A Comparison of UV Cured Wood Floor Finishes to Conventional 2K Coatings

David Folkman

Alberdingk Boley

6008 High Point Road

Greensboro, NC 27407

Introduction

Waterborne (WB) coatings have become a viable choice for the protection of wood floors. Compared to solventborne finishes, they offer advantages such as fast dry times, low VOC and odor and excellent durability. Amongst WB finishes, 3 categories exist :(1) Single component (1K), two component (2K) and Ultra-Violet Cure (UV). These 3 finish types have many common characteristics and a few large differences. While 1K products can meet most of the basic flooring performance requirements, they tend to offer the least durability and will not be included within the scope of this paper.

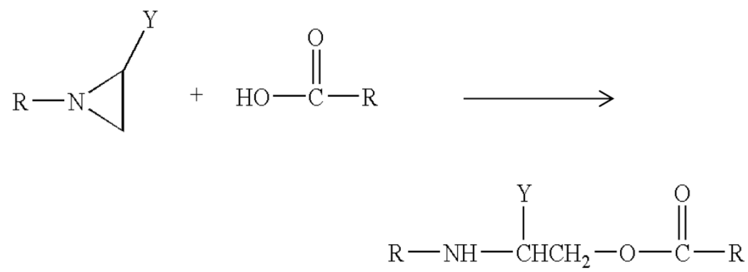
The 2K and UV finishes are built on Polyurethane Dispersion (PUD) chemistry. These resins can be tailor made by the reaction of isocyanates with polyols followed by dispersion and chain extension in water. By varying the isocyanate and polyol type, PUDs can have a broad range of properties. In the case of UV PUDs, the production process is the same but with the inclusion of a reactive acrylate.

Formulation of 2K and UV resins are conducted by finish formulators in very similar ways. Most commercially available additives, i.e. thickeners, defoamers, dullers, flow and leveling agents will perform in similar ways in both WB PUD and UV systems. Additionally, these types of resin are compatible with other types of polymers, e.g. acrylics, WB alkyds and other PUDs. This adaptability will carry through to the finish manufacturer. The same mixers and production techniques can be employed to produce a high quality finish.

On-site application techniques do not have to change as well. The contractor does not need to make alterations to the way they apply the finish. T-Bar, roller and brush application works well as in conventional systems. Because formulas are possible at 30% solids, the finishes will apply at 500 to 600 square feet to the gallon with equal film build like standard finishes.

Another similarity of the 2 systems is their need to dry through the evaporation of water and co-solvent. As these liquids leave, the particles begin to densely pack together. Eventually the particles begin to deform and dissipate into each other. Finally they are completely interfused and form a mechanically stable film. The film is now dry and ready for the crosslinking to take place. It should be noted that drying is not the same as crosslinking. It is essential that all of the water must be removed out of the film for UV cure coatings. Trapped water will cause defects that produce milky-white areas.

The 2K finishes predominantly use 2 types of crosslinkers, polyfunctional aziridines and isocyanates. The polyfunctional aziridine will react with carboxylic acid functionality on the PU backbone (Scheme 1).



Scheme 1. Aziridine reaction with carboxylic acid functionality

This reaction will improve the PUD's physical and chemical resistance properties. Typically, 2 to 3 percent aziridine is stirred into the finish at the job site. Crosslinking results in a tough finish. The pot life of this blend is about 18 to24 hours. After the end of the pot life has been reached, the finish can also be reinoculated and continue to be used. The crosslinking of this combination will be completed in about 24 hours.

One of the most popular crosslinkers for floor finishes is isocyanates. The isocyanate reacts with hydroxyl and carboxyl groups on the polyurethane to produce a high end finish. The isocyanate is typically added to the finish at a 10:1 ratio and then mixed in. This combination will have about a 4 hour pot life and will take about 3 days to fully cure.

The chemistry of UV curing is a photochemical process whereby ultraviolet radiation in the presence of photoinitiator is used to crosslink the coating. The process is achieved through a free-radical mechanism using a photoinitiator to kick off the polymerization. The UV radiation splits the photoinitiator into free radicals which react with the double bonds of the UV resin. This produces more free radicals and the process continues until termination is achieved. With the use of multifunctional resins, a three dimensional network can be created and the crosslink density can be controlled to meet the needs of a variety of coatings applications. Because water is very efficient in viscosity control, the UV resin can have high molecular weight and functionality, leading to higher coating performance. Photoinitiators are added by the formulators during the manufacture of the finish. No post addition is required in the field. Therefore, pot life is not a concern.

