Safety Concerns with New PV Polymeric Materials

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Crystal Vanderpan

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- Joined UL in 1995
- Technical rep on UL STPs for Rigid and Flex PWB Standards
- Subcommittee chairman ASTM D09.07
  - Electrical and Electronic Insulating Materials
- Active in IEC TC82, WG2 PV Modules and Materials
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Getting New PV Materials to Market

What this session will cover –

• Changing PV Market

• Safety Risks

• Performance vs Safety Evaluations

• PV Material Standards Work

• PV Materials Pre-selection Process
PV Growth in US

Cumulative US Grid-tied PV Installations 2000 - 2009

PV Module Landscape is Changing

• PV modules produced between 1990 and 2005
  – Share similar constructions, materials, and manufacturing process

• Traditional PV module recipe
  – Developed with many years of research and testing
  – Good track record
Past and Future PV Performance

• Past performance can’t predict the future
  – New PV module configurations and applications
  – New manufacturers with little PV module experience
  – New manufacturing processes
  – New construction techniques
New Construction Techniques for PV

• New PV materials
  – Thermoplastics, encapsulants and adhesives with low softening / melt temps

• Conductive adhesives to replace solder

• Polymeric mounting systems
Thermoplastic Material Concerns

• Transition away from crosslinked EVA

• More thermoplastic encapsulants and mounting materials in the PV construction

• Thermoplastics flow or creep over time when exposed to high operating temperatures

• Some new materials have melt temperatures less than 100°C
PV Module Temperature Testing

- Worst case module temperatures are not addressed and can be well above 90°C due to:
  - High ambients
  - High irradiance
  - Shading conditions

- Temperature tests are normalized to 40°C
- Chamber cycling is done at 90°C max
PV Polymeric Material Creep or Flow

• Any movement can create problems!
• Risk of shock, fire or mechanical hazards
  – Electrical connections
    • Short or open circuits
    • Displacement of electrical conductors or components
    • Loss of contact pressure
  – Mounting
    • Delamination
    • Loss of mechanical integrity
    • Falling modules or falling glass
PV Evaluation Challenge!

• Existing evaluation programs are not sufficient
  – Do not address all safety concerns as demonstrated by increased product testing failures
  – New generation of PV modules
  – New components
  – New materials
Why Safety Testing?

– 8 years operation in Arizona
– Passed original qualification tests
Backsheet Delamination
I just need a little more cable .....
Delamination or creep can cause these ribbons to open or short circuit.
“Hazard-Based” Engineering Approach

• Analyze the installation
  – Location and intended use
  – Attachment systems, wiring systems, hazards

• Analyze the product
  – Materials, construction, hazards
“Hazard-Based” Engineering Approach

• Utilize existing standards & knowledge
  – Standards may exist for similar products / situations
  – Code requirements may exist

• Test to provide confidence
  – Use UL and/or IEC for PV modules
  – Use other standards to address incidental hazards
Who is UL?

- Underwriters Laboratories Inc (UL) is an independent, not-for-profit safety testing and certification organization.
- Founded in 1894, UL has earned a reputation as a global leader in product safety standards development, testing and certification.

Timeline:
- 1894: UL founded
- 1970: AIMCAL founded
- 1972: UL 94
- 1976: UL 746A
- 1986: UL 1703
- 1993: IEC 61215
- 1996: IEC 61646
- 2004: IEC 61730
- 2007: UL 5703
- Today: 2010
Certification and Product Development Cycle

Performance Certification
IEC 61215 or 61646

If no Follow Up testing:
Modules, components and materials may vary and invalidate performance certification

Pre-design
Design
Prototype
Production
Distribution
Field Products

Safety Certification
IEC 61730 or UL 1703

Consulting
Prelim Investigation
Certification
Manufacture Follow-up Inspection and Testing
Product failure Field Reports

One time evaluation, no Follow Up test
IEC 61730 PV Module Safety

• Scope and Objective
  – Describes the fundamental construction requirements for photovoltaic (PV) modules
  – To provide safe electrical and mechanical operation during their expected lifetime
  – Specific topics assess the prevention of electrical shock, fire hazards, and personal injury due to mechanical and environmental stresses
UL 1703 Safety Standard for PV Modules

