



WATER

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B O R N E RESINS for Industrial Wood Coatings

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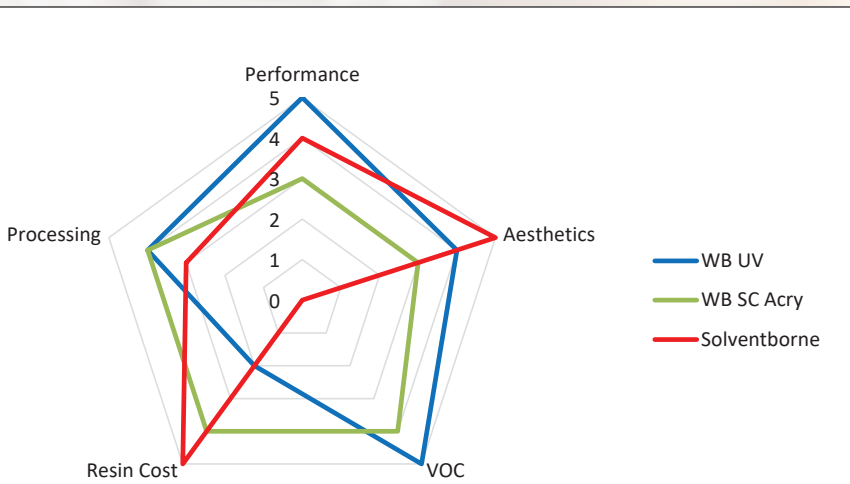
Industrial wood coatings encompass several market areas, including furniture, kitchen cabinets, building products, and decorative coatings. Requirements for these markets largely depend on their field of application.

Exterior performance is focused on high durability and protection against humidity, while interior coatings require properties such as scratch, chemical and abrasion resistance. One of the largest sectors of the interior market is the furniture industry.

Several resin technologies are being used by coatings formulators in this market, including solventborne (SB), waterborne (WB) UV polyurethane dispersions (PUDs), and self-crosslinking acrylics. Several criteria are of importance in considering which technology to use.

Each technology has advantages and disadvantages, and a comparison has been summarized based on the criteria in *Figure 1*. The dominant technology used in North America is solventborne, including nitrocellulose (NC) and acid cure conversion varnish. These coatings have many benefits, including fast dry time and very high gloss, and they enhance the wood appearance. They are also very economical and can be easily applied by spraying, rolling, curtain coat, and dipping.

FIGURE 1—Resin Technology Comparison



However, a significant disadvantage of using these materials is the high level of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) and the limited varnish pot life. Due to increasing regulations for lower VOC and formaldehyde emissions, more environmentally friendly coatings are now in demand.¹ This shift has opened the door to waterborne technologies, including UV PUDs and self-crosslinking acrylics.

UV PUDs are increasingly gaining acceptance in the market as a replacement for solventborne because they have very low emissions. They offer high-end performance with minimal process issues. Since UV PUDs are high-molecular-weight polymers, the crosslink density of the cured networks compared to 100% solids is lower, limiting shrinkage after cure and resulting in excellent adhesion to most substrates. They inherently yield good mechanical performance because they have hard urethane and urea domains that can have hydrogen bonding, coupled with softer domains that come from the choice of raw material building blocks such as the polyols.

Some of the challenges with using WB UV are related to processing. It is essential that water is completely released prior to cure, and factors such as humidity must be considered to minimize production of defective parts due to incomplete drying. Additionally, the cost of this technology is higher compared to SB.

Self-crosslinking (SC) acrylic dispersions are also included amongst WB resin technologies. Overall, they have good durability and can be formulated into high-performance coatings with a low coalescent demand due to phase-separated morphologies in the polymer particles. Several types of morphologies can be achieved depending on the polymerization strategy that is applied, which also influences film properties such as block resistance. These materials can also be blended with WB UV resins to offer a more economical formulation while maintaining excellent performance.

