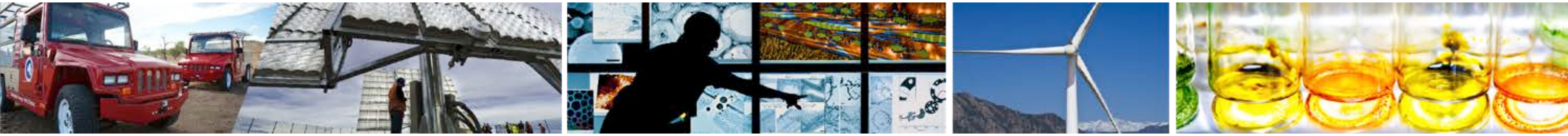
Moving the PV Industry to a Quantitative Adhesion Test Method



Nick Bosco

National Renewable Energy Laboratory

3rd Altas/NIST Workshop on PV Materials Durability

December 8-9, 2015

Scientific Approach to Reducing PV Module Material Costs While Increasing Durability

SuNLaMP
SunShot National Laboratory Multiyear Partnership

Nick Bosco, David Miller, Michael Kempe and John Wohlgemuth
National Renewable Energy Laboratory

Reinhold Dauskardt
Stanford University

Jayesh Bokria
Specialized Technology Resources (STR)

Task I: Metrology Development

Develop metrology for material and module level evaluation

Task II: Historical Survey

Locate historical modules and measure identified material properties with developed metrology

Task III: Exposures, Modeling and Test Development

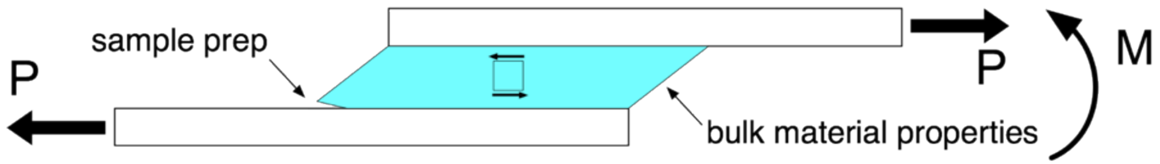
Physically model degradation

Use developed physical models to

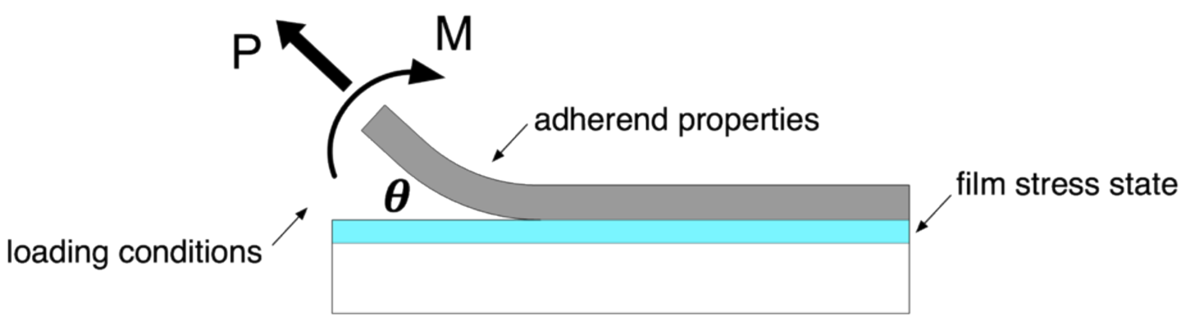
- develop new, lower cost materials
- design equivalent lifetime tests
- compose international test standards
- complete quality control guidelines

limitations of common adhesion tests

lap shear



peel test



fracture mechanics approach

fracture toughness

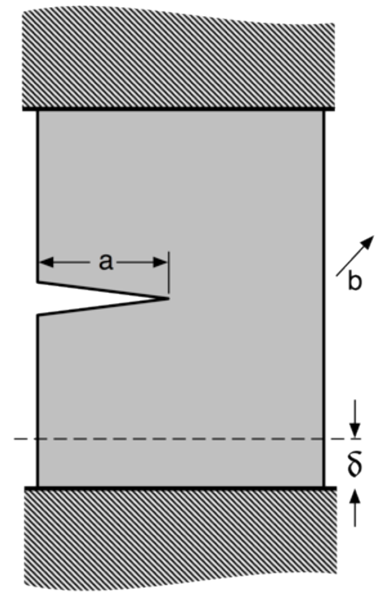
$$G_c = \frac{dW_s}{dA}$$

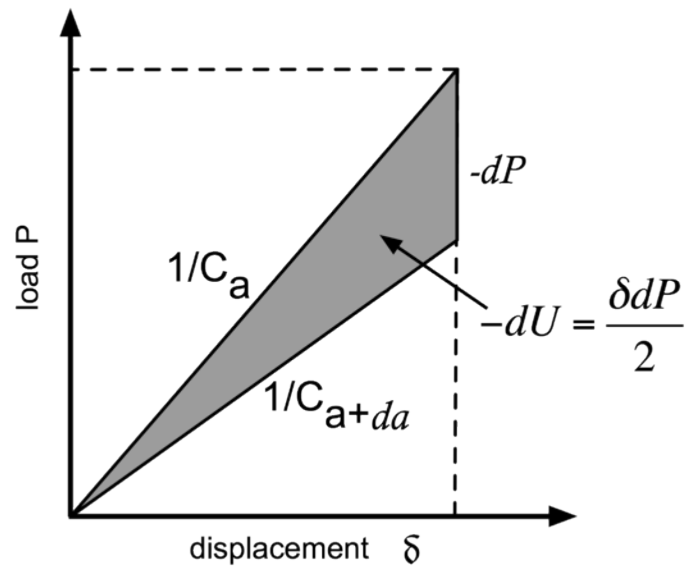
complianc
e

$$C = \frac{\delta}{P}$$

energy release rate
toughness
adhesion
debond energy

$$\boxed{G = \frac{P^2}{2b}\frac{dC}{da}}$$



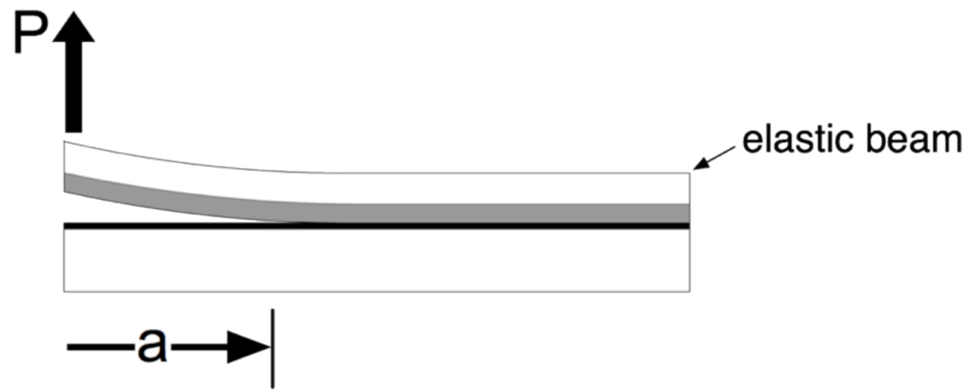


figures inspired by: T.L. Anderson, “Fracture Mechanics” CRC Press, Boca Raton, FL 1995

