New UV-Curable Powder Coating Formulations That Can Create Metallic Finishes On Wood

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Introduction

UV cured powder coatings for medium density fiberboard (MDF) are durable and environmentally-friendly. These coatings have laminate performance qualities with the design capability of wet paint, in a one coat finishing system. UV cured powder coatings are available in opaque, prismatic, metallic, tints and clear finishes. The UV metallic powder coatings presented here provide a new finishing opportunity to the wood coatings market offering solid metal and metallic effect finishes.

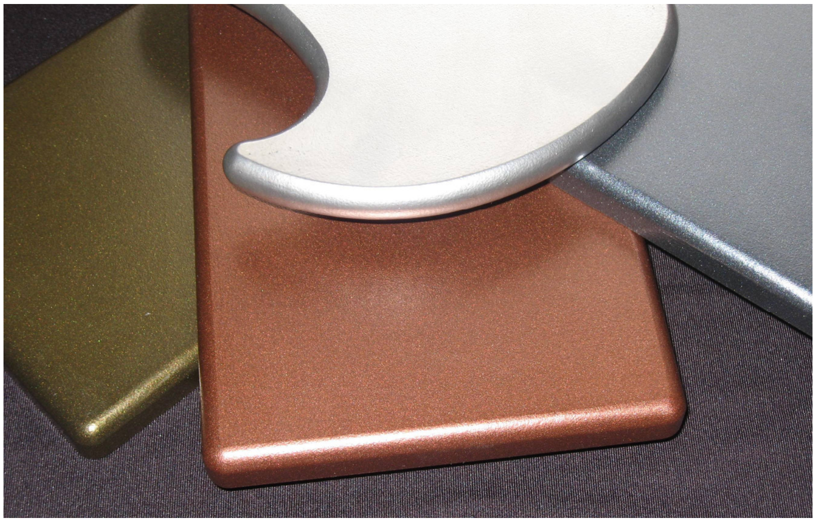

Figure 1: UV cured metallic powder coatings on MDF substrate, Gold, Bronze, Dark Silver and Bright Silver

Traditional metallic liquid finishing is a solvent borne process and require long drying times and multiple coats to achieve the proper coverage and hiding. These materials are hazardous and require air handling equipment, respirators[1]. The inherent toxicity of these coatings requires proper handling and stricter environmental regulations, is increasing the development of green coatings[2]. The development of green coatings limits traditional liquid finishing methods. This paper focuses on the development of UV cured powder coatings to provide metallic finishes in a fast, environmentally friendly, single pass finishing process for MDF substrates. UV cured metallic powder coating appearance and performance properties will be discussed. A basic formulation understanding, manufacturing and application process will be provided.

Powder coating is an industrial finishing technology that has been around since 1960s. Powder coatings provide attractive and durable coatings in a highly efficient solvent free finishing process. Powder coating finishes are available in a wide range of colors, glosses, and textures. Powder coatings have traditionally been used in high use environments due to their superior wear, resilience, and barrier properties. Products include home appliances, industrial equipment, and automotive components. These products have metal substrates well suited for electrostatic powder deposition, where electrostatic charged powder is attracted to the grounded part to form a uniform layer of powder and then undergoes a thermal cycle to melt and flow the powder and cure the coating. The powders contain no solvents and no volatile organic compounds (VOCs). The recapture of powder over spray can be re-introduced into the spray operation yielding close to 95% material utilization[3]. Any powder waste is non toxic and can be put into a process stream or waste stream; recently, the plastics industry utilizes powder waste for filler in their manufacturing process, avoiding the waste stream.

Advantages of UV Powder coatings

UV powder coatings go a step further and combine the environmental and process benefit of powder coatings with the speed of UV curing. The fast speed of UV cured powder coating is attributed to the separation of melt/flow from the cure process. Traditional thermoset powder coatings undergo an oven cycle that melt the powder and requires the material to reach substantially higher temperatures to initiate the polymerization process in the coating. The UV process does not require heat to cure, but rather the molten coating held above 195°F (90°C) for proper penetration of UV energy to initiate the photo initiators[4]. A typical powder viscosity profile, as seen in Figure 2, shows the de-coupling of the melt/flow from the cure process can reduce the flow/cure cycle time by a factor of 10. The reduction in cycle time reduces the space requirement for the operation and maintains substrate integrity due to reduce substrate thermal exposure as will be discussed further.