Areas of concern include the presence of surfactants that are required for the colloidal stabilization of the

TABLE 1—Basic Properties of Water-based Resins

	TYPE	KOENIG HARDNESS BEFORE UV (SEC)	KOENIG HARDNESS AFTER UV (SEC)	MFFT (°C)
UV PUD 1	Polyester PUD	50	155	0
UV PUD 2	Polyester PUD	20	145	0
UV PUD 3	PU-Acrylic Copolymer	10	125	0
AC01	Single phase, self-crosslinking acrylic	—	—	45
AC02	Multiphase, self-crosslinking acrylic	—	—	45
AC03	Multiphase, self-crosslinking acrylic	—	—	22
AC04	Multiphase, self-crosslinking, low surfactant acrylic	—	—	25

polymer particles. Such components can migrate to film surfaces imparting water sensitivity into the film or may lead to foaming issues during formulation. Regarding aesthetics, acrylics also are not especially noted for enhancing the appearance of the wood substrate and most often they lack wet clarity. While WB acrylics are higher solids compared to SB/NC lacquer, they generally do not produce a smooth haptic touch.

In this article, water-based technologies, including UV-curable PUDs and SC acrylics, have been evaluated for industrial wood coatings. These resins have been designed to fulfill the range of requirements needed for adequate protection of the substrates, minimizing formulation issues and ease of processing. *Table 1* provides basic properties of the resins used to formulate these coatings. This investigation will further detail the comparison of these resins to traditional resin types used in these markets.

EXPERIMENTAL

All resins were formulated for industrial wood applications according to the Kitchen Cabinet Manufacturers Association (KCMA)², Architectural Woodwork Standards (AWS)³, and individual furniture manufacturer's specifications. All formulations were adjusted to be equal in solids and included standard additives such as defoamer, surfactant, matting agent, rheology modifier, and photoinitiator. (Example in *Table 2*).

Coated wood panels were prepared following the four steps outlined below:

1. Sprayed approximately 3 wet mils of coating over 18x18 stained maple panel.
2. Air dried for 10 minutes.
3. Force dried for 10 minutes at 50 °C.
4. Cured with a mercury bulb at 500 mJ/cm² (For UV-curable)

After sanding with a 3M Superfine Sanding Sponge, a second coat was applied at approximately 3 wet mils. Repeated steps 2 through 4. There is a wait period of 14 days before testing unless otherwise indicated in the test method.

Furniture Test Methods

Chemical/Stain Resistance: Apply enough chemical/stain to create a 0.25- to 0.5-inch diameter spot on the test panel. Cover with watch glass. Wait 16–20 hours. Remove chemical/stain and wash the surface of the panel with water. Rate each chemical/stain on a scale of 0 to 5, with 0 indicating complete destruction of the film and 5 indicating no effect on the film.

TABLE 2—Water-based UV Formulation

	UV FORMULA
UV PUD 1	79.27
Surfactant	0.57
Defoamer	0.57
Water	17.91
Photoinitiator	0.94
Rheology Modifier 1	0.75
% Solids by weight	35.03
VOC (g/L)	< 10

Chemicals Used: Vinegar, lemon juice, orange juice, grape juice, ketchup, coffee, olive oil, 1% detergent solution, mustard, water, acetone-based nail polish remover, ammonia, VM&P Naphtha, isopropyl alcohol (70%), red wine, Windex, 409 cleaner, Lysol, gasoline, Murphy's Oil Soap, 10% TSP, Betadine, Kiwi black shoe polish, 90 spf sunscreen, and plasticizer.

Chemicals Used (KCMA): Vinegar, lemon juice, orange juice, grape juice, ketchup, coffee, olive oil, 1% detergent solution, mustard, water

Scrape Adhesion: Cut 4x7-inch piece from each test panel. Test adhesion with a BYK Balanced Beam Scrape Adhesion and Mar Tester with 5000 grams of weight using the loop stylus. Rate on a scale of 0 to 5 with 0 indicating complete removal of the film and 5 indicating no effect on the film.