Recently there has been an increase in the number of manufactures of portable UV curing machines. This has caused an increase in the number and types of curing units available on the market as well as a reduction in the cost. The equipment manufacturers offer a full line of machines to do jobs ranging from small rooms to entire warehouses. The power output of the mercury lamps of these machines varies from 1500 watts in the 110V machines to 3000 watts in the 220V machines. Therefore, in order to properly cure the finish the speed the machine travels across the floor must be proportional to its power output. A 3000 watt machine can travel twice as fast as a 1500 watt machine to achieve equal properties. The prices to the contractor for these machines range from about $3500 for a 110V to $7000 and up for a 220V.

Four wood flooring finishes have been evaluated in this project. Two of them are UV cure finishes, one particularly noted for its outstanding chemical and scratch resistance and hard-elastic properties (UV PUD 1). The second has lower hardness prior to cure but is promoted to have overall good properties (UV PUD 2). Also included are 2 commercial 2K water-based floor finishes. The first is a widely used, standard product on the market which requires isocyanate to crosslink (Comm NCO). This finish is often noted as the best floor finish available. The other is a polyfunctional aziridine crosslinked finish that is still amongst the top sellers in this market and is promoted as a very hard finish (Comm Az). The testing was designed around using the Maple Flooring Manufacturers Association (MFMA) gym floor specifications as a guide.

Experimental

The products were formulated as described in Table 1. *The finishes were adjusted to 30% weight solids and a satin gloss.*

	1% Photoinitiator	*2% Photoinitiator*	*3% Photoinitiator*
Water Based UV Resin	*76.39*	*75.39*	*74.39*
Defoamer	*0.16*	*0.16*	*0.16*
Flow Additive	*0.28*	*0.28*	*0.28*
Water	*21.22*	*21.22*	*21.22*
Benzophenone/Alpha Hydroxy Ketone Blend	*1.00*	*2.00*	*3.00*
Silica Duller	*0.75*	*0.75*	*0.75*
Thickener	*0.20*	*0.20*	*0.20*
Total	*100.00*	*100.00*	*100.00*

Table 1. WB UV Formulations

It was of interest to investigate the impact of photoinitiator level (1 to 3 %). Also, the flooring performance was evaluated when the speed of the curing machine was varied from 10 to 30 feet per minute.

Figure 1 shows the VOC of the commercial products as advertised at 125 g/L for the isocyanate crosslinked finish and 350 g/L for the aziridine crosslinked finish. The WB UV finishes have a calculated VOC of 39 g/L.

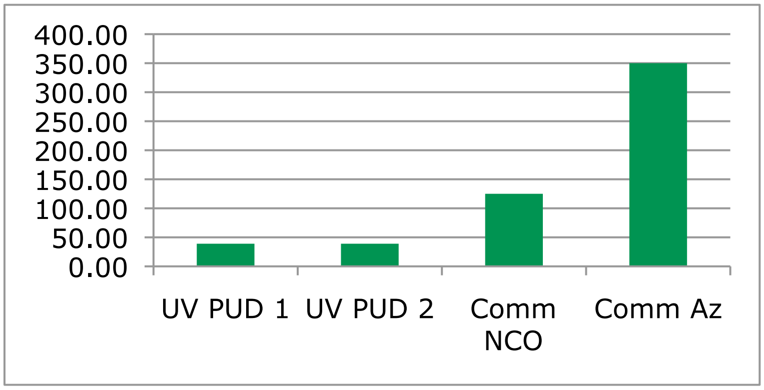


Figure 1. VOC in g/L

The finishes were tested for the following properties:

60 Degree Gloss	Heat Stability	Sanding
Hardness Before Cure	Hardness After Cure	Black Heel Mark Resistance
Adhesion at Recoat	Coefficient of Friction	Taber Wear
Fingernail Mar	Scratch Resistance	Chemical Resistance

Evaluations were performed on the 2K coatings after 1 week of cure, while the UV tests were run immediately after cure.

It should be noted that the gloss of the UV finishes and the commercial aziridine system are in the satin range. The commercial isocyanate finish had a super matte appearance. See Figure 2 for the gloss level range.

