ChemQuest® *actionable insights for success*

More than Just Wood

Low-Temp Cure Powder Coating Technology

ACA Member Webinar

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Kevin Biller

ChemQuest Powder Coating Research

The ChemQuest Group, Inc.

kbiller@chemquest.com

Watch Webinar

Presentation Overview

The concept of low-temperature-cure powder coatings has loomed since the dawn of powder coating technology. In recent years, novel technology has emerged that can be cured at ever-lower temperatures.

This presentation explores the following:

- Why Low-Temperature Cure?
- Heat-Sensitive Substrates
- Dealing with Conductivity
- Low-Temp Cure vs. Ultra-Low Bake
- Low-Temp Cure – Chemistries
- Ultra-Low-Bake Thermosets
- UV-Curable Powder Coatings
- Future Trends

ChemQuest: Actionable Insights for Success

Our Mission is Enabling Our Clients to:

- Build enterprises that challenge established thinking and drive transformation.
- Gain competitive advantage through distinctive, targeted, and substantial improvements that sustain profitable growth.
- Unlock new and hidden insights empowering an organization's smart risk-taking, catalyzing innovation excellence and value creation.
- Be successful — because our success emanates from yours.

ChemQuest by the Numbers

1976	Year the firm was established
~130	Total consultants and technical staff
25	Minimum years of experience in specialty chemicals for senior personnel
100%	Percent of our work that is proprietary, offering a full portfolio of services under NDA

Four Pillars of Expertise

Deliver distinctive, thorough, actionable, confidential, and professional work and support our clients in every aspect of sustained, profitable growth, including:

- Business Strategy & Transformation
- Technology Development
- Operational & Manufacturing Efficiencies
- M&A Advisory Services

Technology Development

Design, formulate, test, accelerate, and scout innovative technology.

- For suppliers, manufacturers, and users
- Advanced lab facilities tailored to CASE R&D and polymer processing
- Services from molecular architecture to sophisticated application research
- Client-owned IP
- Education courses to enhance the capabilities and knowledge of your internal team

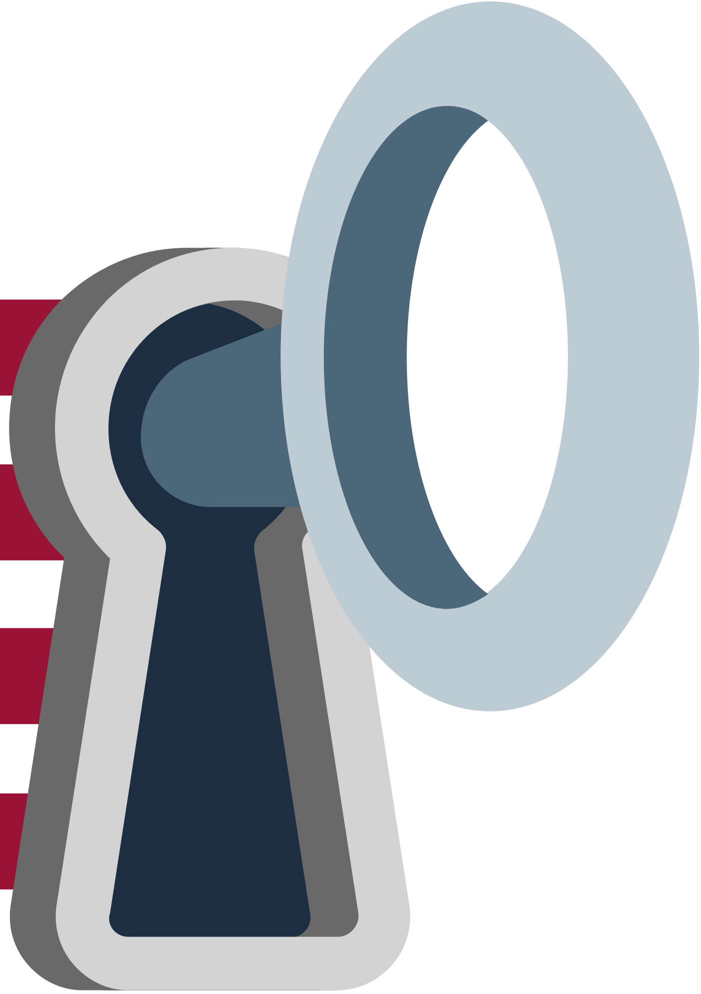
Why Low-Temperature Cure?

Powder Coating Benefits

- No VOCs
- Non-Toxic
  No heavy metals
- Little or No Waste Stream
- Efficient
  Collect and reuse overspray
- High Performance
- Excellent Overall Economics

Low-Temp Cure Opportunities

- Heat Sensitive Substrates
- Pre-Assembled Parts
- Plastic Substrates
- Wood Substrates



Heat-Sensitive Substrates

Pre-Assembled Parts

Electrical Equipment
Motors, generators, switchgear

Pneumatic/Hydraulic Equipment
Door closers, jacks, shock absorbers, suspension parts

Metal/Plastic Assemblies

Gasketed Parts
Plumbing, taps, pumps, valves

Plastic Substrates

Substrate	Composition	HDT (0.46 MPa Load)	Powder Type
ABS	Acrylonitrile Butadiene Styrene	98°C	UV
Acetal Copoly	Polyoxymethylene (ethylene)	160°C	TS
Acrylic	Acrylic	95°C	UV
Nylon 6	Polyamide	160°C	TS
PC	Polycarbonate	140°C	UV
PC/ABS	Polycarbonate/ABS Blend	80-100°C	UV
HDPE	High Density Polyethylene	85°C	UV
PET	Polyethylene Terephthalate	70°C	N/A
PMMA	Polymethylmethacrylate	105°C	UV
PP	Polypropylene	100°C	UV
PS	Polystyrene	95°C	UV
PVC	Polyvinyl Chloride	90°C	UV
Noryl GTX	Polyamide/polyphenylene ether	231°C	TS
PEEK	Polyetheretherketone	160°C	TS