Ballpoint Pen Indentation: Cut 4x7-inch piece from each test panel. Test for ballpoint pen indentation with a BYK Balanced Beam Scrape Adhesion and Mar Tester with 300 grams of weight using the small pen #5785. Wait 1 hour before evaluating the panel. Rate on a pass/fail scale. Any indentation that can be seen from a distance of 24 inches is considered a failure.

Plasticizer Resistance: Apply a 2-inch square piece of red vinyl to the test panel. Apply a force of 1/2 lb/in². Place the specimen in an oven at 50°C for 72 hours. After cooling at room temperature for 1 hour, remove the vinyl square. Evaluate for softening and blistering.

Green Print Resistance: After curing the test panel wait 1 hour and then apply a 2-inch square piece of #10 cotton duck cloth to the finish. Apply a force of 2 lb/in² directly to the duck cloth. Wait 24 hours and then remove cotton duck cloth. Evaluate for printing.

Hot Print Resistance: After curing the test panel wait 14 days and then apply a 2-inch square piece of #10 cotton duck cloth to the finish. Apply a force of 1 lb/in² directly to the duck cloth. Place the specimen in an oven at 60°C for 24 hours. Remove the duck cloth and allow the specimen to cool for 1 hour. Evaluate for printing.

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

Scotch Brite Scratch Resistance: Make a 3 mil draw down on a Form 3B-H Leneta card. Air dry for 10 minutes then, force dry for 10 minutes at 50°C. Cure with mercury bulb at 500 mJ/cm². Wait 14 days before testing. Record the gloss (60°) 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 percentage of gloss lost.

Koenig Pendulum Hardness: Make a 150 micron drawdown on a glass panel. Air dry for 10 minutes, then force dry for 10 minutes at 50°C. Measure Koenig hardness before cure. Cure with mercury bulb at 500 mJ/cm². Measure Koenig hardness 1 hour and 7 days after cure.

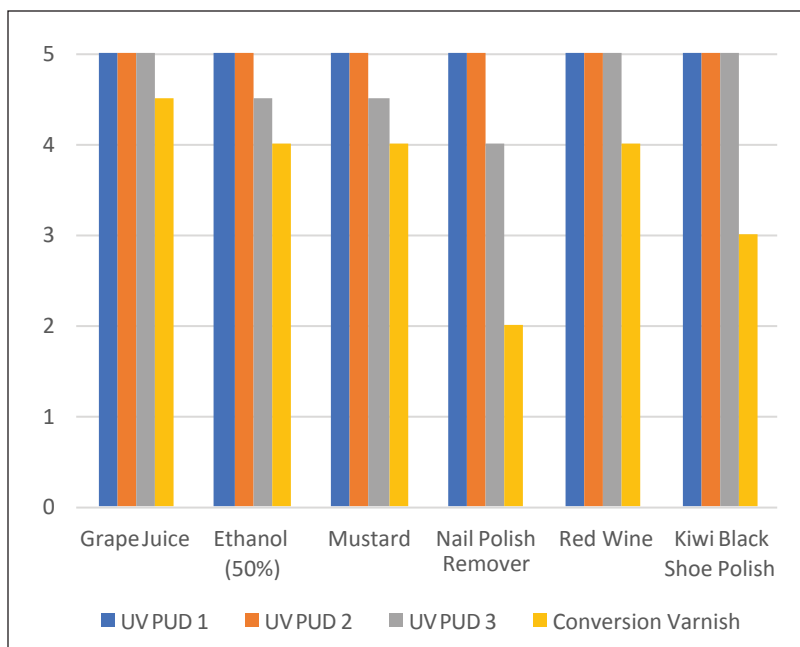
RESULTS AND DISCUSSION

As mentioned previously, one of the predominant choices for solvent-based

coatings for industrial wood applications is conversion varnishes. Conversion varnishes are blends of oil-based alkyds, urea formaldehyde, and melamine. They use a strong acid catalyst such as p-toluene sulfonic acid resulting in a pot life of 24 to 48 hours. Conversion varnishes show very good performance on industrial wood. However, they have very high VOCs and formaldehyde is listed as carcinogenic. A traditional conversion varnish has been evaluated in comparison to coatings based on UV PUDs and SC acrylics. Several tests have been conducted to evaluate performance for furniture/KCMA markets. Various requirements are defined for this market and segmented into institutional versus residential applications

Considering the high crosslink density and stain resistance of UV-cured resins, a more extensive range of chemicals (25 total) was tested for the UV PUDs. Only six chemicals showed differentiation in performance as indicated in Figure 2. The conversion varnish was particularly weak for nail polish remover and shoe polish, but all UV coatings showed excellent resistance. Specifically, UV PUD 1 and UV PUD 2 showed the best performance amongst the group.

