Survey of Mechanical Durability of PV Backsheets

Michael D. Kempe[1], David C. Miller[1], Allen Zielnik[2], Daniel Montiel-Chicharro[3], Jiang Zhu[3], Ralph Gottschalg[3]

[1]NATIONAL RENEWABLE ENERGY LABORATORY (NREL)

[2]ATLAS MATERIAL TESTING TECHNOLOGY LLC

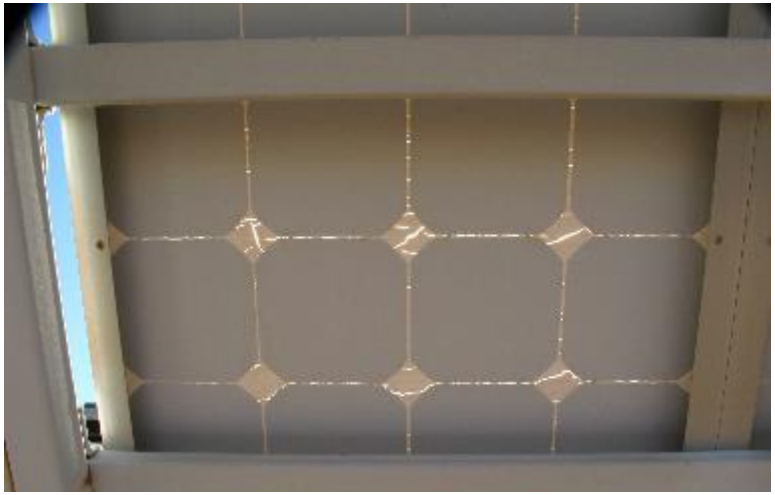
[3]LOUGHBOROUGH UNIVERSITY

Atlas/NIST November 5, 2017

Introduction and Background

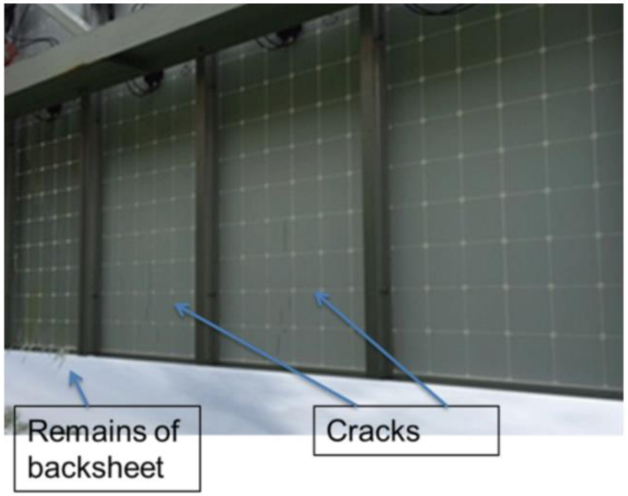
- Backsheets are used primarily to provide electrical insulation for safe operation of a PV module at high voltage with only minor affects on performance.
- Failure typically takes the form of delamination or cracking of the backsheet.
- This work surveys a large number of backsheet films looking at the retention of mechanical properties to prevent the formation of cracks.
- By investigating a large number of materials, the typical ways backsheets might fail can be assessed.
- A total of 56 materials were obtained presumably with some unknown number of replicates.

Cracks Often Develop in Backsheets



TPE backsheet in conjunction with non-UV absorbing EVA. APS star facility.

An example of a polyamide backsheet cracking between cells. Other examples show cracks along tabbing. Cracks can appear after as little as 4 to 5 years.



Single-sided PVDF backsheet with cracks in the machine direction preferentially along busbar ribbons.
*Gambogi et. al NREL 2017 PVMRW

- Current qualification tests will not prevent these failures.
- With increasing cost pressures new materials are being introduced without adequate validation.
- Better testing is needed to provide confidence in new materials

Outline

- Materials and Methodologies
  - Bend test
  - Tensile testing
- Results
  - Overall occurrence of failure modes
  - Specific examples
  - Known polyamide bad material.
- Conclusions

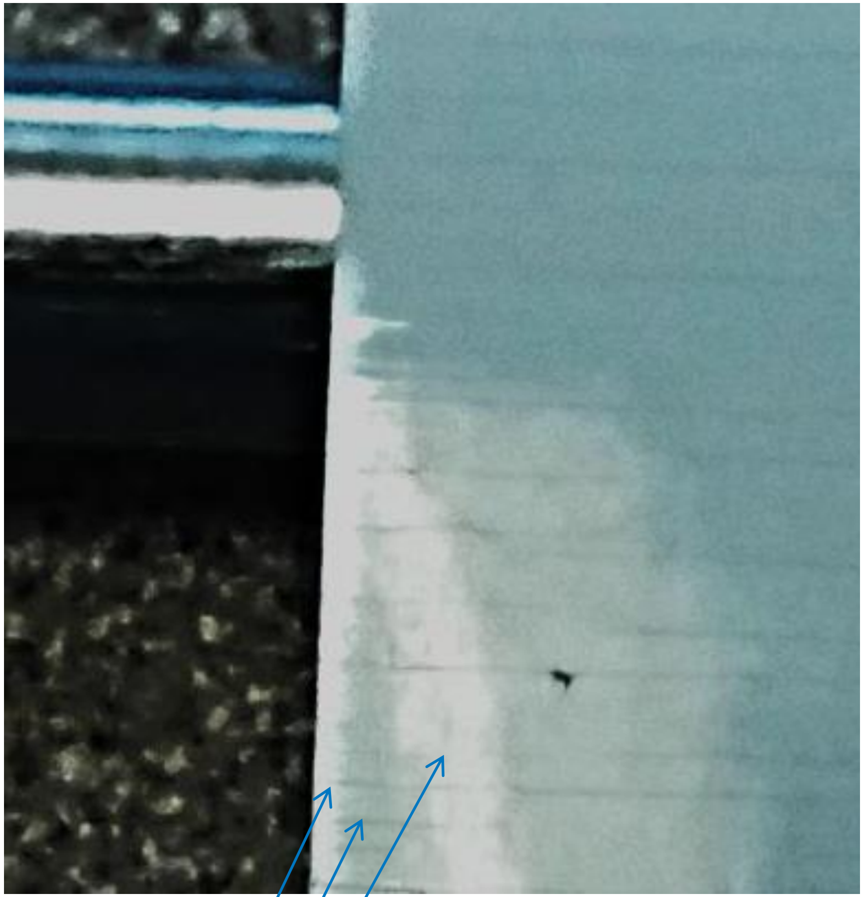
Material Classification

- Backsheet Material Classification (56 samples)
  - Air-Side
    - One sample was a polyamide known to fail in the field.
    - 37 samples had a fluoropolymer on the air side.
      - 14 where PVF
      - 5 were PVDF
    - 16 samples had PET on the air side.
    - Two samples with Polyethylene
  - Cell-Side
    - 19 had a low-vinyl acetate EVA
    - 4 with a polyolefin
    - 18 had a fluoropolymer on the backside (these had fluoropolymers on the air side too)
    - One polyamide
    - 5 had PET
  - 7 samples were transparent.

