DuraMAT

Durable Module Materials Consortium

# Understanding Polymer Material Properties for PV Module Reliability


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DuraMAT Webinar May 2021

Energy Materials Network

U.S. Department of Energy

NREL

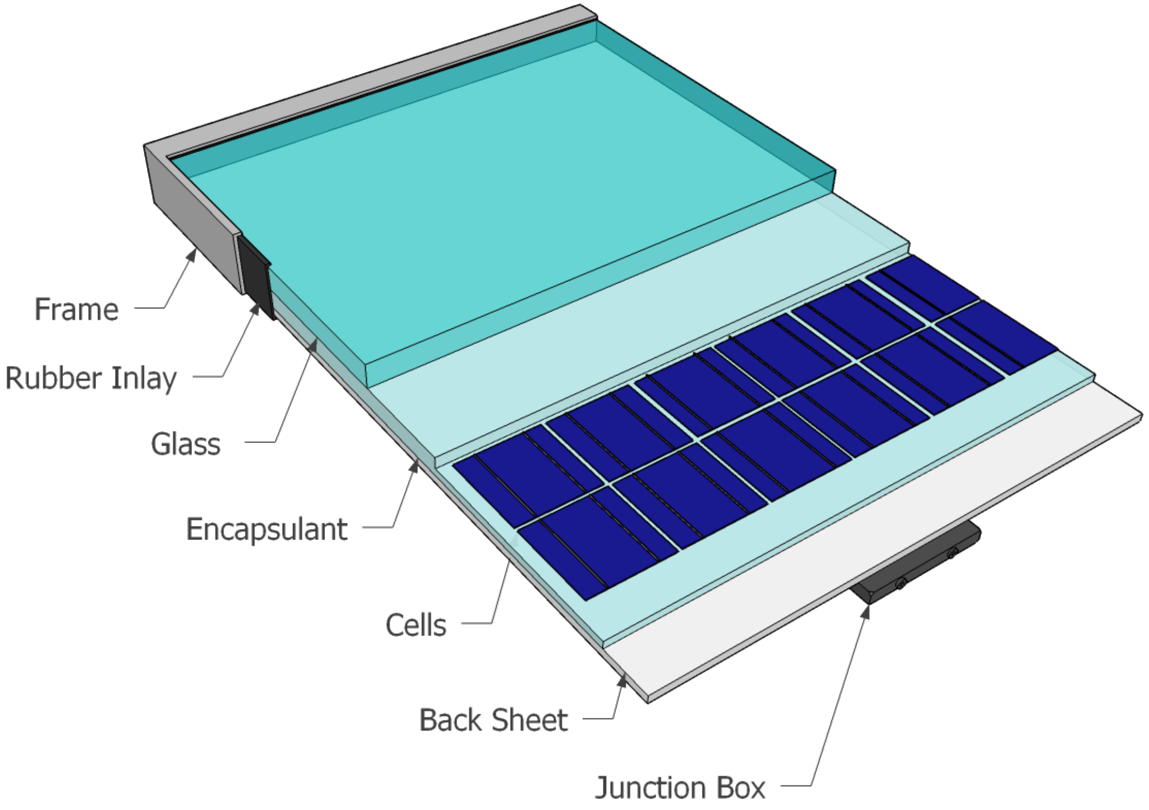
Sandia National Laboratories

BERKELEY LAB

SLAC NATIONAL ACCELERATOR LABORATORY

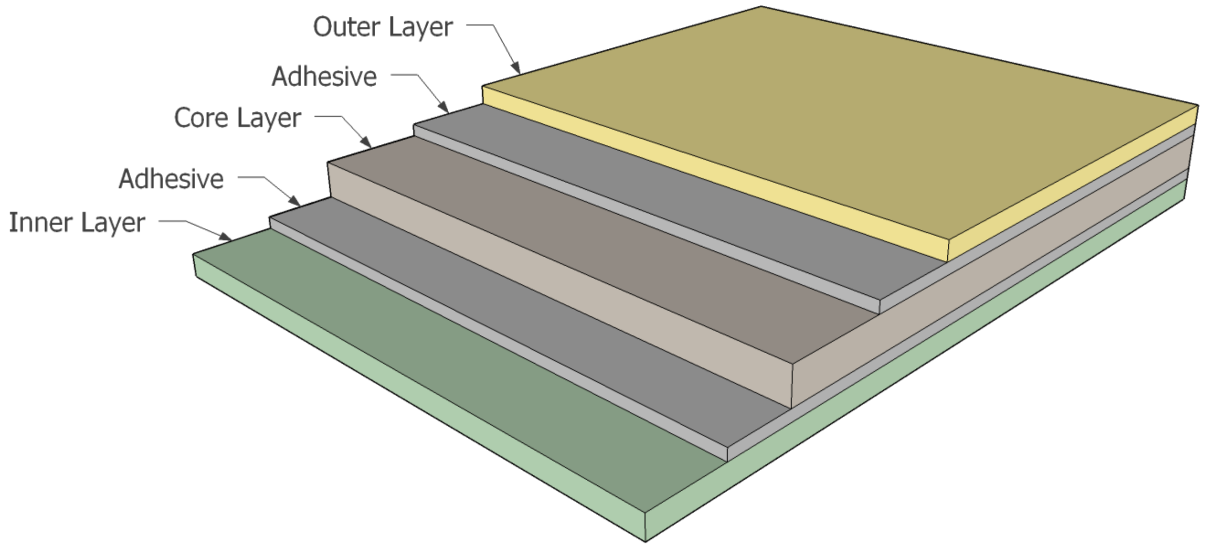
# PV Backsheets

### Typical PV Module Structure




### Typical Multilayer Backsheet Structure

(Typically multi-layered systems, but monolayer backsheets do exist)



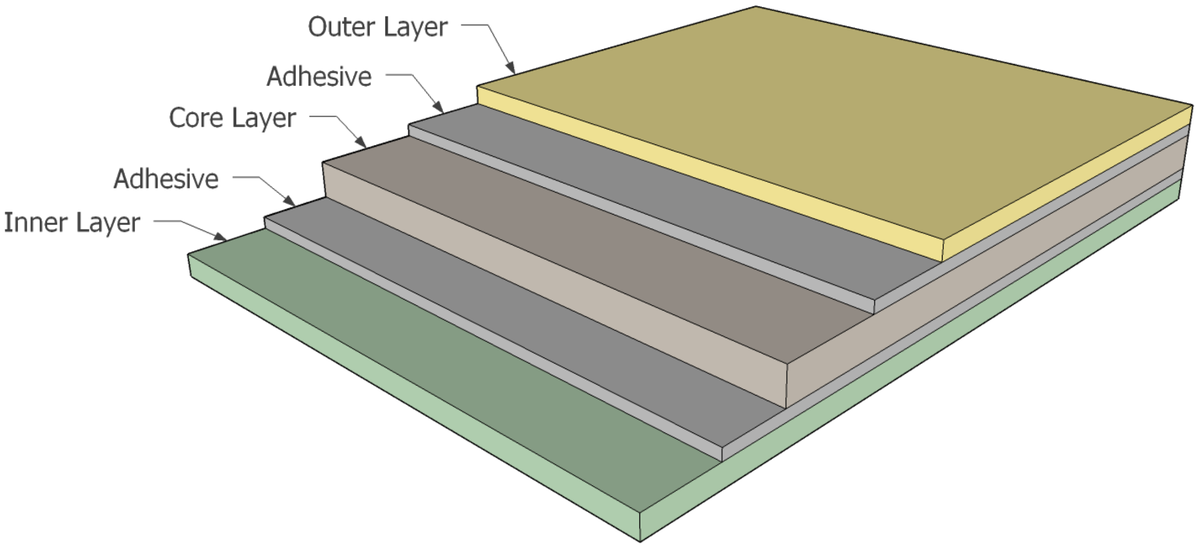

**Primary function is to provide electrical isolation for safe operation**

# PV Backsheets: Key Properties

| Key Properties |
| --- |
| Moisture Barrier |
| Heat Stability |
| UV Resistance |
| Erosion Resistance |
| Mechanical Stability |
| Dielectric Strength |