Wood-Based Products

Substrate	Composition	Maximum Temperature	Powder Type
MDF	Medium-Density Engineered Board	135°C	TS/UV
HDF	High-Density Engineered Board	150°C	TS/UV
Wood Composites	Wood Pulp plus PVC & HDPE, LDPE	150°C	TS/UV
Closed-Grain Woods	Maple, Beech, Birch, Cherry, Poplar, Rubber Tree	140°C	TS/UV
Open-Grain Woods	Oak, Hickory, Ash	100°C	UV

Dealing with Conductivity

Applying Powder to a "Non"-Conductive Surface

Thermal Spray (or plasma)
Thickness control

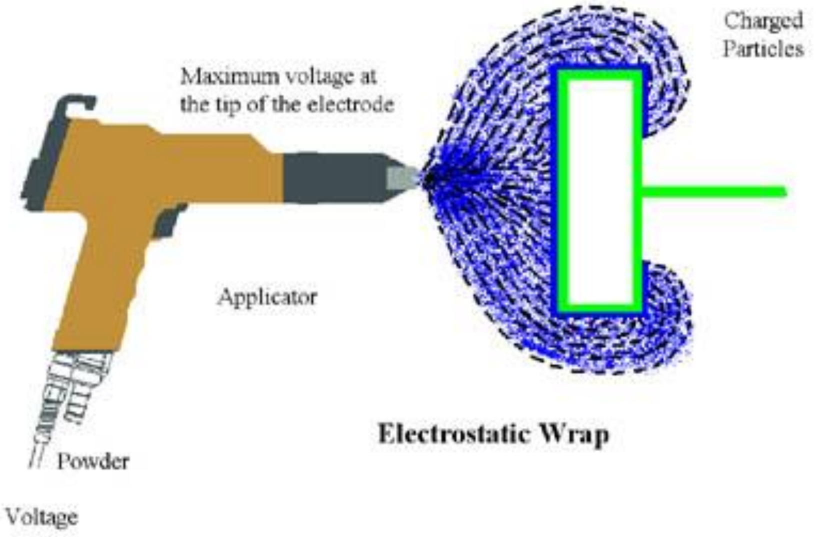
Preheat
Thermal losses

Conductive Primer
Solvent or waterborne?

Conductivity into Plastic
Expensive to incorporate

In-mold Process
Tool is conductive

Conductive Solution
Easy, quick



Low-Temp Cure vs. Ultra-Low Bake

Low-Temp Cure vs. Ultra-Low Bake

Low-Temperature Cure (LTC)

A product offering any significant reduction in curing temperature. Typically, conventional chemistry modified with more active catalysis.

Ultra-Low Bake (ULB)

Sub-150°C designed for alternate substrates and unique curing processes.

- Thermoset
- UV Cure

Low-Temp Cure - Chemistries

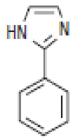
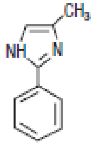
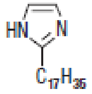
Thermosets

Chemistry	Standard Cure	Low-Temp Cure
Epoxy	15′ @ 175°C	**15′ @ 150°C**
Epoxy Polyester	15′ @ 190°C	**15′ @ 160°C**
Polyester	15′ @ 190°C	**15′ @ 160°C**
Polyurethane	15′ @ 200°C	**20′ @ 150°C**
Acrylic	20′ @ 175°C	**20′ @ 160°C**

Infrared can reduce dwell time.

Epoxies

- Catalysis with Imidazoles, Lewis Acids, etc.
- Available in Curing Agent

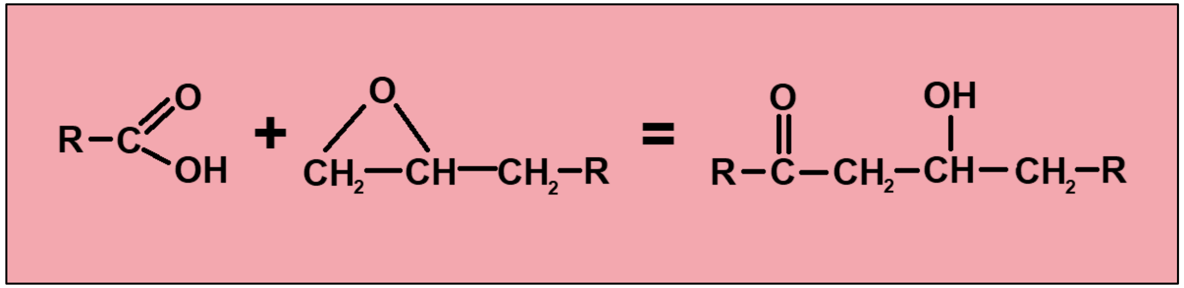
Imidazole	Chemical Structure	Molecular Weight	Appearance	Storage Life (years)	Melting Point °F/°C	Rec PHR
Imicure® AMI-2		82	Pale yellow powder	2	279–293 137–145	1–4
Curezol 2PZ		144	Pale pink powder	3	279–293 137–145	1–4
Curezol 2P4MZ		158	White powder	3	325–360 163–182	3–6
Curezol C17Z		306	White powder	3	187–196 86–91	3–5

Phenolic Curing Agents

Grade	Ph-OH E.W. (g/eq)	Softening Point*1 (°C)	Gel time*2 (sec)	Color (G,max.)	Characteristics/Use
KD-404	230-260	73-85	40-80	1	Fast cure
KD-405	230-260	73-85	100-160	0.5	High adhesion

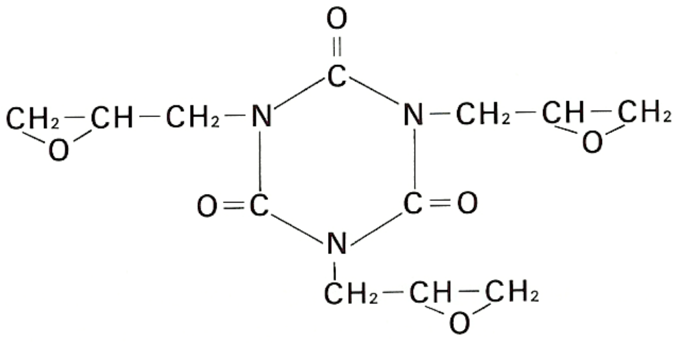
Epoxy-Polyester Hybrids

	50/50 Acid # ~70
200°C 392°F	CRYLCOAT® 1544-4
180°C 356°F	CRYLCOAT 1510-0
	CRYLCOAT 1514-2
	CRYLCOAT 1557-5
	CRYLCOAT 1573-0
170°C 338°F	
160°C 320°F	CRYLCOAT 1540-0
	CRYLCOAT 1593-0
	CRYLCOAT 1506-0



