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The Economics of UV Curing

UV curing delivers many significant advantages over the use of conventional or solvent-borne materials. However, companies are often reluctant to invest in UV-cure technology because their analysis of its true costs and benefits is incomplete. This article considers both cost benefits and advantages relating to product quality, performance, durability, and safety.

Benefits of UV Curing

Process Uptime: UV-curable inks and coatings reduce setup and clean-up time because they do not dry in the equipment.

Energy Consumption: A UV-cure system is more cost-effective than the gas ovens needed for thermal curing. A gas oven consumes 1.10 MBtu/hr., while the UV oven uses only 82 kW – approximately 4x less energy.

Work-in-Progress Reduction: Using UV coatings impacts the cost of work-in-progress by eliminating time-consuming steps in the coating process, particularly baking and cooling.

Cost of Materials: UV materials are commonly believed to be more expensive than waterborne materials, but that belief fails to take all factors into account. For instance, one gallon of 100% solids UV-curable metal coating might cost $60.00 while a gallon of 48% solids coating is only $38.00.

However, the apparent 58% difference is misleading. In fact, when you evaluate solids and coverage, the difference is eliminated altogether. The performance of the UV material more than makes up for that difference in cost once you calculate all of the time- and money-saving benefits outlined in this article.

Capital Equipment Cost: Generally, UV systems cost 50% less than large-capacity thermal systems.

Emissions Treatment: To determine the cost of UV conversion, one must compare the capital and operating costs of heat recovery systems used to remove volatile organic compounds (VOCs) from solvent-based systems.

Maintenance Cost: A conveyor passing through a UV oven is much shorter and less susceptible to damage and/or wear and tear than a thermal conveyor. This reduces the cost of parts, direct labor, and cycle time.

Solvent Collection and Disposal: In traditional systems, solvents and waste inks must be treated as “hazardous waste.” That adds cost and complexity to your operations.

Space Utilization: A typical thermal drying oven occupies between 500 and 1,000 square feet. The equivalent UV curing system requires only 50 to 100 square feet.

Product Quality: UV improves performance characteristics such as gloss, scratch and abrasion resistance, hardness, and adhesion. Exceptional product performance can lead to increased market share or increased sales.

Health & Safety: Because of low levels of solvent, UV materials are generally safer to handle than the solvent materials they replace.

Cycle Time: Reducing cycle time is essential to successful just-in-time manufacturing. UV curing decreases the time required to complete a process step or task by reducing drying time for solvent-borne chemicals, cure time for two-part adhesives, or overall run time for complex print jobs.

Increasing Production Capacity: UV curing increases production capacity and throughput rates, requires less direct labor, and decreases downtime.

Process Not Achievable by Other Means: UV curing’s instantaneous cure reaction, coupled with high-intensity UV lamps, enables extremely high-speed processing. UV curing is also recommended for processing product substrates that cannot tolerate heat or could be damaged by high-energy radiation.

Article written by R.W. Stowe (Heraeus Noblelight America LLC).
Radiation-Curable Components and Their Use in Hard, Scratch-Resistant Coatings Applications

Hard, scratch-resistant, acrylate-based components are used in coatings for plastic substrates in a broad range of applications, from electronics, communications, semiconductor, and data storage to optics, automotive, aerospace, and medical devices. Just as the applications are wide and diverse, the variety of plastics that may be used has increased over time and now includes materials such as poly(ethylene terephthalate) (PET), poly(methyl methacrylate) (PMMA), and polycarbonate (PC).

This article describes a range of high functionality UV-curable products, including both 100% solids oligomers and waterborne polyurethane dispersions, which can be formulated for excellent scratch and abrasion properties as well as weathering performance, supporting their use in exterior coating applications.

Description of Materials Evaluated

Highly Functional Urethanes: The materials investigated are aliphatic urethane acrylates (UA) having a polyester backbone structure. This type of oligomer has long been recognized as having a chemical structure that exhibits excellent durability when subjected to harsh environmental exposure, in either naturally occurring or accelerated weathering conditions. A higher crosslink density generally increases a coating’s hardness and scratch resistance. Thus the oligomers selected for this internal study range in acrylate functionality from six to nine units per molecule and, for the purpose of this work, are identified as CN9006, CN9026, CN9025, and CN9013.