**Typical Multilayer Backsheet Structure**

(Typically multi-layered systems, but monolayer backsheets do exist)



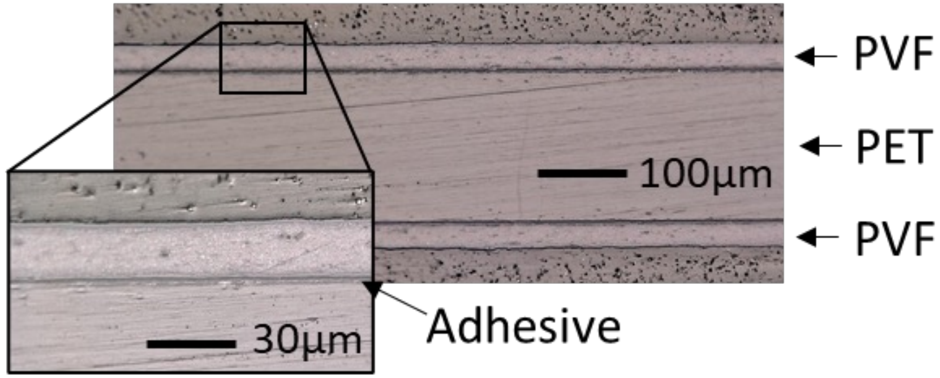

**A compromised backsheet can present a serious safety hazard**

**Accelerates other degradation modes e.g. corrosion**

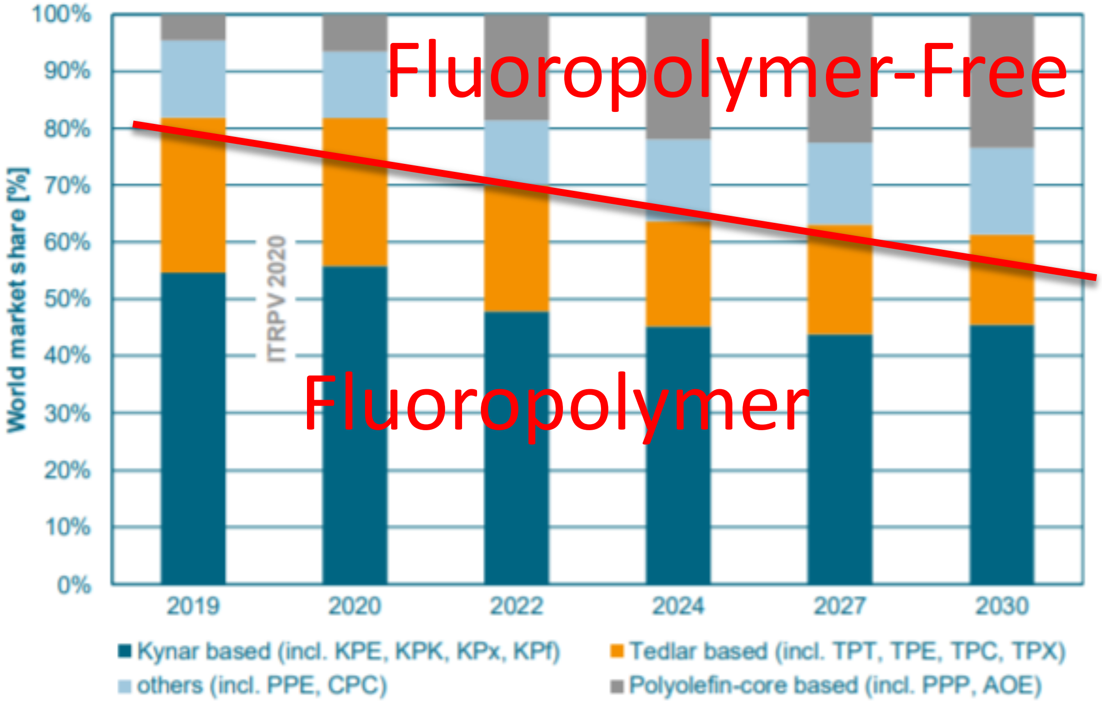
# Fluoropolymer Backsheets

- Historically, backsheets have largely been fluoropolymer-based
  - Polyvinyl Fluoride (PVF)
  - Polyvinylidene Fluoride (PVDF)
  - Usually with a Polyethylene terephthalate (PET) core

