

Accelerated Weathering of Wood Coatings by QUV-A with Direct Water Spray

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Background

Accelerated weathering of coatings for wood by QUV-A with direct water spray closely approximates natural weathering by simulating the erosion and cleaning typical for exterior coated wood, increasing the moisture content of the wood above what is typically found in accelerated test procedures, and subjecting the coating to a much greater thermal shock than condensation methods. This paper examines the performance of various exterior wood coatings under this modified QUV test method.

Introduction

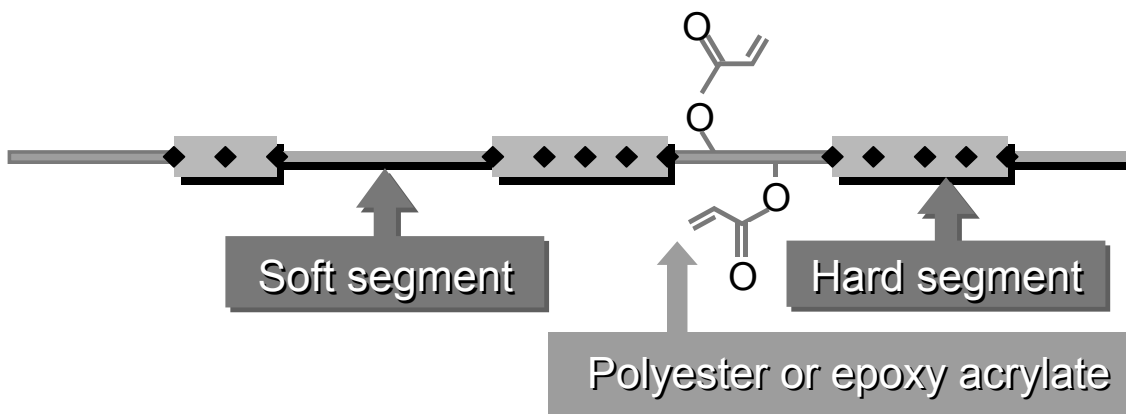
Coatings for exterior millwork such as exterior siding, decks, and doors require distinct performance properties such as excellent light stability, high flexibility, and freeze/thaw cycling properties. New Waterborne (WB) UV-Curing co-solvent free Polyurethane Dispersions (PUD's) were developed to provide excellent exterior weathering properties, high flexibility, enhanced water resistance, and improved adhesion to difficult substrates such as wood and plastic. This paper will describe unique curing capabilities of WB UV PUD's, attributes and performance properties, and weathering results using an innovative accelerated weathering tester designed to simulate outdoor weathering of exterior wood coatings.

Radiation-curing dispersions

A broad variety of products have been commercialized in the wood coatings market over the last decade. The most promising environmentally-friendly technology of these systems is waterborne UV-curing PUDs. The chemical structure of UV-PUD's is quite similar to that of a regular PUD that consists of hard and soft segments. The broad raw material selection available for the design of each segment allows optimization of a huge variety of properties. In most cases, high performance soft segments contribute a certain flexibility, while di(poly)isocyanates and short chain diols contribute hardness and resistance. Several routes for the introduction of acrylic double bonds have been reported. In our experience, the best polymer performance can be obtained by introducing double bonds along the polyurethane chain, rather than to attach acrylic units to only the

end of the chain or to physically blend polyurethanes with acrylic monomers or oligomers. The use of acrylic monomers / oligomers may impart additional industrial hygiene issues and stability concerns.¹⁻³

Fig. 1: Building blocks of UV-curing polyurethane dispersions



Coatings based on PUD's exhibit excellent growth opportunities in the wood coatings market. The key property of this type of coating is its similarity to conventional PUR coatings – i.e. application methods, drying times and performance attributes.

UV-curing aqueous dispersions have a weight-average molecular weight above 200,000; which is many times higher than that of traditional 100% solids UV systems consisting of unsaturated acrylates and reactive thinners - a very striking advantage. That is why the waterborne systems need much less radical crosslinking to obtain the desired properties. This attribute opens up the possibilities for a variety of traditional and unique curing methods. These high molecular weight polymers also reduce the hazards of skin irritancy associated with traditional low molecular weight acrylic oligomers.

