Accelerated UV Test Methods for Encapsulants of Photovoltaic Modules

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Encapsulant Selection Criteria

- Optically Couples Glass to Cells
  - High Photon Transmission.
  - Can’t Yellow Significantly Over Time.
- Cost Must Be Balanced With Performance.
- Must Provide Good Adhesion.
  - Resistant to Heat, Humidity, UV Radiation, and Thermal Cycling.
Light Transmission is Vital for Encapsulant Selection

\[ T = T_{\text{glass}} \ e^{-\left( t_p \alpha_p \right)} \]

\( T_{\text{glass}} = 88.94\% \) and is the transmission through 6.35 mm plate glass.

\( t_p \) is the polymer layer thickness

\( \alpha_p \) is the solar weighted photon absorptivity in the polymer.

\[ T_{\text{cell}} = \frac{\left( 100 + T_{\text{glass}} \right)}{2} \ e^{-\left( t_p \alpha_p \right)} \]
Cost and Photon Transmission are Important Selection Criteria

<table>
<thead>
<tr>
<th>Encapsulant</th>
<th>AM 1.5 Solar Weighted Absorptivity 200 nm to 1100 nm (1/mm)</th>
<th>Transmission to Cells through 3.18 mm glass and 0.45 mm Encapsulant (%)</th>
<th>Approximate Cost Relative to EVA %</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE RTV615</td>
<td>0.000 ± 0.003</td>
<td>94.5 ± 0.3</td>
<td>4.45</td>
<td>PDMS, Addition Cure</td>
</tr>
<tr>
<td>Dow Corning Sylgard 184</td>
<td>0.001 ± 0.004</td>
<td>94.4 ± 0.3</td>
<td>6.97</td>
<td>PDMS, Addition Cure</td>
</tr>
<tr>
<td>Dow Corning 527</td>
<td>0.001 ± 0.003</td>
<td>94.4 ± 0.3</td>
<td>2.33</td>
<td>PDMS Gel, Addition Cure</td>
</tr>
<tr>
<td>Polyvinyl Butraldehyde</td>
<td>0.014 ± 0.005</td>
<td>93.9 ± 0.4</td>
<td>1.50</td>
<td></td>
</tr>
<tr>
<td>EVA</td>
<td>0.014 ± 0.005</td>
<td>93.9 ± 0.4</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>NREL Experimental</td>
<td>0.025 ± 0.006</td>
<td>93.4 ± 0.4</td>
<td>1.28</td>
<td></td>
</tr>
<tr>
<td>Thermoplastic Polyurethane</td>
<td>0.027 ± 0.004</td>
<td>93.3 ± 0.3</td>
<td>2.00</td>
<td></td>
</tr>
<tr>
<td>Thermoplastic Ionomer #1</td>
<td>0.052 ± 0.007</td>
<td>92.3 ± 0.4</td>
<td>1.00</td>
<td>Copolymer of Ethylene and Methacrylic acid</td>
</tr>
<tr>
<td>DC 700</td>
<td>0.067 ± 0.004</td>
<td>91.7 ± 0.3</td>
<td>0.94</td>
<td>PDMS, Acetic Acid Condensation Cure</td>
</tr>
<tr>
<td>Thermoplastic Ionomer #2</td>
<td>0.147 ± 0.007</td>
<td>88.4 ± 0.4</td>
<td>2.00</td>
<td>Copolymer of Ethylene and Methacrylic acid</td>
</tr>
</tbody>
</table>

The approximate cost factor relative to EVA is based on costs quoted by the manufacturer where no effort was made to negotiate a better price. The true cost factor could easily be different by a factor of two.
Long Term UV Resistance Is NOT Evaluated in IEC Standards

- IEC 61215, 61646 and 61730-2
  - “UV Preconditioning Test”
  - 15 kWh/m² between 280 nm and 385 nm
    - Equivalent to 17.7 days of AM 1.5
  - >5 kWh/m² between 280 nm and 320 nm
    - Equivalent to 137 days of AM 1.5

- IEC 62108
  - “UV Conditioning Test”
  - 50 kWh/m² below 400 nm
    - Equivalent to 45 days of AM 1.5
Lap Shear Used to Evaluate Adhesion

$F \approx 5000 \, \text{N}$

Schematic and photo of the lap shear design.
Ce Doped Glass Reduces UV-B

Samples labeled “solarized” had been exposed to 114 W/m^2 (300 nm to 400 nm) in a Ci4000 weatherometer at 60°C and 60% RH.
UV-B/AII Radiation Reduces Adhesion 8 Times Faster

Lap shear strength after exposure to 60 °C/60% RH/2.5 UV suns. Samples #1 and #2 refer to slightly different formulations from the same manufacturer.
High UV Light Transmission Increases Deadhesion

Estimated irradiance at the glass/EVA interface.

- **AM 1.5 Global Irradiation**
- **Starphire Solarized 5.61 mm**
- **Krystal Klear Solarized 6.35 mm**
- **Difference Between Starphire to and 6.35mm Krystal Klear**
Greater Damage is Predicted for UV Transparent Glass

Action Spectrum

\( \sim e^{-B\lambda} \)

Activation Spectrum

\[ E(\lambda) \sim I(\lambda)\lambda e^{-B\lambda} \]

Photon Damage

\[ D \sim \int I(\lambda)\lambda e^{-B\lambda} d\lambda \]

\( B=0.07 \text{ (1/nm)} \)

Other Arbitrary Action Spectra Give Similar Factors

Step Function

Linear Function

<table>
<thead>
<tr>
<th>Action Spectrum</th>
<th>Exponential</th>
<th>Linear</th>
<th>Step</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$B = 0.07 \ (1/\text{nm})$</td>
<td>$\lambda_o = 368 \ (\text{nm})$</td>
<td>$\lambda_o = 354 \ (\text{nm})$</td>
</tr>
<tr>
<td>Tefzel 0.036 (mm)</td>
<td>4.83</td>
<td>4.30</td>
<td>3.63</td>
</tr>
<tr>
<td>Vintage Starphire 5.61 (mm)</td>
<td><strong>3.85</strong></td>
<td><strong>3.40</strong></td>
<td>3.19</td>
</tr>
<tr>
<td>Krystal Klear 3.18 (mm)</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Krystal Klear 6.35 (mm)</td>
<td>0.48</td>
<td>0.43</td>
<td>0.40</td>
</tr>
</tbody>
</table>

At 2.5 UV suns, running 24 h/day (~4X), with 3.4 to 3.85X, it takes 6.2 to 7.0 months to get a 20 year equivalent dose.
Conclusions

- IEC PV Qualification tests do not adequately test UV stability.
- Using highly transmissive glass in test samples can increase the severity of stress testing giving exposure of the correct order of magnitude.
- Cost and light transmission must also be considered in selecting an encapsulant.
- The use of non-ceriated glass will increase the likelihood of glass/EVA delamination.
Acknowledgements

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