FIGURE 2—Chemical Resistance



The coatings based on self-crosslinking acrylics also showed good performance according to the KCMA standard (Figure 3), particularly AC04, which performed the best. It should also be noted that this product has good wet clarity and wood tone and shows excellent hold-out and build on the substrate. It was also observed to have minimal grain raising on the wood surface as compared to the other acrylics. Panels sprayed with conversion varnish show excellent wet clarity, fast drying time, good wood tone and surface wetting.

Water resistance of the coatings has been evaluated by exposure to boiling water and edge soak resistance. In the boiling water test, the panel is directly

exposed to boiling water for a duration of 1 hour and evaluated for any whitening or blistering. The conversion varnish and UV PUD 1 showed only mediocre resistance to boiling water while the other UV coatings showed far superior performance (Figure 4).

All the coatings based on SC acrylics performed far better than the conversion varnish. Performance was better for edge soak testing. This test simulates a detergent-soaked dishcloth laid across a vertical cabinet door. Both the UV-cured coatings and conversion varnish passed with favorable results, while only one of the acrylics (AC01) displayed blushing/blistering. Careful selection of an acrylic must be considered because

surfactants can impart water sensitivity into the film. Thus, it is a great benefit to use materials that contain low amounts of surfactants.

Figure 5 presents the scratch resistance of the coatings and clearly indicates the robustness of UV resins compared to the conversion varnish and SC acrylics. The cured coatings are scratched with a green Scotch Brite scrub pad that contains a 200-gram weight. The gloss is recorded before and after the rubs and a percentage of gloss loss is calculated. The lower the number, the better the performance. All the UV resins performed very well for this test with a gloss loss $\leq 5\%$, while the gloss for the conversion varnish and

FIGURE 3—Chemical Resistance of SC Acrylics

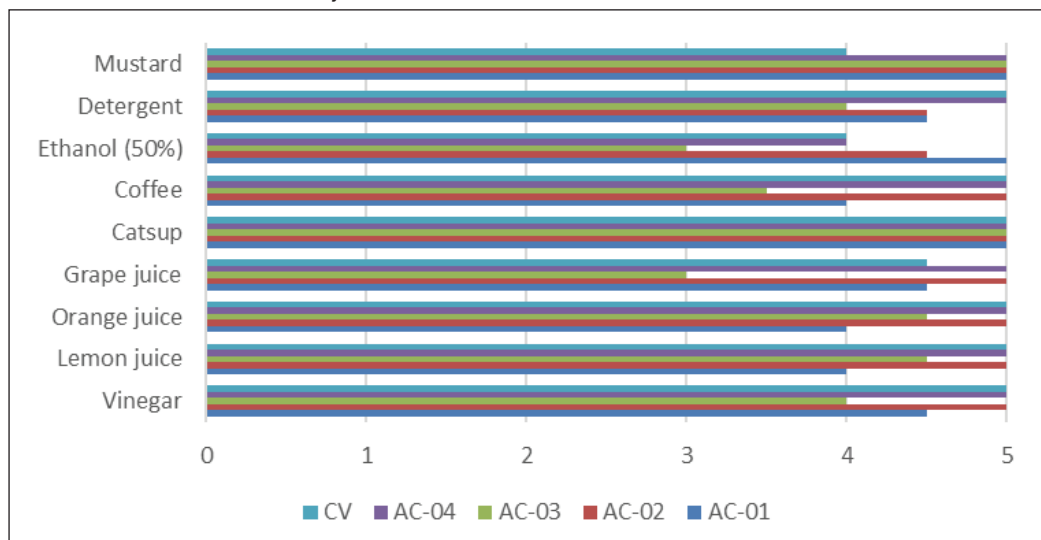
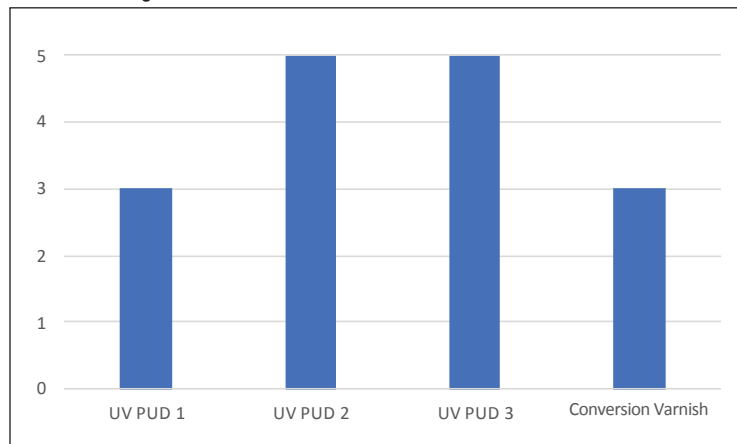