Mandrel Test

- 1.5×8 cm samples are bent around a 6.35 mm diameter mandrel in both directions.
- Testing is conducted every 250 h till failure or 4000 h.
- Usually the cracks are seen, but sometimes you can only hear the cracks forming.

Machine direction sample #35.



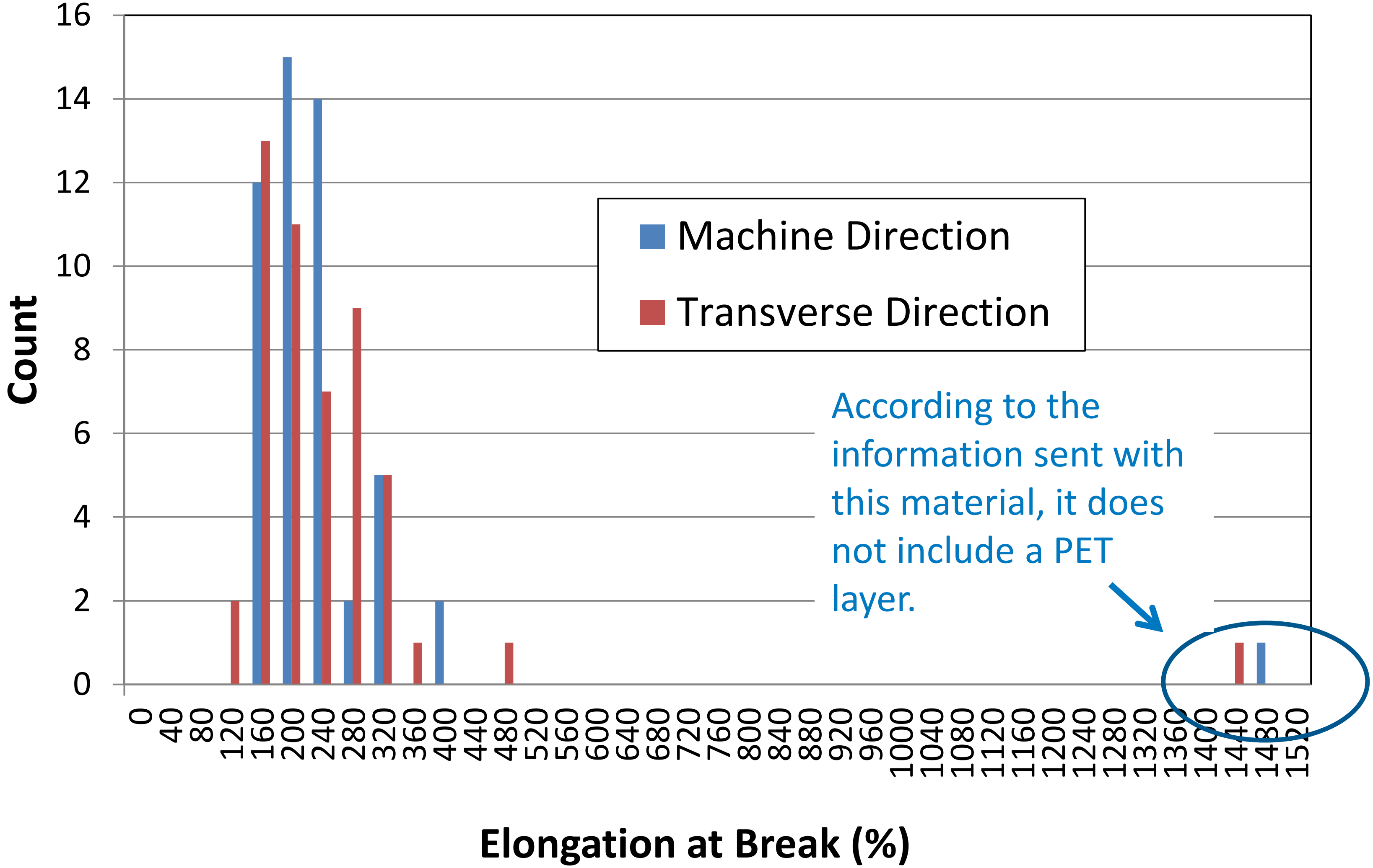
Cracks in transverse direction on cell-side after 750 h.

Mandrel Specimens Mounted for Limited Backside Reflection

- Bend test samples mounted in an Atlas Ci5000 Weather-Ometer, CAT=65°C, 20% RH, BPT=90°C, Irradiance = 0.8 W/m²/nm at 340 nm. This is cycle A3 of the newly proposed IEC 62788-7-2 weathering standard for PV
- For the mandrel specimens, a backing plate was used to minimize the amount of UV light hitting the cell side of the films.
- For tensile test samples, they were similarly mounted but without the backing plate such that reflected light hits the backside of the samples.

