A COMPARISON OF THE PERFORMANCE OF FLUORINATED AND NONFLUORINATED BACKSHEETS

Daikin America Inc.
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Daikin Industries, Ltd.

Daikin Group
15 Billion $ Sales (2011)
200 Companies Worldwide
44,000+ Employees

- Headquarters: Osaka, Japan
- Established in 1934

87%
Air-Conditioning Division
World Rank: #1

10%
Fluoro-Chemicals Division

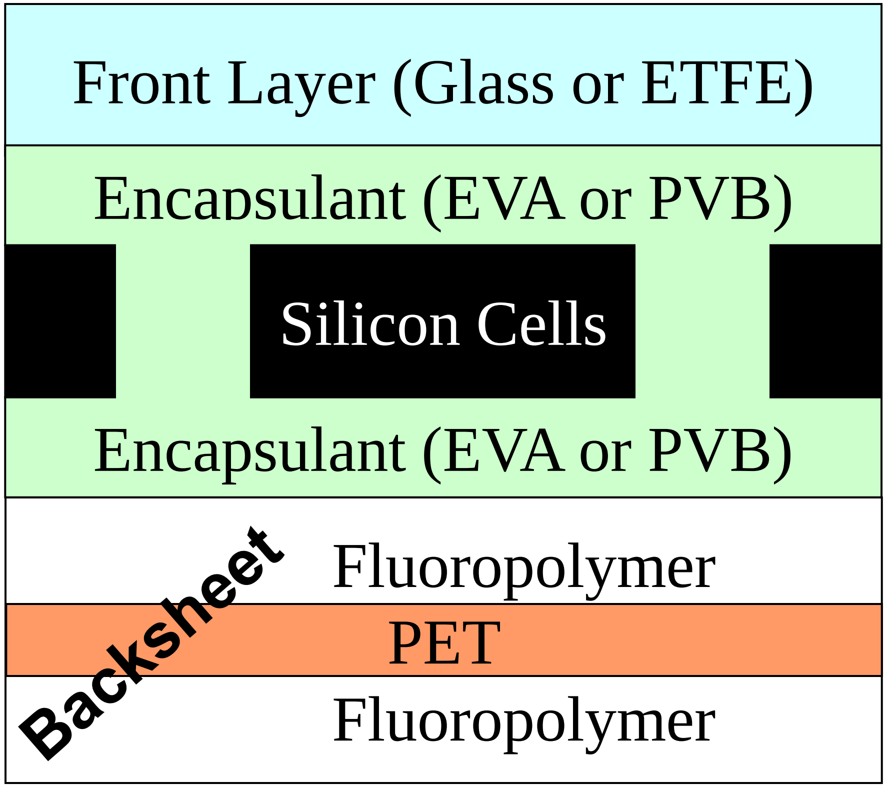
3%
Other Divisions (Computer Graphics, Hydraulics, …)

Backsheet Performance Comparison

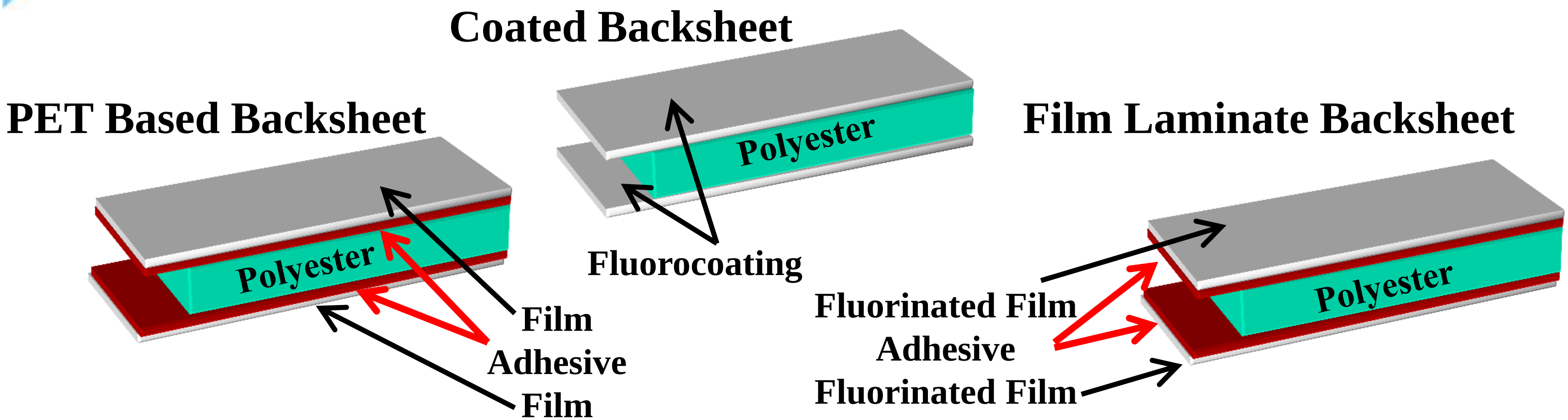
- Photovoltaic backsheets
  - Ultraviolet light
  - Heat
  - Humidity
  - Break down the chemical bonds polymeric materials
    - Discoloration/ gloss reduction
    - Reduced mechanical strength
    - Reduced resistance to humidity
- Exposure
  - Xenon arc weatherometer per ASTM-G155
- Comparison
  - ZEFFLE™ coated backsheets
  - PVF backsheets
  - PVDF backsheets
  - Non-fluorinated laminated backsheet

