IEEE PVSC (virtual/Florida)
Area 9: Module and System Reliability
Session 9E: Material and Module Durability
Monday, 2021/6/21, 14:15-14:45 (MDT)

BACKFLIP: A Comparison of Emerging Non-Fluoropolymer-Based, Co-Extruded PV Backsheets to Industry-Benchmark Technologies

Comparison of market-benchmark BACKsheet technologies to novel non-FLuoro-based co-extruded materials and their correlation and ImPact on PV module degradation rates (BACKFLIP)

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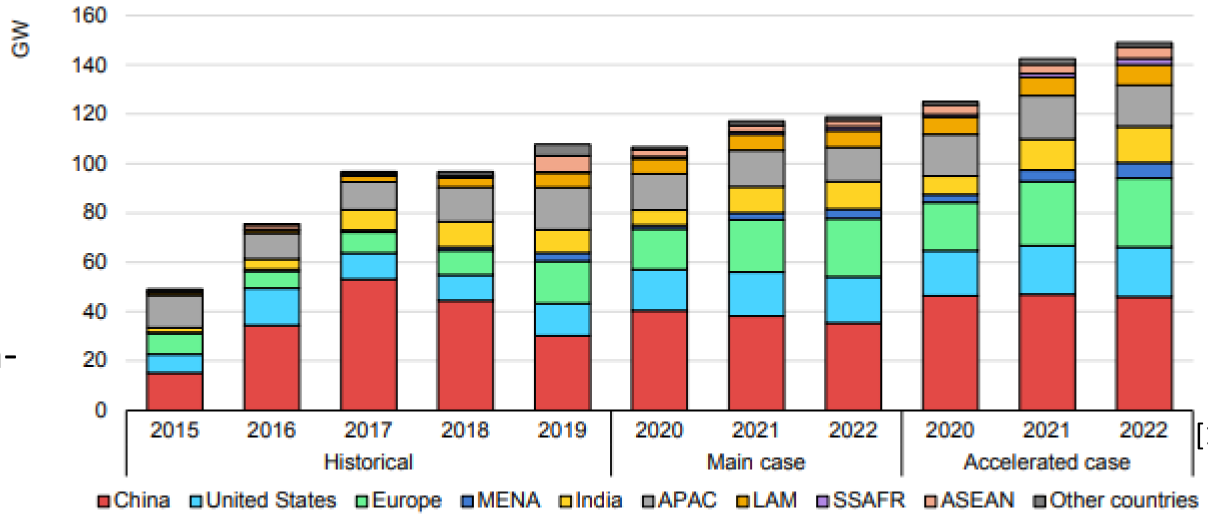
*presenting today

Project Motivation

- Quantifying degradation rate of backsheets will help procuring materials for **30+ years**.
- Today most backsheets on the market have a **PET core**; **polyolefin** materials may provide better properties for backsheets (barrier to water, mechanical properties through UV and hydrolytic environments, etc.)
- End-of-life **regulations may require fluorine-free backsheet** products in future global markets.
- Continued strong market growth is expected enabled by further reduction of the price of solar power ($/kWh) as well as by high-performance, lower-cost materials.
- Societal benefit: products that contain no toxic materials; that preserve precious resources; that can be recycled and have a lower carbon footprint.

~340 Million Solar Panels!!!

Growth of global PV capacity (GW) | 2015-2022



[1]

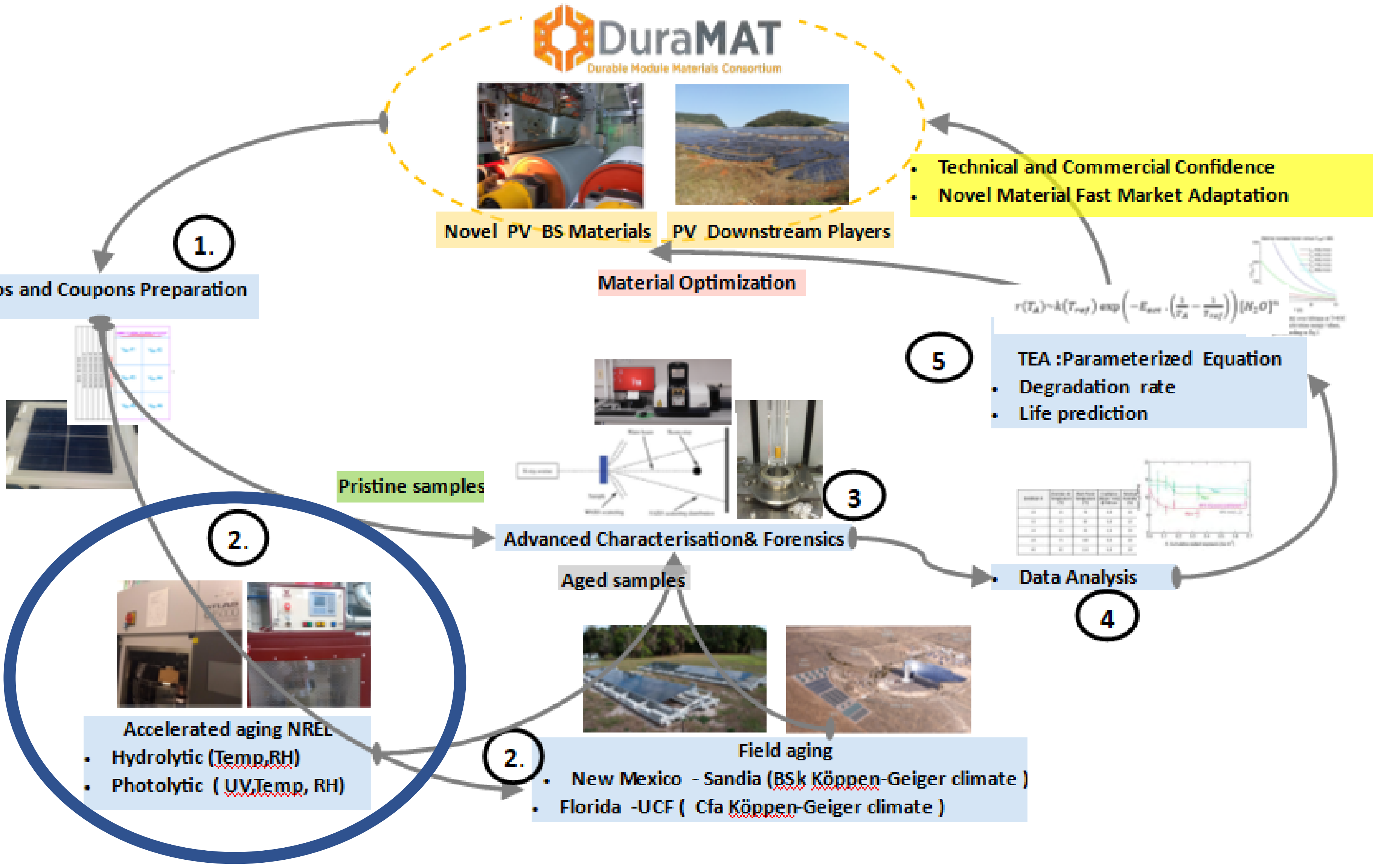
[1] "Solar PV – Renewables 2020 – Analysis," *IEA*. https://www.iea.org/reports/renewables-2020/solar-pv (accessed Apr. 13, 2021).

U.S. DEPARTMENT OF ENERGY · NREL NATIONAL RENEWABLE ENERGY LABORATORY · Sandia National Laboratories · BERKELEY LAB · SLAC NATIONAL ACCELERATOR LABORATORY · DSM

Project Approach

NREL, Sandia, SLAC and DSM Innovations partner to:

- Understand the role of the backsheets on the longevity of modules and their impact on energy yield.
- Study a variety of co-extruded, fluorine-free backsheet materials, and compared to benchmark market backsheets, as-is, artificially-weathered, and when-utilized in a PV module.
- Evaluate the relative rate of degradation of commercial and experimental backsheets.
- Derive parametrized equation that describes degradation rates of backsheets to predict useful life from lab data.



