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DuraMAT
Durable Module Materials Consortium

Combined-Accelerated Stress Testing of PV Modules and Materials

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PEARL PV

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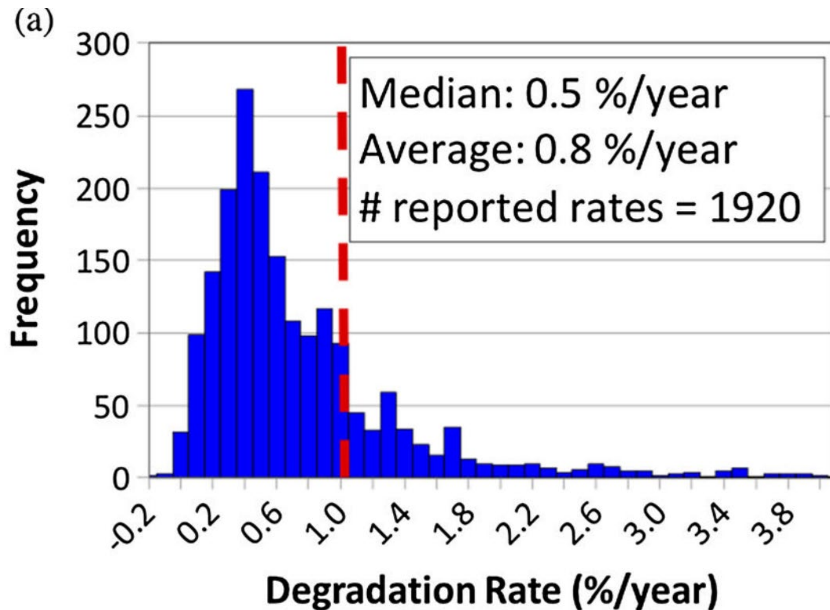
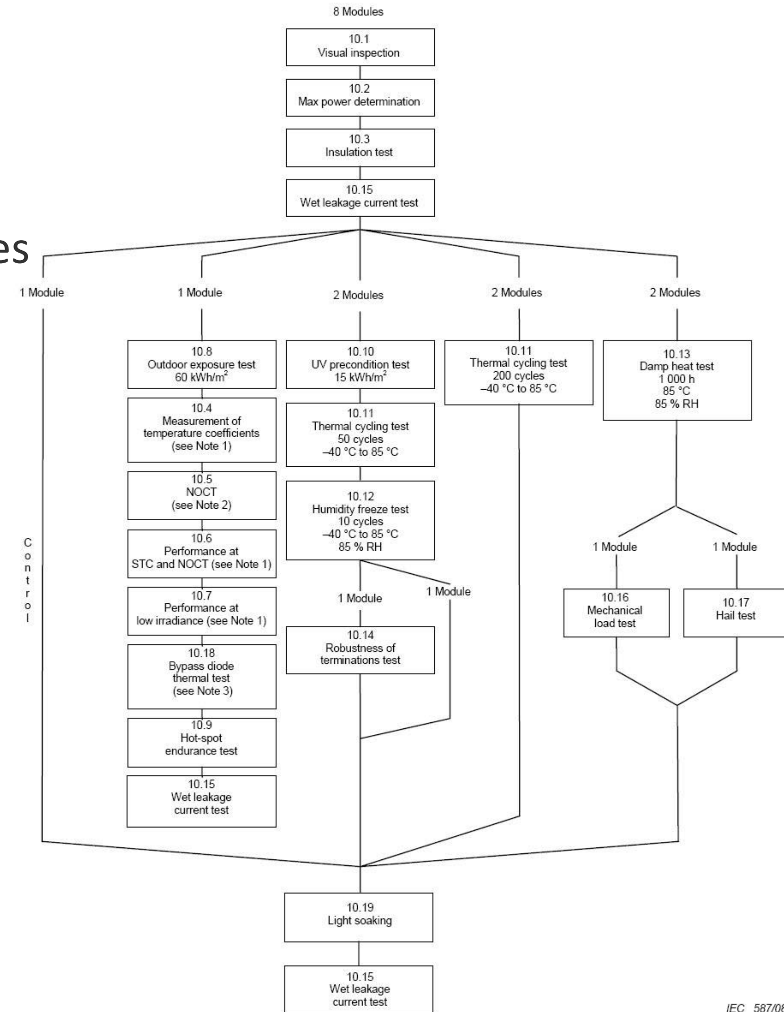
Introduction