Micrograph for PVF/PET/PVF



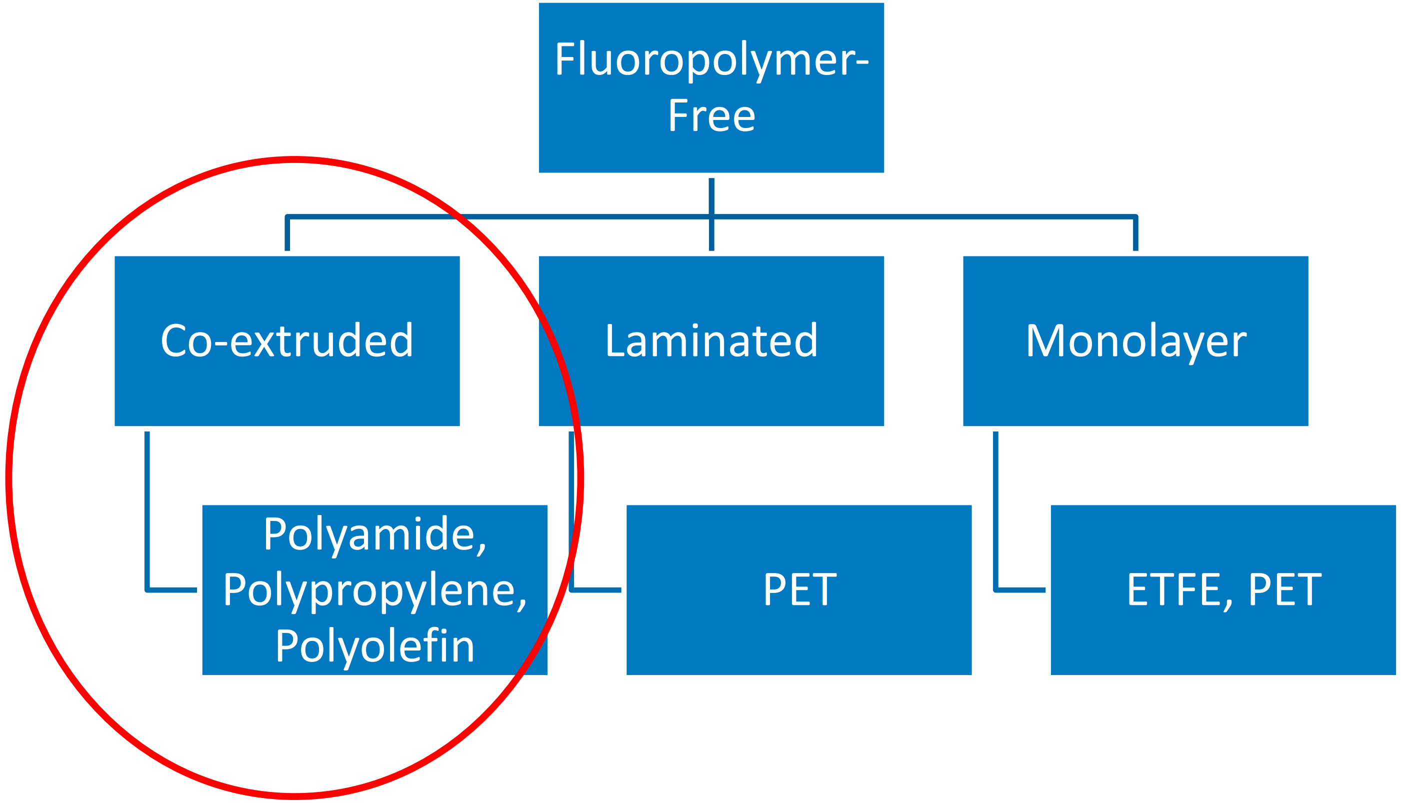

**An Overview of Backsheet Materials for Photovoltaic Modules**
**DuraMAT Webinar May 2020**




VDMA – ITRPV, 2020

# Fluoropolymer-free Backsheets

- Largely driven by cost reduction. Can be replaced with less expensive materials
- Enables a reduction in processing costs through co-extrusion or coatings
- Easier End-of-life handling*




*Aryan et al, A comparative life cycle assessment of end-of-life treatment pathways for photovoltaic backsheets, *Prog. in PV,* 2018

# Co-Extruded Backsheets

AAA: PA-based, coextruded backsheet introduced in 2010

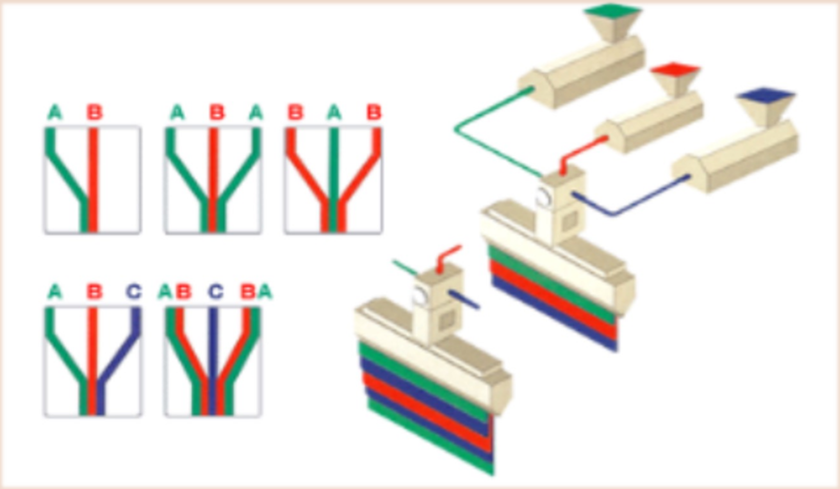
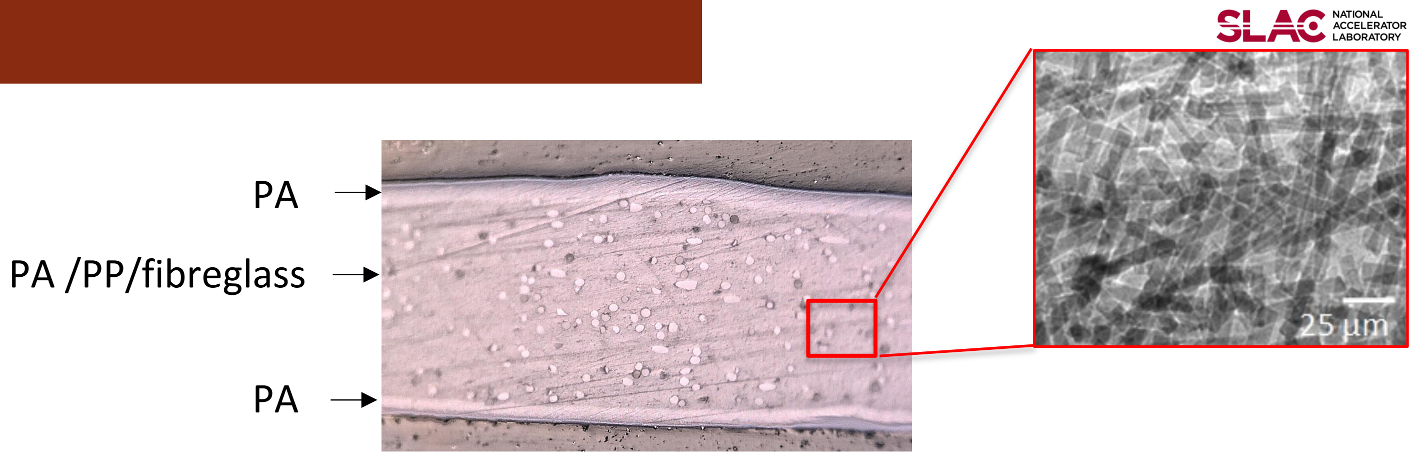



Illustration of the co-extrusion process*

Benefits of co-extrusion:

- Eliminates lamination step
- Eliminates need for adhesive
- Reduces delamination between layers
- Easier material modification (additives. fillers etc)