Section 1: Urethane Acrylate Hard Coats

The first part of this investigation focuses on a series of highly functional aliphatic urethanes and assesses their protective coating properties on a variety of substrates. Table 1 provides a brief description of the oligomers and their attributes.

Table 1: Characterization of “Neat” Oligomer Performance

<table>
<thead>
<tr>
<th>Oligomers Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Code</td>
</tr>
<tr>
<td>CN9006</td>
</tr>
<tr>
<td>CN9026</td>
</tr>
<tr>
<td>CN9025</td>
</tr>
<tr>
<td>CN9013</td>
</tr>
<tr>
<td>CN120</td>
</tr>
</tbody>
</table>
Tabered Haze Testing: Initially, the performance of the neat oligomers was quantified by tabered haze testing, which assesses the effect of surface abrasion, using a Taber® wheel, on the change in haze for a clear coating. A description of the application conditions and performance results are provided in Figure 1.

As these oligomers vary widely in viscosity, acetone was added to each to allow good control of film thickness. A photoinitiator (PI) was added to allow for UV curing. Each mixture was applied to a transparent substrate and UV-cured after removal of the solvent, yielding a dry film thickness of 75 microns. An epoxy acrylate (CN120) oligomer was also tested for comparative purposes.

The light transmission properties were then measured before and after Taber® Testing. The decrease in percent of light transmission is reported as the Delta Haze. The results demonstrate a dramatic shortfall in abrasion resistance of the epoxy acrylate (CN120) as compared to the urethane acrylate (UA) family of oligomers. This result is due in part to the higher functionality of the urethane acrylates, which results in improved surface cure. However, better flexibility of the urethane acrylate materials is also a contributing factor.

Table 2: Characterization of “Neat” Oligomer Performance

<table>
<thead>
<tr>
<th>Oligomer Identification</th>
<th>Tg by DMA, °C</th>
<th>Pencil Hardness</th>
<th>Koënig Pendulum Hardness</th>
<th>0000 Steel Wool Resistance, 50 Cycles, 1.0 Kg Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>CN9006</td>
<td>77.25</td>
<td>8H</td>
<td>116</td>
<td>Pass</td>
</tr>
<tr>
<td>CN9026</td>
<td>74.41</td>
<td>7H</td>
<td>98</td>
<td>Pass</td>
</tr>
<tr>
<td>CN9025</td>
<td>80.0</td>
<td>7H</td>
<td>103</td>
<td>Pass</td>
</tr>
<tr>
<td>CN9013</td>
<td>135.0</td>
<td>7H</td>
<td>128</td>
<td>Fail</td>
</tr>
<tr>
<td>CN120</td>
<td>146.0</td>
<td>9H</td>
<td>138</td>
<td>Fail</td>
</tr>
</tbody>
</table>

Other tests were conducted to quantify the hardness characteristics of each oligomer and results are listed in Table 2. The glass transition temperature (Tg) of a cured film is a fairly good indicator of hardness. Typically, a higher glass temperature yields a film with higher surface hardness. However, high hardness does not always equate to good abrasion resistance. The steel wool resistance data demonstrate this effect. Oligomers having lower Tg values passed the steel wool test while those with the higher Tg values failed.

Figure 1: Tabered Haze Testing

Application and cure conditions:

- Neat Oligomer Tested
  - Cut in 50% Acetone
- Film Thickness: 75–150 microns (after flash off)
  - #5 wire bar used
  - Acetone flashed off prior to cure
- 50 f/m under (2) 300 w/in “H” lamps
- CS-10F wheel under 500g load for 10 cycles

Delta Haze Results

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[americas.sartomer.com/techlit/30112.pdf]
Influence of Various Matting Agents on Abrasion Resistant UV-Cured Coatings