Polyester - TGIC

- Lower molecular weight/T_g
- Catalysis
- Primid (β-hydroxyalkyl amide) – difficult to catalyze



	93/7 Acid # ~33
200°C 392°F	CRYLCOAT® 2437-0
	CRYLCOAT 2401-2
	CRYLCOAT 2471-4
	CRYLCOAT 2689-0
	CRYLCOAT 2441-2
	CRYLCOAT 2488-2
	CRYLCOAT 2425-0
	CRYLCOAT 2430-0
	CRYLCOAT 2440-2
180°C 356°F	CRYLCOAT 2408-0
	CRYLCOAT 2421-5
	CRYLCOAT 2450-2
160°C 320°F	CRYLCOAT 2409-0
	CRYLCOAT 2494-6
	CRYLCOAT 2473-4
	CRYLCOAT 2433-2

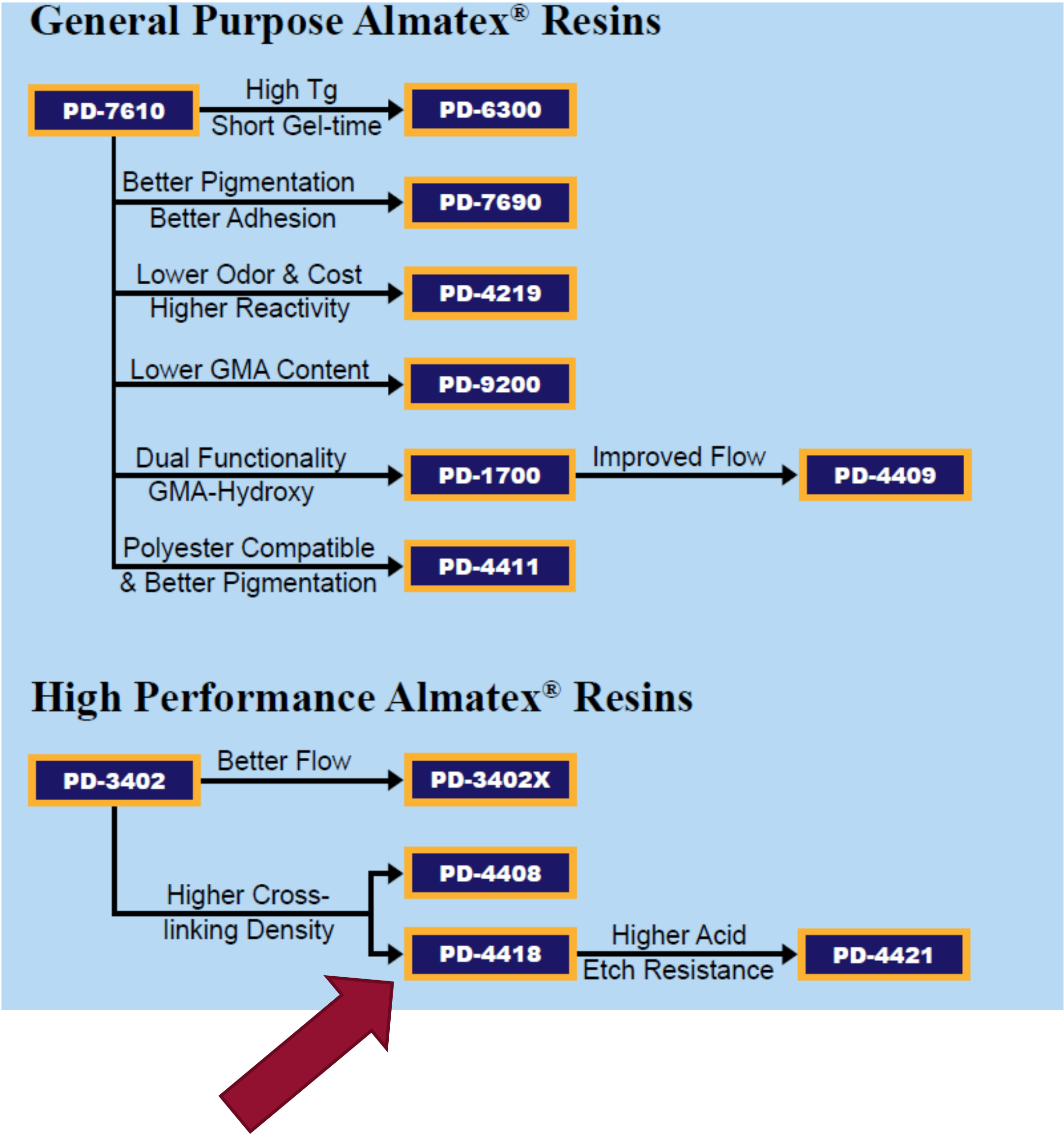
Polyurethane

- OH Polyester – Low Melt Viscosity
- Alcure 4470 Triazole blocked Di-isocyanate
- Tin Catalysis

Curative	Exterior Grade	NCO Equivalent Weight	T_g ºC (approx.)	Baking Schedule	Performance Characteristics
Alcure 4431	Yes	333	55	20 min @ 180ºC	Reduced yellowing and improved UV resistance compared to Alcure 4430
Alcure 4450	No	275	64	20 min @ 160ºC	Polymeric aromatic isocyanate for low-temperature cure Savings over aliphatic curatives Not recommended for long-term UV exposure
Alcure 4470	Yes	212	58	30 min @ 160ºC	Polymeric aliphatic isocyanate E-caprolactam free, Triazole blocked Low-temperature cure