sample and test modification

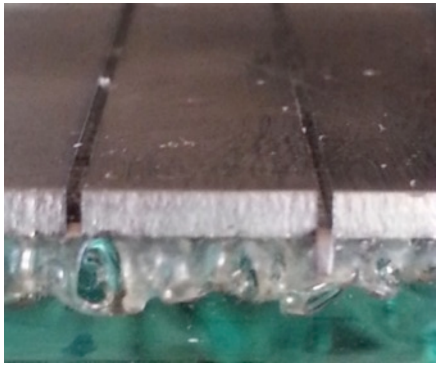
peel test

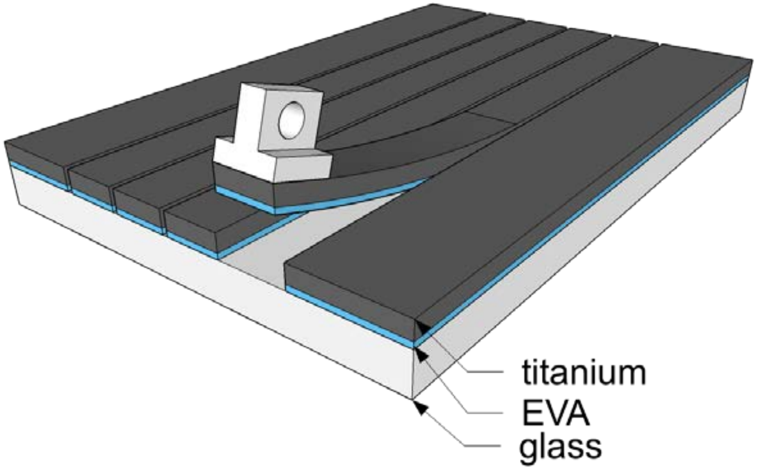
cantilever
beam



single cantilever beam

glass/EVA



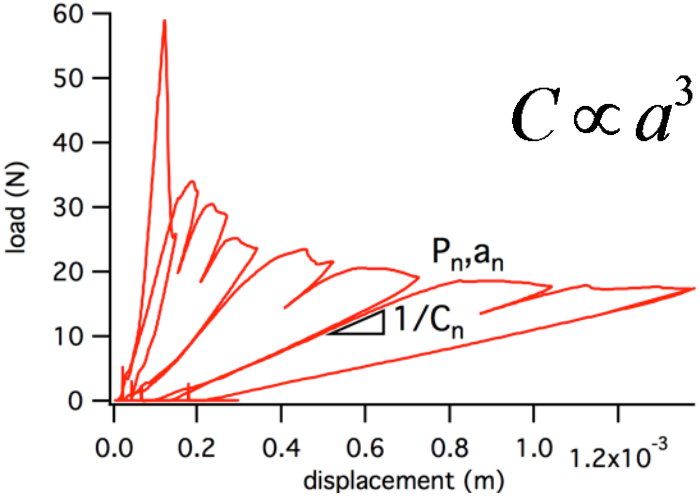


$$G = \frac{6P^2a^2}{b^2h^3E}$$

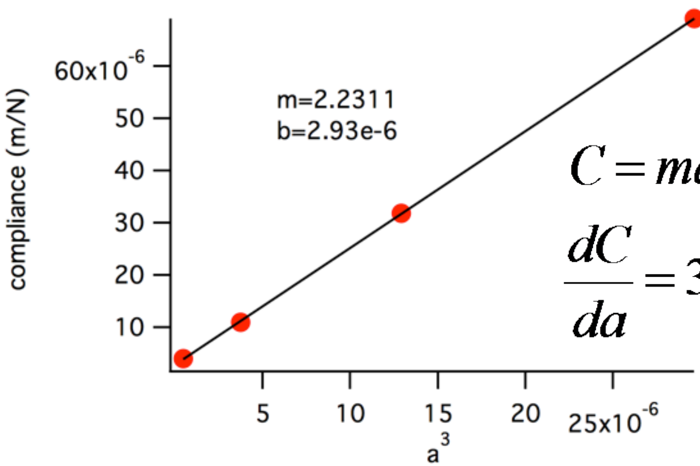
analytical solution

single cantilever beam

0% silane



$$C \propto a^3$$



$$C = ma^3 + b$$

$$\frac{dC}{da} = 3ma^2$$

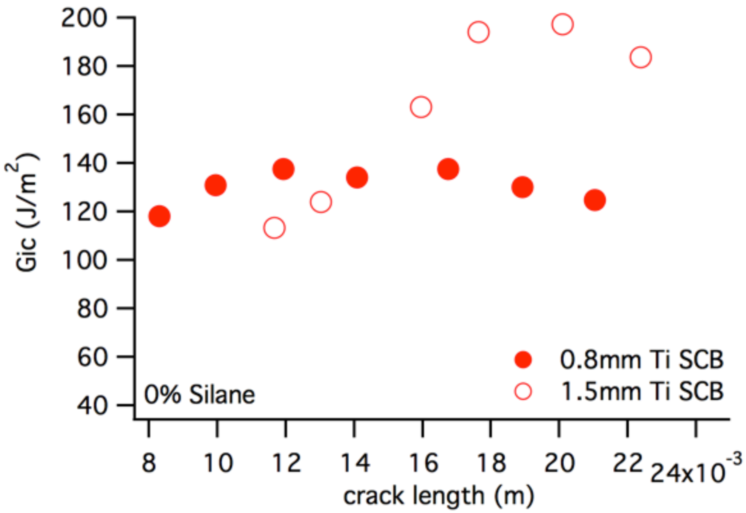
- Load reversals to measure compliance with crack extension
- produce linear fit of compliance with crack extension
- Evaluate toughness at each crack length

