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Reliability Assessment of Rotary Sputter Targets in PV Manufacturing

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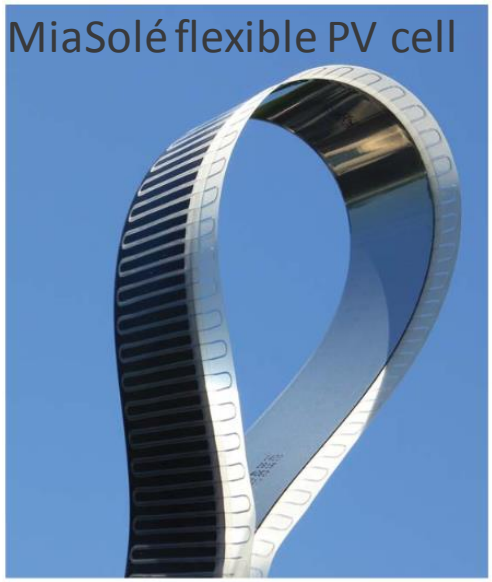
Speaker: Venkata Bheemreddy

Outline

- Background
- Framework for developing a reliable rotary sputter target
- Mechanical property measurements
- Adhesion measurements
- Simulation-based reliability approach
- Results and conclusions

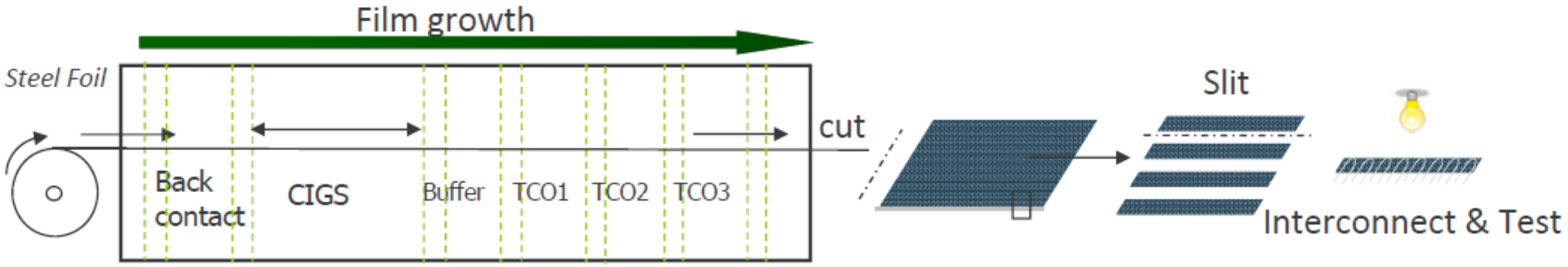
Background

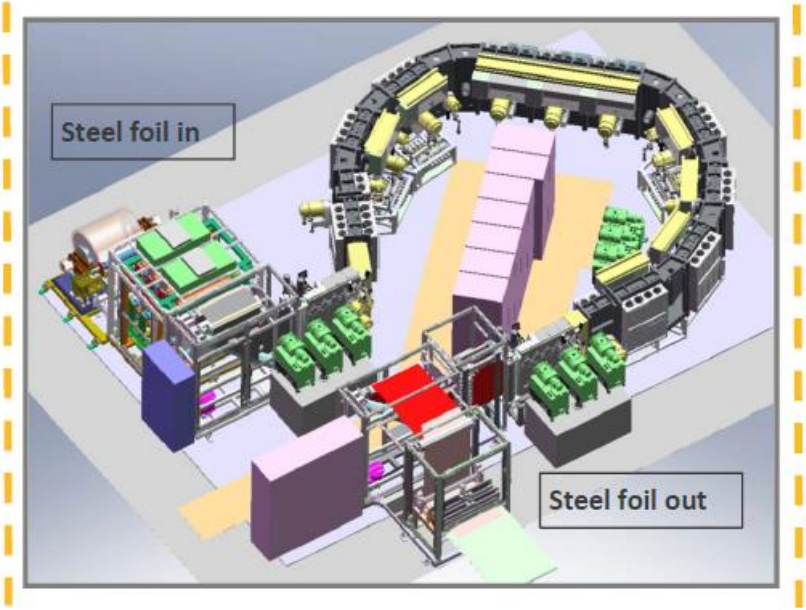


- MiaSolé high efficiency flexible and lightweight PV cells are made using roll-to-roll “All-PVD” deposition process.
- MiaSolé PV cell technology - CIGS (Copper Indium Gallium Selenide).
- Efficiency of PV cell ~17% in production.

Reference: MiaSolé products

Background (contd.)



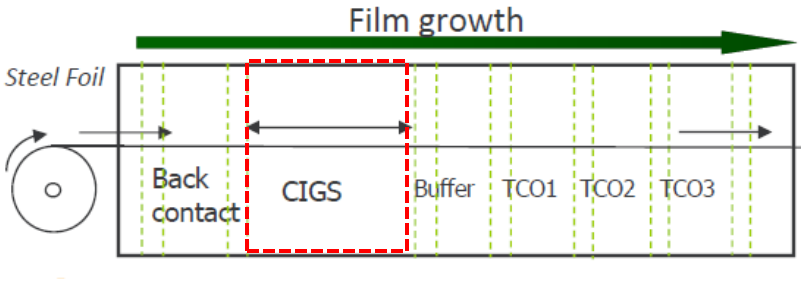


All-PVD deposition using Roll Coater

- All layers formed by high deposition rate sputtering process over a 1 meter wide stainless steel substrate.

Reference: Atiye Bayman, "MiaSolé Flexible Product and Manufacturing," IW-CIGSTECH 7, Munich, Germany, June 2016

CIG Rotary Sputter Target



- CIG layer deposition by magnetron sputtering of rotary targets.
- CIG rotary targets are central to achieving a low cost roll-to-roll PVD manufacturing process.

Cu In Ga → CIG Rotary Targets manufactured by cold spray process at MiaSolé

Challenges in Rotary Sputter Target Development

- CIG alloy compositions change over short product development cycles as part of PV deposition process technology advancement.
- Custom CIG alloy material properties not readily available.
- Characterization in “as-deposited” condition is critical to product (CS target) reliability assessment.
- No established standard for mechanical and adhesion characterization in “product configuration” i.e. on a cylindrical substrate.
- Cost of inducing target failures experimentally is prohibitive and experimentation needs to be kept to a minimum.
- Target failure during process is catastrophic and results in aborting of the entire production campaign with very high cost impact.
- Assessment of thermal-mechanical loads in PVD process is difficult.