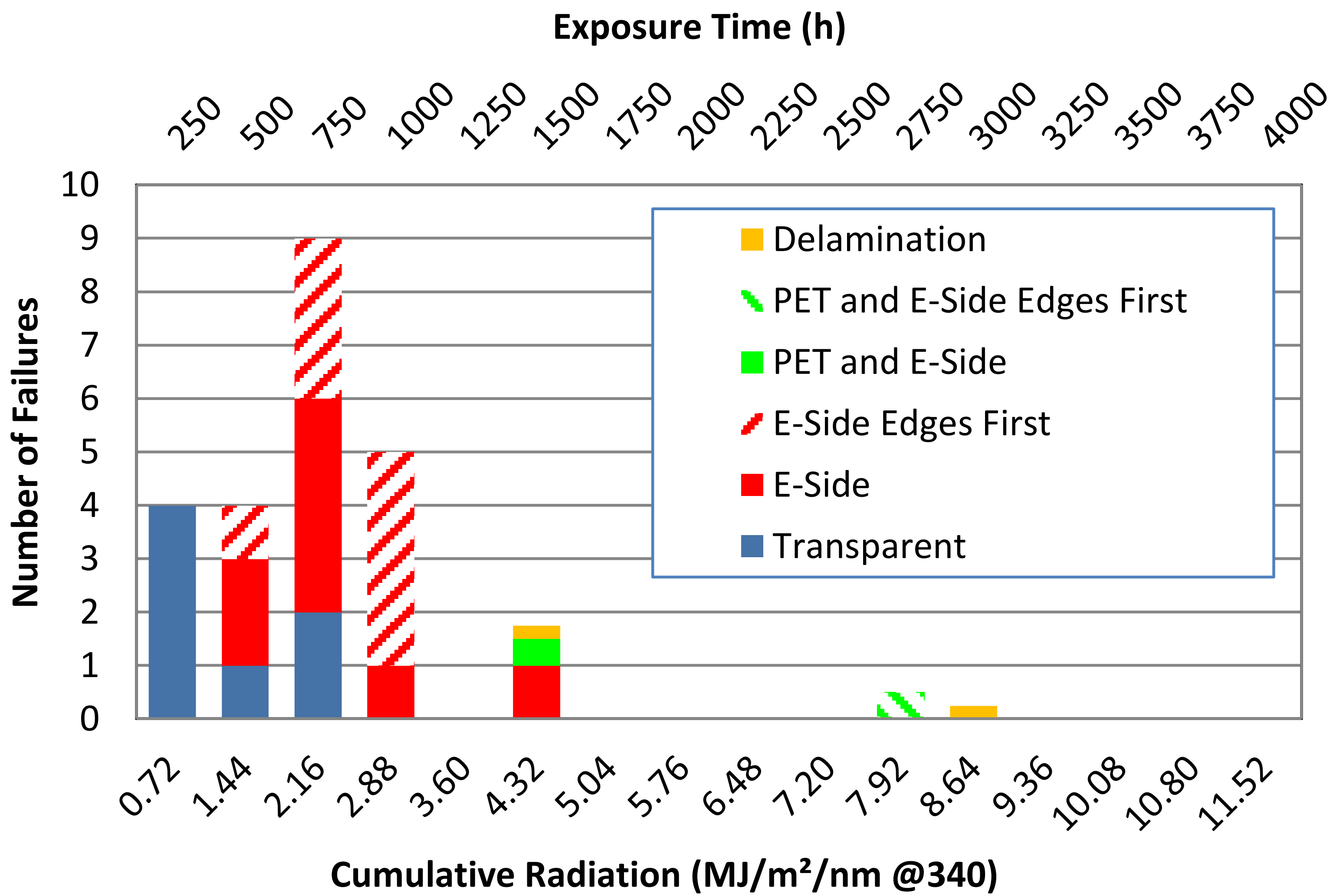
Bend test samples in sample holder for two materials

PET Dominates initial Elongation at break



Testing according to IEC 62788-2, section 4.2.4.
Rectangular test samples, 10 mm×80 mm with 50 mm between the grips, pulled at 50 mm/min.

Most Failure Was in Less than 1000 h (24 total Failures).

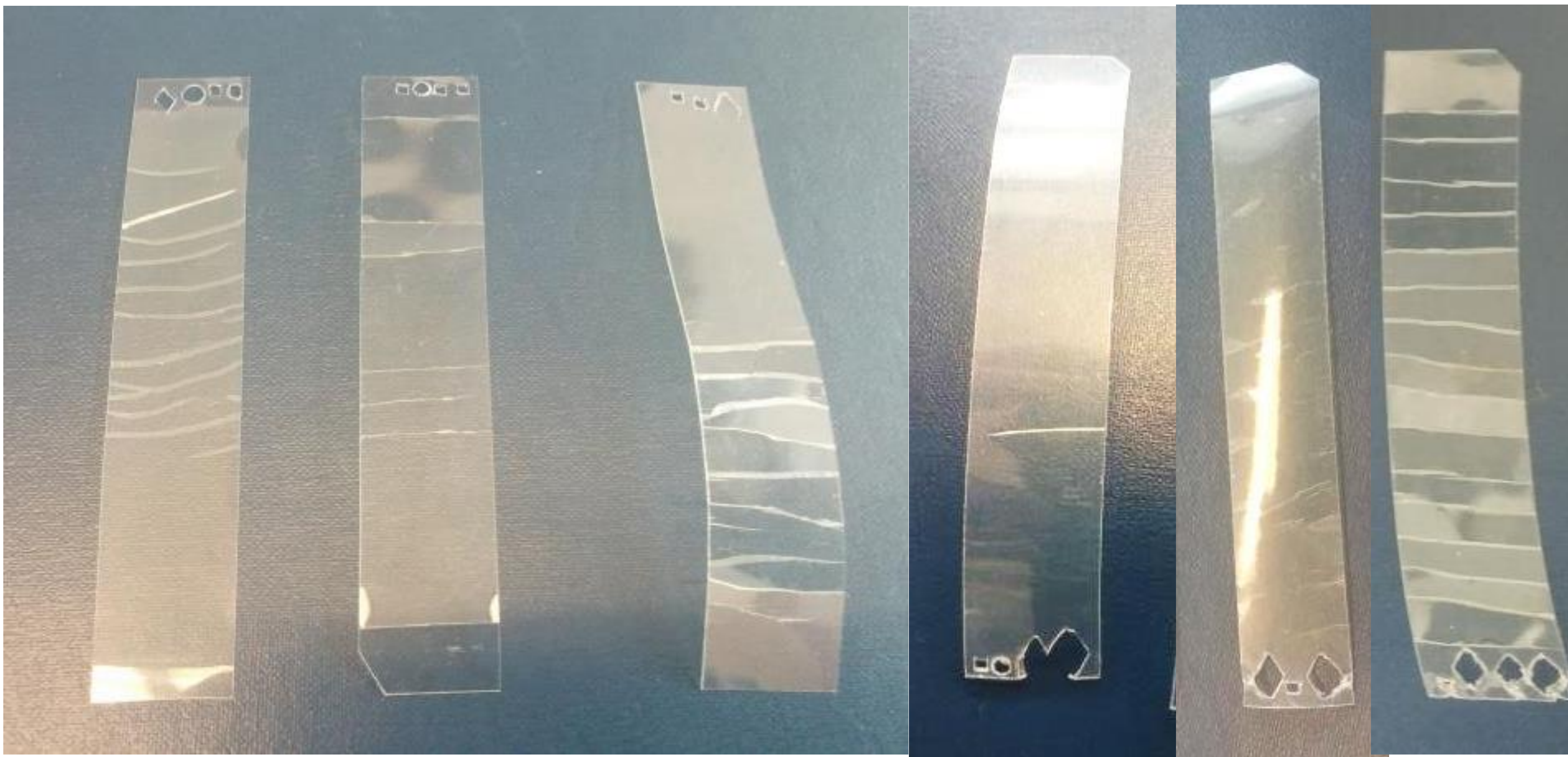


Exposure to 0.8 $W/m^2/nm$ at 340 nm, CAT=65°C, BPT=90°C, 20% RH.