Materials and Test Conditions For the BACKFLIP Study

Arbitrary Index	Backsheet	Construction	Thickness [AVG±2 S.D.] (mm)	Comment
BS-1	PO-1	Coextruded	0.35±0.01	In Development
BS-2	PO-2	Coextruded	0.35±0.02	In Development
BS-3	TPT	Laminate	0.32±0.01	Traditional (reference)
BS-4	APO	Coextruded	0.35±0.01	Recently developed
BS-5	PPE	Laminate	0.36±0.01	Contemporary
BS-6	AAA	Coextruded	0.33±0.02	Known Bad
BS-7	KPf	Laminate	0.29±0.00	Contemporary

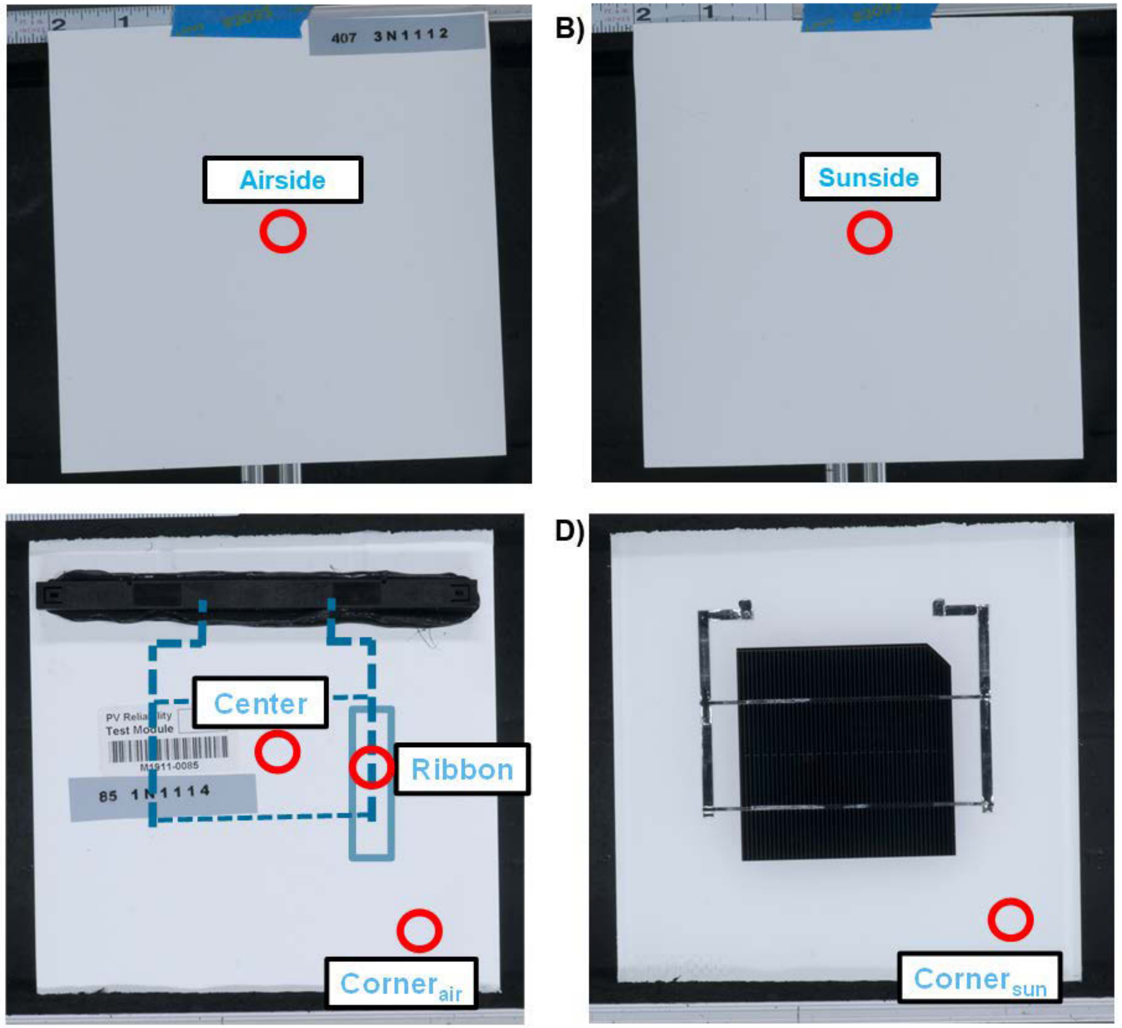
Details of the seven backsheets examined.

Arbitrary Test Index	UV Irradiance ($W \cdot m^{-2}$ at 340 nm)	MiMo Temperature (°C)	Chamber Relative Humidity (%)	Water Spray?
1	0	85	85%	N
2	0	65	85%	N
3	0	45	85%	N
a (A3)	0.80	69	20%	N
b	0.55	59	20%	N
c	0.55	61	~80%	Y
d (A2)	0.80	59	20%	N

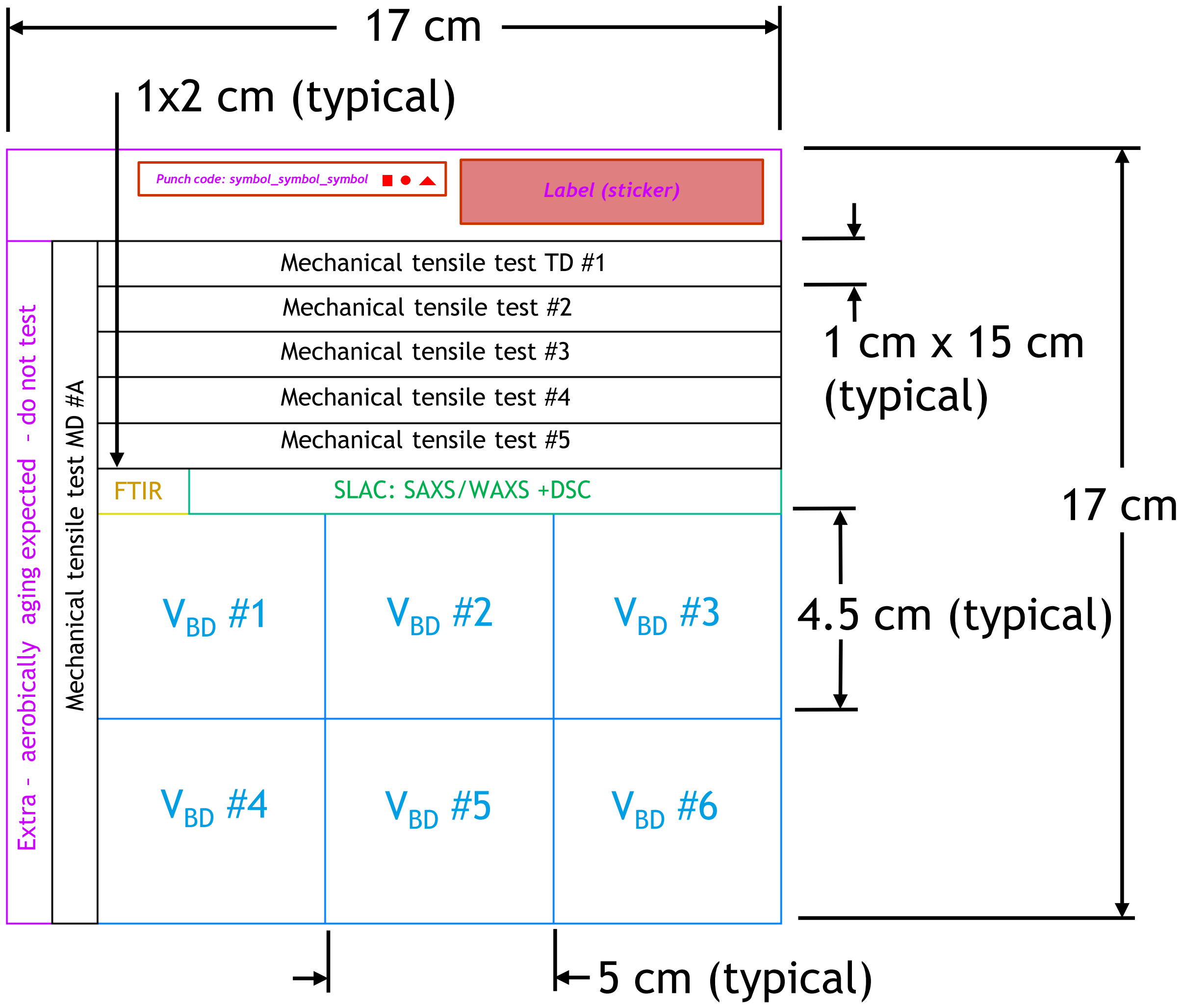
In Progress

Details of the accelerated test conditions for the seven experiments.

Sample Testing Locations

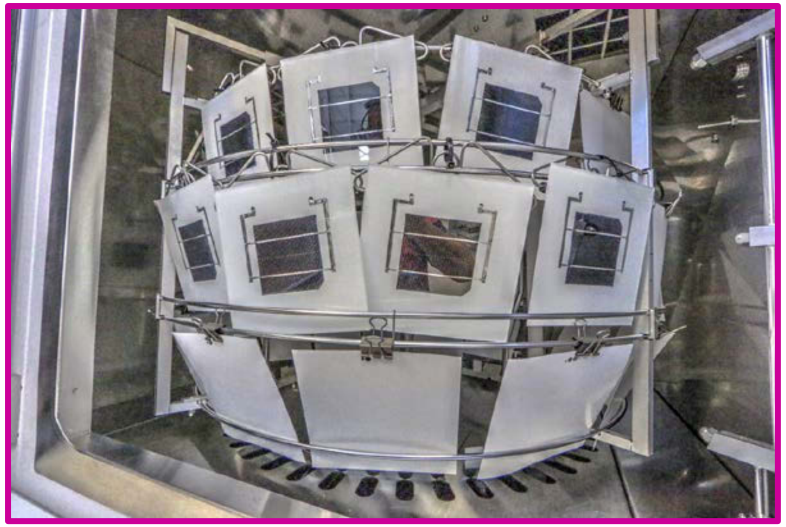


Airside **Sunside**



Artificial Weathering for the BACKFLIP Study

Coupon and MiMo specimens in Xe UV chamber (inside the carousel)



Coupon and MiMo specimens in Xe UV chamber (outside the carousel)

- **UV weathering** performed in high spectral fidelity Atlas "Weather-ometer" Xe lamp chambers.