Solar Panels

- Economics
  - Greater lifetime = Cheaper power
- Construction
  - Outer layers protect against moisture
  - Front layer is typically glass
  - Improve performance of backsheet



Composite Photovoltaic Backsheet

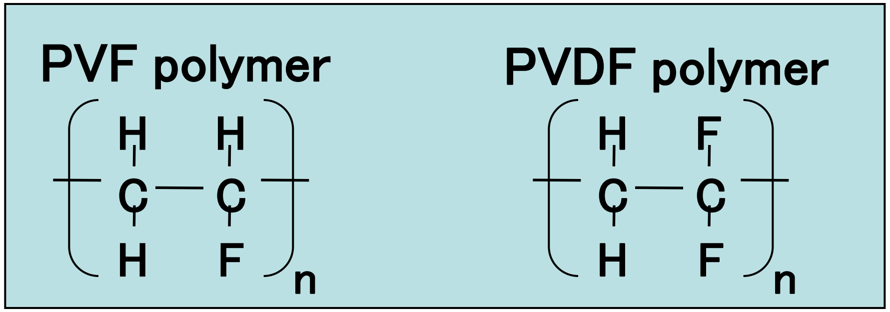


	PET	Coating Type	Film Laminated Type
Backsheet Layers/Interfaces	3-5/2-4	3/2	5/4
Adhesive Layer	Yes	No	Yes
Chemical Foundation	Polyester	4F (TFE)	1F (PVF)/ 2F (PVDF)
Years Outdoor Exposure Data	~15	25	25
Cost/Performance	Fair	Excellent	Good

Backsheet Performance Comparison

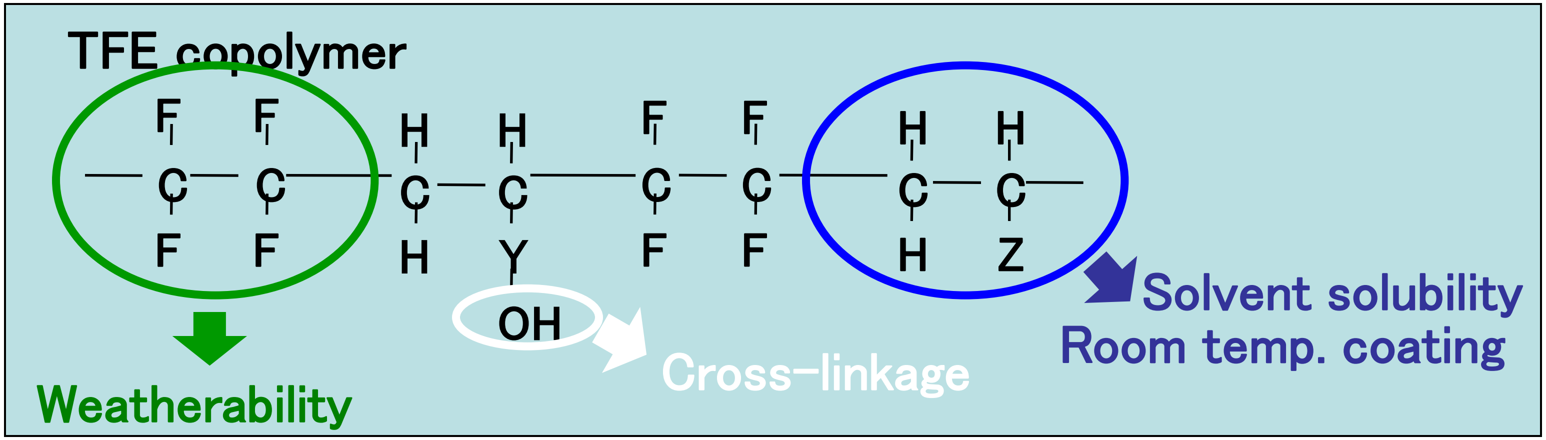
- Fluoropolymers
  - UV resistance
  - Strength and durability
  - Resistance to weathering
  - Electrical insulation

