UV-CURABLE POWDER COATINGS

for Heat-Sensitive Substrates

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INTRODUCTION

Market opportunities for UV-cured powder coatings continue to expand as external drivers focus consumers of OEM coatings to seek new materials and application technologies. Industrial material consumers and processors make material and technological investment and buying decisions based upon a complex set of internal and external criteria. These criteria are a mix of regulatory mandates, perceived end user demands, and economics. All consumers are looking for products and processes that meet environmental regulations, require lower energy consumption, generate lower total applied costs, and produce a higher return on assets.[1] Worldwide consumption of radiation-cured finishing products is growing at a faster rate than the total coatings market. By 2012, radiation-cured products as a percentage of the total coatings market will be 2.2%.[2] UV-cured powder coating has many inherent advantages, including ease of material handling, durability, one-coat processing, and breadth of palette. Additionally, there are significant environmental, economic, and quality advantages when compared to traditional solventborne and waterborne coating technologies. The purpose of this article is to describe and quantify these advantages and benefits and demonstrate the value of UV-cured powder coatings.

Powder coating is an industrial finishing technology with a resilient and durable finish that is solvent-free. Initially introduced as a functional coating in the 1960s, thermal cure or thermoset powder coatings have been developed and adapted over time for a variety of finishing applications. This is primarily due to their superior wear resistance, barrier properties, and cost effectiveness. Common products and uses of thermoset powder coatings are home appliances, industrial equipment, automotive primers and topcoats, and pipe coatings. These products have metal substrates well suited for electrostatic powder deposition and the thermal cycle to melt/flow the powder and crosslink the coating. The cure time for thermoset powder coatings can range from tens of minutes to more than an hour depending on chemistry and part geometry. Thermoset powder coatings on metal represent an estimated 10% of the global coatings market.

UV-cured powder coating and application systems were first developed and commercialized in the late 1990s into the early 2000s. These initial systems were small scale and designed to achieve specific finishing requirements—an electric motor and an automotive radiator. In early 2000, two UV powder on wood (medium density fiberboard, MDF) systems were built in North America and less than a dozen were already present in Europe. The economic incentive for these capital investments was to expand the base of traditional powder coating application and coating chemistry by utilizing the inherent advantages of UV curing. Heat-sensitive materials were a natural product market. UV powder could be used to finish products and materials that heretofore could not be finished with thermal powder

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This paper was presented at the 2010 American Coatings Conference, April 12–14, 2010, in Charlotte, NC.

coatings. UV-powder coatings are manufactured on the same equipment as thermal powder coatings, sell at a higher price per pound, and generate higher gross margins.

Since the introduction and commercialization of UV-cured powder coating, external market conditions have changed, making the advantages and benefits more compelling. The advantage that is easiest to quantify is speed. A UV-cured powder coating system is at least three times faster than thermal powder coating and even faster than liquid finishing. Economic history shows that when two or more technologies compete, the fastest will be the most successful. Capital, cost, and pricing disparities will drive the supply and demand equilibrium, allowing the faster and winning technology to replace the loser(s) or incumbent. The success of the jet aircraft is an example of the faster but more capital-intensive technology replacing the slower and less capital-intensive turboprop aircraft. Jet powered aircrafts increase passenger unit revenue per mile, increase operational efficiency, and lower cost per passenger mile. When the jet aircraft was introduced, customer demand rapidly increased. Sufficient capital was generated to develop succeeding generations of jet aircrafts, further increasing revenues and lowering costs per passenger mile.

This illustration has clear and interesting parallels to UV-cured powder coating and thermal-cure coating systems, as well as other finishing technologies. The initial capital cost of a UV-cured powder coating system is more than a solventborne thermal system. The increased speed produces a faster and greater return on invested capital. UV-cured powder coating will always maintain a speed advantage and a faster return on the capital investment.