$$G = \frac{P^2}{2b}\frac{dC}{da} = \boxed{\frac{P_n^2}{2b} 3ma_n^2}$$

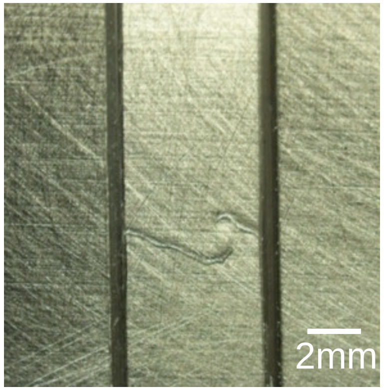
experimental solution

single cantilever beam, coupon level

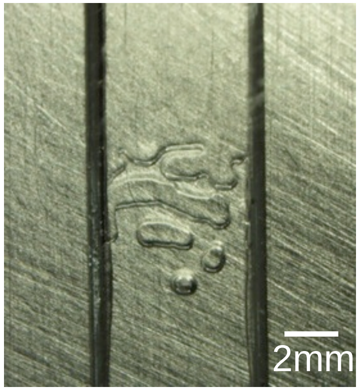
0% silane EVA on glass



Calculate fracture toughness for each crack extension



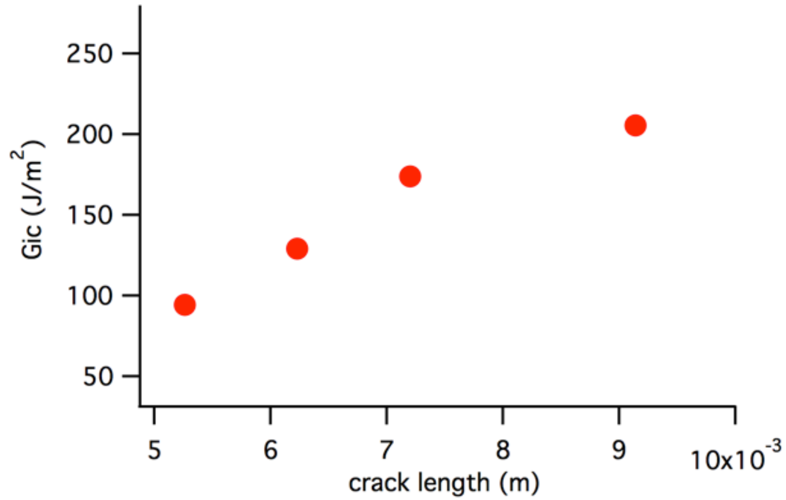
0.8 mm Ti beam

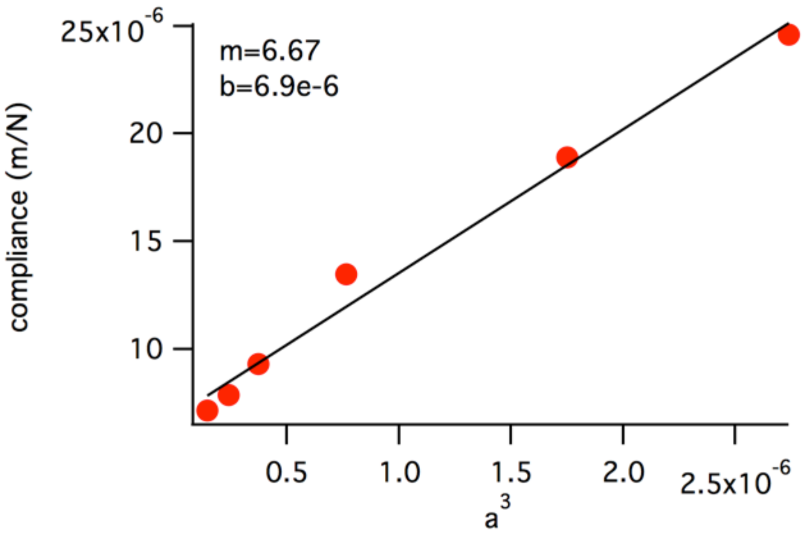


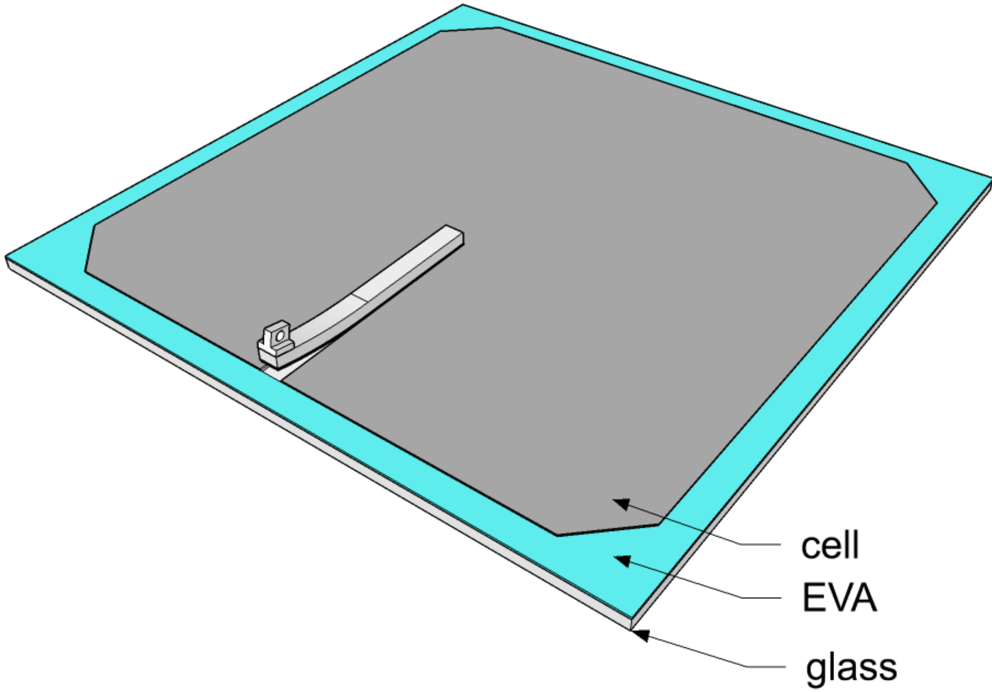
1.5 mm Ti beam

single cantilever beam, module level

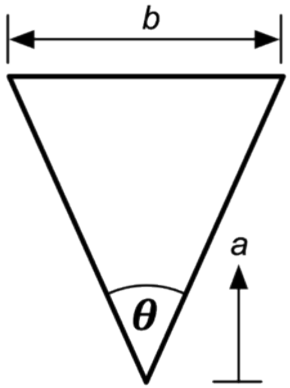
0% silane



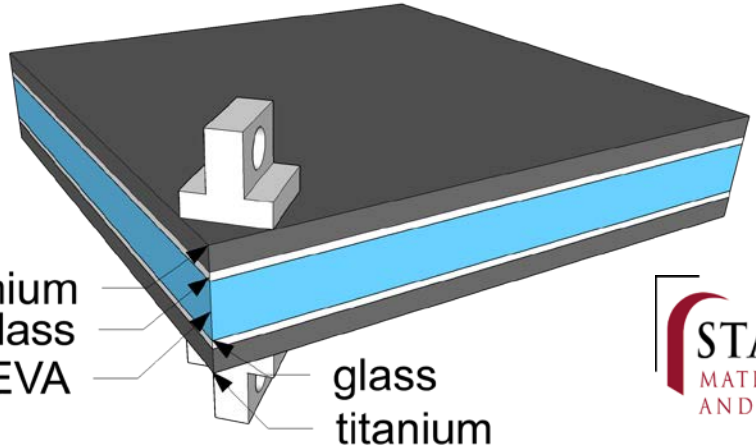




corner adhesion test

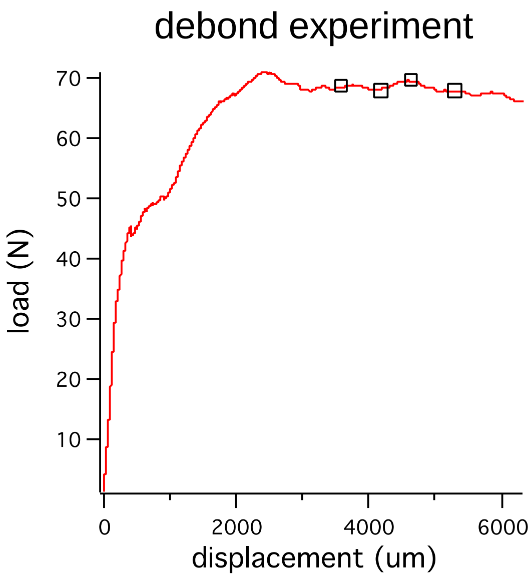


$$b = 2a\tan\left(\frac{\theta}{2}\right)$$

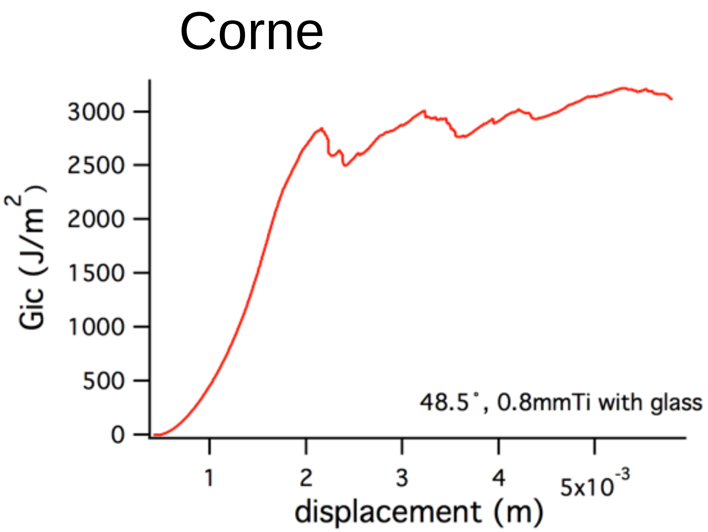


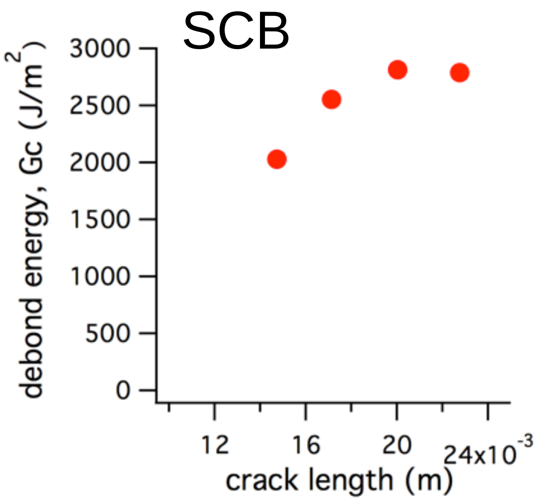
$$G = \frac{P^2}{2b}\frac{dC}{da}$$

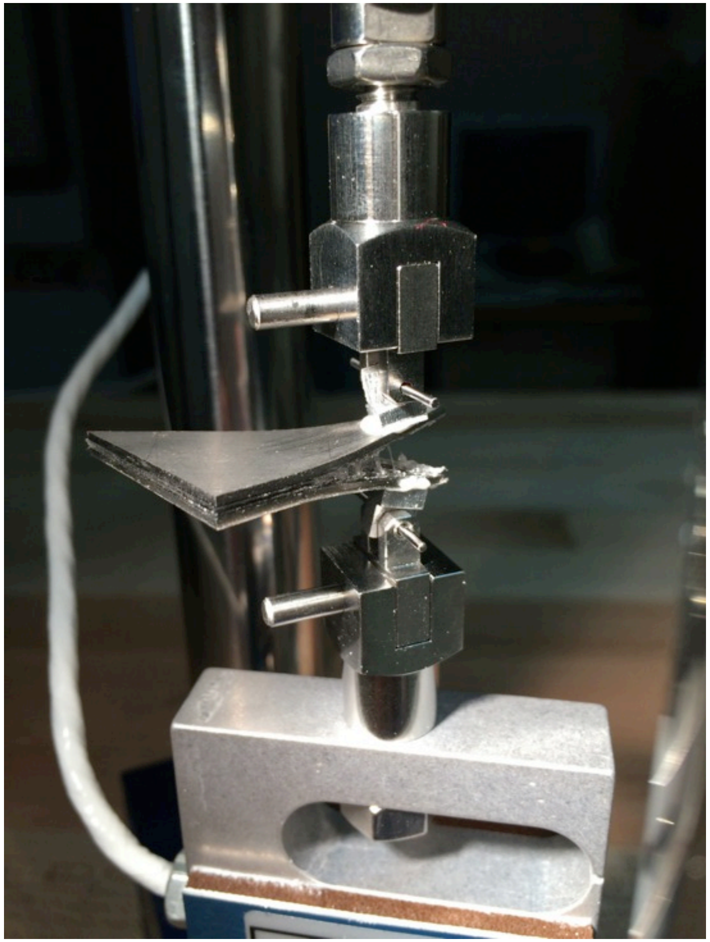
- Change in compliance becomes independent of crack length
- Crack will extend at a constant, critical load