- Strength of the carbon-fluorine bond
  - C-F 116 kcal/mol
  - C-H 95 kcal/mol
  - C-Cl 78 kcal/mol



- Fluoropolymers already used in the industry
  - PVF and PVDF laminates.
  - ZEFFLE™ differs from these due to its use of Tetrafluoroethylene

ZEFFLE™



- Solvent-based
- Developed for building coating
  - Decades of history of good weathering properties
  - Works well in salt water environments
- Resist long-term exposure to ultraviolet light, heat, and humidity

Backsheets Tested

Construction	Sample Name	Materials	Construction
Zeffle PET Zeffle	ZPZ	Commercially Available	Commercially Available
Zeffle PET Primer	ZPE	Commercially Available	Commercially Available
Tedlar PET Tedlar	TPT	Commercially Available	Commercially Available
Tedlar PET Primer	TPE	Commercially Available	Commercially Available
Kynar PET Primer	KPE	Commercially Available	Commercially Available
PET PET Primer #1	PPE # 1	Commercially Available	Commercially Available
PET PET Primer #2	PPE # 2	Commercially Available	Developmental Lamination

Sample Accelerated Aging

- Exposed samples to UV, temperature and humidity fluctuations.
- Atlas Ci5000
  - ASTM G155
    - 120 min cycle
    - **0.35 W/m²**
    - 63ºC rack, 42ºC chamber
    - Phase one: 102 min, 50% RH
    - Phase two: 18 min, constant spray of RO/DI water

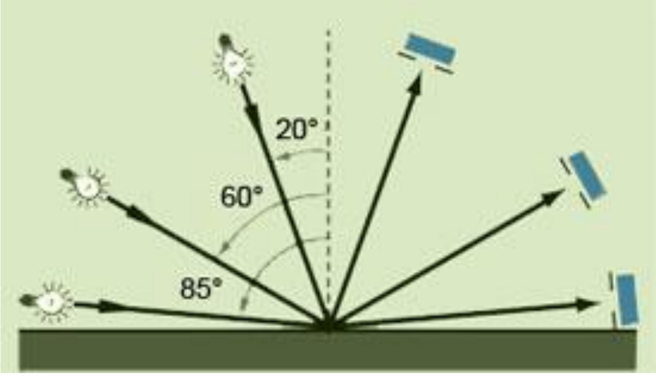
- Outer layer towards the light source
  - Inner layer open to machine
- Tests were ongoing until we reached a failure point.
- Required unrealistic time scales for practical testing.

Dosage vs Real World

- 0.35 W/m^2 is assumed to be the average irradiance during the equinox in South Florida
- This gives us an acceleration factor of 2 to 1
- 1000 hrs of testing = ~84 days of real world solar exposure
  - 7000 hours = ~588 days = ~1.61 years
- This test does not come close to demonstrating extended lifetime performance
  - Designed only to show infant mortality only

Gloss

- Early indicator of the start of problems
- Measured multiple angles
  - 20º low gloss
  - 60º semi gloss
  - 85º high gloss