Current certification tests:

- Mechanism-specific tests
- Targets *known* failure mechanisms
- Applies, at most, two stress factors in combination
- Somewhat sequential
- Not always relevant to modern module architectures



Jordan et al, "*Photovoltaic Degradation Rates—an Analytical Review*", Prog. In Photovoltaics, 2013



Overview of IEC 61215

Introduction

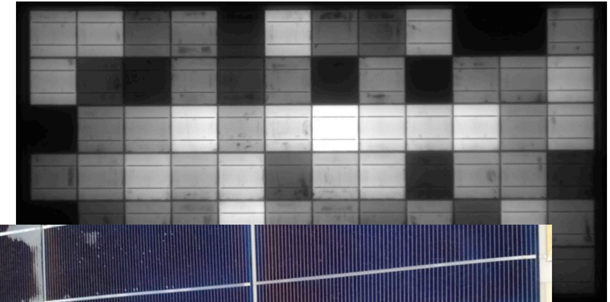
Failure mechanisms missed by conventional tests:

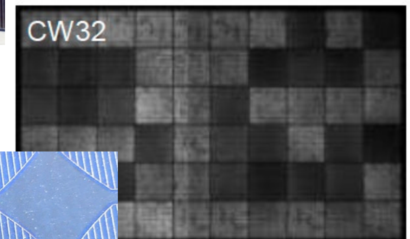
Potential-Induced Degradation (PID):
System voltage, humidity, temperature, light, soiling. (Multiple mechanisms depending on cell technology)

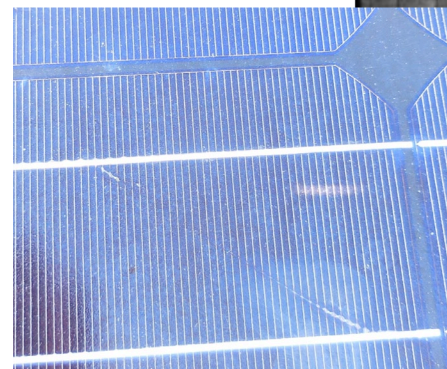
Grid finger corrosion & delamination:
System voltage, humidity, temperature, light, soiling

Light and elevated temperature induced degradation (LeTID):
Light, elevated temperature, current

Snail trails -> delamination:
Mechanical loading, UV, electric field, moisture, impurities

