U.S. Department of Energy
HelioCon
Heliostat Consortium for Concentrating Solar-Thermal Power

Performance and Durability Testing of Advanced Composite Mirror Facets

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June 16th 2024 • ASME ES24

Outline

- Motivation
- Facet structure and establishing a test plan
- Down selection of adhesive materials using peel testing
- Considerations to hermetically seal composite facet
- Results thus far
- Summary

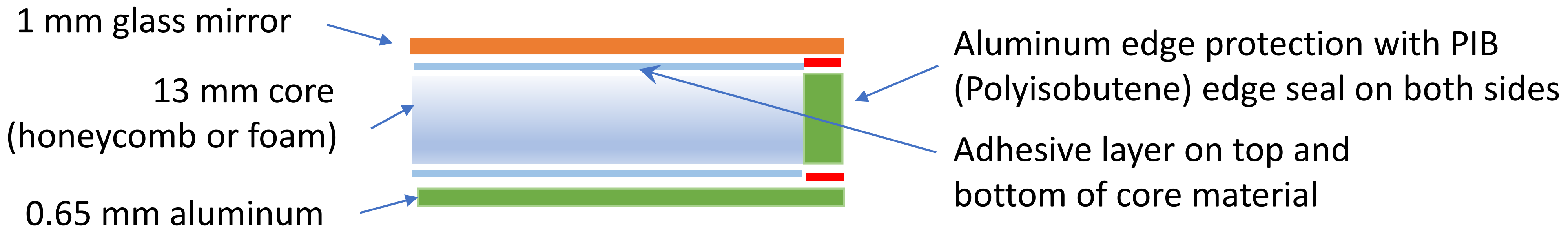
Motivation

- 4 mm mirrors with ~93% reflectivity are status quo for CSP reflectors
- 1 mm mirrors are 95.5% reflective but are too fragile as stand-alone facets
- Heliostats' performance can affect LCOE by 2.3 times greater degree than their cost[1]
- Sandwich facets offer potential benefits
  - Structural which enables reduced supporting steel
  - Weight reduction
  - Operations and maintenance benefits
- Challenges
  - Demonstrate long-term durability
  - Previous work showed too much cost increase
  - Demonstrate optical performance over operational temperature range

[1]J. Coventry et al., Heliostat Cost Down Scoping Study - Final Report. 2016

Facet structure and materials

- 1-year, low-budget project (i.e. can't consider all options but goal is to still provide valuable outcomes)



- 1 mm mirror for improved reflectivity
- Cores choices for weight reduction but provide strength (foam is recycled and lower cost than honeycomb)
- 3 adhesives under consideration due availability/PV scale manufacturing experience/existing NREL lamination equipment
- Edge seal chosen from PV experience and offers potential cost reduction through elimination of solar mirror protective paint, (at scale can mimic insulated glass insert manufacturing)

Details on material considerations

- Mirror backside paint not to exceed 120 C
- Initial consideration of adhesives
  - 3M 588 tape (107 C bond temperature, 2-5s at 15 psi) readily available
  - Ethylene Vinyl Acetate (EVA): 120 C but 10s of minutes for crosslinking, long-term durability proven in PV, low-cost (supply on hand)
  - Polyolefin Elastomers (POE): same reasons as EVA but EVA degradation can produce acetic acid and potential to degrade silver layer while POE should not (supply on hand)
  - Epoxy films or liquid applications *(potential at manufacturing scale but appropriate quantities not readily available)*
  - Construction sandwich adhesives (2 part urethanes, often used, short press time and heating not necessary) *(potential at manufacturing scale but appropriate quantities not readily available)*
- Aramid honeycomb is used by aviation industry to achieve lightweight high strength structures
- Pop Foam: a lightweight, low-cost rigid closed cell foam made from recycled plastic bottles.
- PIB edge seal (used in glass-glass PV modules, manufactured with embedded desiccant to reduce moisture transmission rate compared to other plastics, has been proven that you need a cm of length for moisture diffusion over 1000 hours at 85% humidity and 85 C

