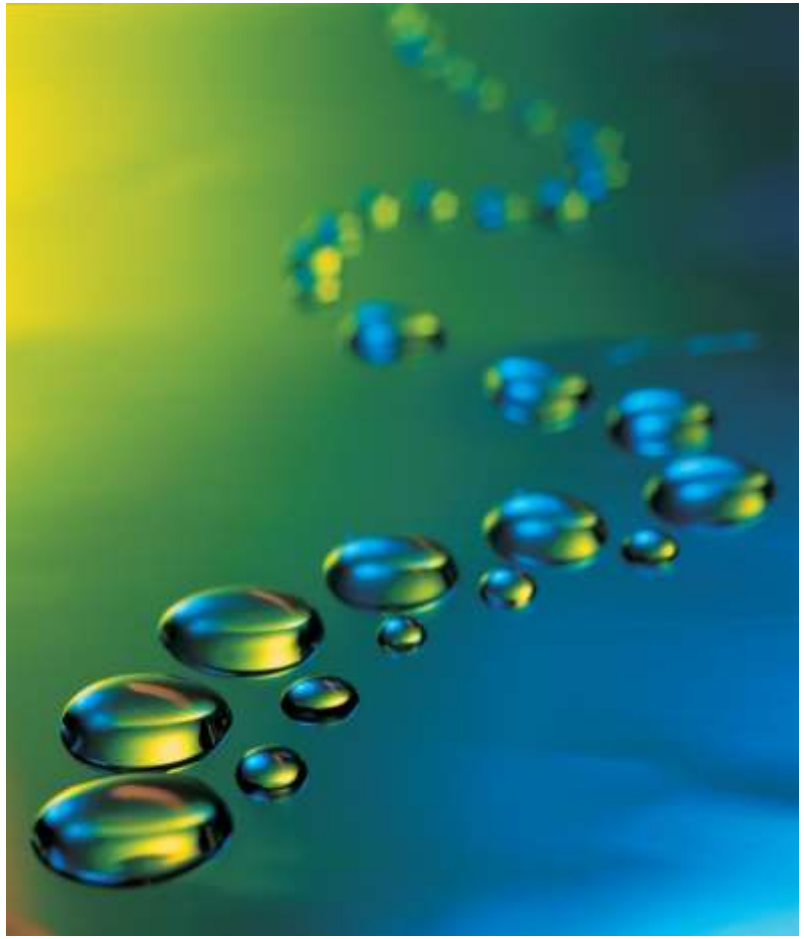
Exterior Industrial Wood Coatings

Traditional Exterior Wood Coatings

Experimental – WB UV for Exterior Wood Phase 1

Experimental – WB UV for Exterior Wood Phase 2

Conclusions



Types of Solvent-based Coatings Used in Industrial Wood Applications

Lacquer –
Nitrocellulose, oil base alkyd or vegetable oils
Applications: Residential furniture

Pre-catalyzed lacquer –
Nitrocellulose, oils or oil-based alkyd, plasticizer, and urea-formaldehyde
Uses weak acid catalyst – butyl acid phosphate
4 month pot life
Applications: Office, institutional and residential furniture

Conversion Varnish –
Oil-based alkyd, urea-formaldehyde, and melamine
Uses strong acid catalyst, PTSA
24 – 48 hour pot life
Highest performance
Applications: KCMA, office and institutional furniture

Solvent-based Coatings for Industrial Wood Applications

Advantages

- Fast drying
- Good wood warmth
- Cost effective
- Easily repaired
- Tolerate climate differences well
- Good chemical resistance
- Good wear resistance

Disadvantages

- High volatile organic compounds (VOC)
- Extreme flammability
- Poor indoor air quality due to odor and formaldehyde emissions
- Pot life (conversion varnish)

Water-based (WB) Alternatives to SB Coatings

WB Acrylics

Self-crosslinking, multiphase, 1K or 2K

Applications: Residential and Institutional Furniture, KCMA

WB Polyurethane Dispersions

Polyester or Polycarbonate, 1K or 2K

Applications: Office furniture

WB Acrylic/Polyurethane Blends

Copolymers or Cold Blends, 1K or 2K

Applications: Residential, Institutional or Office furniture, KCMA

WB UV Curable Dispersions

UV PUDs and Acrylic Hybrids

Applications: Office Furniture, KCMA

Kitchen Cabinet Manufacturers Association (KCMA)

Purpose:

To establish a nationally recognized performance standard for kitchen and vanity cabinets.

Finish requirements:

- Shrinkage and Heat Resistance
- Hot And Cold Check Resistance
- Chemical Resistance
- Detergent and Water Resistance

Architectural Woodwork Standards

Purpose:

To provide design professionals with logical and simple means to comprehensively specify elements of architectural woodwork.

Finish requirements:

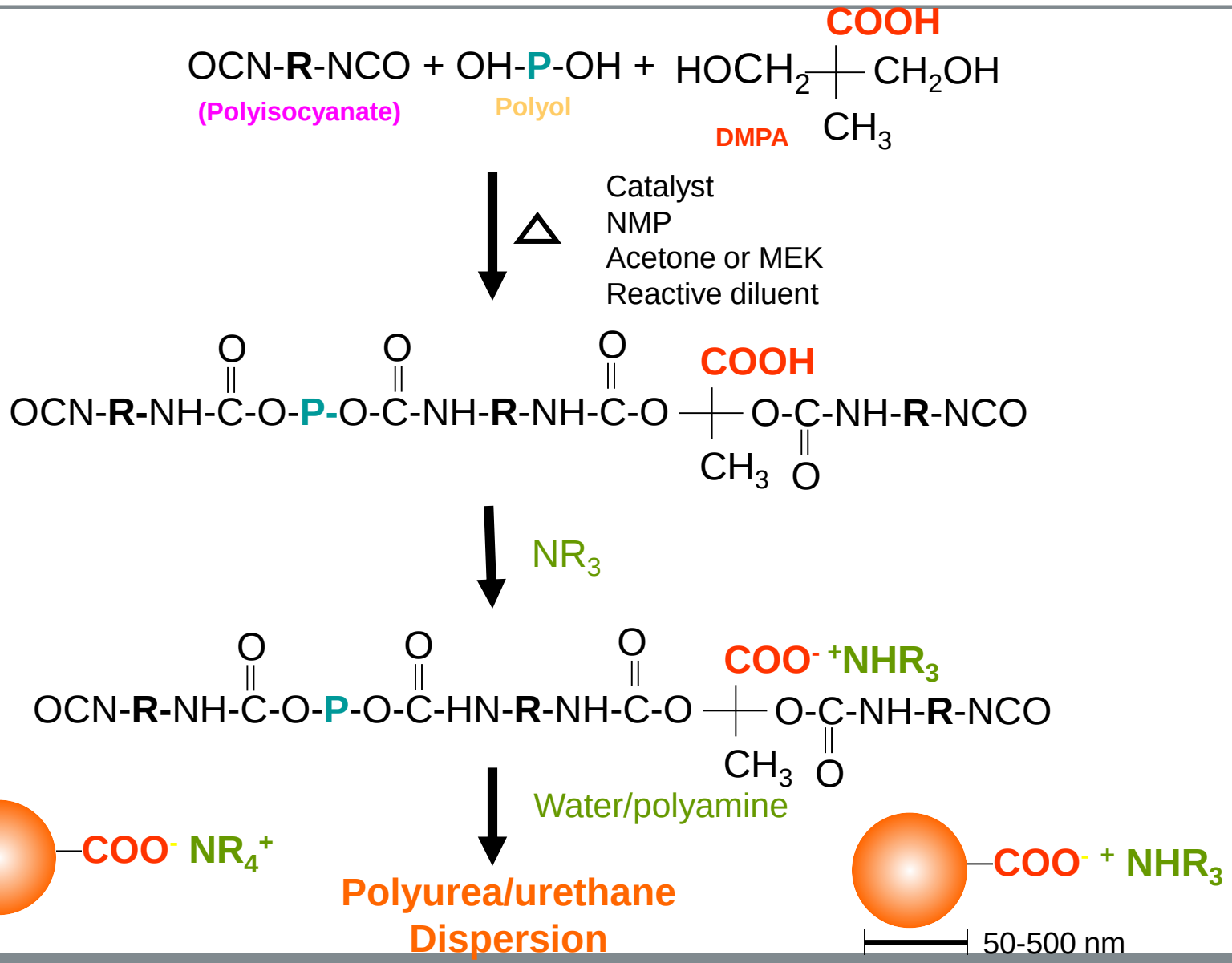
- Chemical Resistance
- Wear Index
- Cold Check
- Adhesion

Industrial Wood Specifications

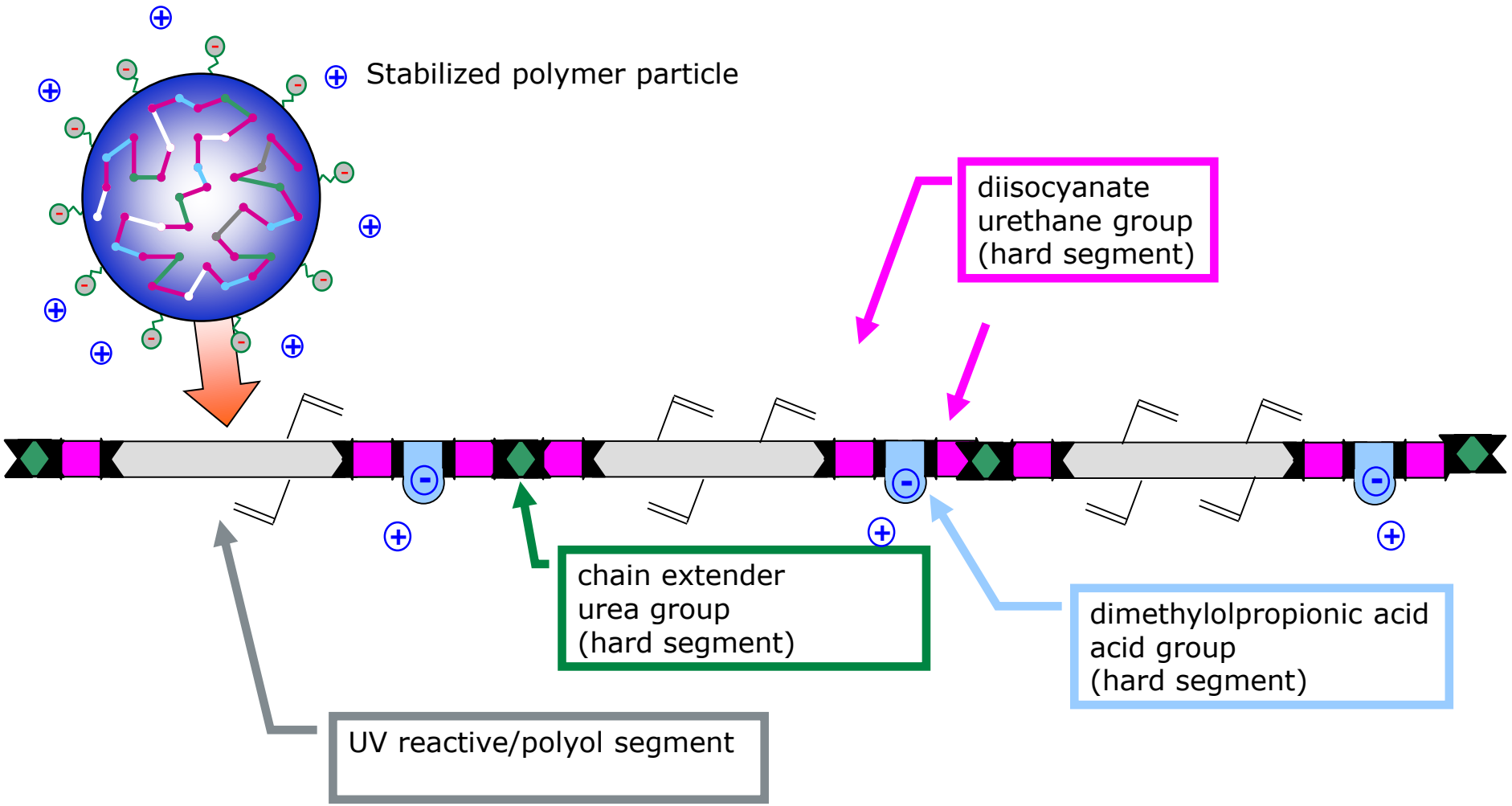
Individual Office Furniture Manufacturer's Specifications

- Chemical/Stain Resistance
- Green Print Resistance
- Toughness/Adhesion
- Plasticizer Resistance
- Hot print Resistance
- Hot/Cold Check Resistance
- Ballpoint Pen Indentation
- Resistance to Discoloration from Office Equipment "Feet"
- Boiling Water Resistance
- Steam Resistance
- Impact Resistance
- Resistance to fading or chalking
- Resistance to yellowing

