Field Applied UV Curable Floor Coatings

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Introduction

Coatings have been UV cured in industrial settings since the 1960s. The graphics industry was one of the first to adopt this technology, with a high gloss coating on cards. Today, there are numerous industrial applications that utilize UV curing as the method of drying or polymerizing their coatings or inks. Many of these industries initially embraced UV curing technology as a way to increase both productivity and performance. More recently, the advantages of energy savings and environmental compliance have also led industries to choose UV curing technology.

In the past five or so years, commercial UV curing has moved out of the factory and into the field, with numerous improvements in UV curing equipment pushing this transformation. Floor coatings are one of the main applications for field applied UV cured coatings. Today, these field applied or on site floor coatings for wood, vinyl, tile, and concrete are all in some phase of commercialization.

The benefits of UV cured field applied floor coatings are similar to factory applied floor coatings: increased productivity and performance. In addition, the immediate cure aspect provides cost savings to the end user through immediate use, and added benefits of quality, since the finish will not be damaged once it is cured.

This paper will review the performance of field applied UV cured floor coatings with that of conventionally cured floor coatings for wood, concrete, and vinyl composition tile (VCT). The benefits and detriments of each curing technology will also be reviewed. Additionally, several UV cure processing and formulating variables will be evaluated regarding their effect on coating performance.

Basics of UV Curing and Field Applied Coatings

Advantages

UV curing is also known as radiation curing or energy curing. It utilizes the ultra-violet (UV) portion of the electromagnetic spectrum, 200-400 nanometers, to physically dry or cure coatings. (Figure 1) The coating actually polymerizes or increases in molecular weight during the curing process. To do this on an industrial scale, lamps that emit UV light replace drying ovens, and the drying takes place in fractions of a second. In a field applied setting, the coating is 100% cured immediately after the curing unit has passed over the coating, and the performance properties are also 100% developed. This means that recoating or return to service can occur immediately after cure. Improved coating performances are generally seen with UV curing, as polymer crosslinking can be customized for specific end uses. Scratch and abrasion resistance, ease of cleaning, and chemical resistance are some of the properties that can be increased with UV curable coatings.

Fast cure speeds and improved performance are not the only benefits of UV curing. Because UV curable coatings are 100% solids, VOCs and HAPs are also very low, generally less than 5% VOC content. Since solvents are not typically used in UV curable systems, inhalation and flammability hazards are essentially non-existent. Also, UV curable coatings are 1K systems, with infinite pot life and long shelf stability.

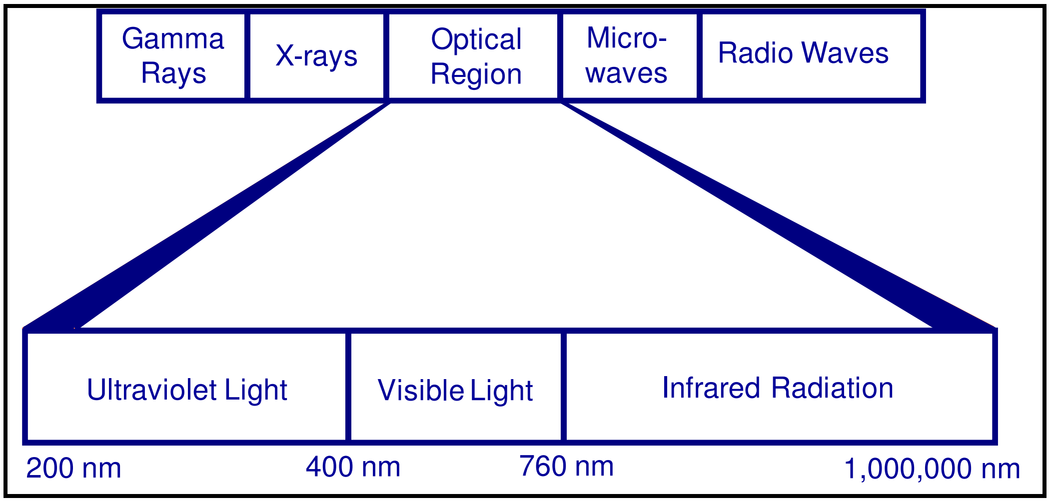

Figure 1. Electromagnetic Spectrum

Disadvantages

Since UV curing is a new process in field applied applications, there will be a learning curve for those formulating, applying and curing the coatings. This disadvantage should disappear as expertise is developed over time. The same learning curve applies to the proper use of the UV curing equipment, and training programs are the best way to insure problem-free curing.

UV curing is a "line-of-sight" process, therefore in order to cure or polymerize the coating, UV light must be absorbed by the coating. Areas that do not absorb UV light will remain in an uncured state. To address this, equipment manufacturers have developed hand held units that are used to cure areas inaccessible to the larger curing units. Also, UV light must penetrate to the bottom of the coating in order to completely cure the coating. This can present problems in very thick coatings or heavily pigmented coatings. Proper selection of photoinitiators and use of multiple coats are some of the solutions currently in use.

