Field-Applied, UV-Curable Coatings for Concrete Flooring

By Peter T. Weissman


Squeegee application.

Concrete floor coatings vary widely—from their chemical nature to their speed of drying, to their physical and chemical performance characteristics. The most common concrete floor coatings are based on two-component Epoxy—Amine or Urethanes (isocyanate – polyol). These systems typically require between two and six hours before they can be recoated and more than 24 hours before they can be returned to service. Additionally, these systems often utilize solvent to extend pot life, improve flow and leveling, or improve adhesion by promoting penetration of the concrete.

Faster curing systems have been developed which include Polyaspartics (isocyanate reacted with prepolymers of amines and maleates) and Methyl Methacrylate (MMA)-based coatings. While the most reactive of these coatings cure very rapidly (from minutes to hours), they dramatically compromise the open time necessary for proper application (sometimes even requiring plural component spray equipment). MMA-based floor coatings also have a high percentage of Volatile Organic Contents (VOCs) and are flammable. In addition, some of the most reactive systems (such as MMA and Polyureas) have a significant and unpleasant odor that typically requires heavy ventilation or air filtration.

Within just the past few years, UV (Ultraviolet)-curable coatings have been developed in an effort to address some of the shortcomings of available concrete coating systems on the market. The most powerful value proposition for the adoption of UV curing for concrete floor coatings is

Table 1

Comparison of common commercial floor coating chemistries

Material	Cure Speed	Price	VOC	Ease of Cleaning	Pot Life	Exterior Durability	Abrasion Resistance
Epoxies	Hours to Days	Low	Low or zero	Moderate	1-4 hours	No	Moderate
Urethane	Hours to Days	Moderate	Low or zero	Moderate	< 1 hour	Yes	Good
Polyurea	Minutes to Hours	Moderate	Low or zero	Moderate	< 1 hour	Some	Excellent
Polyaspartic	Minutes to Hours	High	Low or zero	Moderate	< 30 min	Yes	Excellent
Methyl Methacrylate	1 Hour	High	High	Good	< 10 to 20 min.	Yes	Good
UV-Cured	Instant	High	Low or zero	Excellent	Infinite	Yes	Excellent

near instantaneous cure, which allows a much faster return to service for a given area that is coated. Additional benefits include indefinite pot life, improved cleanability, low to zero VOCs, and excellent exterior durability, as well as excellent abrasion resistance. Table 1 compares various floor coating classifications' qualitative performance for some common properties of interest.

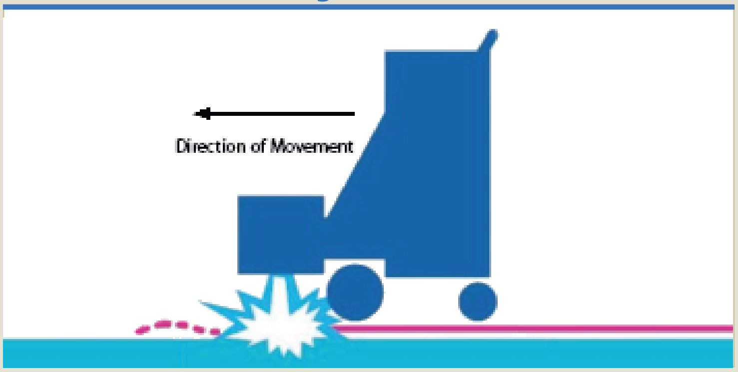
The remainder of this paper will discuss the challenges of moving UV curing technology from factory-applied to field-applied application, procedures necessary for preparation of the floor, application procedures for the coatings, curing of the coatings, and standards that can be used to evaluate a coating's suitability for various concrete applications.

