UV Curing for Wood Applications

By Roy J. Modjewski

Each manufacturer has its own reasons to use energy-cured materials. The most common reasons include: the need for environmentally sound (green) technology, the desire to increase production speed or process optimization, the benefits of improved product performance and the development of new value-added products. Most of the inquiries that I have received are due to the need to reduce VOC emissions. Air regulations are a driving force that is building a need for greener technologies; at the same time, many companies are looking to energy cure coatings to increase their volume of production.

Some companies look to switch to UV due to market forces—a competitor has introduced a higher performance product—and success fosters success in these instances. One area that is currently receiving attention throughout the industry is powder coating for wood. Low to no VOC emissions with the ability to recycle the over spray and a relatively low cure requirement should find uses in a number of applications.

Energy-cured materials provide for enhanced product performance. The physical property information in Table 1 is taken from a successful conversion from water-borne materials to UV. Energy-cure material has a large advantage in physical properties, which not only increases value in the market, but decreases waste by offering a more durable product resulting in less damage due to over-zealous in-plant handling. The higher crosslink density available in energy-cured systems allows for improved physical properties. Table 1 illustrates the difference obtained on one line using three products. The dramatic increase in solvent resistance and scrub resistance is a good representation of this point.

Table 1
Physical Property Comparison

	Paint A Thermoplastic Water-borne	Paint B Thermoset Water-borne	Paint C UV Cured Epoxy Acrylate
Adhesion	100%	95%	100%
Scrub Test	40% Failure	100% Failure	0-10% Failure
100 MEK Rubs	NR	100% Failure	Pass
Stain Resistance			
TSP Solution	10	NR	0
Mineral Oil	4	SE	0
Nail Polish Remover	2	FD	0
Household Bleach	10	FD	0
Coffee	4	FD	0
Alcohol (Ethanol)	5	FD	0
Lemon Juice	6	FD	0
Household Ammonia	8	FD	0
Cola	3	FD	0
Lipstick	4	FD	0
Color Crayon	2	NE	0

Rating systems are different due to different individuals performing tests. However, conclusion can be drawn if an equivalency can be made between test rating systems.

0=NE=No Effect; 1-3=SE=Slight Effect; 4-6=ME=Moderate Effect; 7-8=FD=Permanent Effect; 9-10=Failure

Some application techniques allow for large amounts of material to be applied in one operation. Curtain coating and roll coating are two such techniques. Energy-cured materials do not need to “dry” and, therefore, do not need the sophisticated and lengthy ovens that would be necessary with solvent or water-borne materials.

Fast cure speed without volatile materials and high solids gives energy-cure materials an edge in the area of

Fast cure speed without volatile materials and high solids gives energy-cure materials an edge in the area of high-gloss coatings

high-gloss coatings.

High Depth of Image (DOI) is achievable without a rub and buff operation. Scratch and abrasion resistance is often times superior to what can be achieved using other coating systems.

Cost analysis

The perception of high cost of energy curing does not hold up under close observation. A quick comparison of the cost per gallon is usually the misleading reason that energy-cured 100% solids materials are considered high cost. A more realistic approach is to look at actual applied cost per dry mil. The coatings previously used in the physical property comparison can prove this point. These numbers were taken from a successful line conversion. The assumptions have so far proven to be true.

Assumption 1: Transfer efficiency is the same for both coatings (rollcoat application).
Assumption 2: The same coating thickness will be applied.
Constants used: Application of 1,604 square feet per gallon per mil.

Paint A (thermoplastic rollcoat topcoat): Total solids by volume 32.62%.
Paint A (thermoplastic rollcoat topcoat): Cost per gallon of material of $13.67.

Paint C (energy-cured rollcoat topcoat): Total solids by volume of 99.69%.
Paint C (energy-cured rollcoat topcoat): Cost per gallon of material $35.00

Cost of Paint A (thermoplastic rollcoat topcoat) in $/SQ. FT/Dry mil 0.0262.
Cost of Paint C (energy-cured rollcoat topcoat) in $/SQ. FT/Dry mil 0.0219 or a savings of approximately 17%.

Implementing UV

Education is the key to a successful conversion or startup of an energy-curing production line. A firm partnership of the three essential companies is a requirement: the coating company, the equipment company and the end user should all have the same objective, to get the line producing product as efficiently and as quickly as possible. The strongest partnership and the most open communication produce the most profit for all concerned.

The efficiency of the application method should be a primary concern; a spray operation is much less efficient than a rollcoater or a curtain coater. The shape and complexity of the substrate may determine the application method; however, where possible, look at the operation with the highest transfer efficiency.

