EVA Adhesion Test Method,180^{o}-peel vs. T-peel, in PV applications

- Investigation on Avery Dennison coated and a commercial TPT* backsheets

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Abstract

In all technical specifications of PV backsheets from various suppliers, peel strength with EVA is a key criteria to evaluate long term durability and reliability in the field. However, current test methods (such as 180º-peel or 90º-peel) aggressively overexert any potential forces experienced in the field. Moreover, the peel tests themselves ‘contaminate’ results since they introduce possible failure. Specifically, defects such as micro cracks are likely to form due to high force and peel angle applied.

Avery Dennison developed a coated backsheet formulation based on its 30 years of experience formulating and producing highly engineered UV protection coatings for outdoor applications in auto, aerospace, and housing. Avery’s backsheet has been tested for damp heat (2000 hours), thermal cycles (400) and humidity freeze (20 cycles), and the results highlight excellent (100%) interlayer adhesion (coating←→PET) according to cross hatch adhesion testing (ASTM D 3359).

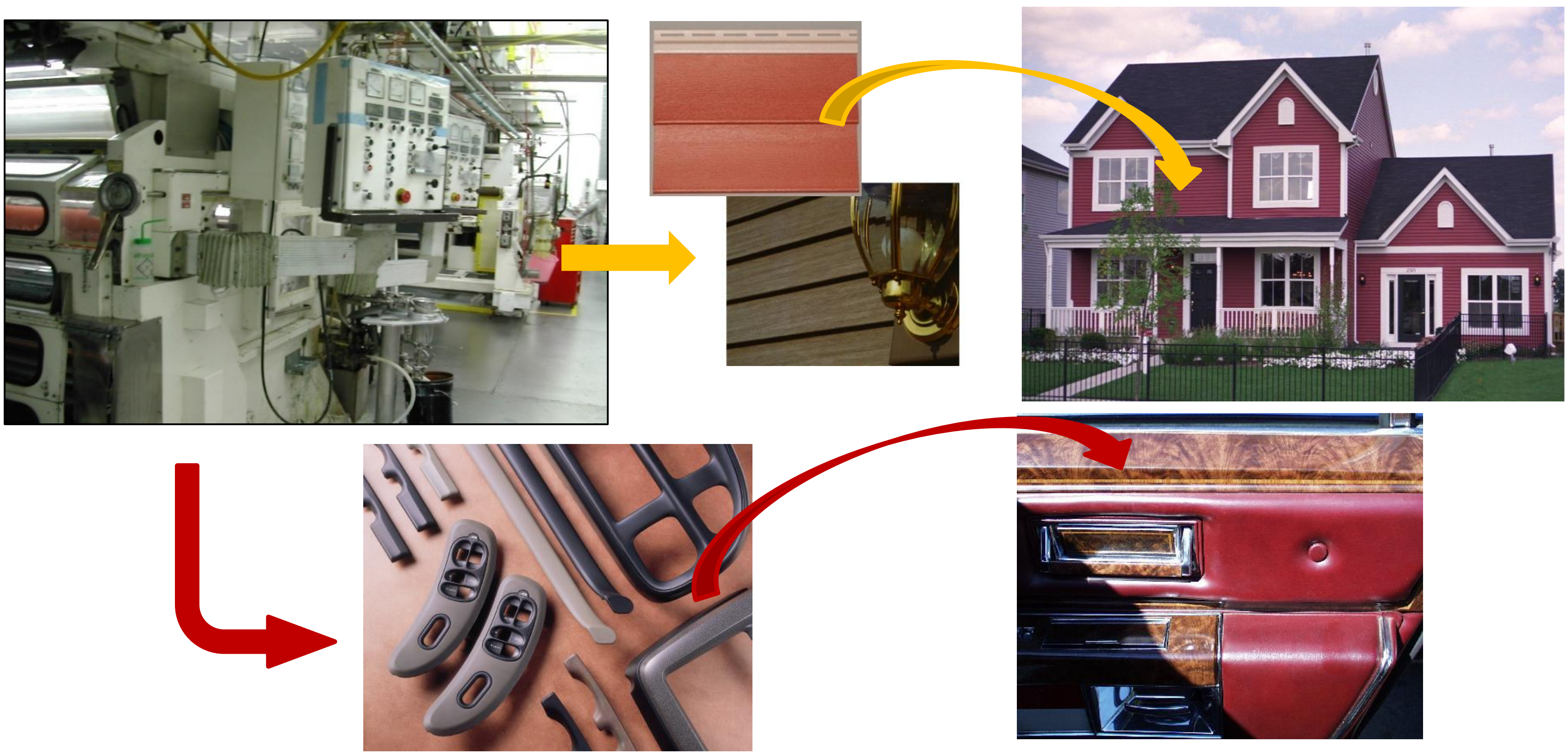
In order to measure bond strength between EVA and the backsheet, Avery Dennison has concluded that T-peel testing (ASTM D 1876) is a appropriately aggressive test of adhesion to proxy for possible module conditions and 25+ year long life *without* introducing failure itself (such as micro cracks when the peel starts), and is both reproducible and consistent unlike 180º peel. Avery Dennison bases its conclusion both on results in its own PV labs and on its extensive experience in the paints and coatings industry where 90º peel testing has been the industry standard for many decades. Using T-peel testing, Avery Dennison’s backsheet delivers high bond strength to EVA (>60 N/cm), with high consistency/reproducibility.

