A COMPARISON OF THE PERFORMANCE OF FLUORINATED AND NONFLUORINATED BACKSHEETS

Daikin America Inc.
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Daikin Industries, Ltd.

Daikin Group
15 Billion $ Sales (2011)
200 Companies Worldwide
44,000+ Employees

- Headquarters: Osaka, Japan
- Established in 1934

87%
Air-Conditioning Division
World Rank: #1

10%
Fluoro-Chemicals Division

3%
Other Divisions
(Computer Graphics, Hydraulics, …)
Backsheet Performance Comparison

• Photovoltaic backsheets
  – Ultraviolet light
  – Heat
  – Humidity
  – Break down the chemical bonds polymeric materials
    • Discoloration/ gloss reduction
    • Reduced mechanical strength
    • Reduced resistance to humidity

• Exposure
  – Xenon arc weatherometer per ASTM-G155

• Comparison
  – ZEFFLE™ coated backsheets
  – PVF backsheets
  – PVDF backsheets
  – Non-fluorinated laminated backsheet
Solar Panels

• Economics
  – Greater lifetime = Cheaper power

• Construction
  – Outer layers protect against moisture
  – Front layer is typically glass
  – Improve performance of backsheet

<table>
<thead>
<tr>
<th>Front Layer (Glass or ETFE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encapsulant (EVA or PVB)</td>
</tr>
<tr>
<td>Silicon Cells</td>
</tr>
<tr>
<td>Encapsulant (EVA or PVB)</td>
</tr>
<tr>
<td>Fluoropolymer</td>
</tr>
<tr>
<td>Backsheet</td>
</tr>
<tr>
<td>PET</td>
</tr>
<tr>
<td>Fluoropolymer</td>
</tr>
</tbody>
</table>
## Composite Photovoltaic Backsheet

### PET Based Backsheet

- **Film**: Polyester
- **Adhesive**: PET Based Film

### Coated Backsheet

- **Polyester**
- **Fluorocoating**

### Film Laminate Backsheet

- **Polyester**
- **Fluorinated Film Adhesive**
- **Fluorinated Film**

### Table of Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>PET</th>
<th>Coating Type</th>
<th>Film Laminated Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backsheet Layers/Interfaces</td>
<td>3-5/2-4</td>
<td>3/2</td>
<td>5/4</td>
</tr>
<tr>
<td>Adhesive Layer</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Chemical Foundation</td>
<td>Polyester</td>
<td>4F (TFE)</td>
<td>1F (PVF)/ 2F (PVDF)</td>
</tr>
<tr>
<td>Years Outdoor Exposure Data</td>
<td>~15</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Cost/Performance</td>
<td>Fair</td>
<td>Excellent</td>
<td>Good</td>
</tr>
</tbody>
</table>
Backsheet Performance Comparison

- **Fluoropolymers**
  - UV resistance
  - Strength and durability
  - Resistance to weathering
  - Electrical insulation

- **Strength of the carbon-fluorine bond**
  - C-F 116 kcal/mol
  - C-H 95 kcal/mol
  - C-Cl 78 kcal/mol

- **Fluoropolymers already used in the industry**
  - PVF and PVDF laminates.
  - ZEFFLE™ differs from these due to its use of Tetrafluoroethylene
**ZEFFLE™**

- Solvent-based
- Developed for building coating
  - Decades of history of good weathering properties
  - Works well in salt water environments
- Resist long-term exposure to ultraviolet light, heat, and humidity

![Chemical structure diagram of TFE copolymer with weatherability and cross-linkage notes]

**TFE copolymer**

- Room temp. coating
- Solvent solubility

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**September 20, 2012**

Ken Milam, et al.
Daikin America, Inc.
## Backsheets Tested

<table>
<thead>
<tr>
<th>Construction</th>
<th>Sample Name</th>
<th>Materials</th>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zeffle PET Zeffle</td>
<td>ZPZ</td>
<td>Commercially Available</td>
<td>Commercially Available</td>
</tr>
<tr>
<td>Zeffle PET Primer</td>
<td>ZPE</td>
<td>Commercially Available</td>
<td>Commercially Available</td>
</tr>
<tr>
<td>Tedlar PET Tedlar</td>
<td>TPT</td>
<td>Commercially Available</td>
<td>Commercially Available</td>
</tr>
<tr>
<td>Tedlar PET Primer</td>
<td>TPE</td>
<td>Commercially Available</td>
<td>Commercially Available</td>
</tr>
<tr>
<td>Kynar PET Primer</td>
<td>KPE</td>
<td>Commercially Available</td>
<td>Commercially Available</td>
</tr>
<tr>
<td>PET PET Primer #1</td>
<td>PPE # 1</td>
<td>Commercially Available</td>
<td>Commercially Available</td>
</tr>
<tr>
<td>PET PET Primer #2</td>
<td>PPE # 2</td>
<td>Commercially Available</td>
<td>Developmental Lamination</td>
</tr>
</tbody>
</table>
Sample Accelerated Aging

- Exposed samples to UV, temperature and humidity fluctuations.
- Atlas Ci5000
  - ASTM G155
    - 120 min cycle
    - 0.35 W/m²
    - 63°C rack, 42°C chamber
    - Phase one: 102 min, 50% RH
    - Phase two: 18 min, constant spray of RO/DI water

- Outer layer towards the light source
  - Inner layer open to machine
- Tests were ongoing until we reached a failure point.
- Required unrealistic time scales for practical testing.
Dosage vs Real World

- 0.35 W/m² is assumed to be the average irradiance during the equinox in South Florida
- This gives us an acceleration factor of 2 to 1
- 1000 hrs of testing = ~84 days of real world solar exposure
  - 7000 hours = ~588 days = ~1.61 years
- This test does not come close to demonstrating extended lifetime performance
  - Designed only to show infant mortality only
Gloss