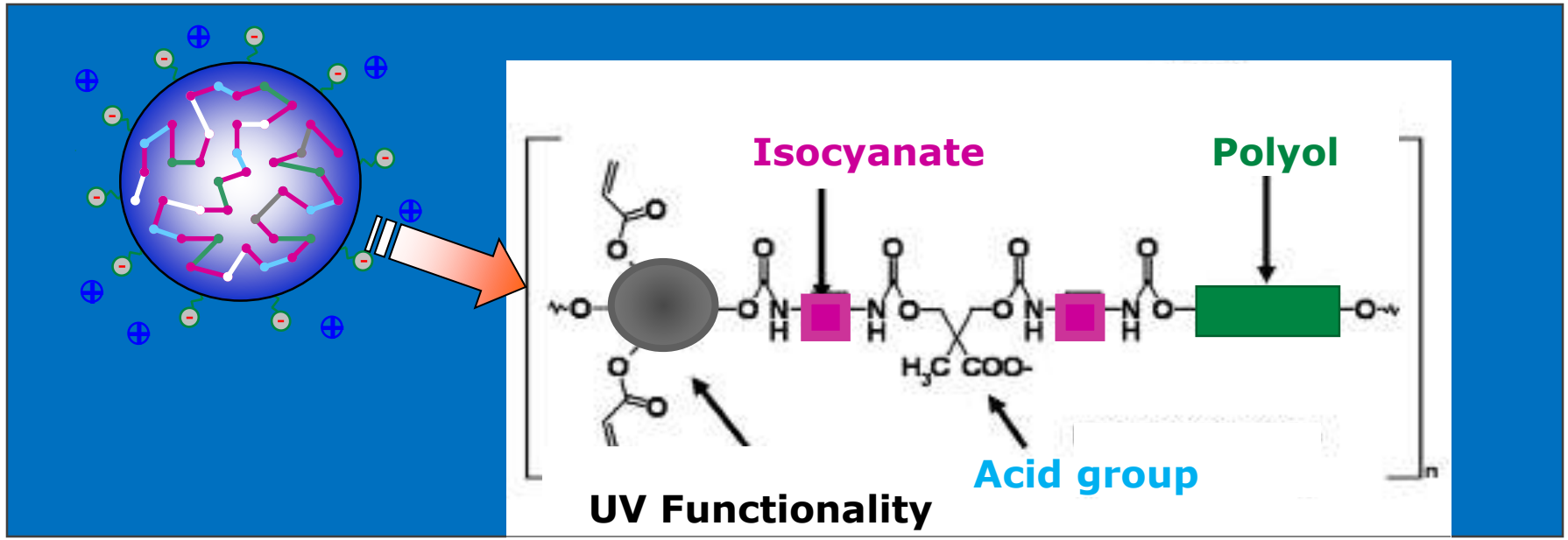
PUD Chemistry



UV curing polyurethane dispersions: polymer structure



WB UV PUDs

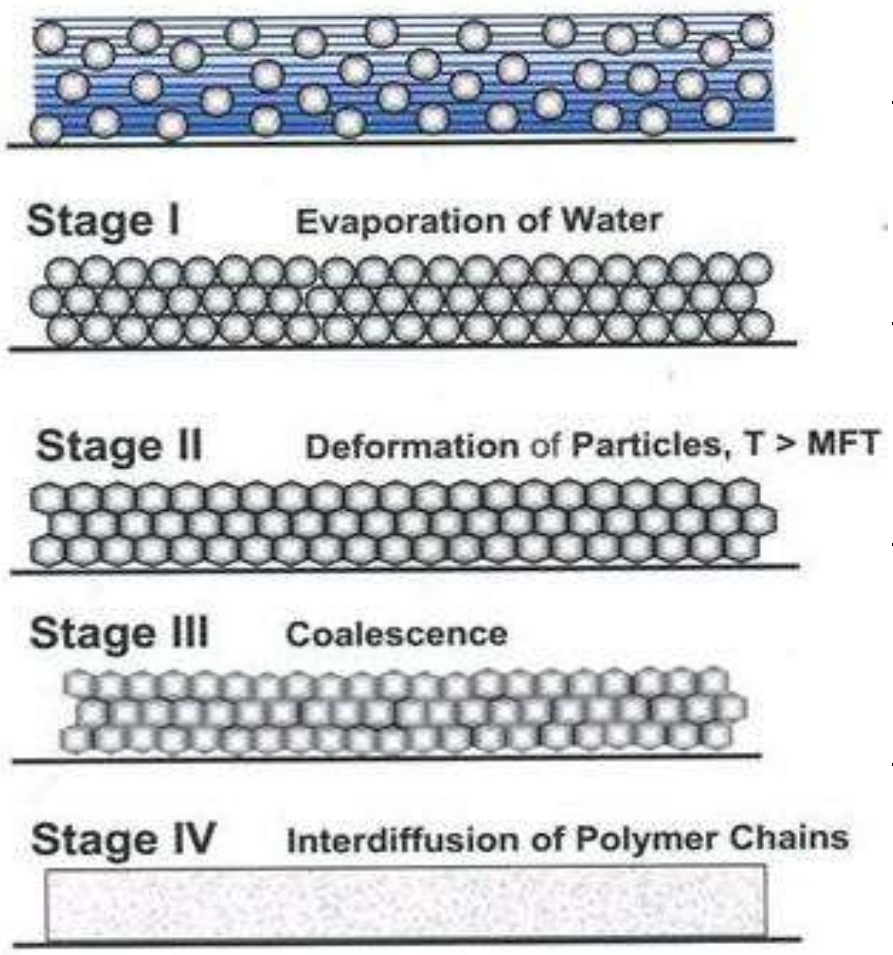


- High molecular weight dispersions
- - Low shrinkage
- - Adhesion to multiple substrates
- Excellent chemical resistance
- Excellent mechanical properties
- Multiple polymer design options
- Low MFFT --- Solvent free formulations; no reactive diluent
- Dual cure options

Coalescence

Radical polymerization

Coalescence



Stage 1 – Water evaporation, particles arrange, dense cubic packing

Stage 2 – Deformation of polymer particles

Stage 3 – Interface of individual particles dissipates

Stage 4 –Interdiffusion of polymer chains, formation of mechanically stable polymer film

Polymerization Reaction

Photo-initiation	PI initiator	$\xrightarrow{\textit{UV Light}}$	R* radicals
Start	R* + M radical resin	$\longrightarrow$	R-M* intermediate
Growth	R-M* + M	$\longrightarrow$	R-M-M*
Termination	R-M* + *M-R	$\longrightarrow$	R-M-M-R

Waterborne UV

Benefits

Excellent appearance
Provides excellent wood protection
Very low VOC
Eco-friendly
Water clean up
High hardness & flexibility
Excellent adhesion
Resoluble / reclaim
Immediate property development

Challenges

Some grain raising
Drying ovens required
Humidity dependence
Finish defects (incomplete dry)

Experimental – WB UV

A study has been conducted to compare the properties of three WB UV coatings with commercially available solvent-based conversion varnish, water-based conversion varnish and water-based pre-catalyzed lacquer. The project plan was to develop high performance WB UV resins and investigate their performance for industrial wood applications.

Commercial Controls

Solvent based Conversion Varnish

Chemistry: Oil based alkyd/melamine/PTSA catalyst

Weight Solids: 50%

Volume Solids: 41%

VOC: <500 g/l

10 parts Conversion Varnish + 1 part catalyst + 3 parts Reducer

Pot Life = 12 hours

Water based Conversion Varnish

Chemistry: Urethane/Acrylic blend/WB Isocyanate

Weight Solids: 28%

VOC <200 g/l

10 parts Urethane/Acrylic blend + 1 part WB Isocyanate

Pot Life = 6 – 8 hours

Water based Precatalyzed Lacquer

Chemistry: Self-crosslinking Acrylic

Weight Solids: 25%

VOC <185 g/l

Water-based UV Products Evaluated

WB UV 1
Chemistry: UV PUD (polyester)/Acrylic Hybrid
Weight Solids: 48%
VOC: <15 g/l
MFFT: 0°C

WB UV 2
Chemistry: UV PUD (polyester)
Weight Solids: 40%
VOC: <40 g/l
MFFT: 0°C

WB UV 3
Chemistry: UV PUD (polyester)/Acrylic Hybrid
Weight Solids: 42%
VOC: <25 g/l
MFFT: 0°C

WB UV Formulations

	A	B	C
WB UV 1	73.12	0	0
WB UV 2	0	83.9	0
WB UV 3	0	0	79.27
Surfactant	0.5	0.57	0.57
Defoamer	0.5	0.57	0.57
Water	23.42	13.26	17.91
Photoinitiator	0.82	0.94	0.94
Rheology Modifier 1	0.66	0.75	0.75
Rheology Modifier 2	0.98	0	0
% Solids by weight	36.62	35.31	35.03
% Solids by Volume	32	32	32
VOC (g/l)	<10	<50	<25

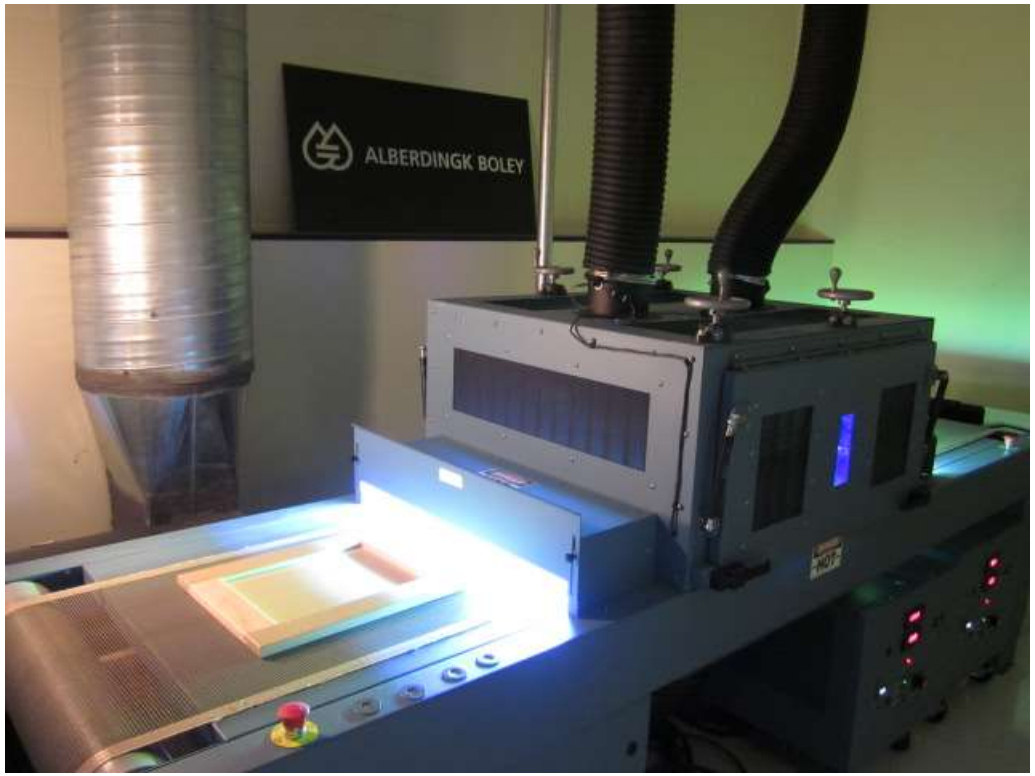
Evaluations on Wood Panels

Application: Spray approximately 3 wet mils of coatings over 18X18 inch stained birch plywood panel. Air dry for 10 minutes. Force dry for 10 minutes at 50C. Cure with mercury bulb at 500 mJ/cm^2. Sand with 3M Superfine Sanding Sponge. Apply a second coat and repeat dry time and curing. Wait 7 days before testing unless otherwise indicated in the test method.

For Door Edge Soak – same as above except use a 4X4 inch oak panel and coat all sides.