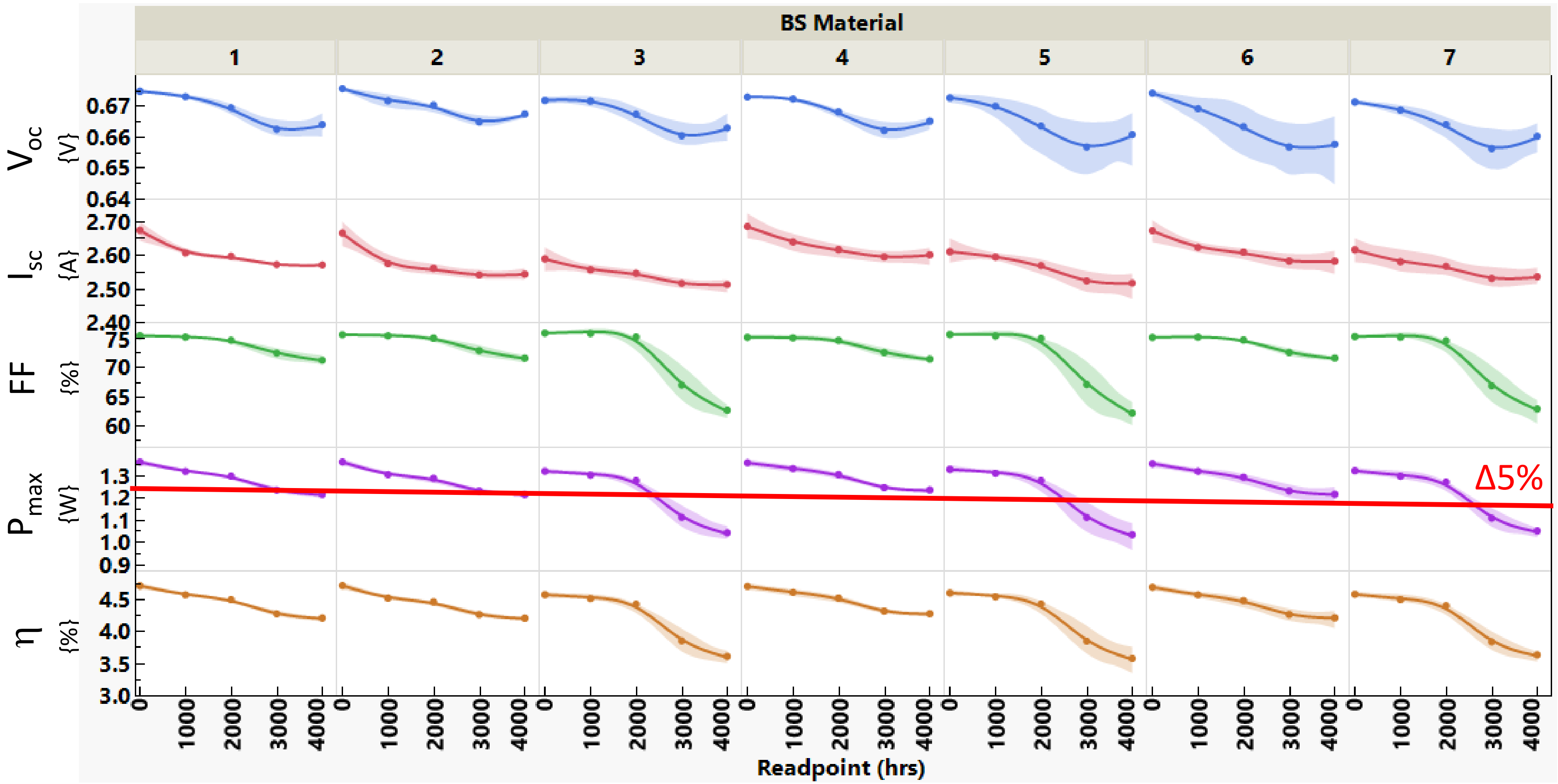
  17 cm MiMo size avoids shading between carousel rows.
  $\Rightarrow$ ¼ cell MiMo's used at NREL.

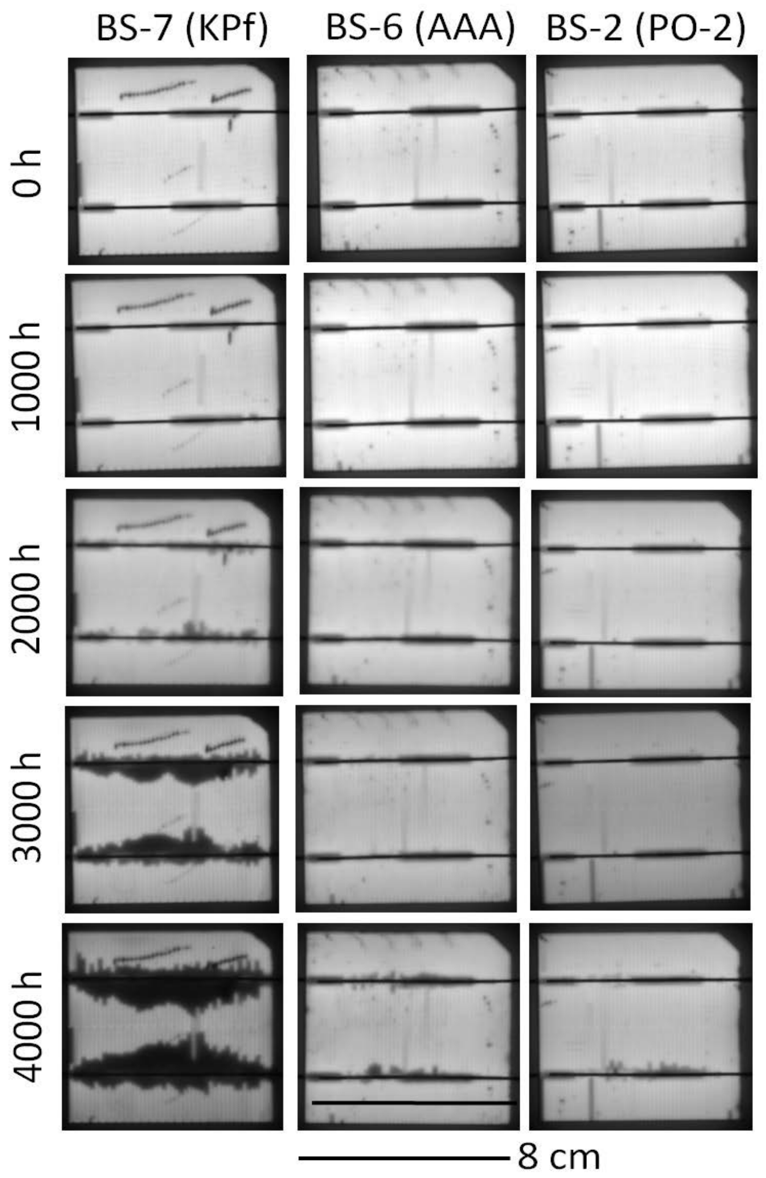
- **Hydrolytic weathering** performed in separate dark chambers.

Coupon and MiMo specimens in hydrolytic chamber

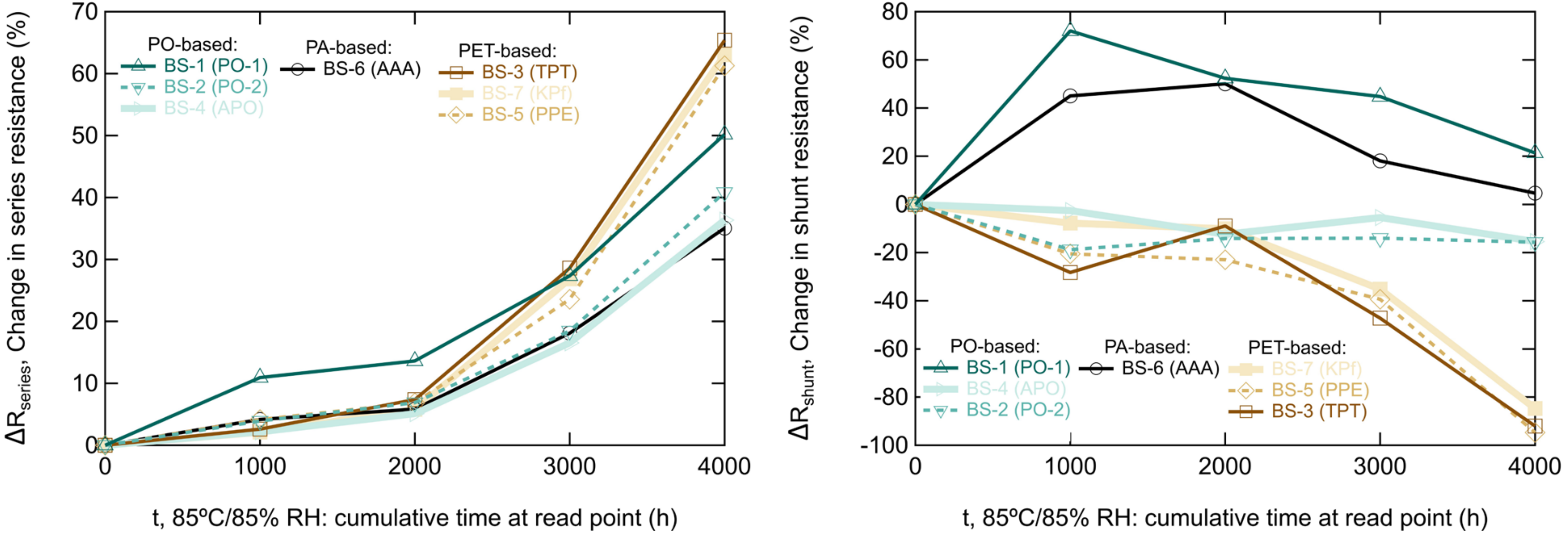
Corrosion of Interconnects Through Damp Heat (85°C/85%RH)

I-V through the 85 °C/85%RH test.