Health & Safety

Acrylate functional raw materials are non-toxic and have very low volatility at room temperature. Therefore, the inhalation hazard is very low, and respiratory protection is generally not necessary. The acrylates may be skin and eye irritants, so eye and skin protection such as safety glasses and gloves are required. Additionally, protection from exposure to the UV light may be required, and is provided by UV-blocking safety glasses and sunscreen for exposed skin areas.

Field Applied versus Factory Applied Coatings
Applying and curing a coating in a factory is a well-controlled process. Moving this process to the field introduces many uncontrolled variables, which means that a robust coating and cure process are needed. Substrate variations are more common in the field, where composition, surface treatment, roughness, porosity, and contamination are all potential issues. The substrate is also larger than the UV cure unit (unlike in the factory). UV leakage at the sides of the curing equipment can prematurely cure the coating at the edges of the cure path. This may cause changes in the surface appearance in this area, the most apparent of these changes commonly referred to as “zipper marks”. Also, care must be taken to insure complete cure of all areas. Overlap criteria for the UV curing unit are typically provided by the coating supplier to assist in achieving complete cure. Dyes that bleach upon exposure to UV can also be added to the coating to indicate cure status.

Field applied UV curable floor coatings are applied like conventional coatings. Wood and VCT coatings are applied with a T-bar or roller. Concrete coatings use a squeegee or roller, and then back roll to insure good appearance. These application methods can result in coating thickness variations. Finally, the UV cure unit is mobile and moves over the substrate. The distance from the UV cure unit to the substrate and the speed of the UV cure unit may both vary during the UV curing process. Equipment design improvements have addressed some of these issues, and are discussed in the next section. In general, however, it is the coating formulation that must be robust enough to overcome all of these issues.

Current Status
Today, UV curable field applied coatings for concrete, vinyl, tile, and wood are all in some phase of commercial development. Concrete coatings are applied in warehouses, factories and homes, wood coatings are used in restaurants, shops and residential settings, tile coatings are found in metro stations, and VCT coatings are applied in hospitals, retail, and institutional buildings.

The equipment for field applied applications has undergone many modifications and upgrades. There are at least six manufacturers, each of whom has a unique construct for their machines. Some of the recent improvements to equipment are shown in Table 1. Many of these improvements address safety issues or process reproducibility.

UV Curable Coatings

Coating Basics
A UV curable coating must contain several basic materials in order to undergo effective curing or polymerization. Additional materials are also required to obtain the desired coating aesthetics. The coating pyramid is often used to demonstrate the use of these materials. (Figures 2 and 3) Materials at the base of the pyramid generally comprise more of the formulation than materials at the top of the pyramid. The base of the pyramid contains the oligomers, which provide the bulk of the coating properties. Next on the pyramid are the diluents, either water or monomers, which are primarily used to obtain the desired application viscosity. Additives are used to enhance the coating performance and/or to change the coating appearance. As in conventional coatings, these additives can be flatting agents, fillers, wetting/leveling agents, defoamers, or slip aids. Pigments can also be added to a formulation for color or special effect. Photoinitiators (PI) are needed to absorb UV light and form free radicals.

Table 1. Recent Improvements in UV Cure Equipment

Feature	Purpose
Shutters - manual control or tied to movement of machine	Reduce accidental UV exposure if machine is lifted or moved Reduce possibility of floor damage
Instant on/off feature - tied to movement of machine	
Tip detectors	
Heat sensors	Reduce possibility of floor damage
Speed Control - self propelled or speed gauge for manual propulsion	Improve process reproducibility
RFID technology	Improve process reproducibility Tracking purposes
Laser guiding technology	Improve process reproducibility
Retractable handles	Better clearance
Light weight	Maneuverability
Emergency shut off on handle	Safety
Shielding	Decrease UV exposure of workers
Mandatory use of UV protective eye wear	
Use of clothing and creams to protect skin from stray UV light	
Cordoning off work areas	
Warning lights	