GMA Acrylics

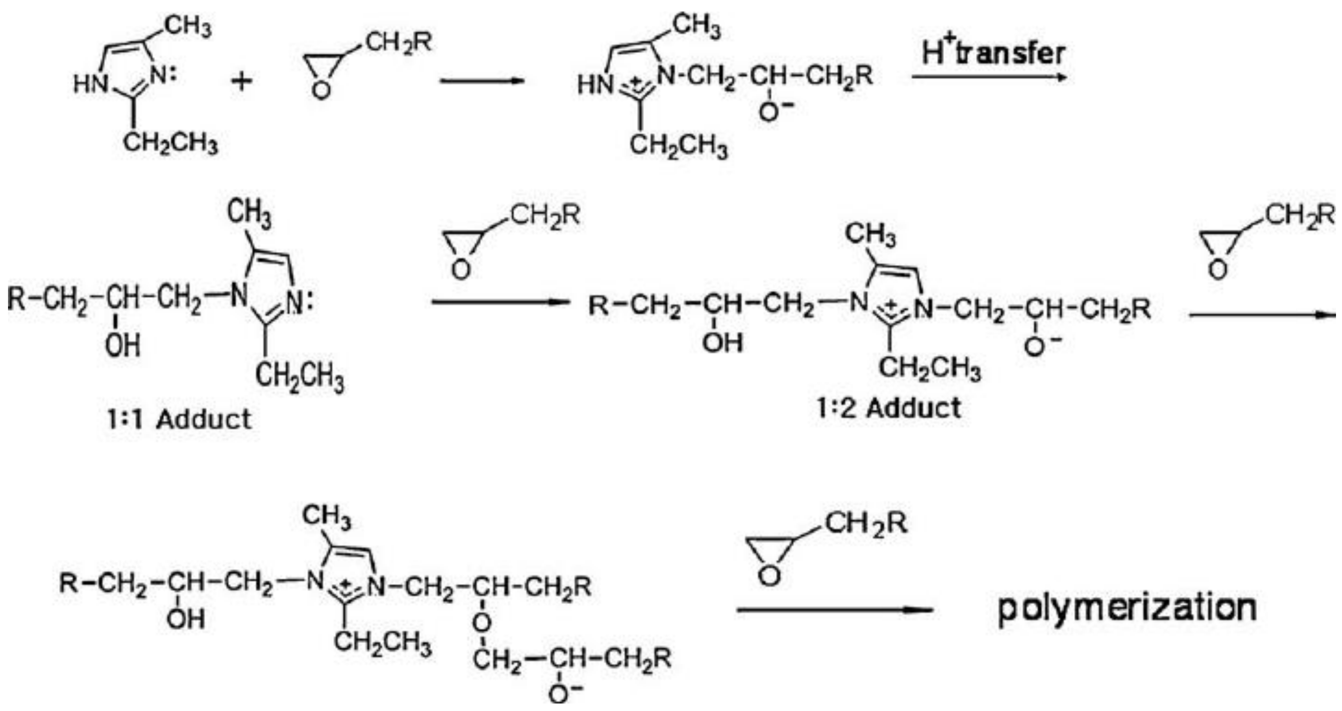
- Lower EEW (epoxide equivalent weight)
- Increased functionality
- Catalysis



Ultra-Low Bake – Thermoset Chemistries

Epoxy

- Homopolymerization
- More catalyst (latency helps)
- Cure as low as 125°C



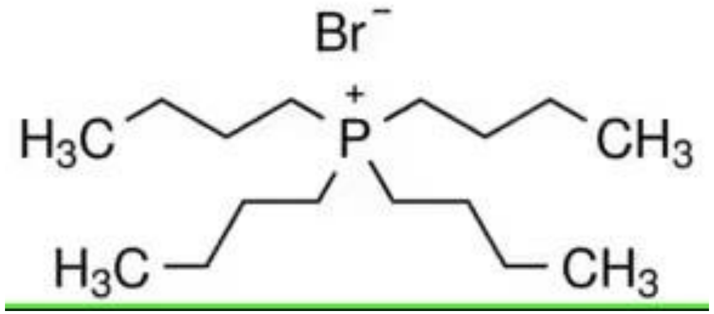
Epoxy-Polyester Hybrid

CRYLCOAT®	Ratio	Acid #	Visc.a	Tg(C°)	Cure	Benefit
• 1574-6	50/50	71	5000	50	140ºC	Low cure for MDF

Polyester - TGIC

Resin	Acid Value mg KOH/g (approx)	Viscosity mPa.s 200ºC	Tg ºC (approx.)	Baking Schedule	Performance Characteristics
Albester 5190	31-37	2000-2600	51	10 min @ 150ºC 25 min @ 130ºC	Excellent storage stability Excellent solvent resistance No blooming at low temperatures

Tetra Butyl-Phosphonium Bromide



GMA Acrylics

- GMA Acrylic – Low EEW (High GMA conc.)
- Additol P-791 - Polyanhydride (Allnex)

Product Specification

	Limits
Appearance	Pale granules
Acid value alcoholic (mg KOH/g)	310-325
Melting range (°C)	80-90
Color, b-value	Max. 15

Starting Formulation

Component	Weight (%)
ADDITOL® P 791	24.0
Acrylic Resin EEW (g/eq) 500 - 550	69.7
Flow Promoter	3.0
UV Stabilizer	1.5
UV Co-Stabilizer	1.5
Benzoin	0.3

Unsaturated Polyester

Unsaturated Polyesters
- Uracross XP-752 (industrial)
- Uracross XP-755 (architectural)

