

## WATERBORNE UV CURABLE RESINS – CHEMISTRIES AND APPLICATIONS

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Waterborne (WB) UV curable finishes have found wide acceptance in wood furniture and cabinet markets and they are becoming popular choices for plastic coatings, soft-feel paper coatings and contractor applied wood floor coatings. WB UV chemistry is gaining market share because it enables the end user to increase production efficiency and to lower solvent emissions. It has become a viable option for manufacturers that traditionally used solvent based coatings because the transition can be easily accomplished by the addition of a UV curing unit at the end of existing paint lines. The overall system is cost effective because it has increased production speeds, a smaller manufacturing footprint, and lower energy costs.

WB UV coatings have many inherent advantages. They offer excellent block resistance and coated parts can be stacked, packaged, and shipped right off the production line. The hardness development in the coating is dramatic and occurs in seconds. WB UV coatings have excellent chemical and stain resistant properties. Viscosity can be easily controlled with traditional rheology modifiers and water. Their high initial molecular weight provides excellent adhesion due to a low level of shrinkage. WB UV systems have a low film build appearance and provide the look of traditional acid catalyzed coating systems which is popular among most furniture and cabinet manufacturers. The gloss of WB UV systems is easily controlled with traditional matting agents. Easy equipment clean up with water ultimately leads to lower costs. These superior performances coupled with fast, low energy UV curing can provide economical productivity advantages.

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 with a photoinitiator as a catalyst. 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

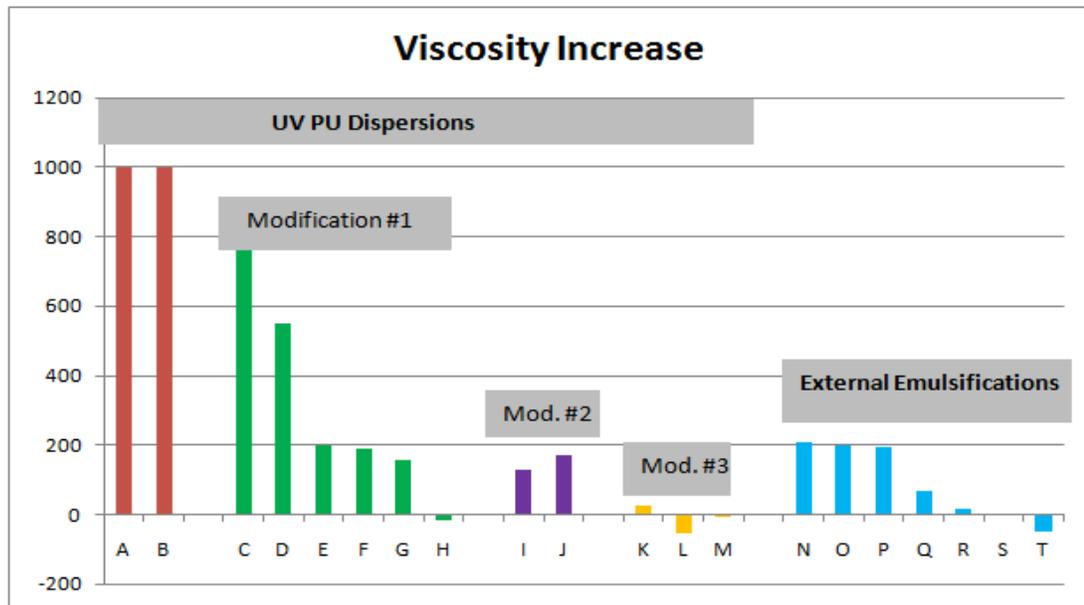
network can be created and the crosslink density can be controlled to meet the needs of a variety of coatings applications. The chemistry of waterborne UV curing follows this reaction process with water being present as the diluent. Because water is very efficient in viscosity control, the UV resin can have high molecular weight and functionality, leading to higher coating performance.<sup>1</sup>

The development of WB UV resin technology has advanced significantly in recent years. Suppliers have a growing ability to tailor the resin for specific performance needs.<sup>2</sup> There are three basic variables used in the industry that influence the final properties of the resin: UV acrylate selection, incorporation method, and modification.<sup>3-5</sup> Because there are multiple combinations and choices resulting from the variables, there are a wide variety of waterborne UV products available with different performance and behavior.