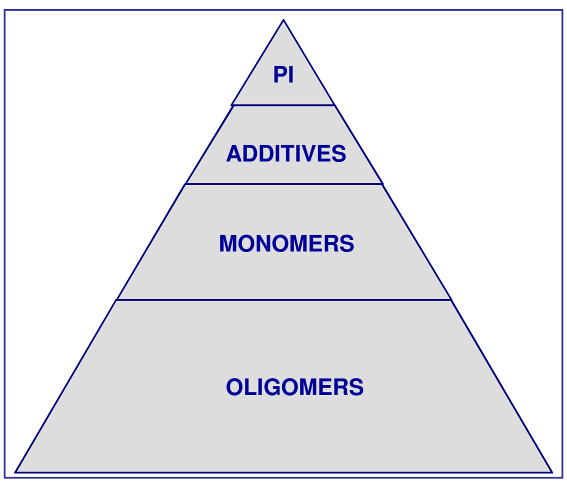

Figure 2. Coating Pyramid: 100% Solids UV

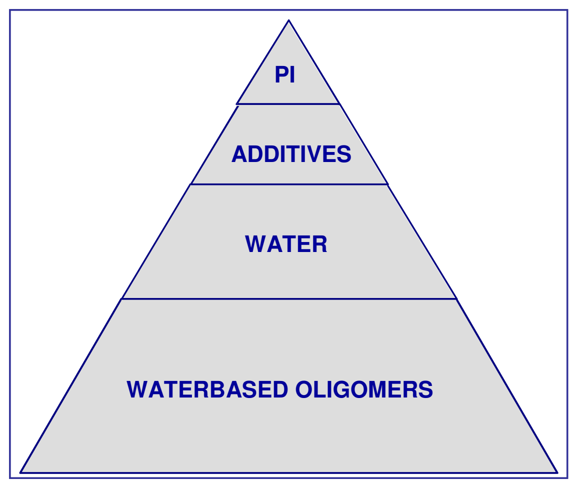

Figure 3. Coating Pyramid: Waterbased UV

Waterbased UV versus 100% Solids UV

In recent years, waterbased UV curable raw materials have been developed in response to several challenges in 100% solids UV curable formulations. This may sound contrary to one of the major benefits of UV curable materials: no need to evaporate water or solvent. However, the main advantages of waterbased UV curable raw materials are their low viscosity (< 200 cP), and their ability to be diluted with water to obtain even lower viscosity. Since field applied UV curable floor coatings require viscosities around 150 cP, waterbased UV curable coatings should be beneficial.

Several UV curable applications, including sprayable wood coatings, currently utilize solvent to reduce their application viscosity to acceptable levels. Waterbased UV allows the elimination of this solvent, and the accompanying disadvantages of VOCs, HAPs, flammability, etc. The use of water as a diluent also allows for thinner dry films than 100% solids UV, in which the wet film thickness equals the dry film thickness. This thinner dry film can provide an improved appearance to the coated substrate. The lower dry coat weight of waterbased UV also allows for easier matting.

Waterbased UV polyurethane dispersions decouple oligomer viscosity from molecular weight. This allows for the development of higher molecular weight materials. These UV dispersions develop lower crosslink densities than 100% UV because of their higher molecular weight. Both of these attributes combine to bring improved properties such as flexibility plus chemical resistance and hardness. Shrinkage is also reduced due the lower crosslink density, and this results in better adhesion and appearance, and the elimination of zipper marks that can occur with field applied 100% solids UV curable coatings.

The use of acrylated monomers as diluents detracts from the oligomeric properties in 100% solids UV, whereas in waterbased UV, the oligomer properties are unadulterated. Many acrylated monomers can be skin irritants. These acrylated monomers are also more mobile than the oligomers, and can migrate into substrates, where UV cure may not occur. The use of water as a diluent can eliminate both of these concerns.

Many of the waterbased UV oligomers are tack free after drying, but before UV cure. This property provides coatings which are more resistant to damage and dust contamination before UV curing. If damage does occur, the dried coating can be buffed to remove the damage before it is UV cured. It also allows the application of a second coat after drying but before UV curing the first coat, eliminating a UV curing step. Table 2 summarizes the comparison of waterbased UV technology to that of 100% solids UV technology.[1]

Field Applied Floor Coatings

Conventional and UV Curable Technologies – Wood

Polyurethanes (PU) make up the majority of wood floor finishes, and include 1K oil modified, 1K waterborne, and 2K waterborne. Swedish finishes (conversion varnishes) have very low usage due to regulatory concerns, and oils and waxes are still used in limited markets to get a beautiful hand rubbed appearance. Waterbased UV curable polyurethanes are just entering the marketplace.

All of the polyurethanes, including UV curable, demonstrate a combination of properties that are beneficial to wood floor coatings, such as high surface hardness, very good chemical resistance, toughness, excellent low temperature flexibility, very good abrasion resistance, and extreme durability. These properties are the result of the polyurethane structure, which consists of both hard and soft segments within the same polymer chain. In order to develop the properties noted above, the polyurethanes must have some degree of crosslinking. This crosslinking can be provided through several different mechanisms: auto-oxidation, isocyanate reactions, aziridine reactions, or UV curing.

Table 2. UV Coating Technology Comparison

Property	100% UV	Waterbased UV
film forming resin	acrylated resin	acrylated medium MW PU
molecular weight	low	medium
cure mechanism	free radical reaction	film coalescence + water evaporation + free radical reaction
crosslink density	high	medium
shrinkage	high	low
adhesion	difficult	easy
flexibility + hardness	difficult	easy
chemical resistance	high	high
diluent	acrylated monomer	water
skin irritation	maybe	no
viscosity	high	low
dry film thickness	high	low
gloss range	20-90	5-80
tack free after dry	no	yes
co-solvents	no	maybe

The isocyanate and aziridine chemistries are two component systems with limited pot life, while the other polyurethane chemistries are one component systems with unlimited pot life. The conversion varnish is a two component system, and the oils and waxes are one component systems. Two component systems with limited pot life can result in wasted product, and deficiencies in product performance due to improper mixing.