Goals and test plan

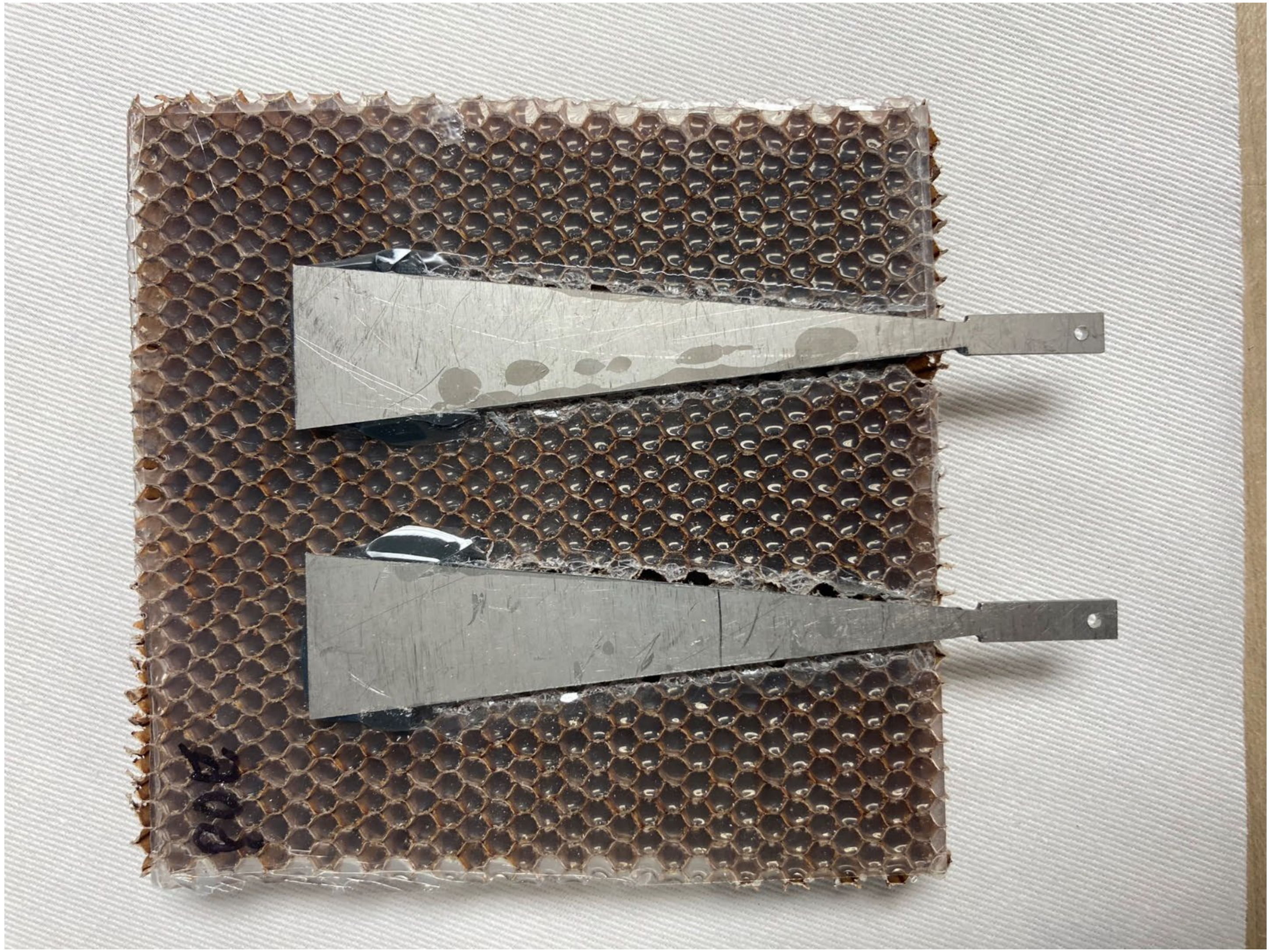
- Use peel testing (determine bond strength) to down select to one adhesive to stay within budget and time constraints
- Prove feasibility of edge seal to protect mirror silver lay (using 3mm indoor mirrors)
- Subject 3 samples each (10 cm by 10 cm sandwich facet coupons of one stack type) to:
  - 1000 hours damp heat (65C/85% RH)
  - 1000 hours of UV plus humidity
  - 240 hours of thermal cycling plus humidity
- Measure and report degradation through above accelerated testing
- Test durability of 1mm mirrors against hail using 61 cm by 61 cm sandwich facets with both honeycomb and Pop foam cores
  - Test at different incident angles and different hail ball sizes until failure