Due to the general nature of laminates versus coatings, a 180-degree peel test could favor one construction (laminates) over others (coated) in an aggressive angled peel test, creating otherwise non-existing failure and therefore misleading conclusions about lifetime, forcing module fabs to purchase unnecessarily higher cost backsheets.

Therefore, Avery Dennison recommends eliminating 180º peel testing with T-peel testing and focusing on test data from damp heat, thermal cycling, humidity freeze, MWTR and cross hatch to demonstrate reliable long term performance in any environmental conditions.

Technology Based on More than 20 Years Out-door Products

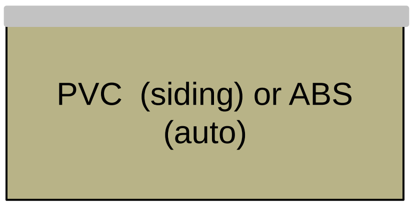
- Avery Dennison has **20+ years expertise** manufacturing high-performance outdoor films for aerospace, automotive, and architectural applications
- PV backsheets employ the **same manufacturing process know-how**



Avery Dennison's Fluoropolymer coated PV Backsheet

20+ years of Avery Dennison fluoropolymer coating technology for vinyl siding

Weather proof fluorocoat

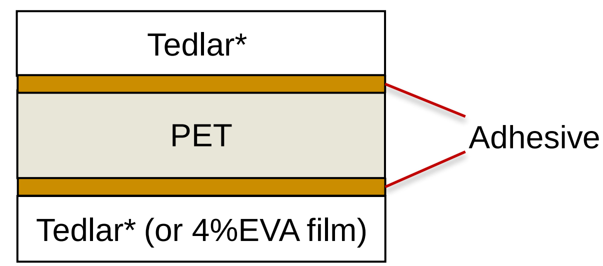


Technology transfer

Avery Dennison FPF Backsheet

Comparison To TPT*

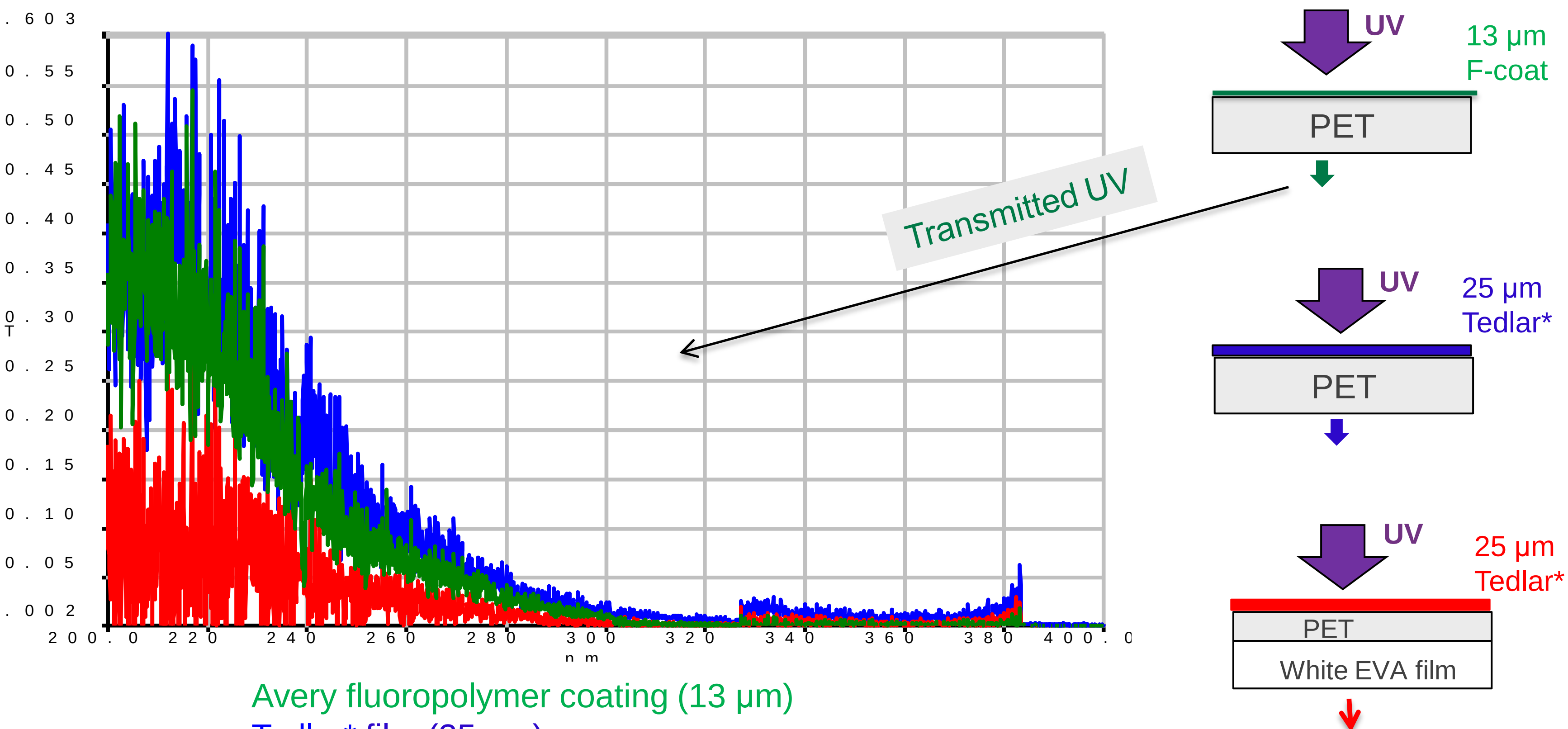
TPT* (or TPE) Backsheet



- The fluoropolymer coating is strongly bonded to PET in a high-speed coating process that precisely meters the coating onto the PET web, delivering impressive aesthetic and long-life *exterior* performance
- By coating vs. laminating, half the thickness of fluoropolymer (13um coat vs. 25um laminate) and <u>no</u> adhesives delivers equal or better performance

UV Protection

For protection of UV, a layer of 13 µm fluoropolymer coating (green) equals to 25 µm Tedlar* (blue), which translates into less material, lower cost, and +/- comparable performance required for 25+ year lifetimes