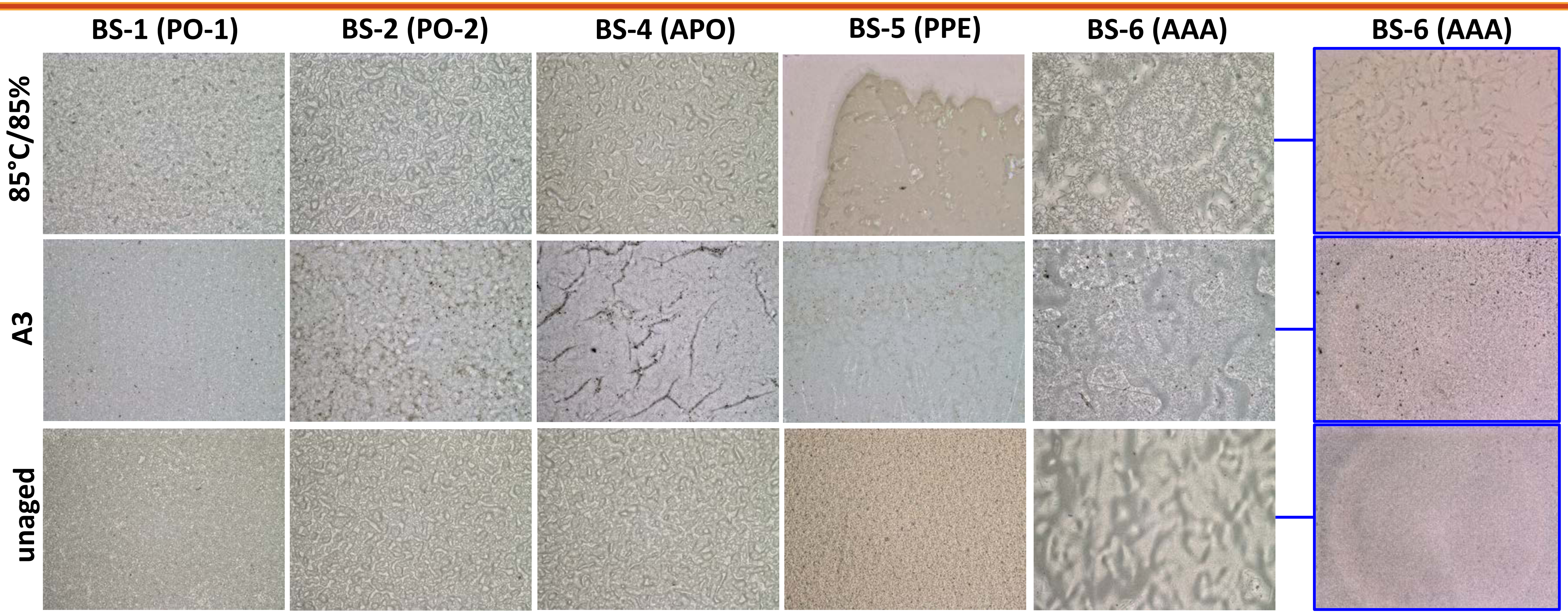




Analyzing the Loss of Power Through Damp Heat (85°C/85%RH)



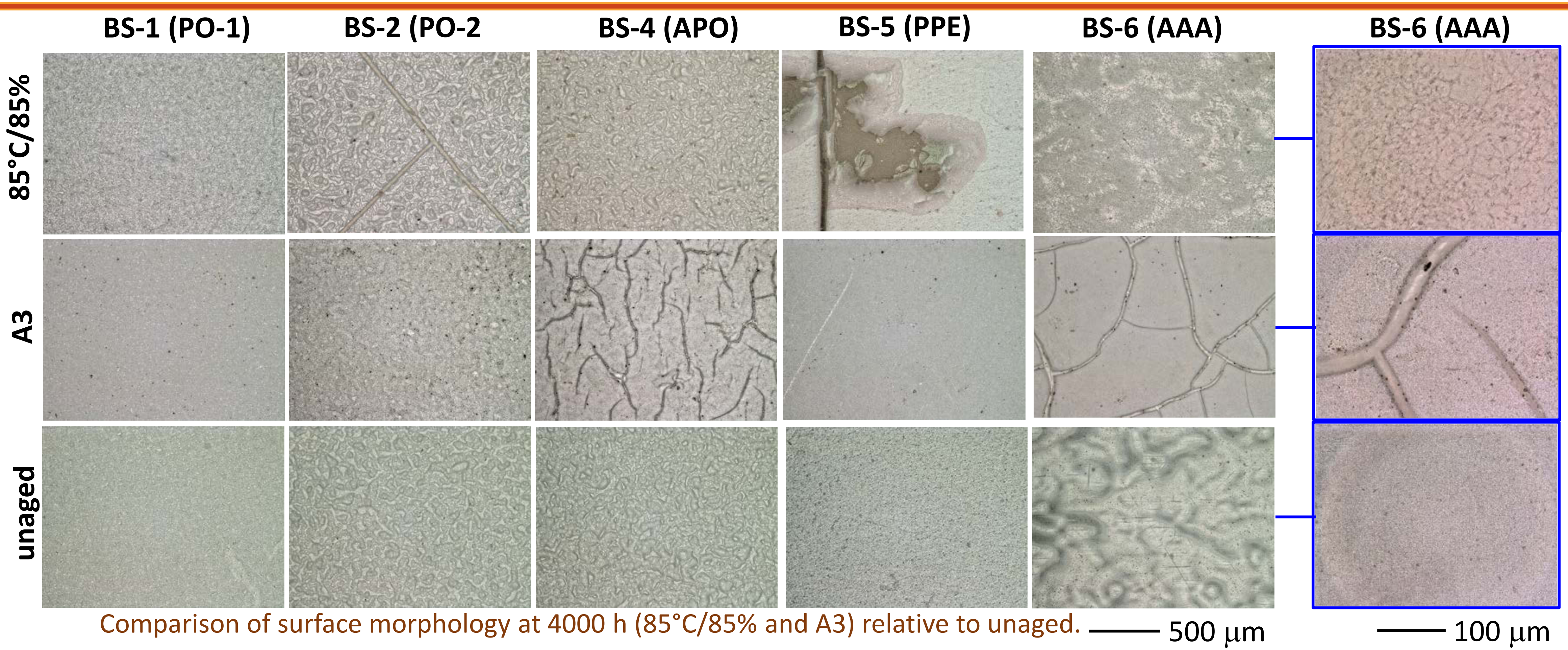
Surface Integrity of Coupon Air Side Surface From Optical Microscopy



Comparison of surface morphology at 4000 h (85°C/85% and A3) relative to unaged.

- Local delamination of surface layer, spalling and cracking of core layer for BS-5 in 85°C/85%. Core probably cracked from handling.
- Micro-cracking of surface layer for BS-4 in A3.
- Incipient micro-cracking of surface layer for BS-6 in 85°C/85%.
- Change in contrast from A3 texture ⇒ roughening of surface for BS-1, BS-2.
- BS-3 and BS-7: no surface damage. ???!!!