Coating wood also imposes certain constraints on the coating material. Wood comes in many varieties: oak, cherry, maple, etc. Each species, with its density, pores, moisture content and dimensional instability, requires a unique approach to produce an aesthetically pleasing finish. Viscosity and surface tension, along with adhesion properties, are some of the variables that should be taken into account when formulating a successful wood coating. The vast array of wood products, including paneling, flooring and furniture, imposes the necessity of matching coating type and application method to best produce a finished product.

Viscosity and surface tension, along with adhesion properties, are some of the variables that should be taken into account when formulating a successful wood coating.

Choosing a coating

The formulator has a number of chemical classes from which to choose in meeting customer requirements. Each class of materials possesses different attributes. There is some overlap between classes, but by recognizing overall trends, a formulator can choose a chemical class that best fits the customer's application.

Assigning general characteristics to a class of compounds is a daunting task. Consider: urethane acrylates are the condensation product of an isocyanate (aliphatic or aromatic) and a polyol (polyether or polyester), end capped with an acrylate moiety (hydroxyethyl acrylate or hydroxypropyl acrylate). Each combination produces different physical properties in the final coating. However, focusing on one representative type, you can develop formulating rules of thumb. Aliphatic urethane acrylates are representative in this class.

◆ Urethane acrylates

Urethane acrylates can exhibit minimal yellowing upon cure and have good outdoor weathering capabilities. They give tough, resilient coatings that are abrasion resistant. The tough nature of the films produced allows high film weights to be applied to dimensionally unstable substrates without cold check cracking. This same high film build yields a coating with good Depth of Image.

Urethane acrylates are expensive compared to other classes of acrylates. They cure at slower speeds than the other materials. This relative lack of cure response, often enhanced by the need for non-yellowing photoinitiator, further increases the formulated cost.

◆ Epoxy acrylates

Epoxy acrylates are the workhorses of the industry. Their low cost and fast cure speeds, combined with very hard cured films and excellent chemical resistance, make them an easy choice for many applications. Structural modifications with amine or ethoxylation further enhance their utility.

Epoxy acrylates are prone to yellowing. The aromatic structures of most epoxy acrylates contribute significantly to their resulting color. Yellowing can be reduced through judicious choice of photoinitiator. However, cost constraints of some applications that demand the use of epoxies at times preclude the option. The high tensile strength and low elongation that give epoxy acrylates their brittleness can also be a detriment when higher film builds or superior adhesion at high film builds is required.

◆ Polyester acrylates

Polyester acrylates' physical properties fall between epoxy acrylates and urethane acrylates. Polyesters exhibit better non-yellowing properties than epoxies, but not as good as aliphatic urethanes. Polyesters are less brittle than epoxies, but not as flexible or tough as urethanes. Cure speeds are faster than urethanes, but slower than epoxies. The cost of polyester acrylates also falls between epoxy acrylates and urethane acrylates. Polyester acrylates are good candidates for coatings in their own right but find use as modifiers to promote specific coating properties in the epoxy acrylate and urethane acrylate classes.

◆ Cationic cure epoxies

Cationic cure epoxy systems occupy a small percentage of the UV curing markets. These materials have advantages that are exploited in coatings for metal. Cationic epoxy systems have not found a major inroad into the wood coating markets. However, they do find use in hybrid cationic and free radical systems. The cationic reaction of an epoxy ring with hydroxyls on the cellulose in wood can increase a hybrid UV system's adhesion. A disadvantage that has prohibited cationic epoxies from more uses in wood coating is their sensitivity to humidity and the fact that some woods are alkaline in nature. Humid conditions inhibit cationic cure response, and an alkaline environment can poison cationic cure mechanisms. Even "dry" wood contains 5% to 9% water, which can affect cure speed. The thermal post cure reaction of cationic epoxies can be useful in a beverage can line, but is a major disadvantage in wood coating lines.

◆ Vinyl ethers

Vinyl ethers are another class of materials that have not found much utility in the wood industry. Vinyl ethers can cure by both cationic and free radical mechanisms. Vinyl ethers in combination with cationic epoxies cure extremely fast, producing very hard, high-gloss coatings. Vinyl ethers, used with unsaturated polyesters, cured by a free radical mechanism, are used in some segments of the wood industry. Blending vinyl ethers with unsaturated polyesters can eliminate major obstacles in each class of materials. Using low cost unsaturated polyester with vinyl ether lowers the overall system cost of pure vinyl ether coating. Replacing styrene with vinyl ethers in unsaturated polyesters eliminates the VOC and toxicity concerns associated with styrene. This also dramatically increases the cure speed.

The high cost of vinyl ethers prohibits considering these materials for many areas. A wider selection of materials is coming onto the market, but there still is a limited range of resins available compared to the acrylate systems.