Framework for developing a reliable rotary sputter target

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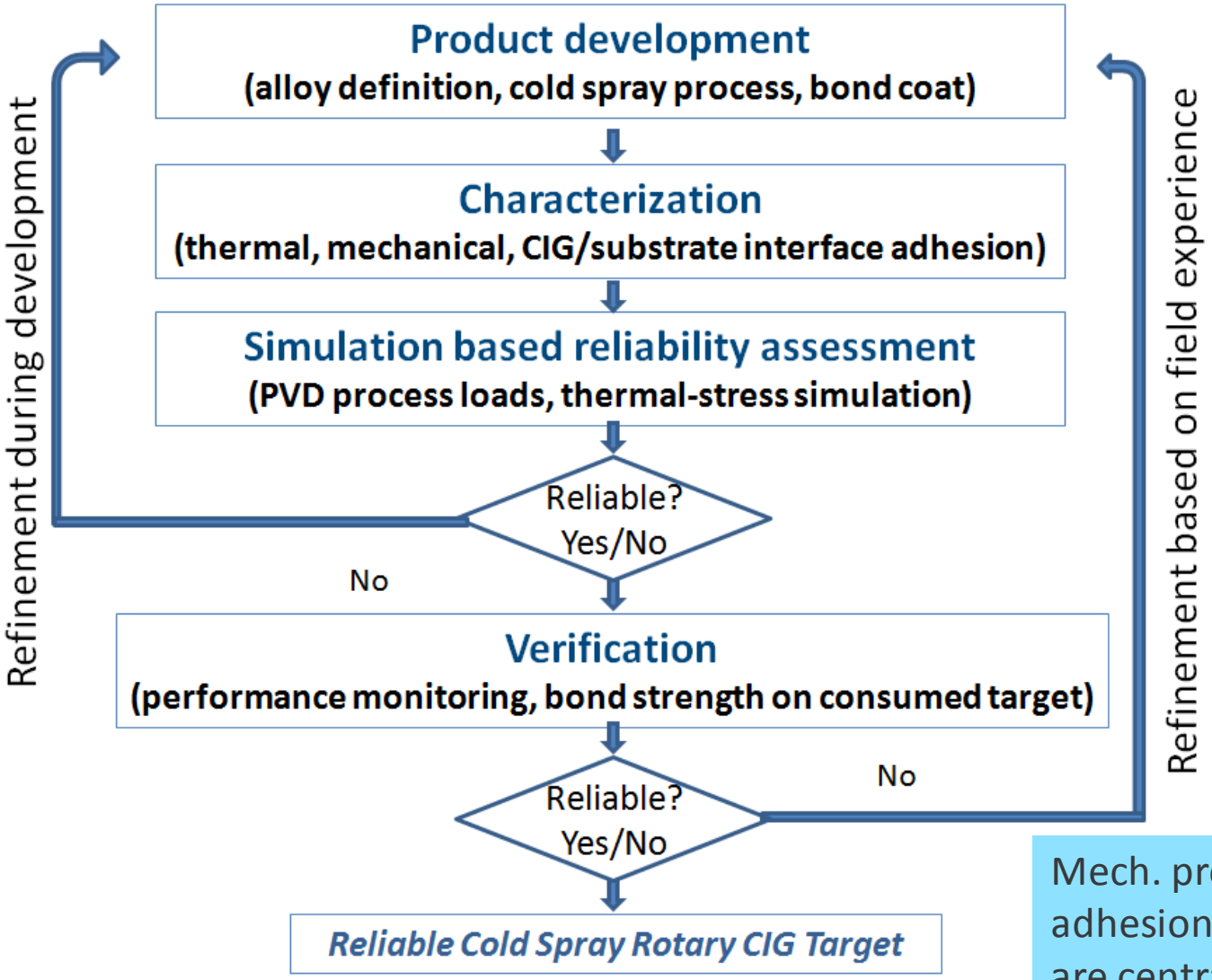
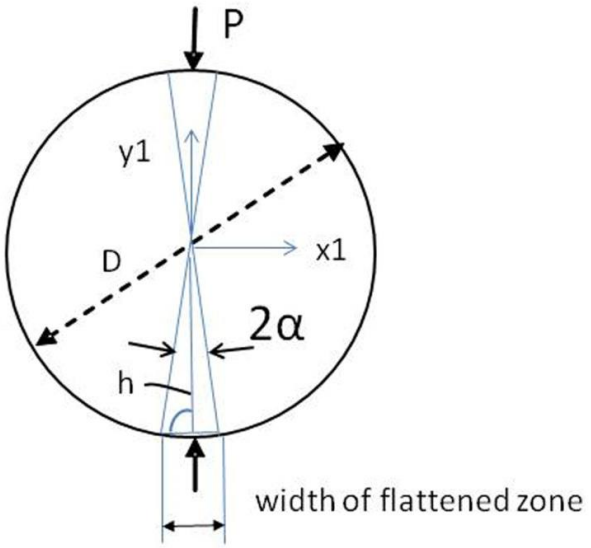


Mech. property and adhesion measurement are central to reliability

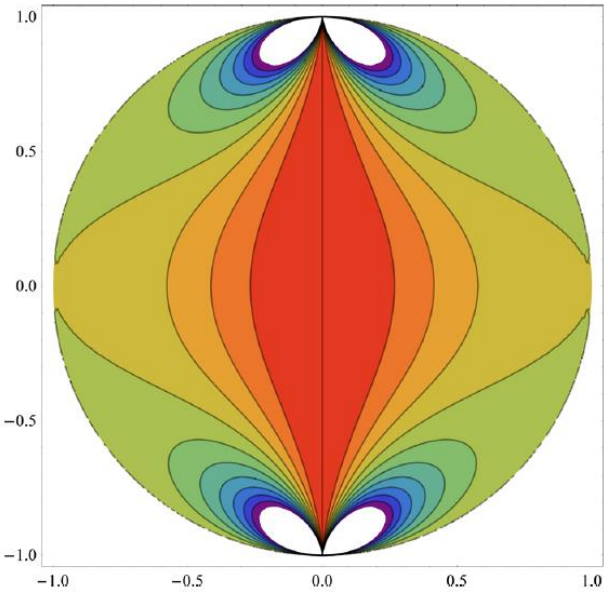
Ref: K. Hardikar, J. Vlcek, V. Bheemreddy and D. Juliano, "Assessing Reliability of Cold Spray Sputter Targets in Photovoltaic Manufacturing," JTST, v26, 2017.