The mechanism of curing liquid coating materials with UV or EB energy radiation is now well understood. Industrial coatings are applied on a substrate to improve some surface properties (low gloss, stain resistance) and/or some mechanical properties such as abrasion or scratch resistance. Both surface and mechanical properties are controlled by the careful choice and combination of resin, initiator, as well as fillers and additives. The adhesion to the substrate and the viscosity of the UV-curable formulation have to be taken into consideration as well. According to the end-use, industrial coatings can require improvements of more than one performance characteristic. But formulating industrial coatings involves trade-offs. The abrasion resistance can be controlled by the addition of some fillers, which generally increases the viscosity of the formulation. Matting agents can be used to control the gloss, but very often they have a negative effect on the abrasion resistance of the final coatings. Abrasion and scratch resistance are critical for a lot of coating applications, but the parameters that will enhance one of these properties might reduce the other. The addition of ultra-fine polyamide powders seems to be an easy way to reach some compromise and get some or all of these mechanical and surface properties while maintaining good adhesion to the substrate and a low viscosity formulation. This paper describes the behavior of ultra-fine polyamide powders, ultra-fine co-polyamide powders, and silica additives when formulating UV-curable systems. Viscosity of the UV-curable formulation, radiation curing modification, gloss control, coating’s friction, additive dispersion within the coating, and abrasion resistance were studied.

Experimental
UV-Curable Formulation

The base urethane-acrylate formulation (Table 1) consists of a mixture of acrylic monomers, such as isobornyl acrylate, 1,6 hexanediol diacrylate, dipentaerythritol pentaacrylate, and ethoxylated trimethylolpropane triacrylate with a urethane acrylate oligomer. This formulation is recommended for top coats on rigid and flexible plastic substrates. Prior to the addition of ultra-fine polyamide powders, key attributes of the system are a good adhesion to the plastic substrate and a good combination of hardness and flexibility.

<table>
<thead>
<tr>
<th>Component</th>
<th>Nature</th>
<th>Weight (grams)</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>CN981</td>
<td>Urethane Acrylate</td>
<td>30</td>
<td>Sartomer</td>
</tr>
<tr>
<td>SR506 C</td>
<td>Isobornyl Acrylate</td>
<td>12.8</td>
<td>Sartomer</td>
</tr>
<tr>
<td>SR238</td>
<td>1,6 Hexanediol Diacrylate</td>
<td>33.7</td>
<td>Sartomer</td>
</tr>
<tr>
<td>SR454</td>
<td>Ethoxylated Trimethylolpropane Triacylate</td>
<td>5</td>
<td>Sartomer</td>
</tr>
<tr>
<td>SR399</td>
<td>Dipentaerythritol Pentaacrylate</td>
<td>5</td>
<td>Sartomer</td>
</tr>
<tr>
<td>BPO</td>
<td>Benzophenone</td>
<td>2.7</td>
<td>Various</td>
</tr>
<tr>
<td>Alpha Hydroxy Ketone</td>
<td>2-Hydroxy-2-Methyl-1-Phenyl-1-Propanone</td>
<td>1.8</td>
<td>Various</td>
</tr>
<tr>
<td>Additives</td>
<td>Ultra-fine Polyamide Powders or Silica</td>
<td>0 to 10</td>
<td>Arkema</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 to 10</td>
<td>Various</td>
</tr>
</tbody>
</table>

Table 1: UV-Curable Top Coat Formulation

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Acrylate functional modifiers can be used to replace solvents and conventional epoxy diluents in two-component epoxy coating systems. Conventional two-component solvent-borne epoxy coatings also require up to 24 hours to cure at ambient temperatures and may not cure at all at temperatures below 55°F. M Cure® acrylate functional reactive diluents and modifiers are low viscosity, moderate molecular weight acrylate ester monomers and oligomers that are added to the resin side of an epoxy coating formulation. They react rapidly with the amine curing agent through Michael addition polymerization to provide an alternative to epoxy-mercaptan technology to speed the cure at temperatures down to 10°F.

Figure 1 shows the effect of M Cure® diluents and modifiers on the cure times of coatings based on bisphenol A diglycidyl ether (BADGE) epoxy resin and 20% by weight M Cure® modifier addition. The graph illustrates a wide range of cure times, dependent on the specific modifier used. It shows a clear correlation between fast cure time and low acrylate equivalent weight (AEW). M Cure® 400 modifier, having the lowest AEW, is the most reactive and provides the fastest cure time.

At 35°F, all of the acrylate modifiers are still reactive enough to accelerate the cure rate of the coatings. This performance results in much shorter cure times than the neat BADGE epoxy control. Once again, M Cure® 400 modifier is the most effective modifier, decreasing low temperature cure times from greater than 20 hours to just three hours.