- Evaluate electrical shock hazards
  - Product and application

- Evaluate fire resistance & propagation hazards
  - Product and application

- Verify evaluation through testing

- Provide subsequent “Follow-Up” inspection of manufacturing locations
UL 5703 PV Backsheet Materials

• Outline of Investigation

• Scope – Evaluation of PV materials including backsheet and encapsulant materials
  – Long term temperature rating evaluations
  – UL746A Short term property characterization

• Frontsheet and conductive adhesive requirements to be added

• Provide subsequent “Follow-Up” inspection of manufacturing locations
Applications

- Enclosure
- Support of Live Parts
- Outer Enclosure
- Barrier / Liner
- Junction Boxes
- Thermal Index

![Diagram of solar panel components]

<table>
<thead>
<tr>
<th>A. Solar Cell</th>
<th>B. Glass</th>
<th>C. Encapsulant</th>
<th>D. Back Cover</th>
<th>E. Fiberglass</th>
<th>F. Interconnect Ribbon</th>
<th>G. Bus Ribbon</th>
<th>H. Frame</th>
<th>I. Edge Seal</th>
</tr>
</thead>
</table>

UL the standard in safety
Material Property Requirements

• Short Term (depends on operational category)
  – Encloses live parts
  – Direct support of live parts
  – Outer surface for the module
  – Internal Barrier (in lieu of spacing requirements)

• UV / Water Exposure

• Long Term (all polymeric materials must have):
  – Rating of $T_{max} + 20^\circ C$, where $T_{max}$ is the max measured temperature during the Temperature test
  – If material is backsheet / frontsheet, shall be min 90$^\circ C$
Short Term Material Tests

• Comparative Tracking Index (CTI)
  – determine spacing requirements with addition of wet contaminant

• Dielectric Strength (DS)
  – establish insulation resistance baseline

• High Current Arc Ignition (HAI)
  – simulate loose connections and broken leads

• Hot Wire Ignition (HWI)
  – determine ignition properties when adjacent to or supporting an insulated or uninsulated wire

• Volume Resistivity (VR)
  – determine if material is an insulator or a semi-conductive material
Relative Thermal Index (RTI)

• A temperature assigned to the dielectric material
  – Does not unacceptably degrade the material
  – Electrical and Mechanical properties

• Determined by a benchmark comparison of temperature, time, and critical property degradation after long-term thermal aging
Harmonization of IEC and UL Standards

• Goal to minimize national differences
  – IEC 61730 Amendment

• Revisions include
  – Standardize PV material characterization tests
  – Module level tests to address creep, flow, displacement and delamination failures
  – New outlines for PV Connectors, Cables and J-Boxes
International Information Transfer

IEC PV Plastics Project Team

UL 61730 ↔ IEC 61730
IEC PV Material Characterization Project Team (TC82, WG2)

• **Scope**
  – Develop PV material property characterization requirements

• **Hazard Based Analysis**
  – Used to determine material characterization tests

• **88 International members**
  – Module, adhesive, backsheet, and encapsulant mfrs, industry experts, certification bodies, and national labs
IEC PV Material Task Groups

• Adhesives and Conductive Adhesives
• Backsheets and Frontsheets
• Edge Sealants and Potting Materials
• Encapsulants
• Partial Discharge
• Weathering/accelerated aging
IEC PV Material Meeting Schedule

• Material Project Team
  – Meet twice a year with TC82 WG2
  – Next meeting May 2011 Shanghai, China

• Task groups
  – Meet in between WG2 meetings via teleconference with Internet meeting (web-meeting) and/or face to face meetings
IEC PV Material Project Team