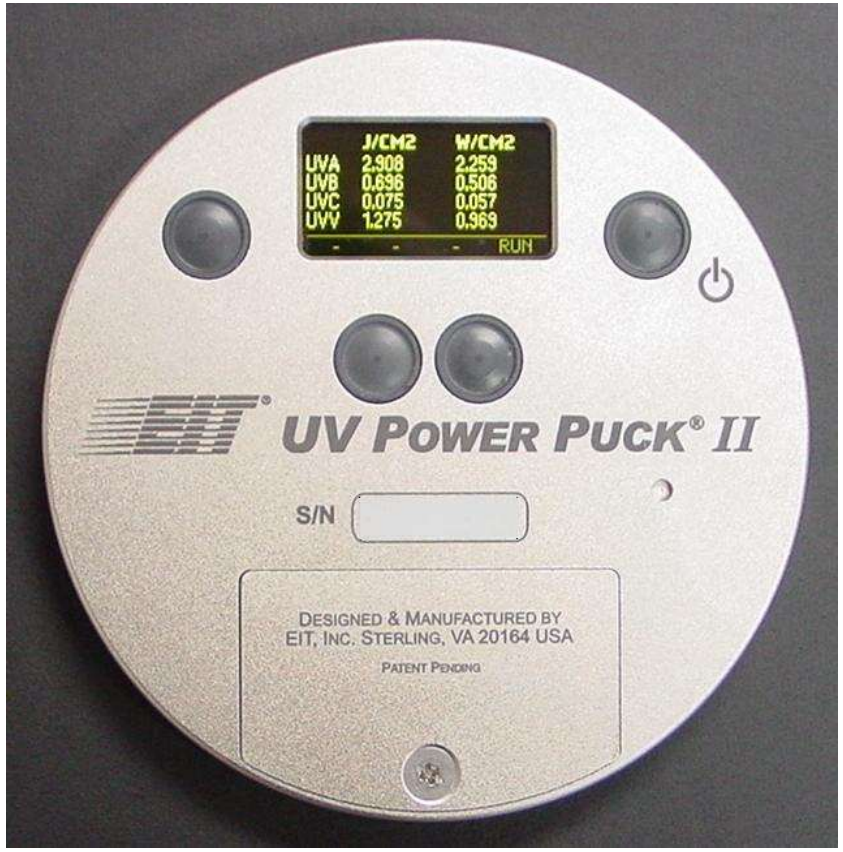
Test for:

Chemical resistance
Plasticizer resistance
Print resistance
Boiling water resistance
Scrape adhesion
Ball Point Pen Indentation
Door Edge Soak
Hot and Cold Check



Measure machine power output

Power Puck



Chemical/Stain Resistance

Test method:

Apply enough chemical/stain to create a ¼ - ½ inch diameter spot on the test panel.

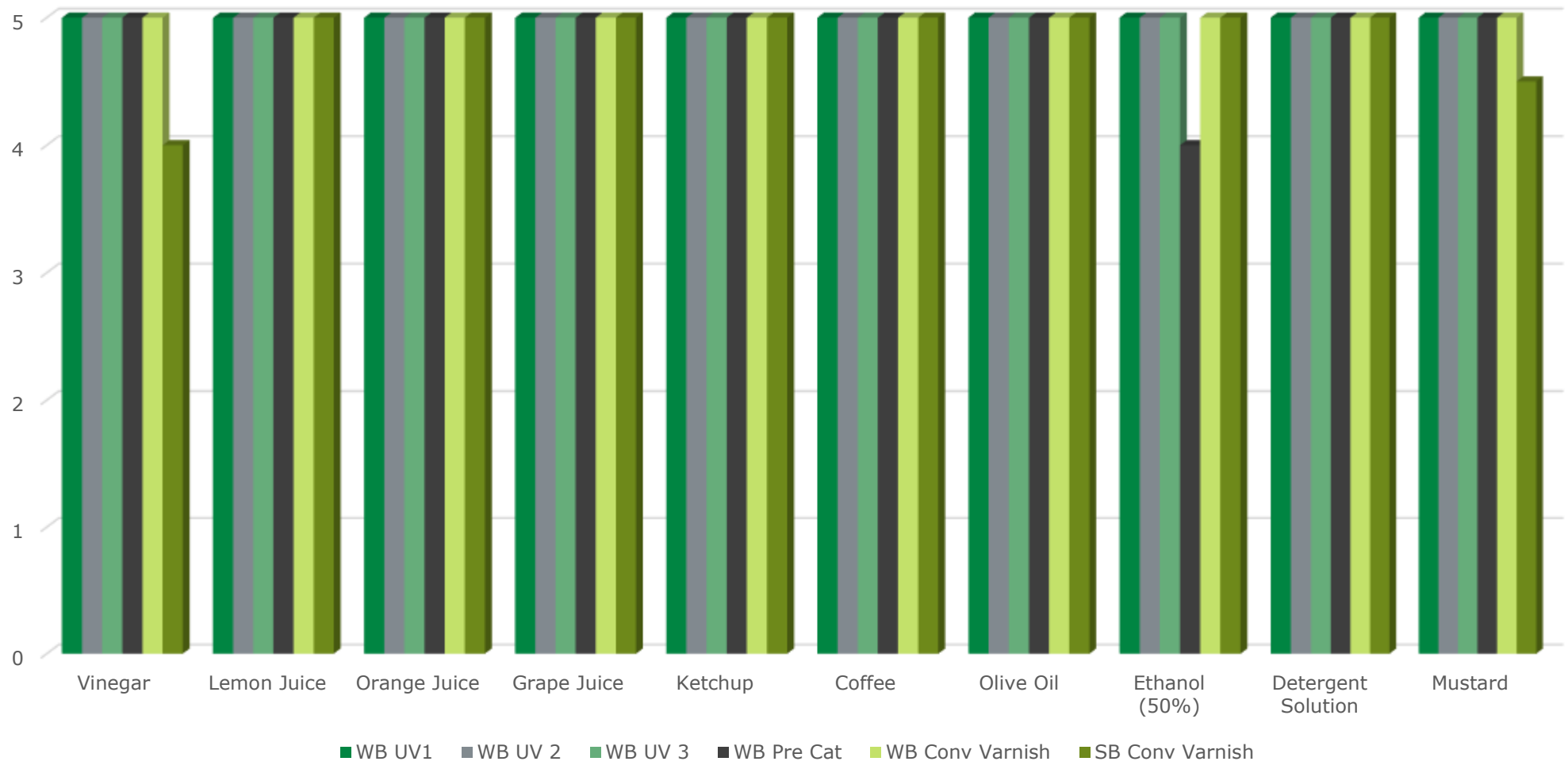
Cover with a watch glass.

Allow chemical/stain to dwell according to specification.

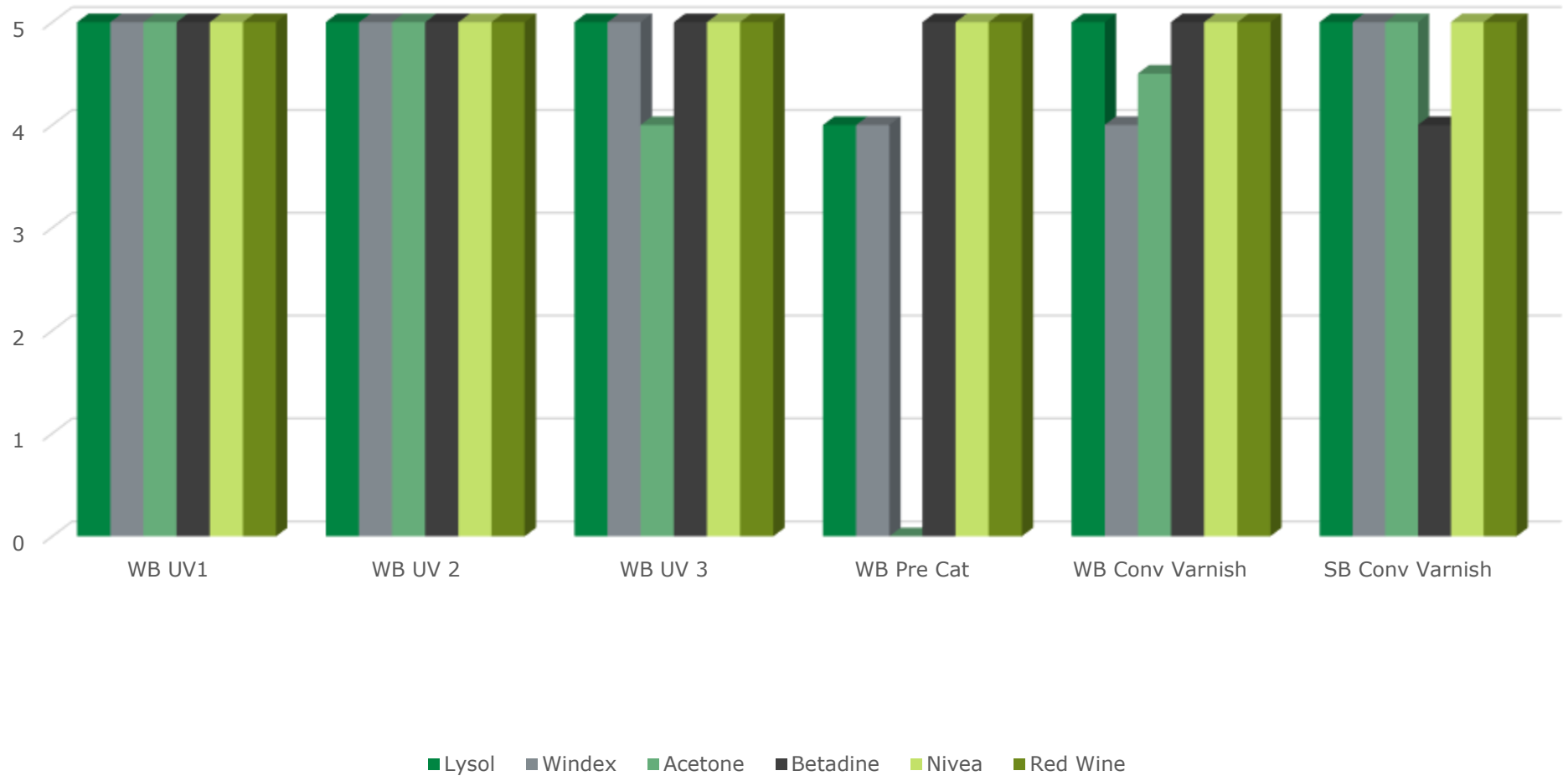
Remove chemical/stain and wash the surface of the panel with water.

Rate each chemical/stain on a scale of 0 to 5 with 0 being complete destruction of the film and 5 being no effect on the film.

Chemical Resistance – KCMA – 24 hour dwell (except mustard 1 hour dwell)