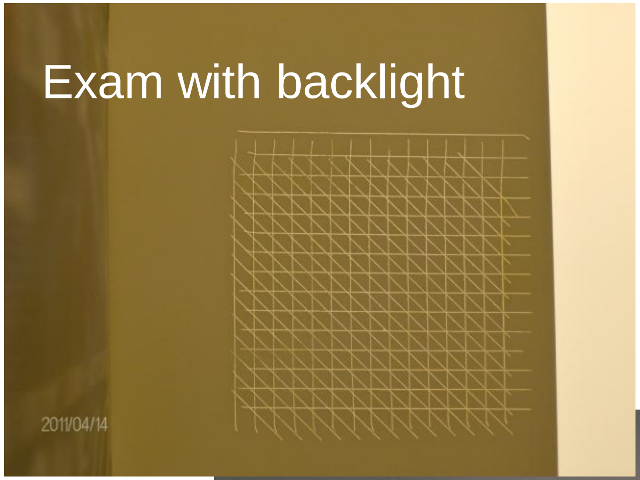
Avery fluoropolymer coating (13 µm)
Tedlar* film (25 µm)
TPE backsheet (25 µm Tedlar*+125 µm PET+50 µm EVA film)

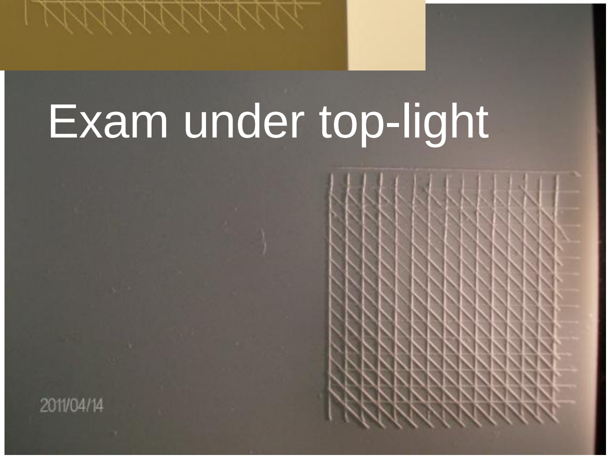
Avery Dennison's FPF Backsheet Delivers ~Double IEC Standards

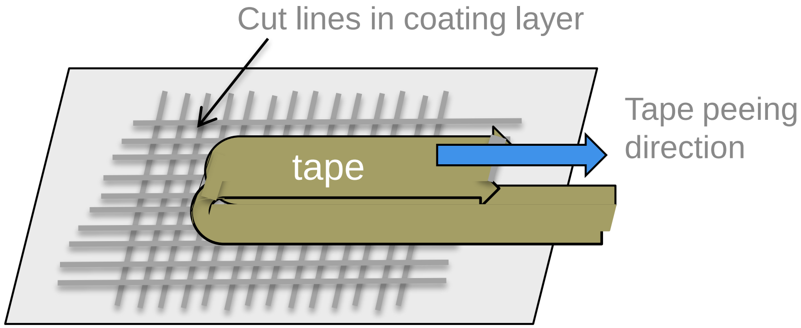
Testing Name	Test Method	Units	value	2X / extra test
EVA peel strength	ASTM D1876 (T-peel)	N/cm	> 60	180^o peel, large data variation
Water vapor transmission rate (WVTR)	ASTM F1249 (ASTM E96)	g/m^2day	< 1.4 (23℃/100%RH) < 2.5 (38℃/100%)	after 1000 hours of DH, no change (free standing backsheet)
Damp heat 85/85	IEC61215.10.13	1000 hr	No visual defects, no delam, slight discoloration (ΔE< 2)	**2000 hr**, no visual defects, slight discoloration (ΔE< 2) and **no delam**
Thermal cycling	IEC61215.10.11	200 cycles	No visual defects, no delam, no discoloration (ΔE< 1) ,	**400 cycles**, no visual defects, **no delam**, (ΔE< 1)
Humidity freeze	IEC61215.10.11	10 cycles	no visual defects, no discoloration, no delam	**20 cycles**, no visual defects, no delam, no discoloration, **no delam** (ΔE< 0.5)
Evaluation coating adhesion to PET (cross hatch)	ASTM D3359	%	100% (or 5B)	100% after QUV 1000hr 100% after DH 2000hr 100% after TC 400 cycle 100% after HF 20 cycles

