Study of PV Backsheet Early Degradation Signs in Field and Relevance with Lab Accelerated Aging Tests

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DuPont Photovoltaic Solutions

For over 40 years

our material innovations have led the photovoltaics industry forward, and helped our clients transform the power of the Sun into power for us all. Today we offer a portfolio of solutions that deliver **proven power and lasting value** over the long term. Whatever your material needs, you can count on quality DuPont Photovoltaic Solutions to deliver the performance, efficiency and value you require, day after day after day…
Materials are Best Assessed by Looking at Outdoor PV Performance

- Photovoltaic modules are exposed to a wide range of stress conditions (UV, temperature, moisture, thermal cycling, and internal voltage) simultaneously and sequentially;

- Current IEC standards are very mild and mostly are single or double stress conditions’ tests at the same time due to equipment limitation;

- “Long-term outdoor exposure is the ultimate test for all module components, material quality and manufacturing quality.”
  Artur Skoczek, Tony Sample, and Ewan D. Dunlop, 
Global Concerns of PV Module Field Failures

Defects of PV modules in the field are not uncommon, with most of these defective modules using non field-proven materials. Defects are seen even among systems in use less than five years. Field studies have reported:

- 22% of global modules have shown visual defects\(^1\)
- Backsheet defects = 7.5%

PV module defects increased from 19% in 2013 to 48% in 2015\(^2\)

Backsheet defects = Particularly Serious

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\(^1\) From a global field-module survey including more than 70 global installations, (1.9 MM+ modules at 450+ MW) in NA, EU and AP.

\(^2\) TUV Rheinland Intersolar 2015, Roundtable Solarpraxis
Yellowing: Indicates Polymer Degradation and correlates with loss of Mechanical Properties

- Yellowing witnessed in many different fields, in > 6 different countries with less than 5 years in the field
  - China, USA, Germany, Belgium, Spain, Israel

Yellowing is an indication of polymer degradation and can place modules at risk for failure and safety.
Yellowness vs. Loss of Mechanical Properties

Backsheets from Fielded Modules (red) and from UVA accelerated tests (blue)

- Yellowness of backsheet measured on j-box side
- Elongation loss measured on backsheet

Loss of mechanical properties is due to polymer degradation and correlates with backsheet yellowness for field and accelerated testing. Significant loss of elongation with yellowness $b^* > 4$. 

UVA, 65W/sqm, 70°C BPT, 3000 hours = 195kWhr/sqm, 18 year desert equivalent
Field exposures ranged from 4 to 14 years

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Cracking: Backsheet Loses Insulation and Places Modules at High Risk for Failure and Safety

- 4yrs solar farm in Spain, 2.3MW;
  - Polyester-based Backsheet cracking with ~50% of modules cracked. Some cannot pass wet leakage test.

- 4yrs solar farm in north American, 40kW;
  - PVDF-based Backsheet cracking & delamination 57% of modules cracked

- 4yrs solar farm in west China, 20MW;
  - PA-based Backsheet large amount of cracking with ~40% of modules cracked.

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Micro-cracking (only visible under microscope): Early signs that can lead to Visual Cracking and Mechanical Property Loss

Micro-cracks observed on PA backsheet in 2013 (1yr after installation) under SEM

Visual cracks observed in 2016 (4yrs) on >40% modules in 20MW solar farm

<table>
<thead>
<tr>
<th>PA Backsheet % Elongation loss after 4 years in Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>% ELONGATION</td>
</tr>
<tr>
<td>Initial</td>
</tr>
<tr>
<td>4 years field aged</td>
</tr>
</tbody>
</table>

Significant mechanical property loss – PA backsheet is brittle
Micro-cracking also observed in PVDF and FEVE backsheets

PVDF, 2.5yrs, micro-cracks
FEVE, 3yrs, micro-cracks & pinholes
Tedlar® PVF, 18yrs, no cracks
Corrosion: Glass-Glass field failures observed

Observation:
- **Bus bar corrosion, EVA browning**
- **Power loss**

Location: Hainan (China), Time: 15 years

Observation:
- **Bus bar corrosion**
- **Power loss**

Location: Okinawa (Japan), Time: 11 years

Observation:
- **Bus bar corrosion**
- **Power loss**

Location: Shanghai (China), Time: 5 years

Observation:
- **Extensive breakage**

Location: Yunnan (China), Time: 10 years

- Multiple failures: Power Loss & Breakage across regions, and Applications (roof + ground)
- Higher corrosion rates are likely due to trapping of acetic acid by the glass backpanel.
PET Core Polymer Degradation: Correlates with Mechanical Property Loss

- **Molecular weight**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core layer PET at cell shielding</td>
<td>19100</td>
</tr>
<tr>
<td>Core layer PET at cell space</td>
<td>12000</td>
</tr>
<tr>
<td>Outer layer PET at cell shielding</td>
<td>20400</td>
</tr>
</tbody>
</table>