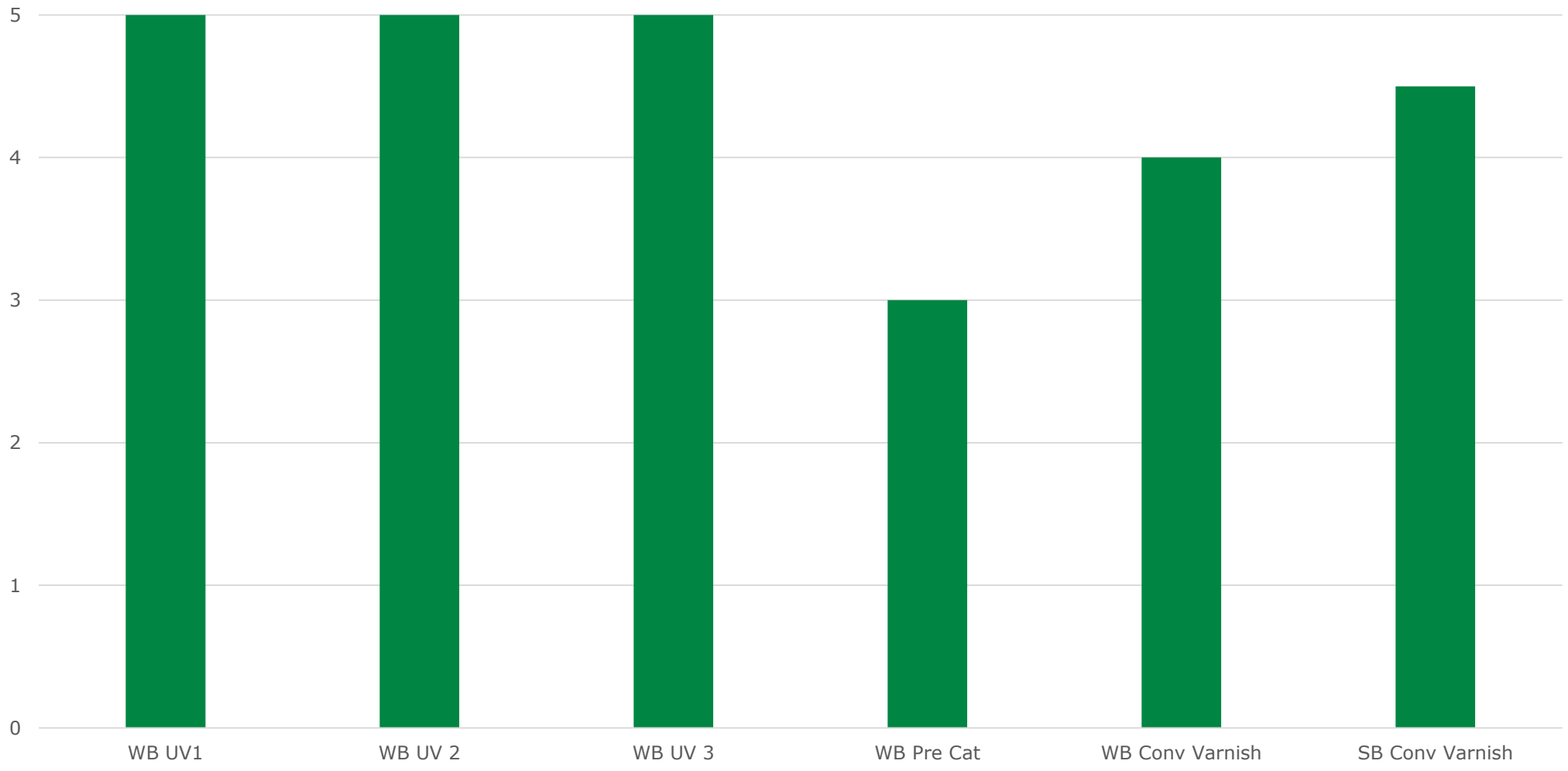


Chemical Resistance – Furniture Specifications – 16 hour dwell

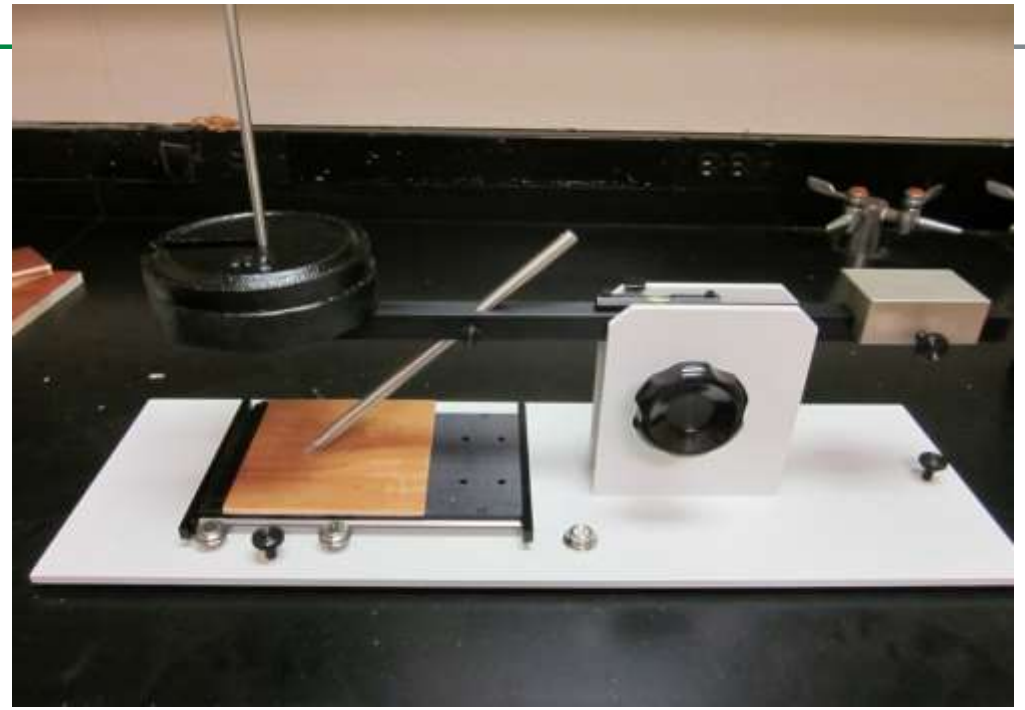


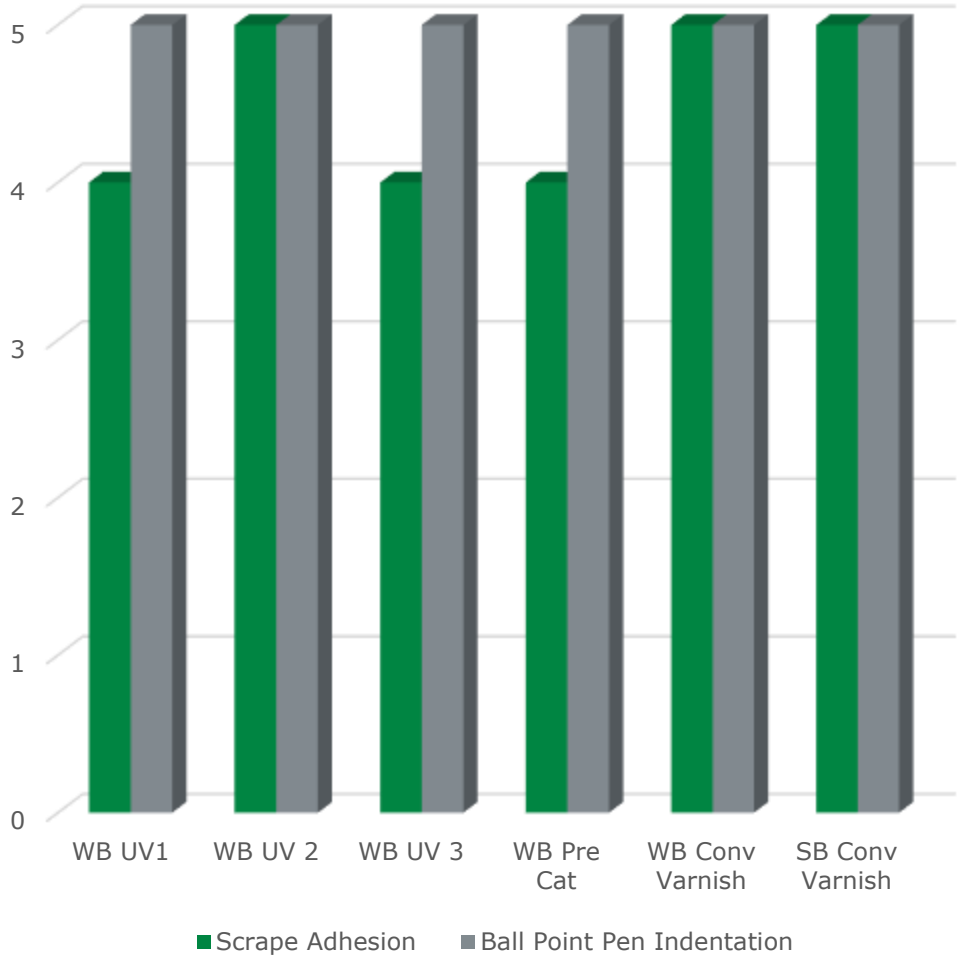
Boiling Water Resistance:

Apply 10 ml boiling water to the test panel. Place a ceramic cup full of boiling water on top of the 10 ml of water. Wait 1 hour. Remove the cup and wipe with a paper towel. Wait 24 hours. Evaluate for whitening.



BYK Balanced Beam Scrape Adhesion and Mar Tester





Scrape Adhesion – Cut a 4X7 inch piece from each test panel. Test adhesion with 5000 grams of weight using the loop stylus. Rate on a scale of 0 to 5.

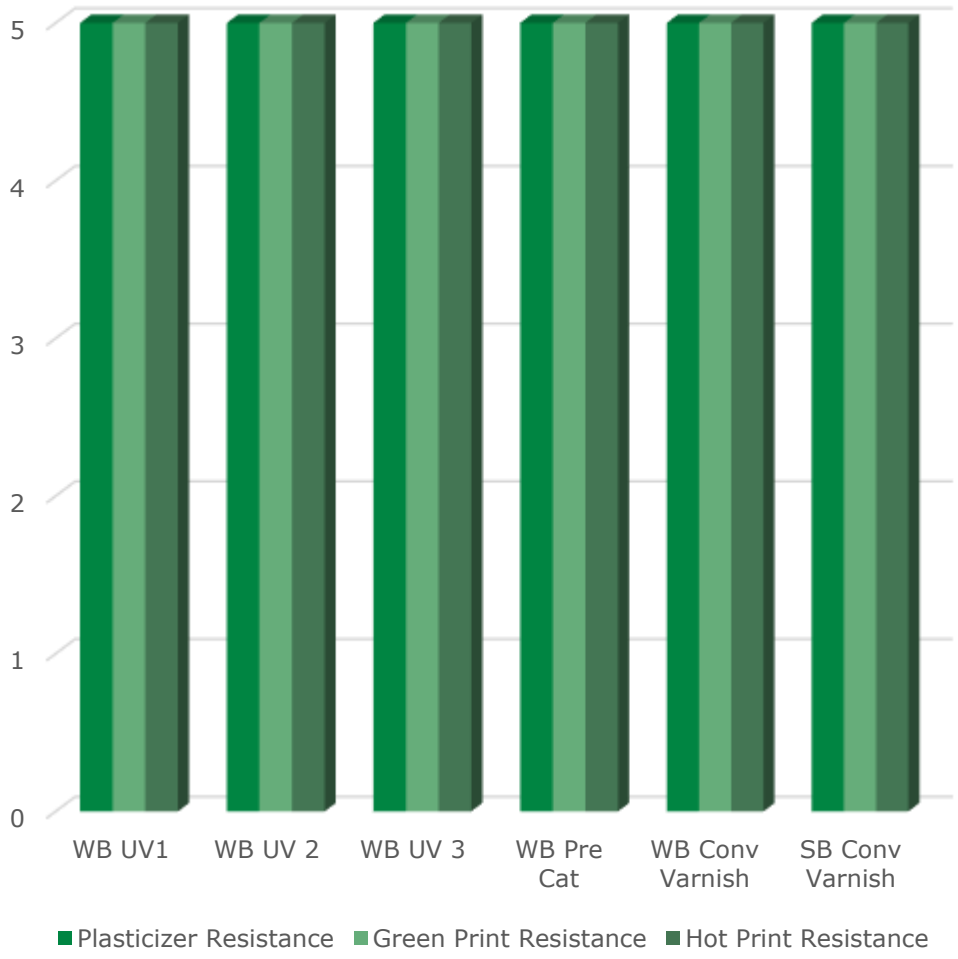
Ball Point Pen Indentation – Cut a 4X7 inch piece from each test panel. Test with the small pen attachment (#5785) and 300 grams of weight. Rate on a scale of 0 to 5.

Print and Plasticizer Resistance

Green Print Resistance - After curing test panel wait 1 hour the apply a 2 inch square piece of #10 cotton duck cloth to the finish. Apply a force of 2 lb/square inch directly to the duck cloth. Wait 24 hours then remove the cotton duck cloth. Evaluate for printing.

Hot Print Resistance - After curing the panel wait 14 days then apply a 2 inch square piece of cotton duck cloth to the finish. Apply a force of 1 lb/square inch directly to the duck cloth. Place the specimen in the oven at 60C for 24 hours. Allow the specimen to cool to room temperature and then remove he duck cloth. Evaluate for printing.

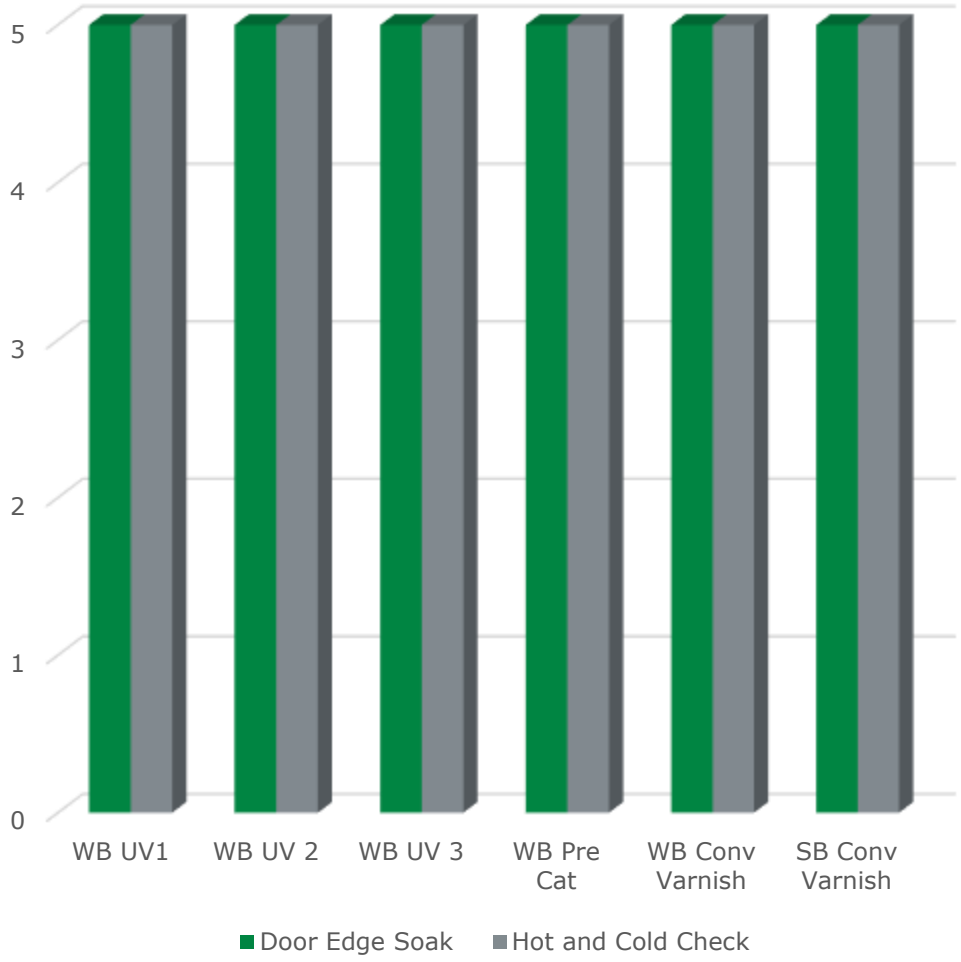
Plasticizer Resistance - Apply a 2 inch square piece of red vinyl to the test panel. Apply a force of ½ lb/square inch. Place the specimen in the oven at 50C for 72 hours. After cooling at room temperature for 1 hour, remove the vinyl square. Evaluate for softening and blistering.