UV Curing

UV radiation initiates coatings cure in the presence of photoinitiators. It can be either by free-radical or cationic mechanisms. Numerous models and types of UV curing equipment are available from many suppliers. Typically the curing systems consist of a high voltage power supply, a control panel and a curing head. Two types of lamps are typically used in UV curing i.e. regular arc lamp and microwave lamp. The spectral output of the lamps can be adjusted by doping the lamps with various trace metals. Each lamp has specific outputs measured in nanometer wavelength. The challenge of the formulator is to match the absorption of the photoinitiator to the spectral output of the lamp to cure the coatings, especially in highly-filled/pigmented systems. The desired result is a highly crosslinked film that can meet several market standards. Additionally, UV coatings are environmentally friendly – most systems are typically solvent-free so emissions (VOC/VHAP's) and flammability are not a concern.

Waterborne UV-Curable PUD's for Exterior Coatings

New UV-curable PUD's have been developed to meet the demanding property requirements for exterior coatings. These new materials are comprised of high-end aliphatic di(poly)-isocyanates and select polyols that contribute to tough elastic properties. Table I shows the typical properties of a UV-curable PUD and Table II shows the property range obtainable when formulating clear coatings based on UV-curable PUD's:

Table I: Typical properties of UV-Curable PUD raw material

Solids %	approx. 40% supplied in water
Viscosity	< 50 sec (Ford 4 cup)
pH	7.0 – 8.0
Particle size	50 nm – 150 nm (Horiba)

Table II: Typical physical properties of clear formulations based on UV curable PUD's designed for exterior coatings:

Hardness before UV - pendulum (D4366-95)	10 - 20 sec .
Hardness after UV- pendulum (D4366-95)	60 - 100 sec.
Film Clarity	Excellent
Elongation ISO 527-2	30 - 80%
Tensile Strength ISO 527-2	1600 – 4000 psi
Blocking, 0.15 Kg/cm ² , 16 hr 50°C	4

Formulations based on UV curable PUD's are easily modified to meet various application methods such as brushing, conventional spray, airless spray, vacuum coating, and roll-coating. Conventional waterborne additives can be used to improve surface wetting, defoaming, block resistance, and surface appearance properties. The low photoinitiator demand for UV-curable PUD's improves cost efficiency compared to traditional UV curing coatings. Standard UV absorbers and light stabilizers can be incorporated into formulations to improve exterior durability and gloss retention. Additions of acrylic emulsions are possible to improve cost performance and enhance specific property requirements. Coatings formulated with waterborne UV coatings can provide the following benefits:

- High Productivity
- Outstanding Weathering, even in clear
- One Component
- High Elasticity, even at low temperatures
- Excellent Chemical Resistance
- Tough and Scratch Resistant
- Various Application Methods
- Physical Drying Properties
- High UV-reactivity
- Fast Water Release
- Suitable for Clear and Pigmented Coatings
- Very Low VOC, Environmentally Friendly
- Reduced Emissions
- Safer to Handle

Weatherable Millwork Coatings

The term millwork is used to define a wide range of manufactured components for the construction industry. These components are used for both interior and exterior applications such as windows, doors and molding. Interior and exterior coatings can have a completely different set of property requirements based on their end-use.

For example, several high-end window manufacturers offer 10 year warranties on the durability of the finish on exterior windows. The topcoats used are generally very high performance coatings, since they require very high weathering resistance, gloss retention, and flexibility properties. Two component (2K) polyurethanes are used because of their high-performance properties.