On June 1, 2007, the European Community Regulation on chemicals, REACH (Registration, Evaluation, Authorization, and Restrictions of Chemical Substrates) went into effect. REACH was established to give the industry more responsibility for risk management in the manufacturing and use of chemical materials and products. An additional objective of REACH is to encourage companies to substitute dangerous and high-risk materials with safer material choices. A chemical material with volatile organic compounds (VOC) content in any amount is classified under REACH as a dangerous and high-risk chemical material. Many liquid finishing lacquers, varnishes, and paints have VOC content in varying percentages. UV-curable powder coatings are free of VOC components and hazardous air pollutants (HAPs) that would be REACH classified as dangerous and high risk.

UV-cured powder coatings have life cycle advantages that liquid coatings do not have (see *Appendix* A). Solid materials are easier to blend, process, control, and apply than liquid materials. UV-cured powder coatings can be sprayed to re-use or sprayed to waste without the need for complex or specialized material handling equipment and containment requirements. Color changes can be accomplished in minutes. Loose powder that escapes into the work environment can be cleaned up with a standard industrial vacuum cleaner. Powder waste material is sent to industrial processors who use the waste material as a compounding additive in plastic manufacturing, keeping the material out of the waste stream. The manufacture and application of UV-cured powder coating is not subject to any environmental permit restrictions or requirements.

Energy productivity is another fundamental value associated with UV-cured powder coating. A typical UV-cured powder coating system will utilize natural gas and electricity to energize the oven system and electricity to energize the UV lamp curing system. Solventborne and a waterborne systems require four to eight times the oven capacity to flash and cure the coating. VOC compounds produced in solventborne finishing will also require additional energy for air handling equipment to incinerate and remove VOCs to meet air quality standards.

A differentiating characteristic of UV-cured powder coating is the separation of the melt/flow and cure functions (*Figure* 1). This separation enables the processor to control melt/flow and cure functions with precision and efficiency—maximizing energy, improving material utilization, and—most importantly—increasing production quality. The operator is able to control the application process and limit defects such as picture painting, pin holing, and out gassing. The separation of flow from cure allows for adjustments during system

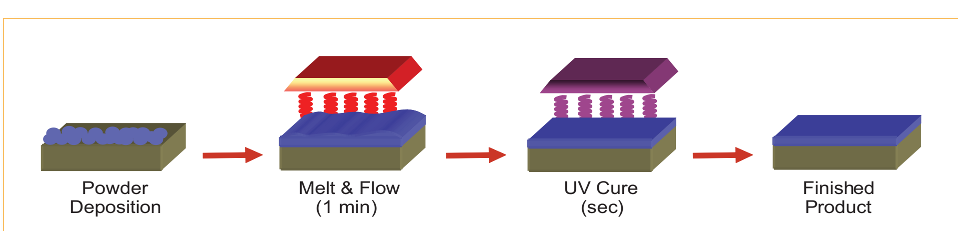

Figure 1—Illustration of UV-cured powder coating application process.

Table 1—Model of a UV-Cured Powder vs. Solventborne Coating System

	Line (ft)	Max # of parts on line	Line speed (FPM)	1 Rotation (hr)	Rotation/ hr	Parts per hour	Line set up (hr) - A -	Time to finish last part (hr) - B -	Total time to finish 150 parts A+B	Parts per hour	Efficiency
UV Powder	200	50	10	0.33	3	150	0.92	0.33	2.3	66.67	222%
Solvent	800	200	10	1.33	0.75	150	2.67	1.33	5	30.00	

Assumptions:

- Run size – 150 parts
- Part size – 9 sq ft finished all sides ¾ in. thick stock
- Comparable line density and speed
- Finish film build
  — UV powder – 2.0 to 3.0 mils dependent on substrate
  — Solventborne paint – 1.0 mil dry film thickness
- Oven/cure conditions
  — UV powder – 1 min melt, seconds UV cure
  — Solventborne – 30 min at 264°F
- Line set up
  — Powder color change – 15 min
  — 2 set up runs
- System parameters from above
- Illustration does not include substrate

operation and results in fewer defects and a higher quality product. At any one time, there are fewer products on the UV-cured powder coating line than when compared to other finishing technologies. The fast finishing process of UV-cured powder coating provides the important benefit of low substrate thermal exposure. Heating a porous substrate can cause gasses from within the material to escape and can form surface defects in the coating. UV-cured powder coating minimizes the substrate's thermal exposure to provide a high quality finish on a variety of substrates that will be discussed later in this article.