Mechanical Property Measurements: Brazilian Disc Test

- Brazilian disc test enables modulus and strength measurements.
- Compression test performed with a circular disc loaded at diametrically opposite points. Resulting stresses induce tensile failure along the diameter.



$$\sigma_{x(0,0)} = \frac{2P}{\pi D t}$$



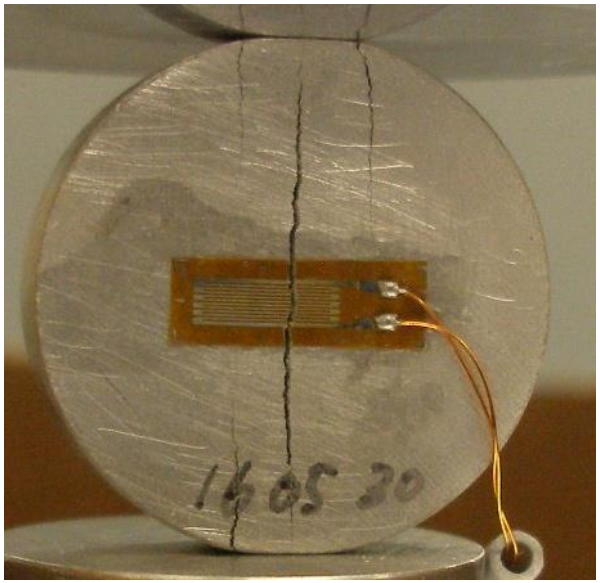
Along x=0, uniform tensile stress leads to vertical crack formation

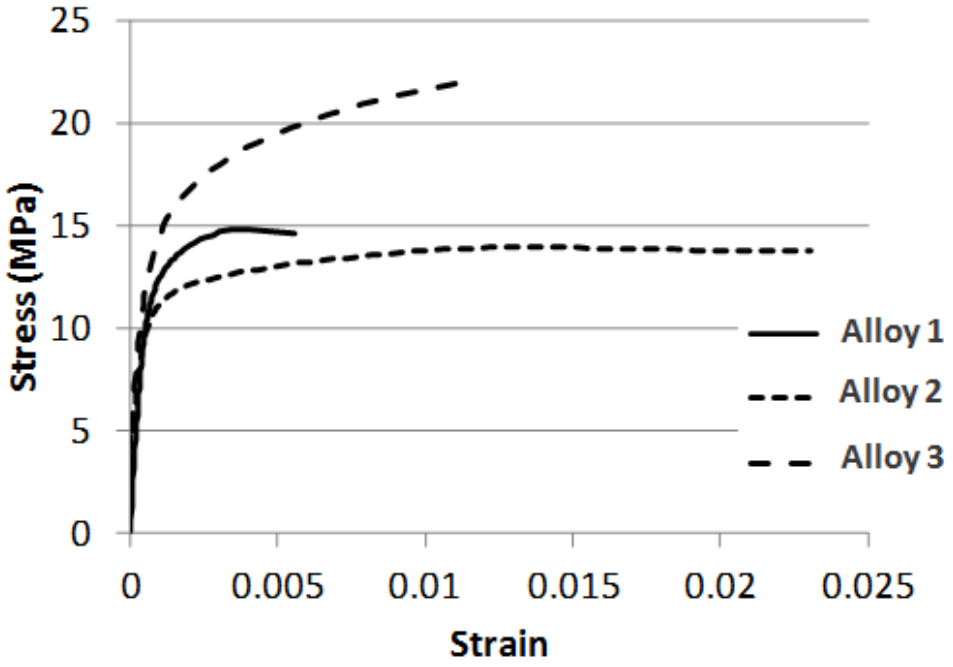
Brazilian disc test
Normalized stress (σ_{xx})

Ref: Johannes Vlcek, Kedar Hardikar and Dan Juliano, JTST, v26, No. 6, 2015

Mechanical Property Measurements: Brazilian Disc Test

- Strain gauge equipped samples allow acquisition of stress-strain data and elastic modulus.

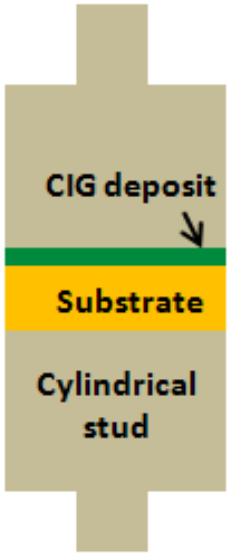




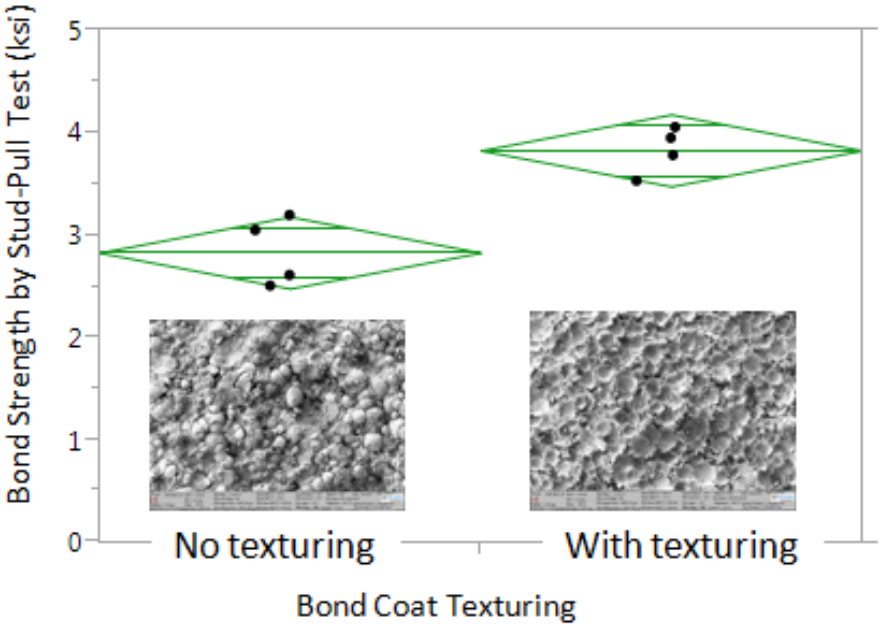
Ref: Johannes Vlcek, Kedar Hardikar and Dan Juliano, JTST, v26, No. 6, 2015

Adhesion Measurements: Stud-Pull

- Conventional stud-pull technique (ASTM C633) is suitable for deposits on a flat surface.
  - Does not provide product-level (rotary target) characterization.
  - Good as a screening test only.