Environmental regulations are continually changing to reduce both plant emissions and VOC's of formulated coatings. These mandates can be enforced on a Federal level, State level, or even a local level. For example, the South Coast Air Quality Management District (SCAQMD) has mandated Rule 1136 for clear and pigmented sealers, topcoats, and primers. The VOC limit will be reduced to 250 grams/liter. The following table illustrates several organization proposals:

Table III: Industrial Maintenance Coating VOC Limits for 2005.⁴

Organization	Grams/Liter
National VOC Rule	450
OTC Rule	340
DE,NJ,MD,NY,PA,VA	340
CARB SCM - STAPPA/ALAPCO	250
SCAQMD	250

Millwork manufacturers are demanding low VOC, high productivity, and high performance coatings from their paint suppliers. Wood coatings based on UV-PUD's can be formulated at less than 150 grams/liter and provide excellent application and performance properties.

Sunshine Curing Coatings

UV coatings are used predominantly in OEM factory applications that require very fast production speeds and superior performance properties. Recent work has been carried out to develop WB UV coating formulations that can be UV cured by natural sunlight. This technology is being explored for potential application in the DIY exterior wood coatings market. In addition to wood coatings, this technology may be applicable for other market areas such as exterior concrete coatings.

The Sun emits ultraviolet radiation in the UVA, UVB, and UVC bands, but because of absorption in the atmosphere's ozone layer, 98.7% of the ultraviolet radiation that reaches the Earth's surface is UVA⁵. Because of the high molecular weight of UV PUD's, it is possible to formulate coatings that both physically dry and photo-polymerize with direct UVA radiation from the sun. This is accomplished by using WB UV PUD's in combination with select photo-initiators that have distinct absorption peaks in the UVA range between 315 - 400 nm.

Sunshine curing coatings will definitely have their limitations, particularly the need for direct sunlight to photo-polymerize a coating film. Based on developmental screening performed in cloudy conditions in Pittsburgh, PA., the amount of direct sunlight required to develop surface hardness is surprisingly low.

Experiments were performed to evaluate both surface hardness and through hardness properties utilizing various curing methods. A formulation was prepared consisting of a UV-curable PUD, thermoplastic PUD, photo-initiators, and typical surfactants and

defoamers used in waterbased formulations. The volume solids of the formulation was about 24% solids and VOC at less than 1 lb./gal. The liquid coatings were applied to glass panels at 8 mils wet resulting in 1.5 – 2.0 mils dry (about 37 microns). Several glass panels were coated to evaluate the various curing methods as follows:

1. High intensity lamp emitting UVA, UVB, and UVC (mercury lamp)
2. Low intensity lamp emitting UVA only (4 minute exposure time)
3. Direct sunlight in Pittsburgh, PA. (horizontal exposure)
4. Dark room – no light

Figure II shows coating film surface hardness properties using a pendulum hardness tester. Surprisingly, the surface hardness is very similar at 1 day, 3 days, and 5 days for the various UV curing methods, including sunshine cure. The dark room panel shows the dramatic effect on hardness from no UV exposure. The sunshine curing panel continues to increase in hardness considerably after 5 days, whereas the other UV-curing methods increase very slightly.

Micro-hardness testing was also performed to measure the through-cure properties of the coating films. A diamond indenter is used to penetrate the films at 1.5 microns depth to measure the through hardness. The results in Figure III show moderately different hardness numbers based on the type of curing method used. The sunshine cured films have lower through hardness properties initially and at 7 days. However, as seen in Figure II and Figure III, the surface hardness and through hardness properties continue to increase over time for the direct sunlight films.

Figure II:

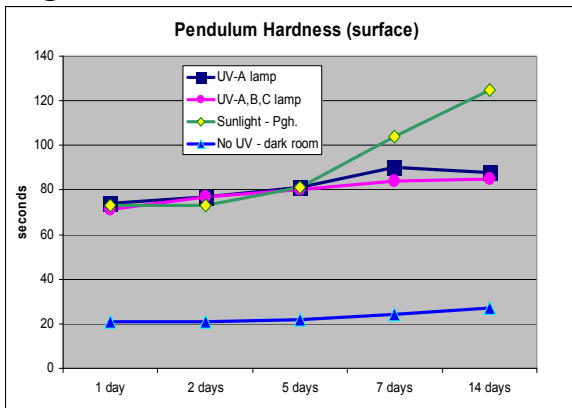
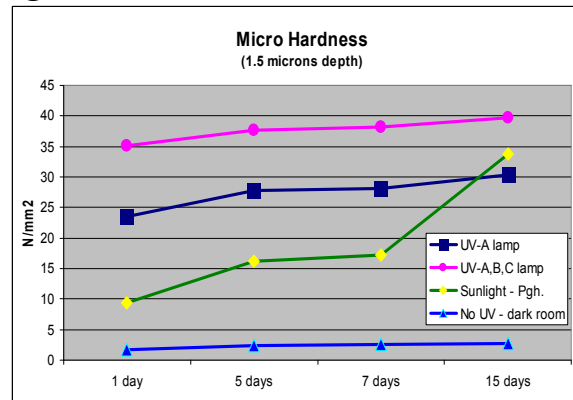