Challenges of Adapting UV Curing Technology to the Field

UV energy has been used industrially to polymerize (or "dry") coatings for more than 35 years. Common uses are scratch- and abrasion-resistant coatings for wood flooring, adhesives, hard coats for automotive forward lighting, and adhesives for DVDs, just to name a few. While there have been small efforts in field-applied applications of UV curing (including some flooring activities) for at least the past 20 years, it was the introduction of UV-cured automotive refinish primers by PPG in 2002 that ushered in a new era of field-applied UV coatings.[1] Until that time, UV-curable coatings were almost entirely relegated to OEM application in which the application and curing equipment are fixed pieces of machinery. In these systems, the application of the coating to the part is typically highly automated by utilizing engineer-controlled roll coaters, spray equipment, printing machines, etc. The curing lamp is virtually always in a static position and utilizes focusing reflectors to achieve maximum energy density of the UV light for optimal cure of the part. If the surface of the part to be cured is three-dimensional, multiple lamps are utilized to achieve maximum uniformity of exposure.

Figure 1

Schematic of UV curing unit



In field-applied, UV-curable coatings, the part to be coated is static while the UV lamp is mobile and the area to be cured is much larger than the aperture of the UV lamp. Another difference in field-applied floor coatings, when compared to OEM coatings, is the substrate itself. The substrate (in this case the floor) is highly variable in qualities such as surface roughness, porosity, level and type of surface contaminates, and hardness, to name a few. These fundamental differences between the OEM application and the field-applied application of UV technology have significant implications for safety, equipment and the coating itself.

Equipment Challenges

Over the past three years, field-applied, UV-curable coatings for both wood flooring and concrete flooring have begun to take hold. The most basic UV-curing unit for curing field-applied floor coatings consists of a mobile cart that houses the power supply for the lamp. The lamp is attached to the front of the cart and the wheel base of the cart is narrower than the width of the lamp. Figure 1 shows a schematic of a very basic curing unit

In field-applied concrete flooring, many of the standard engineering controls that had been diligently developed by industry and designed into UV-curing systems in order to protect workers from the health hazards of exposure to UV light had to be rethought. Some of the earliest equipment for curing field-applied UV floor coatings had no shutter system and no speed control. These high-powered systems (most are 220 volt, three-phase units) produced enough heat that, if the lamp were at full power and held stationary for more than just a few seconds, it was possible to actually spall the concrete. These initial systems also did a poor job of shielding around the light, and there was a great deal of reflection of UV energy off the floor which placed workers at risk of exposure to UV. The condition of the concrete also created specific issues that are at least partially dealt with via equipment engineering controls.

Concrete floors are highly variable in their overall condition. Most will have some number of cracks and divots. The surface roughness may also vary significantly from just a few microns to many tens of microns. The challenges these present to the coating that can be managed through the chemistry will be discussed shortly. For the equipment, there are two significant implications. First, it is difficult to position the lamp very close to the concrete (i.e., within a millimeter or two), since the lamp unit itself will move vertically as the unit is pushed across the floor. Second, the coating thickness is not at all uniform when compared to an OEM application. In flooring, the nominal thickness of the coating is typically 75 to 100 microns (0.003 to 0.004 inches) with variations of up to 25% or even 50% being common. As will be described in greater detail later, it is critical that there be sufficient power in the lamp system for light to reach through the coating to the coating-concrete interface despite these large variations in coating thickness. In addition, if the speed at which the lamp is moved over the coating is also highly variable, process control can become impossible.

Safety and PPE

The mobile nature of the UV-curing unit for floor coatings, along with the fact that curing often takes place with a number of other persons working in close proximity, means that Personal Protective Equipment (PPE) is essential to the safe operation of the equipment and handling of the coatings. The industry has adapted specific PPE recommendations made by RadTech in order to protect persons working with this equipment. A key to safe operation of the equipment is UVA/UVB-blocking polycarbonate eye glasses. Eyeglasses that conform to ANSI Z87.1 and EN166-1FT are recommended. These must be worn by anyone working in close proximity to the UV machine. To reduce any accidental exposure to UV, it is recommended that personnel wear long-sleeve shirts, long pants and SPF 45 sunscreen on any exposed area of skin.