The volatile organic content (VOC) of floor finishes has become important in recent years. Several states have enacted legislation to limit the VOC content in paints and coatings. California leads this legislation, but the OTC states (Ozone Transport Commission; mainly the Northeast states) have also enacted legislation. The limits for floor finishes (topcoats) are 275 g/l in Southern California, and 350 in Northern California and the OTC states. This eliminates 1K oil modified polyurethanes, conversion varnishes, waxes, and some waterborne polyurethanes from use in these areas.

All wood floor finishing is a multi-coat system. Three to four coats are typical, and may include stains, sealers and finishes (topcoats). The stains and sealers may be solventborne or waterborne, and are typically fast drying. The topcoats are applied after the stain/sealer coats. The drying time of the topcoat varies from around three hours for waterborne systems and conversion varnishes to around ten hours for oil modified polyurethanes. Drying is not necessary for oils and waxes, but buffing is done between topcoats. The dry time is the time required between the applications of the multiple topcoats.

After the final topcoat has been applied, the coating must be allowed to fully develop its performance properties. Since some of these times can be quite long, recommendations on return of the floor to service are classified as time to light traffic and time to rug replacement. For UV cure finishes, all of these times are immediately after UV cure. This provides a substantial advantage over all of the other technologies, but especially the other polyurethane technologies, which recommend 24 hours before light traffic, and 7-14 days before rug replacement.

The price of these floor finishes varies from $25/gallon for 1K oil modified polyurethanes to $93/gallon for 2K isocyanate cured waterborne polyurethanes to $150/gallon for 1K waterbased UV cured polyurethanes. With the exception of the UV cured finish, the price does not appear to be related to ease of use (pot life, dry time), cure time, or regulatory issues (VOC, flashpoint).

Table 3 summarizes the data presented above, which were obtained from product brochures and data sheets. In a previous paper the product performance of a number of commercial conventional wood floor finishes were discussed and compared to a starting point formulation for a UV curable waterbased floor finish. Data from these evaluations are also shown in Table 3.[2] The UV curable finish clearly outperforms the conventional finishes in hardness, solvent resistance, and chemical resistance.

Table 3. Value Proposition of a Field Applied UV Curable Wood Floor Finish

Technology	1K Oil Modified PU	1K Water-borne PU	2K Water-borne PU	2K Water-borne PU-2	1K Waterbased UV PU
Cure Type	oxidative	oxidative	aziridine	isocyanate	**UV**
Pot Life (hours)	n/a	n/a	8-24	4-6	**n/a**
Dry Time between Topcoats (hours)	8-12	2-3	2-3	2-3	**2-4**
Time to Light Traffic (hours)	24	24	24	24	**immediate after UV cure**
Time to Rug Replacement (days)	14	7-14	7-14	7	**immediate after UV cure**
VOC (g/l)	450 - 550	220 - 350	235 - 390	240 - 350	**<200**
Flashpoint (°F)	110	>200	>200	>200	**>200**
Price $/gallon	25	42	75	93	**150**
Adhesion	+	++	++	++	++
Nickel Test	-	---	+	+	+
BHMR	++	+	++	++	++
Hardness	-	-	-	+	++
Solvent Resistance	+	--	+	-	++
Chemical Resistance	-	--	-	-	++

Conventional and UV Curable Technologies - Concrete

All conventional concrete coatings are multi-component systems, and the two-component epoxy/amine and urethane (isocyanate/polyol) are the most common. These epoxy and urethane coatings require more than one day before return to service. Faster curing systems include polyaspartic and methyl methacrylate coatings, which can be returned to service in hours instead of days. However, the pot life of these fast curing systems dramatically compromises the open time necessary for proper application, and can result in wasted product and deficiencies in appearance and product performance.

The rate of cure of multi-component systems are also limited by temperature, and are often unacceptable for refrigerated end uses or cold weather application. Other disadvantages of conventional concrete coatings include volatile organic content (VOC), odor, ease of cleaning, exterior durability, and abrasion resistance. UV curable concrete coatings can address many of the shortcomings of these conventional concrete coatings. Table 4 summarizes the major points of comparison between conventional and UV curable concrete coatings.[3] Also, improvements in durability, hardness, solvent resistance, and chemical resistance have been noted in the literature of UV curable concrete coating suppliers.[4]

Table 4. Comparison of Conventional and UV Curable Concrete Coatings

COATING TECHNOLOGY	CURE SPEED	POT LIFE	VOC	ODOR	EASE OF CLEANING	EXTERIOR DURABILITY	ABRASION RESISTANCE	PRICE
EPOXY	Hours to Days	1-4 Hours	Low	Low	Moderate	No	Moderate	Low
URETHANE	Hours to Days	< 1 Hour	Low	Low	Moderate	Yes	Good	Moderate
POLYUREA	Minutes to Hours	< 1 Hour	Low	Low	Moderate	Some	Excellent	Moderate
POLYASPARTIC	Minutes to Hours	< 30 Minutes	Low	Low	Moderate	Yes	Excellent	High
METHYL METHACRYLATE	1 Hour	< 10 - 20 Minutes	High	High	Good	Yes	Good	High
UV CURABLE	Instant	Infinite	Low	Low	Excellent	Yes	Excellent	High