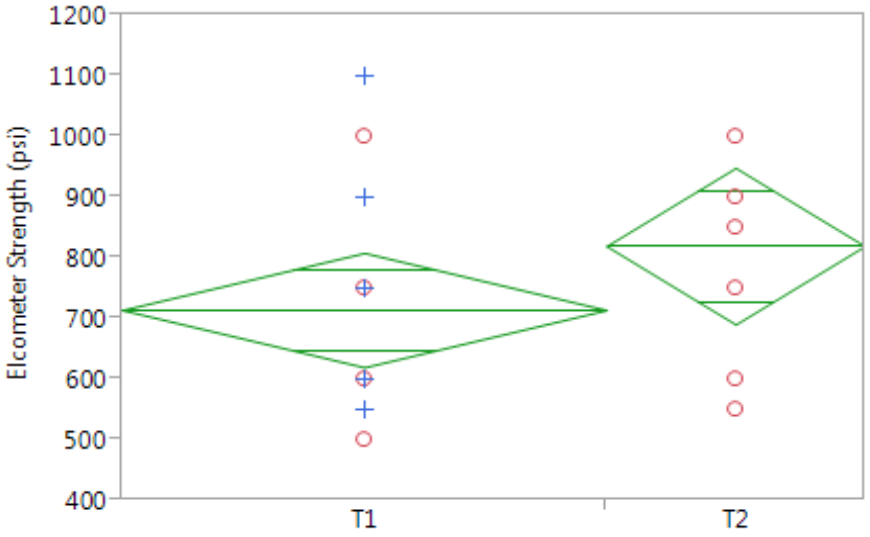
ASTM C633: Test configuration

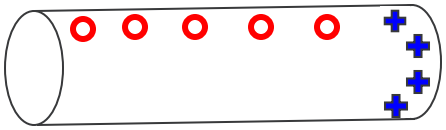


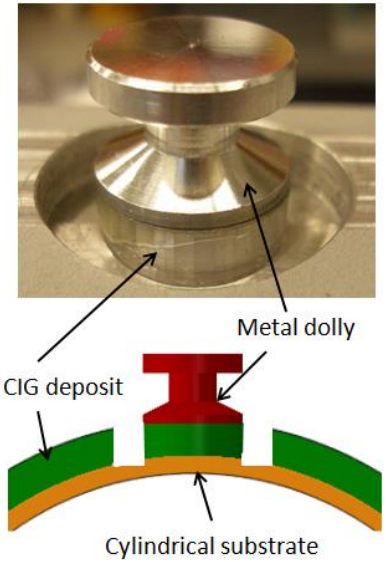
Enhancing bond strength by texturing the bond coat layer (screening test)

Elcometer® Test on Curved Surface

- Adaptation of stud-pull method on curved surfaces is provided by Elcometer ® test (ASTM D4541).
- Enables product level characterization but does not enable model development.
  - Sample preparation is not easy.
  - Variations in edge conditions lead to variation in measured strength.