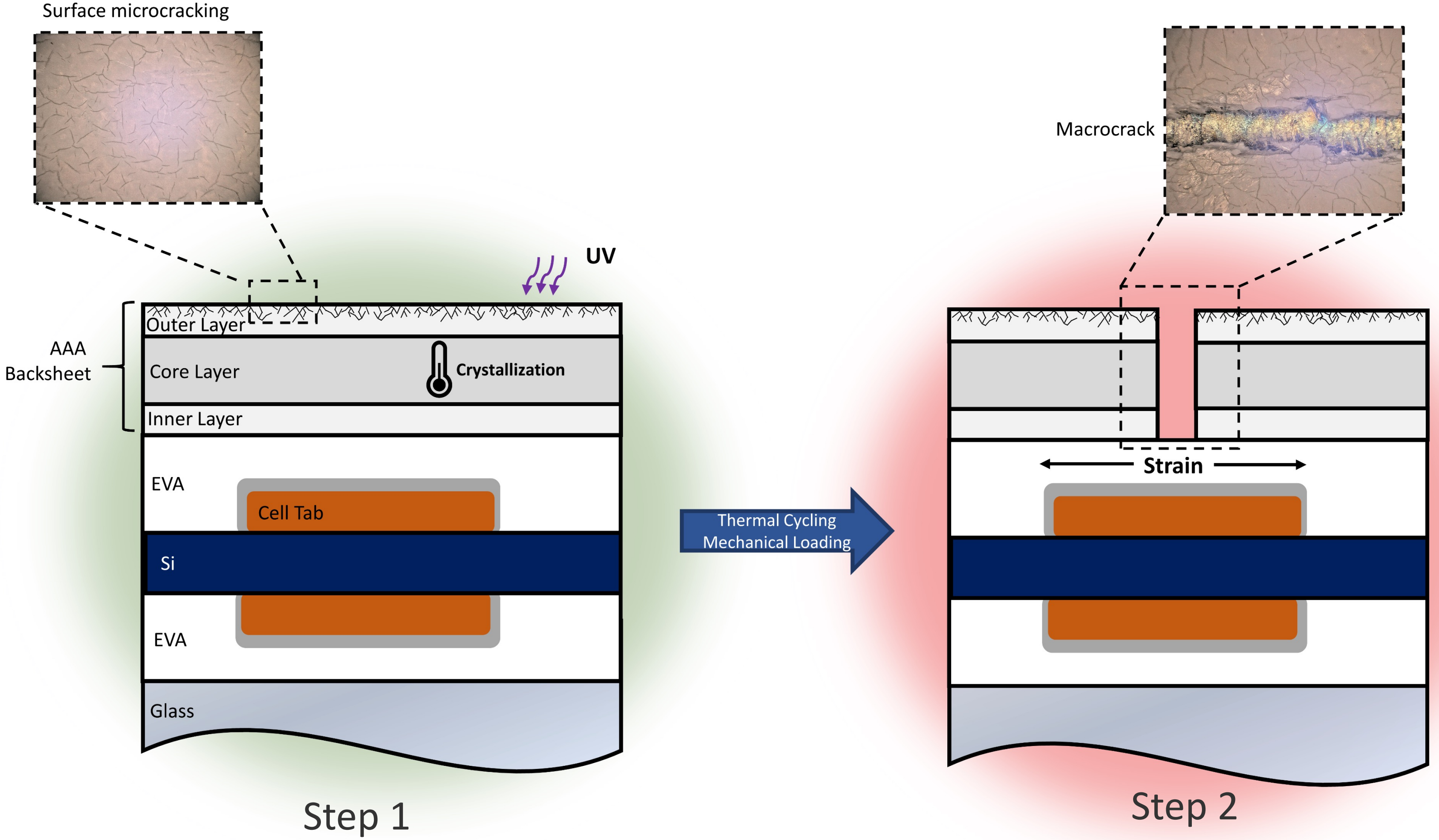

*C. Thellen et al.: "Co-extrusion of a novel multilayer photovoltaic backsheet based on polyamide-ionomer alloy skin layers" in PVSEC, Amsterdam 2017

# Co-Extruded Backsheets: AAA

Failure is a 2-step process:

Step 1: Microcracking / fracturing of the outer layer due to photo-oxidation and crystallization of the polypropylene

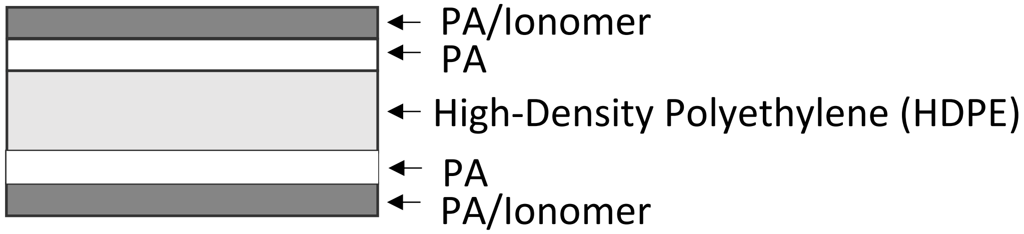
Step 2: Macrocracking, or through cracking, due to thermomechanical/mechanical strain




Owen-Bellini, M., Moffitt, S.L., Sinha, A. et al. Towards validation of combined-accelerated stress testing through failure analysis of polyamide-based photovoltaic backsheets. *Sci Rep* 11, 2019 (2021).

# Co-extruded Backsheets: Photomark Reflections

Photomark Reflections – 255 (“PMR”)




- PA/Ionomer blended outer layers
- PA intermediate layers
- High-Density Polyethylene Core layer
- $TiO_2$ white pigment or carbon black pigment
- Talc filler for dimensional stability
- Co-extruded