Surface Integrity of MiMo Air Side Surface From Optical Microscopy



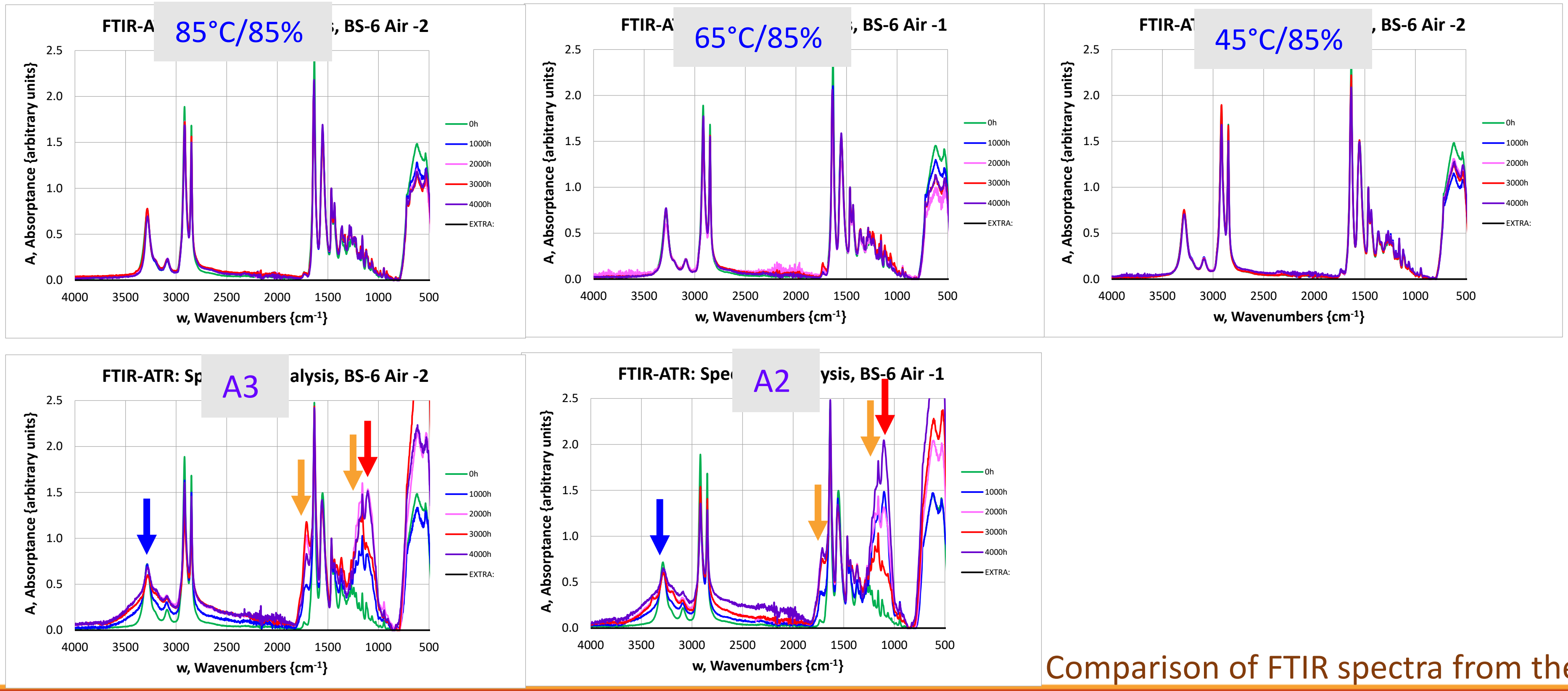
Comparison of surface morphology at 4000 h (85°C/85% and A3) relative to unaged.

In addition to coupon observations:

- Surface scratch (observed all BS's) shown for BS-5.
- Micro-cracking BS-2 in 85°C/85%.
- Micro-cracking of surface layer for BS-6 from A3. No incipient micro-cracking in A3.
- BS-4, BS-6: biaxial mud crack geometry presumably results from added misfit strain in MiMos.

FTIR Confirms Surface Degradation for BS-6 (AAA, Air Side)

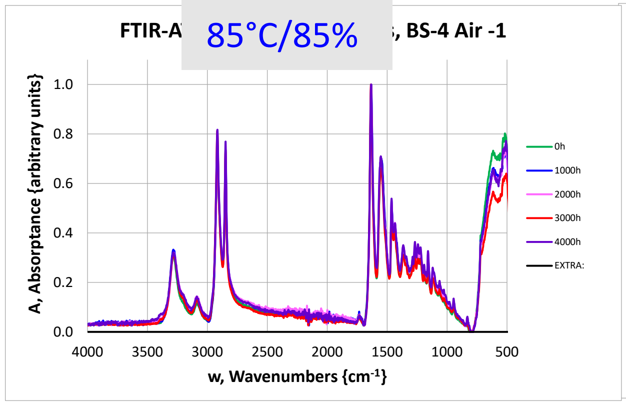
- Spectra changed for UV weathering only… photodegradation:
  - -Peak broadening about 3282, 2912 cm^{-1}. Peak enhancement at 1710, 1159 cm^{-1}. New peak at 1102 cm^{-1}.
- No changes observed from hygrometric weathering (incipient micro-cracking observed in microscopy).
  - -Second thermal degradation mechanism (by chain scission)?
  - -Roughening of surface, facilitating cracking?

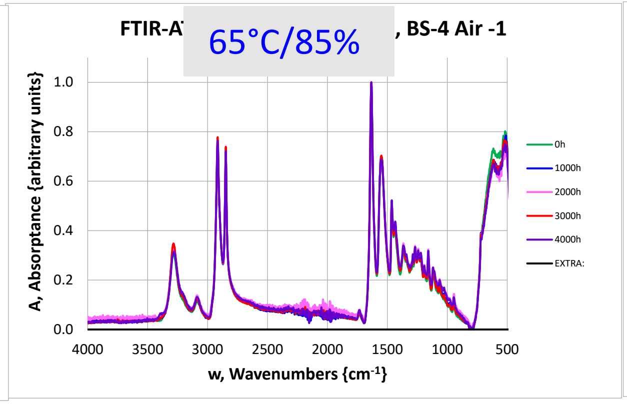


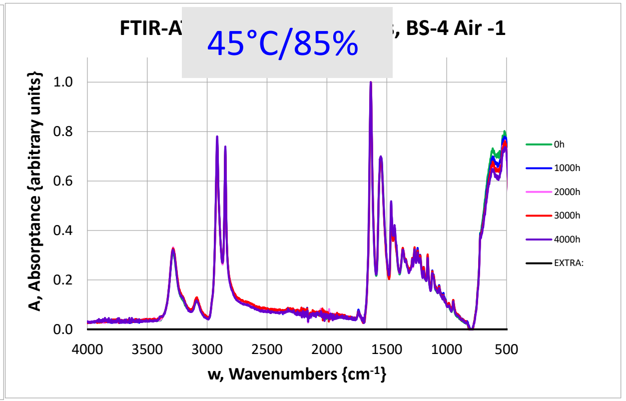
Comparison of FTIR spectra from the 5 completed experiments.

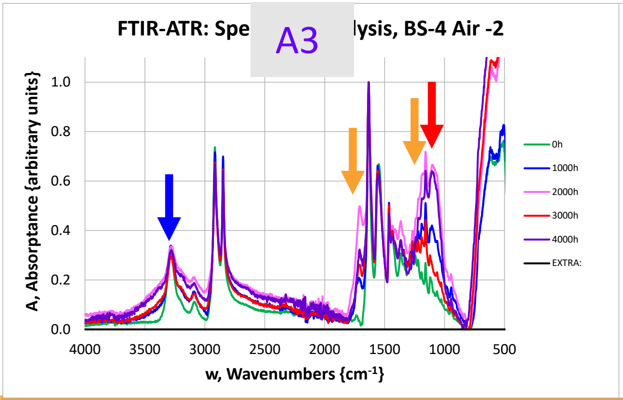
FTIR Confirms Surface Degradation for BS-4 (APO, Air Side)

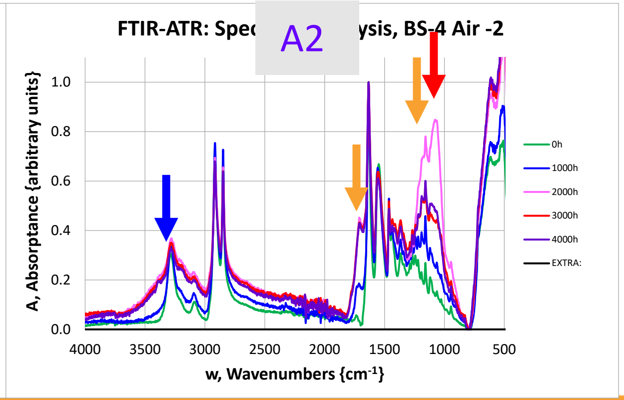
- Spectra changed for UV weathering only… photodegradation:
  - -Peak broadening about 3280, 2914 cm^{-1}. Peak enhancement at 1708, 1157 cm^{-1}. New peak at 1080 cm^{-1}.
  - -UV damage occurs with micro-scale mud cracking observed in optical microscopy.
- BS-6 and BS-4 use PA layers.







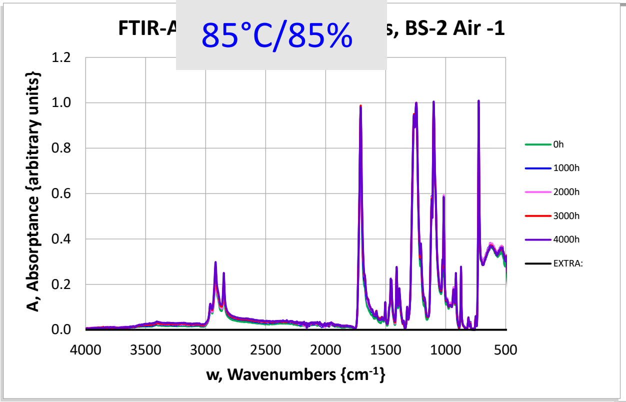


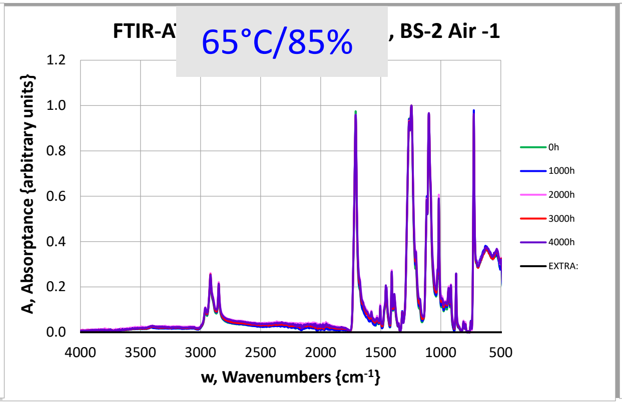


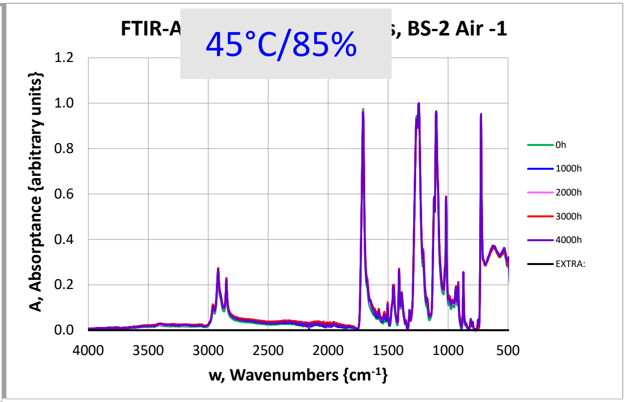
Comparison of FTIR spectra from the 5 completed experiments.