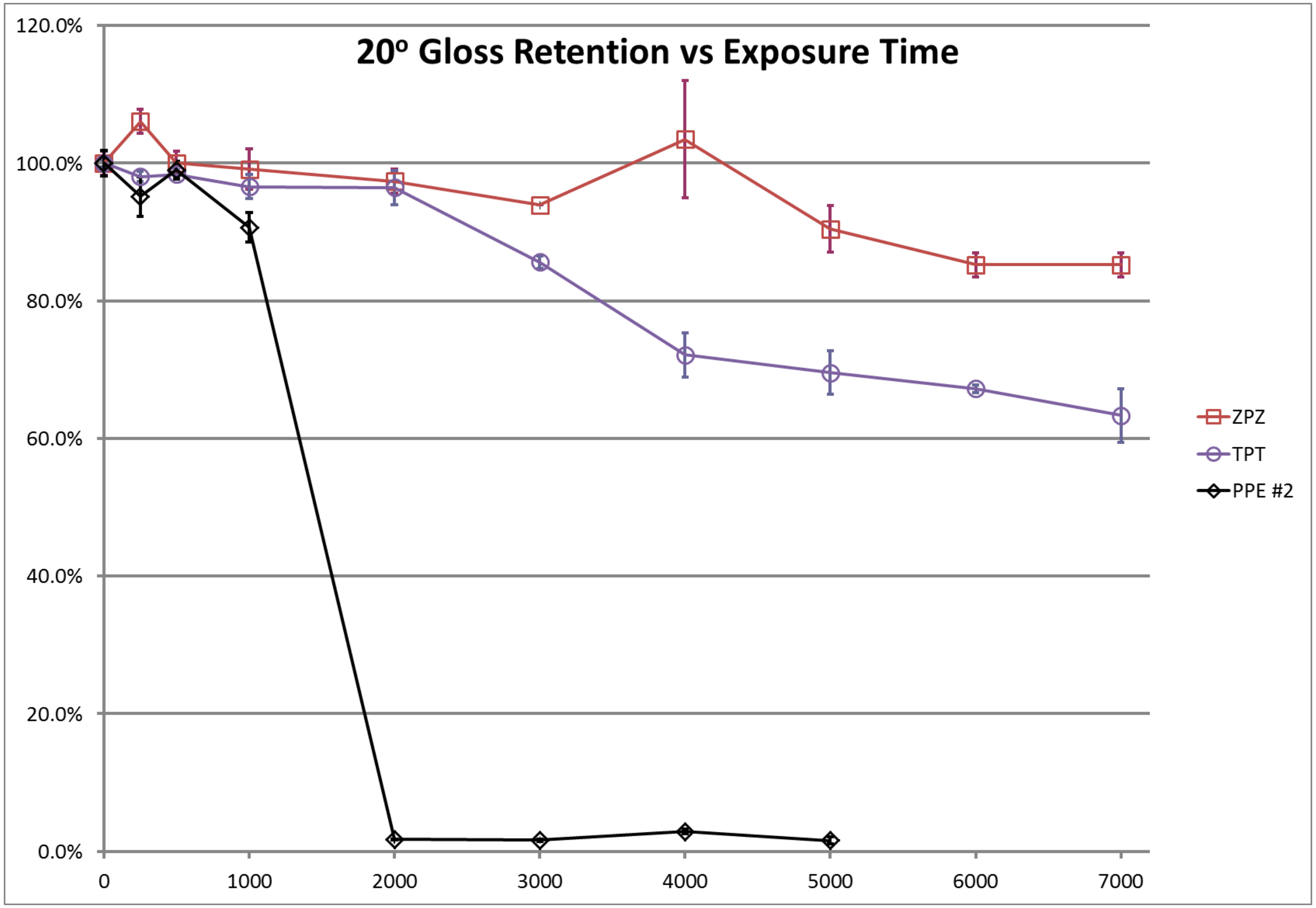
- Initial gloss levels vary widely
  - Interested in change over time

Gloss

- Gloss results
  - PPE#2 backsheets exhibited a step change in all gloss angles at 2000 hours
  - Both PET based backsheets exhibit significantly decreased gloss
  - Set original value as 100%
  - 95% confidence interval shown with Y axis error bars

Sample	Age	% 20º Gloss Retention
ZPZ	7000	85.2 %
ZPE	7000	106.6 %
TPT	7000	63.4 %
TPE	7000	74.9 %
KPE	7000	73.0 %
PPE #1	7000	10.1 %
PPE #2	5000	1.6 %

Gloss



PET shows a significant decrease in gloss over time.

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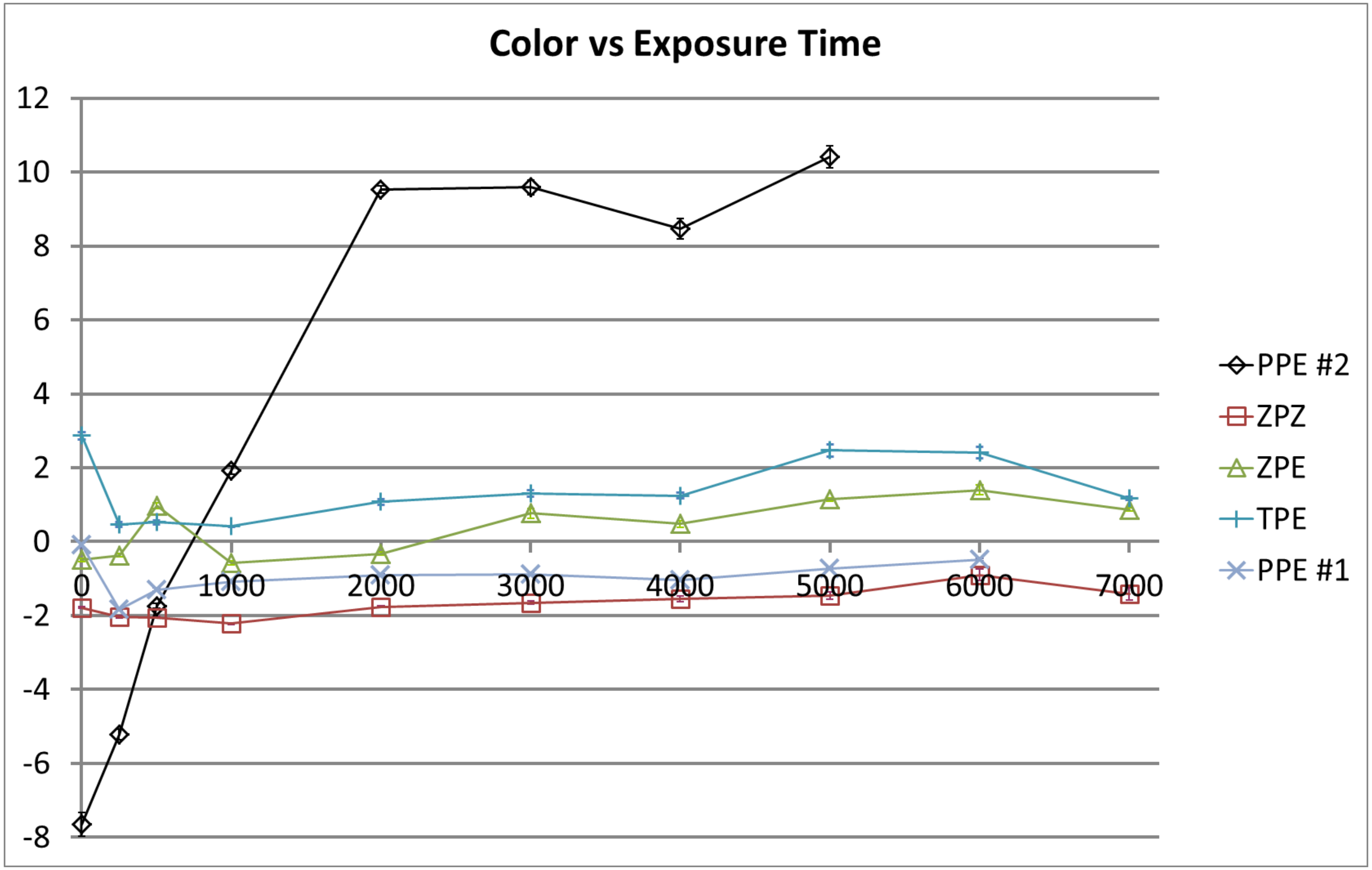
Color