- ➢ Amorphous
- ➢ T_g 50-55°C
- ➢ WPU 500

Peroxide Catalysis

Vinyl Ether Urethane
- Uracross 3307

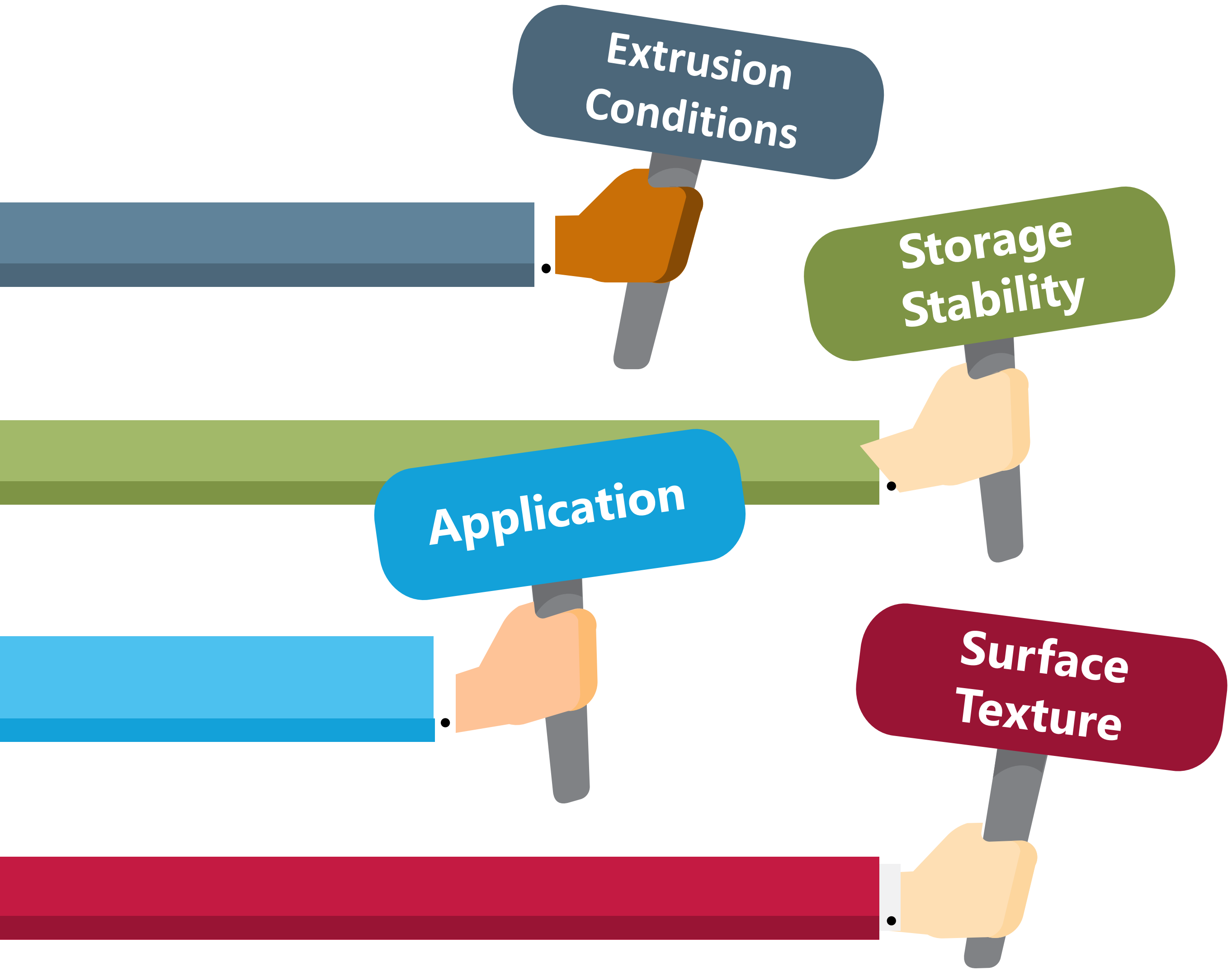
- ➢ *Crystalline*
- ➢ Tm 100°C
- ➢ T_g -58°C
- ➢ WPU 200

Bio-Based Polyester-Amide

Battelle Technology

- COOH Functional
- Cure with TGIC or PT-910
- 85% Bio-based COOH Polyester-Amide Resin
- 135 to 180°C Cure Window
- Excellent Smoothness
- Excellent Impact Resistance
- Excellent UV Durability

Low-Temp Cure Caveats



Extrusion Conditions are Critical

- Low dwell time
- Cooler barrel temps

Storage Stability

- May require reefer transportation
- Controlled storage temp and application system
- Shelf-life limitations