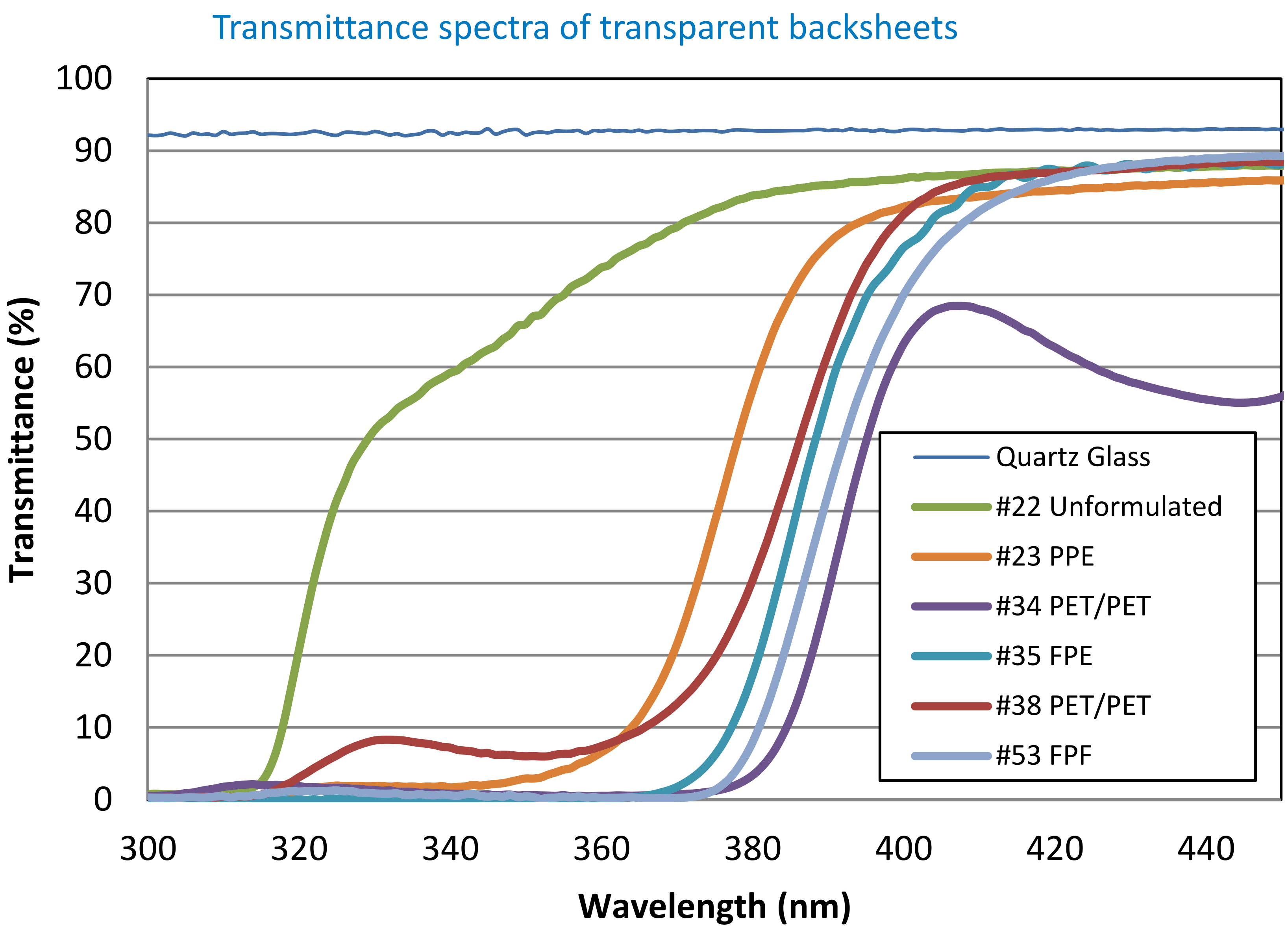
All 7 of the Transparent Backsheets Failed Quickly

- This is a significant concern for bifacial modules

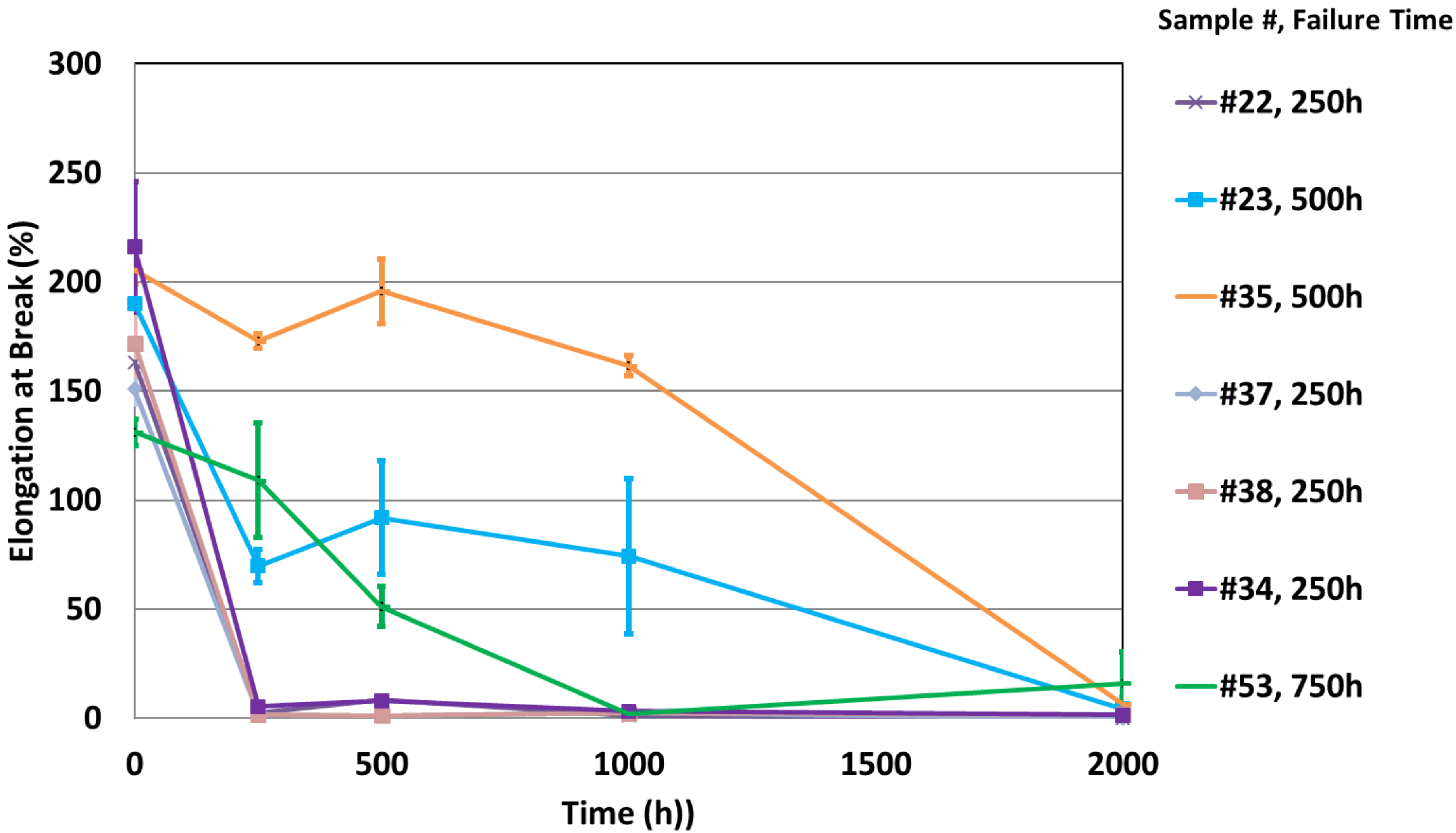
#38 UV-PET 250 h | #37 Unstabilized PET 250 h | #22 Unstabilized PET 250 h | #35 FPE 500 h | #23 P/P/E 500 h | #53 FPF 750 h