Normally, the chemistry used to make UV-curable coatings is not toxic; however, they are frequently skin irritants. Thus, it is recommended that nitrile gloves be used by those handling these coatings or by persons who may come in contact with the uncured coating. If accidental skin exposure to the coating does occur, abrasive soap and water are recommended for its removal.

Equipment manufacturers have moved quickly to address many of these concerns. Table 2 describes some of the engineering controls and recommendations that have been put in place to improve both safety and process controls.

Formulation Challenges

Several unique aspects of UV-cured, field-applied concrete coatings impact the chemistry. First, as was mentioned above, the substrate itself is highly variable in its porosity, hardness and roughness. Hardness and porosity of the concrete impacts the tendency of the coating to be absorbed into the concrete where it is not accessible to the UV light and, therefore, will not polymerize. Cracks, which are common in concrete, are also areas where these coatings can become hidden from enough UV light to initiate polymerization. Viscosity, raw material molecular weight and rheoligical aids can all be used to help control the tendency of the coatings to be absorbed into the concrete. However, care must be taken so the coating remains in intimate contact with the concrete or adhesion may be compromised. Some companies have developed two-component, dual-cure systems (thermally initiated as well as

Table 2

Engineering controls, PPE and procedure for safe operation of field-applied floor coating lamp systems

Feature	Purpose
Shutters – either manually controlled or tied to movement of the machine	• Reduce possible accidental exposure as the machine is lifted or moved • Reduce possibility of damaging a floor
Speed Control – either manually pushed with a speed readout gage, or mechanically driven	• Improve process reproducibility
Shielding	• Decrease exposure of workers to UV
Mandatory use of UV protective eye wear	• Decrease exposure of workers to UV
Use of clothing and creams to protect skin from stray UV light	• Decrease exposure of workers to UV
Cordoning off a safety area within which PPE is mandatory	• Decrease exposure of adjacent areas and the workers within them to UV

Backroll application.

UV initiated) so that the coating can still polymerize in areas hidden from the UV light. However, two-component systems inherently have a pot life associated with them that tends to take away from the value proposition of indefinite open time.

A less obvious consequence of changing from OEM applications to field-applied applications is a result of the ratio of the size of the coated areas to be cured relative to the size of the UV light. In OEM applications, the width of the part being cured is always narrower than the width of the UV lamp it passes underneath. The exact opposite is true in field-applied concrete floor coatings, where large areas of coating are applied to the floor and then a relatively small lamp is rolled over top of the coating curing as it proceeds. As the lamp is rolled over the coating, it rapidly transforms from 100% uncured to fully cured as it is exposed to the light. At the edges of the light there exists a zone of exposure where light leakage is sufficient to initiate polymerization but insufficient to drive it to completion. This causes a cure gradient to be present at any particular point in time, which exists from some two to three inches away from the edge of the lamp, where the conversion is zero, to the center of the lamp where the conversion reaches nearly 100%. In the case of the front edge of the lamp, this is of little consequence as the lamp moves forward relatively quickly and the cure gradient zone is ever moving into a region of the high intensity part of the light that drives the coating to full conversion. However, the adjacent edges of the light that are perpendicular to the direction of lamp travel are a different situation.

These adjacent edges are also characterized by the cure gradient zone as described above. Unlike the front edge, this partially cured material remains in that state until the light is turned around and overlaps this same area on the return pass. If these systems were cured by either ring opening or additional chemistry, this might not be a problem. However, unlike some of these other reactions, radical double bond conversion reactions shrink significantly (up to 25% by volume for the types of materials used in coatings formulations).[2] In this region of partially cured material, the coating is not yet vitrified and, as the shrinkage occurs, the coating can distort. This sometimes shows up as physical markings that resemble a zipper and have in the industry been appropriately coined “zip marks.” These zip marks are difficult to eliminate entirely, but certainly the development of formulations that minimize shrinkage also minimize this phenomenon. This shrinkage phenomenon can also make matte coatings very difficult.