Highest Rating (ASTM 3359) of Coating-PET Bonding

After crosshatch test (tape lift/adhesion test), 100% coating adhesion (5B rating) achieved.
Note: shown below, diagonal cut lines are more aggressive/hasher than the ASTM 3559 standard

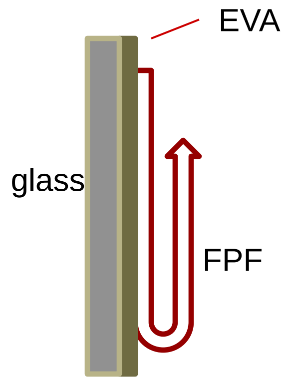




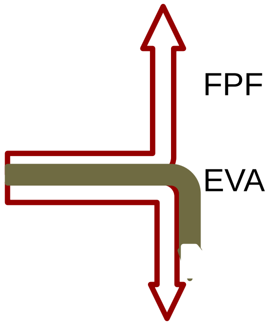


ASTM 3559 Classification	percent area of removed coating
5B	0%
4B	<5%
3B	5-15%
2B	15-35%
1B	35-65%
0B	>65%

Coated Backsheet
- Difference observed between 180º-peel and T-peel



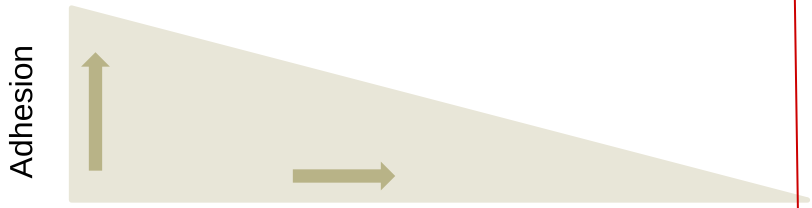
180-peel variation



T-peel variation

180-peel variation

adhesion (N/cm)	failure mode
14	PET / coating
↓	↓
104	coating / EVA



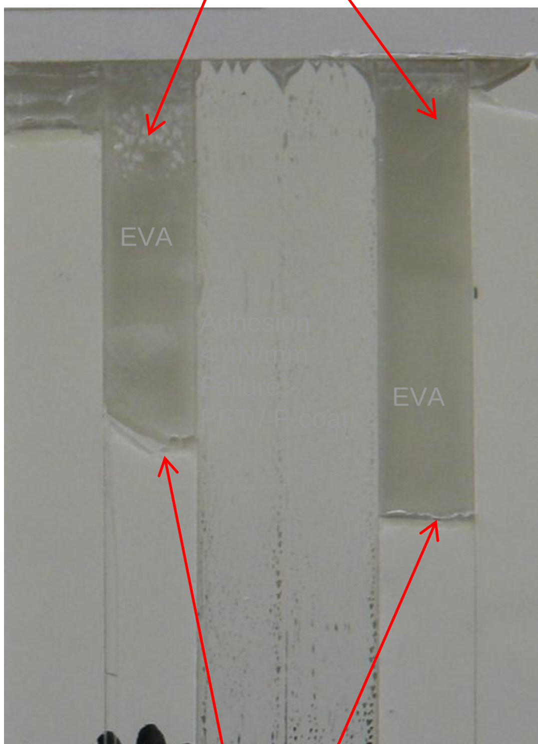
PET / coating failure increased

T-peel variation

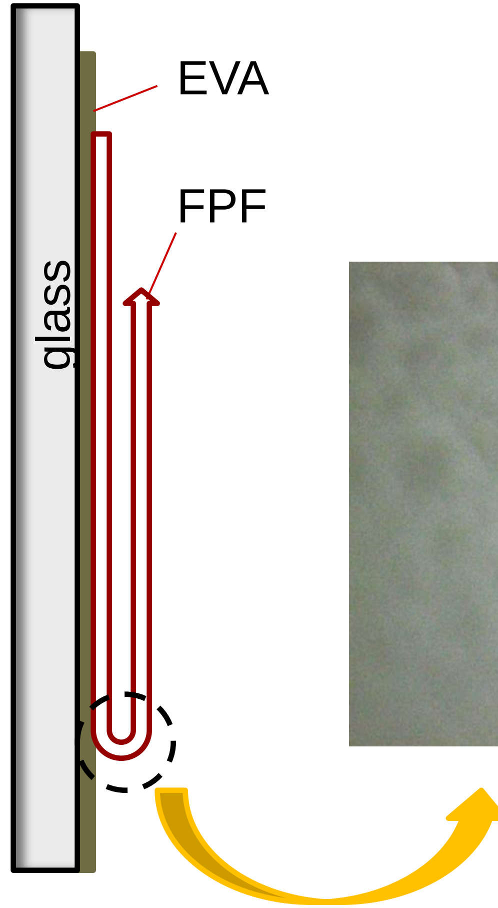
adhesion (N/cm)	failure mode
68	coating / EVA
81	coating / EVA

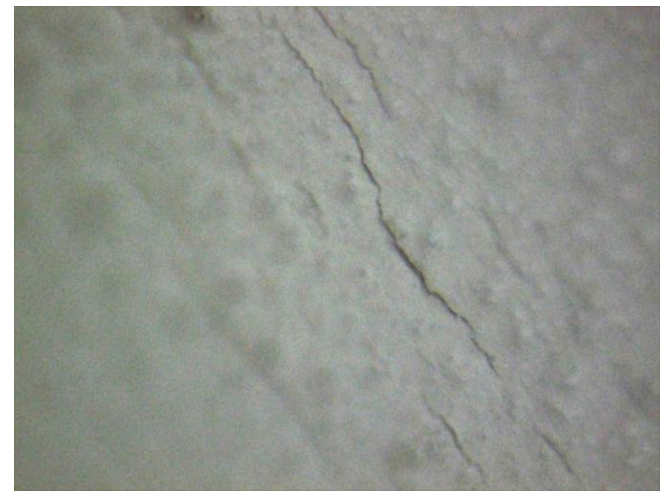
Concerns for 180º Peel of Coated Backsheet

