Advantages of UV Curing in Composite Manufacturing

Jonathan Shaw. Ph.D.
Cytec Coating Resins
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UV Curing Basics
  - Materials/Formulations
  - Lamps
  - Cure Process

Advantages & Considerations
When Using UV Curing
  - Productivity
  - On demand curing
  - Line of sight cure

Current Use of UV Curing in Composites
  - Pultrusion
  - Filament Winding
  - CIPP

Future Uses of UV Curing in Composites
What is Ultra-Violet (UV) curing?

- Using UV energy or visible light, as opposed to heat, solvent evaporation, or oxidation (air-drying), to convert a liquid formulation to a solid material

- Types of energy used:
  - Ultra Violet (UV): 200 – 400 nm
  - Visible light: typically 380 - 450 nm
UV Curable Formulations

OLIGOMER(S)  
Bulk matrix properties

MONOMERS  
Viscosity control / properties

ADDITIVES

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<table>
<thead>
<tr>
<th>Oligomer Characteristics</th>
<th>Properties</th>
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<tbody>
<tr>
<td>Epoxy Acrylates</td>
<td>fast curing, hard, chemical/solvent resistant</td>
</tr>
<tr>
<td>Aliphatic Urethane Acrylates</td>
<td>flexible, tough, non-yellowing, best weathering properties</td>
</tr>
<tr>
<td>Aromatic Urethane Acrylates</td>
<td>flexible, tough, lower cost than aliphatic urethanes</td>
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<tr>
<td>Polyester Acrylates &amp; Diluted Polyesters</td>
<td>low viscosity, good wetting properties, adhesion, special applications</td>
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Oligomer Structures

Epoxy acrylate

Vinyl ester

Bis A epoxy

Advanced Bis A epoxy

Unsaturated polyester
UV Curing Basics
Materials

Monomer (Diluent) Characteristics

<table>
<thead>
<tr>
<th>Visc. Reduction</th>
<th>Cure Speed</th>
<th>Flexibility</th>
<th>Adhesion</th>
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<tr>
<td>Mono-Func.</td>
<td></td>
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<tr>
<td>Di-func.</td>
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<td>Trifunc. &amp; Higher</td>
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UV Curing Basics

**Materials**

**Monomer (diluent) Structures**

- **Monofunctional Acrylate - IBOA**
  - Viscosity (cps, 25°C): ~9
  - Vapor Pressure (Pa @ 25°C): 1.3

- **Difunctional Acrylate - HDDA**
  - Viscosity (cps, 25°C): ~7
  - Vapor Pressure (Pa @ 25°C): 2.0

- **Styrene**
  - Viscosity (cps, 25°C): ~1
  - Vapor Pressure (Pa @ 25°C): 6.7

*Source: CYTEC*
UV Sources

- Mercury lamps
  - Arc lamps
  - Microwave

- UV-A Fluorescent

- LED

- Lamp selection needs to go hand in hand with formulation and process development
UV Lamps

Mercury Lamp Output

- More energy at shorter wavelengths
- Some energy at longer wavelengths

Doped Mercury Lamp Output

- Less energy at shorter wavelengths
- More energy at longer wavelengths
Free Radical Polymerization

• **UV Initiation**
  \[ I + \text{UV Energy} \rightarrow 2 I^* \]
  \[ I^* + M \rightarrow IM^* \]
  \[ I = \text{photoinitiator} \]

• **Thermal Initiation**
  \[ I + \text{Thermal Energy} \rightarrow 2 I^* \]
  \[ I^* + M \rightarrow IM^* \]
  \[ I = \text{e.g. peroxide} \]

• **Propagation**
  \[ IM^* + M \rightarrow IMM^* \]
  \[ IMM^* + M \rightarrow IMMM^* \]
  \[ IMMM^* + M \rightarrow IMMMMM^* \]

• **Termination**
  \[ P\sim M^* + \cdot M\sim P \rightarrow P\sim M\sim M\sim P \]
  \[ P\sim M^* + I \rightarrow P\sim M\sim I \]

\[ I = \text{Initiator} \quad M = \text{Monomer (or any acrylate)} \quad P = \text{Polymer chain} \]
UV Curing Basics
Process

UV Curing
(2.5 mil wet film on Leneta chart, 100 fpm, 2 x mercury lamps)
UV Curing Advantages