- **Viscosity**

<table>
<thead>
<tr>
<th>Sample</th>
<th>IV, dL/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core layer PET at cell shielding</td>
<td>0.929</td>
</tr>
<tr>
<td>Core layer PET at cell space</td>
<td>0.693</td>
</tr>
<tr>
<td>Outer layer PET at cell shielding</td>
<td>0.800</td>
</tr>
</tbody>
</table>

- **Loss of PET Mol wt and viscosity at cell spacing indicate polymer degradation from frontside UV light**

- **Backsheet was highly degraded. Backsheet could not be removed from module due to high brittleness**

Tedlar® PVF film- 0.4um/year- lost 9.1 microns over 25yrs’ service in California

PVDF film- 1.8um/year reduced 4.5um with 2.5yrs field exposure in Yunnan, CN

Backsheet cross sections- measure thickness under label and outside label to determine erosion level
### Thickness Erosion: Some Backsheets Show Remarkable Outer Layer Thickness Reduction at Early Stage in Field

<table>
<thead>
<tr>
<th>Backsheet Surface</th>
<th>Location</th>
<th>Climate</th>
<th>Years Deployed</th>
<th>Erosion Rate (um/year)</th>
<th>Years to erode outer layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tedlar® PVF</td>
<td>California</td>
<td>Arid</td>
<td>25</td>
<td>0.36</td>
<td>106</td>
</tr>
<tr>
<td>Tedlar® PVF</td>
<td>Beijing</td>
<td>Temperate</td>
<td>18</td>
<td>0.22</td>
<td>173</td>
</tr>
<tr>
<td><strong>Tedlar® PVF Average</strong></td>
<td></td>
<td></td>
<td><strong>22</strong></td>
<td><strong>0.3</strong></td>
<td><strong>140</strong></td>
</tr>
<tr>
<td>White PET</td>
<td>Tibet</td>
<td>Plateau</td>
<td>9</td>
<td>2.3</td>
<td>11</td>
</tr>
<tr>
<td>White PEVE Coating</td>
<td>Qinghai</td>
<td>Cold Arid/desert</td>
<td>1.5</td>
<td>2.3</td>
<td>11</td>
</tr>
<tr>
<td>PVDF coating</td>
<td>Xinjiang</td>
<td>Cold Arid</td>
<td>1.5</td>
<td>3</td>
<td>6.7</td>
</tr>
<tr>
<td>PVDF film</td>
<td>Yunnan</td>
<td>Subtropical</td>
<td>2.5</td>
<td>1.8</td>
<td>14</td>
</tr>
</tbody>
</table>

- Tedlar® PVF resists erosion and erosion durability exceeds 25 years while some others show remarkable thickness reduction at early stage.
- Minimum thickness (~10um) of backsheet outer layer must be maintained to block UV and protect the core layer.
Hot Spot Resistance: Hot Spot can Result in Bubbling, Cracking and Burn-through

PVF Film Has 30~40°C Higher Softening Temperature Than PVDF and Thus Better Hot Spot Resistance

*JIS K7196 Heat Deformation Test- weighted stylus impinges on sample being heated, thermal transitions noted
Tedlar® Field Case: 18yrs Old Tedlar® TPT Installation in Beijing Has Retained Thickness and Still Looks Good

18yrs field module with TPT backsheet shows low power loss rate (0.7%/yr)

Tedlar® from field after 18yrs

Standard PVF

TiO₂

Tedlar® film shows no degradation after 18yrs field service

TPT backsheet maintains 160.8% elongation and 92.1 Mpa tensile strength
**DuPont: the Leading Specialty Material Supplier in PV**

**DuPont™ Tedlar® PVF film** is the ONLY backsheet material with 30+ Years field proven record

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**DuPont™ Solamet® Metallization Pastes** driving higher energy conversion efficiency

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Tedlar® film-based backsheets have been protecting solar panels since 1978

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PET

PVDF

THV

Nylon

Specialty PET

Coated Flouro

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25 years solar panel warranty requirement

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PET

PVDF

THV

Nylon

Specialty PET

Coated Flouro

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25% increase in solar panel power

70% paste laydown reduction

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Laydown consumption per MW (kg)

2005

2011

2017

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The Solutions: Materials Matter™

• Field-proven materials deliver long-term performance and lasting value.

• DuPont™ Tedlar® PVF film-based backsheets superior insulation and weatherability are field-proven to reduce system defects. This leads to:
  – Improved electrical safety.
  – Reduction of ground faults.
  – Increased system availability.
  – Reduced operational expenses.
  – Lower LCOE

Extending System Lifetime
FROM 10 → 25 YEARS CAN LOWER LCOE BY 60%

Materials Matter™
The use of field-proven materials is critical to the long-term performance and reliability of your system.