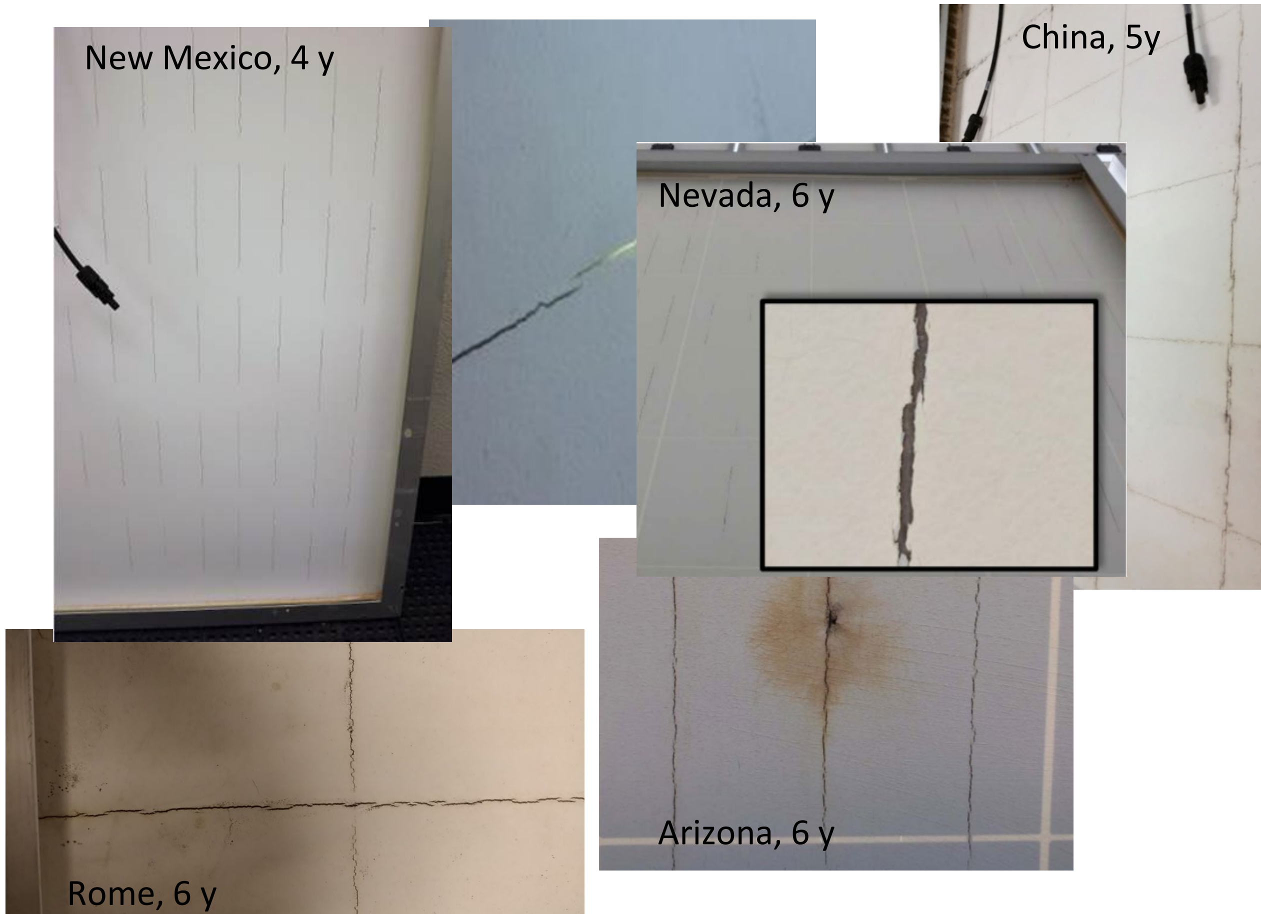






Introduction: PA-backsheet failure

Polyamide backsheet disaster



- Upwards of 12GW deployed
- 90% failure rate in 6 years
- **Despite passing certification**
- **You cant always know what to test for**

Roy Choudhury et al "*Material Degradation Impacting performance of PV modules in the field*"
NREL PV Reliability Workshop 2019

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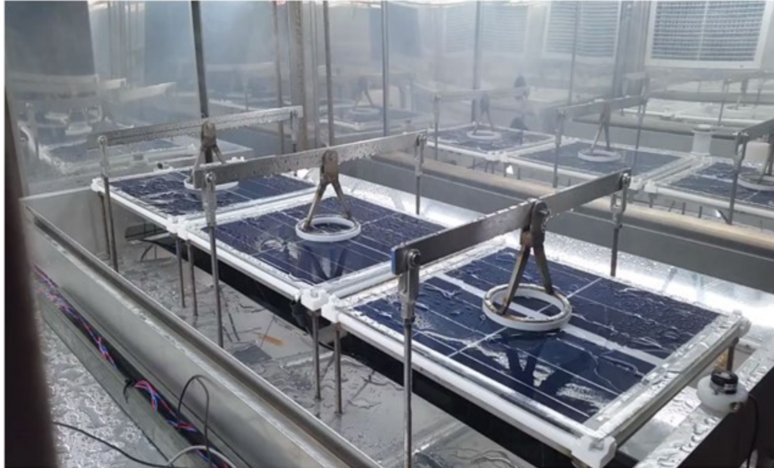
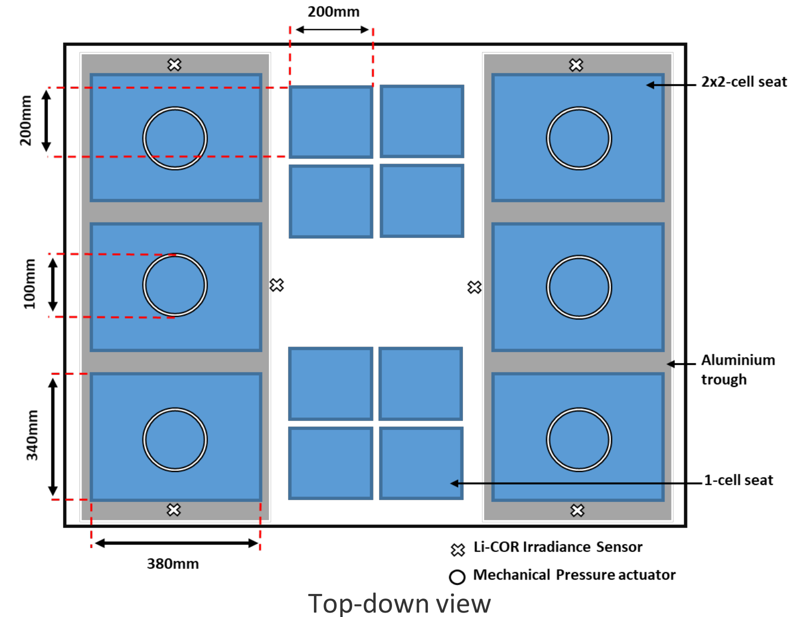
Combined-Accelerated Stress Testing