Samples for peel testing

- Columns from left to right are the adhesive materials: 3M tape, POE, and EVA (the tape is an orangish color while the POE and EVA cure clear)
- Rows from top to bottom are each of the surfaces of adhesion: aluminum, backside mirror paint, Pop foam, Aramid honeycomb
- Note that the adhesive material has been laminated between the given material and a strong ultra-thin glass that is then adhered to a titanium beam for peel testing

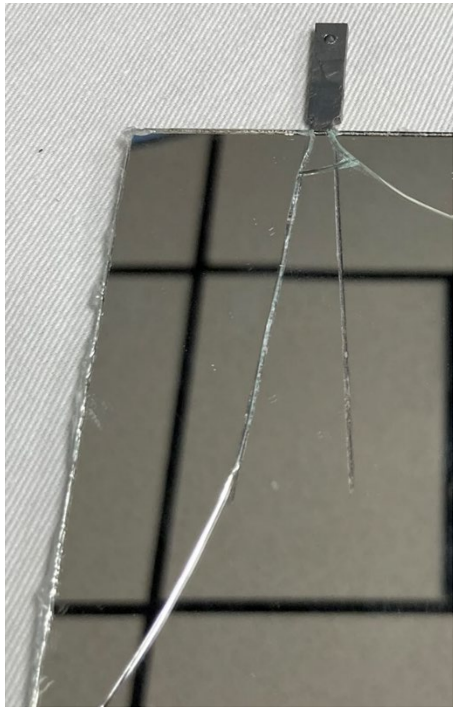
A sample prepared for peel testing

- Here the POE/Honeycomb sample has 2 titanium beams adhered to the ultra-thin glass with epoxy. The glass is cut along the edges of the beam
- The ultra-thin glass is known to have a suitably strong bond with POE, EVA and epoxy while the titanium also has a strong bond with the epoxy. The bond between the POE and the honeycomb is the weakest and therefore the bond that is measured as it breaks when peeling.



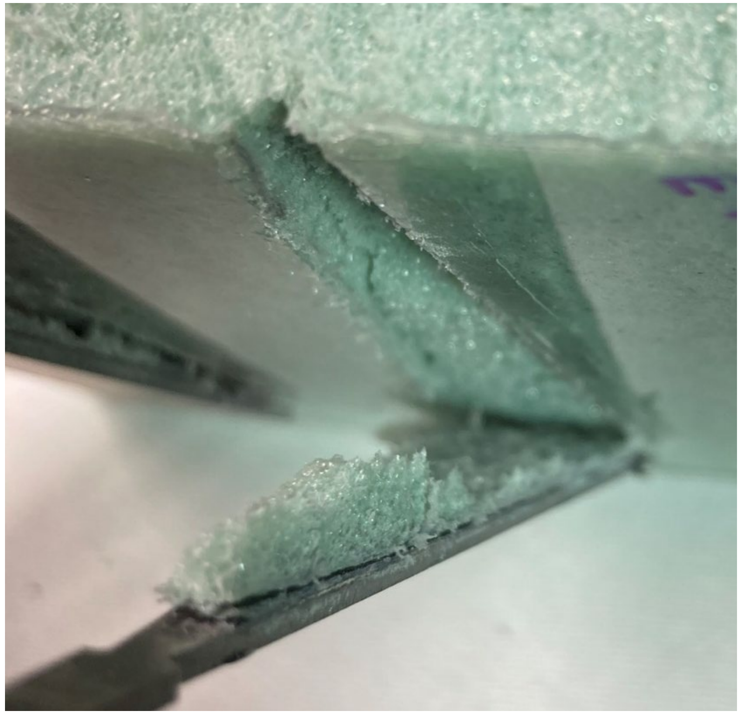
Selected images during peel testing

EVA/honeycomb, an initial tear out of honeycomb at the tip is followed but good measurement of debonding