TOMARK WORTHEN

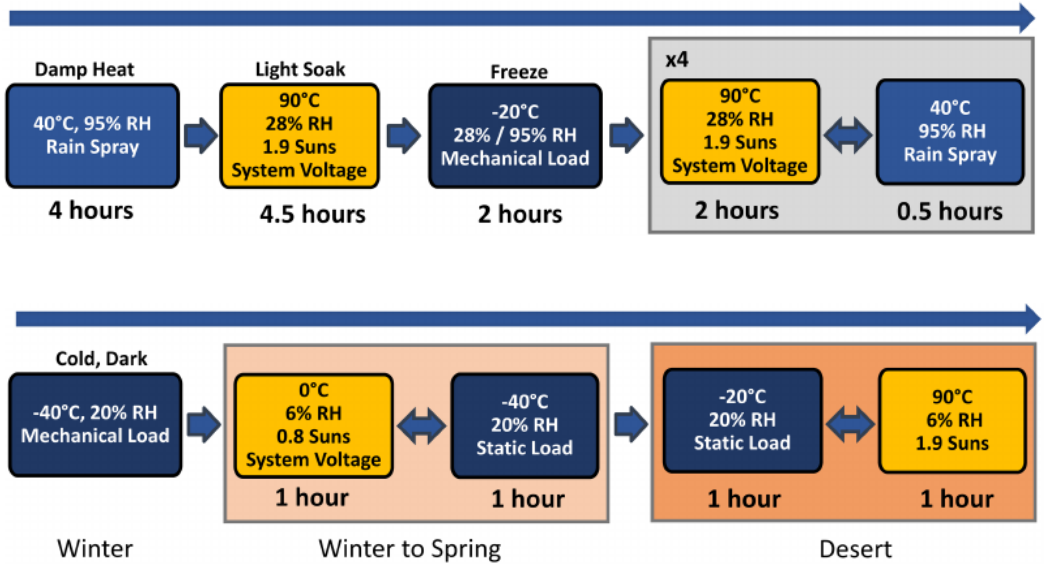
PhotoMark® Reflections™ 255

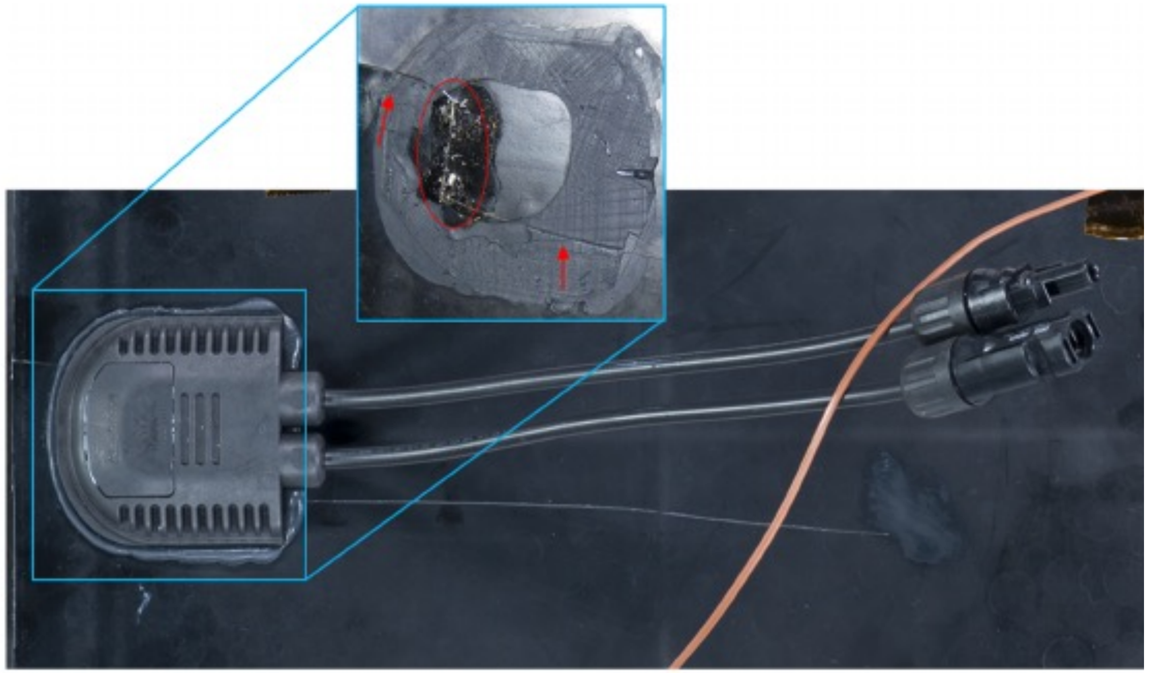
Overview

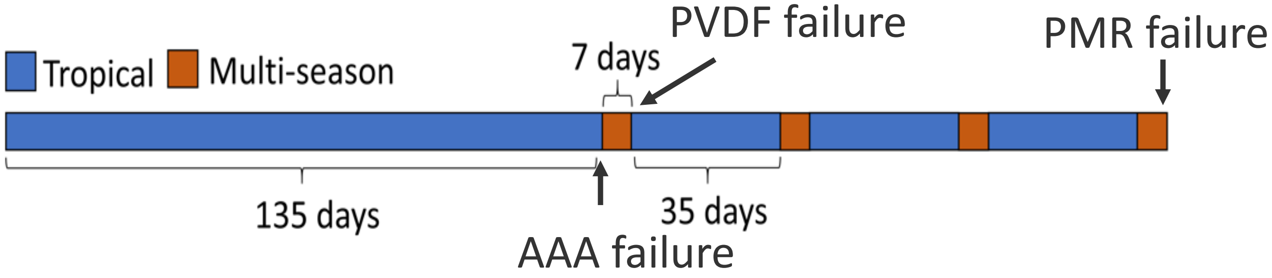
What's better than a durable backsheet with no PET or Fluoropolymers? How about a durable backsheet with no interlayer adhesives?

That's right – Tomark-Worthen has created a revolutionary new backsheet based on a proprietary polyamide alloy that is weatherable, dimensionally stable and cost effective - and it does not contain any Fluoropolymer or PET layers and does not use any adhesives! Our backsheet is not susceptible to hydrolysis or UV degradation.

# Photomark Reflections: Accelerated Aging





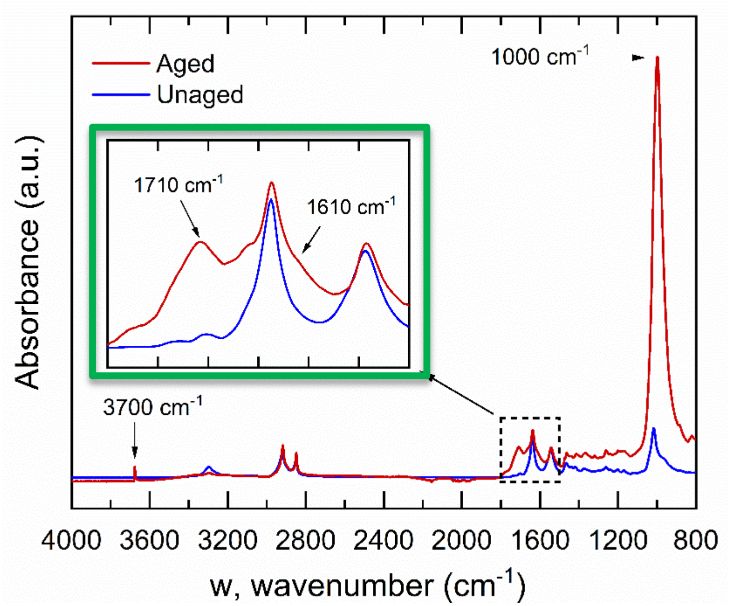


Owen-Bellini, M., *et al.* (2020). Advancing reliability assessments of photovoltaic modules and materials using combined-accelerated stress testing. *Prog Photovolt Res Appl.*, 1–19.

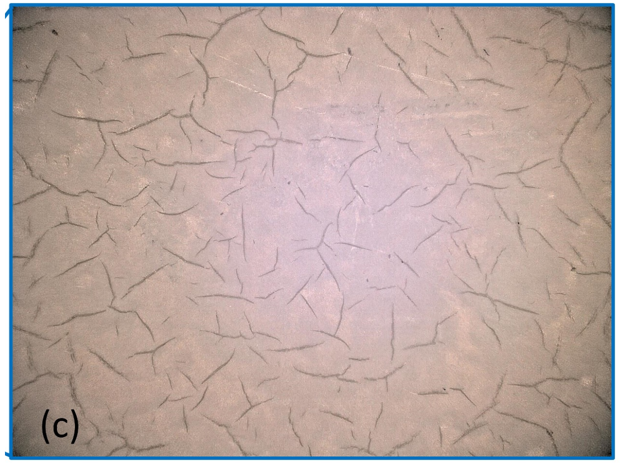
Hartman, K., *et al.* (2019). Validation of Advanced Photovoltaic Module Materials and Processes by Combined-Accelerated Stress Testing (C-AST). *In Proceedings of the 46th IEEE PVSC*, 2243–2248.