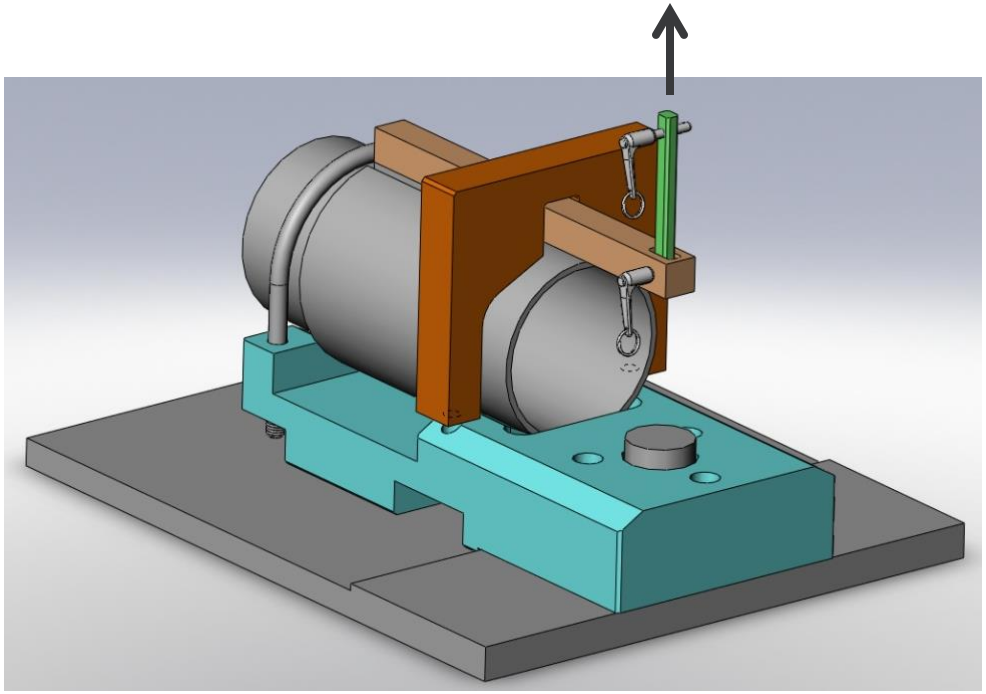


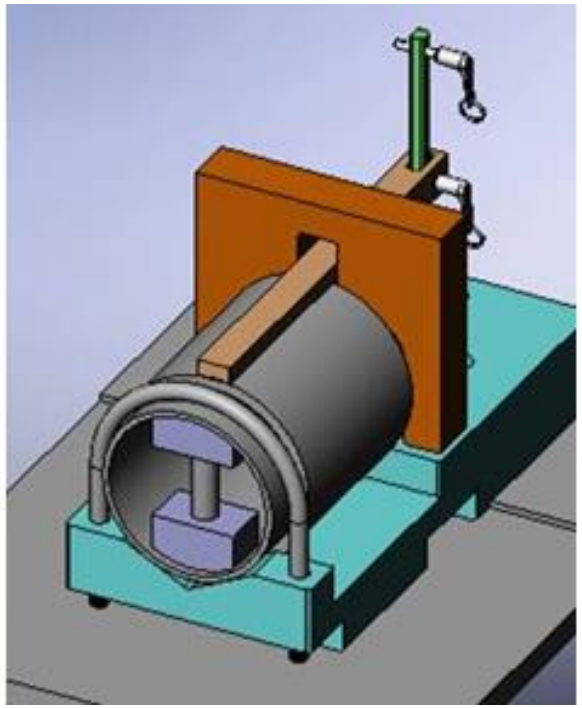
Need for a Custom Test

- Current established standards based on stud-pull technique have limitations
  - Testing on curved surfaces shows large variations.
  - Edge conditions and misalignments can dominate results.
  - Do not enable model development for reliability assessment of targets; however, can be used as screening tests.
- Need a custom test for adhesion in rotary sputter targets
  - Should be fracture mechanics based.
  - Should enable testing in as-deposited condition.
  - Should enable simulation based reliability assessment.

Lever Test Method

- Custom lever test is developed by adapting Double Cantilever Beam and Single Cantilever Beam testing methods.
- Test enables development of an interface model for simulation based reliability assessment.





Lever Test Method (contd.)

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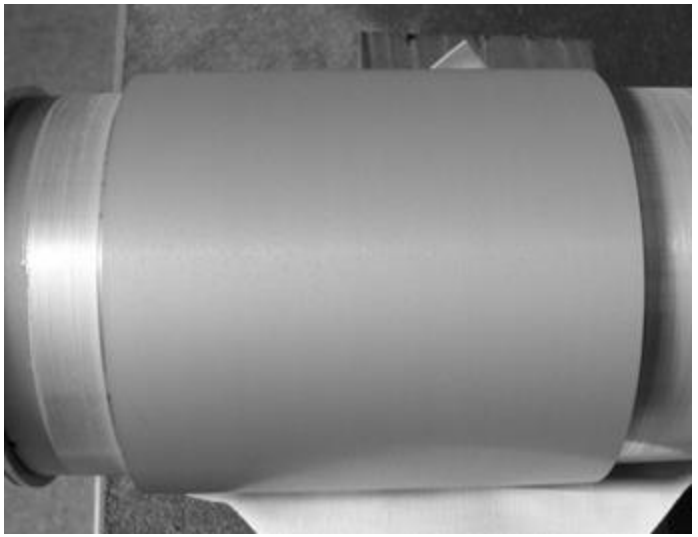
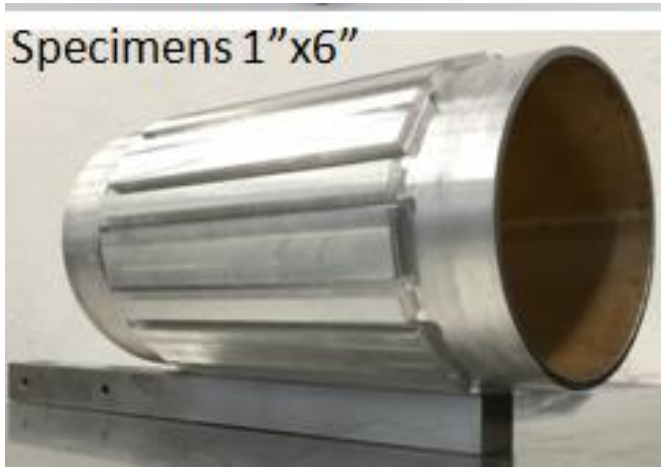
Sprayed segment or target

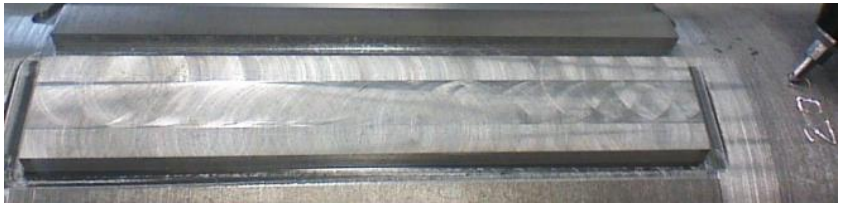
Turning : surface and edges





Slot milling

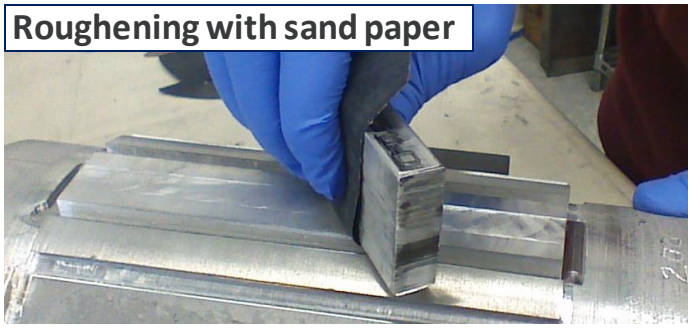
As-machined surface



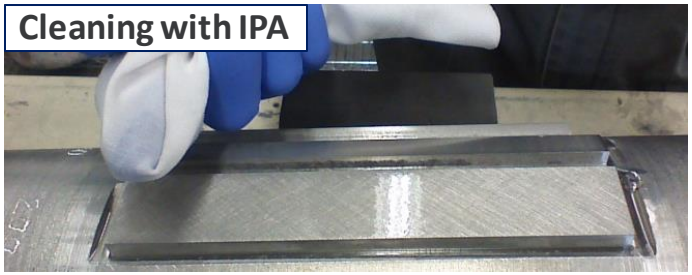
Lever Test Method (contd.)

