NATIONAL
LABORATORY
OF THE ROCKIES

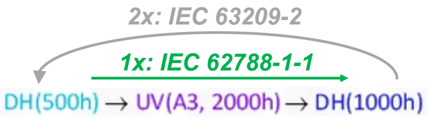
Lessons from the IEC Durability of Adhesion Accelerated Test Sequence

Rachael L. Arnold*, David C. Miller, Aubrey Jackson
National Laboratory of the Rockies, Golden, CO, USA
*Contact: rachael.arnold@nlr.gov

Background

Interfacial delamination, a long-standing reliability concern, remains to be verified with the durability of adhesion aging sequence in IEC 62788-1-1 and IEC 63209-2. The **proposed accelerated test sequences** are being demonstrated using the fracture mechanics-based single cantilever beam (SCB) method.

Samples were created to compare the adhesion of EVA encapsulant to glass or to solar cells. The EVA encapsulants have varying amounts of the siloxane coupling agent which enhances adhesion at the EVA interfaces. The encapsulants may have experienced varying pre-shrinking techniques during manufacturing, which should reduce differences in strain and adhesion between the sample periphery and center.



Sequence based on Miller et. al, https://doi.org/10.1002/pip.3255 for:
conditioning *then* hydrolytic aging: Damp Heat (dark, 85˚C, 85%RH)
UV photodegradation: IEC 62788-7-2 A3 → 0.8 W/m² UV, 65˚C, 20%RH

STR 15585 (UV-T) Encapsulants

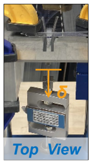
EVA-A: 5% siloxane
EVA-B: 100% siloxane
} pilot line fabrication – "old" (unknown pre-shrinking)

EVA-C: 100% siloxane ← from production line – "new" (balanced change in dimension)
(suspected A and B to have expired in package)

For SCB adhesion test preparation and method details, see the poster NLR/PO-5K00-93108 in the 2025 PVRW proceedings.

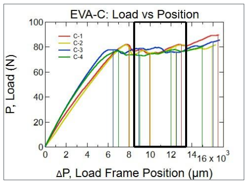
Single Cantilever Beam Adhesion Testing

Load frame: Delaminator (DTS Company)
Load Cell Capacity: 180 N
Displacement Velocity: 10 μm/s



Top View

Bottom View



Raw data from adhesion test, including ***marked points****.*

Equation A.3 from the IEC 62788-6-3 standard is used to find the debond energy at discrete read points.

$$G_c = \frac{P_c}{2\tan(\theta/2)} \frac{\Delta_i}{a_i^2}$$

P_c = critical load
θ = included beam angle
Δ = load line displacement
a = debond length

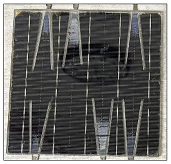
Recent Results

DH(500h) → UV(A3, 2000h) → DH(1000h) → DH(500h) → $\boxed{\text{UV(A3, 2000h)}}$ → DH(1000h)

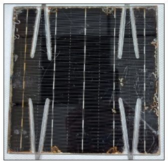
Cell Adhesion Data

Materials
Substrate Glass: 5.7-mm Low Iron Starphire (Vitro)

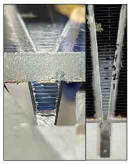
Cells: >152-mm, Mono-Si, PERC, BiFi Anti-PID front (CSI)



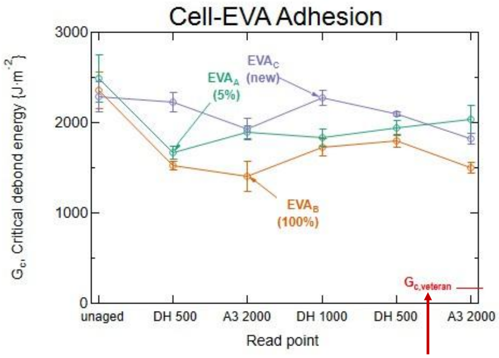
Unaged EVA-C after SCB test.



EVA-C, 2nd DH 500h before SCB test.



EVA-A, 1st A3 2000h during and after SCB test.

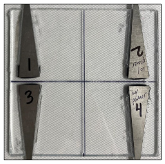


G_c, Critical Threshold (Veteran Modules): 160 J/m²
Bosco et. al, DOI:10.1109/PVSC.2017.8366641

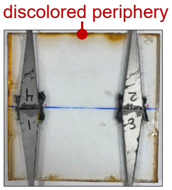
Glass Adhesion Data

Materials
Substrate Glass: 5.7-mm Low Iron Starphire (Vitro)

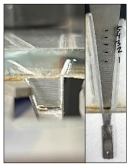
Superstrate Glass: 0.1-mm Willow (Corning Inc.)



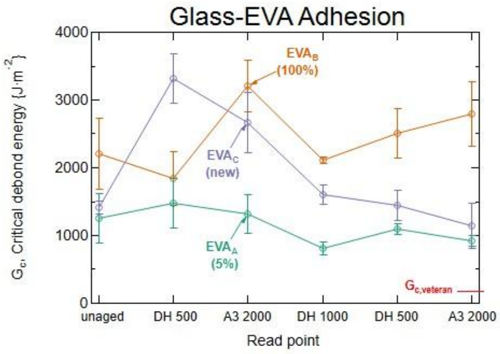
Unaged EVA-C before SCB test.



EVA-C, 2nd DH 500h before SCB test.

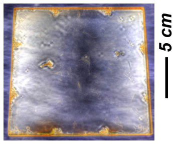


EVA-A, 1st DH 1000h during and after SCB test.

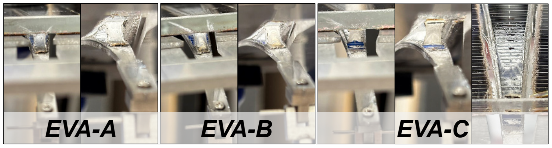


Periphery vs Center

- Lack of strain in PE imaging except at local features suggests only O_2/H_2O (scission vs. cross-linking) dominates edge vs. center results (all EVA's).
- EVA-C debonds from substrate glass before A and B.



EVA-A (g-g), after 2nd A3 2000h



Images of representative beams during SCB testing after second DH 500h aging: EVA-A front and side views, EVA-B front and side views, EVA-C front, side, and top views (left to right).

Summary

- Complete accelerated test sequence and SCB adhesion.
- Additional characterizations: photoelasticity imaging, microscopy (EVA morphology), FTIR (polymer structure)

Recommended IEC Revisions

- **Use A3 for glass-glass and A1 for glass-cell to achieve similar $T_{specimen}$ ~ 70˚C during UV weathering.**
- Coupon mounting method (swiss clips caused damage in UV weathering), specimen conditioning (after aging), test distance (from periphery) need improvement.
- Thick glass may be bonded to reinforce an embrittled glass substrate.
- Test within manufacturer's shelf-life.

Acknowledgement: The authors would like to thank Dr. Nick Bosco of NLR and Dr. Alan Liu of Stanford for their discussion related to SCB testing and analysis.

This work was authored by the National Laboratory of the Rockies for the U.S. Department of Energy (DOE), operated under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Critical Minerals and Energy Innovation Solar Energy Technologies Office for agreement 52785 The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

PV Reliability Workshop (PVRW) 2026
Lakewood, CO, USA
February 24-26, 2026
NLR/PO-5K00-98784