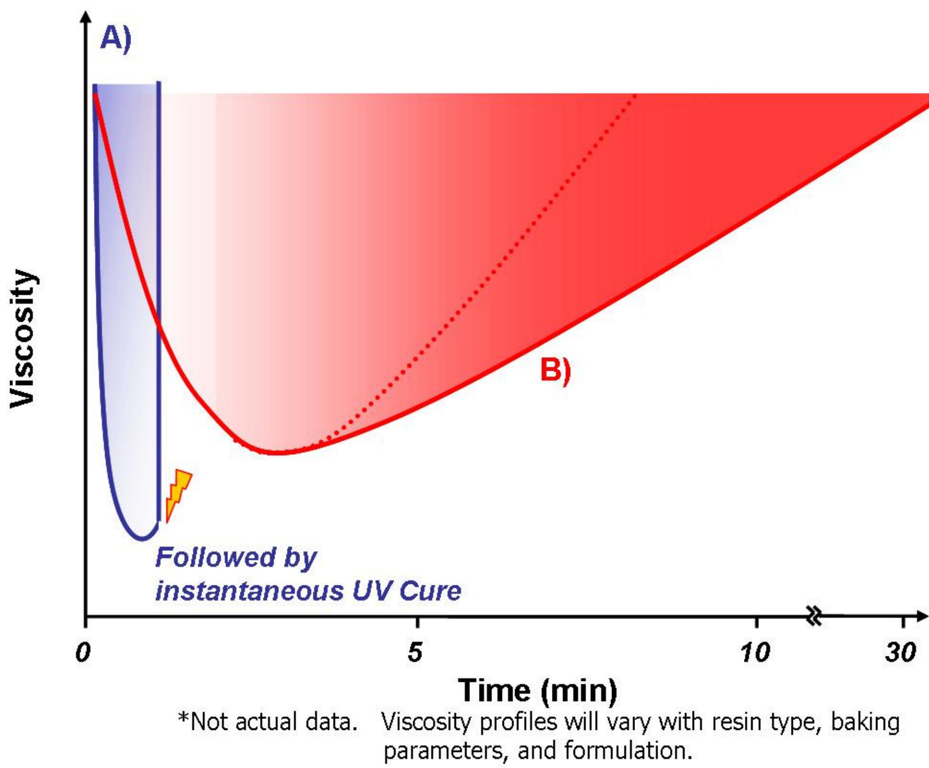

Figure 2: Viscosity profile during oven dwell cycle for A) UV cure powder and B) Thermal cure powder.

The development of low temperature cure powder coatings provides a thermal cure process for MDF substrate. A test conducted on MDF specimens subjected to the UV melt/flow and thermal oven cycles indicated changes in the substrate integrity. The UV melt/flow cycle provided a surface temperature of 168°F and no change in the MDF specimen while the thermal cure cycle showed significantly higher surface temperature of 217°F and edge cracking throughout the MDF specimen. Edge cracking, known as post-cure cracking has lead to the use of thicker powder film builds, up to 4 times higher, to hide or minimize cracking appearance on the coating surface[4]. UV powder coatings minimal thermal exposure does not degrade the substrate material and enables lower film builds. In addition, the low substrate surface temperatures provide reduced part cooling time reducing the need for long cooling tunnels and saving plant floor space.