Sample surface preparation

Roughening with sand paper

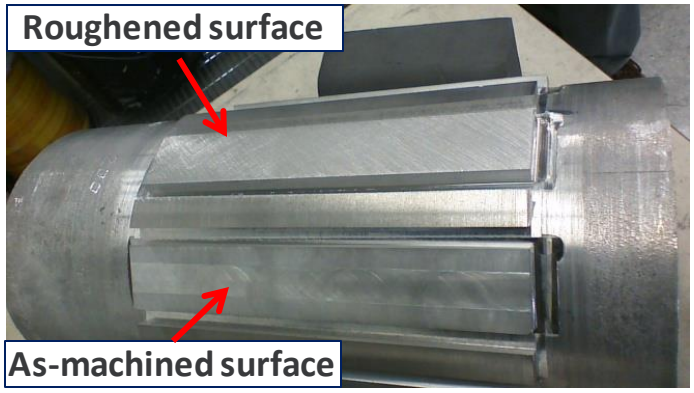


Cleaning with IPA



Roughened surface

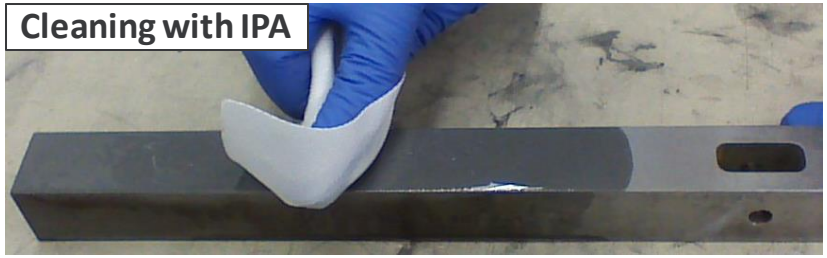
As-machined surface



Lever surface preparation

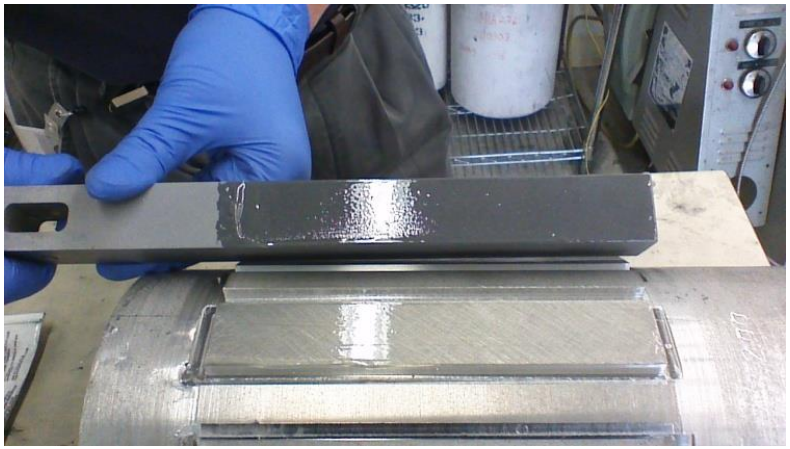
Grit blasting

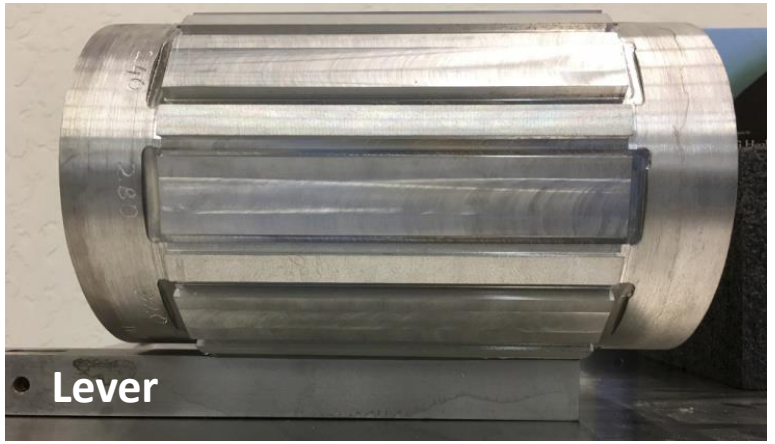
Cleaning with IPA



Grit blasted lever surface

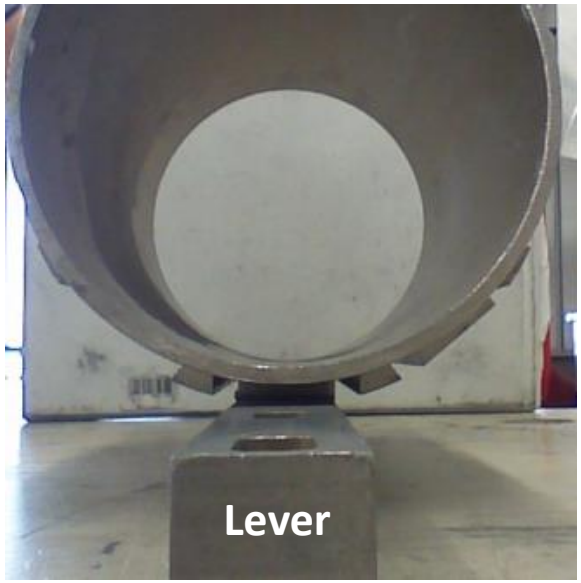
Lever Test Method (contd.)