# Photomark Reflections: Surface Degradation

- Increase in peaks at 1710cm$^{-1}$ (FTIR): photo-oxidation of polyamide

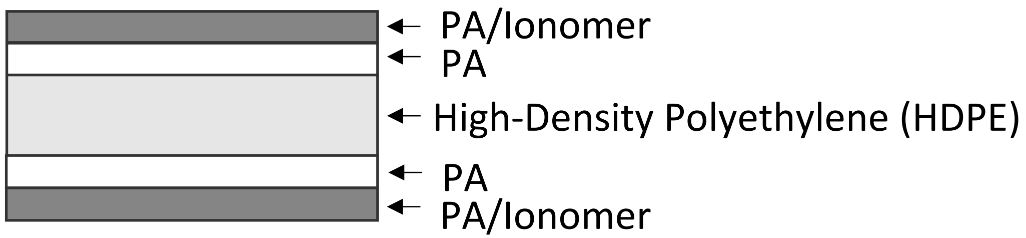



Surface microcracking of AAA attributed to UV photo-oxidation



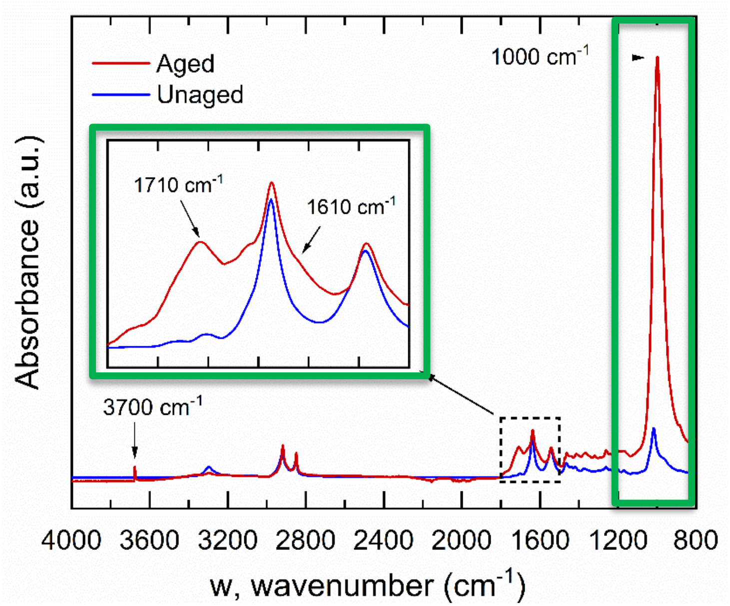

2mm

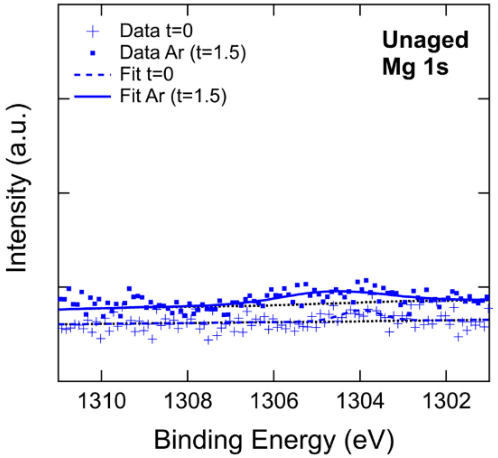
- Microcracking was not observed in the aged PMR
- Could be a result of the PA/Ionomer blended outer layer

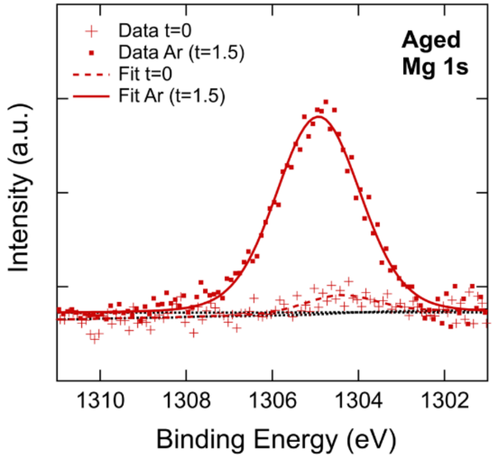


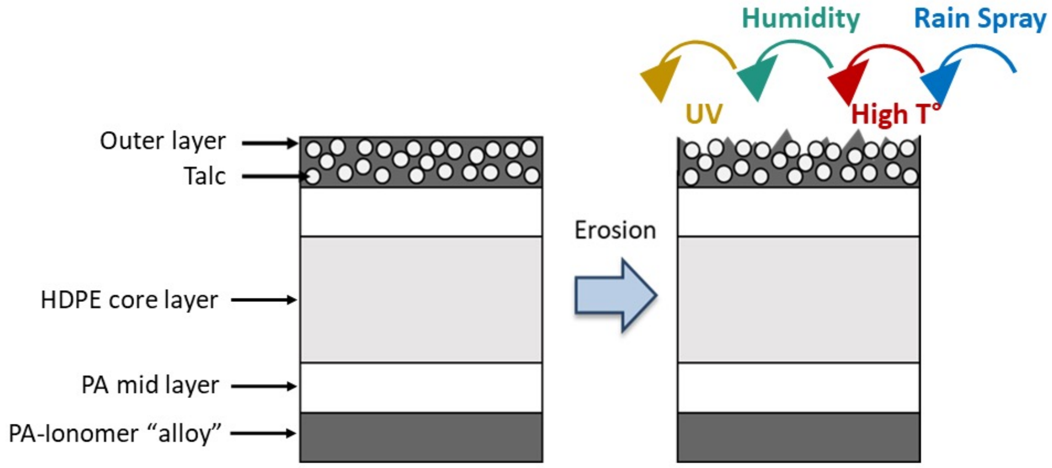
# Photomark Reflections: Surface Degradation

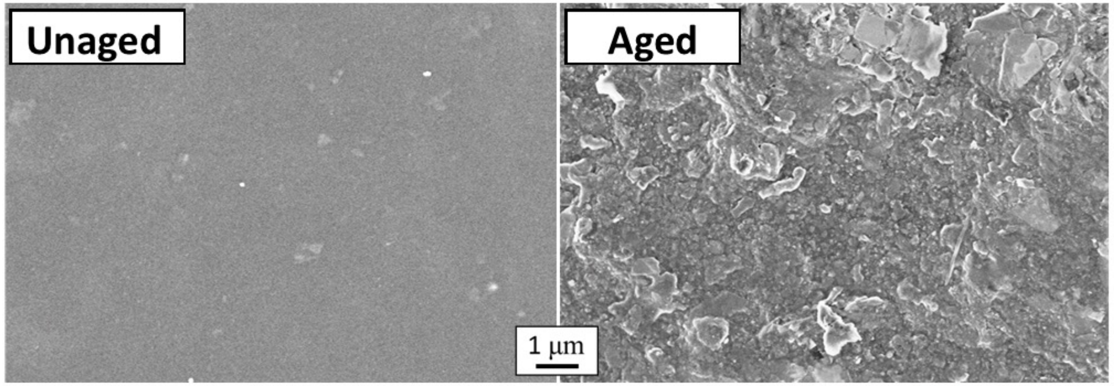
- Increase in peaks at 1710 (FTIR): photo-oxidation of polyar
- Significant increase in peak at 00 cr
  from talc mineral filler