Matting agents work by causing small perturbations at the surface of a coating, essentially causing a micro-roughness that refracts light—thus dulling the surface.[3] Shrinkage that occurs at the edge of curing necessarily causes the surface in this region to be distorted in a way that is different from the surrounding material and, thus, the gloss is also different. The impact is to cause stripes of higher gloss which correspond to the edges of the curing unit as it proceeds across the coated area. Again, reducing the shrinkage of the coating will aid in minimizing this effect. This remains a problem in search of a solution.

The final major area that is difficult for field-applied concrete coatings is the use of colors. Color is frequently found in concrete coating, with the majority of pigmented coatings being some shade of gray. However, numerous safety colors such as red and yellow are also frequently used. UV curing these relatively thick coatings while maintaining full hiding is exceptionally difficult due to the necessity of having UV light penetrate the entire depth of the coating. Making matters even more difficult is the variability in the roughness and general condition of the concrete itself. Even under good conditions, it is difficult to obtain a nominal coating thickness on concrete floor with a variation of less than 25% thickness. Photoinitiator choice and level is critical to the success of UV-curable pigmented concrete floor coatings. However, dosage control has also been found to be critical and equipment will play a role as to whether or not one succeeds with these coatings.

Floor Preparation for Coating with UV

Floor preparation varies significantly based on the condition of the concrete, old coatings that need to be removed, contamination of the concrete, and moisture issues for on-grade slabs. Fundamentally, all of these issues need to be considered when preparing the concrete surface, no matter what resin floor is being applied. There are three common methods used to prepare concrete for resin coatings: chemical washing/cleaning, mechanical shot blasting and diamond grinding.

Chemical washing and cleaning is used primarily for the preparation of garage floors. Typically, an acid wash is used to remove light contaminates from the surface of the concrete and provide a light etching for the coating upon which to adhere. However, this technique can often leave contaminates (such as oils) below the surface of the concrete, which can then exude into the coating or interrupt the bond line interface between the coating and the concrete. This method of concrete preparation is not considered sufficient when the concrete to be coated is in light or heavy industrial applications.

Mechanical etching of the concrete surface is considered the ideal method of preparation for the application of a resin coating and is consistent with the preparation necessary for a UV-curable coating. The roughness of the concrete surface after preparation is of paramount importance for UV coatings. Shot blast is a quick, cost-effective method to obtain a clean surface to which the UV coating can adhere. However, shot blasting can also result in extreme roughness and unevenness of the substrate if it is not performed by a skilled technician. This roughness and unevenness can result in the requirement of an excessively thick primer coating (as much as 0.5 to 1 mm or 0.020 to 0.040 inches) making the coatings difficult to properly cure.

By contrast, diamond grinding with a quality three-head orbital grinder can result in an exceptionally flat floor. This flat surface is ideal for UV coatings. In this case, a relatively thin (0.1 to 0.15 mm or 0.004 to 0.006 inches) primer coat can be applied and is sufficient to obtain the very flat surface necessary to utilize a UV-curable color coat in the process. However, in the case of older floors that have been repeatedly coated (whether it is the entire floor or just lines or signage), shot blasting is often the only practical (from a time perspective) method of completely removing these coatings from small cracks, from divots, or just due to the unevenness of the entire concrete area to be coated. In this case, there are two options. One can either use a UV coating designed for high build applications (0.25 to 1 mm or 0.010 to 0.040 inches) or an additional grinding step can be used after the shot blasting to achieve a surface with greater uniformity, thus allowing the use of a thinner primer coat.

Application of UV-Cured Coatings

Application is another area of dramatic deviation from previous uses of UV-curable coatings. Normally, UV-cured coatings are applied using precision equipment, such as roll coaters, spin coaters or printing presses. Here, the UV coating is applied utilizing conventional trade practices such as squeegees and paint rollers. The basic process of applying the coating to a previously prepared concrete slab is indicated in the steps below.