In addition to faster, low temperature cure time, acrylate modifiers provide an epoxy coating with a better balance of hardness and flexibility using the same formulation listed above. This combination is outstanding for applications such as concrete floor coatings and secondary containment. Figure 2 shows the hardness and falling weight impact results for the M Cure® monomer products. The results demonstrate that higher acrylate functionality modifiers maintain the hardness of the epoxy control due to additional crosslinking. All of the modifiers significantly improve the impact resistance and M Cure® 201 yields the best balance of properties.

Lower molecular weight amine curing agents, such as aliphatic amines and some cycloaliphatic amines used for low temperature curing of epoxy coatings, can migrate to the surface of the coating and react with atmospheric moisture and carbon dioxide prior to cure. This reaction, referred to as “amine blush,” deteriorates coating surface properties and recoatability.

**Figure 1: Acrylate Effect on Cure Time**

**Figure 2: Effect of Hardness and Flexibility**

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**Formulation:**

80% BADGE Epoxy, 20% M Cure® Modifier

1:1 Stochiometric Equivalent of 80/20 Ancamine® 2143*

Cycloaliphatic/Ancamine® 1608* Aliphatic Amine mixture

*Ancamine® 2143 and Ancamine® 1608 are manufactured by Air Products and Chemicals, Inc., Allentown, PA.

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The Versatility of Peroxide Curing

Similar to UV/EB radiation curing, acrylate- and methacrylate-functional monomers and oligomers can be polymerized through a free-radical process where peroxide initiators are used in place of photoinitiators. With the proper selection of monomers or oligomers, formulators can produce peroxide-cured coatings that cure at both ambient and elevated temperatures for numerous applications on a variety of substrates such as wood, metal, plastic, and concrete.

100% solids peroxide-curable systems are an excellent solution to lower the use of volatile organic compounds (VOCs), quicken drying times, and enhance performance. Peroxide curing enables coatings formulators to meet the demands of regulatory compliance and produce better products using conventional coating equipment.

Examples of excellent peroxide curing applications include:

- Use of (meth)acrylate functional monomers as “reactive plasticizers” for PVC plastisol dip coatings and pumpable sealants.

- Replacement of styrene and methyl methacrylate monomers (MMAs) by a (meth)acrylate functional monomer as modifiers to polyester-based gel coats.

- Use of (meth)acrylated functional monomers as additives to high-solid, solvent-based alkyd coatings such as decorative coatings.

- Formulation of 100% (meth)acrylate functional coatings for exceptional exterior durability for applications such as automotive finishes and high-performance industrial maintenance coatings.

The following specific applications detail how Sartomer’s (meth)acrylated functional monomers and oligomers and other specialty chemicals can be used to increase the performance of peroxide-cured coatings.

PVC plastisol dip coatings and pumpable sealants are single-component systems that are cured at elevated temperature. They contain a significant amount of a plasticizer to improve rheology and provide flexibility.

Figure 1: Effect of Acrylic Modification of Plastisols on Film Hardness

Figure 2: Effect of Acrylic Modification of Plastisols on Adhesion

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How Does it Feel? Recent Advances in UV-Curable Soft Touch Coatings

Soft touch or soft feel coatings are employed to create a variety of haptic effects on plastic, paper, and metal substrates. Haptic effects can improve consumers’ perceived value of the product and influence them to buy the product over other similar products. Thus it is no wonder interest in soft touch coatings has increased in recent years. Soft touch coatings span a variety of markets including cosmetic packaging, automotive interiors, small electronics, and appliances.

The term soft touch coating is used very broadly to describe any coating that provides a soft luxurious feel. While simple in concept, it is actually quite difficult to achieve in practice because of the highly subjective nature of feel and the range of feel effects desired. While feel types are observer dependent, they are generally described in terms of things known to be soft: rubber, velvet, peach skin, rose petals, silk, leather, suede, etc. Achieving soft touch coatings of various feel types is necessary to fit the requirements of a wide range of applications and products.