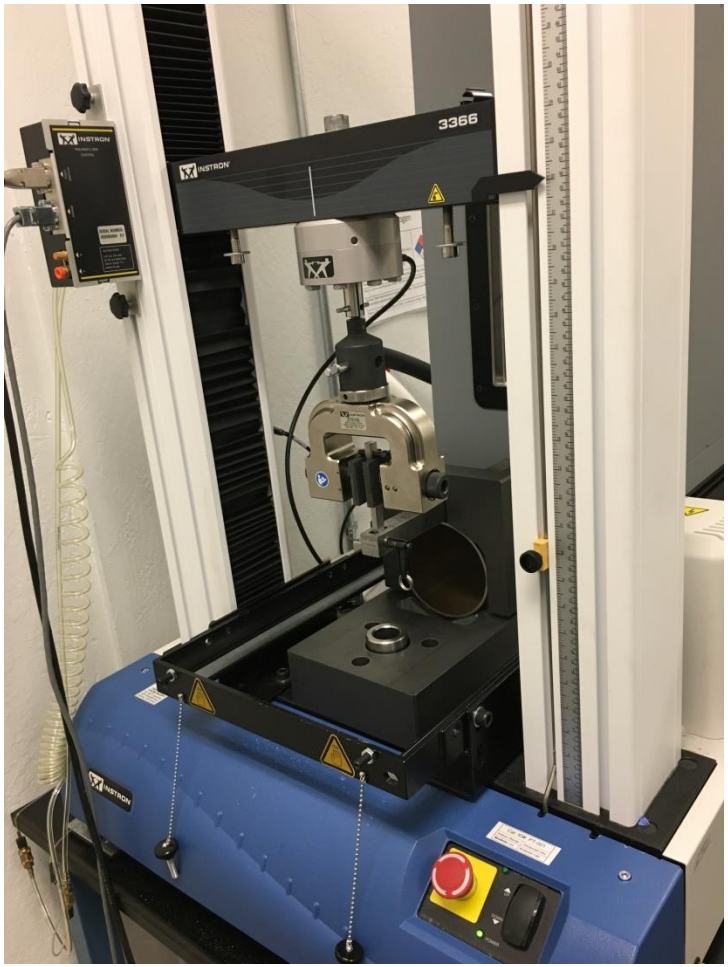


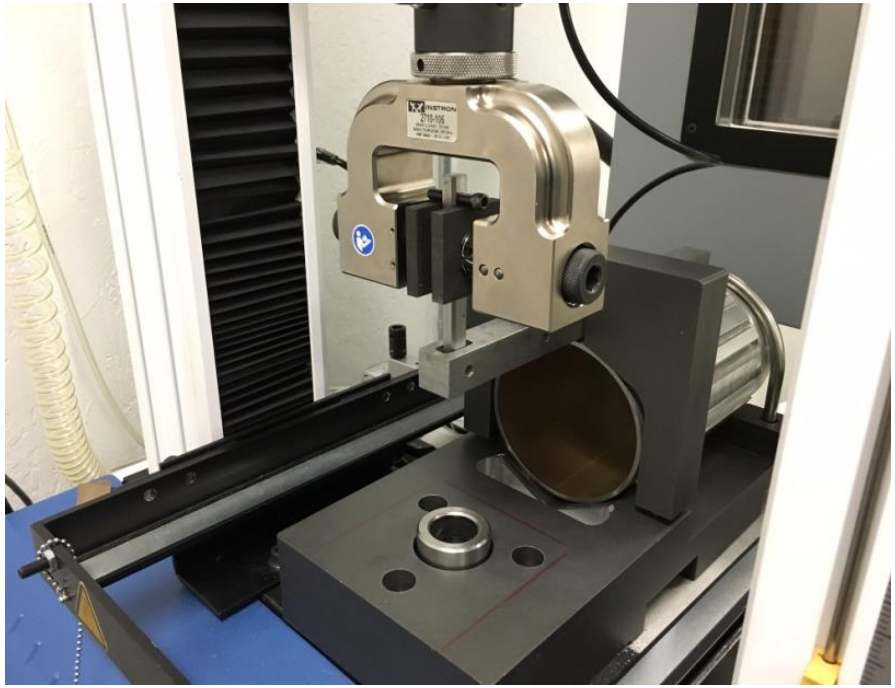
Gluing lever to specimen surface, 24 hrs cure

Two component glue:
- Araldite AW 106 resin
- Hardener HV 953 US)



Lever Test Method (contd.)

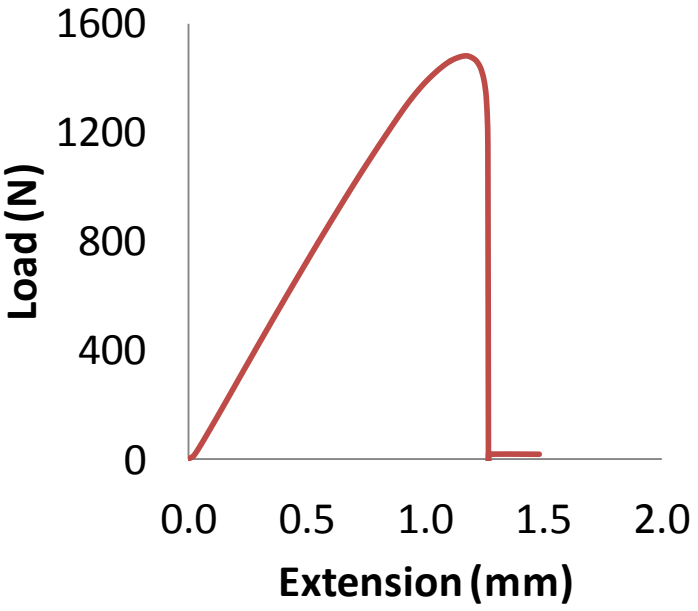




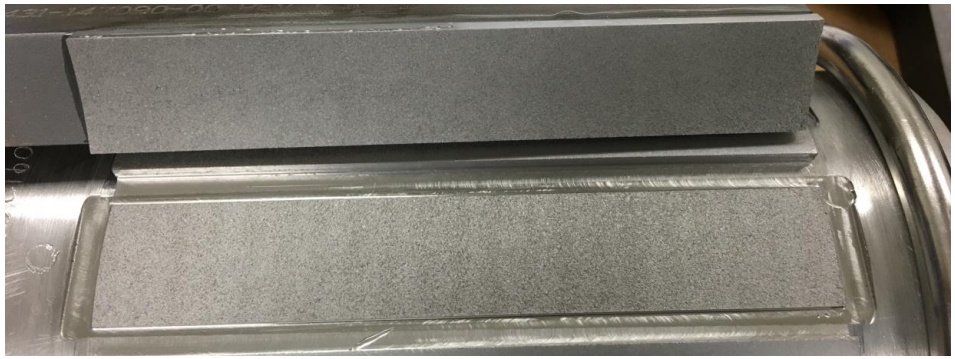
Displacement controlled loading on Instron ® 3366 universal testing system

Lever Test Method (contd.)

- Work of fracture is used as a metric along with peak load for evaluating interfaces.



Example load-displacement curve



Example fracture surface in lever test

Lever Test Method (contd.)