There is a large selection of UV acrylates available with varying backbones and functionalities. The type and amount of this UV functional material used in the final product impacts the final crosslink density of the coating. Types of UV acrylates include acrylics, epoxies, urethanes, and polyesters. It is becoming more common to use these oligomeric or polymeric compounds to add double bond functionality rather than monomeric acrylates.<sup>6</sup>

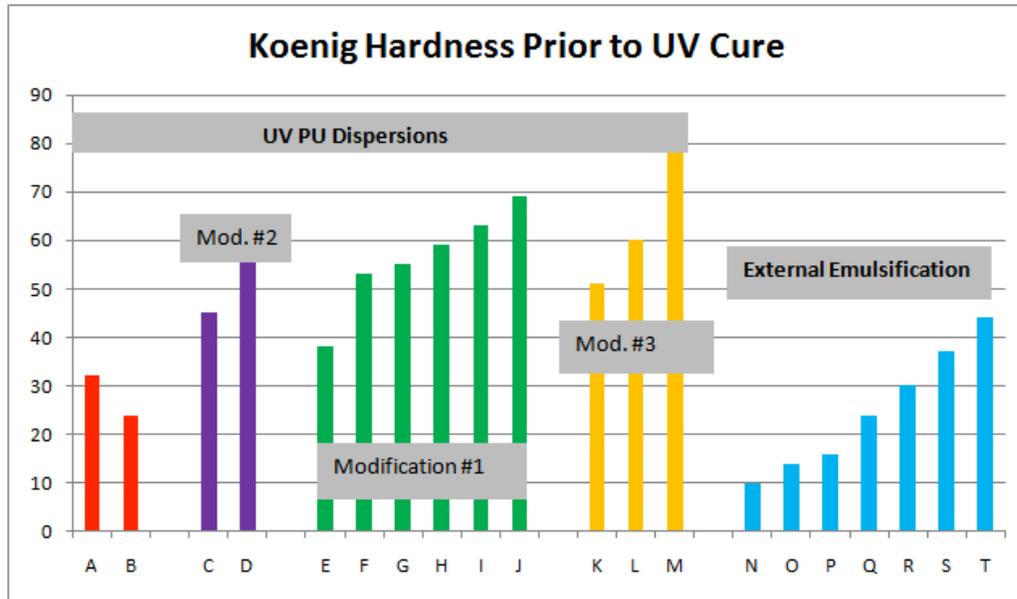
The processing and incorporation of the UV acrylate determines the overall polymeric structure of the final resin and contributes to the macro-properties of the coating. External emulsification and self-emulsifiable dispersions are two examples of UV acrylate incorporation methods. External emulsification is simply the process of distributing the acrylate into water with an emulsifier and high shear forces. This emulsification process is very sensitive and stability issues can arise during the process or in the formulated coating. However, this product type offers the advantages of higher solids and an easy and direct conversion of current 100 percent solid UV systems to waterborne UV using the same basic chemistry.<sup>7</sup> The second method of acrylate incorporation uses polyurethane chemistry to create a UV functional polyurethane dispersion (PUD). These UV PUDs can be polyether, polyester, and/or polycarbonate based and are often referred to as dispersions, UV curable PUDs, or acrylated PUDs. They offer the advantages of polyurethanes such as flexibility and toughness and show the highest growth rate in waterborne UV technology due to their unique performance. There are multiple design and processing parameters that are available for final resin design in the UV PUD family.

The third variable, modification of the resin, is a key differentiator that fine tunes the behavior and performance of the final coating. The modification can be incorporated during or after processing, can include multiple incorporation methods, and can involve other chemistries. These modifications are not typically defined by the supplier and are a key to product differentiation. Common industry examples of such modifications include post addition of an acrylic emulsion to improve exterior durability, modification with surfactants to improve shelf life stability, or the addition of an externally emulsified acrylate to adjust drying properties and crosslink density. Figure 1 shows the effect of incorporation method on elevated temperature (50C) stability.