**Productivity**
Seconds to cure vs. minutes or hours

**No reaction until exposure to UV energy**
“Cure on Demand”, reduced waste, long pot life

**Single component formulas**
Eliminates mixing errors found in 2 component systems

**Regulatory concerns (VOC emission)**
Low emissions, low volatility components, reduced styrene emissions
**UV Curing Considerations**

**Line of sight curing**
All areas of the composite must be exposed to UV energy
Lamp placement critical, but not difficult

**Absorbance of system**
Components that absorb/block UV will interfere with cure
Glass is relatively UV transparent, C fiber is most challenging
Thick composites also a challenge, but newer long wavelength PI allow for up to ½” thick cure in one pass

**Shrinkage**
All reactions generate shrinkage
Mitigate with selection of diluents, oligomers
UV Curing in Composites
Pultrusion

Challenges of thermally cured pultrusion lines
- Line speed dependent on oven size and heat transfer rate
- Two component resin system leads to pot life concerns and waste
Benefits of UV cured pultrusion lines

- Fast line speeds due to rapid UV cure process
- On demand cure means very long pot life and less waste
- Lamp installation without major line reconfiguration
- Physical properties comparable to conventional systems
- Low volatility of oligomers and monomers means lower emissions
- Cure process depends on UV intensity, NOT ambient temperature
UV Curing in Composites
Filament Winding

Challenges of thermally cured filament winding lines
• Line speed limited by tendency of resin to “mist” at high rotation
• Two component resin system leads to pot life concerns and waste
• Challenge to control consistency of fiber / resin ratio
• Continuous part rotation necessary during heating
• Mandrel turnover may be slow
Characteristics of UV cured filament winding lines

- **Lamp in position A gels resin onto fiber:**
  - Improves consistency of fiber resin ratio
  - Reduces resin waste dripping from mandrel
  - Gives tackiness to resin that allows for more complex winding patterns and different winding angles

- **Lamp in position B gives final cure:**
  - No need for long oven cure
  - Faster mandrel turnaround
  - Good dimensional stability
Characteristics of UV cured filament winding lines

- On demand cure means very long pot life and less waste
- Lamp installation without major line reconfiguration
- Physical properties comparable to conventional systems
- Low volatility of oligomers and monomers means lower emissions
- Cure process depends on UV intensity, NOT ambient temperature
UV Curing in Composites
Cure in Place Piping

- Challenges of thermally cured in place pipe
  - 2 component prepregs need refrigeration to avoid early cure
  - Large volumes of heated water or steam and long times needed for cure
  - Emissions of volatile components need to be controlled
• Characteristics of UV cured in place pipe
  • No temperature control required for uncured prepregs (must avoid sunlight)
  • Short cure times mean fast return to service
  • Heated water or steam not required
  • Physical properties comparable to conventional systems
  • Low volatility of oligomers and monomers means lower emissions
  • Cure process depends on UV intensity, NOT ambient temperature
In Field Use

- UV Technology is moving out of the plant and into the field –
  - Field Applied Coatings for wood, concrete, VCT

- UV Composite curing is starting to move that way as well
  - In field repair (open mold or vacuum bag)
    - Concrete bridges & supports
    - Wind turbine blades

- Driver is Fast Return to Service
Closed Mold Techniques

- Critical factor is transmission of UV energy to the composite
- Smaller flat parts present the lowest challenge as glass can be used for one of the mold surfaces.
- Three dimensional parts may be possible when using LRTM or other techniques that allow for UV transparent or translucent materials to be used.
- Longer wavelength lamps and photoinitiators help with depth of penetration
Fast cure speed of UV enables
- Increased process speeds without loss of properties
- Shorter cycle times, quicker mandrel re-use
- Fast return to service with full properties
- Better control of fiber volume consistency
- Reduced emissions

Cure on Demand leads to
- Long pot life
- Less resin waste, recycling of unused resin
- Cure speeds independent of ambient temperature

Variety of oligomers and monomers allows for
- Tailoring of physical properties and excellent viscosity control

Possibilities for using UV cure in the field or via closed mold processes in the future
Thank you.
(Please visit our table top display)

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• Questions?

  Dr. Jonathan Shaw
  Cytec Industries Inc.
  Jon.shaw@cytec.com
  (678) 255-4742