Combined-accelerated stress testing (C-AST)

- **Combines multiple stress factors of the natural environment**
- **Agnostic testing philosophy – not targeting specific mechanisms**
- **Allows discovery of mechanisms in new module designs / materials *before deployment***
- **Improved risk assessment**

Combined-Accelerated Stress Testing: Chamber





Top-down view

Modified Atlas XR-260 :

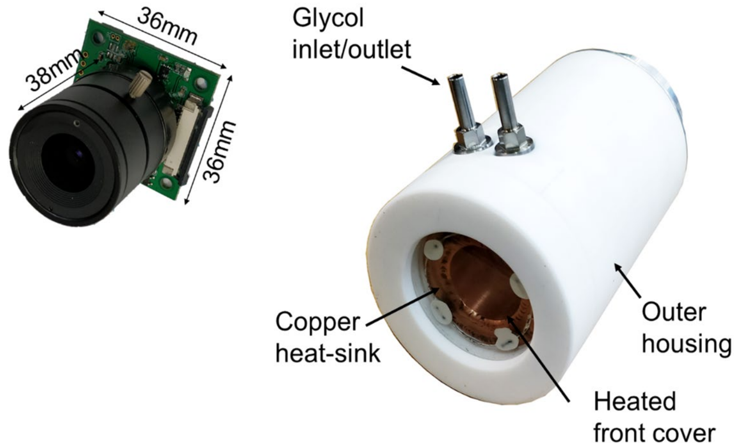
- -40°C to 90°C temperature control
- 5% to >95% relative humidity
- 2-sun Xenon-arc light exposure
- Water spray (front and back)
- Mechanical loading
- System-level voltage (±1500 V)
- Reverse Bias
- Variable load resistors
- Reflective troughs (below sample plane)

Up to 6 4-cell mini-module + 8 single-cell modules + coupons

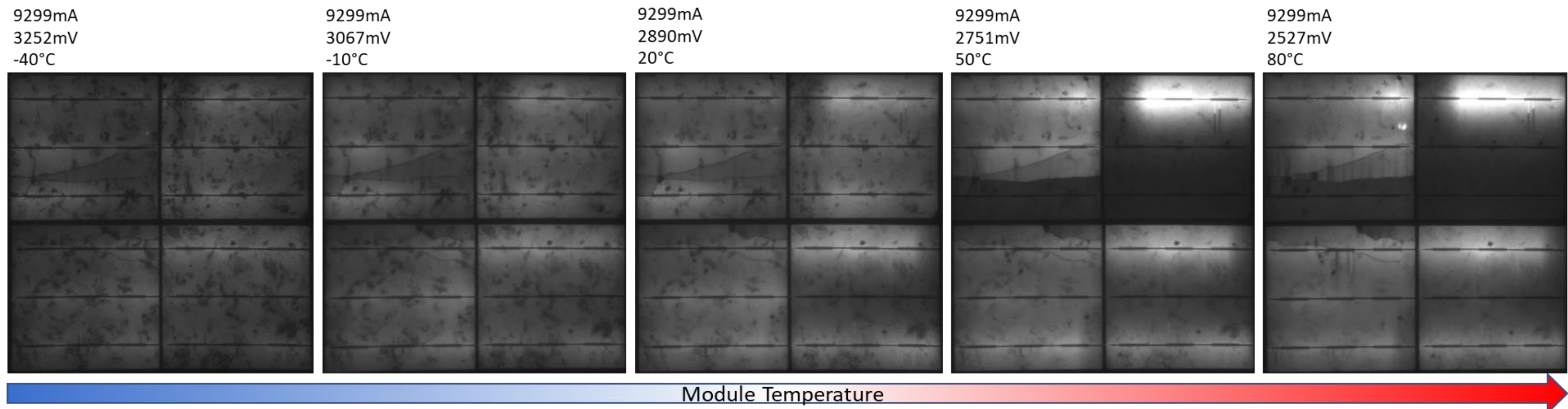
- Rear surface module temperatures
- LI-COR Irradiance sensors
- Humidity monitoring
- Leakage current monitoring
- Module power monitoring