• Short and Long Term Goals
  – Work related to IEC safety, design, and performance standards
  • IEC 61730, IEC 61215, IEC 61646
  – Characterization of safety and performance
  – Review and prioritize test lists based on safety and performance
  – Create retest variation guidelines
  – Compliance criteria based on design and application
  – Preselection guidelines for modules
<table>
<thead>
<tr>
<th>Hazard</th>
<th>Failure Mechanism</th>
<th>Test</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Shock</td>
<td>Voltage tracking – voltage causing a permanent electrically conductive carbon path after application of wet contaminants.</td>
<td>CTI</td>
<td>IEC 60112</td>
</tr>
<tr>
<td>Electric Shock</td>
<td>Material electrically conductive</td>
<td>Volume Resistivity</td>
<td>IEC 60167</td>
</tr>
<tr>
<td>Electric Shock</td>
<td>Insulation thickness consistency</td>
<td>Partial discharge</td>
<td>IEC 61730-2</td>
</tr>
<tr>
<td>Electric Shock</td>
<td>Mechanical protection from tearing</td>
<td>Tensile Strength, Tear Resistance, Cut Test</td>
<td>ISO 527-3, ASTM D1004, IEC 61730-2</td>
</tr>
<tr>
<td>Electric Shock</td>
<td>Mechanical support of junction box due to movement or stretching of backsheet</td>
<td>Puncture Properties</td>
<td>ASTM D7192</td>
</tr>
<tr>
<td>Electric Shock</td>
<td>Superstrate / Glass movement/creep</td>
<td>Creep/flow test, Dynamic Mechanical Analysis (DMA)</td>
<td>D6382</td>
</tr>
<tr>
<td>Electric Shock</td>
<td>Substrate / Encapsulant movement from J-box and cable weight</td>
<td>Bond strength, Peel strength, Intra-layer adhesion</td>
<td>SAE Automotive or IEC 60950-1 (2.10.11)</td>
</tr>
<tr>
<td>Electric Shock</td>
<td>Interfacial Delamination/adhesion</td>
<td>Bond strength, Peel strength, Intra-layer adhesion</td>
<td>SAE Automotive or IEC 60950-1 (2.10.11)</td>
</tr>
<tr>
<td>Electric Shock</td>
<td>Water ingress from delamination</td>
<td>Water Absorption</td>
<td>ISO 62</td>
</tr>
<tr>
<td>Flammability</td>
<td>Additional fuel for the fire</td>
<td>Flammability test, Radiant Heat Ignitability (Cone Calorimeter test)</td>
<td>IEC 60695-11-10, ISO 5657</td>
</tr>
<tr>
<td>Flammability</td>
<td>Insulated or uninsulated wire attaining red heat during a fault causing possible ignition</td>
<td>HWI or Glow Wire</td>
<td>IEC 60695-2-20</td>
</tr>
<tr>
<td>Mechanical</td>
<td>Loose connections and broken leads in the vicinity of the polymer material causing arcing</td>
<td>HAI</td>
<td>IEC 60695-1-1</td>
</tr>
<tr>
<td>Mechanical</td>
<td>Mechanical failure due to degradation of insulating material</td>
<td>Tensile Strength and Tensile Elongation</td>
<td>ISO 527-3, IEC 60216-5 (thermal aging)</td>
</tr>
<tr>
<td>Mechanical</td>
<td>Thermal stress due to material expansion</td>
<td>Thermal Expansion (CTE)</td>
<td>ISO 11359-2</td>
</tr>
<tr>
<td>Mechanical</td>
<td>Adhesion to glass and backsheet</td>
<td>Bond strength, Peel strength, Intra-layer adhesion</td>
<td>SAE Automotive or IEC 60950-1 (2.10.11)</td>
</tr>
<tr>
<td>Mechanical</td>
<td>Inter-layer adhesion of backsheet</td>
<td>Bond strength, Intra-layer adhesion</td>
<td>SAE Automotive or IEC 60950-1 (2.10.11)</td>
</tr>
<tr>
<td>Mechanical</td>
<td>Surface treatment, chemical, corona treatment</td>
<td>Surface finish rating scale for machined metals?</td>
<td>??</td>
</tr>
</tbody>
</table>
Potential Solutions to Assembly Challenges

• Pre-selection of materials

• Select alternate materials with higher temperature ratings for assembly
Pre-selection

• The process of assessing and choosing materials for electrical products.
Advantages of Pre-selection

• Aides in material selection during the design stage

• Compare and evaluate performance levels

• Eliminate testing each material in specific part configurations

• Faster qualification of alternate materials

• Pre-selection successfully used as a material performance specification in product standards for decades

• Faster time to market
Summary

✓ Enables users to locate suitable materials for higher temp applications

✓ Pre-selection programs eliminate the need to test each material in each specific part configuration

✓ Faster qualification of alternate materials

✓ Confidence that the materials continue to meet requirements (type testing and on-going verification)

✓ Faster time to market
Thank You
for your attention
and future participation!

Crystal Vanderpan
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