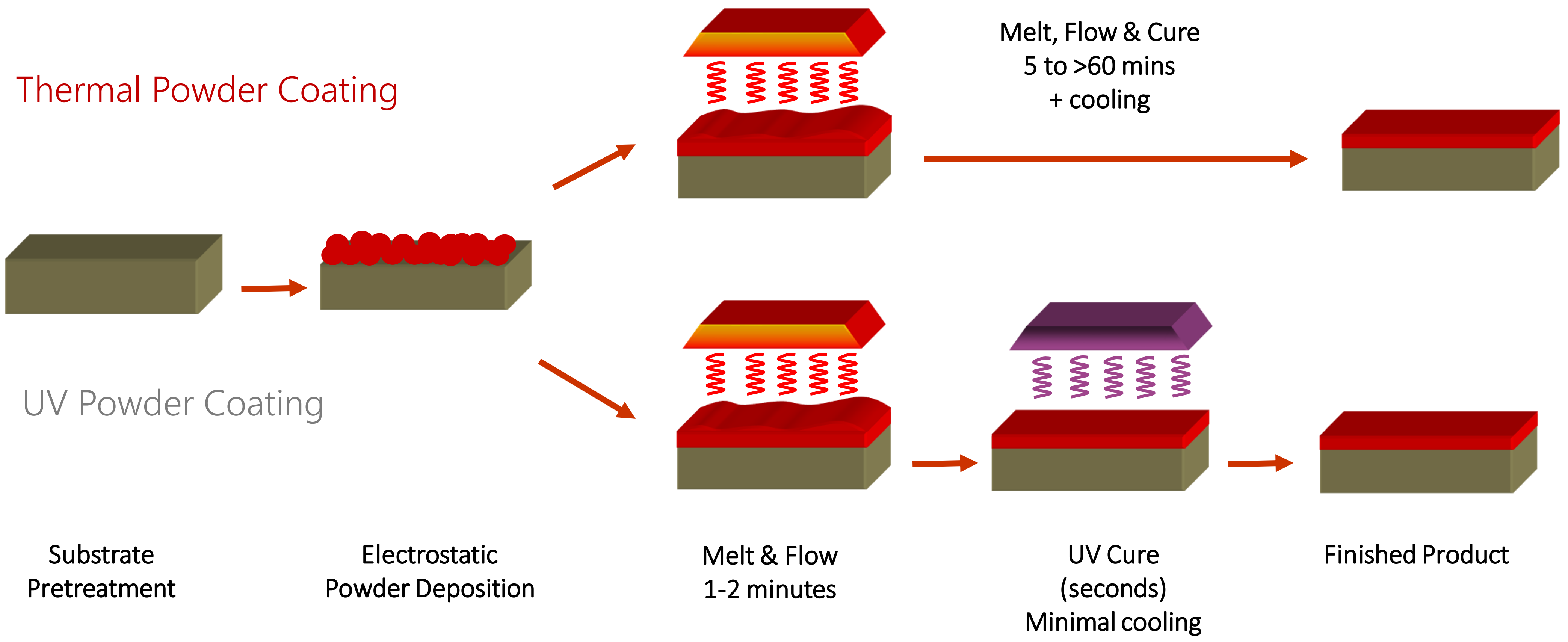
Application

Impact fusion

Smoothness?

UV-Curable Powder Coatings

The UV Curing Process



KEYLAND POLYMER UV POWDER Courtesy of Keyland Polymer

UV-Cure Powder Process

Infrared: 60 sec

UV Cure: 7 fmp

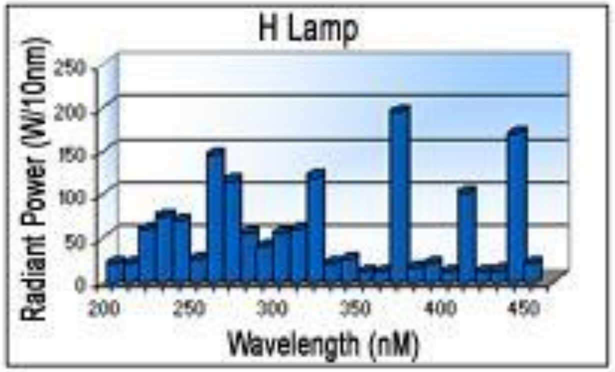
UV Lamps

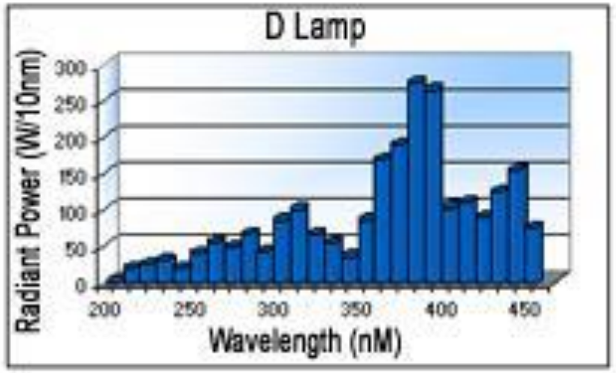
Mercury Vapor

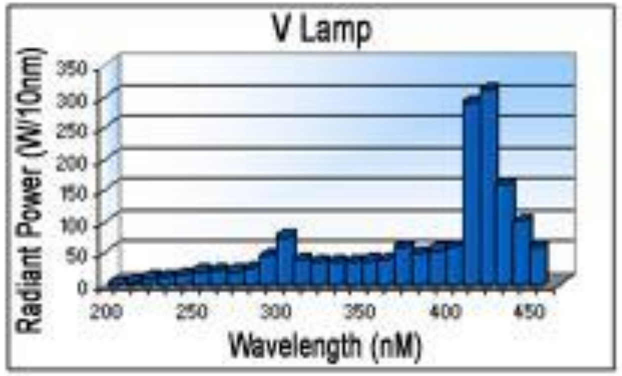
- H – Mercury
- D – Iron Doped
- V – Gallium Doped