1. Dispense the coating onto the area to be coated.
2. Spread evenly with either a rubber squeegee or 1/8-inch nap, lint-free roller.
3. Back roll with a larger (wider) 1/8-inch nap, lint-free roller until coating is of uniform thickness with minimal or no lapping marks.

Completed Rapidshield application.

4. Cure using a portable curing unit (more about this later).

It is important that the required film build of coating be uniformly applied to the area being coated. Spreading the coating over the area via a squeegee is preferred over rolling, as it is quicker and reduces air entrainment in the coating. However, back rolling with a large roller is also important to improve the uniformity and final appearance of the coating. Care must be taken not to leave large, visible overlap marks from


Rapidshield application.

the back rolling. After back rolling, the amount of time the coating should be allowed to de-air depends upon which coating layer has been applied. Small bubbles in either a primer coat or color coats are not nearly as critical as bubbles in the topcoat.

Curing of the UV Coating

The method of curing a UV-curable coating is what truly separates it from the other floor coating technologies. As with all UV curing, it is not only the effective irradiance that is important but also the effective energy density, particularly when curing colors. Insufficient irradiance or energy density can result in coatings that are undercured. Undercuring can manifest itself in the most obvious case such as a coating that is not yet solid. However, particularly in the case of pigmented coatings, the coating can easily be cured on the surface but the bottom of the coating will be lacking cure. This may show up as poor adhesion of the pigmented coating to the primer or, if severe enough, the coating can still be liquid underneath. For topcoats, undercure can negatively impact the surface cure and make the coating more susceptible to abrasion, staining and loss of gloss.

There is also the danger of overcuring a coating, in particular a primer or color coat, which will be subsequently overcoated. Overcuring such coatings will compromise the adhesion of the next coating to the first and, thus, compromise the integrity of the entire system. In extreme cases of overcuring, it may even be possible to physically damage the coating. Such damage typically shows up as cracking or discoloration. Thus, when operating the curing unit, it is critical that the coating supplier's guidelines for exposure be strictly followed.

In general, it is only the speed of the curing unit and, thus, the dose that the operator can control, thereby impacting the cure of the coating. The energy density is typically a fixed parameter of the curing unit's physical and electrical specifications. Also typically fixed is the spectral output of the lamp (this must be tuned to the photoinitiators used to make the coatings) by the choice of a standard medium-pressure mercury vapor lamp or a doped mercury vapor lamp. In general, it is impractical to switch lamp types during the course of a job.

Care must be taken during curing of the floor coating to ensure as much uniformity as possible over the entire area to be cured. Speed should be held as constant as possible and the specific overlapping criteria established by the coatings manufacturer should be carefully followed.

Suitability of UV-Cured Concrete Floor Coatings

Determining the "suitability for use" of a floor coating is exceptionally difficult due to the large number of issues—such as concrete contamination and moisture in on-grade slabs—outside of the control of the coating supplier and often the contractor. Suppliers give general guidelines for use of their products but do not warranty suitability for a specific application. Typically, the end-user must make judgments based on data supplied by the coatings suppliers or on the experience of the contractor performing the work. A review of Internet-available supplier technical data sheets shows there is little consistency of the data reported. Often what is reported is whatever the suppliers believe is advantageous for their technology (i.e., the epoxy supplier provides tensile strength and modulus data, while a polyurethane supplier will provide flexural modulus and mandrel bend). However, often the reported properties are not particularly relevant to the performance of the coating when applied to the concrete.