Table 1: MDF Thermal Study Results

	Oven Cycle		Post Oven Cycle			
	Time (min)	Temperature	Surface Temperature	Post Oven	Results	Total Time (min)
Thermal	12	300°F	217°F	12 min. to achieve 94°F	Cracking through edge	24
UV Process	1	400°F	168°F	4 min. to achieve 94°F	No cracking	5

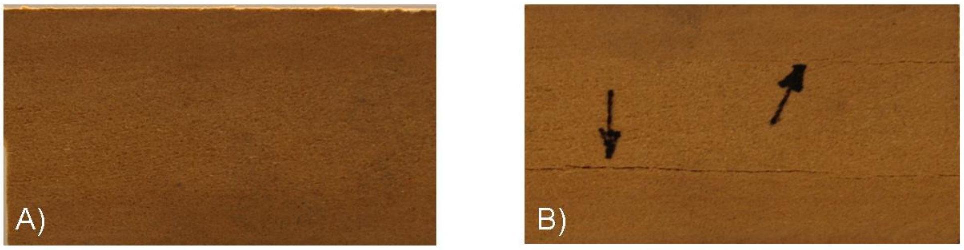

Figure 3: MDF Thermal Study Results A) 1 minute at 400°F B) 12 minutes at 300°F

UV cured powder coatings provides versatility and flexibility in design. The powder coating process provides a seamless uniform finish on all surfaces of MDF. MDF can be machined with a variety of edge features, including through cuts, bull nose, round over, or water fall edges, to provide a unique surface geometry. Although the available MDF thickness are ½" to 1 ½" thick sheets, MDF can easily be built to form 3 dimensional shapes as seen in Figure 4. The electrostatic attraction of powder coatings to the MDF substrate enable complex design and built up parts to be powder coated with ease. The uniform powder deposition on MDF provides a seamless finish that would be impossible for traditional laminate processes.

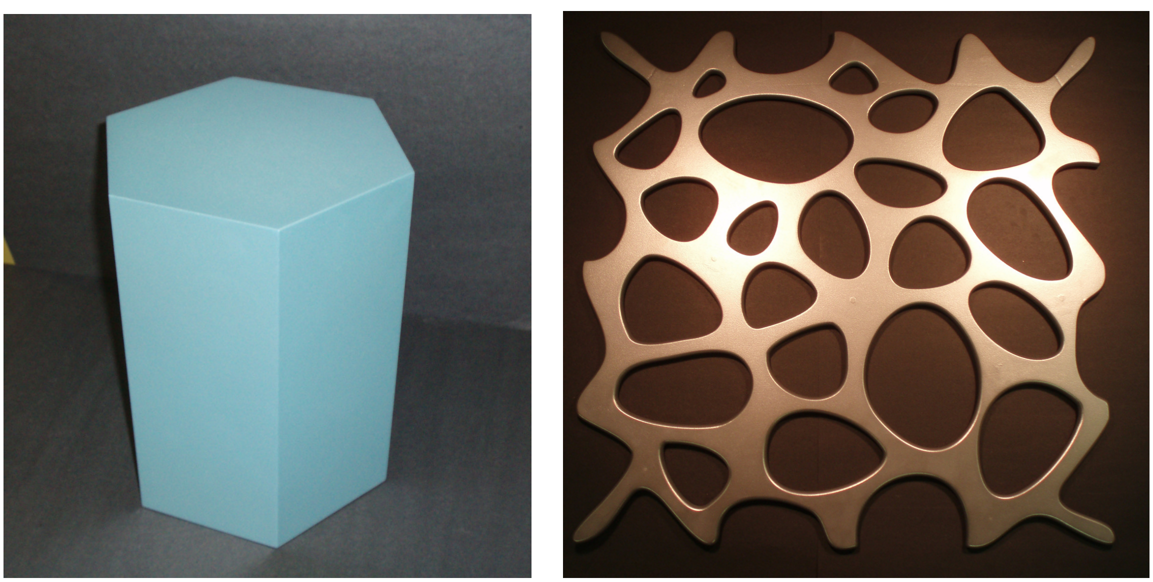

Figure 4: Image of UV cured powder coating on 3 dimensional MDF shape (Left). Image of Silver Metallic UV cured powder coating on MDF lattice (Right).