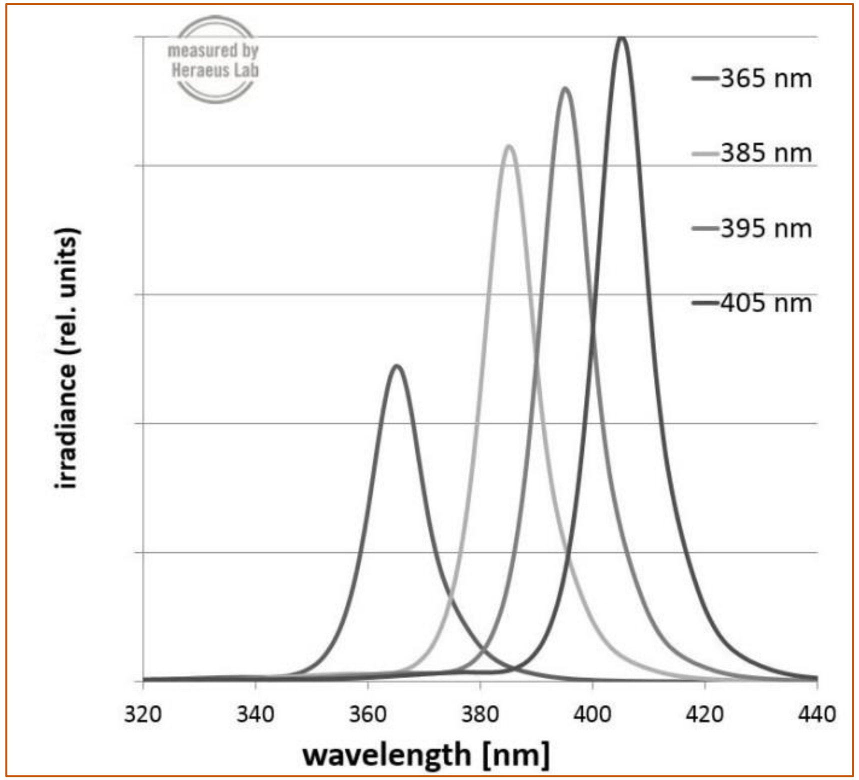
LED

- 365 nm
- 385 nm
- 395 nm
- 405 nm









UV Lamps

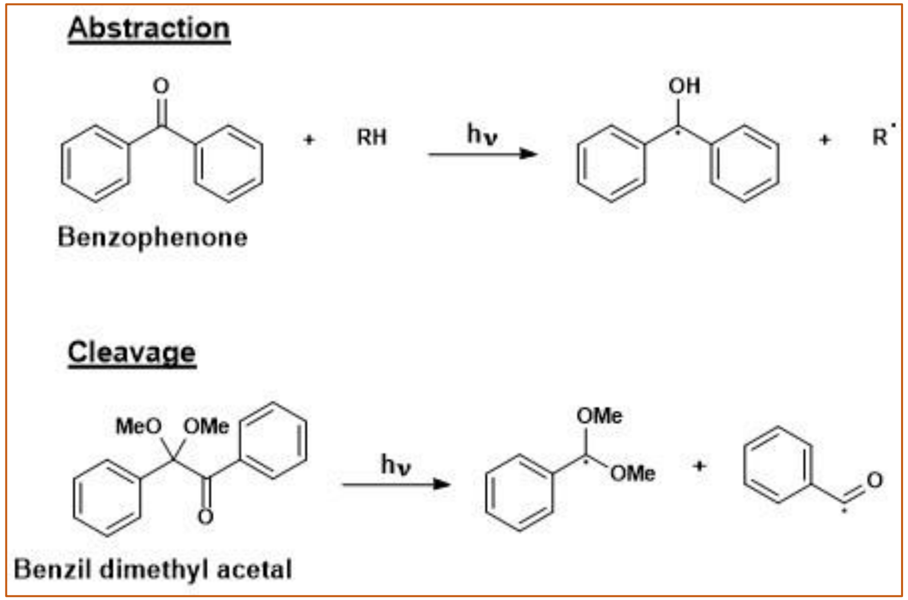
UV-Cure Lamp Types

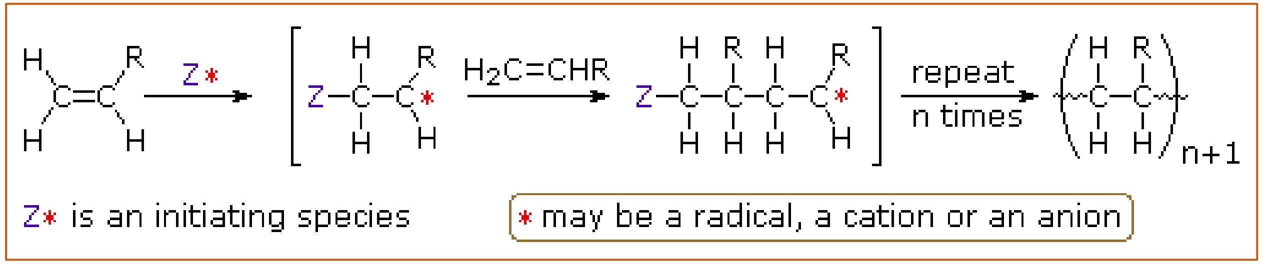
UV Lamp	Wavelength Range (nm)	Powder Coating Type
Standard Mercury	240-320	Clear Coats
Iron Doped Mercury	320-400	Clear Coats and Metallics
Gallium Doped Mercury	410-440	Pigmented and Thick Film

UV-Curable Powder Chemistries

Free Radical UV Cure

- Photoinitiator responds to UV energy, forming free radicals
- Chain-growth polymerization is initiated
- Can be inhibited by oxygen





Free Radical-Cured Binders

Acrylated/Methacrylated

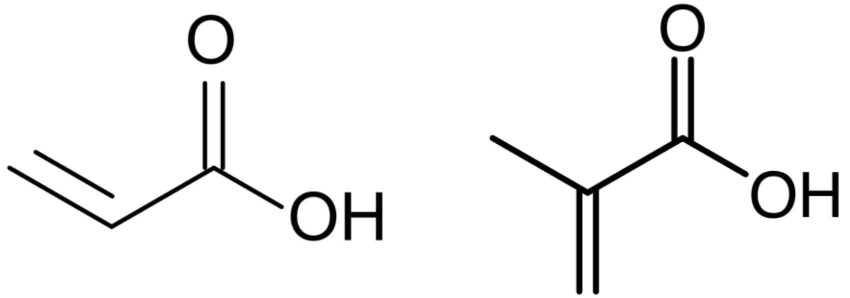
- Polyester
- Epoxy
- Urethane
- Homopolymerized

Unsaturated Polyester

- Divinyl ether crosslinker 73:27
- Maleate – vinyl ether copolymerization

Low T_g, Low Melt Viscosity

- Processing conditions
- Storage stability



Understanding Photoinitiators (PIs)

- A photoinitiator is a molecule that creates reactive species when exposed to radiation.
- Absorption bands of the PI should be matched with the emission spectrum of the light source.
- May be better suited to through cure or surface cure, clear, or pigmented
- 0.5% to 5.0% formula weight
  DOE to determine the best level for a formulation

Benefits of UV Cure

- Separates melt from cure
- Low processing temperature
- Smaller footprint
- Lower energy costs
- Shorter time
- Heat-sensitive substrates and assembled parts

Drawbacks of UV Cure

- Line-of-sight curing
- Pigment loading and film thickness limitations
- Limited selection of raw materials and chemistry
- Transportation and storage stability
- Capital expenditure
- Material cost

UV-Curable Powder

Work conducted under ESTCP WP-0801 Ultraviolet Curable Powder Coatings with Robotic Curing for Aerospace Applications

Robotic UV-Cure Powder Coatings

Recent effort has been made to cure UV powder coatings on large objects in the field.

This work, conducted by SAIC (Science Applications International Corporation) under a U.S. government grant, has investigated the use of robotics to melt and cure the powder coating after deposition to a surface.