To date most, if not all, of the work on field applied UV curable concrete coatings has been based on 100% solids UV materials. In contrast, work on field applied UV curable wood coatings has been based almost exclusively on waterbased UV materials. As discussed earlier, waterbased UV coatings can deliver benefits to field applied concrete coatings. More specifically, some of these benefits are: elimination of zipper marks, ease of matting, elimination of skin irritation concerns, and the ability to recoat without intermediate UV curing steps. A recent paper evaluated the use of waterbased UV coatings in field applied decorative concrete applications, and found comparable performance to the excellent performance previously seen with 100% solids UV curable concrete coatings. This data is presented in Table 5.[5]

Conventional and UV Curable Technologies – VCT

Conventional VCT coatings are typically based on waterborne acrylic copolymers. These coatings are short-lived due to low durability, and require frequent polishing/renovation. They can be classified as low, medium, or high maintenance depending on the frequency of required burnishing, which can be from one to five times per week. Additionally, these coatings are frequently stripped and reapplied. Thus, the maintenance costs and down times associated with these coatings can be quite high.

UV curable coatings can address many of the issues associated with conventional VCT coatings. They are durable and stain resistant, resulting in a low maintenance coating with reduced aggregate costs and down times. The properties of UV curable coatings are also fully developed immediately after UV cure, providing immediate return to service with floors that are resistant to damage. Table 6 summarizes the comparison of UV and conventional VCT coatings. The data for this comparison were obtained from manufacturer data sheets and brochures.

Recent lab work compared the performance of field applied UV curable VCT coatings with a medium maintenance and a low-medium maintenance conventional VCT coating. Both 100% solids and waterbased UV coatings were evaluated, and the results are discussed later in this paper.

Table 5. Comparison of Field Applied UV Curable Waterbased and 100% Solids Concrete Coatings

	WATERBASED UV	100% SOLIDS UV
GLOSS	74	90
ADHESION	4A	4A
PENCIL HARDNESS	4B	2B
SOLVENT RESISTANCE (MEK double rubs)	200+	200+
CHEMICAL RESISTANCE (24 hour spot test)		
Mustard	5	4 - Stain
Water	5	5
Formula 409	5	5
Pickle Juice	5	5
Brake Fluid	5	5
Transmission Fluid	5	5

5 – No coating lift/distortion/stain
4 – No coating lift/slight distortion/slight stain
3 – Slight coating lift/moderate distortion/moderate stain
2 – Moderate coating lift/severe distortion/severe stain
1 – Severe coating lift/complete stain

UV Cure Processing and Formulating Variables

In 100% solids UV curable coatings, shrinkage upon cure can be significant, which can then develop stress in the coating. As the coating relaxes over time, this stress is removed, and the coating properties can change as a result. Many refer to this as "dark cure", although it is doubtful that additional curing is taking place. In waterbased UV curable coatings, shrinkage is greatly reduced, so stress build in the coating should be diminished, resulting in coating properties that do not change over time. Table 7 demonstrates that the properties of both the 100% solids coating and the waterbased coating are the same immediately after cure and over a period of 72 hours, indicating that no "dark cure" is occurring in either coating.[2] This confirms that UV curable coatings achieve fully developed properties immediately after UV cure.

Table 6. Comparison of Conventional and UV Curable VCT Coatings

PROPERTY	WATERBASED CONVENTIONAL FINISH	WATERBASED UV CURABLE COATING	100% SOLIDS UV CURABLE COATING
Number of coats (average recommendation)	**4-5**	**2**	**1**
Application Time (relative)	**4-5 x**	**2 x**	**x**
Total Dry Time (hours)	**2-2.5**	**3-4**	**0.5 (flow/level)**
UV Cure Time (relative)	**0**	**1-2 x**	**x**
Time to Fully Developed Properties (days)	**4**	**immediate after UV cure**	**immediate after UV cure**
Maintenance Time (relative)	**high**	**low**	**low**
Lifetime (relative)	**x**	**4-10 x**	**4-10 x**
Coverage (sq ft/gallon)	**2000-3000**	**500**	**500**
Aggregate Cost (Equipment and Coatings)	**-**	**+**	**+**
Strippability (relative)	**+**	**+/-**	**+/-**

Since floor finishes typically use multiple coatings, the effects of the number of UV coatings and their curing processes were previously investigated. For waterbased UV coatings that are tack free before cure, a second coating may be applied as soon as the first coating has dried. An intermediate UV cure step is not required, but may be used if desired. In order to facilitate intercoat adhesion, an intermediate cure step should use less energy than that required for full cure (typically 1/3 of full cure). If the first coating is fully cured, another way to insure intercoat adhesion is to lightly sand before application of the second coating.

Table 8 shows that the properties are essentially unchanged for a one coat system, a two coat system that has been individually cured, or a two coat system that has been simultaneously cured.[2] The only differences are small changes in gloss, and a softer coating for a one coat system. Since both time and energy can be saved by simultaneously curing a two coat system, and there is no effect on coating properties, this is the recommended procedure if two UV topcoats are desired.