Manufacture Process

UV powders are manufactured using the same mechanical process as traditional thermoset powder coatings. The raw materials are blended in a high speed mixer to produce a dry homogenous pre-mix of materials. The pre-mix is then fed into the extruder where it undergoes a hot melt compounding process. The extruder consists of one (single) or two (twin) rotating screws encased in a heated barrel. The extruder melts and mixes the raw materials in areas of high shear into a hot uniform melted blend. This molasses-type material, extrudate, is squeezed between chilled rollers onto a belt for further cooling. After the material has cooled, it is brittle and is passed through a chipper or flaker to break the extrudate into small pieces for handling. In the grinder, the extrudate undergoes size reduction by high speed impact of the solids against each other and the inter surfaces of the mill. A final sieve of the powder to remove any oversized material and the powder is ready to be packaged for shipment to the customer.

UV Powder Formulation

UV powder is comprised of resin, photoinitiators, additives and pigments. The resin component for UV powder coatings are acryalate based polyester, polyurethane, and epoxy. The photo initiator when exposed to intense UV energy absorbs the energy and causes molecular cross-linking and polymer bonding throughout the coating, illustrated in Figure 5. Additives are used to provide gloss and texture control as well as improve a specific coating property, such as scratch or mar resistance. Pigments are used to provide the color in the coating and responsible for the opacity of the coating.

The proper combination of photo initiator blend and UV lamp are important to ensure proper curing of the coating will occur. In general, ultra violet light is radiant energy between 200 and 450 nm. In clear and tinted clear powder coatings the use of the alpha-hydroxy ketone (α-HK) type photoinitiator absorbs short wavelengths of UV energy emitted from a mercury or “H” lamp. In pigmented powder coatings the bis-acyl phosphine oxide (BAPO) type photoinitiator absorbs higher wavelengths of UV energy from a gallium doped mercury lamp (“V” bulb). The combination of α-HK and BAPO photoinitiator can provide the surface and through cure desired in a pigmented powder coating system[6].

Maintaining proper UV light transmission through the coating requires consideration of pigment particle size and loading percentage. The larger particle size of metallic pigments and high reflectivity suit them well for UV powder coatings. Metallic effect pigments are post blended with finished powder rather than incorporated with standard pigments. Post blending of these pigments allows the pigment to retain its shape, surface area, and luster that otherwise would be broken down during various stages of the powder manufacturing process. The metallic pigments chosen for this study are mica based pigments and traditional leafing grade aluminum pigments.

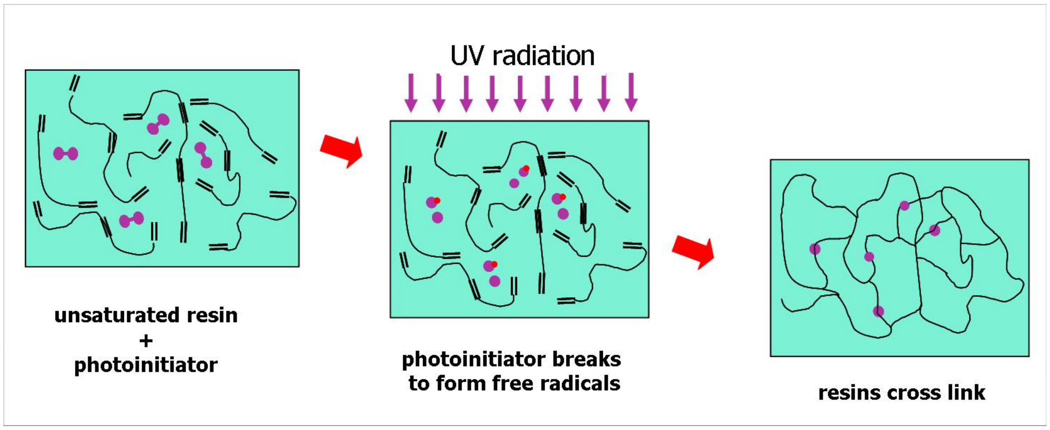

Figure 5: UV powder cure cycle

Application Process

UV powder application on MDF substrate consists of 4 steps; pretreatment of the MDF board, powder application, powder melt and flow, and UV cure.   A typical UV powder application line to powder coat MDF is illustrated below in Figure 7.