In several tests the mirror cracked along beam lines showing the bond strength was greater than the mirror strength

The 3M tape showed elasticity, providing inconclusive results in some scenarios



EVA/foam, continuous tear out of foam showed that the bond strength of EVA to foam is greater than the internal foam strength

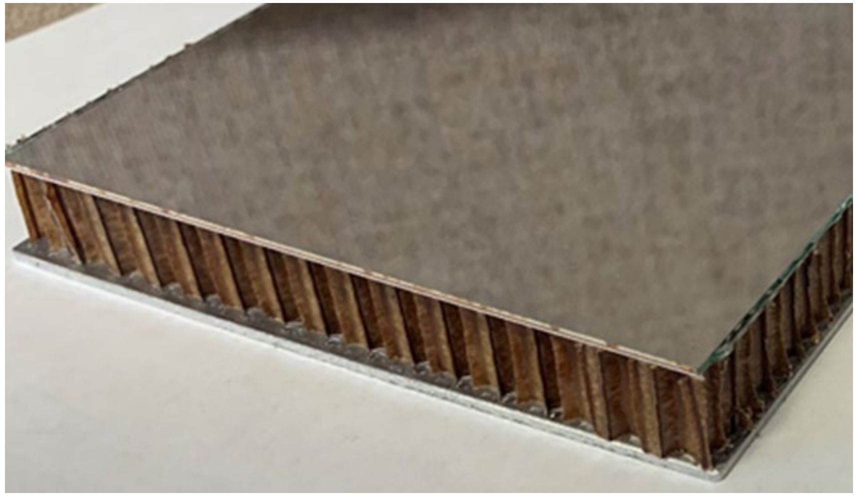
Peel test conclusions and path forward

- The EVA significantly outperformed the POE and 3M tape
  - EVA/honeycomb bond strength 1160 and 1360 J/m2
  - EVA/aluminum bond strength 3646 and 3845 J/m2
  - EVA bond was stronger than foam or mirror material strength
- The 3M tape was second in bond strength to the EVA but some tests were inconclusive due to elasticity of the tape
  - Note the tape was significantly more challenging to set up for lamination
- POE bond strength was poor with the mirror paint (78 and 114 J/m2)

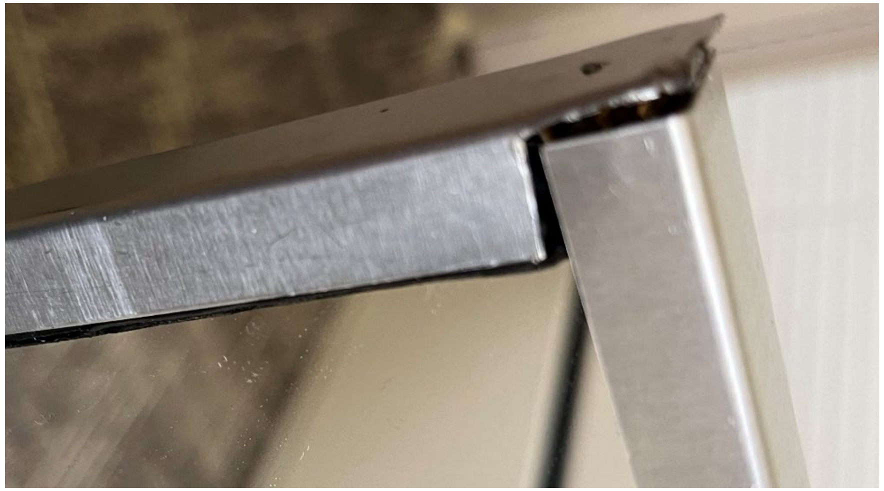
- *Note that there are a variety of formulations of EVA and POE and formulations can be tuned for specific applications and lamination curing temperatures and times*