Photoinitiator levels are an important processing variable for UV curable coatings. Previous work for one system has shown that formulations with lower photoinitiator levels, although adequate, have a narrow cure window, only 50 – 60 fpm. Increasing the photoinitiator level resulted in a wider cure window, from 50 fpm to >99 fpm.[2] Formulations with wide cure windows allow greatly different cure speeds to provide the same coating properties, thus providing flexibility to the contractor who applies and cures the coating. In optimizing the coating formulation, the photoinitiator concentration should be chosen to meet both cost constraints and the desired width of the cure window.

Table 7. Property Development versus Time for
100% Solids and Waterbased UV Curable Coatings

	TIME AFTER UV CURE						
	initial	1 hour	4 hours	8 hours	24 hours	48 hours	72 hours
GLOSS							
100% solids UV	90	90	90	90	90	90	90
Waterbased UV	75	75	75	75	75	75	75
ADHESION (610 tape)							
100% solids UV	4A	4A	4A	4A	4A	4A	4A
Waterbased UV	5B	5B	5B	5B	5B	5B	5B
MUSTARD RESISTANCE (60 min: 100% solids; 30 min: waterbased)							
100% solids UV	4	4	4	4	4	4	4
Waterbased UV	5	5	5	5	5	5	5
PENCIL HARDNESS							
100% solids UV	4B	4B	4B	4B	4B	4B	4B
Waterbased UV	3B	3B	3B	3B	3B	3B	3B
SOLVENT RESISTANCE (MEK double rubs)							
100% solids UV	200+	200+	200+	200+	200+	200+	200+
Waterbased UV	200+	200+	200+	200+	200+	200+	200+

5 – No coating lift/distortion/stain
4 – No coating lift/slight distortion/slight stain
3 – Slight coating lift/moderate distortion/moderate stain
2 – Moderate coating lift/severe distortion/severe stain
1 – Severe coating lift/complete stain

Experimental Details

Materials

VCT tiles were obtained from Armstrong: Civic Square, pattern 54004. The unfinished side was used for evaluation after cleaning with isopropanol to remove dust and wiping dry.

Foam brushes (3 inch) were obtained from Home Depot. An Accuscan moisture meter from Delmhorst Instrument Co. was used to determine moisture content of the concrete tiles. Fine mesh filters were obtained from Gardco.

Two conventional floor finishes based on waterbased acrylic copolymers were used as received from the manufacturer. The directions for use were followed for each of these products.

Oligomers, monomers, photoinitiators, defoamers, and waterbased UV curable polyurethanes were obtained from Cytec Industries Inc., and were used as received. Additives were obtained from Byk Additives & Instruments, silica from PQ Corporation, butyl carbitol from The Dow Chemical Company, and ammonium hydroxide from EMD Chemicals, and were used as received. Deionized water was prepared using a Barnstead NANOpure® Diamond™ Analytical ultrapure water system Model D11901.

The coatings were cured using a laboratory cure unit from HID Ultraviolet, LLC. This laboratory cure unit consists of a mobile curing unit (Bulldog 15-3000) equipped with a 250 watts per inch medium pressure continuous wave xenon lamp. It is mounted on a conveyor system with variable belt speed (Dynomometer) to enable ease of laboratory work. The curing unit was calibrated using a 390 Belt Radiometer from International Light Technologies.

Table 8. Coating Properties of a Single Coat System versus a Two Coat System (Waterbased; Individually and Simultaneously UV Cured)

	SINGLE COAT	TWO COATS INDIVIDUALLY CURED	TWO COATS SIMULTANEOUSLY CURED
GLOSS	17.5	15.3	19
ADHESION	5B	5B	5B
NICKEL TEST	4-distortion	4-distortion	4-distortion
PENCIL HARDNESS	4B	HB	HB
BHMR	5	5	5
SOLVENT RESISTANCE (MEK double rubs)	200+	200+	200+
CHEMICAL RESISTANCE (24 hour spot test)			
Mustard	5	5	5
Betadine	5	5	5
RIT dye (navy, undiluted)	4-stain (5 at 30 minutes)	4-stain (5 at 30 minutes)	4-stain (5 at 30 minutes)
Xylene	5	5	5
Ethanol	5	5	5
Isopropanol	5	5	5
Water	5	5	5

5 – No coating lift/distortion/stain
4 – No coating lift/slight distortion/slight stain
3 – Slight coating lift/moderate distortion/moderate stain
2 – Moderate coating lift/severe distortion/severe stain
1 – Severe coating lift/complete stain

Procedures
The waterbased UV coatings (Table 9) were prepared by agitating the waterbased polyurethanes, then adding the defoamer. The remaining components were preblended, and then added to the waterbased UV polymer mixture while continuing to agitate. Mixing was continued for 5 minutes after all the components were incorporated. The mixture was strained through a 190 micron fine mesh filter to remove particulates, and then allowed to de-air for 24 hours. The viscosity of the resulting formulation was measured at 25° C using a Brookfield DV-II + viscometer equipped with a #21 spindle.