Owen-Bellini et al, "*Advancing reliability assessments of photovoltaic modules and materials using combined-accelerated stress testing*", Prog. in Photovoltaics: Research and applications, 2020

Combined-Accelerated Stress Testing: *In-situ* EL



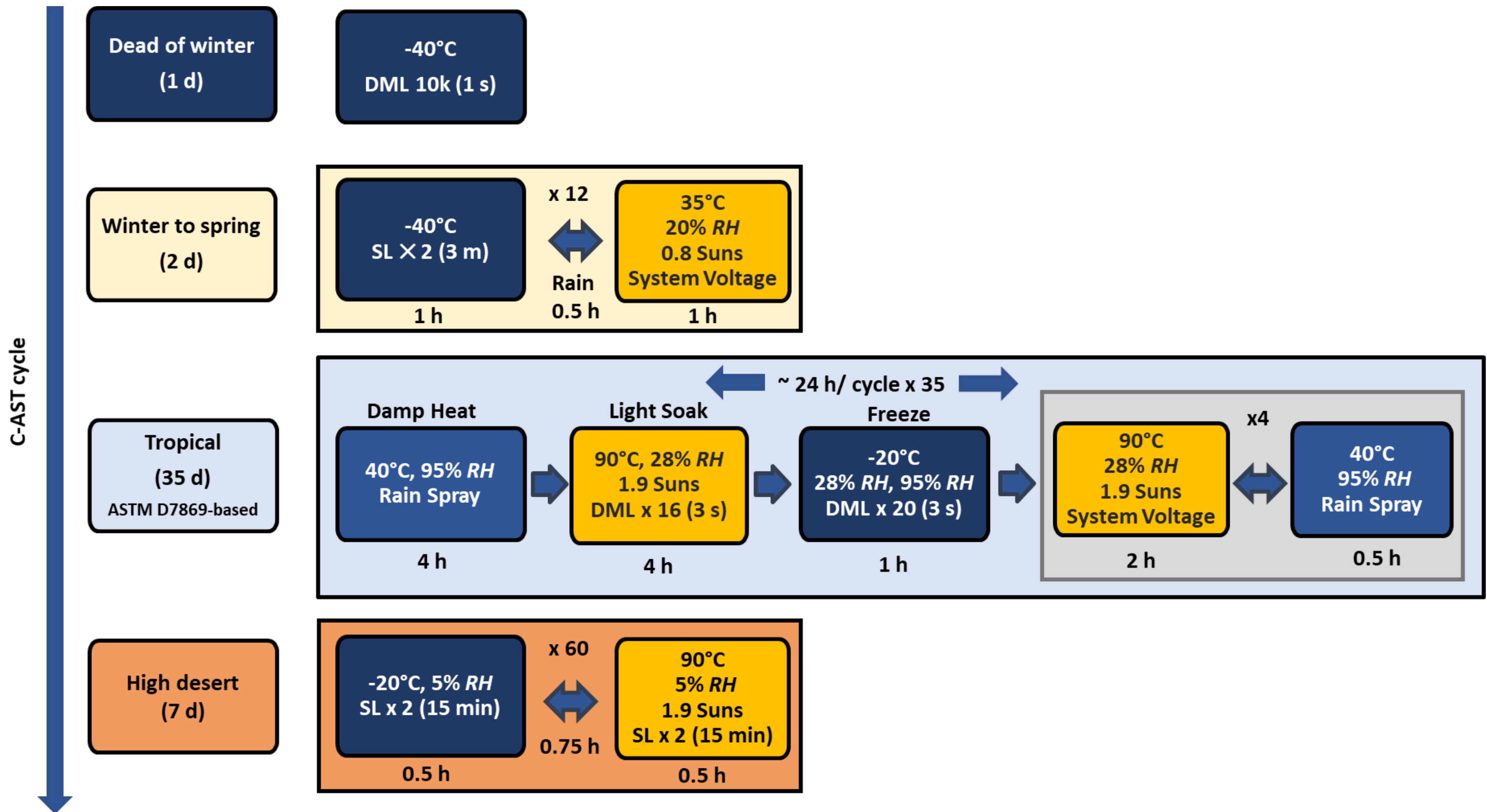
- Sony IMX219PQ 8.08Mpixel CMOS camera with an Arducam LS-61018CS lens is used for imaging
- Raspberry Pi connected
- Camera has small form factor (36mm x 36mm x 38mm) and is very low-cost (~$50)
- A custom-designed camera housing has been developed to protect camera from the harsh conditions of the chamber



