More than Just Wood
Low-Temp Cure Powder Coating Technology

ACA Member Webinar
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The ChemQuest Group, Inc.
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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

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

### 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

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

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

Infrared can reduce dwell time.

<table>
<thead>
<tr>
<th>Chemistry</th>
<th>Standard Cure</th>
<th>Low-Temp Cure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy</td>
<td>15’ @ 175°C</td>
<td>15’ @ 150°C</td>
</tr>
<tr>
<td>Epoxy Polyester</td>
<td>15’ @ 190°C</td>
<td>15’ @ 160°C</td>
</tr>
<tr>
<td>Polyester</td>
<td>15’ @ 190°C</td>
<td>15’ @ 160°C</td>
</tr>
<tr>
<td>Polyurethane</td>
<td>15’ @ 200°C</td>
<td>20’ @ 150°C</td>
</tr>
<tr>
<td>Acrylic</td>
<td>20’ @ 175°C</td>
<td>20’ @ 160°C</td>
</tr>
</tbody>
</table>
Epoxies

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

### Phenolic Curing Agents

<table>
<thead>
<tr>
<th>Grade</th>
<th>Ph-OH E.W. (g/eq)</th>
<th>Softening Point(^{\circ}) (°C)</th>
<th>Gel time(^{\circ}) (sec)</th>
<th>Color (G, max.)</th>
<th>Characteristics/Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>KD-404</td>
<td>230-260</td>
<td>73-85</td>
<td>40-80</td>
<td>1</td>
<td>Fast cure</td>
</tr>
<tr>
<td>KD-405</td>
<td>230-260</td>
<td>73-85</td>
<td>100-160</td>
<td>0.5</td>
<td>High adhesion</td>
</tr>
</tbody>
</table>
# Epoxy-Polyester Hybrids

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Acids</th>
</tr>
</thead>
<tbody>
<tr>
<td>200°C 392°F</td>
<td><strong>CRYLCOAT® 1544-4</strong></td>
</tr>
</tbody>
</table>
| 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**  |

![Chemical Reaction](attachment:image.png)

\[
R-COOH + CH_2-CH=CH_2-R \rightarrow O \quad \text{R-C-CH_2-CH=CH_2-R}
\]
Polyester - TGIC

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

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>200°C (392°F)</td>
<td>• CRYLCOAT® 2437-0&lt;br&gt;• CRYLCOAT 2401-2&lt;br&gt;• CRYLCOAT 2471-4&lt;br&gt;• CRYLCOAT 2689-0&lt;br&gt;• CRYLCOAT 2441-2&lt;br&gt;• CRYLCOAT 2488-2&lt;br&gt;• CRYLCOAT 2425-0&lt;br&gt;• CRYLCOAT 2430-0&lt;br&gt;• CRYLCOAT 2440-2</td>
</tr>
<tr>
<td>180°C (356°F)</td>
<td>• CRYLCOAT 2408-0&lt;br&gt;• CRYLCOAT 2421-5&lt;br&gt;• CRYLCOAT 2450-2</td>
</tr>
<tr>
<td>160°C (320°F)</td>
<td>• CRYLCOAT 2409-0&lt;br&gt;• CRYLCOAT 2494-6&lt;br&gt;• CRYLCOAT 2473-4&lt;br&gt;• CRYLCOAT 2433-2</td>
</tr>
</tbody>
</table>
## Polyurethane

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

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

- Lower EEW (epoxide equivalent weight)
- Increased functionality
- Catalysis
Ultra-Low Bake – Thermoset Chemistries
• Homopolymerization
• More catalyst (latency helps)
• Cure as low as 125°C
# Epoxy-Polyester Hybrid

<table>
<thead>
<tr>
<th>CRYLCOAT®</th>
<th>Ratio</th>
<th>Acid #</th>
<th>Visc.a</th>
<th>Tg(°C)</th>
<th>Cure</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1574-6</td>
<td>50/50</td>
<td>71</td>
<td>5000</td>
<td>50</td>
<td>140°C</td>
<td>Low cure for MDF</td>
</tr>
</tbody>
</table>
## Polyester - TGIC

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

Tetra Butyl-Phosphonium Bromide

\[
\text{Br}^- \quad \text{H}_3\text{C} \quad \text{P}^+ \quad \text{CH}_3
\]

\[
\text{H}_3\text{C} \quad \text{P} \quad \text{CH}_3
\]

\[
\text{H}_3\text{C} \quad \text{P} \quad \text{CH}_3
\]
GMA Acrylics

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

**Product Specification**

<table>
<thead>
<tr>
<th></th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>Pale granules</td>
</tr>
<tr>
<td>Acid value alcoholic (mg KOH/g)</td>
<td>310-325</td>
</tr>
<tr>
<td>Melting range (°C)</td>
<td>80-90</td>
</tr>
<tr>
<td>Color, b-value</td>
<td>Max. 15</td>
</tr>
</tbody>
</table>

**Starting Formulation**

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADDITOL® P 791</td>
<td>24.0</td>
</tr>
<tr>
<td>Acrylic Resin EEW (g/eq) 500 - 550</td>
<td>69.7</td>
</tr>
<tr>
<td>Flow Promoter</td>
<td>3.0</td>
</tr>
<tr>
<td>UV Stabilizer</td>
<td>1.5</td>
</tr>
<tr>
<td>UV Co-Stabilizer</td>
<td>1.5</td>
</tr>
<tr>
<td>Benzoin</td>
<td>0.3</td>
</tr>
</tbody>
</table>
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

Thermal Powder Coating

Melt, Flow & Cure
5 to >60 mins + cooling

Finished Product

UV Powder Coating

Substrate
Pretreatment

Electrostatic
Powder Deposition

Melt & Flow
1-2 minutes

UV Cure
(seconds)
Minimal cooling

Finished Product

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-Cure Lamp Types

<table>
<thead>
<tr>
<th>UV Lamp</th>
<th>Wavelength Range (nm)</th>
<th>Powder Coating Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Mercury</td>
<td>240-320</td>
<td>Clear Coats</td>
</tr>
<tr>
<td>Iron Doped Mercury</td>
<td>320-400</td>
<td>Clear Coats and Metallics</td>
</tr>
<tr>
<td>Gallium Doped Mercury</td>
<td>410-440</td>
<td>Pigmented and Thick Film</td>
</tr>
</tbody>
</table>
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

**Abstraction**

\[
\text{Benzophenone} + RH \xrightarrow{hv} \text{product} + \text{R}'
\]

**Cleavage**

\[
\text{Benzil dimethyl acetal} \xrightarrow{hv} \text{product} + \text{product}
\]

\[
\begin{align*}
\text{Initiation:} & \quad Z^* \\
\text{Chain Growth:} & \quad Z \xrightarrow{H_2C=CHR} Z \xrightarrow{\text{repeats n times}} \left( \text{product} \right)_{n+1}
\end{align*}
\]

\(Z^*\) is an initiating species

\(*\) may be a radical, a cation or an anion
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
- Smaller footprint
- Shorter time
- Low processing temperature
- Lower energy costs
- Heat-sensitive substrates and assembled parts
Drawbacks of UV Cure

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

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

More than just MDF
Composites, molded plastics

Real Michael Addition (malonate) Chemistry (allnex)
WO-2022236519 – Powder Coating Composition Blend
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.
Thank you
Questions? Comments?
Feel free to email me:

kbiller@chemquest.com

https://chemquest.com