Adhesion >> 40 N/cm
Failure: F-coat / EVA

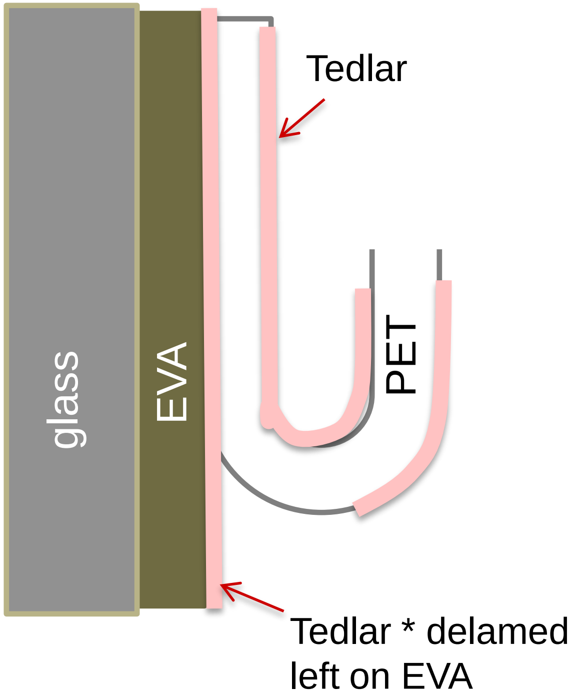


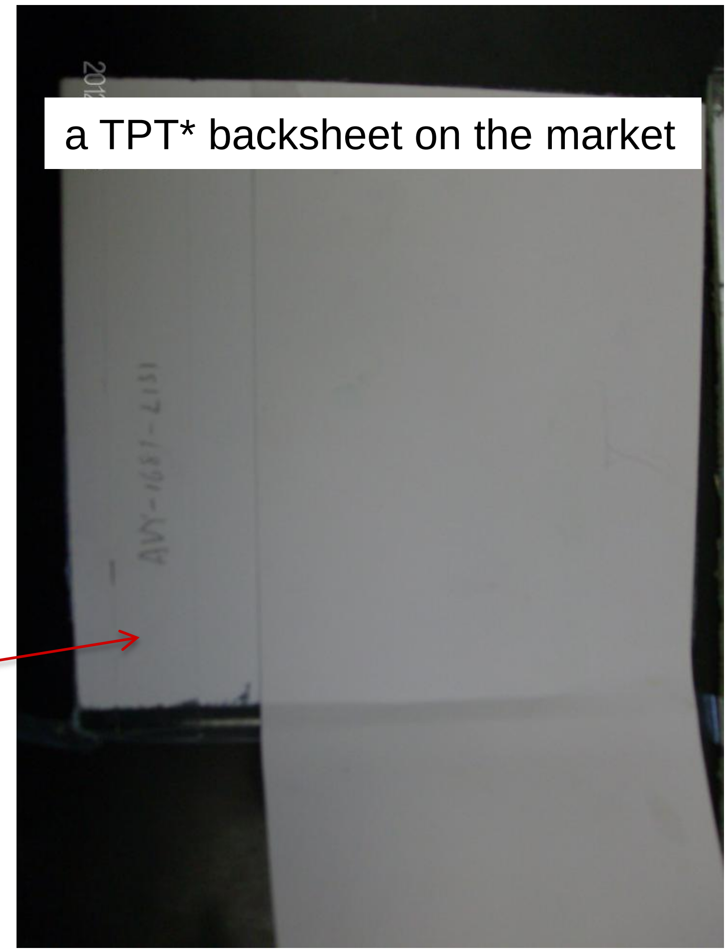
Backsheet
Broken point





Concerns for 180º-peel of Laminated Backsheet (TPT*)





Inter layer failure, T layer 100% delam'ed from PET, adhesion = 6 N/cm

Conclusions

- Historical data indicates that A PV module will not encounter forces like 180º, 90º, or T-peel[1]; therefore, 180º peel does not truly reflect a realistic failure mode in PV modules

- Comparing to 90º, or T-peel, 180º peel is highly likely to *create* defects, such as cracks, when the test starts, especially for a sharper folding at a high bond strength between backsheet and EVA

- Compared to 180º peel, T-peel is sufficiently aggressive and appropriate for all current backsheet constructions and can also be equally aggressively/ accurately applied to measure EVA adhesion and no glass needed (backsheet/EVA/backsheet laminate)

- Adhesion failure in a backsheet laminate sample (backsheet/EVA/glass or backsheet/EVA/backsheet) highlights interface with lowest interfacial adhesion (so measuring the peel strength prior to failure indicates lowest interfacial adhesion strength for layers between two 'clamped' layers)

- 180º peel testing is no longer appropriate (in fact inaccurate as it introduces failure mechanisms) for back sheet constructions on the market today and may lead to backsheet over-engineering and higher cost

[1] **J.Wohlgemuth, NREL,** "Module Component of PV Tutorial", Integration of Renewable & Distributed Energy Resources Conference, 6 Dec 2010; and **David DeGraaf, et al., Sun Power Corp,** "Degradation Mechanisms in Si Module Technologies Observed in the Field; Their Analysis and Statistics", NREL 2011 Photovoltaic Module Reliability Workshop, 16 Feb 2011

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