◆ Styrene

Styrene containing unsaturated polyesters is the least expensive chemical class for UV curing. Although these materials cure very slowly compared to other materials, they are used extensively in fillers for particleboard and medium density fiberboard. These unsaturated polyesters provide an excellent sanding foundation for further finishing steps.

The volatility of styrene has always been a concern with these systems. Styrene is driven off during cure. VOC emissions, along with slow cure speeds, are limiting factors for continued use.

Rules of thumb

A summary of formulating rules of thumb for the chemical classes used in wood coating is:

Cure speed	epoxy>polyester>urethane>unsaturated polyester
Hardness	epoxy≥unsaturated polyester>polyester>urethane
Yellowness	epoxy>polyester≥unsaturated polyester>urethane
Cost	urethane>polyester>epoxy>unsaturated polyester

With these rules of thumb and an understanding of the market segment served, one can see why a given chemical class dominates certain market segments. There is substantial overlap in these markets as each manufacturer seeks to differentiate itself in its market; but for the most part, urethane acrylates are used in hardwood and resilient flooring (U.S. market), ski and snow board coatings and coatings for fine and medium price point furniture. Epoxy acrylates are used for plywood and paneling topcoats, paper coatings, ready to assemble (RTA) furniture topcoats and hardwood flooring (European markets). Polyester acrylates are used for paper coatings, RTA furniture and hardwood flooring (European markets). Unsaturated polyesters are used for particleboard and MDF fillers and low-cost, low-cure-speed topcoats.

Application methods

Just as there is a "best fit" for each chemical class to a market segment, there is a best fit of application technique for the article to be coated. Each application method has its advantages and disadvantages. A look at the advantages and disadvantages for each application method—spray, rollcoat, curtain coat and vacuum coat—suggests a market segment that has a "best fit." Each of these application methods is only a general category. Spray may be by conventional air spray, HPLV, HVLP, air assisted airless, or electrostatic bell or disc. Rollcoat may be differential, direct or reverse with various roll types. Curtain coat can be pressure head, flow head (WEIR) or roller curtain coater. Vacuum may be slot or edge. Each specific variation in application technique represents a refinement. Not all variations dramatically change the application rules. If we attempt to match each application method with an area of use assuming no change in current production operations, a logical association can be seen. Case goods furniture fits spray only. Disassembled parts such as drawer sides and some shelving have been done by other methods, but overall finish is spray applied. Some medium-price point furniture is finished partly assembled—as a dining room table top with the skirt attached. This is obviously sprayed. Again, drawer sides and shelving may be finished separately.

Chairs and various wood parts for custom conversion vans and cars are currently being finished with spray UV. Some kitchen cabinet door frames, paneled doors and drawer fronts are finished by spray. Moldings can also be included with spray, especially in a small spray chamber with automatic recirculating of the overspray.

Some medium-price point furniture and most RTA furniture are finished as flat stock. Edges are finished after the topcoat is applied. These market segments play into the strengths of rollcoating. Kitchen cabinets and vanity door frames also lend themselves well to this application method.

Paneling and plywood lines run at relatively high speed and apply low coating weights of 5 grams to 10 grams per square meter. This is an excellent fit for rollcoat application. Achieving a richer look often means applying more material. A high-gloss coating can achieve a high DOI with more material. Curtain coating fits well with higher film builds and finishing flat stock.

Vacuum coating is an efficient method of coating long, linear pieces and edges of panels. Transfer efficiencies can approach 100% with UV cure coatings. Line speeds are relatively fast, making this method particularly UV cure friendly.

It all adds up

How can one put this all together to produce an aesthetically pleasing product that meets all the physical property requirements? A partnership must be formed with all the parties concerned. The formulator knows the chemical class needed to meet the physical property requirements and can pick a formulation, or develop one, which specifically matches the capabilities of the application equipment. The equipment supplier knows the equipment necessary to meet the manufacturer's production needs and methods of operation.

Through a series of tests, specifically designed to test both the equipment and the coating, all parties learn the operations needed to produce an acceptable product. Only through the information exchange that results during these tests can the equipment supplier and the supplier of the coating meet the needs of the person finishing the product. The manufacturer learns the strengths and limitations of all pieces in this coating operation needed to produce his product. Each finished product has a unique solution and best-fit operation.

UV cure coatings and application methods are not magic. Only through sound matching of required physical properties, coating formulation, application technique and substrate configuration can a coatings system succeed with the minimum of frustration, labor and capital expenditure. Through a partnership in which all parties educate and support each other, a finishing system can be devised that produces the maximum profit for all involved.

—Roy Modjewski is R&D group leader, Akzo Nobel, High Point, N.C.