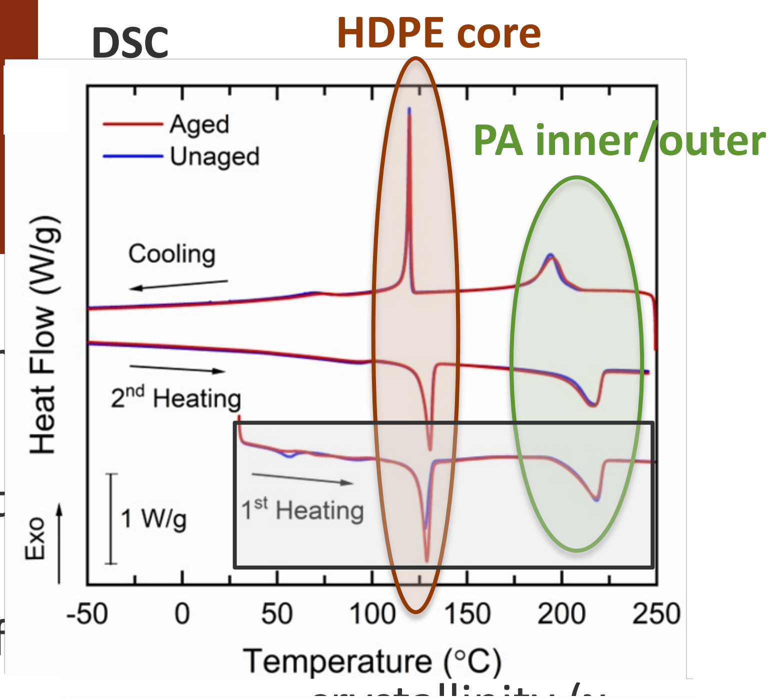



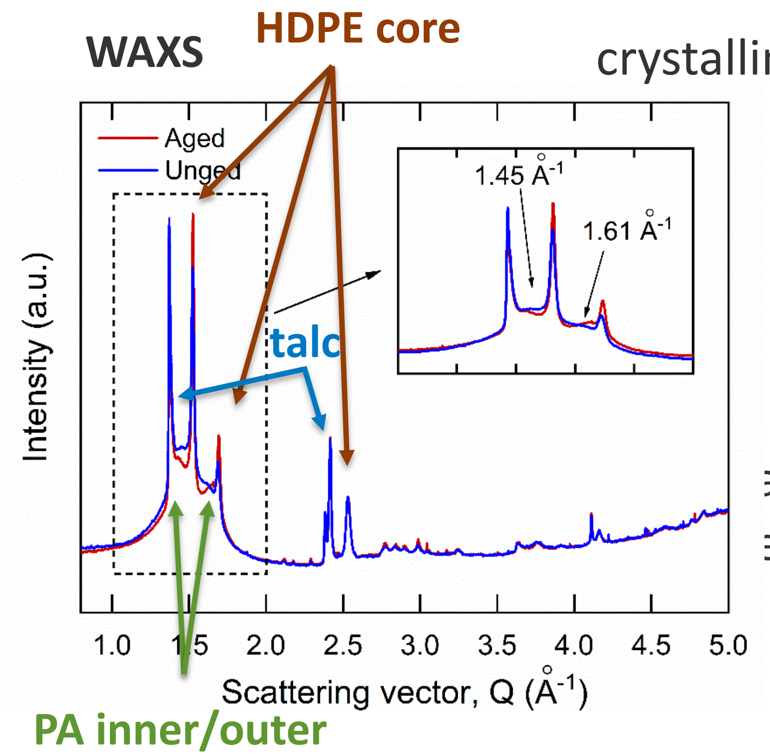



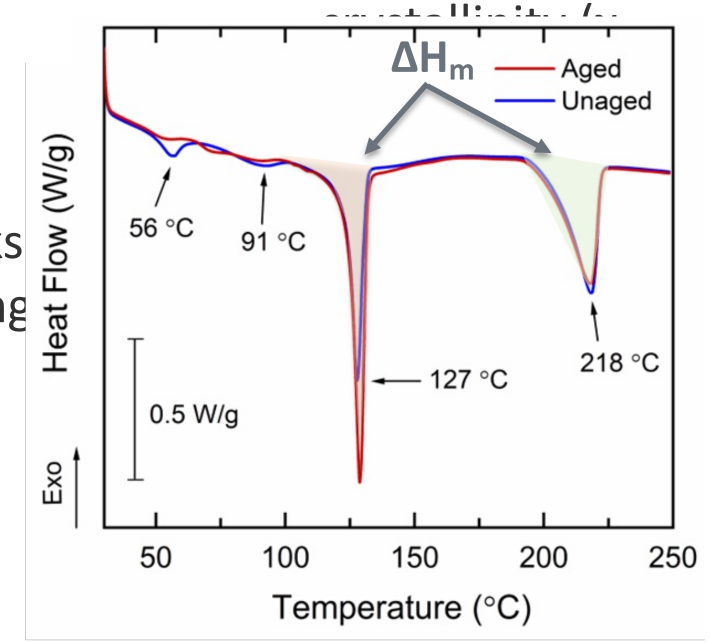

- Higher amount of Mg detected on the surface (XPS): talc = $Mg_3Si_4O_{10}(OH)_2$
- Increase in surface roughness after aging (SEM): hypothesis of surface erosion

# Photomark Reflections: Structural Changes



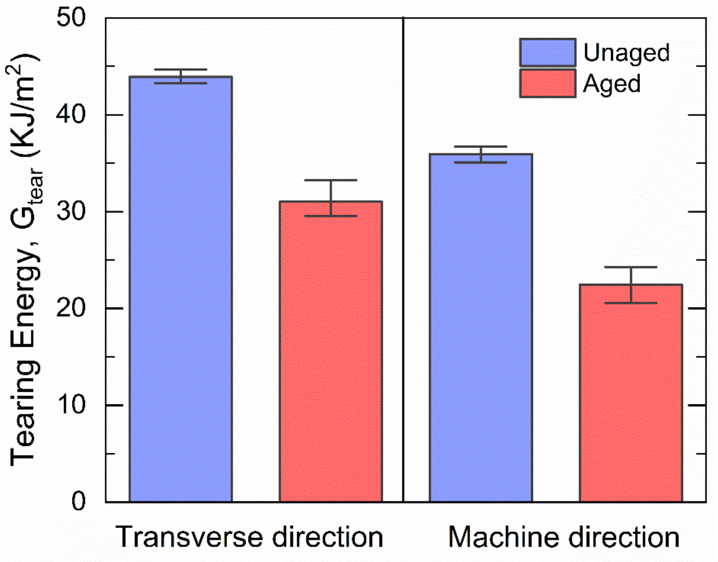

- Identification of materials in the backsheet based on the position of th
  and thermal transitions (DSC)
- Quantification of changes in crystallinit
  (DSC):
  - 29% increase in enthalpy o f
    (prc
    (%))
  - Small decrease in $\Delta H_m$ of P/
  - No shift in crystallization aks
    eng