The 100% solids UV coating was prepared by mixing under agitation all components shown in Table 9, except the oligomer for coating properties and the defoamer. The oligomer, which had been heated overnight at 65° C to reduce viscosity, was then added under agitation, followed by the defoamer. Mixing was continued for twenty minutes to insure homogeneity. The mixture was then allowed to de-air for 24 hours. The viscosity of the resulting formulation was measured at 25° C using a Brookfield DV-II + viscometer equipped with a #21 spindle.

The UV coatings and conventional finishes were applied to the vinyl composition tiles with a foam brush at a wet film thickness of 6-7 mils (UV) and 1 mil (conventional), as measured with a Gardco wet film gauge. One coat each of waterbased UV and 100% solids UV was applied. Four coatings of each conventional finish were applied, with approximately 30 minutes drying time between coats. The waterbased coatings and finishes were allowed to dry, as determined with the Accuscan moisture meter. After drying (waterbased) or flow/leveling (100% solids UV), the UV curable coatings were UV cured at an exposure of 300 mJ/cm^2 (waterbased UV), and 400 mJ/cm^2 (100% solids UV).

Coating properties of the VCT coatings were determined as shown in Table 10. These properties were evaluated immediately after UV cure, and 24 hours after the last conventional coating was applied.

Results

Table 11 shows the properties of two conventional VCT floor finishes and three starting point formulas for UV curable coatings. The UV curable coatings consisted of waterbased matte, waterbased gloss, and 100% solids gloss. One coat each of the UV curable coatings was applied resulting in a dry coating thickness of approximately 2 mils for the waterbased coatings, and 6 mils for the 100% solids coating. Four coats of the conventional floor finishes were applied, resulting in a final dry coating thickness of about 1 mil. The UV curable coatings were cured as indicated in Table 9.

Discussion

Table 11 shows that gloss and hardness is about the same for the UV and conventional gloss VCT finishes. Increased hardness is seen with the matte waterbased coating, and this may be due to the presence of the matting agent particles. The matte coating also has the expected lower gloss. Adhesion and solvent resistance are much improved for the UV curable coatings, and the UV curable coatings show much better chemical/stain resistance for all twelve of the chemicals that were tested.

Table 9. Starting Point Formulations for UV Curable VCT Coatings

PRODUCT	MATTE WATERBASED UV (%)	GLOSS WATERBASED UV (%)	GLOSS 100% SOLIDS UV (%)	PURPOSE/PROPERTY
Waterbased UV Curable Polyurethane 1	89.32	--	--	Resin for desired coating properties
Waterbased UV Curable Polyurethane 2	--	93.32	--	Resin for desired coating properties
UV Curable Oligomer 1	--	--	25.00	Resin for desired coating properties
UV Curable Oligomer 2	--	--	15.00	Resin for surface cure
UV Curable Monomer 1	--	--	20.00	Multi-functional monomer for cross-linking and hardness
UV Curable Monomer 2	--	--	27.60	Monomers for viscosity reduction
Water (deionized)	0.50	--	--	Diluent for viscosity adjustment
Ammonium Hydroxide (28%)	0.50	--	--	Base for pH adjustment
Matting Agent	3.00	--	--	Matting agent for gloss reduction
Defoamer	0.18	0.18	2.00	Additive for foam control
Butyl Carbitol	1.00	1.00	--	Coalescing agent for film formation
Additive	2.00	2.00	--	Additive for flow and leveling
Photoinitiator Package	3.50	3.50	5.40	Photoinitiator for surface and through cure
Amine Synergist	--	--	5.00	Additive for surface cure
	100.00	100.00	100.00	
Coat at 5-7 mils with a T-bar or flat pad applicator on VCT, and allow to dry or flow and level				
UV cure at exposure necessary to get a mar free surface (mJ/cm^2)	500 typical	500 typical	400 typical	Crosslinked polymer for resistance properties and aesthetics

Conclusion

The performance of field applied UV curable waterbased and 100% solids VCT coatings has been compared to that of conventional VCT floor finishes. The UV curable coatings show better adhesion, solvent resistance, and chemical/stain resistance than the conventional floor finishes. This improved performance is applicable to the floor finish immediately after the UV curing step. No extended cure

Table 10. Methods of Measurement of Coating Properties

PROPERTY	METHOD
Cross-Cut Adhesion	ASTM D 3359-07; Test Method B; 610 tape
Pencil Hardness	ASTM D 3363-05
Chemical Resistance (Spot Test)	ASTM D 1308-02; with various exposure times, and various methods of application
Solvent Resistance (MEK Double Rubs)	ASTM D5402-06 (Method 3; 2 lb. ball peen hammer)
60° Gloss	ASTM D 523
Nickel Test	Drag a standardized nickel on edge across the coated wood using firm pressure
BHMR (Black Heel Mar Resistance)	Impact the coated wood with the edge of a black shoe heel, by using a backward motion of the leg

time is needed for the development of the properties. These improved properties translate to decreased maintenance times, and reduced aggregate costs.