- Color changes indicate differences in the condition of a surface.
- Yellowness index using ASTM E313
- Initial values also varied widely here, please compare changes.
- Confidence Intervals of 95% are also shown here.

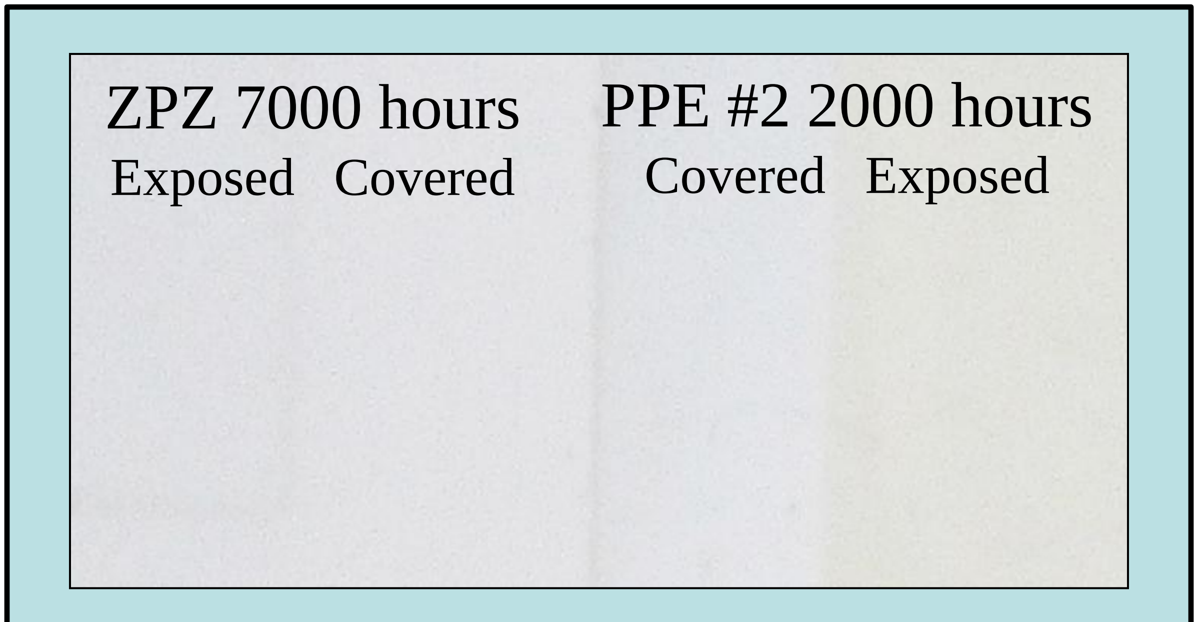
Color



PET shows significant yellowing over time.

Color

- Exposed area vs. the area covered by the sample holder



PPE #2 visibly degrades after only 500 hours under UV.