UV Absorber not Sufficient to Protect the PET Layer



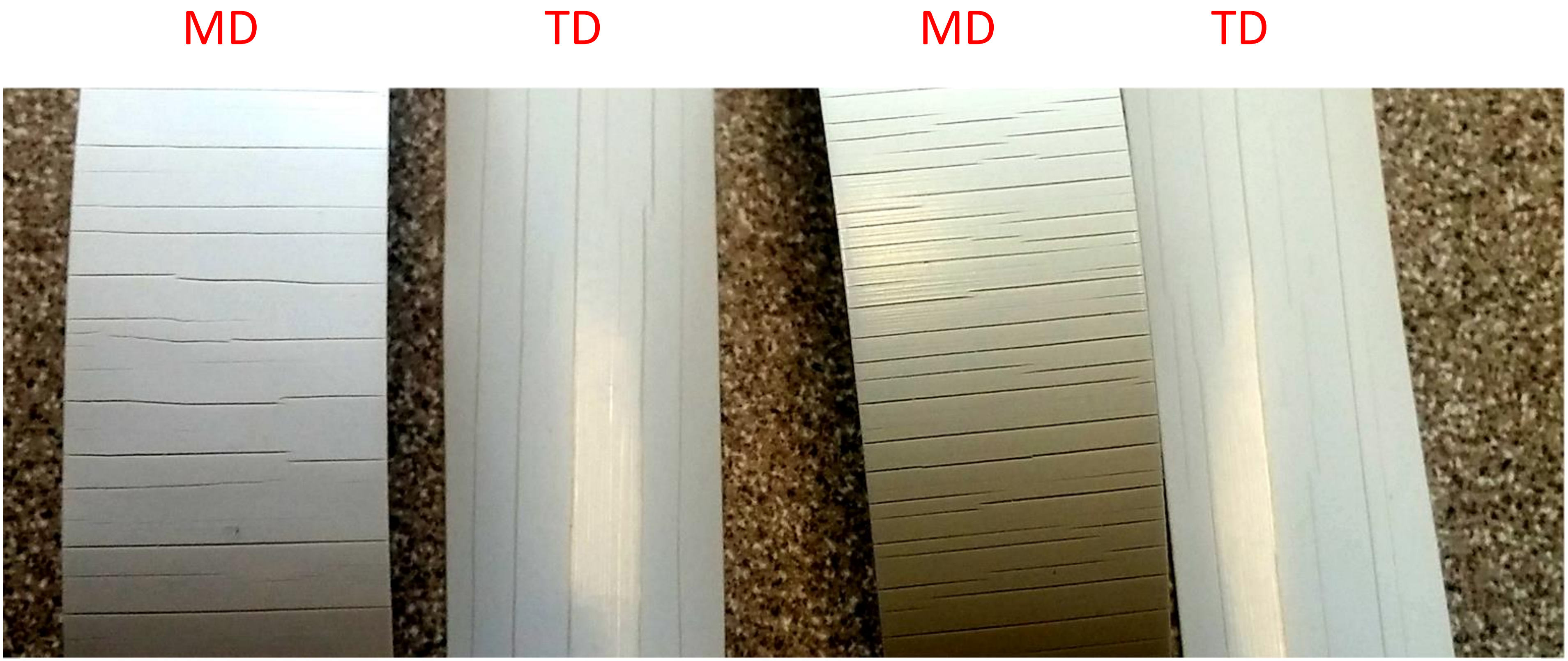
Transparent Samples Lost their ETB Quickly



- Even though #35 failed the Bend test after 500 hour, ETB is evaluating the effect on the bulk of the film which allowed it to retain ETB long after cracks were forming in the bend test.

Transverse Direction Cracks Almost Always Dominate

- Cracks usually dominate in the transverse direction but never in the machine direction.
- Residual strain significantly affects cracking.



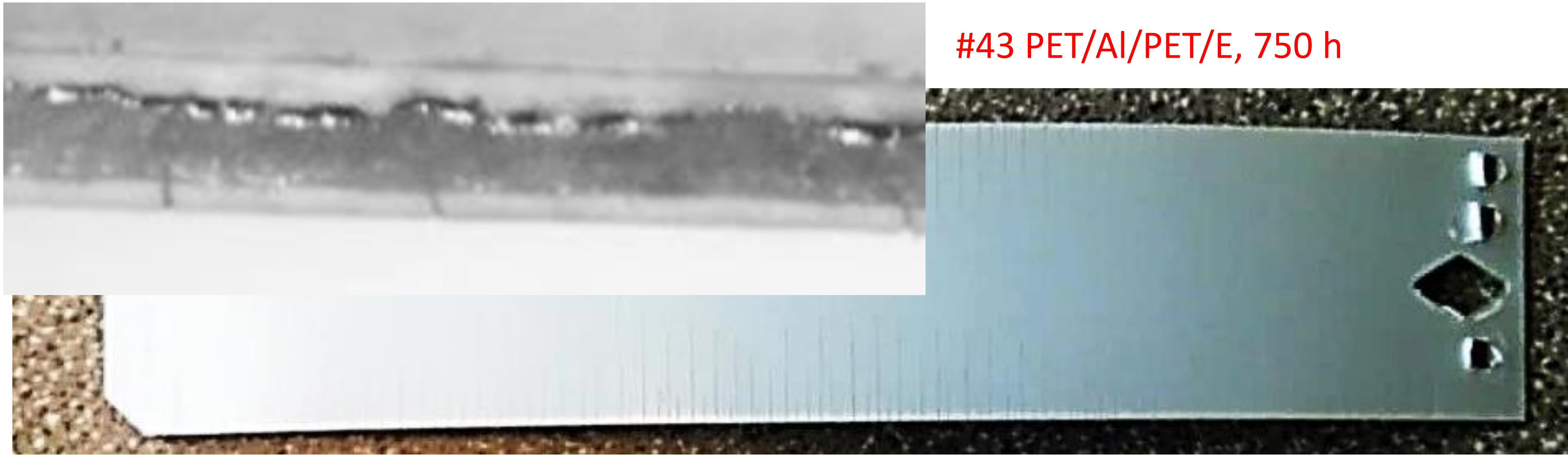
Cell-Side of Material #1, PVF/PET/Low-VA EVA, 750 h exposure