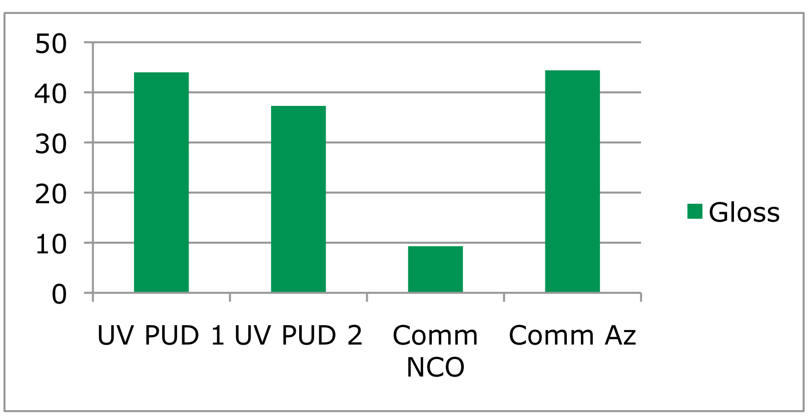


Figure 2. Gloss levels for wood finishes

***Stain Resistance* (ASTM D 1308):** Materials:

DI Water, 1.5% Pine Sol solution, Vegetable Oil (4 hour dwell)

50% alcohol/water solution, Naphtha, Beer (Yuengling) and Coca-Cola (1 hour dwell)

On a Leneta chart a 3 mil wet film was cast and allowed to dry and cure. A 1-2 inch diameter pool of the staining liquid was applied and allowed to stand on the surface at 25°C for 1 or 4 hours under a watch glass. The watch glass was removed and the coating rinsed with water and allowed to dry for 60 minutes. Evaluation for any objectionable alteration of the surface, such as discoloration, change in gloss, blistering, softening, swelling, or loss of adhesion indicated failure.

Heat Stability: Samples were placed into a 50°C oven for 48 hours and examined for freedom from sediment and suspended solid matter.

Sanding: All samples were subjected to sanding with a 100 grit sanding disk and observed for "gumming" or rolling.

Adhesion: Cross-hatch adhesion test.

Fingernail Mar: On a Leneta chart a 3 mil wet film was cast and allowed to dry and cure. Samples were rubbed with a fingernail and noted for any marring.

Coefficient of Friction: On a Leneta chart a 3 mil wet film was cast and allowed to dry and cure. Using a spring balance connected to 100 gram weight with a leather shoe, slowly increase the force until the weight begins to slide. Make sure the spring balance is parallel to the surface. The reading on the spring balance scale when the load begins to slide is a measure for the static friction. The coefficient of friction $\mu = Ff / Fn$ The finish must achieve a CoF reading between 0.50 to 0.70.

Black Heel Mark Resistance: On a Leneta chart a 3 mil wet film was cast and allowed to dry and cure. Using a hockey puck to simulate a black heel, strike the film to produce a black mark.

Scratch Resistance: On a Leneta chart a 3 mil wet film was cast and allowed to dry and cure. Record the gloss (60^o) of the coating. Apply a 2 inch square from a green Scotch Brite Scrub Pad. Place a 200 gram weight on the pad. Slide the pad back and forth across the surface of the coating for 10 double rubs. Remove the pad and record the gloss. Report % gloss lost.

Koenig Pendulum Hardness: Make a 150 micron draw down on a glass panel. Measure Koenig hardness before cure.

Results and Discussion

All of the samples passed most of the chemicals with exception of the 50%/50% isopropyl alcohol/water test. Figure 3 indicates which samples showed failures after1 hour exposure. For the UV cure coatings it is clear optimal performance can be achieved by either increasing the photoinitiator level or by decreasing the speed of the machine. This result emphasizes the need to balance the speed of the machine with the photoinitiator level to achieve the desired properties. It is not clear why the isocyanate crosslinked finish failed this test.

	UV PUD 1	UV PUD 1	UV PUD 1	UV PUD 2	UV PUD 2	UV PUD 2	Comm NCO	Comm Az
	1% PI	2% PI	3% PI	1% PI	2% PI	3% PI	n/a	n/a
10 FPM	**Pass**	**Pass**	**Pass**	**Pass**	**Pass**	**Pass**	**n/a**	**n/a**
20 FPM	**Pass**	**Pass**	**Pass**	**Fail**	**Pass**	**Pass**	**n/a**	**n/a**
30 FPM	**Fail**	**Pass**	**Pass**	**Fail**	**Fail**	**Pass**	**n/a**	**n/a**
2K After 1 Week	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**Fail**	**Pass**