Since consumer products are exposed to repeated wear and contaminants throughout their life cycle, soft feel coatings must also be durable. Balancing the wear resistance of a coating while maintaining a soft feel is an additional challenge. Wear resistance for soft feel coatings is typically created by crosslinking multifunctional isocyanates with polyols. Although they have excellent feel properties, two-part urethane coatings have disadvantages such as pot life limitations, long cure times, and hazards of isocyanate handling. To address these issues as well as to improve durability, formulators and product designers look increasingly toward UV-cured soft feel coatings.

Two-part isocyanate systems create a structure with hard regions from the isocyanates distributed in softer regions created by the polyols. The structure created is very regular because polyols can only react with isocyanates and vice versa. In a UV-system one cannot easily control one type of acrylate reacting with itself or a different acrylate. Consequently, a less regular structure is formed when hard and soft acrylic monomers/oligomers are combined in a UV-curable system, Figure 1. Despite the lack of a regular structure of hard and soft segments, the proper design of oligomers and monomers can create a UV-curable soft feel coating with improved properties over a traditional two-part urethane.

In any soft touch coating, solid particle surface additives, including silica and polymeric waxes, play an important role in imparting soft touch effects. Therefore, for our work silica was incorporated into the coatings, Table 1. Solvent was also added to reduce the viscosity of the formulations and provides enough shrinkage to allow for the migration of the solid particles to the film surface, reducing friction and imparting a soft feel.

Through experimental design, we have developed three new products for UV-curable soft touch coatings with tailorable feel types. Table 2 shows the liquid properties of these products. CN6500 can be used alone for a silky coating or in combination with CN6502 for a velvety coating. CN6501 has excellent velvety feel when formulated with other Sartomer monomers. The normalized data in Figure 2 show new products that improved durability over the industry standard two-part urethane coatings tested and exhibit little to no decrease in soft touch feel quality. In addition to enhanced durability, the UV-curable systems have infinite pot life, short cure times, and no free isocyanate.

**Table 1: Soft Touch Coating Base Formulation**

<table>
<thead>
<tr>
<th>Component</th>
<th>Percent</th>
<th>Percent based on:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylate Resin</td>
<td>38</td>
<td>on total</td>
</tr>
<tr>
<td>Methyl ethyl ketone: butyl acetate</td>
<td>55</td>
<td>on total</td>
</tr>
<tr>
<td>Disperbyk® 2008(^1)</td>
<td>10</td>
<td>on silica</td>
</tr>
<tr>
<td>Acematt® 3300(^2)</td>
<td>8.5</td>
<td>on resin</td>
</tr>
<tr>
<td>Irgacure® 1173(^3)</td>
<td>5</td>
<td>on resin</td>
</tr>
</tbody>
</table>

(1) BYK-Chemie GmbH (2) Evonik Industries (3) IGM Resins B.V.

**Table 2: Properties for New UV Soft Touch Products**

<table>
<thead>
<tr>
<th>CN6500</th>
<th>CN6501</th>
<th>CN6502</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>Colorless to slightly yellow liquid</td>
<td>Liquid to waxy solid</td>
</tr>
<tr>
<td>Viscosity</td>
<td>10,000</td>
<td>2,000</td>
</tr>
<tr>
<td>Color, Alpha</td>
<td>16</td>
<td>16</td>
</tr>
</tbody>
</table>

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Figure 2: Properties of UV-Curable Soft Touch Coatings

Article written by Lisa Spagnola, Jeff Klang, and Manjuli Gupta.
Featured Products

**CN2601 Brominated Aromatic Acrylate Oligomer for Flame Retardant Applications**

Sartomer Americas has introduced an oligomer for UV/EB-curable coatings, CN2601. This brominated aromatic acrylate oligomer has a high refractive index and functions as a flame retardant in UV/EB coatings.

**Product Performance:**
- Good chemical resistance
- Good water resistance
- High refractive index
- Flame retardant

**CN9302 Dual Cure Urethane Acrylate**

Bearing both acrylate and isocyanate (NCO) functionality, this oligomer can be used in UV/EB-curable, twopart urethane, and dual cure formulations. In UV/EB formulations, the reactive isocyanate allows for secondary moisture cure of shadowed areas for enhanced coating performance.

**Product Performance:**
- Two-stage cure
- Adhesion promotion
- Abrasion and chemical resistance

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