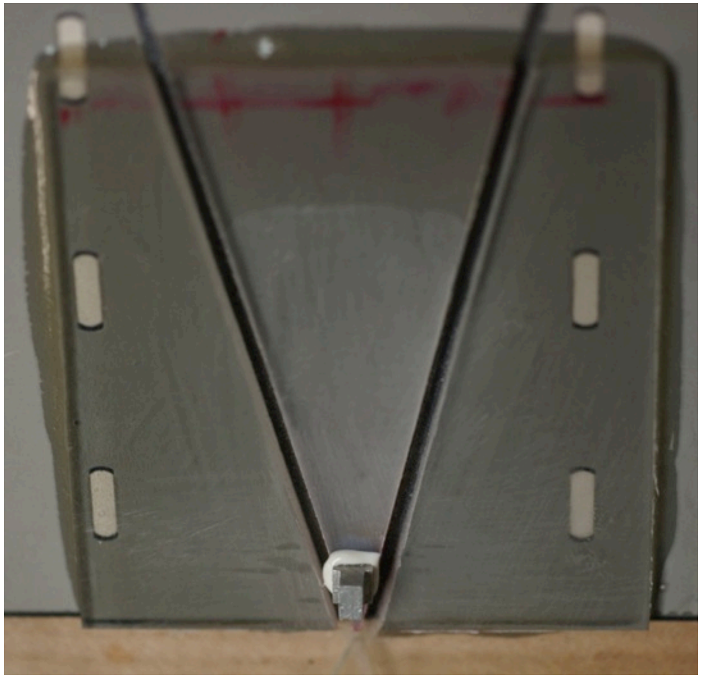
corner adhesion test, coupon level



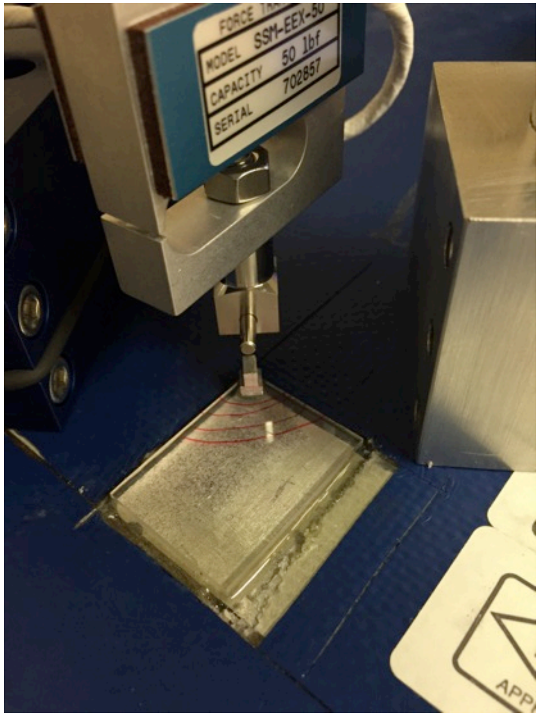




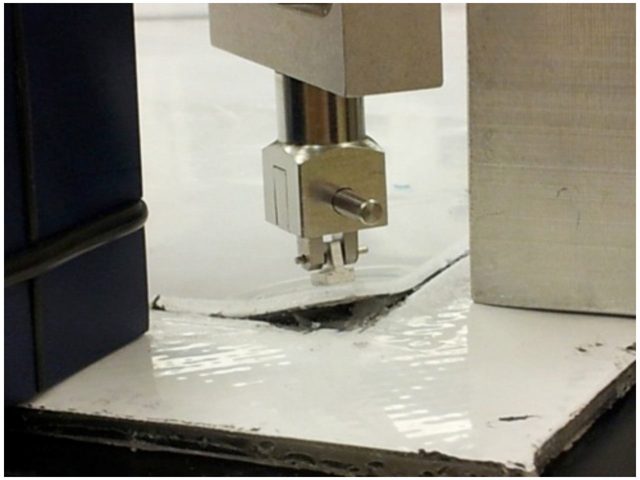
corner adhesion test, module level



corner adhesion test, module level



applied to module cell



applied to module backsheet

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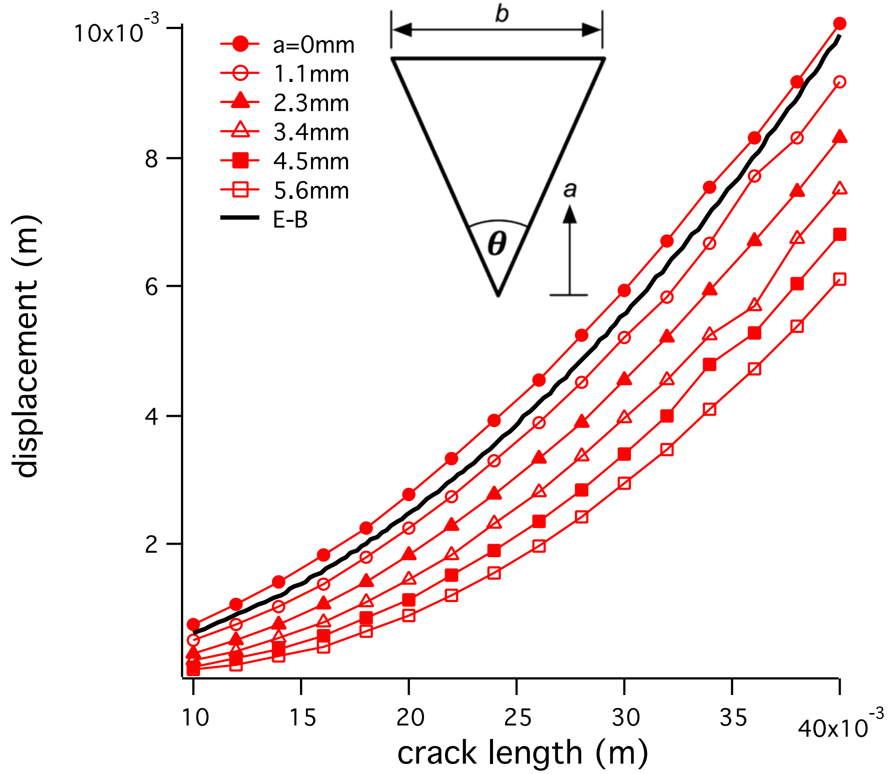
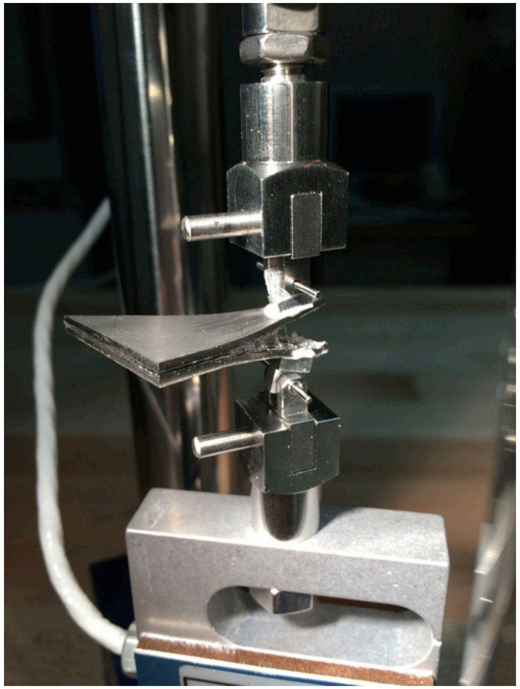
corner adhesion test- tab inset