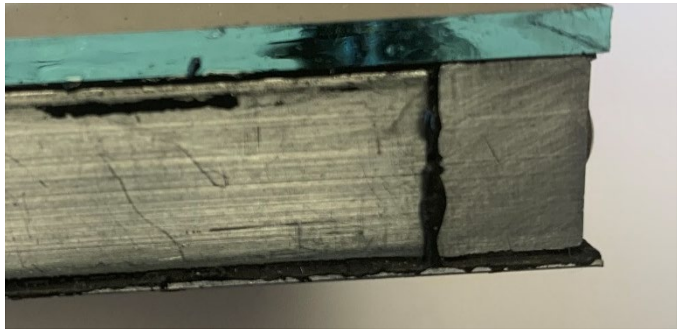
- **For these particular specimens the results justified with moving forward making further sandwich mirror samples with EVA**

Considerations to hermetically seal facets

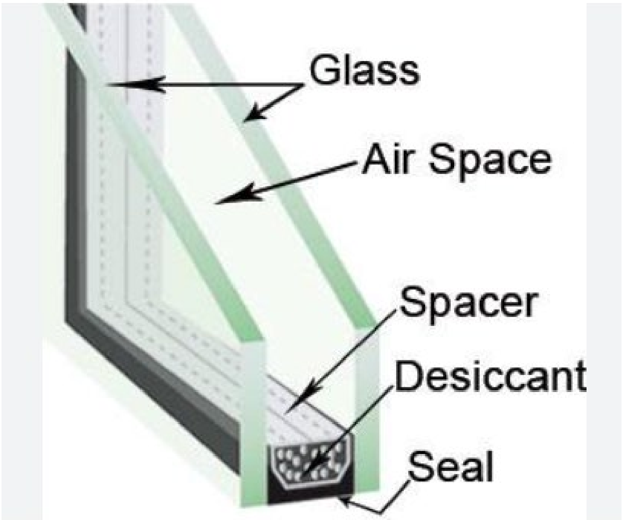


- A sandwich facet like the one to the left will allow water vapor to transmit through the honeycomb and through the EVA layer
- Using expensive protective paint on the back of the mirror has worked for CSP but the goal here is to use and edge seal to eliminate the need for the expensive paint



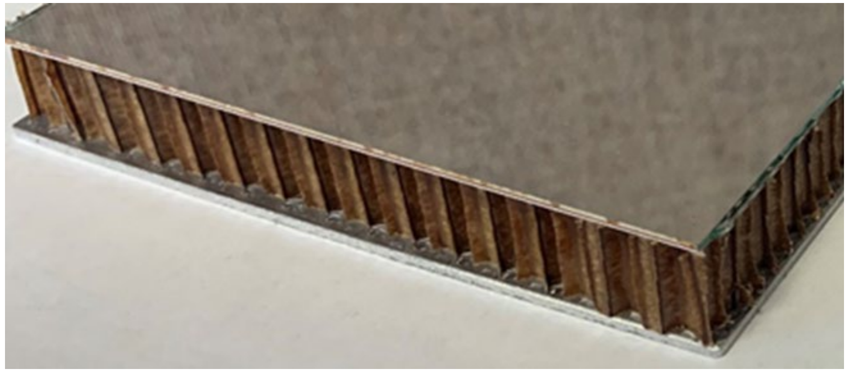


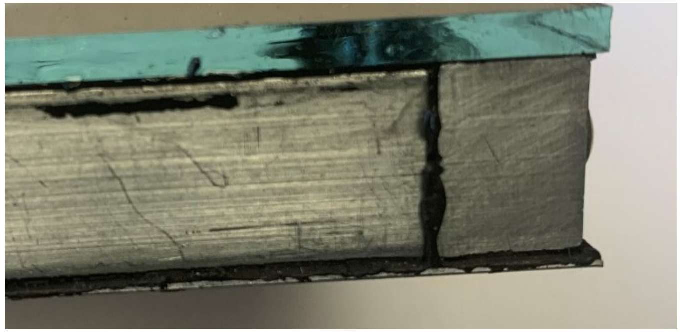
1 variant of window inserts



Sample lamination and accelerated testing

- Laminated @10 psi vacuum and 120 C for 1400 s
- EVA, Aramid honeycomb, 0.65 mm aluminum back sheet
- 10 cm samples consist 3 mm indoor glass (no solar backside paint) and aluminum block and PIB edge seal
- 61 cm samples for hail test have 1.1 mm glass and aluminum wrap
- Samples have been in DH for 1.5 weeks, 1 week of thermal cycling plus humidity, and 1 week of UV plus humidity (first degradation measurements next week)