Often the Cracks Originate From the Sides (9 materials)

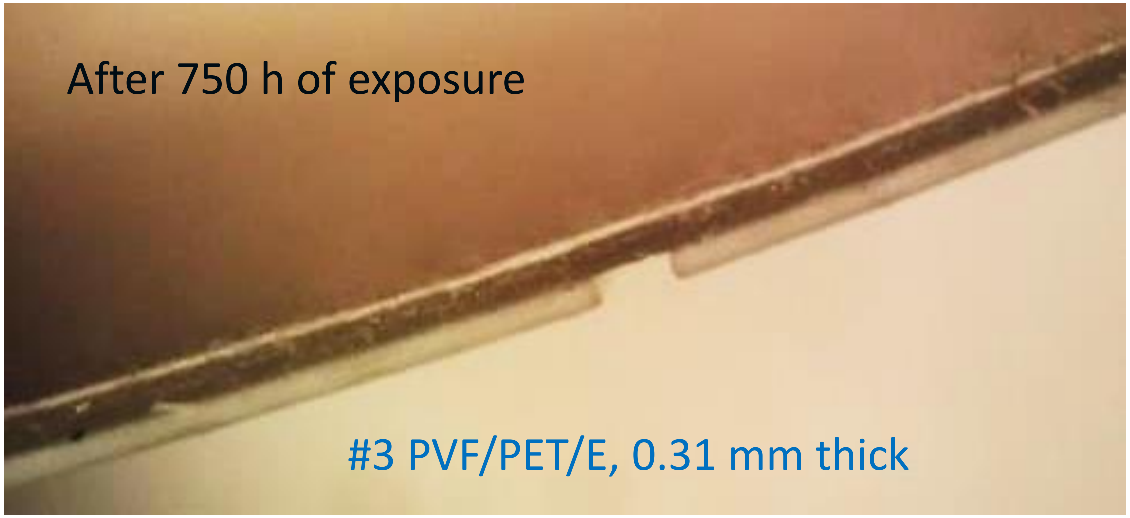
- Machine direction Sample
- Cracks start at the side and don't fully propagate across

#30 PVF/PET/E, 750 h

#43 PET/Al/PET/E, 750 h



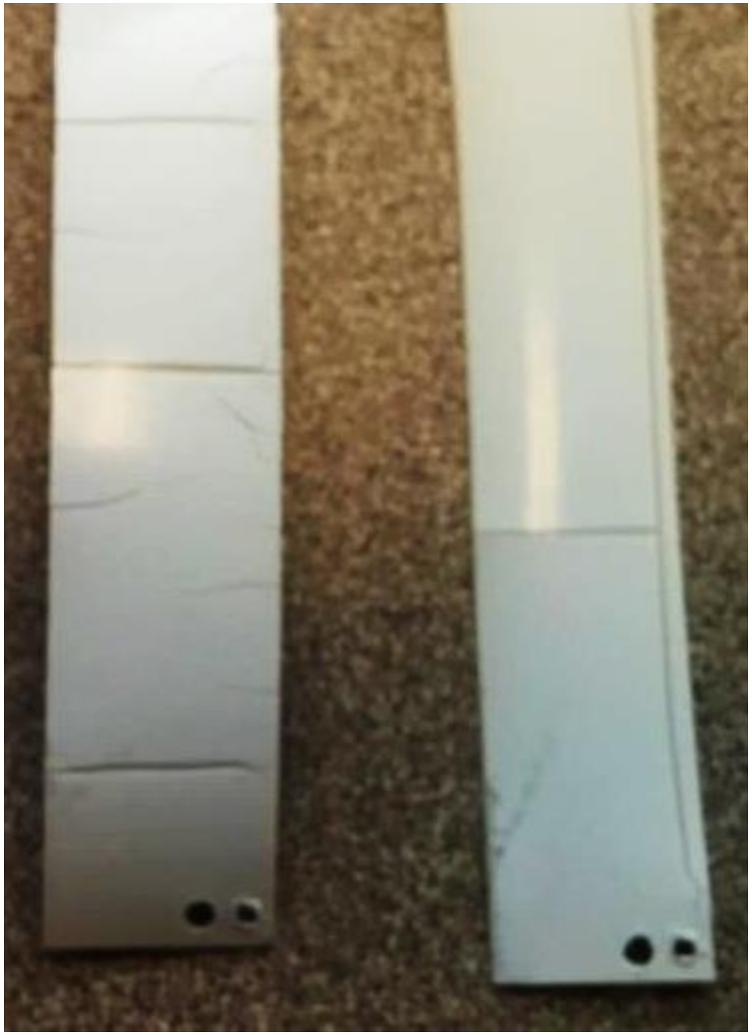
Cracks Will Happen When Material #3 is Deployed



- The "E" layer experienced a very large amount of shrinkage.
- In other experiments, even when laminated to an EVA layer, this shrinkage still occurred.
- This is a thermally activated degradation.