Example of temperature effects on a pre-cracked 4-cell module

Owen-Bellini et al, "*Methods for In Situ Electroluminescence Imaging of Photovoltaic Modules Under Varying Environmental Conditions*", Journal of Photovoltaics, 2020

Combined-Accelerated Stress Testing: Test Protocol



DML = Dynamic Mechanical Loading
SL = Static Loading

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Backsheet Failures: Polyamide

Backsheet Failures:

Polyamide-based backsheet

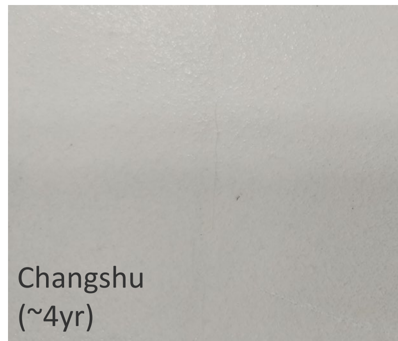
Macro cracking over underlying features (cell tabbing) following 4.5 months (cumulative)

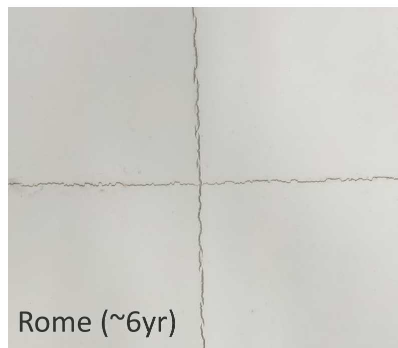
Important result since PA failures could not be reproduced in the standard stress tests

25 mm

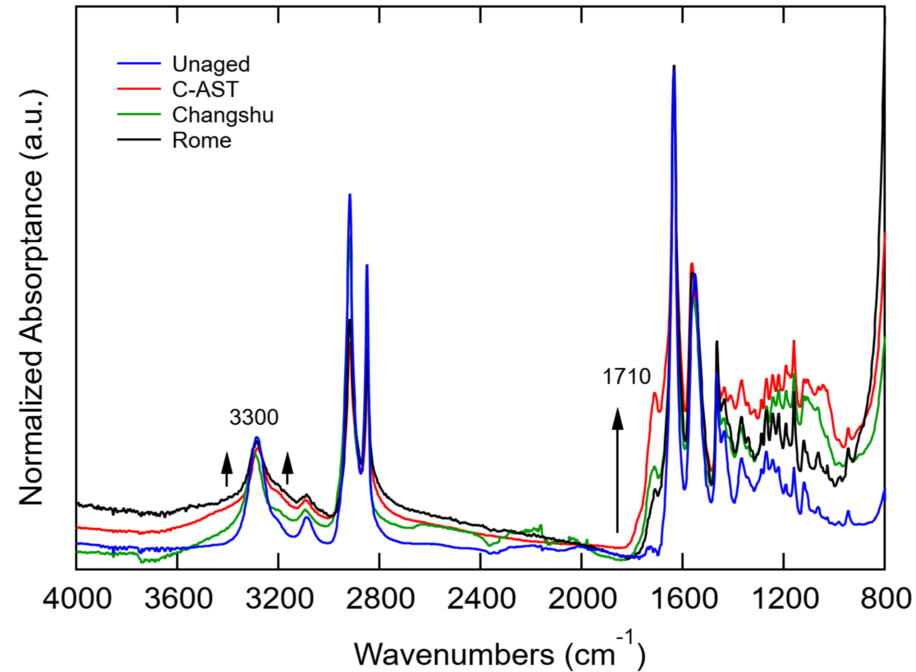
Surface micro-cracking covering entire backsheet surface