Other KCMA requirements

Edge Soak: Place a cellulose sponge in a plastic container. Level container and fill with detergent solution (1% Dawn® dish soap by weight in water) to one half inch below top level of sponge. Place panel on sponge, cut side down. Permit to stand for 24 hours.

Hot and Cold Check Resistance: Cut a 4”X4” piece from each panel. Cycle as follows: Place panel in humidity cabinet at 50C and 70% humidity for one hour. Remove for 30 minutes and allow to reach original room temperature and humidity. Place in freezer at -10C for one hour. Remove and allow to reach original room temperature and humidity. Repeat for five cycles.



Conclusions

All the WB UV coatings have excellent chemical resistance. WB conversion varnish and SB conversion varnish have very good chemical resistance. WB Pre-Cat Lacquer has adequate chemical resistance for KCMA coatings.

WB UV 2, WB conversion varnish and SB conversion varnish have the best scrape adhesion.

All the coatings have excellent ball point pen indentation, plasticizer resistance, hot print and green print resistance, hot and cold check resistance and edge soak.

All the WB UV coatings have superior boiling water resistance.

WB UV coatings have excellent properties for interior industrial wood applications.

Exterior Wood Coatings

Environmentally friendly exterior wood coatings are traditionally made from WB acrylic dispersions and PUDs.

Both 1K and 2K coatings are used.

WB acrylics provide excellent UV stability.

PUDs provide excellent flexibility, a necessity because wood is dimensionally unstable.

Blends of acrylic dispersions and PUDs are typically used for optimal performance.

Project Plan – Phase 1

Identify the best combination of UV resin and exterior grade acrylic modifying resin.

Evaluate hardness development, block resistance, water resistance, cure response and QUV resistance.

Evaluate each coating with 2 different photoinitiator packages to determine optimal cost performance package.

Experimental Developments

	UV Type	Modification Type
UV 1	UV PUD Hybrid 1	Self X-linking acrylic resin 1
UV 2	UV PUD Hybrid 2	Self X-linking acrylic resin 1
UV 3	Emulsified UV Acrylate	Self X-linking acrylic resin 1
UV 4	UV PUD Hybrid 1	Self X-linking acrylic resin 2
UV 5	UV PUD Hybrid 2	Self X-linking acrylic resin 2
UV 6	Emulsified UV Acrylate	Self X-linking acrylic resin 2
UV 7	UV PUD	No modification

Formulations – Phase 1

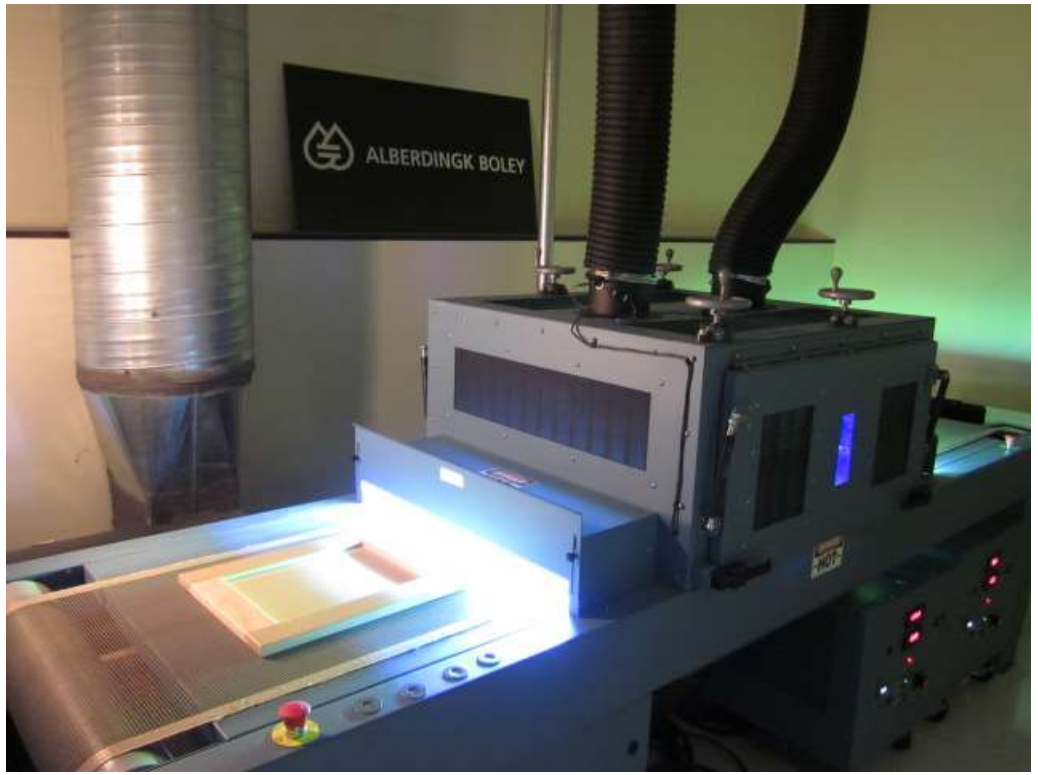
	A	B	C	D	E	F	G
UV 1	133.57	133.57	0	0	0	0	0
UV 2	0	0	129.37	129.37	0	0	0
UV 3	0	0	0	0	117.18	117.18	0
UV 4	0	0	0	0	0	0	151.07
UV absorber	0.84	0.84	0.84	0.84	0.84	0.84	0.84
HALS	0.84	0.84	0.84	0.84	0.84	0.84	0.84
PI - Alpha hydroxy ketone	1	1	1	1	1	1	1
PI - Acyl phosphine oxide	0	1	0	1	0	1	0
water	34.5	34.5	38.4	38.4	55.89	50.89	17
	H	I	J	K	L	M	N
UV 4	151.07	0	0	0	0	0	0
UV 5	0	146.87	146.87	0	0	0	0
UV 6	0	0	0	134.68	134.68	0	0
UV 7	0	0	0	0	0	167.86	167.86
UV absorber	0.84	0.84	0.84	0.84	0.84	0.84	0.84
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

Curing Parameters

In Phase 1 all coatings were cured at 800 mJ/cm^2.

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.



Measure % Cure by IR

Equation

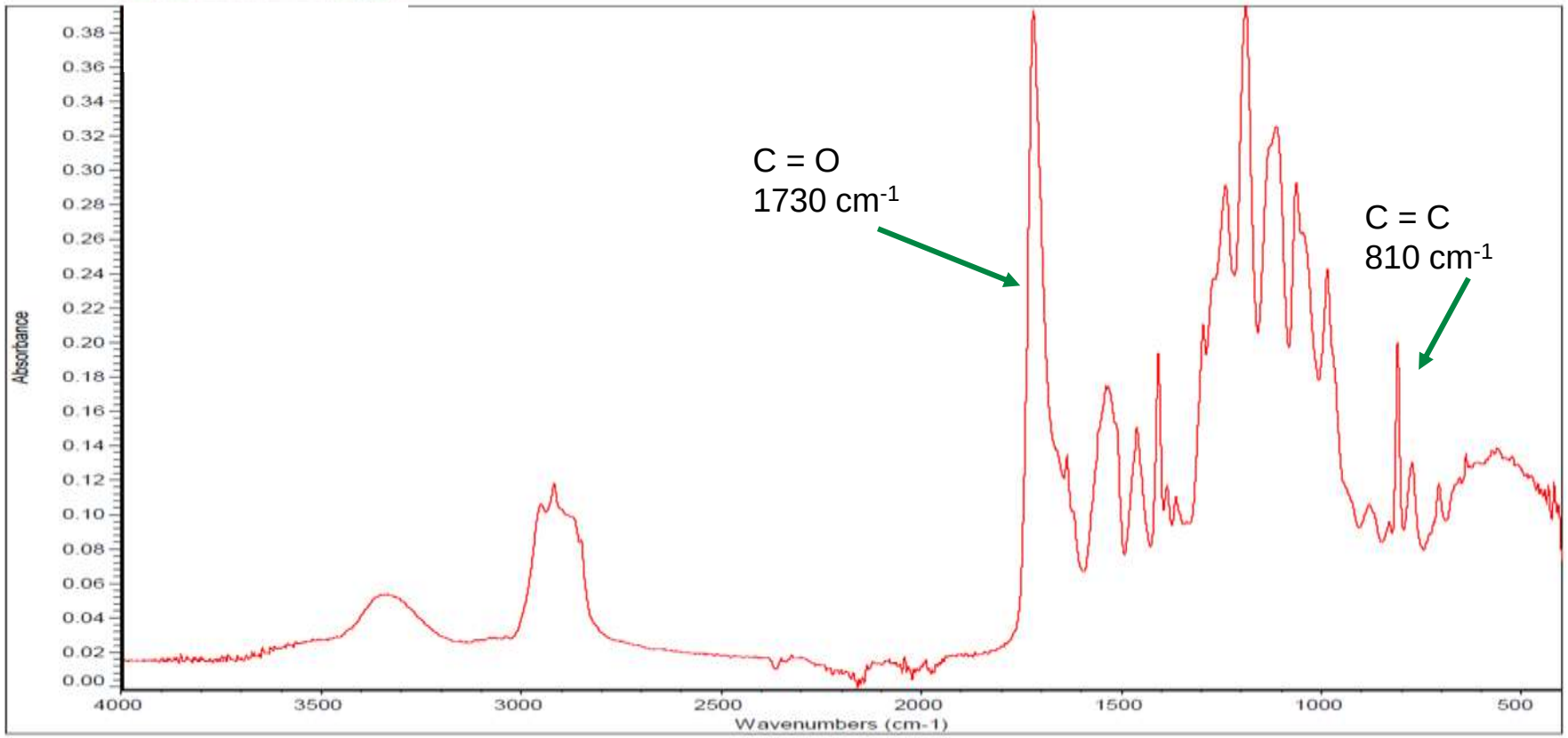
2 peaks (810 cm-1 and 1730 cm-1) were investigated. The peak at 810 is a C=C which reacts during UV exposure. The peak at 1730 is a C=O and will not react during UV exposure.

$$\text{Relative concentration of UV cured group (\%)} = \frac{[A]_{810}^{UV}/[A]_{1730}^{UV}}{[A]_{810}^{0}/[A]_{1730}^{0}} \times 100, \quad (2)$$

where $[A]_{810}^{0}$ is the IR absorbance at 810 cm^{-1} before UV irradiation, $[A]_{1730}^{0}$ the IR absorbance at 1730 cm^{-1} before UV irradiation, $[A]_{810}^{UV}$ the IR absorbance at 810 cm^{-1} after UV irradiation and $[A]_{1730}^{UV}$ the IR absorbance at 1730 cm^{-1} after UV irradiation.