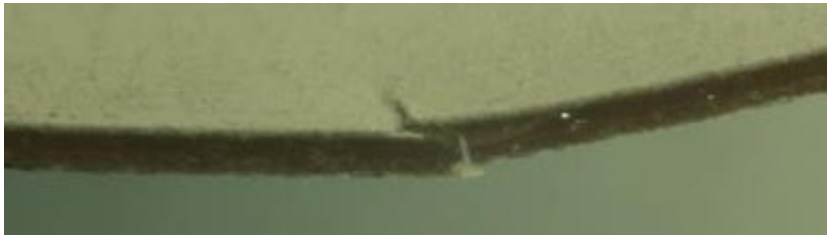
Cell-side image

MD TD

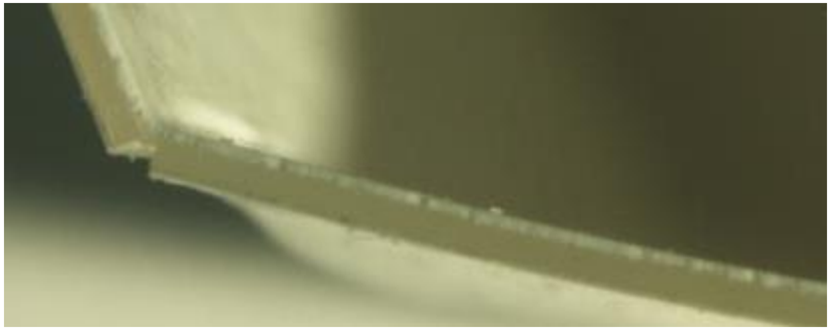


Only Three PET Failures in Opaque Backsheets

Material #16 PVF/PET/PVF after 2750 h



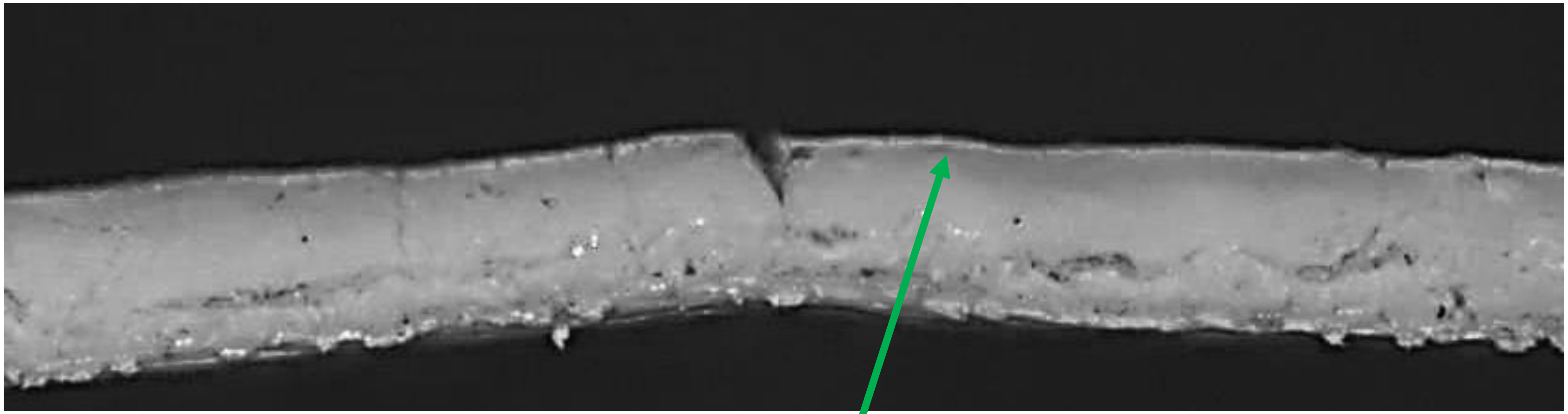
Material #26 PET/PET/"E" after 1500 h



Material #33 PET/PET/"E" failed after 1750 h

- View from the edge of three samples with PET failure.
- Cracking only seen in the fluoropolymer where the PET cracked.
- Delamination occurred on both sides of the PET in one material.
- No instances of an opaque surface PET layer failure were seen.

#56 Polyamide Developed a High Modulus where it was Hotter

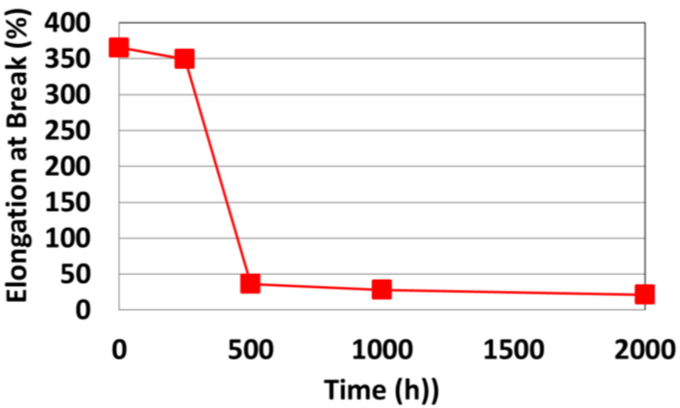


Edge of shaded area

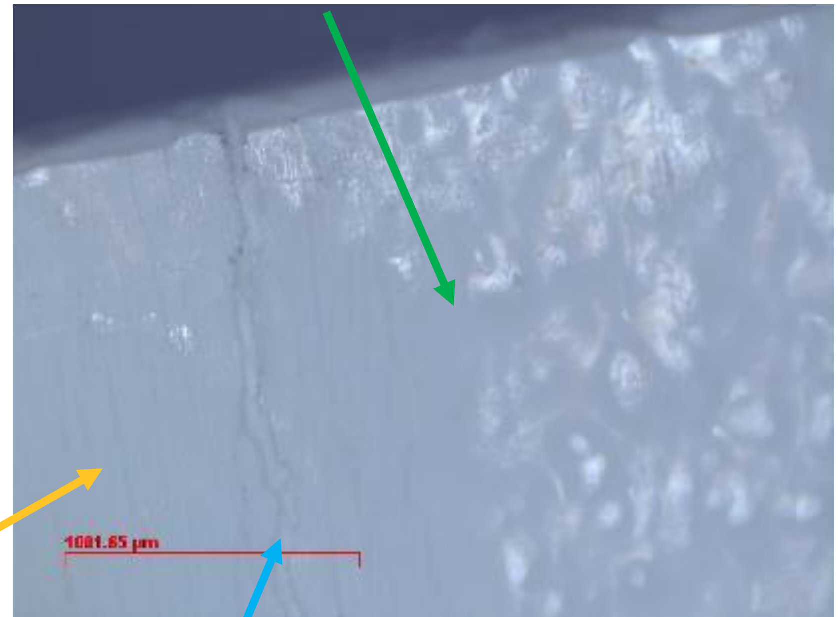
- The area under the metal holder would be hotter because of greater light absorption.
- The ends had a significantly higher modulus and retained the glossy surface appearance. This region occupied a well defined boundary both visibly and physically.
- When bent, the stress concentration at this boundary sometimes caused cracking after 3000 h of exposure.
- This implies that the embrittlement of this material is likely to be very highly thermally activated.

#56 Small Surface Cracks in UV exposed region only

Bulk properties Failed Quickly



Edge of shaded area



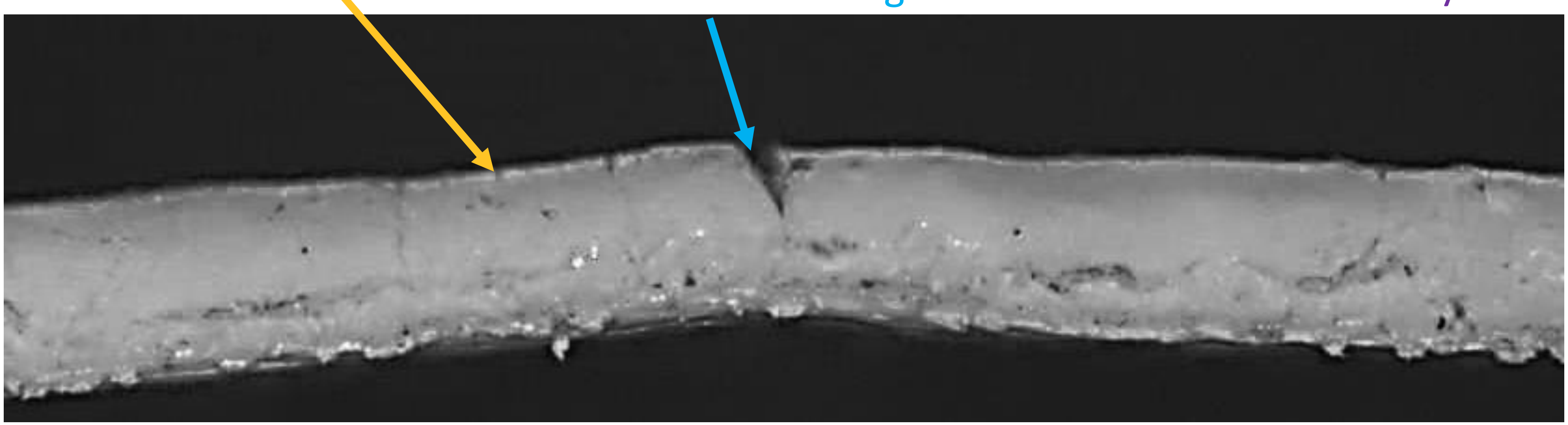
UV light alone will not produce cracks that penetrate the whole backsheet.