Hail testing

- Setup meets IEC 61215 requirements
- Testing thus far 25 mm hail ball at angles of incidence from 45-90 degrees all in the center region of the mirror
- IEC requires testing at various locations of a solar panel
- Future tests will increase hail ball size and velocity until failure

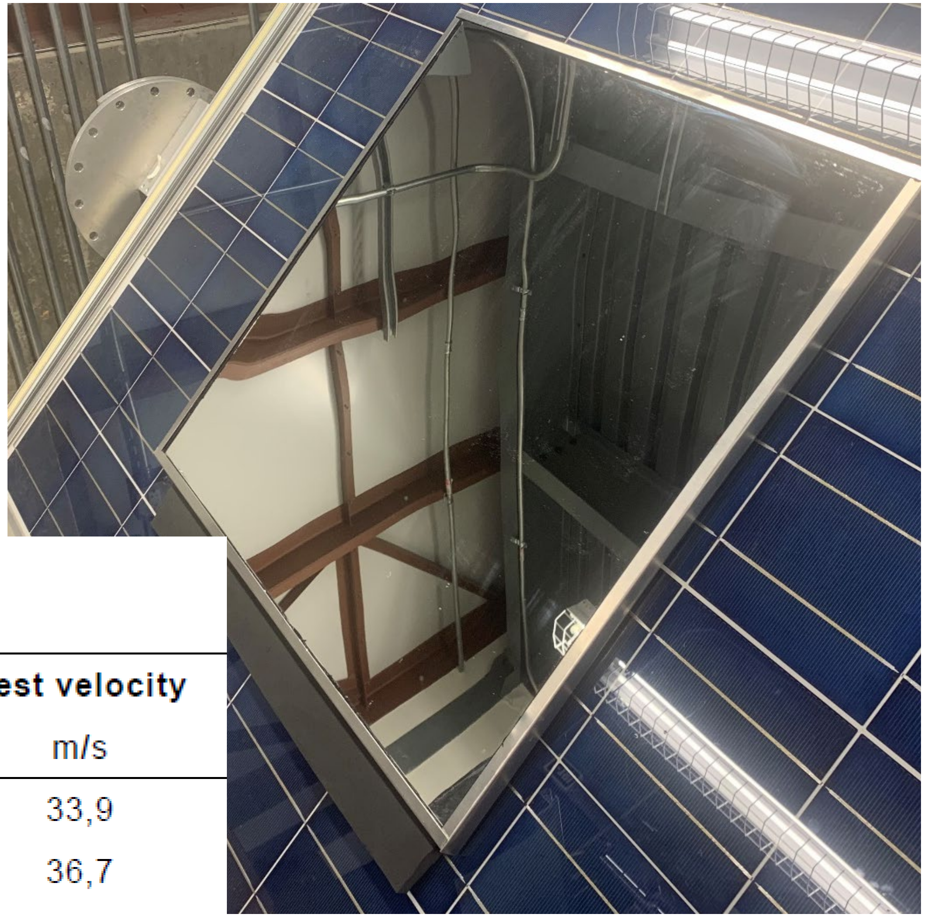


Table 2 – Ice-ball masses and test velocities

Diameter mm	Mass g	Test velocity m/s	Diameter mm	Mass g	Test velocity m/s
25	7,53	23,0	55	80,2	33,9
35	20,7	27,2	65	132,0	36,7
45	43,9	30,7	75	203,0	39,5

Conclusions

- 3 adhesive materials were tested for mirror facet lamination with EVA having much better bond strength compared to POE and 3M 588 tape
- Samples are undergoing accelerated environmental testing with results to come (indoor mirrors being tested to prove facet packaging can protect the silver layer)
- 1.1 mm non-tempered glass laminated with EVA, honeycomb, and a 0.65 mm aluminum backsheet survived 25 mm hail at 34 m/s

Thank you

Q&A

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