Backsheet Failures: Polyamide





FTIR-ATR for AAA outer surface: unaged, C-AST aged and field aged samples



Increase in 1710cm^{-1} wavenumber peak suggests photo-oxidative reactions which could be responsible for surface microcracking

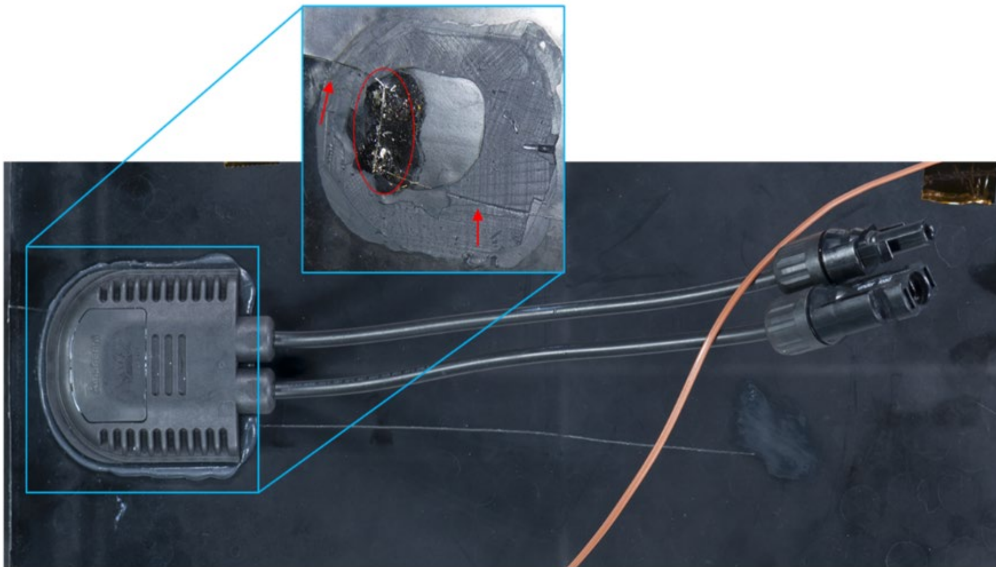
Similar changes in FTIR-ATR spectra observed in fielded modules.

Owen-Bellini et al, "*Towards validation of combined-accelerated stress testing through failure analysis of polyamide-based photovoltaic backsheets*", Scientific Reports, 2021

Backsheet Failures: Polyamide

Backsheet Failures:

PA-Ionomer Composite



Cracking of PA-Ionomer composite

Failed by through-cracking after 9 months in C-AST

Lasted twice as long as the Polyamide-only backsheets

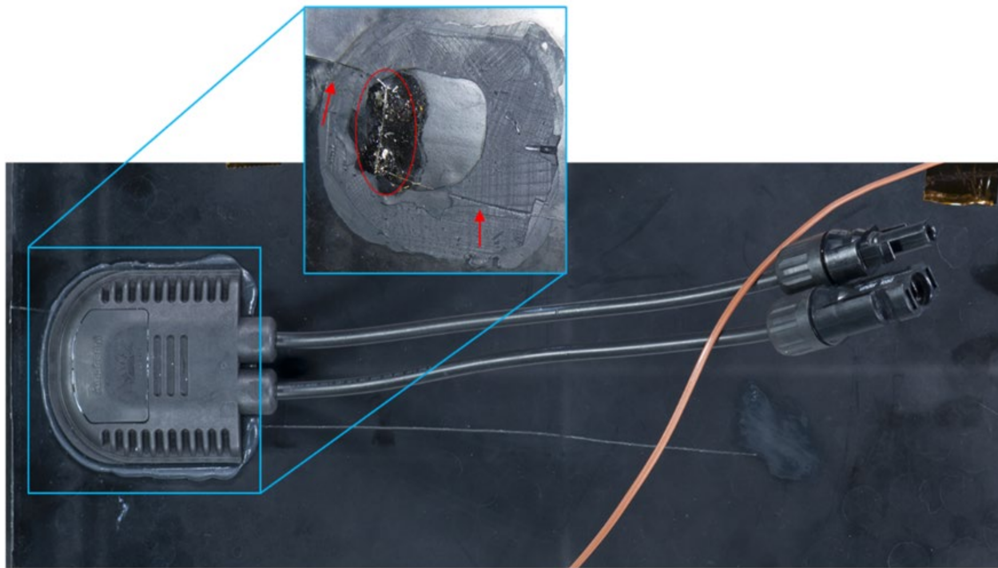
Cracking was not dictated by underlying features like the other PA backsheet