A UV-cured powder application system can have a plant footprint of 2,050 sq ft, as compared with a solventborne finishing system of comparable output which requires a footprint in excess of 16,000 sq ft. Assuming an average rental of $6.50 per sq ft per year, an estimated UV-cure system annual cost would be $13,300 vs. $104,000 for solventborne.

The faster speed of UV-cured powder coating systems equates to improved productivity. *Table* 1 compares a UV-powder system and a solventborne system, both with equal line speed and density. The time required to finish 150 parts with an automatic spray UV-cured powder system is 2.3 hr. The time required to finish with an automatic spray solventborne system is 5 hr. The UV powder system provides a 222% improvement in productivity, or 36 parts per hour. It is important to note that as the run becomes longer, the efficiency advantage will diminish. However, system parity will never be reached. UV-cured powder coating will always maintain a speed advantage and will provide a faster return on the invested capital.

Assuming a selling price of $10 per part with a 30% gross margin (total gross margin $450); the 2.3 hr to finish with the UV-cured powder system has a $195/hr contribution margin. The same selling price per part and 30% gross margin, the 5.0 hr to finish with a solventborne system has a $90/hr contribution margin. The UV-cured powder system has a contribution margin benefit of $105/hr. The contribution margin advantage over the annual 1,750 production hours has a contribution margin advantage of $183,750/year.

In addition, the UV-cured powder coating has an applied material cost advantage compared to low-solids solventborne coatings. A solventborne industrial coating is composed of 25% solids and has a 30% material utilization with a conventional spray application. A 1 mil dry film thickness has an applied cost of $ 0.28 per sq ft. UV-cured powder coatings contain no solvents or liquids and are 100% solid, enabling the powder reclaim a 95% material utilization in the finishing operation. A typical UV-cured powder film build of 2 mils provides a continuous and uniform finish; slightly rougher substrates of wood products may require 3 mils for uniform finishes. A 2 mil cured film thickness has a material applied cost of $ 0.11 per sq ft. The UV powder system provides a $ 0.17 per sq ft material applied cost advantage or 60% reduction in material applied cost. One million sq ft annual finishing capacity can provide an applied cost advantage of $170,000.

The manufacturing plant space requirement for a UV-cured powder system and solventborne system, 2,050 and 16,000 sq ft respectively, has a difference of 13,950 sq ft. This difference, assuming the real estate cost of $6.50 per sq ft, provides a UV powder system with a real estate advantage of $90,700. The total annual cost advantage of a UV-cured powder coating system is $444,450 for the illustration presented here. Because a UV-cured powder coating system does not generate VOC, it is reasonable to assume there is a cost advantage associated with the elimination of solvent disposal, permits, and incineration costs that were not included in our illustration. Without knowing the BTU output of a comparable liquid system, it is not possible to correlate an accurate energy benefit of a UV-powder system. However, it is reasonable to assume that when comparing systems of equal line speed and line density, the thermal system consumes more energy per part than the UV-cured powder system.

UV CHEMISTRY

UV-cured powder coatings contain resin, photoinitiators, additives, and pigments. Standard resin chemistries are available for interior and exterior applications. Photoinitiators absorb high intensity ultraviolet light to cause molecular crosslinking throughout the coating. Additives can modify the coating surface to improve a specific property, such as scratch or mar resistance. Pigments and extenders are used to add opacity and color to the coating. A variety of colors, special effects, metallic, and multi-component powders provides a wide array of finishes and appearances, as seen in *Figures* 2 and 3.

