Toughened Epoxy Resin Systems for Filament Winding

Epoxy Research Resin RSL-4515 / EPIKURE™ Curing Agent 3300 and Epoxy Research Curing Agent RSC-4577

Introduction

Epoxy Research Resin RSL-4515/EPIKOTE Curing Agent 3300 or Epoxy Research Curing Agent RSC-4577 is based on a toughened epoxy cured with very low viscosity cycloaliphatic amines. The systems low viscosity and high toughness make it favorable for good fiber wet-out for filament windings for all composite pressure vessels (including Type IV vessels). It will allow the manufacture of an all carbon tank without increase in cost (via reduction in wall thickness).

Suggested Uses
- Composite Structures
- Pressure Vessels

Features
- Low Viscosity
- Good Elongation
- High Toughness

Typical Properties

Table 1 / Typical Component Properties

<table>
<thead>
<tr>
<th>Method</th>
<th>Units</th>
<th>Epoxy Research Resin RSL-4515</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxide Equivalent Weight</td>
<td>ASTM D1652 g/eq</td>
<td>177</td>
</tr>
<tr>
<td>Viscosity @ 25°C (77°F)</td>
<td>ASTM D1545 cP or mPa·s</td>
<td>5,800</td>
</tr>
<tr>
<td>Density @ 25°C (77°F)</td>
<td>ASTM D1475 g/cc</td>
<td>1.18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method</th>
<th>Units</th>
<th>EPIKURE Curing Agent 3300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amine Value</td>
<td>ASTM D 2896 mg KOH/g</td>
<td>630-670</td>
</tr>
<tr>
<td>Amine Hydrogen Equivalent Weight</td>
<td>calculated g/H eq</td>
<td>43</td>
</tr>
<tr>
<td>Viscosity @ 25°C (77°F)</td>
<td>ASTM D1545 cP or mPa·s</td>
<td>12-19</td>
</tr>
<tr>
<td>Color</td>
<td>ASTM D1544 Gardner</td>
<td>250 max.</td>
</tr>
<tr>
<td>Density @ 25°C</td>
<td>ASTM D1475 g/cc</td>
<td>0.92</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method</th>
<th>Units</th>
<th>Epoxy Research Curing Agent RSC-4577</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amine Value</td>
<td>ASTM D 2896 mg KOH/g</td>
<td>400-600</td>
</tr>
<tr>
<td>Amine Hydrogen Equivalent Weight</td>
<td>calculated g/H eq</td>
<td>52</td>
</tr>
<tr>
<td>Viscosity @ 25°C (77°F)</td>
<td>ASTM D1545 cP or mPa·s</td>
<td>10-50</td>
</tr>
<tr>
<td>Density @ 25°C</td>
<td>ASTM D1475 g/cc</td>
<td>0.93-0.98</td>
</tr>
</tbody>
</table>
Mix Ratio | Material | 1 | 2
--- | --- | --- | ---
| Epoxy Research Resin RSL-451, pbw | 100 | 100 |
| EPIKURE Curing Agent 3300, pbw | 24 | |
| Epoxy Research Curing Agent RSC-4577, pbw | | 29 |

1 pbw = parts by weight

Mixing Instructions
The stated mixing ratio should be followed carefully. Adding more or less hardener than desired will result in an incomplete cure with limited performance that cannot be corrected. Resin and curing agent must be mixed carefully. Mix until no clouding is visible in the mixing container. Special attention must be paid to the walls and bottom of the mixing container when mixing by hand.

Typical System Properties

<table>
<thead>
<tr>
<th>Table 2 / Properties of Resin System</th>
<th>Units</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity at 25°C (77°F)</td>
<td>cP or mPa·s</td>
<td>1115</td>
<td>573</td>
</tr>
<tr>
<td>Pot Life(^1) (time to double initial viscosity @ 25°C)</td>
<td>minutes</td>
<td>58</td>
<td>90</td>
</tr>
<tr>
<td>Working time(^2) at 25°C (77°F)</td>
<td>hrs</td>
<td>115</td>
<td>256</td>
</tr>
<tr>
<td>Gel time(^3) at 30°C (77°F), 100g</td>
<td>minutes</td>
<td>109</td>
<td>210</td>
</tr>
</tbody>
</table>

\(^1\) Brookfield Viscometer
\(^2\) Time to peak temperature, based on 100g mass
\(^3\) Shyodu gel time

Graph 1 / Viscosity Development @25°C (77°F), 10 grams
### Graph 2 / Temperature Development @25°C (77°F), 100 grams