A different approach to evaluating floor coatings can be seen in the European Standard EN 1504-2: Products and systems for the protection and repair of concrete structures – Definitions, requirements, quality control and evaluation of conformity – Part 2: Surface protection systems for concrete. This standard defines the requirements for products that are meant for five "principles:"

1. Protection against ingress;
2. moisture control;
3. physical resistance/surface improvement;

TABLE 3

Performance test associated with EN 1504-2

Property	ISO	ASTM	Description
Viscosity (cP)		D2196-05	for non newtonian fluids
Specific Gravity	2811-1 / 2811-2	C 128	
Coefficient of Thermal Expansion	EN 1770	C531	Thermomechanical Analysis
Abrasion Resistance (mg/1000 cycles, CS17, 1Kg)	ISO 5470-1	D4060	Taber Abrasion
Adhesion by cross-cut test	ISO 2409	D3359	Relevant for Intercoat adhesion only
Adhesion strength by pull-off (N/mm2 or MPa)	EN 1542	D7234 or D4541	Primers/Sealers or entire system
Slip/skin resistance	EN 13036-4		Pendulum Test
Permeability to water vapor	ISO 7783-1/ 7783-2	E96 / E96M-05	Class I: Permeable Class III: Not permeable
Capillary absorption and permeability to water	EN 1062-3		For Exterior applications
Chemical resistance	2812-1	D543-06	Emersion Test: Containment
Impact resistance	6272-1	D 6905	No cracks or delaminations
Fire classification	EN 13501-1		
Antistatic behavior	EN 1081		Class I Explosives Class II (Explosive Hazardous Substances)
Adhesion on wet concrete (N/mm2 or MPa)	EN 13578		
Adhesion after thermal compatibility (N/mm2 or MPa)	EN 13687-1 EN 13687-2 EN 13687-3		7dys @ 70°C Water Storage Freeze-thaw w/ and w/o deicing salt
Dry Heat Resistance		ASTM D2485-91 (2007)	Service Life Exposure

4. resistance to chemicals; and
5. increasing receptivity by limiting moisture control.

Table 3 lists some of the performance tests and associated ISO and ASTM test methods that are part of the EN1504-2 standard.

Conformity of a coating or coating system is evaluated based on the test specified for each "principle." Coatings that conform to the standard are issued a European Community (EC) certificate of conformity and may be labeled with the CE mark for the "principle" to which they conform. Not all tests are required (though each "principle" does have certain tests that are required), but rather the standard identifies meaningful tests that an end-user can evaluate and decide if they are applicable to his/her end use. The end-user may also wish to add other properties to the list of tests in Table 3, such as gloss, Rz values, VOC and (for UV-curable coatings) irradiance and energy density.

Conclusions

There are many choices of concrete floor coating technologies available in today's market such as epoxies, polyurethanes (and other isocyanate based systems) and methymethacrylates. Recently, UV-curable coatings have been developed specifically for concrete. These coatings cure nearly instantaneously, allowing the area being coated to be returned to service hours and even days before the aforementioned coatings. However, the challenges of moving UV technology from tightly controlled OEM applications to the highly variable environment of field-applied applications range from equipment development and modifications, to safety procedures and guidelines, to formulation modifications that deal with the porosity and variability in the concrete.

Though methods used to prepare

the concrete floor for a UV coating are similar to those for other concrete coating technologies, concerns over the flatness of the floor were shown to be more critical for UV coatings. The methods for applying UV coatings were likewise determined to mimic those of other technologies, and important parameters involving the coating thickness and uniformity were identified. The need to achieve acceptable cure by using equipment that delivers the appropriate irradiance and energy density and by controlling the speed to deliver the proper energy were also discussed. Both undercure and overcure conditions should be avoided. Finally, the need to be able to evaluate concrete floor coatings for suitability for use was discussed. European standard EN1504-2 was outlined and suggested as proper methodology for determining suitability for use.

The information discussed above shows that despite the many challenges associated with bringing UV technology to the world of concrete coatings, transformations have successfully occurred. The high cure speeds of UV technology allow a floor contractor to apply coatings to areas they could never have considered before due to the long time required before they could be returned to service.

References

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