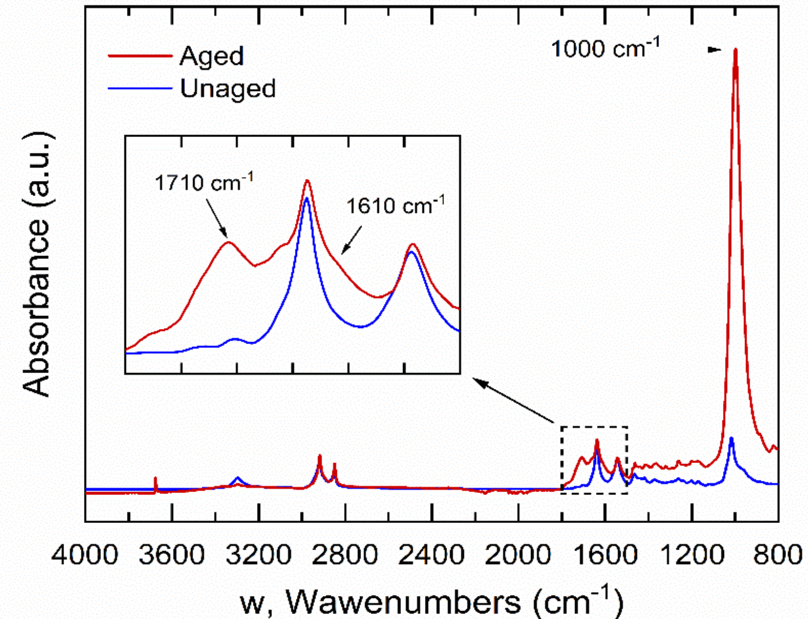
Ulicna et al, "*Failure Analysis of an Improved Polyamide-Based, Fluoropolymer-Free Backsheet After Combined-Accelerated Stress Testing*", 2021

Backsheet Failures: Polyamide

Backsheet Failures:

PA-Ionomer Composite





Cracking of PA-Ionomer composite

Similar increase in 1710cm^{-1} suggests photo-oxidation also occurring in this material.

But NO microcracking like previous backsheets

Suggests improved formulation

Ulicna et al, "*Failure Analysis of an Improved Polyamide-Based, Fluoropolymer-Free Backsheet After Combined-Accelerated Stress Testing*", 2021

Additional Failure Modes/Mechanisms

Modes	Types/issues	Stress factors
Fatigue, breakage	Cell spacing, cell thickness/nature, ribbon dimensions/bends, non-solder distance, solder/ECA quality	Mechanical and thermomechanical stress on conductors. Current leading to joule heating in the conductors
Light-induced Degradation	B-O, Fe-B, sponge LID	Light + temperature
	LeTID	
	UV LID	
Yellowing & optical losses	Photochemical degradation of polymers, ion migration	Light, temperature, humidity, electrical-bias
Backsheet cracking & delamination	Oxidative, photo, hydrolytic reactions, localized stress	Heat, light, voltage, moisture and mechanical stress
Corrosion, cell-front delamination	Oxidative, hydrolytic; electro & photo-catalytic reactions	Heat, humidity, light, system voltage bias, mechanical stress
Potential-Induced Degradation	Polarization, shunting, ion migration, insufficient isolation	Heat, humidity and system voltage bias, modulated by sunlight

Owen-Bellini et al, "*Advancing reliability assessments of photovoltaic modules and materials using combined-accelerated stress testing*", Prog. in Photovoltaics: Research and applications, 2020

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Conclusions

- Detection of new failure mechanisms can be achieved ***before*** deployment through combined-accelerated stress testing

- C-AST could be used as a benchmarking tool for new PV materials

- C-AST is an important research tool, but comes with high capital requirement. C-AST could and should be used to develop more appropriate sequential tests sequences

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Durable Module Materials Consortium

Thank You

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Photovoltaic Reliability Workshop (PVRW) 2021

All Virtual

Registration $30

When: Monday, February 22 – Friday, February 26

Website (for information, will be):

https://www.nrel.gov/pv/pvrw.html

Registration
https://pvrw.nrel.gov/user/register

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