Figure 3. IPA resistance test results

All of the finishes passed testing for heat stability, sanding, adhesion, fingernail mar and CoF. Figure 4 shows the hardnesses of the finishes as measured in Koenig seconds. UV PUD 1 is significantly harder than UV PUD 2 prior to UV cure. High hardness is essential to allow walking on a coated floor before curing. It also allows the application of 2 coats before the final cure. Walking on UV PUD 2 will leave undesirable footprints on the floor surface. The hardness data shows us the immediacy of the UV cure. While the 2K systems took 1 week to reach their final hardness, the UV cured finishes achieved their hardness within seconds and most of the UV formulations were significantly harder than the 2K coatings. It was also noted the photoinitiator can have a plasticizing effect on the uncured finish. This effect can be seen in the hardnesses of UV PUD 2 at equal speed. The hardness goes down slightly as the photoinitiator level is increased. As expected, as the curing speed is increased the hardness decreases as well. Thus, it would be critical for contractors to understand the speed/performance balance during application.

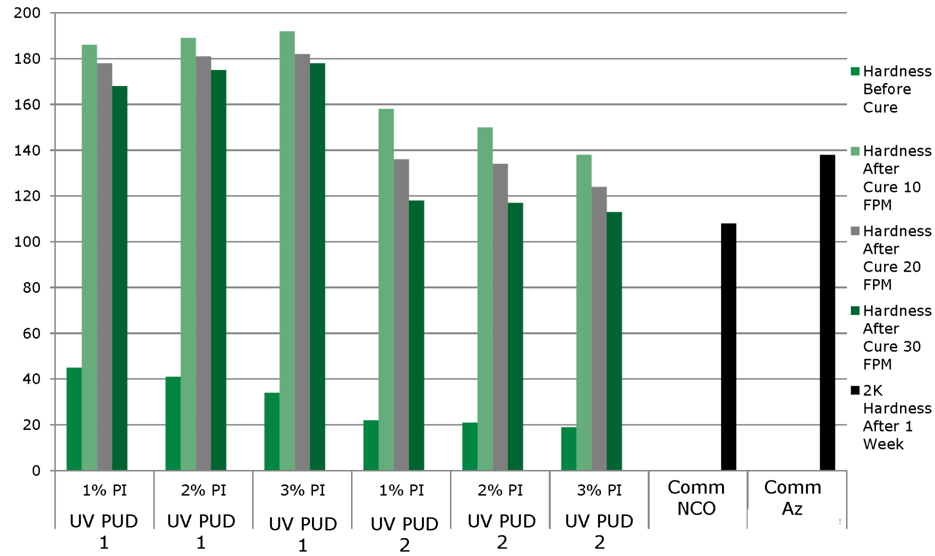


Figure 4. Koenig hardness in seconds

The black heel mark resistance (BHMR) was evaluated by striking the coating with a hockey puck. Figure 5 shows that both UV finishes have better BHMR than the isocyanate crosslinked finish. With the proper combination of machine speed and photoinitiator level, they both outperform the 2K finishes.

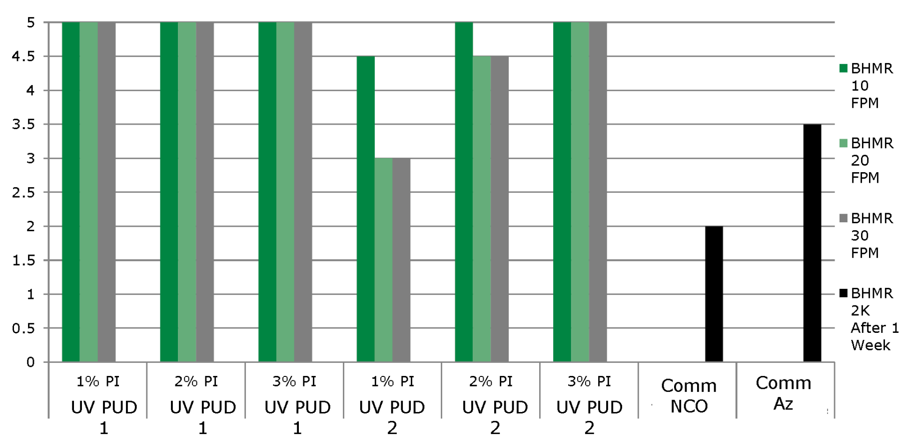


Figure 5. BHMR

The taber wear was measured in milligrams lost after 1000 cycles with 1000 grams load using the CS-17 wheel. Figure 6 shows the aziridine crosslinked 2K finish had the poorest results while the UV cured finishes performed as well or better than the isocyanate crosslinked finish. The UV polymers have been custom designed to give hard-elastic features that make these materials less brittle.