The proper combination of UV energy dose, intensity, and wavelength are important parameters to ensure complete cure in a UV-cured powder coating. The UV energy dosage (J/cm^2) is the total amount of energy received in the coating. The energy dosage (J/cm^2) is the energy intensity (W/cm^2) multiplied by the exposure time (sec). Typically, pigmented systems require a dosage in the UV "V" range (395–445 nm) of 3,000 mJ/cm^2; and depending on the application dosage, this can be as low as 1,000 mJ/cm^2. The proper intensity of UV energy is important to allow the UV light to penetrate through the depth of the coating. The proper intensity will depend on the coating application, thickness, and formulation.

There are several types of medium pressure mercury vapor UV lamps available for UV curing of powder coatings. Mercury lamps ("H" bulb) provide short wavelength UV energy (220–320 nm) that is suited for clear and tinted applications. Mercury lamps with an iron additive ("D" bulbs) provide higher wavelength energy (320–400 nm) that aid in curing for low level pigmented systems. Lamps with a gallium additive ("V" bulb) provide a strong output of long wavelength energy (405–440 nm) and are the workhorse for pigmented systems. Long wavelength energy penetrates more effectively through thicker and heavily pigmented coatings than shorter wavelength. It is important to consult with your formulator when designing a coating system to ensure the proper combination of UV lamps and photoinitiators is used.

Figure 2—UV-cured powder coatings on MDF.

Figure 3—UV-cured powder coating metallic finishes on MDF.

APPLICATION AND PERFORMANCE

UV-cured powder coatings are suited for a number of heat-sensitive materials and applications. The low temperatures and high speed of UV-cured powder coating make ideal conditions to powder coat plastic and wood composite materials. Plastics have low melting points, limiting the amount of heat a part can withstand before physical deformation occurs. The high speed of finishing and low-substrate thermal exposure make UV-cured powder coatings a very suitable finishing material for coating plastic materials (*Table* 2). The low conductivity of these materials requires a pretreatment step to the substrate to provide a conductive surface for electrostatic powder application. Surface activation may be necessary for improved adhesion. UV-cured powder coating can provide highly resilient and durable coatings for plastic substrates.

Table 2—Performance Results of UV-Cured Powder Coating on Various Plastic Substrates

Plastic	Pretreatment	Cross Hatch[a]	Impact Resistance[b]	Pencil Hardness[c]
Nylon 6	Yes	5B	50 in.	2H
Sabic GTX Noryl Resins	No	5B	50 in.	2H
Fiberglass - Pultrusion	Yes	5B	50 in.	2H
SMC	Yes	5B	50 in.	2H

(a) ASTM D 3359 Method A – cross hatch.
(b) NEMA LD3-2005, 3.8 ½ lb steel ball drop.
(c) ASTM D3363 Scratch Resistance, Wolff-Wilborn.

Figure 4—Product examples of UV-cured powder coating on MDF: built up MDF parts (left) and multi-component UV-cured powder coatings (right).

UV-cured powder coating on engineered wood composite, MDF, provides great design versatility. MDF is a readily available by-product of the wood industry and is a uniform and highly durable substrate used in a variety of finishing processes. UV-cured powder coating on MDF provides design flexibility and seamless finishing, not matched by wet and laminate finishing processes. MDF preheating enables the substrate to become conductive for electrostatic powder application.[3] Performance results of UV-cured powder coating on MDF shown in *Table* 3 are equal, or in many cases superior, to laminate materials. The UV process offers a plasticity of design and functionality not found in other wood-based products or coatings. Product applications include retail, point of purchase displays, work surfaces, and office furniture (*Figure* 4).

UV-cured powder coatings are well suited to coat pre-assembled components containing heat-sensitive materials. Pre-assembled components can contain a number of different parts and materials that are required to function properly. These heat-sensitive materials may be plastic, rubber seals, electronic components, and gaskets or lubricating oils. Minimizing thermal exposure of these components is critical to maintain their performance and tolerances. The first commercial application of UV-cured powder coating was finishing a fully assembled electric motor (*Figure* 5). The fully assembled motor contains electrical wiring and

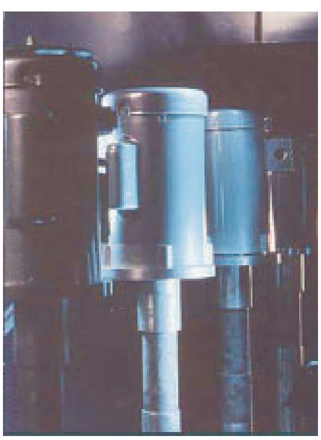

Figure 5—Pre-assembled part finished with UV-cured powder coating.