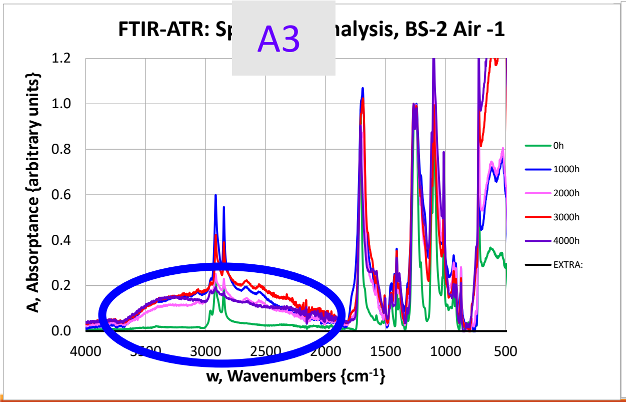
FTIR Confirms Surface Degradation for BS-2 (PO-2, Air Side)

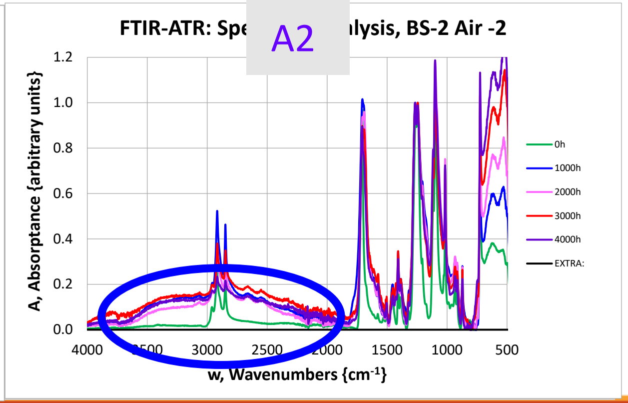
- Spectra changed for UV weathering only… photodegradation:
  - -Peak broadening about 2914, 2847 cm^{-1}.
  - -UV damage occurs with micro-scale surface roughening in optical microscopy.
- No indication of hygrometric degradation, despite camera & microscope observation of surface cracking.







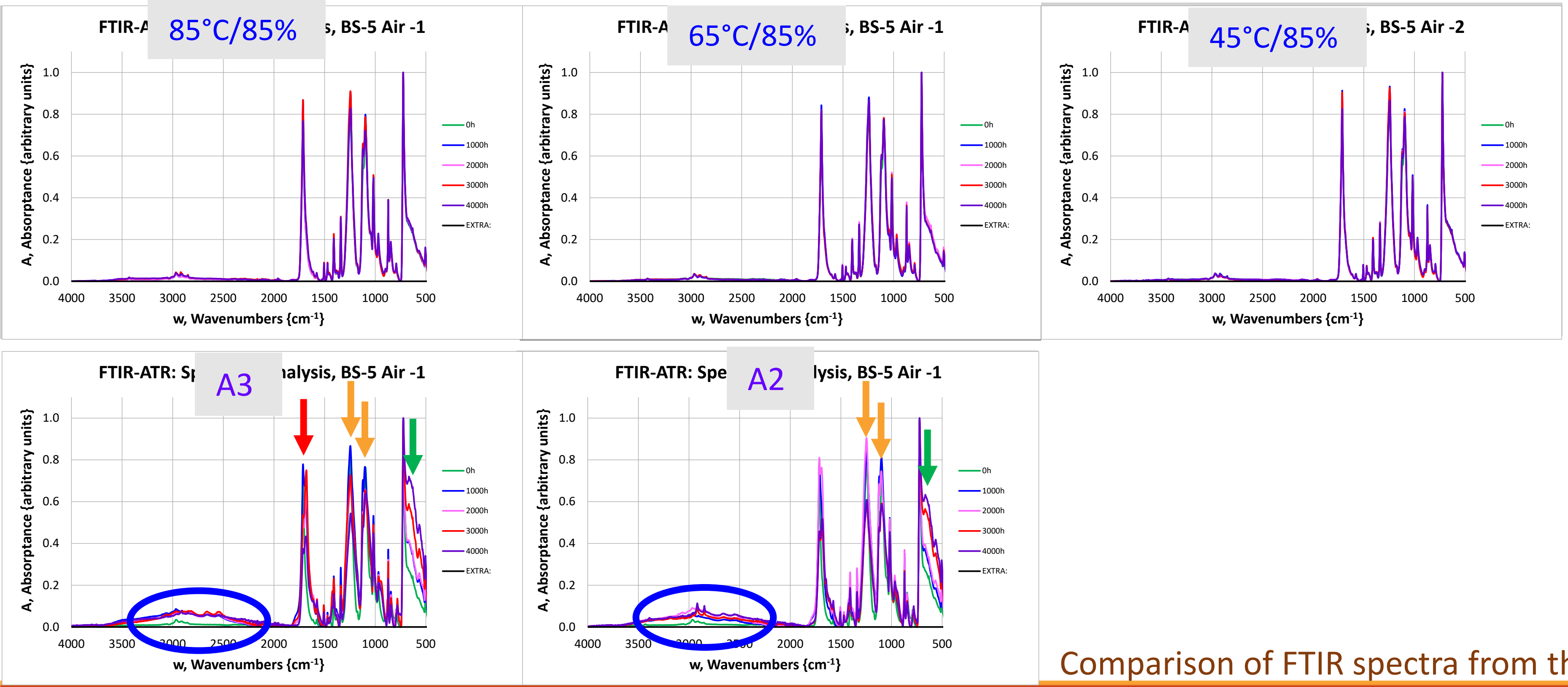




Comparison of FTIR spectra from the 5 completed experiments.

FTIR Confirms Surface Degradation for BS-5 (PPE, Air Side)

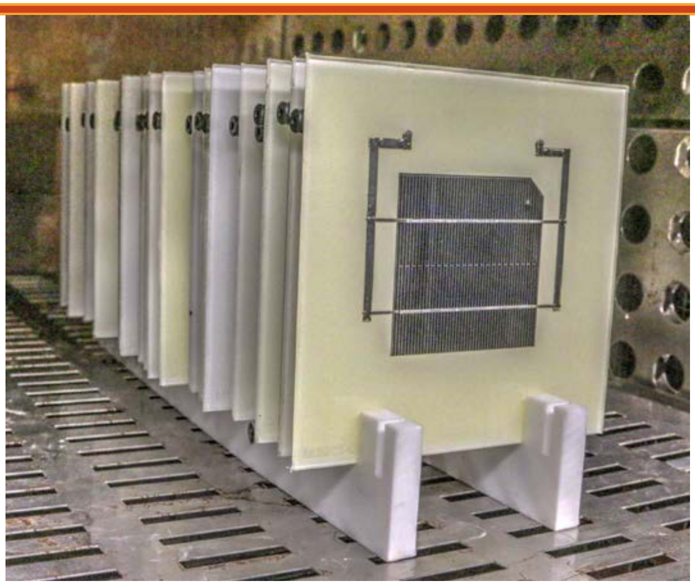
- Spectra changed for UV weathering only… photodegradation:
  - -Broadening of 2914, 2845, 2653, 2539 cm^{-1} peak region.
  - -Shift from 1711 to 1677 cm^{-1}.
  - -Loss of intensity at 1237, 1092 cm^{-1}. Increased intensity at 667 cm^{-1}.
  - -UV damage occurs with embrittlement, spalling, delamination of surface layer in optical microscopy.
- FTIR examines surface only, no information related to the core layer. Sample depth ~2 μm for ATR crystal.