FEM simulation

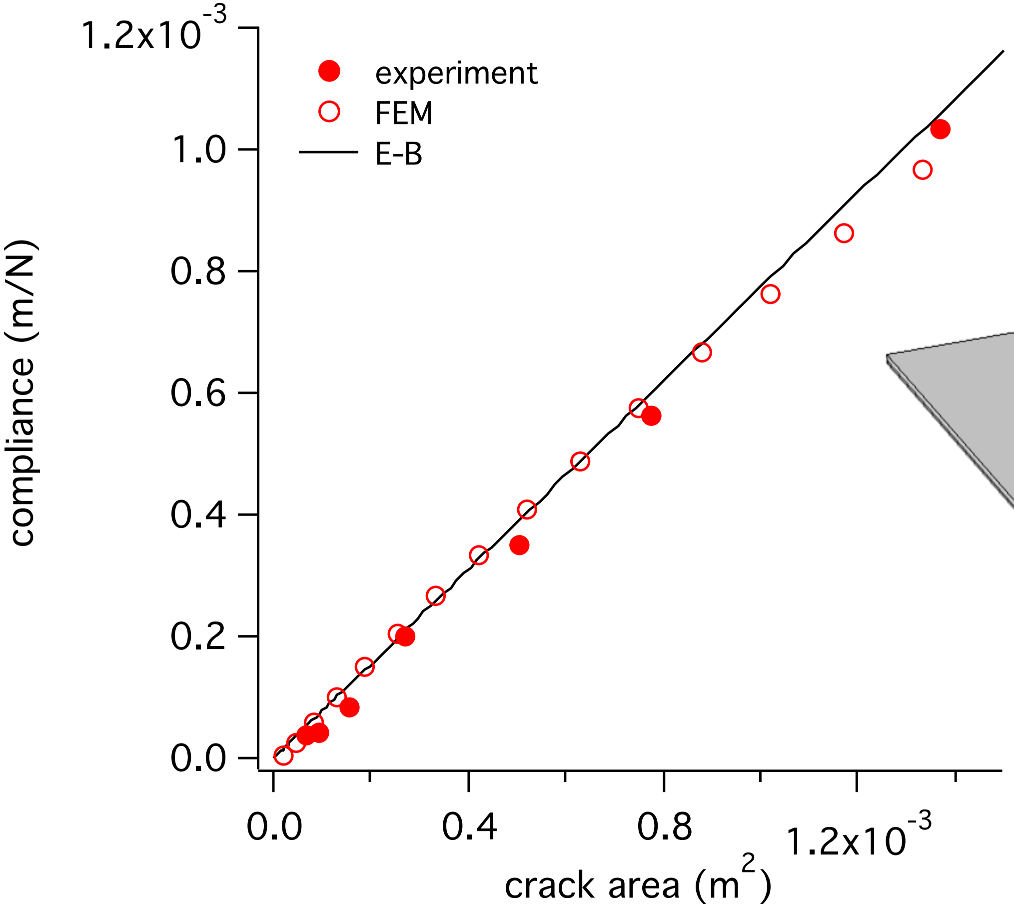


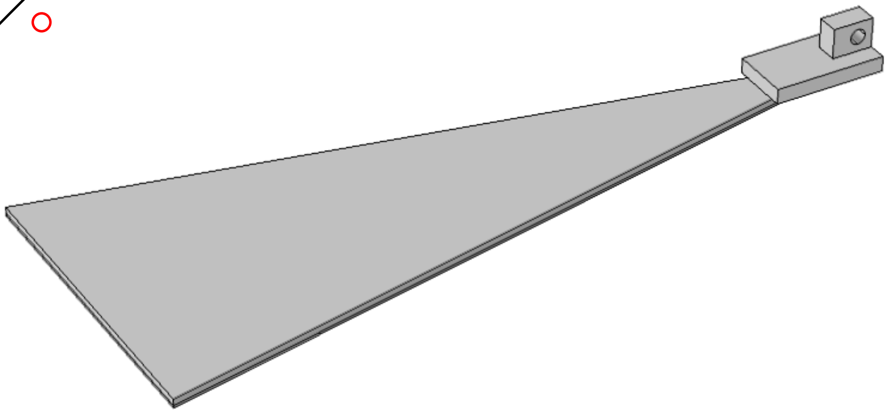


- Tab inset leads to an inaccurate measurement

validation- tab offset

- Application of the load at the beams tip is required for an accurate analytical solution.

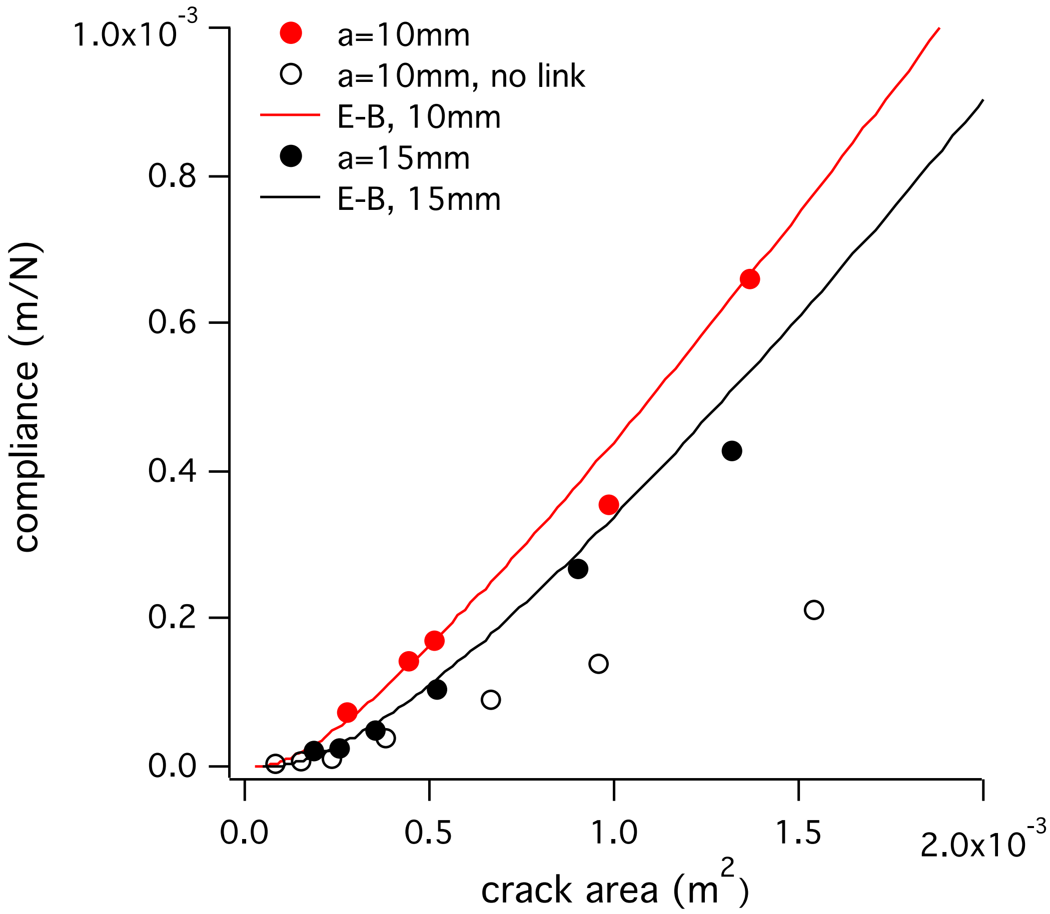


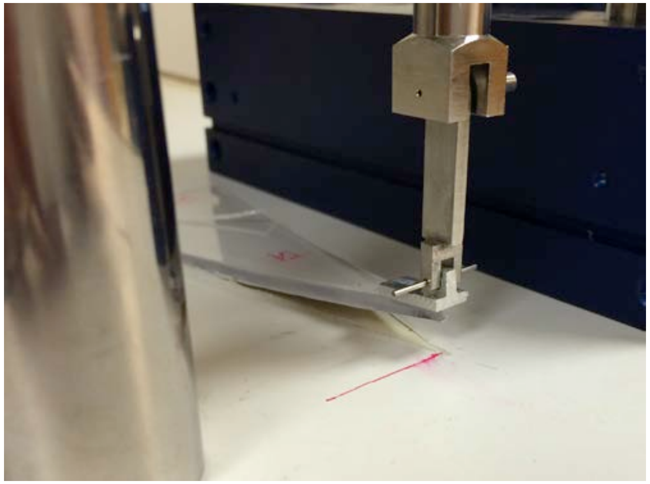


$$\left(\frac{dC}{dA}\right) = \frac{3}{Eh^3 \tan\left(\theta/2\right)^2}$$

experimental-loading link

- Addition of an articulating link in the loading train is required to minimize in-plane tractions on the beam's tip and ensure an accurate analytical solution.





validation- tab offset

- Two solutions

offset tab

offset beam

- Triangle beams fabricated to accommodate a fastener at their tip.
- Tab location ensures an analytically correct measurement.
- Reusable tab fastened to beam is not depended on a secondary adhesive for testing.