Table 3—Performance Results of UV-Cured Powder Coatings on MDF

Test Method	Category	Test Description	Performance Results	
ASTM D 4138 Method A	Film thickness	Tooke Gauge— Destructive	3–4 mils	3–4 mils
ASTM D 4060	Abrasion resistance	Taber Abrasion CS-17 Wheel 500 gm, 500 cycles	32.4 mg loss	15 mg loss
ASTM D 3363-05	Scratch resistance —Pencil hardness	Hardness—Wolff-Wilborn 300 gm load, 45°/no scratch	2H	3H
NEMA LD3-1995	Impact resistance	224 g steel ball (1/2 lb) 1 ½ in. dia.	No cracking at at 55 in.	No cracking at 30 in.
NEMA LD3 – 2005 3.4	Cleanability/ Stain resistance	Reagents: 10% citric acid, vegetable oil, coffee, milk, catsup, mustard, vinegar, red lipstick, grape juice, black permanent marker, water washable black marker, and # 2 pencil	No permanent effect on sample surface	
PCI # 8	Cure	MEK swap – 50 double rubs	No softening or color loss	No softening or color loss
	Color match	C Lab – Cool white fluorescent illuminant dE cmc<1.0	dEcmc < 0.75	
NEMA LD3 –2005 3.4	Hot water	Pool of boiling water placed on surface, pot placed in water for 20 min	No blistering	
ASTM D 4587	QUV	Industrial coatings – 1000 hr	dB < 1.0	
ASTM D 3359 Method B	Adhesion	Cross hatch adhesion – MDF must be present on piece of coating removed	No loss of adhesion	No loss of adhesion

other heat-sensitive components. In this application, the UV-cured powder coating provides low substrate thermal exposure to maintain the functional integrity of all the components within the motor assembly. UV-cured powder coatings are well suited to provide durable and resilient coatings to a variety of pre-assembled and heat-sensitive products.

CONCLUSION

The consumption of UV-cured powder coating is increasing. Designers are creating more products that use UV-cured powder coatings and end users are using more UV-cured powder coated components in their products. UV-cured powder coating is perceived and recognized as a viable chemistry and a reliable material for a variety of substrates and product applications.

The continuing challenge is to educate the market about the benefits and advantages of UV-cured powder coating. This is an advanced and developing chemistry and is a highly efficient and productive application technology. Higher demand for UV-cured powder coating will increase the flow of investment capital into the UV-cured powder coating segment of the coatings industry. As demand increases, the incremental cost of system components and constituent chemistries will decrease, thus lowering the total applied cost of finished products. UV-cured powder coatings meet the ever-growing worldwide demand for environmentally friendly and energy efficient coatings. The future for UV-cured powder coating looks very bright. CT

References

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Appendix A—TECHNOLOGY COMPARISON

Properties	Powder		Liquid			Notes
	UV	Thermal Ultra-Low Bake	UV	Waterborne	Solventborne Set as Standard	
Environmental	++	++	++	+	0	Global, pollution, VOC, PBT, HAPs, REACH compliant
Safety, flammability	++	++	+	+	0	
Health risk (workers)	++	++	0	+	0	Toxicity, irritation (skin)
Energy consumption	+	0	+	0	0	Total process
Curing mechanism	Free radical	Addition reaction (thermal) energy	Free radical	Various	Various	
Speed of curing	Sec	Min	Sec	Min	Min	
Storage stability	+	++	++	0 Freezing	0	Shelf life
Finish coats to produce a finished product	++	++	0	0	0	
Material utilization	++	++	0	0	0	Powder>95%, liquid< 60%
% Solids application	++	++	+	0	0	
Volatile compounds	++	++	++	+	0	No solvent, coalescent

Note: Solventborne coating technology is control standard.