Color

- PET Samples
  - PPE #2 exhibited the most change
    - Visible change at 500 hours
    - 2000 hours

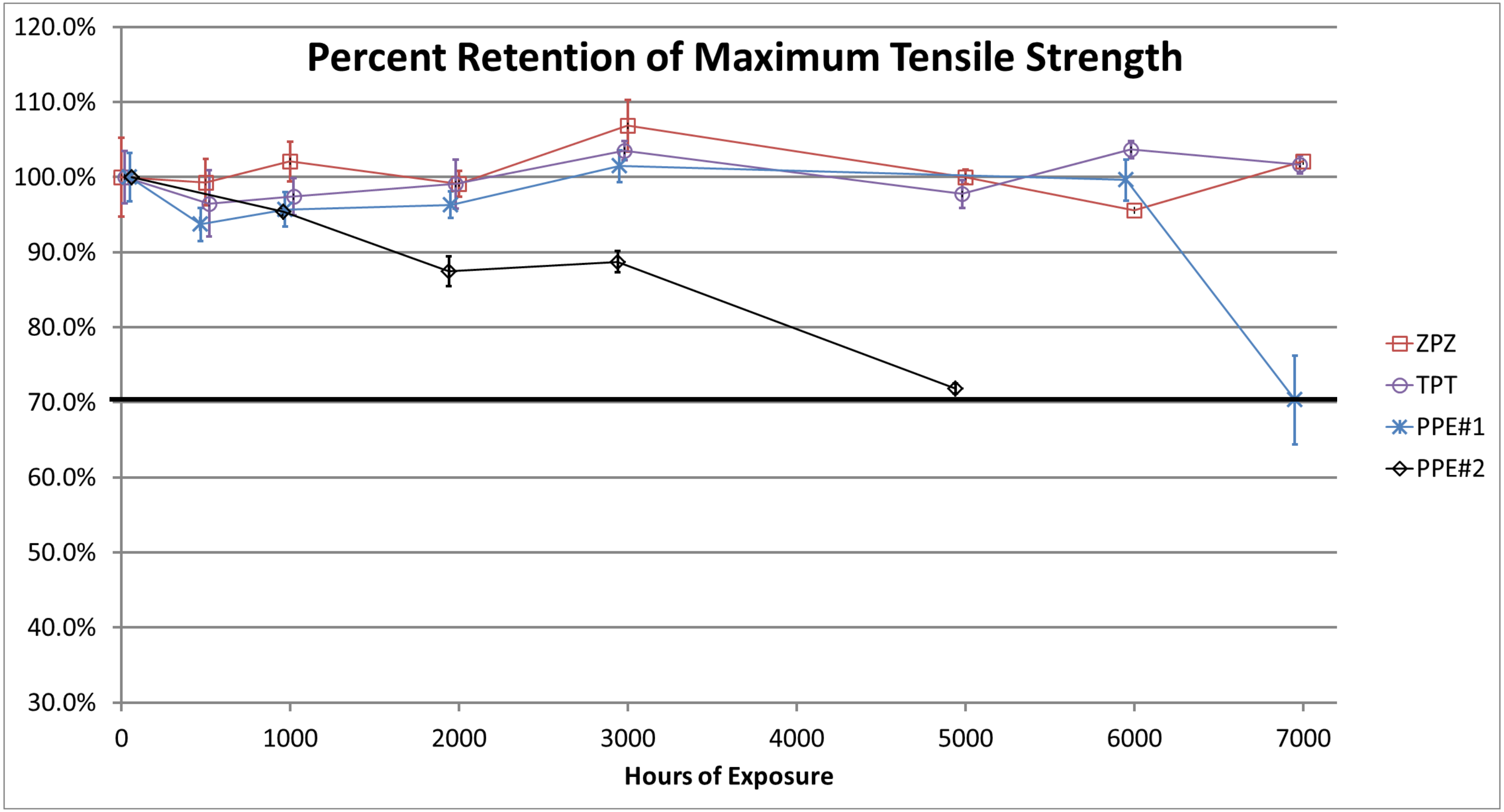
- Fluoropolymer samples
  - Little to no change in coloration even after 7000 hours

Tensile Strength

- Following ASTM 882
  - Determine the change in mechanical properties
  - Initial strain rate was set to 10 mm/mm-min.
  - Each exposure condition was tested.