Figure III:



In addition to hardness properties, solvent resistance was evaluated and the results showed very similar performance for the various UV curing methods. The films placed in the dark room showed substantially lower solvent resistance compared to the UV cured films.

Weathering Device

In 1996, an extensive European wood project called “Arwood” (A reliable artificial weathering test for wood coatings) was approved to develop a standard artificial weathering method for wood coatings. The project involved ten wood research institutes and four industrial partners. The principal aim of the project was to assess the durability of exterior wood coatings in a short period of time, and also demonstrate good correlation to natural weathering⁶.

A standard method was identified after numerous round robin exposure trials with different coating systems, wood substrates, and artificial weathering conditions. The results of the research project lead to the following conclusions⁶:

- fluorescent UV lamps UVA-340 are well suited to simulate the degradation effects of sunlight
- both condensation and water spray must be included to simulate the different aspects of moisture during weathering

Based on the conclusions from the “Arwood” project, a QUV-A with direct water spray and fluorescent UV-A lamps was selected to evaluate various wood coating formulations. This device closely approximates natural weathering by simulating the erosion and cleaning typical for exterior coated wood, increasing the moisture content of the wood above what is typically found in accelerated test procedures, and subjecting the coating to a much greater thermal shock than condensation methods.

An essential feature of the QUV’s condensation system is that panels actually form the side wall of the test chamber and provide the closure that keeps the hot water vapor inside the chamber. During the condensation cycle, the water is heated by a heating element under the water pan. Water vapor fills the test chamber, which reaches 100% humidity at equilibrium. Vapor continually condenses on the test panels, which are kept at a lower temperature by room air on the back surface of the wood substrates. Condensation runs off the test panels and back into the water pan.

The water spray is mainly used to remove degraded material from the surface and to produce frequent cold shocks. The water spray also simulates the erosion and cleaning typical for exterior coated wood. Any combination of spray and/or condensation can be programmed. The spray system consists of 12 spray nozzles (6 on each side) and the associated piping, controls and drain. The nozzles are mounted between the UV lamps. When the QUV is spraying the lamps are off. The design of the QUV-A with water spray can be seen in Figure IV.

The UVA-340 bulbs were selected because of their similar UV wavelength to direct sunlight. The spectral output of the UVA-340 lamps can be seen in Figure V.

Figure IV⁷

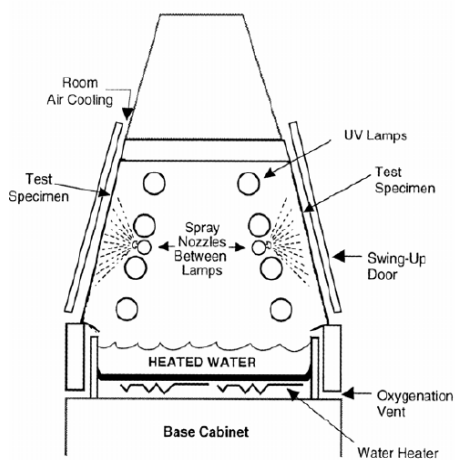
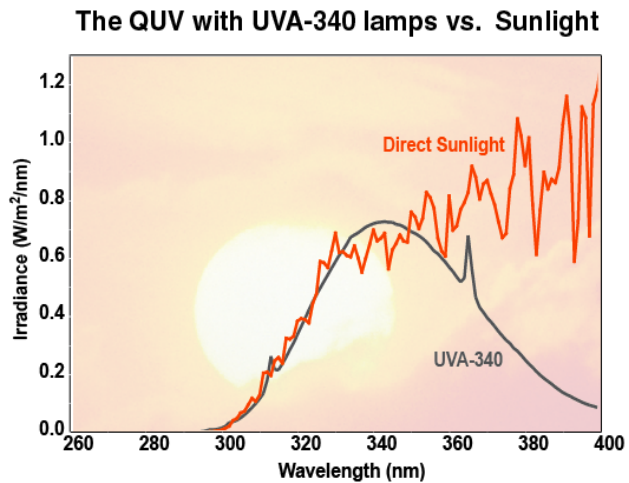