### Table 3 / Typical cured properties of neat resin system

**Epoxy Research Resin RSL-4515/EPIKURE™ Curing Agent 3300**

<table>
<thead>
<tr>
<th>Method</th>
<th>Units</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cure Schedule</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 1 followed by</td>
<td>hrs/°C (°F)</td>
<td>1/66 (151)</td>
<td>1.5/82 (180)</td>
</tr>
<tr>
<td>Step 2</td>
<td>hrs/°C (°F)</td>
<td>4/96 (205)</td>
<td>1.5/150 (302)</td>
</tr>
<tr>
<td>Tg by</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSC (20°C/min)</td>
<td>ASTM D-3418 °C (°F)</td>
<td>109 (228)</td>
<td>134 (273)</td>
</tr>
<tr>
<td>DMA - E’ onset</td>
<td>ASTM D-4065 °C (°F)</td>
<td>112 (234)</td>
<td>135 (275)</td>
</tr>
<tr>
<td>DMA – tan delta peak</td>
<td>°C (°F)</td>
<td>121 (250)</td>
<td>143 (289)</td>
</tr>
<tr>
<td>Tensile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength at Yield</td>
<td>ASTM D-638 ksi</td>
<td>12.6</td>
<td>12.5</td>
</tr>
<tr>
<td>Strength at Break</td>
<td>ksi</td>
<td>11.4</td>
<td>11.8</td>
</tr>
<tr>
<td>Elongation at Yield</td>
<td>%</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>%</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Modulus</td>
<td>ksi</td>
<td>472</td>
<td>456</td>
</tr>
<tr>
<td>Fracture Toughness, K_Q</td>
<td>ASTM E-399 psi-in(^{1/2})</td>
<td>1596</td>
<td>1070</td>
</tr>
</tbody>
</table>

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**Typical Cured State Properties**

Table 4 / Typical cured properties of neat resin system

| Epoxy Research Resin RSL-4515/Epoxy Research Curing Agent RSC-4577 |
|---|---|

<table>
<thead>
<tr>
<th>Method</th>
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<tr>
<td>Cure Schedule</td>
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<tr>
<td>Tg by</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSC (20°C/min)</td>
<td>°C (°F)</td>
<td>95 (203)</td>
<td>101 (214)</td>
</tr>
<tr>
<td>DMA - E' onset</td>
<td>°C (°F)</td>
<td>96 (205)</td>
<td>98 (208)</td>
</tr>
<tr>
<td>DMA – tan delta peak</td>
<td>°C (°F)</td>
<td>104 (219)</td>
<td>109 (228)</td>
</tr>
<tr>
<td>Tensile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength at Yield</td>
<td>ASTM D-638 ksi</td>
<td>10.7</td>
<td>11.3</td>
</tr>
<tr>
<td>Strength at Break</td>
<td>ksi</td>
<td>9.3</td>
<td>9.1</td>
</tr>
<tr>
<td>Elongation at Yield</td>
<td>%</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>%</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Modulus</td>
<td>ksi</td>
<td>456</td>
<td>452</td>
</tr>
<tr>
<td>Fracture Toughness, Kc</td>
<td>ASTM E-399 psi-in(^{1/2})</td>
<td>1217</td>
<td>1739</td>
</tr>
</tbody>
</table>

**Composite Fabrication / Filament Winding**

The low viscosity and long working life of the resin system make it desirable for Filament Winding.

- **Mixing** – A high shear mixer is recommended to insure complete mixing. Mixing time should be kept to a minimum to avoid excess heat build-up of the resin system, as this can reduce the working life of the system.

- **Resin Bath** – The resin impregnation bath temperature should be as close to 25 °C (77 °F) as possible to maximize working life. However, slightly elevated temperatures may be required to obtain the appropriate viscosity for fiber wet-out.

- **Process** – A suggested cure cycle would include 1-2 hours at 60-80°C, followed by 1-3 hours at 90-150°C, using a ramp rate of 0.5-2.0°C/minute. The optimum temperatures will depend on parameters such as part thickness.
General Information

These are starting formulations and are not proven in the user’s particular application but are simply meant to demonstrate the efficacy of the products and to assist in the development of the user’s own formulation. It is the user’s responsibility to fully-test and qualify the formulation, along with the ingredients, methods, applications or equipment identified herein (“Information”), by the user’s knowledgeable formulator or scientist, and to determine the appropriate use conditions and legal restrictions, prior to use of any Information.

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