- Early indicator of the start of problems
- Measured multiple angles
  - 20° low gloss
  - 60° semi gloss
  - 85° high gloss
- Initial gloss levels vary widely
  - Interested in change over time
Gloss

- Gloss results
  - PPE#2 backsheets exhibited a step change in all gloss angles at 2000 hours
  - Both PET based backsheets exhibit significantly decreased gloss
  - Set original value as 100%
  - 95% confidence interval shown with Y axis error bars

<table>
<thead>
<tr>
<th>Sample</th>
<th>Age</th>
<th>% 20° Gloss Retention</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZPZ</td>
<td>7000</td>
<td>85.2 %</td>
</tr>
<tr>
<td>ZPE</td>
<td>7000</td>
<td>106.6 %</td>
</tr>
<tr>
<td>TPT</td>
<td>7000</td>
<td>63.4 %</td>
</tr>
<tr>
<td>TPE</td>
<td>7000</td>
<td>74.9 %</td>
</tr>
<tr>
<td>KPE</td>
<td>7000</td>
<td>73.0 %</td>
</tr>
<tr>
<td>PPE #1</td>
<td>7000</td>
<td>10.1 %</td>
</tr>
<tr>
<td>PPE #2</td>
<td>5000</td>
<td>1.6 %</td>
</tr>
</tbody>
</table>
PET shows a significant decrease in gloss over time.
Color

• Color changes indicate differences in the condition of a surface.
• Yellowness index using ASTM E313
• Initial values also varied widely here, please compare changes.
• Confidence Intervals of 95% are also shown here.
PET shows significant yellowing over time.
Color

- Exposed area vs. the area covered by the sample holder

<table>
<thead>
<tr>
<th>ZPZ 7000 hours</th>
<th>PPE #2 2000 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposed</td>
<td>Covered</td>
</tr>
<tr>
<td>Covered</td>
<td>Exposed</td>
</tr>
</tbody>
</table>

PPE #2 visibly degrades after only 500 hours under UV.
Color

- **PET Samples**
  - PPE #2 exhibited the most change
    - Visible change at 500 hours
    - 2000 hours

- **Fluoropolymer samples**
  - Little to no change in coloration even after 7000 hours
Tensile Strength

• Following ASTM 882
  – Determine the change in mechanical properties
  – Initial strain rate was set to 10 mm/mm-min.
  – Each exposure condition was tested.

• In the following graph tensile stress at break is shown.
  • Confidence Intervals at 95%
Tensile Strength

Percent Retention of Maximum Tensile Strength

PPE loses Tensile strength faster than all other materials.
Single sided samples lose tensile strength faster than double sided.
Tensile Strength

• Some deterioration was observed
  – Some samples have failed (70% of the original properties) after several thousand hours of testing
  – Failures due to humidity or irradiation or both?
• PPE #2 samples failed first
• Some asymmetric samples (i.e. TPE, KPE) have begun to show deterioration.
• Samples protected from both sides have not failed after 7000 hours
Adhesion

- **ASTM 3359**
  - 10 by 10 set of 1 mm squares.
  - Apply Permacel 99 tape and wait for 90 seconds.
  - Removed at 180° and a steady rate.
  - Rating it 0A through 5A.
    - # of squares not damaged.
    - 0 to 100 where 100 is the best result.
    - Test 5 locations per sample and average.

- Confirmed testing was uniform across all samples.
  - 180° Peel test on Instron @ 250 mm/min.

<table>
<thead>
<tr>
<th>Sample</th>
<th>N/cm ± 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZPZ</td>
<td>4.67 ± 0.63</td>
</tr>
<tr>
<td>TPT</td>
<td>4.71 ± 0.36</td>
</tr>
<tr>
<td>PPE #2</td>
<td>4.94 ± 0.33</td>
</tr>
</tbody>
</table>
# Adhesion

No Fluoropolymers fail adhesion at 7000 hours.

<table>
<thead>
<tr>
<th>Exposure Time</th>
<th>ZPZ</th>
<th>ZPE</th>
<th>TPT</th>
<th>TPE</th>
<th>KPE</th>
<th>PET #1</th>
<th>PET #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1000</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>92.4</td>
</tr>
<tr>
<td>2000</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>24</td>
</tr>
<tr>
<td>3000</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>6000</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>7000</td>
<td>100</td>
<td>99.4</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
Adhesion

- PPE #2 delaminates completely by 3000 hours
  - Failure of interlayer adhesive
- Laminated constructions all share the concern of failed adhesive
  - TPT and PPE are incorrect
## Backsheet Results

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>2000 Hour Results</th>
<th>7000 Hour Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gloss</td>
<td>Color</td>
</tr>
<tr>
<td>ZPZ</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>ZPE</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>TPT</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>TPE</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>KPE</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>PPE # 1</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>PPE # 2</td>
<td>✗</td>
<td>✗</td>
</tr>
</tbody>
</table>

Legend: ✓ = Pass, ✗ = Fail
Conclusions

• Fluorinated materials
  – Little to no significant changes in backsheets protected on both sides
  – Samples beginning to fail only at 6000 and 7000 hours for samples protected on one side

• Degradation Evident in PPE Constructions
  – Loss of gloss in both samples
  – Significant changes in the coloration
  – Delamination
  – Failure in the maximum tensile stress
Conclusions

• Solar panels are expected to last 20-30 years
• Current test method requires a very weak dosage
  – Very long testing times
• More stringent sunlight exposure will help accelerated testing
• Materials protected with fluoropolymers from both sides show the best performance over time
Thank you for your time.

Questions or Comments?

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