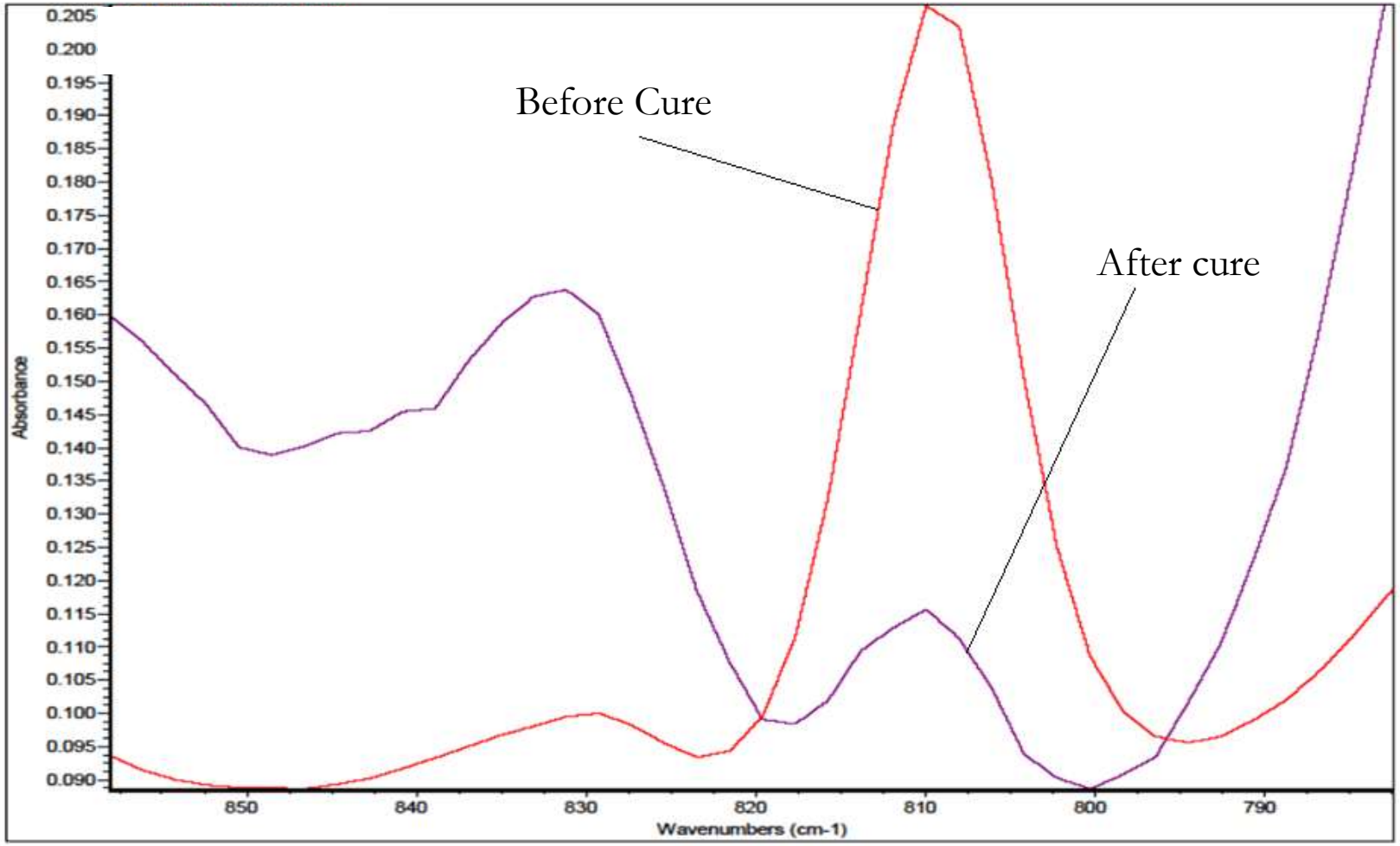
Y.-J. Park et al. / *Journal of Adhesion Science and Technology 22 (2008) 1401–1423*