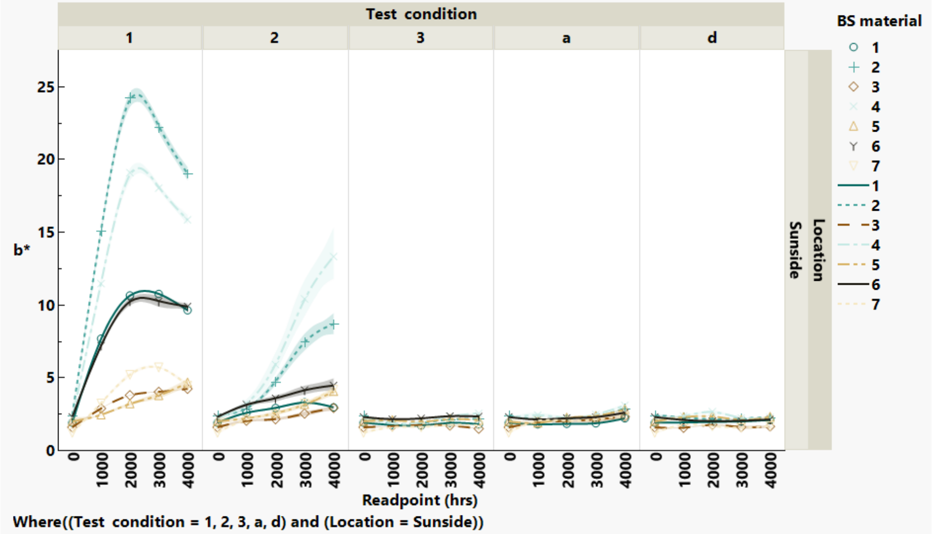
Comparison of FTIR spectra from the 5 completed experiments.

Background: MiMo Discoloration in the BACKFLIP Study

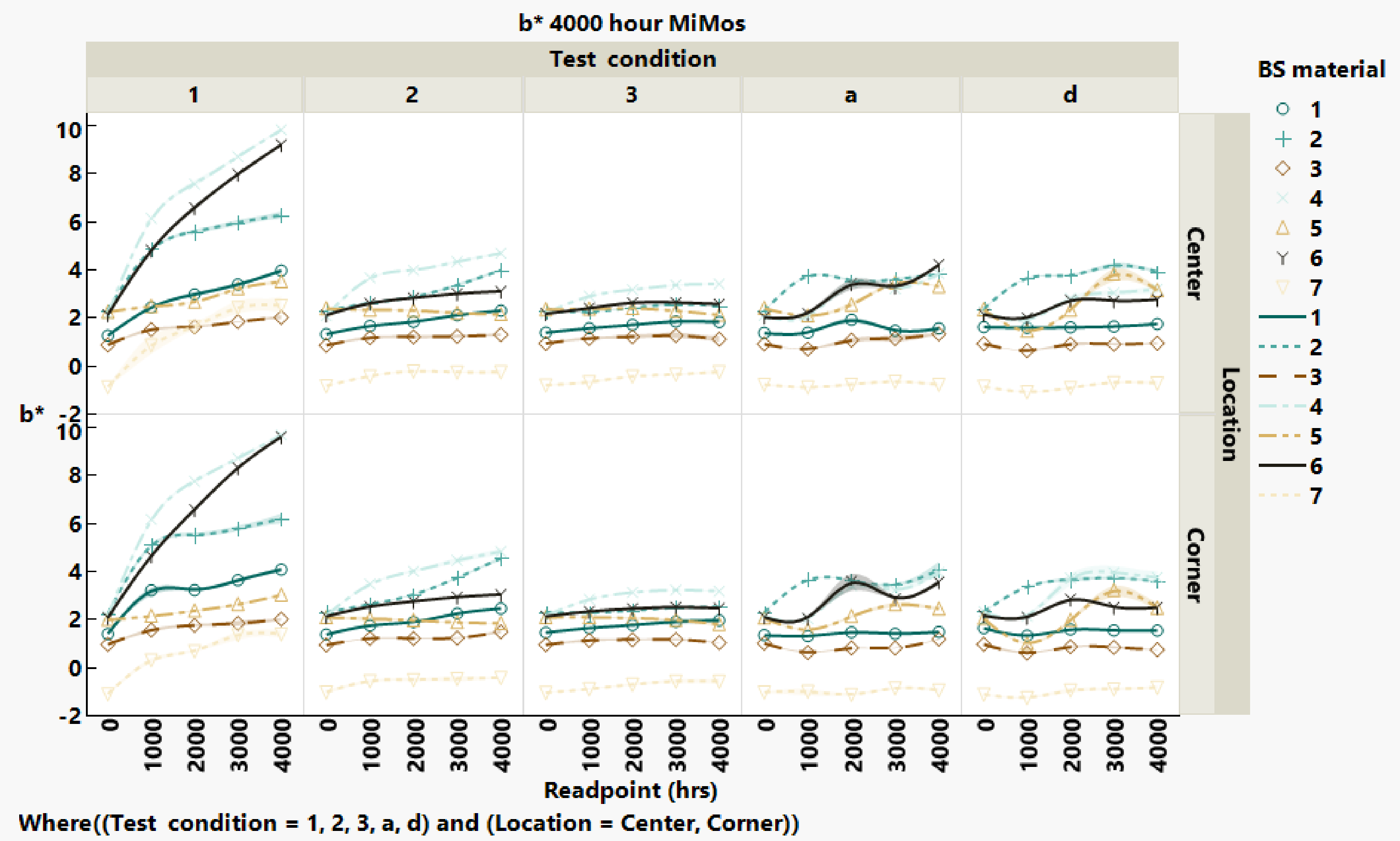
-Overt discoloration observed early (~300h) in experiment 1: 85°C/85%.
-Suspect interaction between EVA/backsheet or EVA/E-layer on backsheet.



MiMo appearance early in Damp Heat experiment.

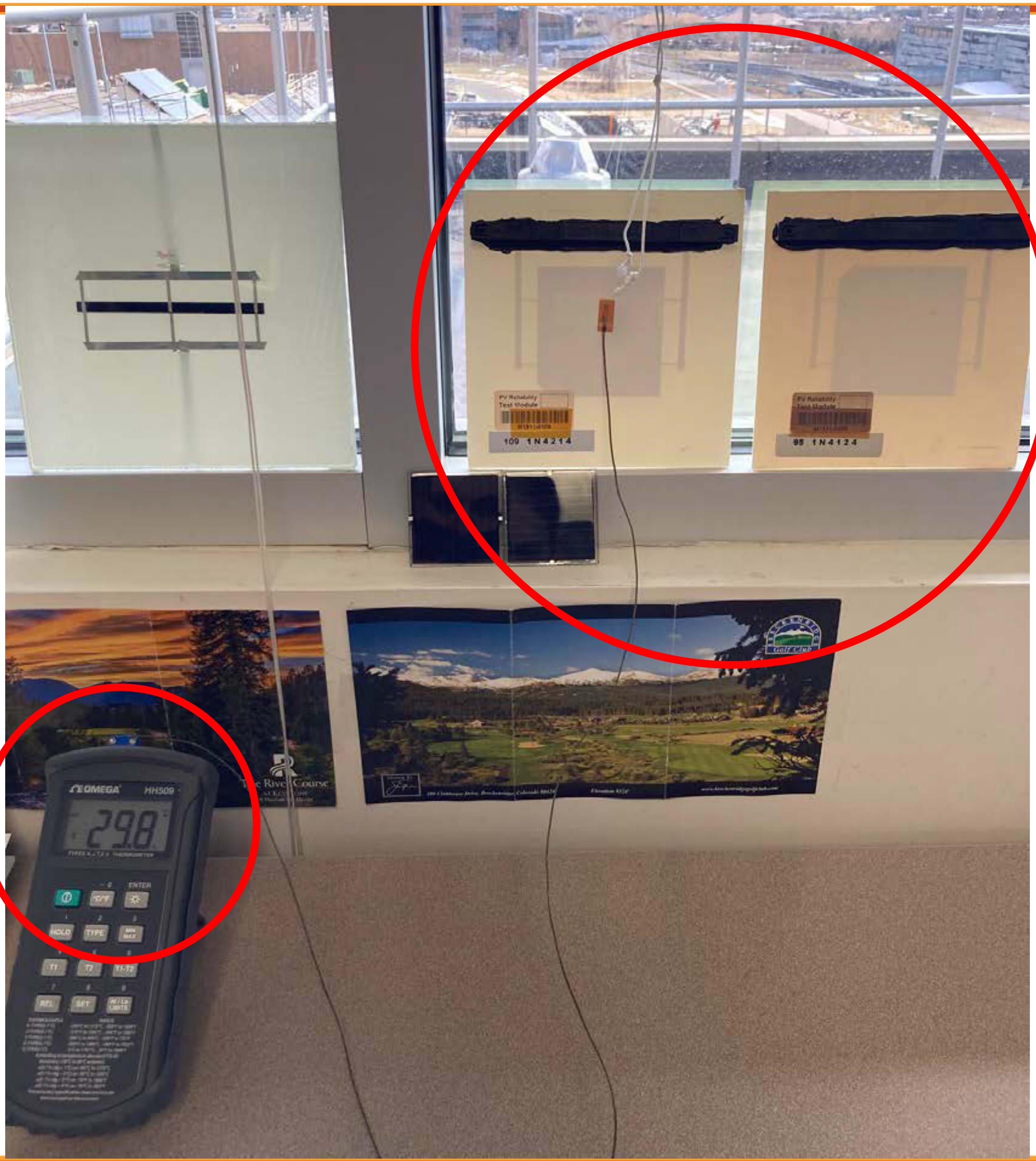


Comparison of b* (yellow-blue) for MiMo *sun side*.



Comparison of b* (yellow-blue) for MiMo *air side*, center and corner.

