Module Accelerated Stress Testing and Prediction of Field Performance

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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…
Outline

- Introduction
- Field Examples
- Key Stress Conditions in the Field
- Accelerated Stress Conditions and their Relation to Field
- Conclusions
Introduction

• IEC qualification test conditions were developed to identify early life failures due to poor component selection, manufacturing process and/or module design
• Extended IEC qualification testing (2x or 3x DH, TC, HF) does not predict long term performance
• New accelerated test methodologies need to be developed to accurately predict long term performance and adequately assess changes to materials, module design and processing
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 study results:

DuPont 2016 Field Study

- No defect: 78.0%
- Cell: 11.3%
- Backsheet: 7.5%
- Encapsulant: 2.7%
- Other: 0.5%

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

TUV Rheinland 2015 Study

- PV module defects increased from 19% in 2013 to 48% in 2015\(^2\)
- Backsheet defects = Particularly Serious

\(^1\) 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
Field Examples of Backsheet Inner Layer Yellowing

- 2 year old fielded module in a desert region in USA - PVDF-based backsheet
- 9 year old fielded module in Tibet - PET-based backsheet - 100% modules yellowed in 10kW field

Field examples of Backsheet Outer Layer Yellowing

- Yellowness measured on 12 rooftop modules deployed 15 years in Japan.
  - Significant yellowing even on the interior of array (b* of 13-20)
  - Highest yellowing is along edges with highest UV exposure (b* up to 27)

Source: Modules provided by AIST; DuPont analysis

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Field Examples of Backsheet Outer Layer Cracking

4 years old module from Spain - 2.3 MW field, 2 module types, large percentage affected - PA backsheet

5 year old module from Italy – large crack tripped inverter - PA backsheet

9 year old module from Canada – large crack in PET-based backsheet

4 year old module from Canada - four 10 kW installations, 57% of modules affected - PVDF backsheet

4 year old module from Canada with backsheet in advanced state of degradation - PVDF backsheet

Remains of backsheet
Key Stress Conditions in the Field

- Direct UV
- High Temperature
- Thermal Cycling
- Mechanical Abrasion
- Transmitted and Reflected UV
- Moisture Ingress (Humidity & Condensation)
- Atmospheric Chemicals
- Glass
- Mechanical Load
- Internal Electric Fields
- Junction box with adhesive
- Front encapsulant
- Tabbed silicon cell strings
- Back encapsulant
- Backsheet

PID and corrosion
Key Stress Conditions in the Field

Direct UV/visible light exposure
- New encapsulants transmit more UV to the backsheets inner layer
- Higher UV stability for backsheets needed

High temperature and thermal cycling exposure
- Closed roof mounting
- Localized heating from shading and hot spots

Mechanical stress exposure
- Snow, wind, etc.
- Installation and mount-related stress
- Localized stress from cell edges, busbar ribbons, tabbing wires

Reflected UV/visible light exposure
- UV exposure of the backsheets outer layer from ground (albedo)
- Roof, water, ground cover depending on installation

Mechanical abrasion
- Sandstorms
- Installation

Internal voltage stress
- Potential-induced degradation (PID) and corrosion
- Heat generated from resistive losses
Accelerated Conditions and their Relation to Field

• Accelerated testing protocols attempt to recreate stress conditions in the field at higher stress levels including
  – higher temperature
  – higher humidity
  – higher irradiation intensity
  – larger temperature range
  – faster temperature variation

  in order to identify field-related failures and eliminate the cause

• Simultaneous and sequential exposure of these accelerated stress conditions allows better prediction of synergistic effects
Module Accelerated Sequential Testing (MAST)

Repeated sequential stress mimics field degradation not detected by single tests and current industry standards. Sequential exposures are applied to same module.
Sequential Test Results Compared to Field Results

**Polyamide backsheet - cracking**
- Cracked, 5 years in Spain

**PVDF backsheet - cracking**
- Cracked, 5 years in Canada

**PET backsheet - yellowing**
- Yellowing, 15 years in Japan

**Field Examples**
- Polyamide backsheet - cracked, 5 years in Spain
- PVDF backsheet – Cracked, 5 years in Canada
- PET backsheet - Yellowing, 15 years in Japan

**MAST Sequential Accelerated Test**
- DH 85C/85%RH
- UVA 1.2W/sqm (340nm), 70C BPT
- TC 85°C => -40°C per IEC 61215

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MAST Alternative Testing Sequences

Damp Heat & Thermal Cycling
Combines two important stress factors in a shorter test not requiring full size, expensive UV equipment.