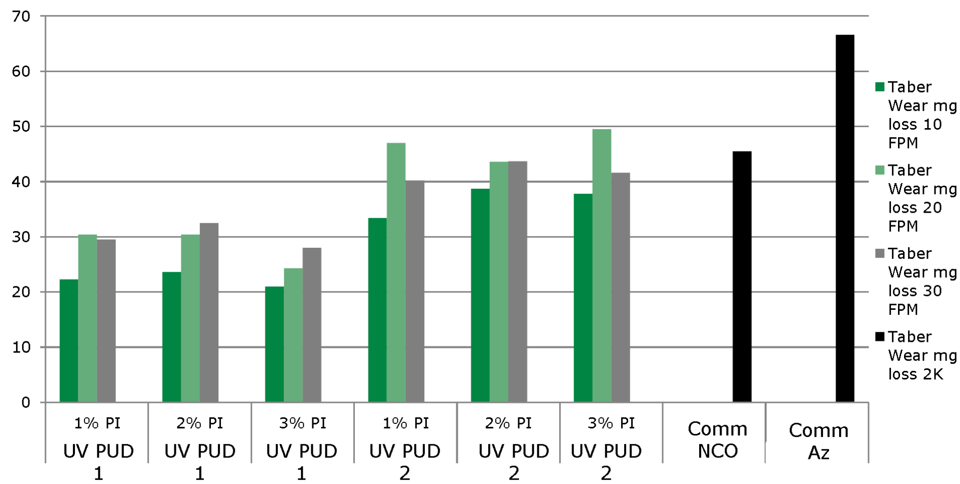


Figure 6. Taber abrasion

Gloss Loss is measured by taking a green Scotch Brite pad with a 200 gram weight and passing it over the film ten times, recording the gloss before and after. The higher the number, the more gloss loss. Figure 7 shows both of the UV cure finishes significantly outperform the 2K systems. While all of the finishes are based on polyurethane chemistry and have densely crosslinked networks, the higher hardnesses of the UV cured surfaces contribute to lower gloss losses.

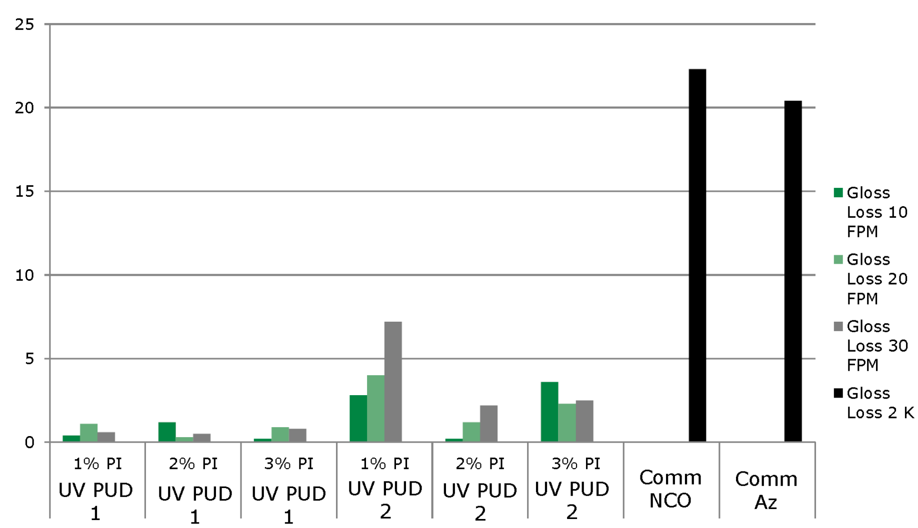


Figure 7. Gloss Loss

Conclusion

In this study, WB UV finishes have been compared to WB 2K finishes according to specifications outlined by MFMA. The WB UV coatings show clear performance advantages including, better BHMR, scratch resistance, taber wear resistance and higher hardness. The UV formulations are also significantly lower in VOC, have a longer pot life and remove the need to handle any crosslinking chemicals on the job site increasing the safety of workers. Due to the immediate cure of this technology, productivity improvements can be gained by quicker return to service. These benefits are clearly recognized in the industry and have recently led to the creation of a new group of materials recognized by the MFMA, "Group 6 – High Gloss UV Finishes". Further developments are in progress investigating the application of UV finishes on vinyl composite tile (VCT).