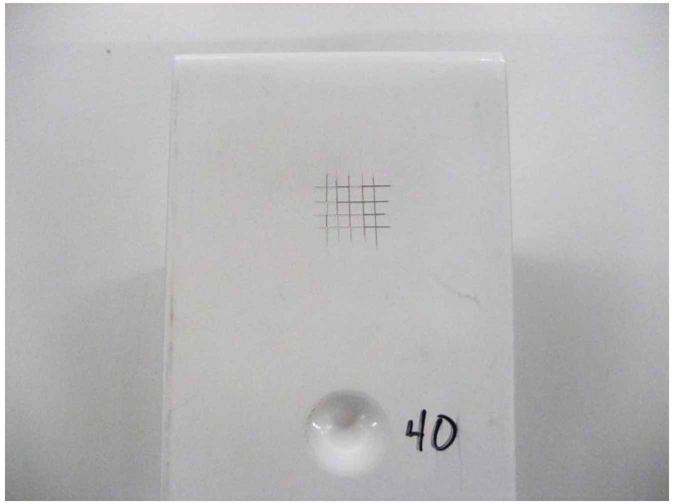
The powder is:

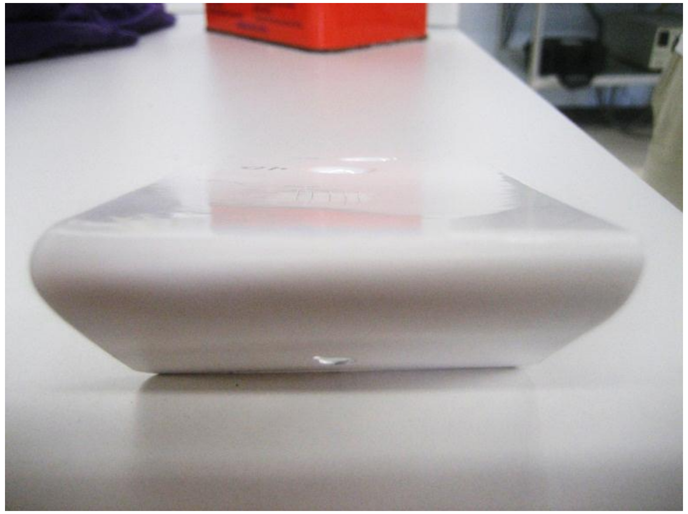
- Applied conventionally to the substrate using an electrostatic method
- Melted by robotically passing an infrared emitter over the surface
- Molten film is cured under swiped UV light; both the IR and UV devices can be affixed to the same articulated robot arm

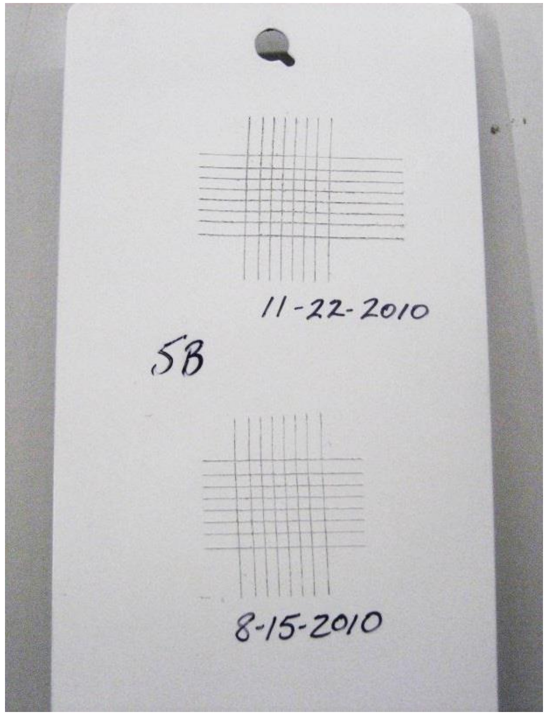
Robotic UV-Curable Powder Coating Process

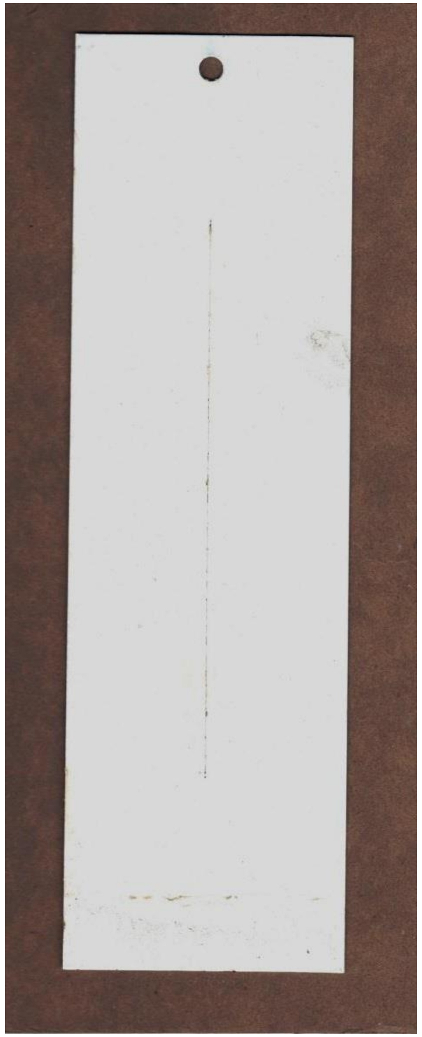
1. Apply Powder Electrostatically
   Single coat
2. Melt at 100-120°C with Infrared
3. Cure Robotically with UV
4. Done!

UV-Curable Powder Coating









3,700 hrs Salt Fog

Powder Chemistries: UV Cure vs. Ultra-Low Bake

UV Cure

- Shorter time
- Small footprint
- Lowest energy use

Ultra-Low Bake

- Standard equipment
- All colors/thicknesses
- Low energy use
- More chemistries available

UV Cure

- Line of sight
- Cap ex
- Film thickness
- Physical storage stability

Ultra-Low Bake

- Manufacturing challenges
- Smoothness
- Limited temperature
- Chemical storage stability

Future Trends

Future Trends

Real Michael Addition (malonate) Chemistry (allnex)

WO-2022236519 – Powder Coating Composition Blend

More than just MDF

Composites, molded plastics

Low-Temp Cure Summary

- Low-temperature-cure (LTC) powders can significantly reduce energy costs.
- Ultra-low-bake (ULB) powders open up a world of alternative substrates to the powder coating market.
- Application to non-conductive substrates schemes are well-known and scalable.
- UV-cure powder coating technology is alive and well.
- Novel technology is being introduced by raw material suppliers.
- Powder coating producers are investing in the development and commercialization of LTC and ULB powder technologies.

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Thank you
Questions? Comments?
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