Surface cracks

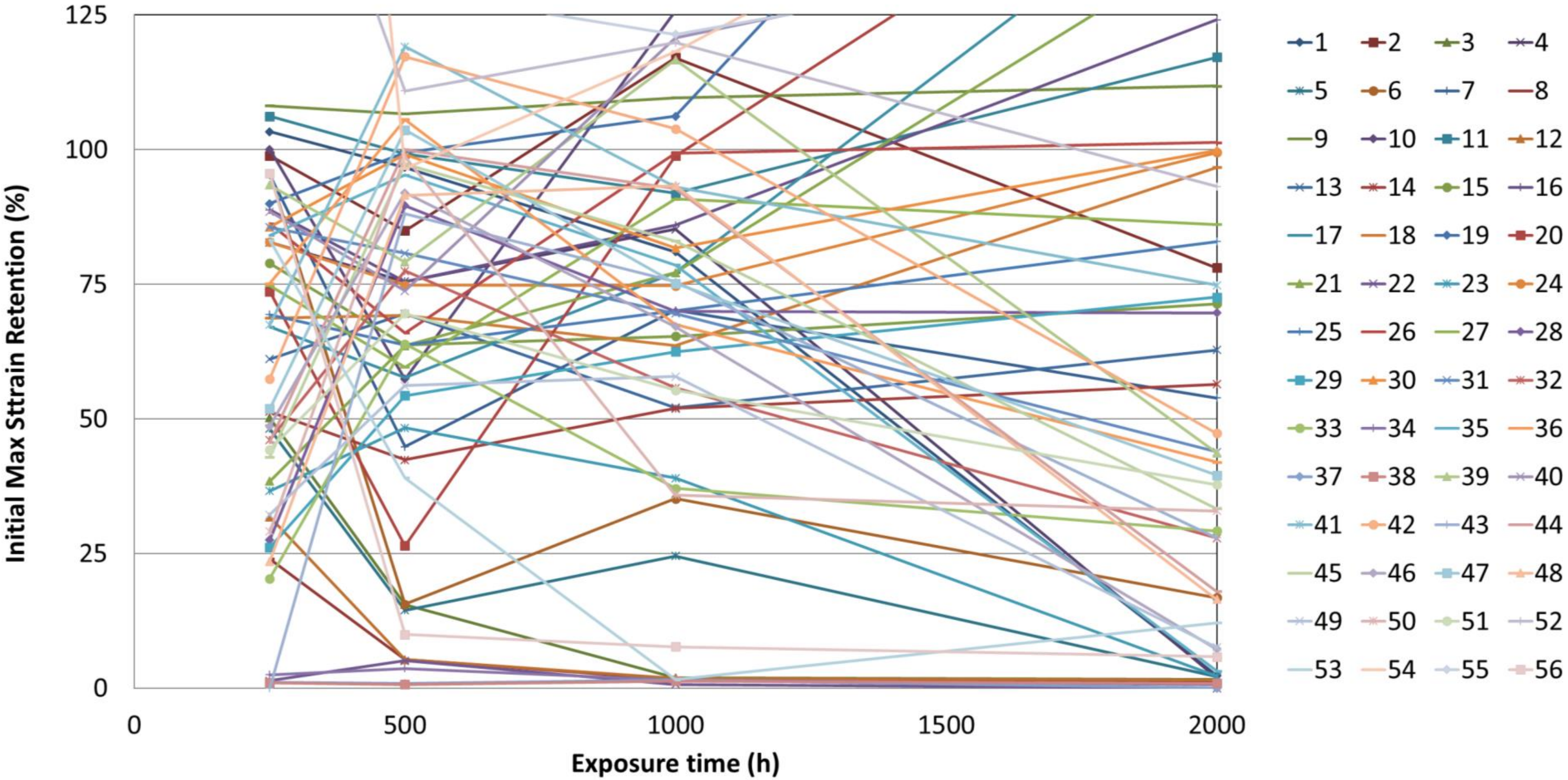
UV exposed side

Crack from bending

Non-UV exposed Glossy side



Tensile Testing According the IEC 62788-2



- New IEC 61730 amendment proposes: 50% retention after 2000h while allowing for preconditioning of up to 200 h, and a minimum of 25% ETB. Or at least 25% ETB after 4000 h of exposure.
- Based on the 50% relative retention criteria and 25% absolute ETB at 2000 h, only 26 samples passed. However, it should be noted that we specifically sought out many materials we thought would fail so we are not surprised at this finding.
- This criteria would eliminate sample number 56 which is known to fail in the field.

Conclusions

- All of the clear/transparent samples have cracked.
- No Fluoropolymer layers have cracked except in combination with a PET failure.
- No pigmented PET films caused failure
- Some combinations of “E” layers and/or PET layers are the only ones that have failed.
- The polyamide film did not fail the bend test, but the proposed tensile testing in the amendment to 61730 would not pass this material.
- Testing a free standing film is not adequate for backsheet evaluation. More work is still to be done.

Acknowledgements

- Kurt Scott
- Nancy Phillips
- David Burns
- Tom Earnest
- Rene Eugen
- Ryuhei Metabi
- Scott Fowler
- Emily Parnham
- Xiaohong Gu
- Chris Flueckiger
- Takao Amioka
- Bengt Jaeckel
- Bill Brennan
- Gerhard Kleiss
- Greg Obrien
- James Bratcher
- John Wohlgemuth
- Juergen Jung
- Kiyoeru Miyake
- Marc Brandenburg
- Masahide Yodogawa
- Michael Koehl Marina Temchenko
- Nick Powell
- Peter Seidel
- Ryuhei Metabi
- Sean Fowler
- Shying Yang
- Steve McMaster
- Shin Watanabe
- Toshiaki Hayashi
- Bill Gambogi
- Xiaohong Gu
- Kaan Korkomaz
- Byron McDanold
- Trevor Lockman
- Ian Tappon

- **Many Others…**