Damp Heat: 1000 hours

Thermal Cycling: 200X

Water Spray Intervals: 3000 hours UVX

UVA & Water Simulation
Combines UV and rainfall simulation, common weathering test conditions using commercially available weatherometer.

DH/TC exposure to assess backsheets cracking in full size modules.

ASTM G155 or SAE J1960 protocols in a weatherometer for backsheets coupon or minimodule.
Results of Alternative Sequential Test

Sequential Accelerated Test

Cracks with Polyamide based backsheet

Field Examples

Polyamide backsheet - cracked, 5 years in Spain

Cracks with single-sided PVDF backsheet

Cracked and degraded 1s PVDF backsheet <5 years in the field
Weathering Test Results

Sequential Accelerated Test

Yellowing in PET-based Backsheets

Loss of Mechanical Properties in PET-based Backsheets

Field Examples

15 year rooftop- yellowed PET backsheet

9 year ground mount- cracked PET backsheet
### Comparison of Sequential Accelerated Test Results

#### Sequential Test Summary

<table>
<thead>
<tr>
<th>Test</th>
<th>Sequence</th>
<th>Measurement</th>
<th>Format</th>
<th>Unit</th>
<th>Tedlar®PVF</th>
<th>PVDF</th>
<th>FEVE</th>
<th>Tedlar®PVF TPE</th>
<th>PVDF</th>
<th>FEVE</th>
<th>Nylon</th>
<th>UVPET / HPET</th>
<th>UVPET / PET</th>
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<tbody>
<tr>
<td>1</td>
<td>UVA1000-DH1000 2X(TC200-UVA1000)</td>
<td>Yellowing</td>
<td>Full size module, Minimodule or backsheet samples</td>
<td>b*</td>
<td>0.8</td>
<td>OK</td>
<td>0.6</td>
<td>0.2</td>
<td>0.6</td>
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<td>3.7</td>
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<tr>
<td></td>
<td></td>
<td>Mechanical Loss-Cracking</td>
<td>Full size module, Minimodule or backsheet samples</td>
<td>observe or % elongation loss</td>
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<td>Micro Cracking</td>
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<td>Cracking</td>
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<td>Cracking</td>
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<td>DH1000 2X TC200</td>
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<td>Mini module</td>
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<td>OK</td>
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<td>Cracking</td>
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<td>OK</td>
<td>OK</td>
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<tr>
<td>3</td>
<td>UVX-water spray-3000 hours</td>
<td>Yellowing</td>
<td>Minimodule or Backsheet</td>
<td>b*</td>
<td>0.1</td>
<td>0.2</td>
<td>0</td>
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<td>Mechanical Loss-Elongation</td>
<td>Minimodule or Backsheet</td>
<td>% Elongation Loss</td>
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<td>80-100</td>
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</tbody>
</table>

#### Outdoor Performance

| Years in Field | Years | 34 | 4 | 4 | 26 | 7 | 9 | 7 | 6 | 19 |

#### Field

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Modules</th>
<th>Tedlar®PVF</th>
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<th>FEVE</th>
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Good correlation of sequential test results and field defects
Conclusions

• Fielded module defects are commonly seen, recent surveys show increasing levels of defects often due to untested newer materials
• Backsheet defects include frontside yellowing and airside yellowing and cracking- yellowing is an indication of polymer degradation
• Sequential tests have been developed that match field exposure levels and reveal defects better than single stress exposures
• Three sequential test conditions have been identified for module testing, examples provided showing good predictability of field defects
• Shorter test time with better prediction are the goals of current accelerated test activities