Figure V⁷



The method, specifications and time duration for the weathering study are as follows:

QUV-A Accelerated Weathering Tester - ASTM G-154-06, cycle 7

- 2000 hours total duration
- Bulb type: UVA – 340 bulb
- Irradiance: 1.55
- Conditions:
 - 8 hours UV @ 60°C
 - 0.25 hours water spray with no light and no temp. control
 - 7 liters/minute of water during spray
 - 3.75 hours condensation @ 50C

Sunshine cured coating formulations

A project was designed and implemented to evaluate the weathering properties of various sunshine-cured WB UV wood coatings. The main objective was to test coating performance using a novel QUV designed for exterior wood coatings. Several formulation variations were made to evaluate the effects of UV absorbers (UV-A's), hindered amine light scavengers (HAL's), and / or binders.

Test panels consisted of 3" x 12" pine substrates that were pretreated with a commercial wood preservative. Coatings were applied by brush and allowed to cure by direct sunlight for a minimum of 7 days before testing. The test coatings consisted of clear formulations only, with variations made to the UV-A's, HAL's, and binders. Some blending and over coating of commercial white stains were also tested. The following coating systems were evaluated for each formulation:

1. Three coats of clear – self-sealed
2. One coat of commercial white stain followed by two coats of clear
3. Two coats of commercial white stain with 25% addition of clear coatings

Table IV gives an overview of the UV-curing clear coating systems that were tested.

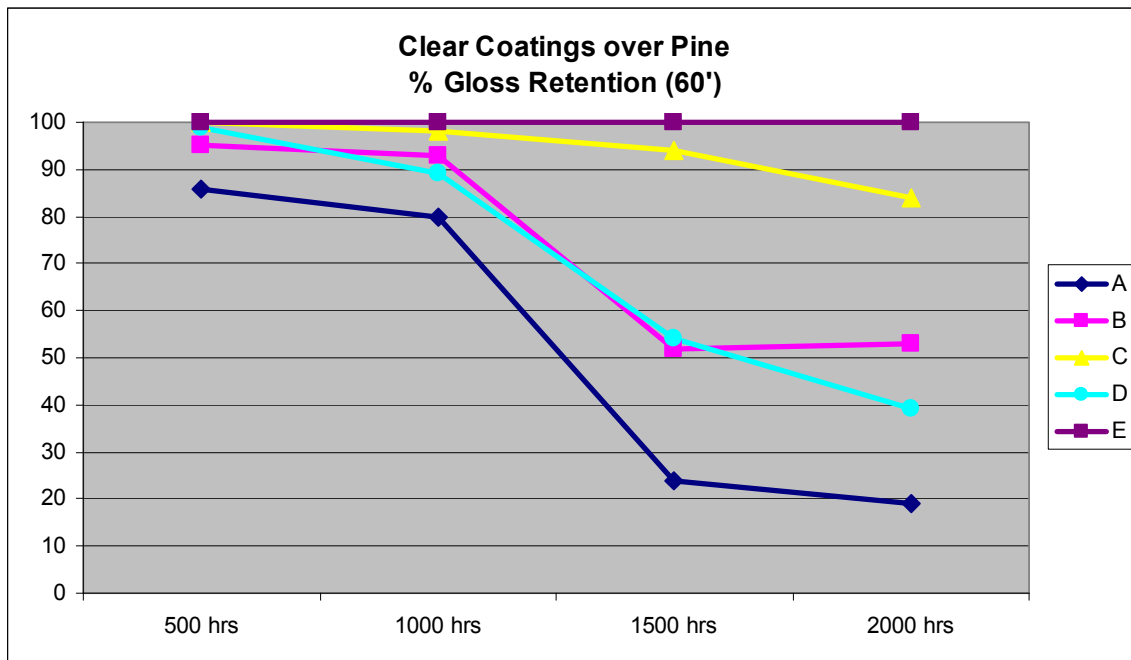
Table IV:

A	UV-PUD with no UVA or HAL's
B	UV-PUD with both UVA and HAL's
C	UV-PUD with both UVA and HAL's
D	UV-PUD / Acrylic with both UVA and HAL's
E	UV-PUD with combo UVA / HAL's

Weathering test results

The 5 coating systems were evaluated at 500 hour intervals. Table V shows the 60 degree % gloss retention of the clear coatings directly over pine wood substrates. As seen in Table V, the gloss retention of the various coatings differs significantly. The control system (A) without any UV-A's or HAL's showed the poorest gloss retention properties. Coating systems B and D demonstrated moderate gloss retention properties. Coating systems C and E, based on UV PUD's and select UVA's and HAL's, exhibited excellent gloss retention properties.

Table V



In addition to gloss retention properties, the coatings were evaluated for general appearance properties. These assessments included color, coating cracking, bleed-through, substrate cracking, and yellowing. These properties were rated on a visual scale from 0 (no change) to 5 (severe change or effect). Table VI shows the results of the general appearance effects. The designated ratings were totaled in column six and the lower number shows the best performing systems. Coating systems B, C and E provided the best overall performance based on visual defects.

Systems B, C, and E provided excellent non-yellowing properties as indicated by the delta E results after 2000 hours exposure. The clear coatings were applied over a white stain to evaluate the actual yellowing of the clear coating and not the wood substrate. Systems A and D showed the worst overall performance, particularly poor bleed-through properties as indicated in column 4.

It should be noted that the rating for wood cracking in column 5 is based solely on the wood substrate and may not be a factor of the actual coating. A duplicate set of panels were sent to Florida to evaluate natural weathering for a period of 2 years. The performance results will be evaluated and reported every 3 months.

Table VI

	2000 HRS	2000 HRS	2000 HRS	2000 HRS		2000 HRS
	<i>color - clear over pine</i>	<i>clear coating cracking</i>	<i>Bleed through - Clear over white stain</i>	<i>wood cracking - clear over pine</i>	<i>Total</i>	<i>Delta E - Clear over white stain</i>
A	4	4	4	1	13	19.8
B	1	2	1	1	5	1.3
C	2	0	1	0	3	1.2
D	2	0	4	2	8	6.0
E	2	0	0	3	5	0.9

Visual assessment legend:

0	no change
1	very slight
2	slight
3	moderate
4	severe

Conclusion

1. UV-curing aqueous dispersions have a very high molecular weight that enables film forming properties without UV and requires much less radical crosslinking to obtain the desired properties. This attribute opens up the possibilities for a variety of traditional and unique curing methods including sunshine curing.
2. New Waterborne UV-Curing co-solvent free PUDs provide excellent exterior weathering properties, high flexibility, and improved adhesion to difficult substrates such as wood and plastic. Both clear and pigmented coatings are possible.
3. Formulations based on UV curable PUDs are easily modified to meet various application methods such as conventional spray, airless spray, vacuum coating, and roll-coating. Conventional waterborne additives can be used to improve surface wetting, defoaming, block resistance, and surface appearance properties.
4. The incorporation of UV absorbers and light stabilizers are definitely recommended based on accelerated weathering testing. Different types of UV-absorbers and/or light stabilizer showed variations in overall weathering performance properties and should be tested in the formulation.
5. Environmental regulations are continually changing to reduce both plant emissions and VOCs of formulated coatings. Coatings based on UV-Curable PUDs can meet these new stringent environmental regulations.

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