Table 12 summarizes the performance data and the technology comparison data that was presented earlier. It clearly shows the benefits of a UV curable VCT floor finish.

Whether applied on wood, concrete, or VCT, UV curable coatings have clear advantages over conventional coatings. UV curable coatings for these three substrates have some advantages in common, such as fast return to service with fully developed properties, and reduced VOCs. Other improvements are specific to substrate, such as no pot life issues for concrete or wood coatings, and improved adhesion for VCT. Table 13 summarizes the general benefits of UV curable coatings versus conventional coatings for wood, concrete, and VCT substrates.

References

1. *"New UV- Curable Coatings for the Resilient Flooring Industry",* D. Bontinck and M. Idacavage. *RadTech Report*, May/June 2003, pages 50-55.

2. *"Field Applied UV Cured Topcoats for Wood",* J.A. Arceneaux. Proceedings, Third International Coating Wood and Wood Composites Conference, September 2009.

3. *"Field-Applied, UV-Curable Coatings for Concrete Flooring"*, P.T. Weissman. *RadTech Report*, January/February/March 2009, pages 25-32.

4. See www.rapidshield.com and www.uvolvecoatings.com

5. *"Field Applied UV Curable Concrete Coatings"*, J.A. Arceneaux. Proceedings, Second Annual Coatings for Concrete Conference, February 2010.

Table 11. Properties of Conventional and UV Curable VCT Floor Finishes

PROPERTY	MATTE WATERBASED UV	GLOSS WATERBASED UV	GLOSS 100% SOLIDS UV	MEDIUM MAINTENANCE FINISH	LOW-MEDIUM MAINTENANCE FINISH
GLOSS	7	84	88	78	70
ADHESION	5B	5B	5B	0B	0B
PENCIL HARDNESS	B	4B	4B	4B	4B
SOLVENT RESISTANCE (MEK double rubs)	200+	200+	200+	10	10
CHEMICAL RESISTANCE (24 hour spot test)					
Mustard	5	5	3 - Stain	3 - Stain/Dist	3 - Stain/Dist
Betadine	4 - Stain	5	3 - Stain	1- Stain	1- Stain
RIT Dye (navy, undiluted)	5	5	3 - Stain	3 - Stain	3 - Stain
Xylene	1 - Distortion	3 - Distortion	2 - Distortion	1 - Lift	1 - Lift
Olive Oil	5	5	5	5	3 - Distortion
Formula 409	5	5	5	1 - Lift	1 - Lift
Vinegar	5	5	5	2 - Distortion	2 - Distortion
Water	5	5	5	4	3 - Distortion
Ethanol (50%)	4 - Stain	4 - Distortion	5	1 - Distortion	1 - Distortion
Isopropanol (99%)	4 - Stain	5	5	1 - Lift	1 - Lift
Isopropanol (70%)	4 - Stain	4 - Distortion	5	2 - Lift	2 - Lift
Windex	5	5	5	1 - Lift	1 - Lift
NICKEL TEST	4 - Distortion	4 - Distortion	4 - Distortion	1 - Lift	1 - Lift
BLACK HEEL MARK RESISTANCE	5	5	5	5	5

5 – No coating lift/distortion/stain
4 – No coating lift/slight distortion/slight stain
3 – Slight coating lift/moderate distortion/moderate stain
2 – Moderate coating lift/severe distortion/severe stain
1 – Severe coating lift/complete stain

Table 12. Value Proposition of Field Applied UV Curable VCT Floor Coatings

PROPERTY	WATERBASED CONVENTIONAL FINISH	WATERBASED UV CURABLE COATING	100% SOLIDS UV CURABLE COATING
Application/Dry/Cure Time	+	+	++
Immediate Property Development	--	++	++
Maintenance Time	--	++	++
Lifetime/Durability	--	++	++
Aggregate Cost (Equipment and Coatings)	-	+	+
Strippability	+	+/-	+/-
Gloss	+	+	+
Adhesion	--	++	++
Hardness	+	+	+
Chemical/Stain Resistance	--	++	++

Table 13. Value Proposition of Field Applied UV Curable Floor Coatings on Wood, Concrete, and VCT

PROPERTY	UV CURABLE COATING		
	WOOD	CONCRETE	VCT
Pot Life	+/=	+	=
VOC	+	+	+/=
Odor	=	+/=	=
Application/Dry/UV Cure Time	=	-	++
Immediate Property Development	++	++	++
Return to Service Time	++	++	++
Ease of Cleaning	+/=	+	++
Maintenance Time/Costs	no data	+	++
Lifetime/Durability	+	+	++
Aggregate Cost (Equipment and Coatings)	-	-	+
Strippability	not applicable	not applicable	+/-
Gloss	=	=/-	=
Adhesion	=	=	++
Hardness	++	+/=	+/=
Chemical/Stain Resistance	++	+/=	++
Solvent Resistance	++	+/=	++
Hot Tire Pickup Resistance	not applicable	+	not applicable
Black Heel Mark Resistance	=	not applicable	=
Nickel Test	+/=	not applicable	++

General References

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