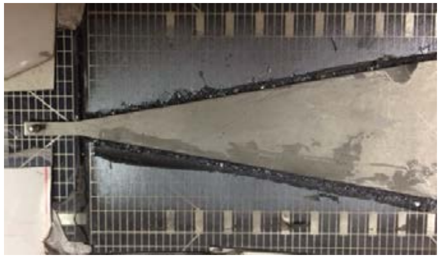
sample preparation

Backsheet

- 3mm polycarbonate/acrylic beam
- Loctite 495 adhesive (applied on beam)
- Loctite 7452 accelerator (applied to backsheet)
- Section around beam with a sharp blade

sample prep and experimental

- Remove backsheet and cell metalization
  - Heat-gun, razor and elbow grease
  - Wet sand in a solvent

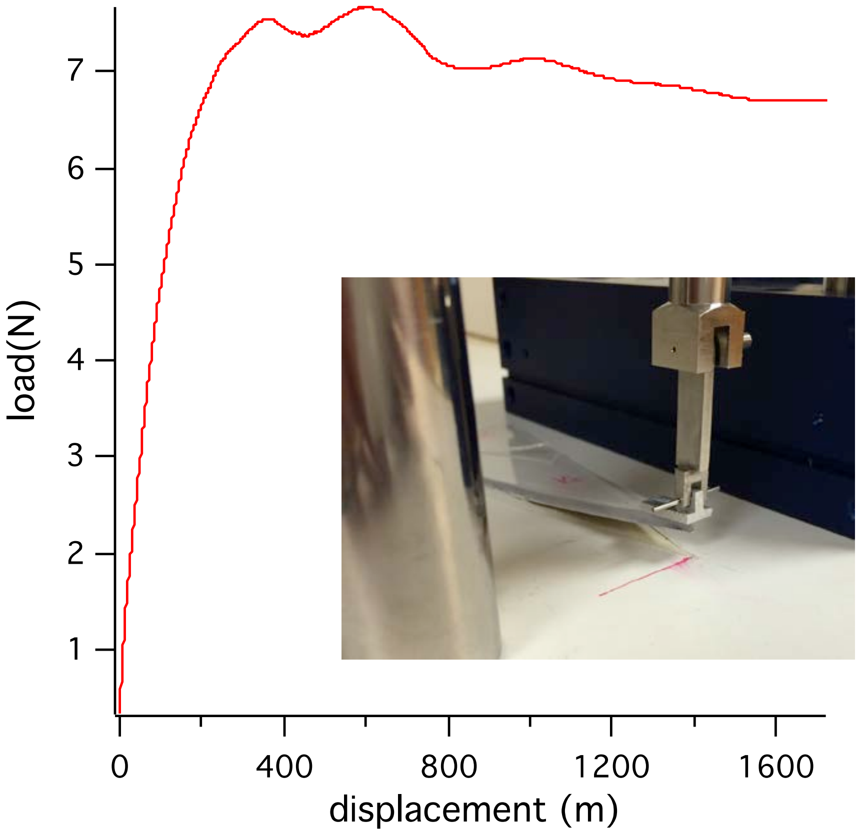


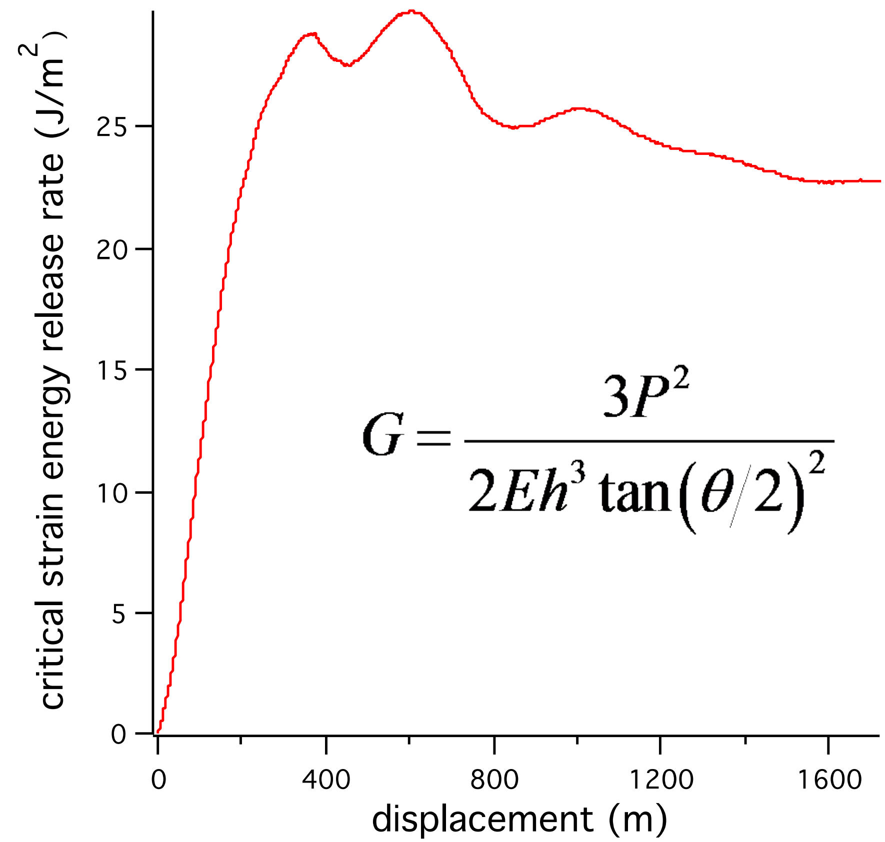
- Adhere beam and section cell
  - 0.86 o6 1.6mm Ti beam
  - 3M DP420 adhesive
  - Diamond or carbide tip scribe

- Apply a constant displacement rate and monitor load response
  - Tab attached to beam with a 0-80 fastener

- Use plateau load for G_{ic} calculation

experimental measurement SMUD Arco module- exposed backsheet

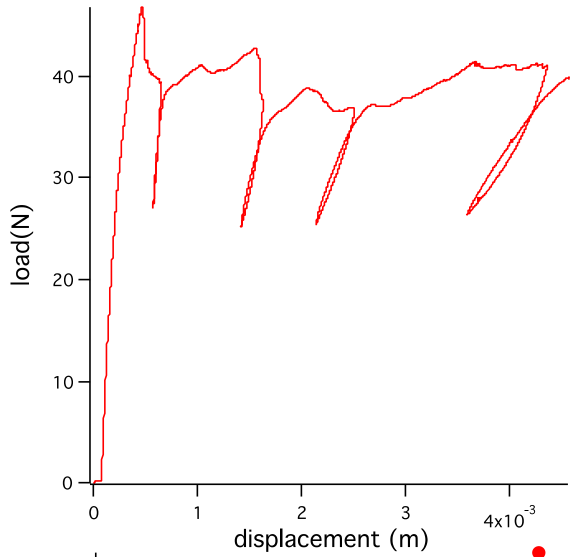


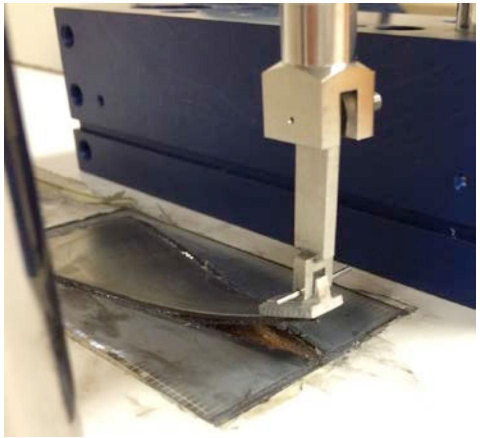


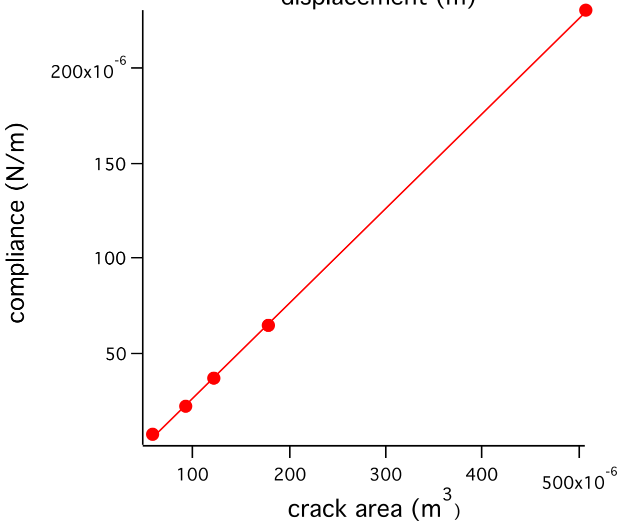
$$G = \frac{3P^2}{2Eh^3 \tan\left(\theta/2\right)^2}$$