Level of tack prior to UV cure is an important feature and criteria for UV coating customers and is typically defined for each UV resin. Some customers prefer the coating to develop significant hardness before UV cure, while others prefer the coating to remain tacky. A hard coating surface can protect parts from dust contamination before entering the UV chamber and can also allow a level of performance development even if some areas of the part do not receive sufficient UV radiation. A soft or tacky surface allows better flow into wood pores before UV cure and can help the overspray to be

re-emulsified and reused. Figure 2 shows the effect of incorporation method on tack prior to UV cure.



Another design option for WB UV resins is the incorporation of functional groups with dual cure potential. With these resins, additional crosslinking can occur by reaction of polar groups with polyisocyanates. Advantages of dual curing systems include increased hardness, adhesion, scratch resistance, and chemical resistance. Dual cure is especially recommended for three-dimensional parts in which some sections are not exposed to UV radiation.

Not only is the WB UV coating impacted by the type of resin used, but it is also affected by the other formulation ingredients: surfactants, defoamers, waxes, matting agents, pigments, photoinitiators, and rheology modifiers. With the exception of photoinitiators, the ingredients behave the same in WB UV coatings as they do in traditional acrylic emulsions or polyurethane dispersions. The photoinitiator is one of the key components for a UV coating and should be chosen carefully. With the increased popularity of WB UV coatings, photoinitiator manufacturers are now producing many water-stable versions of their standard products.

The choice of photoinitiators is determined by several factors including coating type, light source, and additive package. The first

consideration is whether the coating is clear or pigmented. For clears, an alpha-hydroxy ketone or benzophenone photoinitiator is recommended. For pigmented coatings, bis or mono -acyl phosphine oxide in addition to the alpha-hydroxy ketone or benzophenone should be used. The absorbance of the photoinitiator should be matched with the spectral output of the light source for maximum cure potential. Levels of photoinitiator must be determined experimentally. Adding too much can hinder cure because the excess will act as a UV absorber and prevent the UV radiation from penetrating into the coatings.

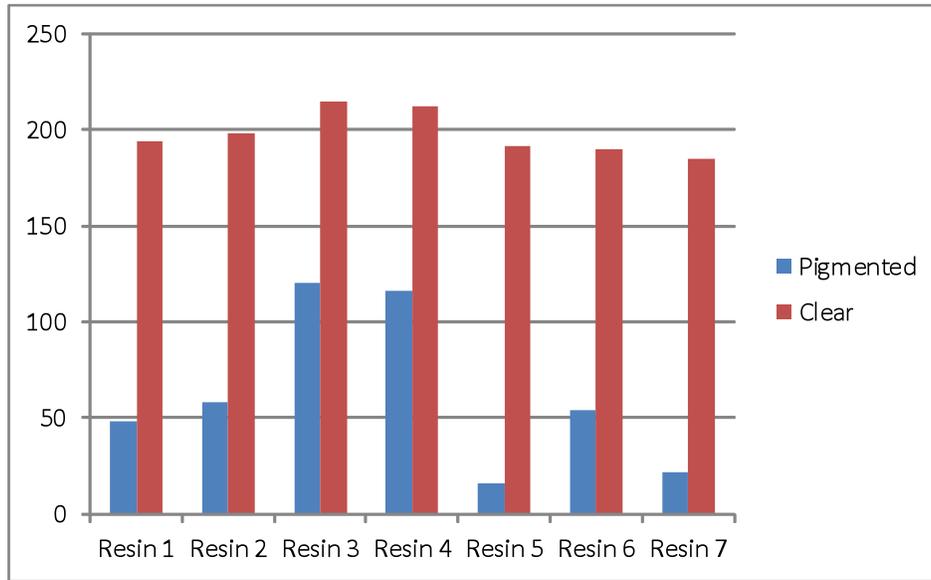
The amount of UV exposure impacts the degree of cure for the coating, and therefore has a major impact on performance capabilities. The amount of exposure can be impacted by several factors of the UV production line: irradiance, spectral distribution or wavelength, line speed, and reflector placement. For most UV curable coatings, energy alone is not an adequate measure of level of exposure; therefore, all factors must be specified for consistent cure and performance. For example, a low irradiance for a long time period does not yield the same result as a high irradiance exposure for a short time period.