Experiment: Can Light Facilitate Photobleaching of BS-4 (APO)?



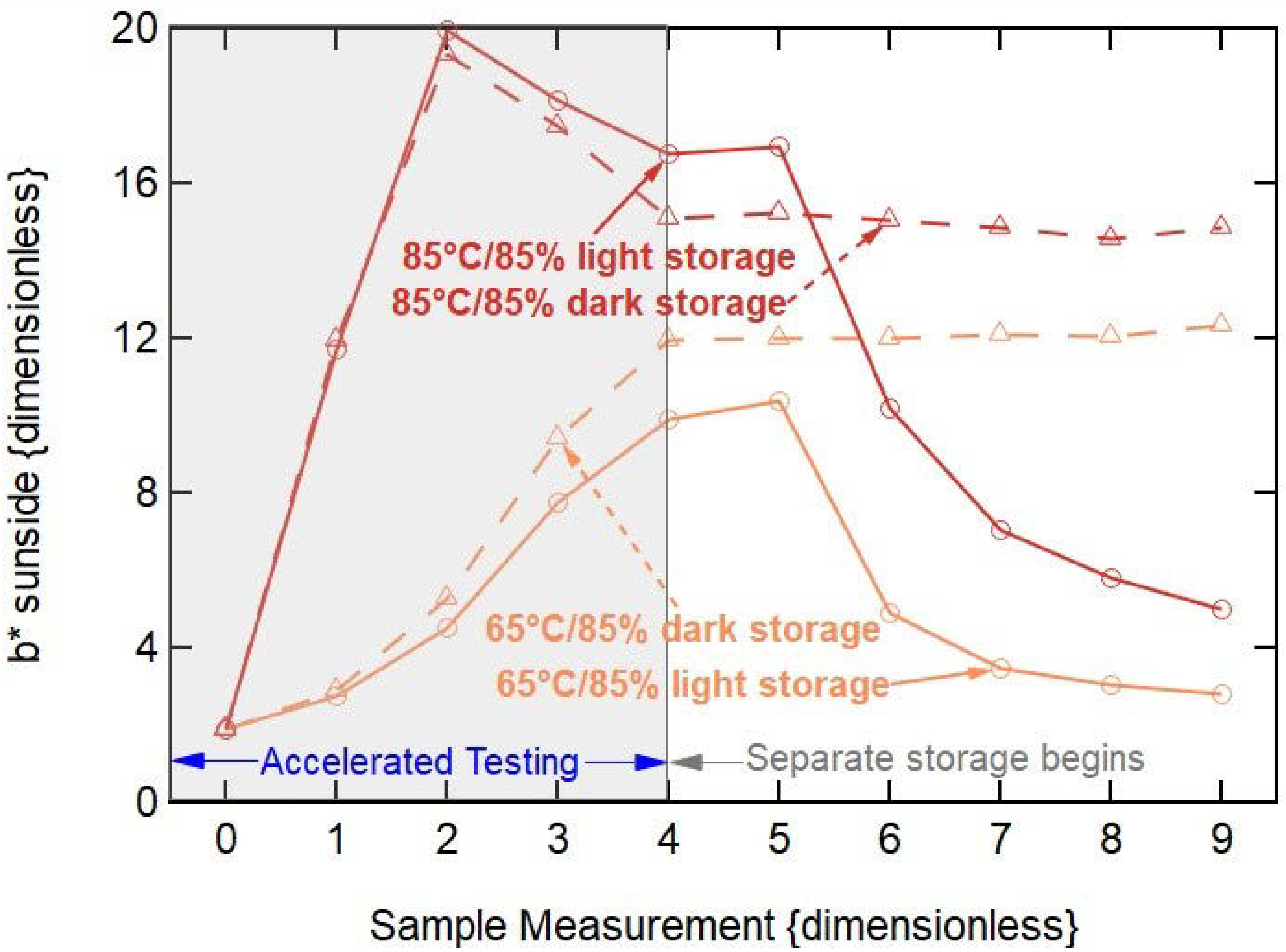
1 MiMo from 85 °C/85% and 65 °C/85% facing sun side out.

-Samples facing east. Direct light < 4 h·d^{-1} (CO mornings typically sunny).

-Indoor location: T_{max} 41 °C observed ~ 10 am.

Intermittent monitoring of the temperature

Evolution of b*, BS-4 (APO) Sun Side Through Darkness and Light



- Substantial photobleaching observed after accelerated testing.
- Both 85 °C/85% and 65 °C/85% affected.
- How close will final b* approach initial color?

Surface and Bulk Damage Identified, But Not (?Yet?) Connected

Bulk characterizations distinguish BS-3, -5, -7.

- Suspect damage mechanism of hydrolysis (of PET core).
- Degradation affects PV performance.

Surface characterizations distinguish BS-1 -2, -4, -6.

- **Suspect surface damage mechanism of UV photo-scission**.
- Surface damage may enable bulk damage in a longer duration accelerated test. TBD.
- **Safety concerns may arise for surface damage.**

Arbitrary Index	Backsheet
BS-1	PO-1
BS-2	PO-2
BS-3	TPT
BS-4	APO
BS-5	PPE
BS-6	AAA
BS-7	KPf

CHARACTERIZATION METHOD	BS's AFFECTED (material(s))	SPECIMEN GEOMETRY	EXPERIMENT(S)	NOTE
DSC	3, 5, 7	coupon	A2, A3, 85C/85%	
I-V	3, 5, 7 (PET-based)	MiMo	85°C/85% RH	
EL	3, 5, 7 (PET-based)	MiMo	85°C/85% RH	
camera	1, 2, 4, 6 (non-PET)	MiMo	85°C/85% RH	discoloration
camera	5 (PPE)	coupon (sun side)	85°C/85% RH	macro-cracking
microscope	5 (PPE)	coupon (air side)	85°C/85% RH	micro-cracking
microscope	4, 6 (PA-based)	coupon (air side)	A2, A3	micro-cracking
microscope	5 (PPE)	MiMo (air side)	85°C/85% RH	micro-cracking
microscope	2, 4, 6 (non-PET)	MiMo (air side)	A2, A3	micro-cracking
FTIR	2, 4, 5, 6	coupon (air side)	A2, A3	
b*	1, 2, 4, 6 (non-PET)	MiMo	65C/85%, 85C/85%	discoloration

Implications

- Accelerated tests need to invoke relevant damage (probably not just DH or A3). Consider sequences, transient, & combined tests.
- **Characterizations need to verify all essential aspects of concern** (performance, not just cracking or discoloration).
- **Surface & bulk degradation: Do they always correlate? What is the resiliency of core layers, other than PET?**

See also, on materials characterization in this study:
Uličná et. al., IEEE PVSC, 2021/6/23 at 13:15 EDT
in area 5C: ADVANCED CHARACTERIZATION OF PV MATERIALS AND DEVICES

Acknowledgements

The authors would like to thank BACKFLIP contributors including:

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Note: DSM Advanced Solar B.V. is now Endurans Solar Solutions B.V.

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If you have interest in UV weathering, see PVQAT TG5, e.g. https://www.pvqat.org/project-status/task-group-5.html

Any questions that we do not get to? Reach out to us:

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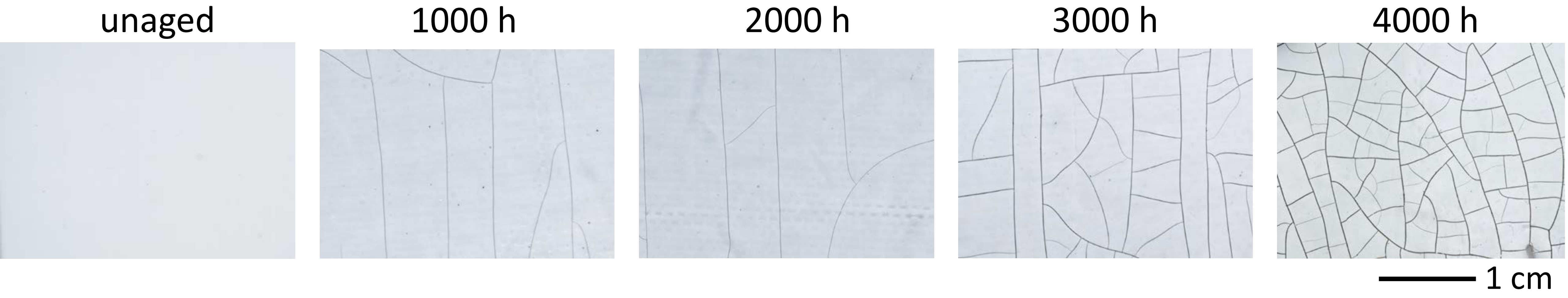
NREL/PR-5K00-80362

Cracking of the BS-5 (PPE, Coupons Only) Sun Side



•Camera photos: macro-cracking of BS-5 coupons on sun side.
•Observed through A3, A2 experiments.
-Also observed in auxiliary (“Type-5”) coupons (laminated backsheet and encapsulant) in A3.
•No cracking of BS-5 coupons in hygrometric weathering or in BS-5 MiMos.
•Added mechanical constraint of layers in MiMo likely prevents cracking.
•Unlikely that transfer of additives prevents cracking here (as observed in auxiliary coupons).

(Supplemental Material/Reference)