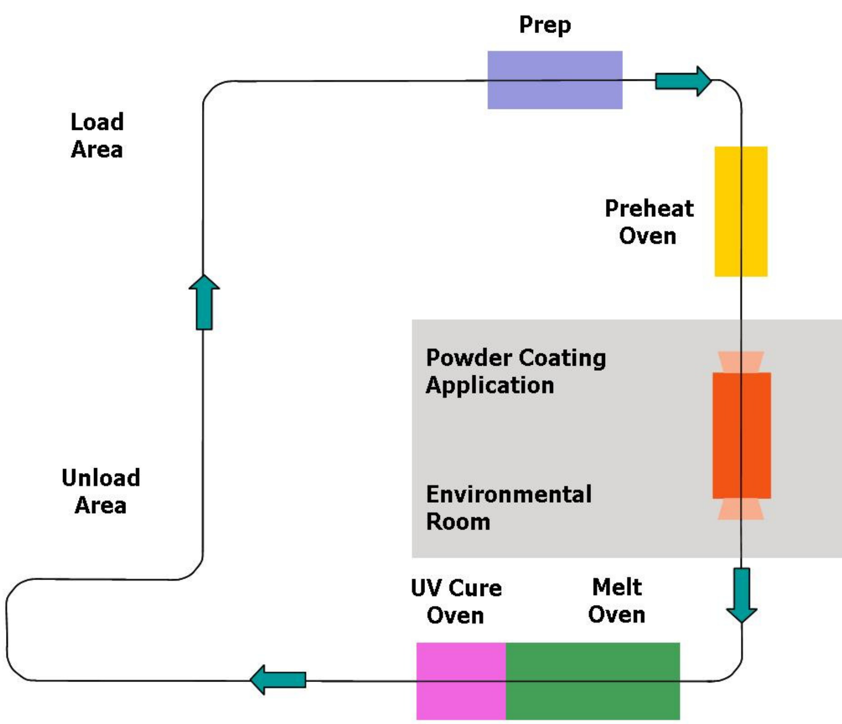

Figure 6: UV Powder Application Process for MDF

The MDF pretreatment includes sanding, blowing off, and preheating. Sanding will remove wood fibers protruding from the surface. For smooth high gloss finishes sanding may be required to remove these fibers, however if a textured finish is desired sanding may not be necessary. Once the parts are blown off they are ready for the preheat oven. The preheat oven brings the board temperature to between 180°F to 250°F that is necessary for powder deposition. Typically an MDF board will contain 4-9% moisture. The heating of the board will cause some moisture and air to outgas from the board, leaving behind a uniform moisture profile on the board surface to provide board conductively for powder deposition[4].

The UV powder is applied using electrostatic principles in which powder is negatively or positively charged, and directed to toward the grounded substrate. The charge is applied to the powder either through a corona field, called Corona charging, or induced friction referred to as Tribo charging. The moisture in the MDF board has been driven to the surface to create a ground that will attract the charged powder particles. The powder will wrap around the part providing coverage on the part edges and the opposing side.

Once the powder has been deposited the part goes to the melt and flow oven where the surface temperature of the part is between 180°F to 250°F. Here the powder is brought to a molten state to flow to the desired surface finish. The part dwell time is 1 minute before it is exposed to intense UV energy for only a few seconds. The photo initiators absorb the UV energy and begin the polymerization process through out the coating.

A typical film build for a UV powder coating is between 3-4 mils (73.4 – 98.0 microns). The single pass finishing process of a 1 minute preheat oven, powder deposition, 1 minute melt/flow and seconds for UV cure can operate at 10 feet per minute. A typical line size of 200 feet can enable a raw MDF part to be finished in an attractive metallic powder coating in 20 minutes.