Another impact on the degree of cure comes from bulb choice, which is not dependant on the UV resin but is determined by the photoinitiator and the opacity of the film. Bulbs with shorter wavelengths are used for clears and for surface cure of pigmented coatings. Bulbs with longer wavelengths are used for through cure of pigmented coatings and with certain additives such as UV absorbers and nanoparticles. When multiple light sources are needed, the bulb with the longest wavelength should be used first to ensure that the coating gets through cure before surface cure. Otherwise, micro-wrinkling and other film defects can occur.

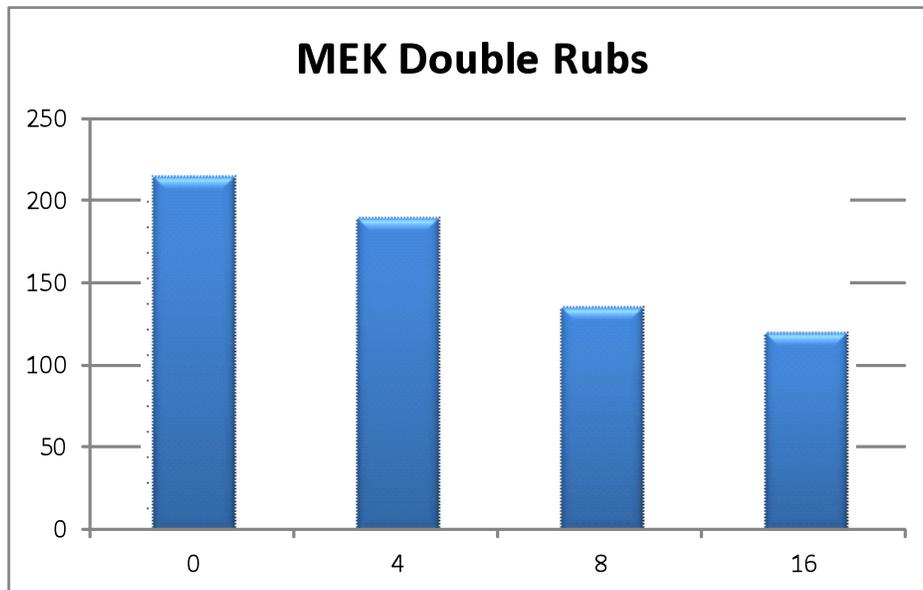
One key to optimal cure is to insure that the photoinitiator in the system is able to absorb UV radiation from the light source. Since pigments reflect, scatter, and absorb UV radiation, a reduction in the rate of polymerization can occur in pigmented UV coatings. This can ultimately affect the crosslink density, chemical resistance, gloss and adhesion of the coating. All pigments have their own characteristic UV absorption curves and care must be taken to choose photoinitiators that absorb in a different range than the pigment.

As with other waterborne resins, certain WB UV resins have a greater affinity for pigment wetting. When the pigment is fully encapsulated by the resin, better chemical resistance is obtained because there is less porosity in the film. Pigment affinity is largely determined by monomer / oligomer /

polyol composition. Figure 3 shows the difference in MEK double rubs in clear and 16 PVC white pigmented coatings.



PVC plays a role in the degree of cure in a pigmented WB UV coating. Typically, the lower the PVC the better the cure response. Figure 4 shows the MEK double rubs at a given PVC in a white WB UV coating.



Waterborne UV coating technology is continuing to improve as raw material suppliers and coatings manufacturers better understand the value proposition of this technology. As these coatings become more robust and higher performing, WB UV systems will continue to replace other chemistries due to increased production efficiencies and low VOC emissions. This is evident in the high volume cabinet and wood furniture markets where WB UV coatings are becoming the standard technology mainly due to their low build appearance and their enhanced performance in chemical and block resistance. With improved processing and raw material selection, more waterborne UV resins are being introduced to the market. These resins can meet the needs of customers requiring high performance standards and environmentally friendly chemistries.

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