FIGURE 4—Boiling Water Resistance



SC acrylics was reduced by 25–42%. The lower MFFT acrylics performed very similarly to the conversion varnish. Further improvements could be made by blending PUDs with the acrylics to improve abrasion resistance. The high molar mass of the UV PUDs, the dense crosslinked network and the unique morphology of polyurethanes (hard and soft domains) results in a superior balance of chemical and mechanical properties.

Koenig hardness was also measured after UV cure and drying for 7 days (SC acrylics) (Figures 6 and 7). While all the coatings produced hard surfaces (>100 seconds), the conversion varnish and UV PUD 1 were among the hardest (>140 seconds). UV PUD 1 also has moderate hardness prior to UV cure. This provides some benefit especially for blocking properties where coated parts may have some contact prior to curing and surface scuffing is not desired. All the acrylics were much softer in hardness, but AC 04 was the hardest amongst the group (Figure 7). Despite this difference, acrylic-coated parts could meet the blocking performance requirements in an industrial environment.

All the coatings showed good fingernail mar resistance. Further testing with the UV-cured coatings also produced passing results for scrape adhesion, hot and green print resistance, and plasticizer resistance.

CONCLUSION

Waterborne UV-curable PUDs and SC acrylic emulsions are a suitable alternative to SB finishes for industrial wood coatings. They can be formulated at lower VOCs, have no issues with pot life, and can produce a high-performance coating. Waterborne UV technology will continue to penetrate industrial sectors as raw material suppliers and coatings manufacturers better understand the value proposition of this technology.

The UV coatings in this study performed very well in all tests as specified by KCMA and some furniture manufacturer standards. SC acrylics offer a favorable cost/performance balance and further improvements can be gained by blending with PUDs and/or addition of a crosslinker.