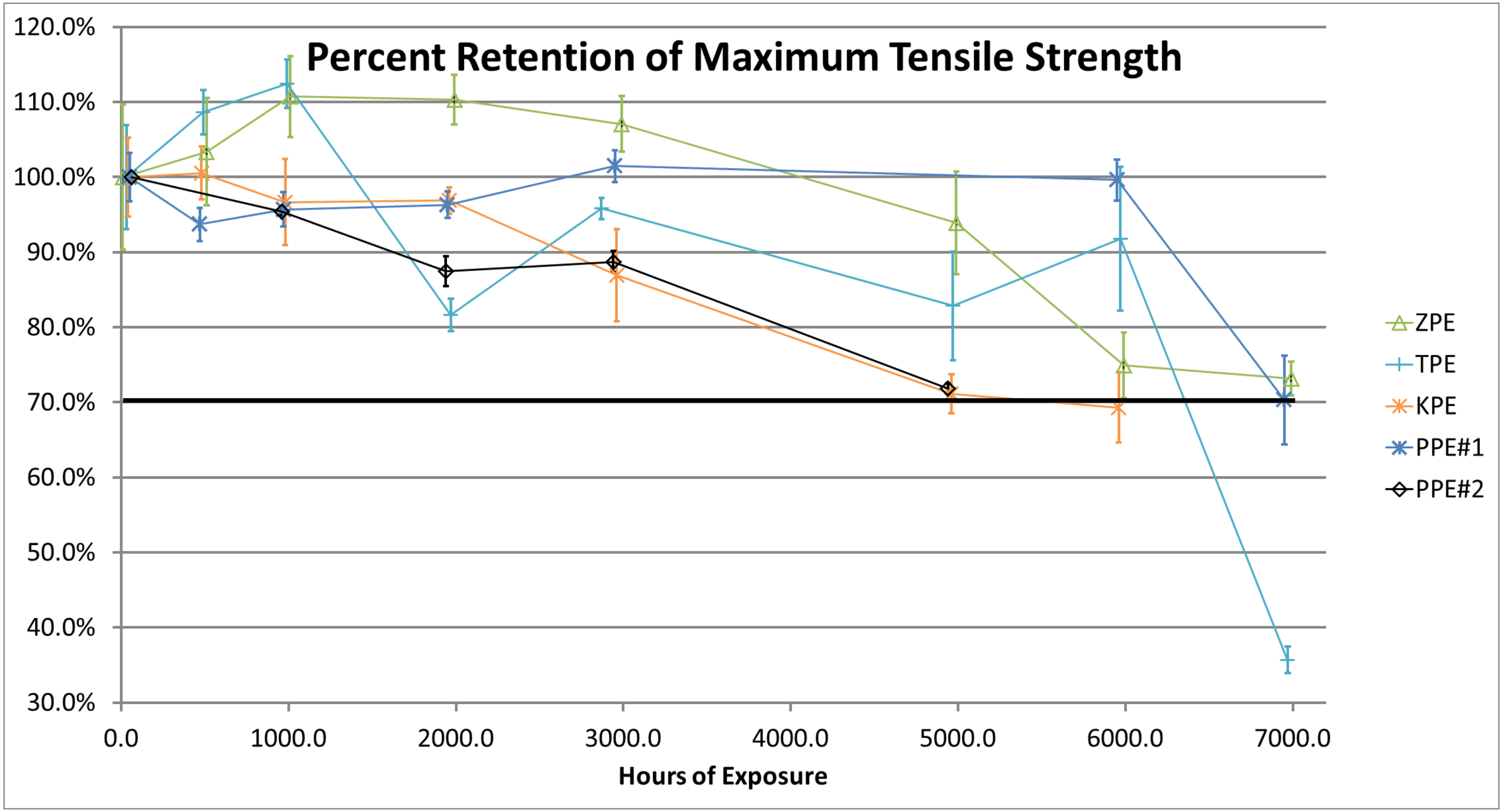
- In the following graph tensile stress at break is shown.
  - Confidence Intervals at 95%

Tensile Strength



PPE loses Tensile strength faster than all other materials.

Tensile Strength



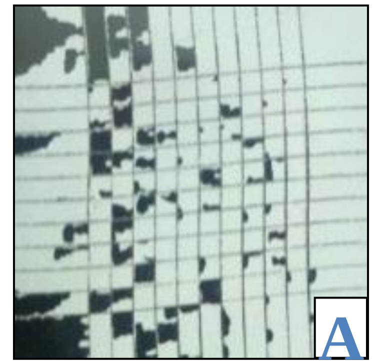
Single sided samples lose tensile strength faster than double sided.