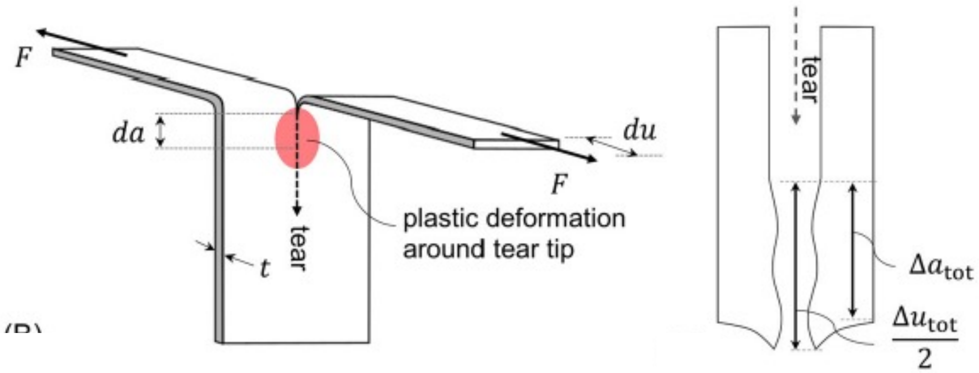


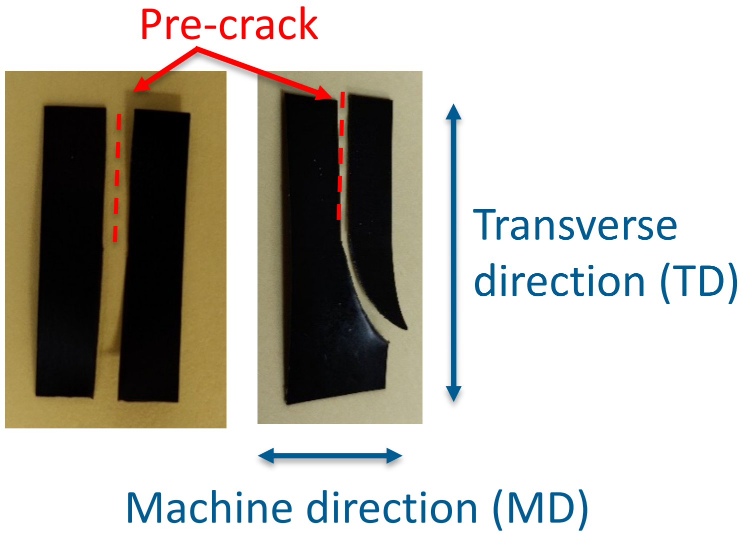
# Photomark Reflections: Mechanical Degradation

- Trouser tear test: correlate the changes in material properties with backsheet mechanical properties
- Lower tear energies upon aging confirm backsheet embrittlement caused by increased crystallization of HDPE core layer
- When tearing aged backsheet in TD, tear propagated in weaker MD: same as the crack leading to failure in C-AST




Yuen, P. Y., Moffitt, S. L., Novoa, F. D., Schelhas, L. T., & Dauskardt, R. H. (2019). Tearing and reliability of photovoltaic module backsheets. *Progress in Photovoltaics: Research and Applications*, *27*(8), 693-705.



# Photomark Reflections: Surface Degradation

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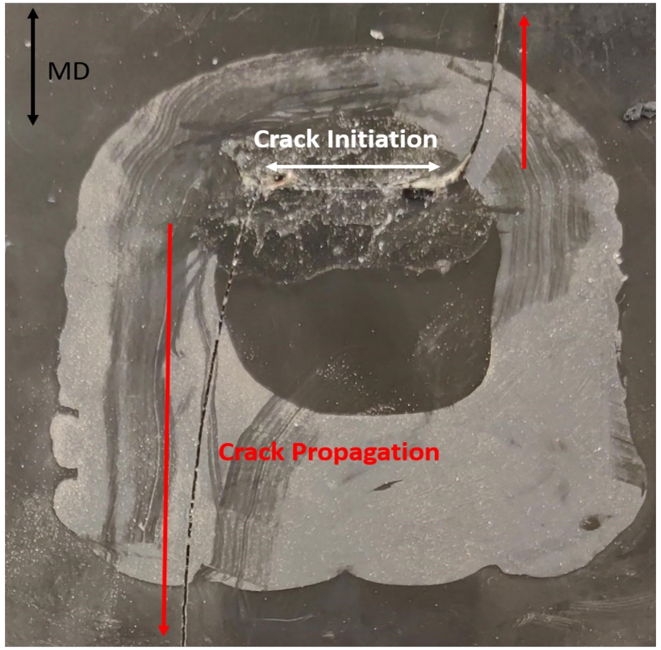


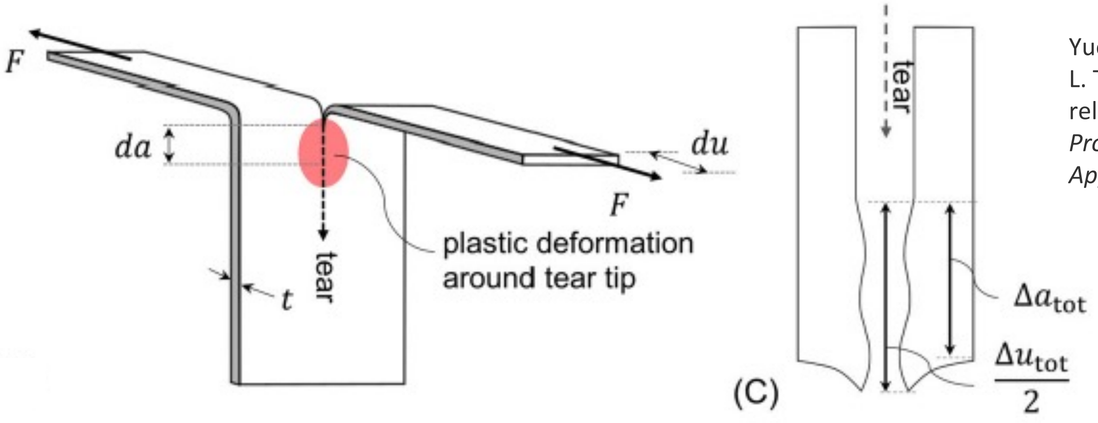


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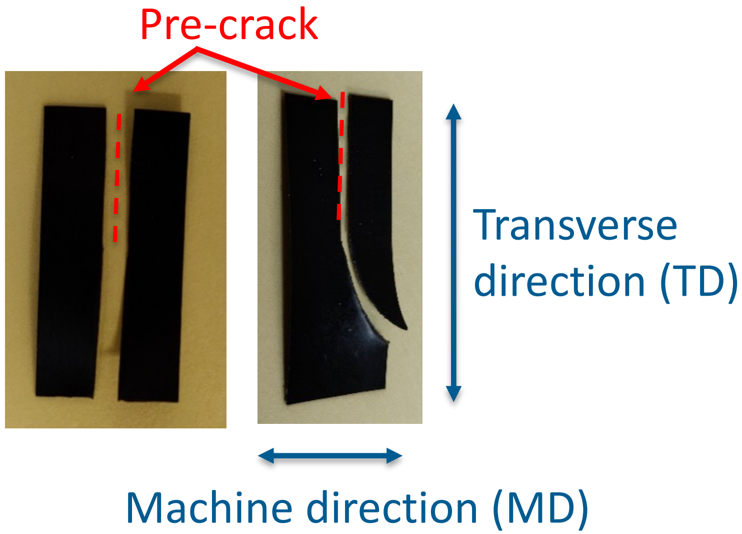

# Part 1 Conclusions

- **Novel polyamide-based, fluoropolymer-free, co-extruded backsheet** “PMR” showed improved durability and robustness than AAA and PVDF with **C-AST**
- PMR backsheet ultimately failed in C-AST by through-thickness cracking
- Surface, structural and mechanical properties were investigated through advanced **material characterization** techniques:
  - Microscopic changes in surface roughness revealed **surface erosion** of the **polyamide** outer layer and **photo-oxidative degradation**, but no microcracking
  - Cause of failure attributed to the **increase in crystallinity** of the **polyolefin** core layer leading to **embrittlement** confirmed by lower tearing energy