Infrared Spectroscopy



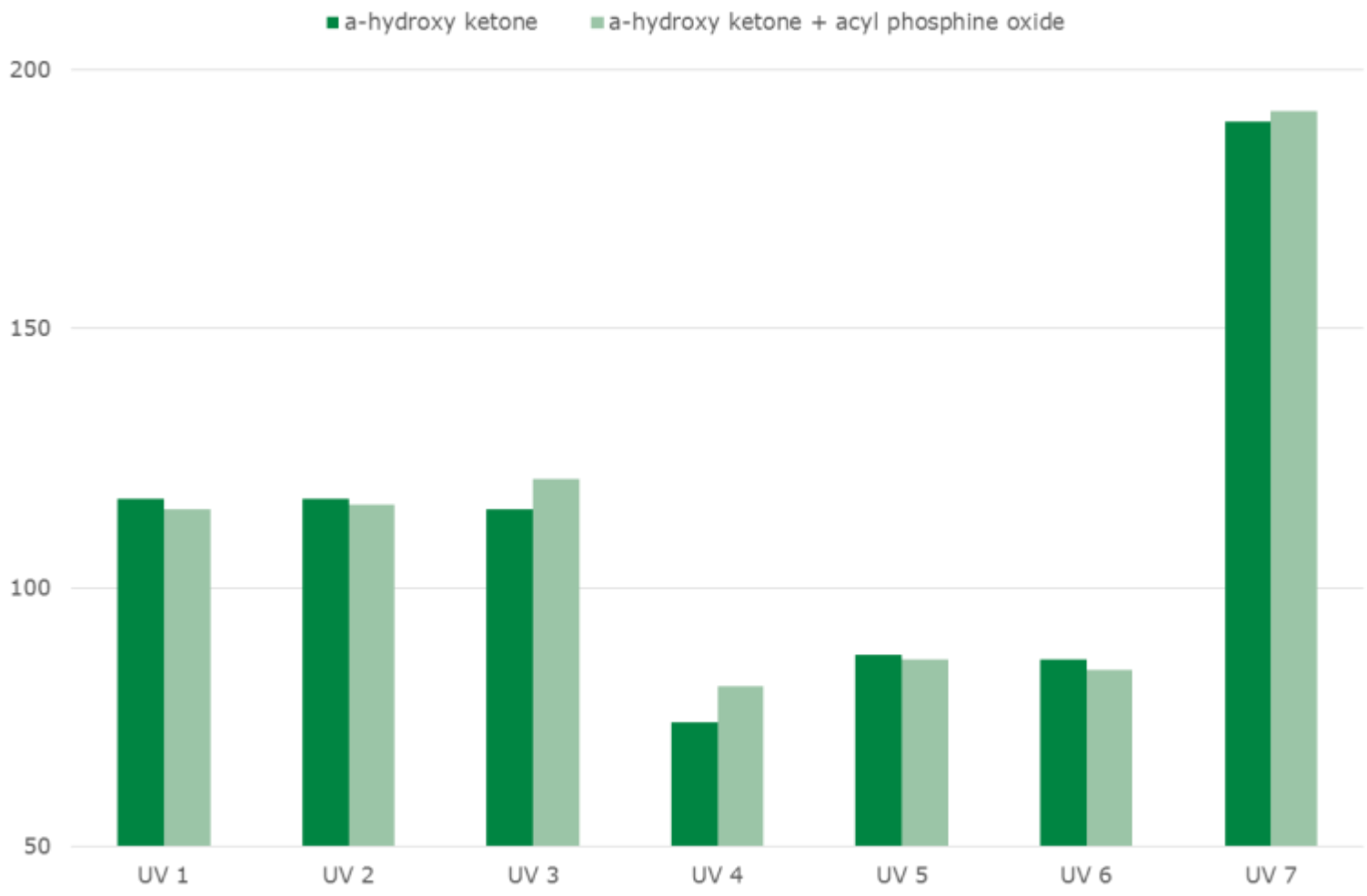
Measure % Cure by IR

- Peak differences at 810 nm



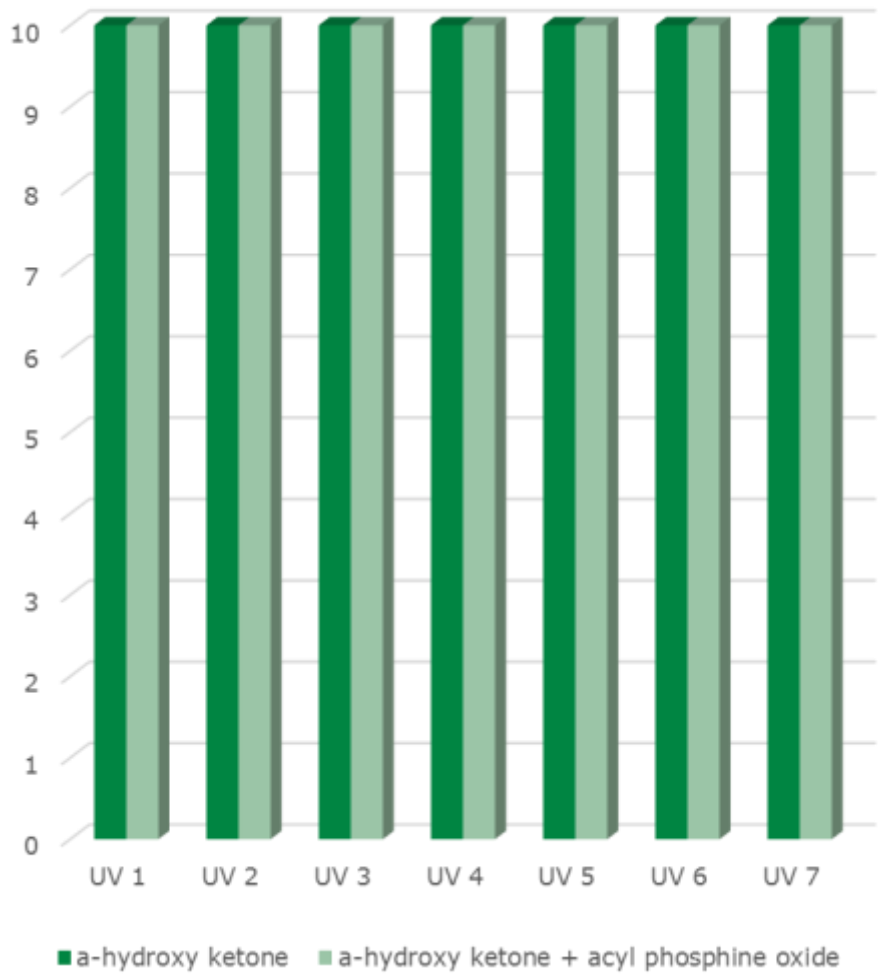
Cure Response - % Cure

Koenig Hardness Development

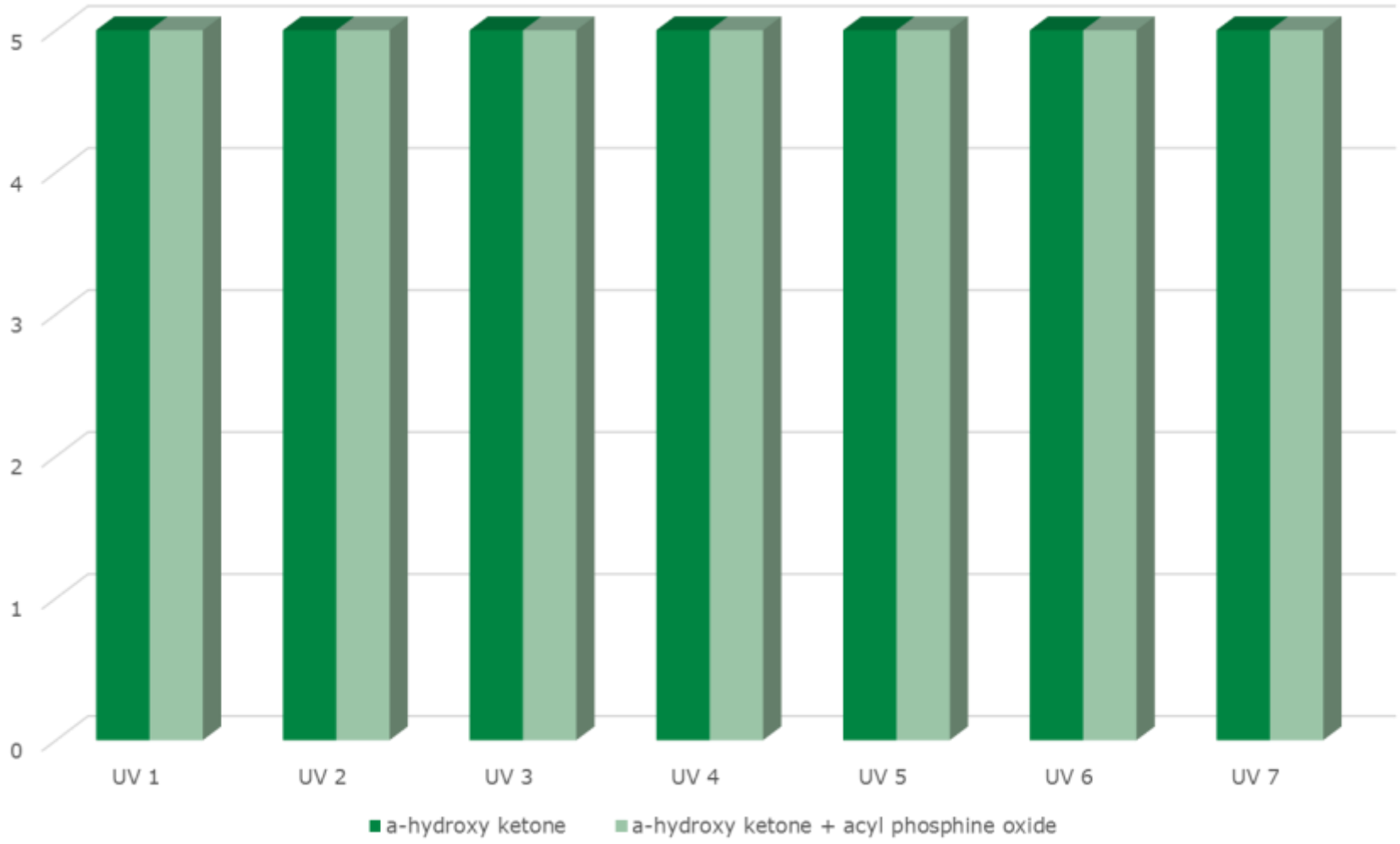


Block Resistance

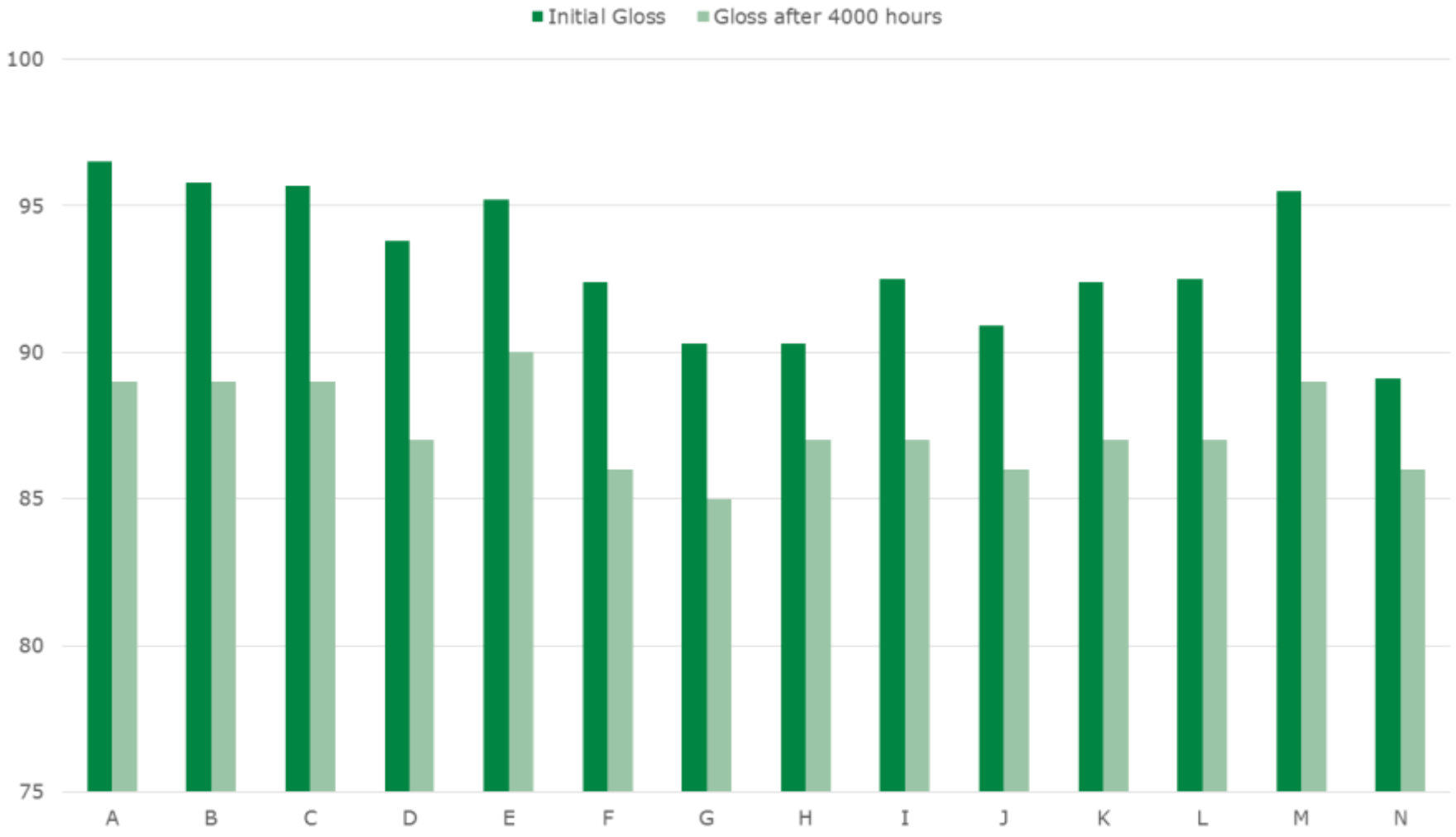
Make a drawdown on a 3B-H Leneta chart using a 3 mil bird bar. Air dry for 10 minutes then force dry for 10 minutes at 50C. Cure. Cut off a 1” X 8.5” strip from the card perpendicular to the draw down direction. Cut this strip in half to give two 1”x 4.25” strips. Put the two pieces together with each 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.



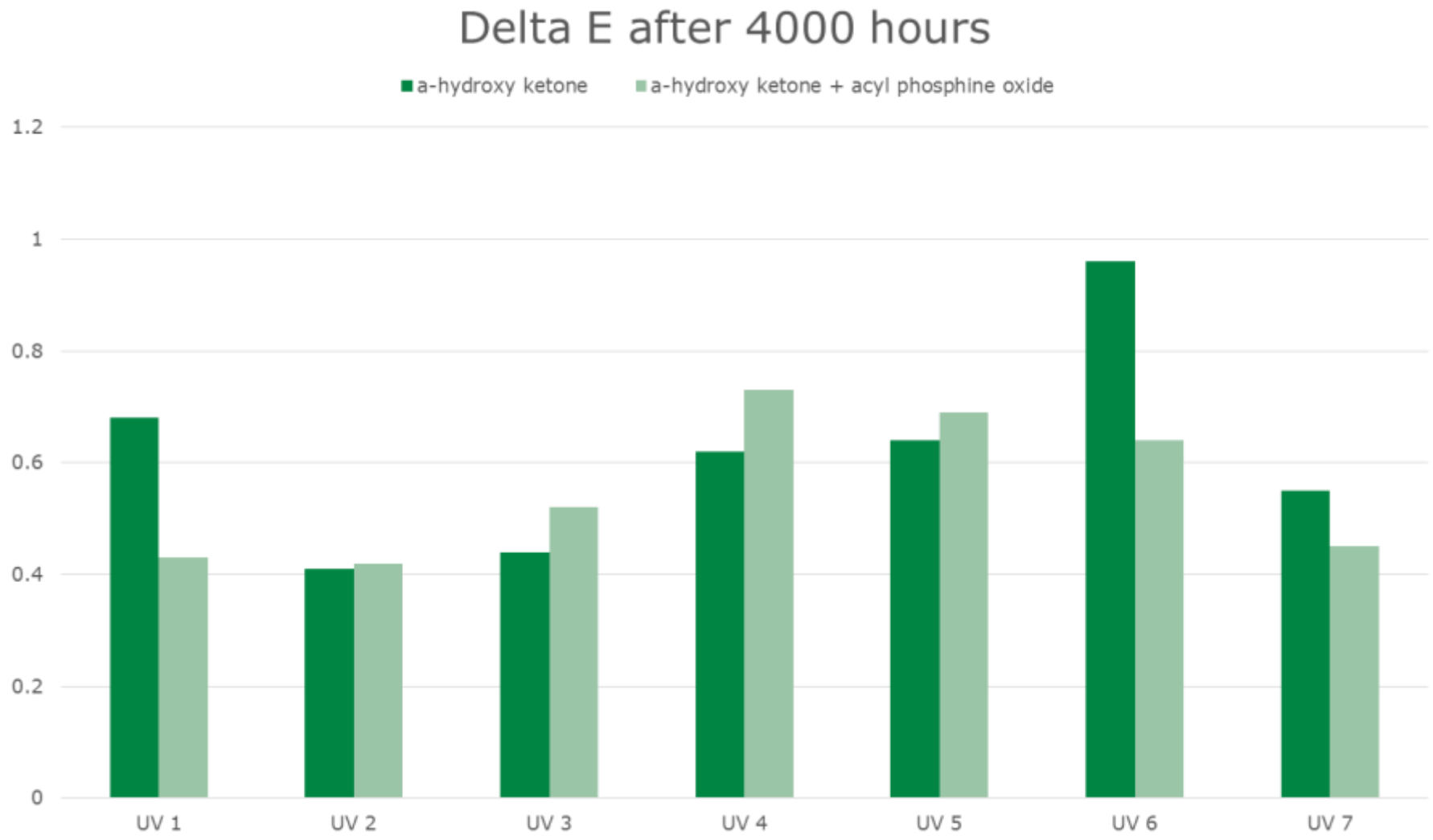
Water Resistance



QUV – Gloss Retention



QUV – Color Retention



Discussion – Phase 1

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 were eliminated from the study due to low cure response and hardness development.

UV 1, UV 2 and UV 7 continued to 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.

QUV resistance was repeated on poplar substrate.

Coatings were formulated using traditional defoamers, surface tension modifiers, wax emulsion and rheology modifiers.

The solids of the coatings was controlled with water.

American Architectural Manufacturers Association

The American Architectural Manufacturers Association (AAMA) is made up of window, door, skylight, curtain wall and store front manufacturers, suppliers and test labs. These large and small companies represent both residential and commercial applications.

AAMA members develop and update the standards that are referenced in many national and state building codes.

AAMA offers a third party product certification program to provide manufacturers with the means to independently demonstrate product performance to their customers via the AAMA Certification Label.

http://www.aamanet.org/

Formulations – Phase 2

	O	P	Q
UV 1	74.83	0	0
UV 2	0	72.48	0
UV 7	0	0	89.42
UV Absorber	0.96	0.96	0.91
HALS	0.48	0.48	0.46
Surfactant	0.34	0.34	0.32
Wax	2.95	2.95	2.8
Defoamer	0.34	0.34	0.32
Photoinitiator	0.55	0.55	0.52
water	19.32	21.68	5.02
Rheology modifier	0.24	0.24	0.23
Wt. Solids (%)	36.41	36.41	36.41
VOC (g/l)	8.71	11.37	65.54

Panel Preparation

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

Spray approximately 4 wet mils of coating over a 4 X 6 inch unstained southern yellow pine panel.

Air dry for 10 minutes.

Force dry for 10 minutes at 50C.

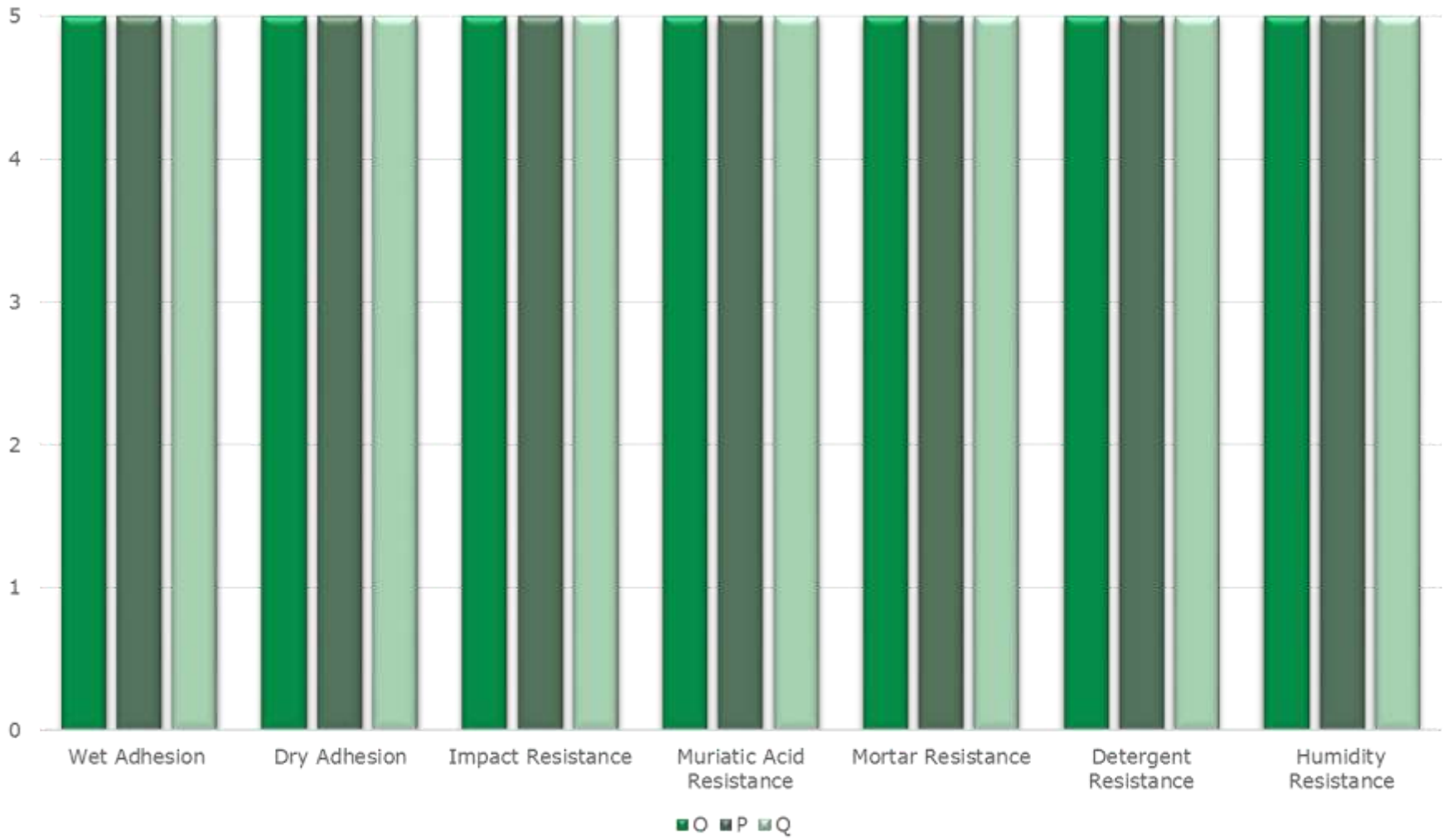
Cure with a mercury lamp at 800 mJ/cm^2.