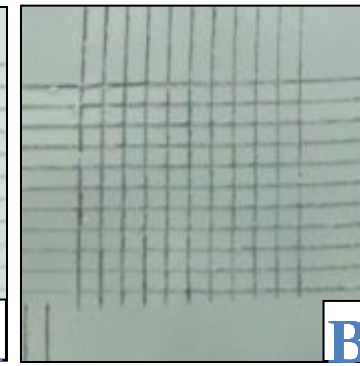
Tensile Strength

- Some deterioration was observed
  - Some samples have failed (70% of the original properties) after several thousand hours of testing
  - Failures due to humidity or irradiation or both?
- PPE #2 samples failed first
- Some asymmetric samples (i.e. TPE, KPE) have begun to show deterioration.
- Samples protected from both sides have not failed after 7000 hours

Adhesion

- ASTM 3359
  - 10 by 10 set of 1 mm squares.
  - Apply Permacel 99 tape and wait for 90 seconds
  - Removed at 180^{o} and a steady rate
  - Rating it 0A through 5A
    - # of squares not damaged
    - 0 to 100 where 100 is the best result
    - Test 5 locations per sample and average
- Confirmed testing was uniform across all samples
  - 180^{o} Peel test on Instron @ 250 mm/min





Sample	N/cm ± 95% CI
ZPZ	4.67 ± 0.63
TPT	4.71 ± 0.36
PPE #2	4.94 ± 0.33

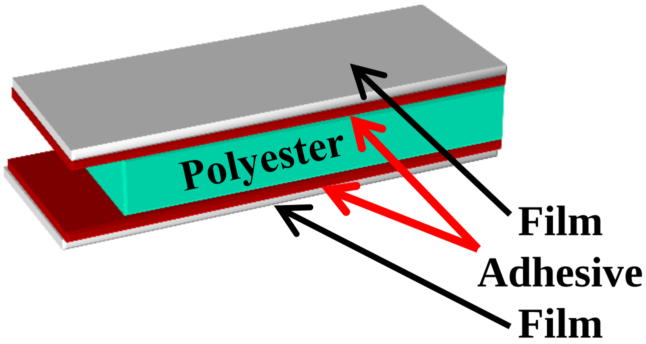
Adhesion

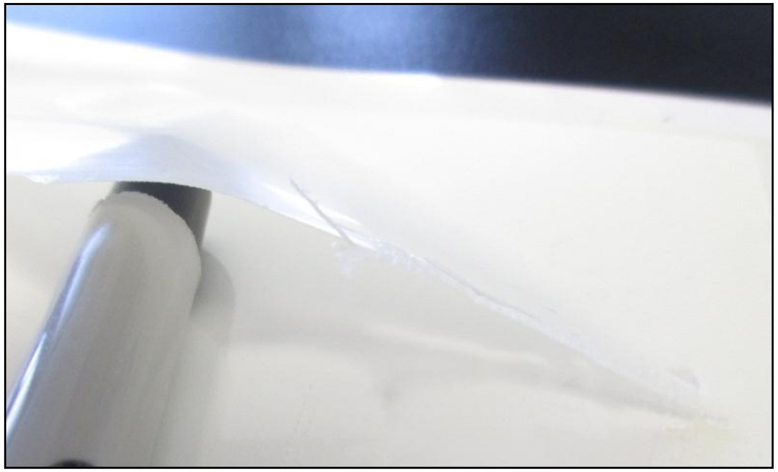
Exposure Time	ZPZ	ZPE	TPT	TPE	KPE	PET #1	PET #2
0	100	100	100	100	100	100	100
1000	100	100	100	100	100	100	92.4
2000	100	100	100	100	100	100	24
3000	100	100	100	100	100	100	0
6000	100	100	100	100	100	100	
7000	100	99.4	100	100	100	100	

No Fluoropolymers fail adhesion at 7000 hours.

Adhesion

- PPE #2 delaminates completely by 3000 hours
  - Failure of interlayer adhesive
- Laminated constructions all share the concern of failed adhesive
  - TPT and PPE are incorrect





Backsheet Results

Sample Name	2000 Hour Results				7000 Hour Results			
	Gloss	Color	Tensile	Adhesion	Gloss	Color	Tensile	Adhesion
ZPZ	✓	✓	✓	✓	✓	✓	✓	✓
ZPE	✓	✓	✓	✓	✓	✓	✓	✓
TPT	✓	✓	✓	✓	✓	✓	✓	✓
TPE	✓	✓	✓	✓	✓	✓	✗	✓
KPE	✓	✓	✓	✓	✓	✓	✗	✓
PPE # 1	✓	✓	✓	✓	✗	✓	✗	✓
PPE # 2	✗	✗	✓	✗	✗	✗	✗	✗

Conclusions

- Fluorinated materials
  - Little to no significant changes in backsheets protected on both sides
  - Samples beginning to fail only at 6000 and 7000 hours for samples protected on one side
- Degradation Evident in PPE Constructions
  - Loss of gloss in both samples
  - Significant changes in the coloration
  - Delamination
  - Failure in the maximum tensile stress

Conclusions

- Solar panels are expected to last 20-30 years
- Current test method requires a very weak dosage
  - Very long testing times
- More stringent sunlight exposure will help accelerated testing
- Materials protected with fluoropolymers from both sides show the best performance over time

Thank you for your time.

Questions or Comments?

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