Appearance Capability

The UV metallic powder coatings presented here provide a new finishing opportunity to the wood coatings market with lustrous and metallic effect finishes. Solid metals of gold, bronze, dark silver and bright silver have been developed to provide a unique finishing solution for MDF material. Examples of the solid metals are shown in Figure 1. One example of the design capability of UV metallic powder coatings is shown in the silver lattice in Figure 4 Right. The machine ability of MDF material makes it ideal for creative designs for any number of applications. Decorative metallic effects are capable to provide silver metallic effect to any color. Shown below in metallic effect are blue, orange, red, and orange in Figure 7. The metallic effects provide the flop of a metallic to a non traditional metallic color.

Figure 7: UV Cured Metallic Effect Powder Coatings

Performance Results

UV powder coatings provide good mechanical properties and durable surface finish. The performance of standard opaque UV cured powder is presented with the results for the solid metallic finishes and metallic effects in Table 2. The solid metallic and metallic effect finishes provide a durable high impact resistance coating able to with stand 70 in/lbs of impact force similar to the standard opaque finishes. The solid metallic finishes have similar abrasion performance as the opaque and barrier properties were tested and were resistant to discoloration and blistering. The surface finish of the smooth non textured metallic effect finish could attribute to the lower material loss from the abrasion resistance tests.

The durability of these coatings was evaluated based on stain ability, clean ability, and burnish. The stain resistance study looked at reagents exposed to the coating for 24 hours, upon which the removal of the stain from the coating was evaluated and graded by which cleaner is required to remove the stain. The solid metallic was able to with stand cleaning from all cleaners except acetone. The use of commercial cleaner to remove the pencil and lipstick reagents can be attributed to the textured finish that retains the reagent in the low spots of the texture. The stain ability for the metallic effects finishes withstand commercial cleaner and require the use of acetone to remove permanent marker. The burnish resistance test was developed to provide an indicator for removal of metallic from the coating surface. The solid metal finish did not show any sign of burnishing while the metallic effect finishes had slight removal of the metallic from the coating surface.

The solid metallic finishes provide the coating durability and performance of an opaque powder coating. The metallic effects provide the mechanical performance desired of a UV cured powder coating, however there is limited burnish resistance in this formulation. This study has shown the use of mica based pigments did not impact the powder coating performance under the testing protocol detailed here.

Conclusion

The use of mica based metallic pigments provides an exciting method for formulating metallic finishes in UV cured powder coatings. This coating technology and formulation capability provides a finishing application to provide new and exciting finish opportunities for the wood coatings market.

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Table 2: Performance Date for UV Curable Powder coatings

Test Category	Standard	Opaque [D]	Metallic Effect	Solid Metallic
Adhesion	ASTM D3359[A] Method B	No loss of adhesion	No loss of adhesion	No loss of adhesion
Abrasion Resistance	ASTM D4060[A] CS-17 wheel, 500gm load, 500 cycles	34.2 mg	21.4 mg	30.5 mg
Impact Resistance	NEMA LD3-2005[B], 3.8 224 g (1/2 lb) steel ball drop test	No cracking at 35”	No cracking at 35”	No cracking at 35”
Cure	#8 Solvent Cure Test[C] MEK (methyl ethyl ketone) 50 double rubs	No soften, slight loss of gloss	No soften, loss of metallic	No soften, slight loss of metallic
Boiling Water Resistance	NEMA LD3-2005[B], 3.5 Pool of boiling water (10 ml) placed on specimen and pot placed in pool for 20 minutes.	No blistering or discoloration	No blistering or discoloration	No blistering or discoloration
Clean ability / Stain Resistance	NEMA LD3-2005[B], 3.4 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 Cleaners: water, commercial cleaner, commercial cleaner w/ baking soda, acetone	No effect	• Acetone to remove permanent marker	• Commercial cleaner to remove pencil & lipstick • Acetone to remove permanent marker
Rub Resistance	100 cycles, 2” straight movement with 2 kg weight	No effect	Slight rub off	No effect
Notes	A American Society for Testing and Materials, West Conshocken, Pa B National Electrical Manufactures Association, Rosslyn, Va C Powder Coating Institute, Alexandria, Va D UV powder coating tests performed by Stork Herron Laboratories			