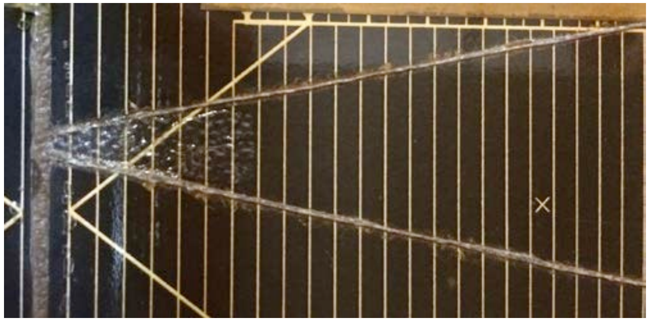
experimental measurement

SMUD Arco module- unexposed EVA/glass

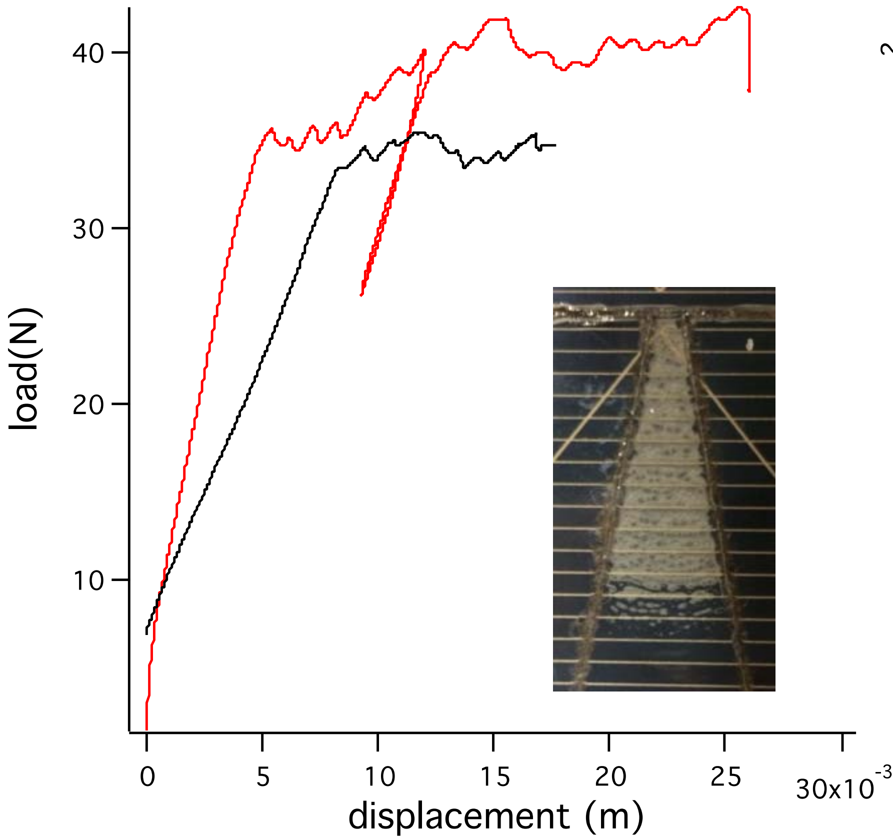


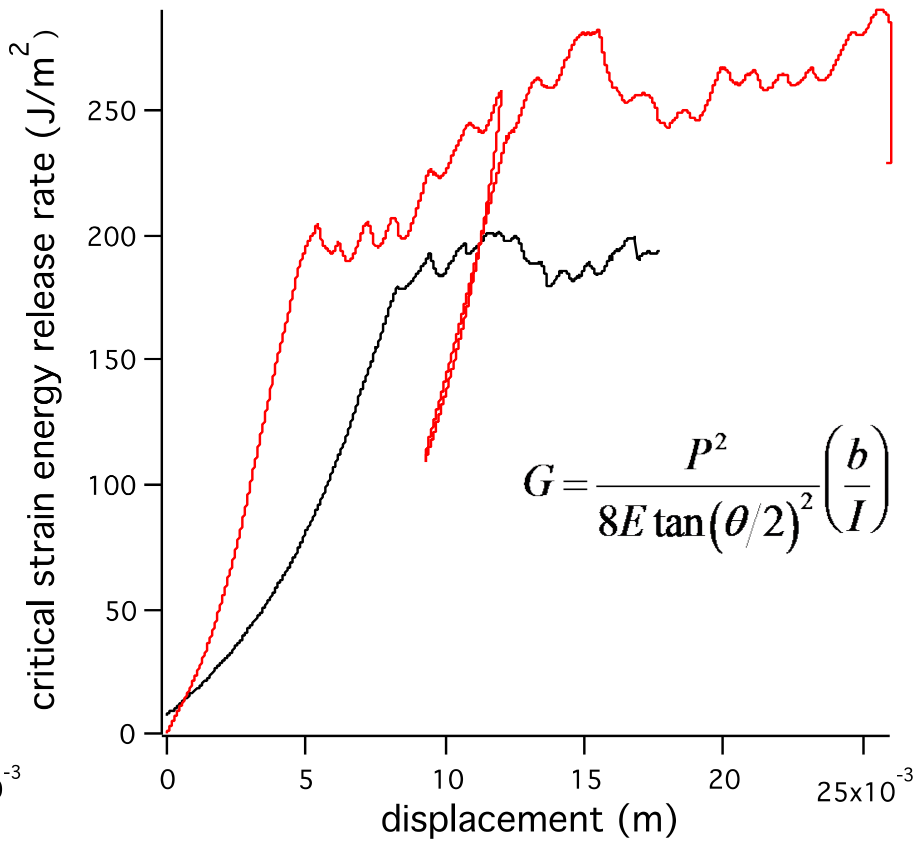






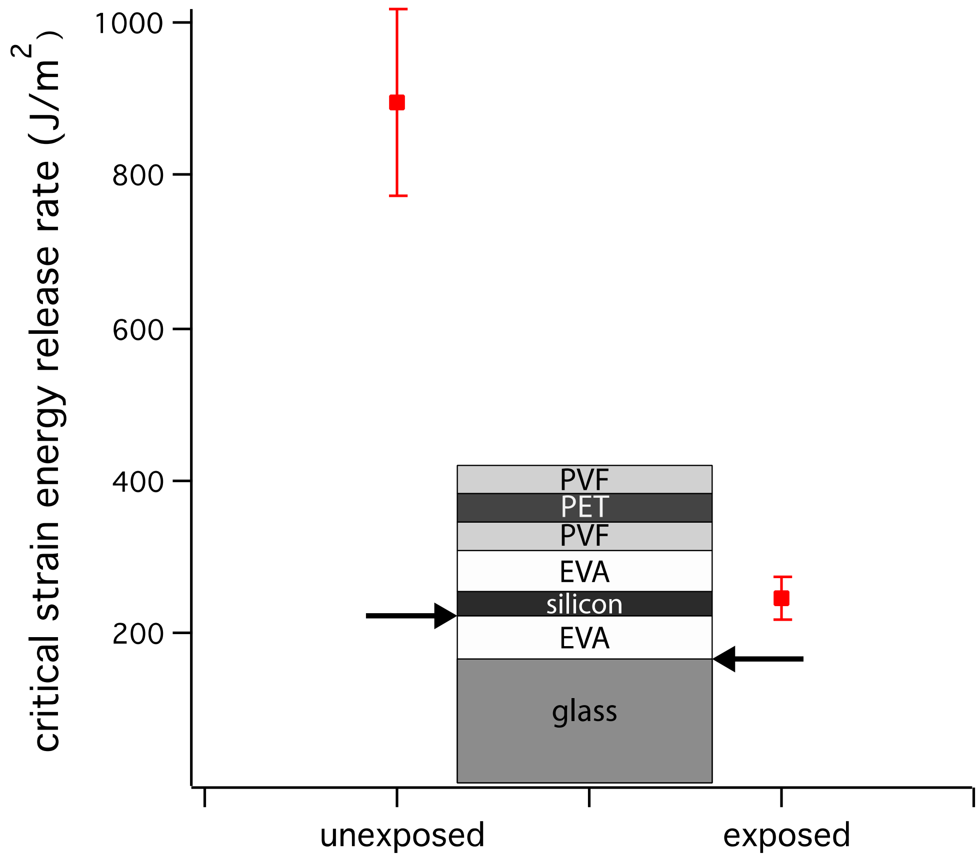
experimental measurement SMUD Arco module- exposed EVA/glass