Sand with a 3M Superfine Sanding Sponge.

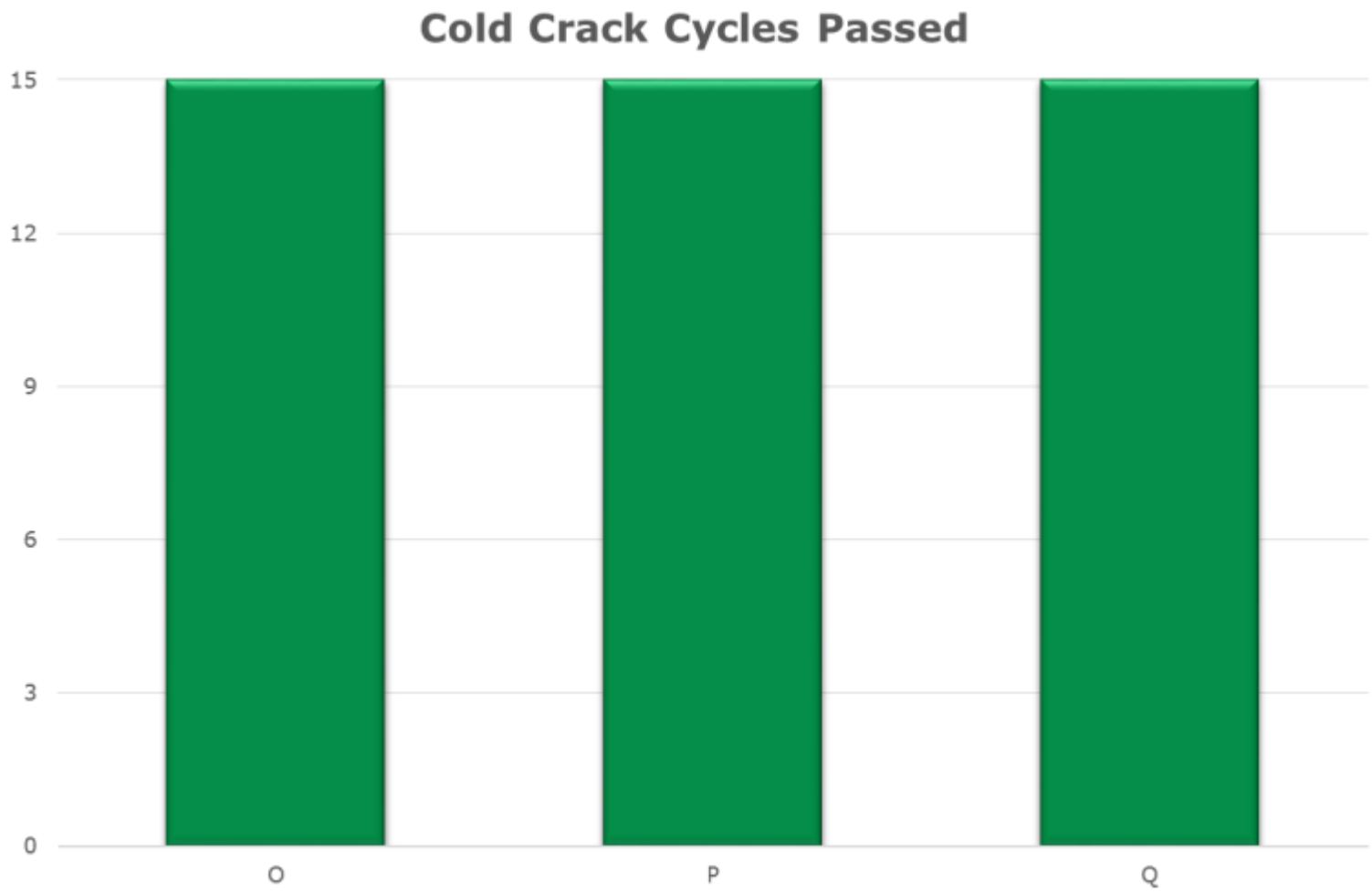
Repeat steps 1 – 4.

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



Data

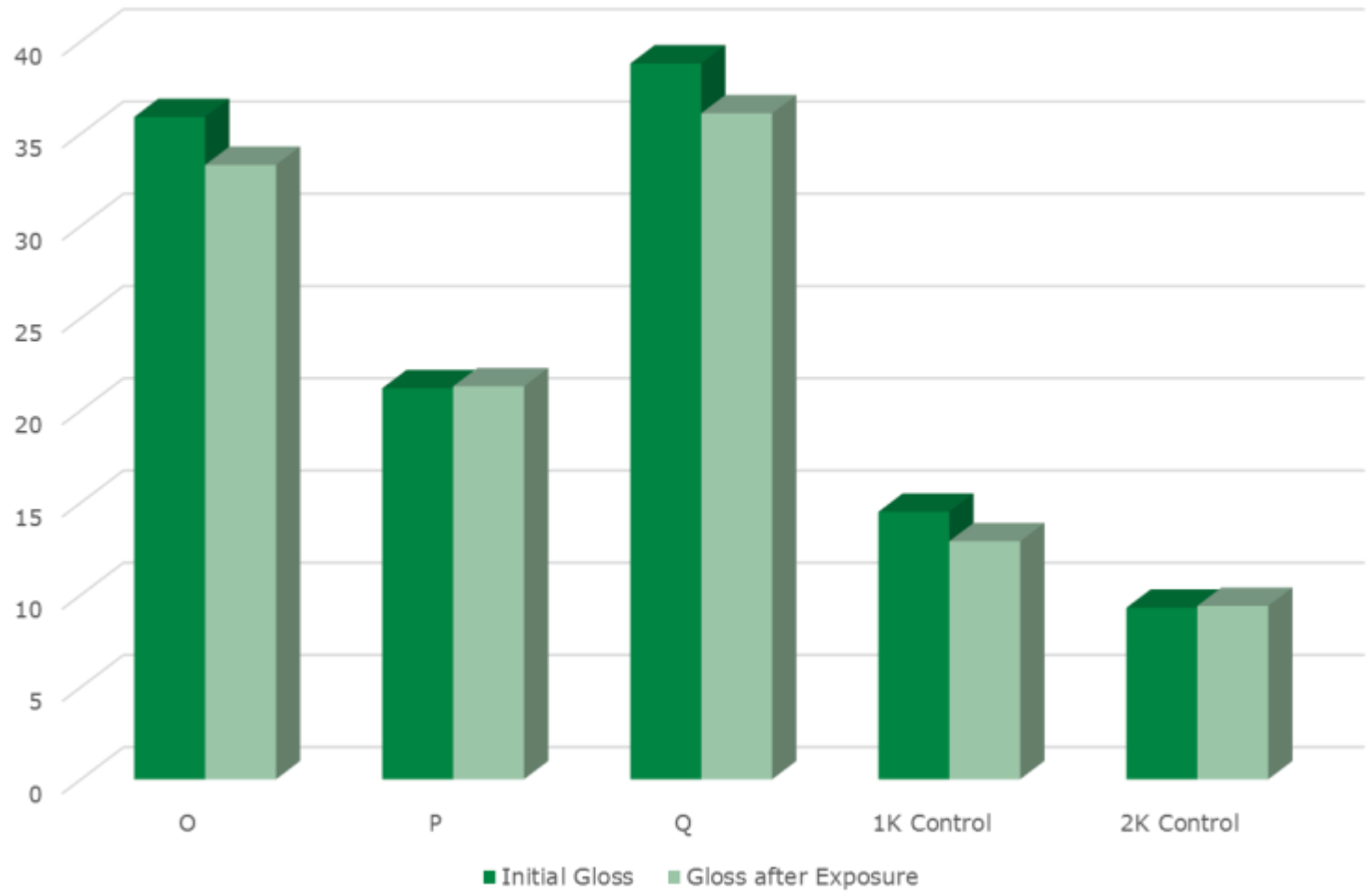


QUV Panels after 1700 hours

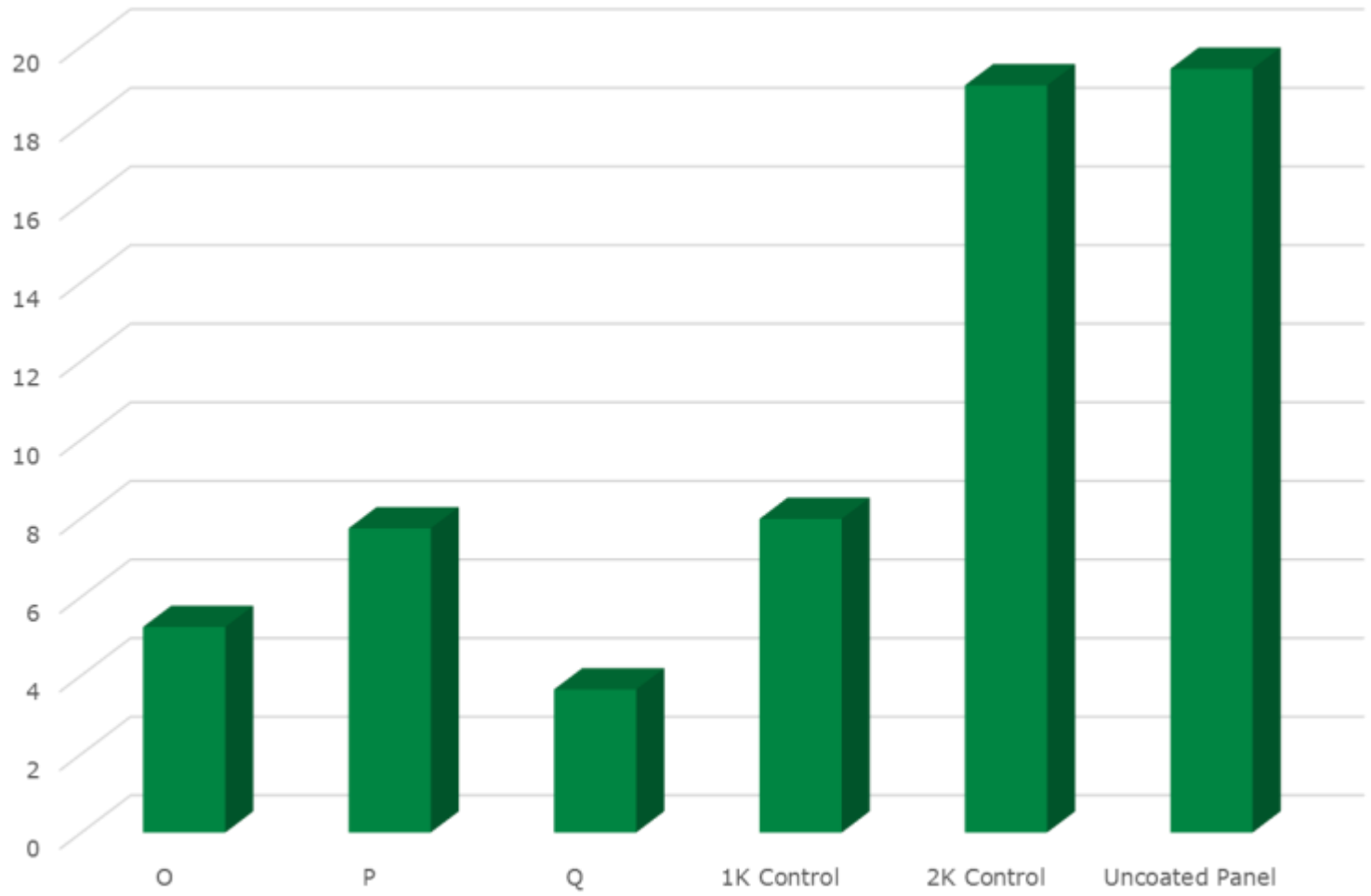
Cyclic - 4 hours UVA340 @ 60C; 4 hours condensation @ 50C

Panels for QUV testing were prepared in the same way as the AAMA panels except the substrate was 2 X 4 inch poplar panels.

QUV – Gloss Retention – 1700 Hours



QUV – Color Retention – Delta E after 1700 hours



Discussion

All coatings passed the AAMA 653-14 tests.

Gloss retention is excellent on all coatings.

Controls performed poorly in QUV color retention. These products are typically used as a topcoat over a stain or pigmented basecoat. The stain/basecoat provides UV protection for the wood.

This study examined clear self-sealing topcoats over a very light colored wood.

The experimental samples all had good QUV color retention

Conclusions

Coatings made from WB UV resins are excellent candidates for industrial wood coatings for both interior and exterior applications. They have very good chemical resistance and mechanical properties. They can be formulated at low VOCs and have low toxicity. They are viable alternatives to solvent-based chemistries.

Questions?

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