FIGURE 5—Scratch Resistance Comparison

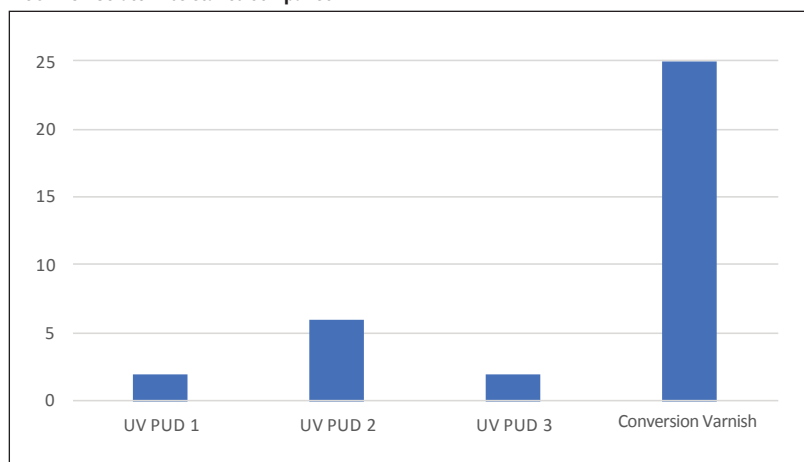


FIGURE 6—Koenig Hardness of UV PUDs

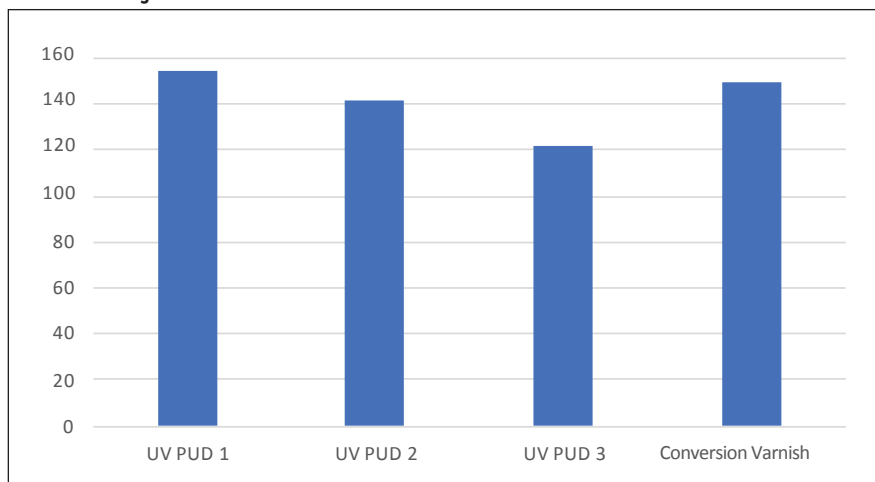
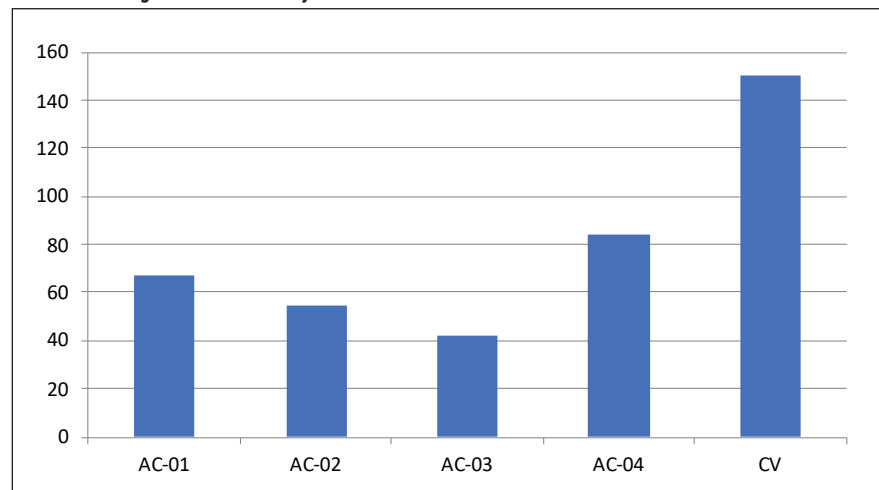


FIGURE 7—Koenig Hardness of SC Acrylics



A new acrylic with low-surfactant content has also been introduced. This new development additionally offers improved application characteristics derived from excellent atomization and wood wetting, good optical clarity comparable to SB systems, wood warmth and low grain raising as compared to conventional acrylics. Further developments continue investigating pigmented formulations. ❄

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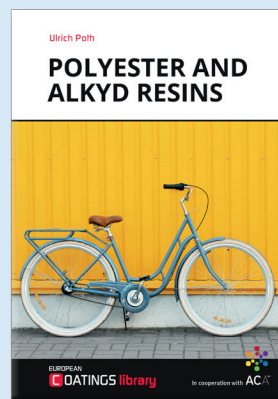
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