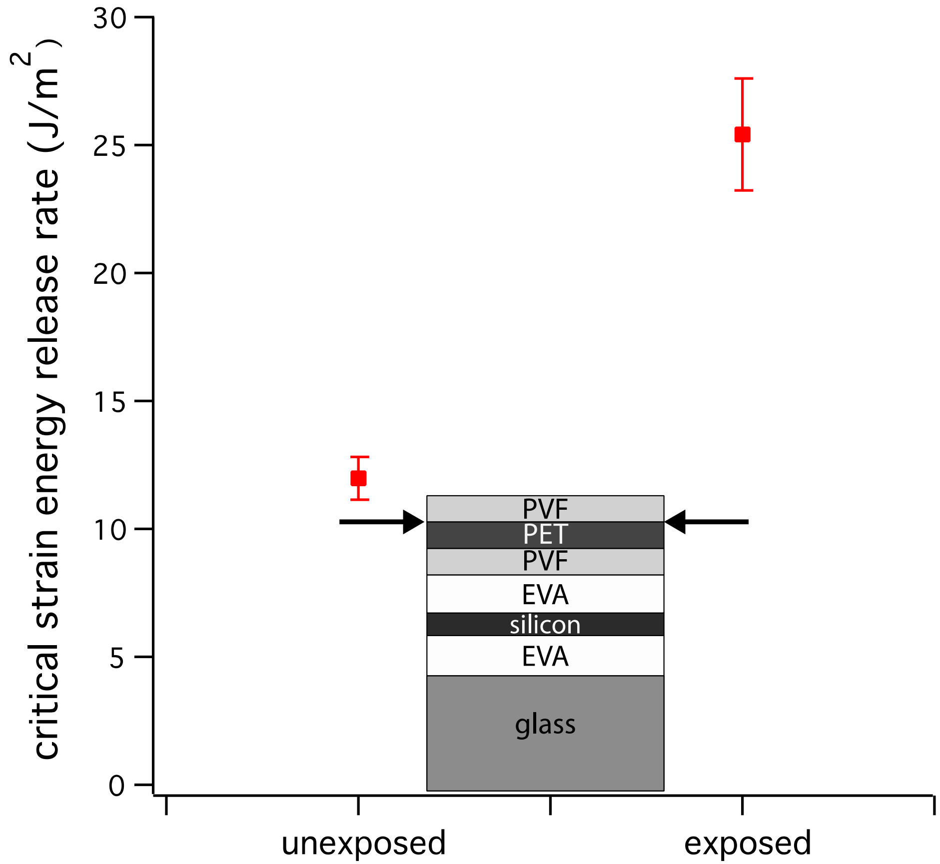
experimental measurement

SMUD Arco module- EVA



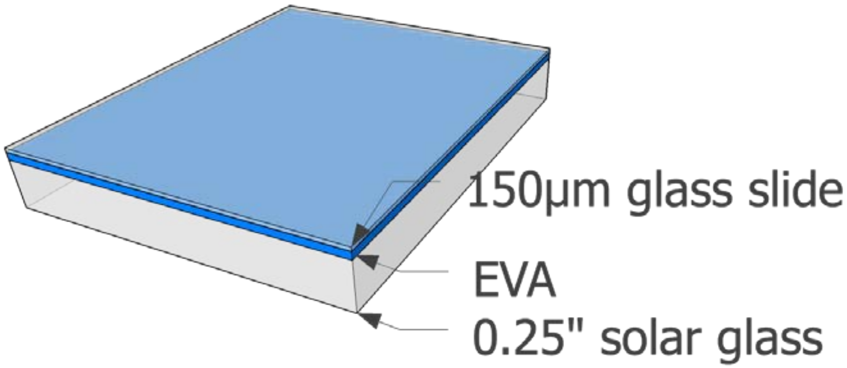
experimental measurement

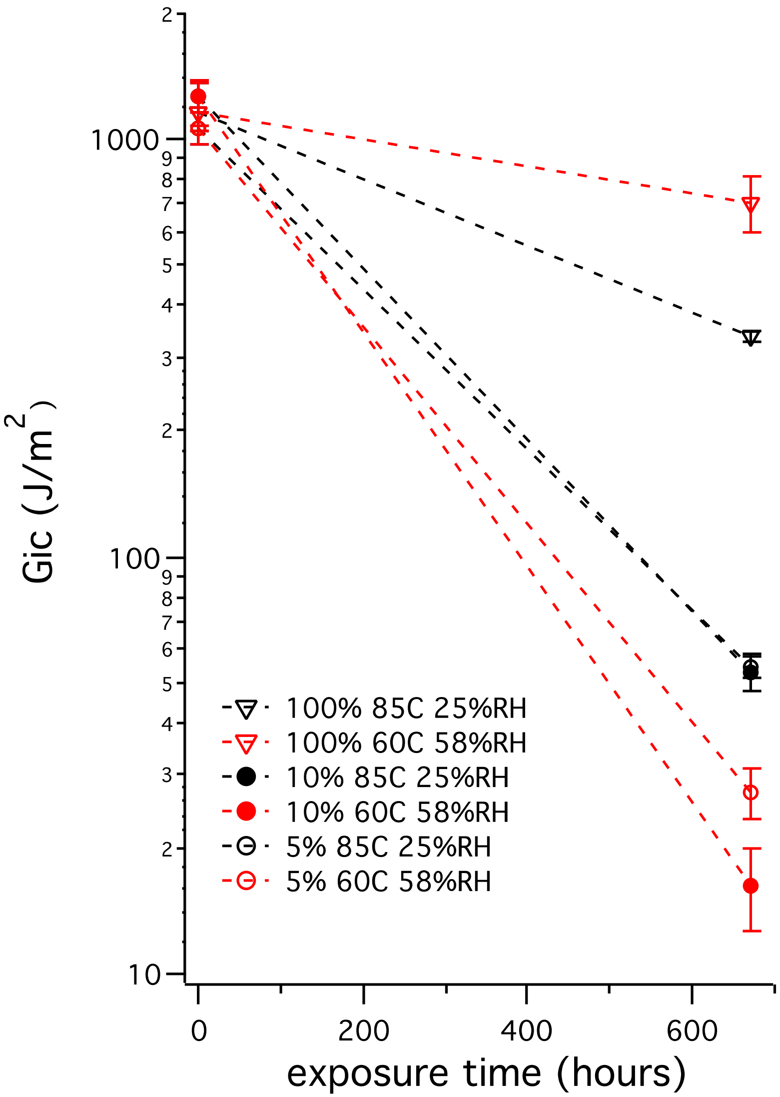
SMUD Arco module- backsheet



experimental measurement

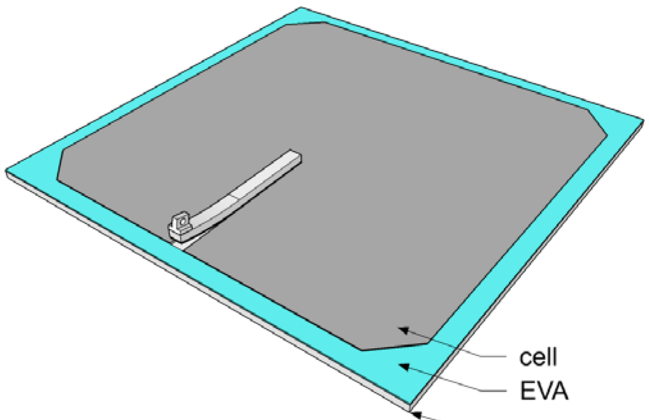
EVA- silane content

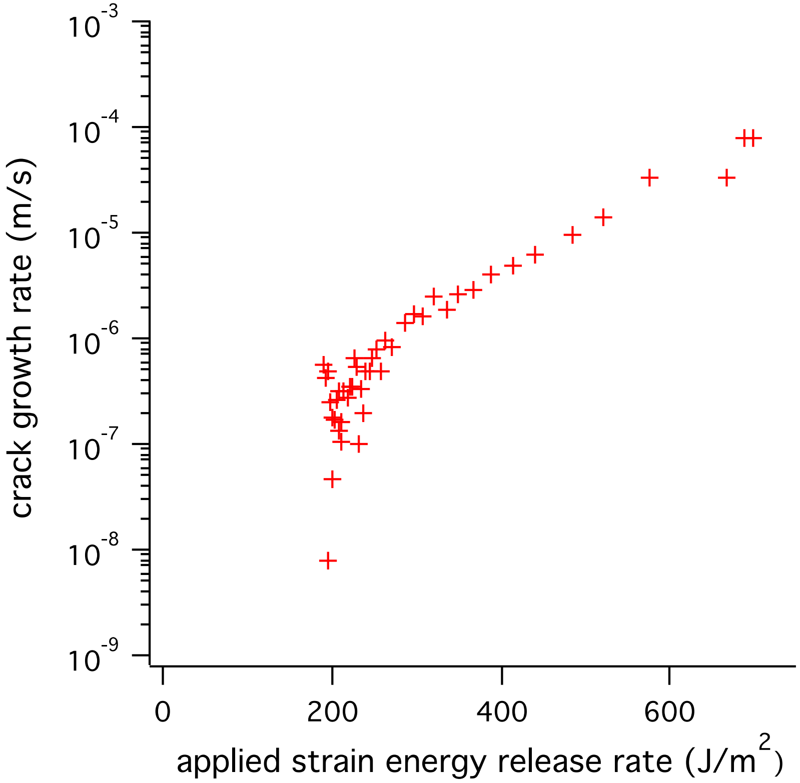




experimental measurement

EVA subcritical





direction

- Ongoing NREL scientific work is focused on applying the FM method to characterization for all PV interfaces

- We will develop protocols for applying this technique to all relevant material systems

- This work will provide the scientific basis for incorporating these techniques into future revisions of international standards