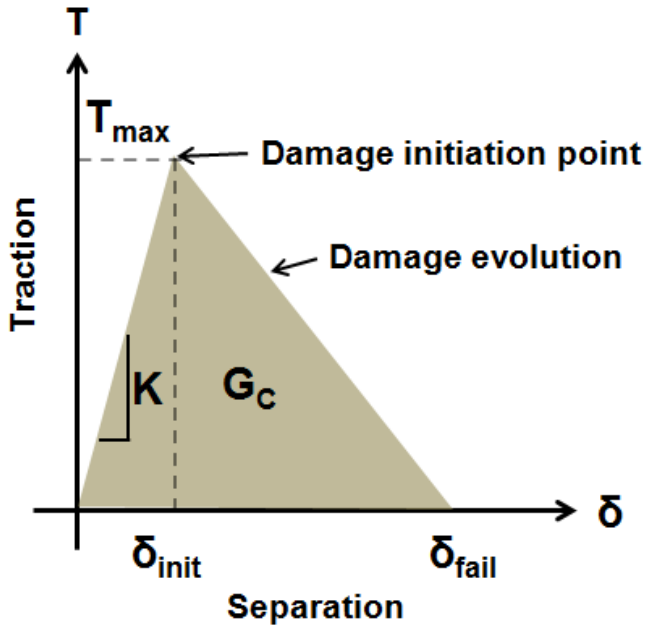
Example failure modes in lever test

Valid for interface characterization

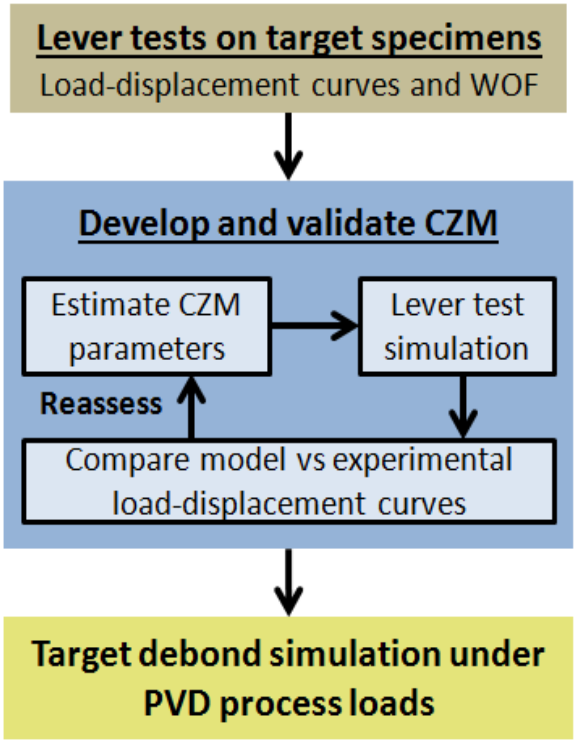
Invalid for interface characterization

Cohesive Zone Model using Lever Test

- Cohesive zone model (CZM) provides a unified framework to simulate crack initiation and crack propagation.
- Lever test data enables comparison of different bond conditions and development of a CZM.



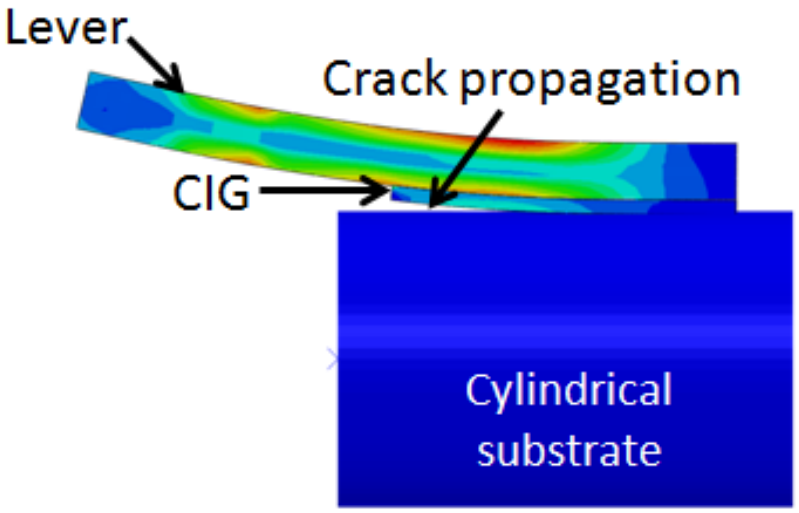
Traction separation law in CZM



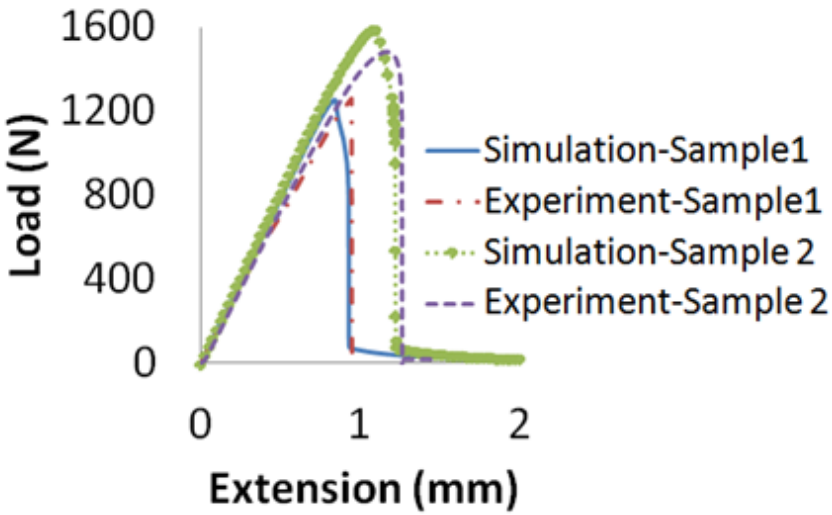
Ref: K. Hardikar, J. Vlcek, V. Bheemreddy and D. Juliano, "Assessing Reliability of Cold Spray Sputter Targets in Photovoltaic Manufacturing," JTST, v26, 2017.

Results-I

- Lever test in conjunction with CZM provides distinction between failed target bond strength (sample 1) and for the target that survived process conditions (sample 2).



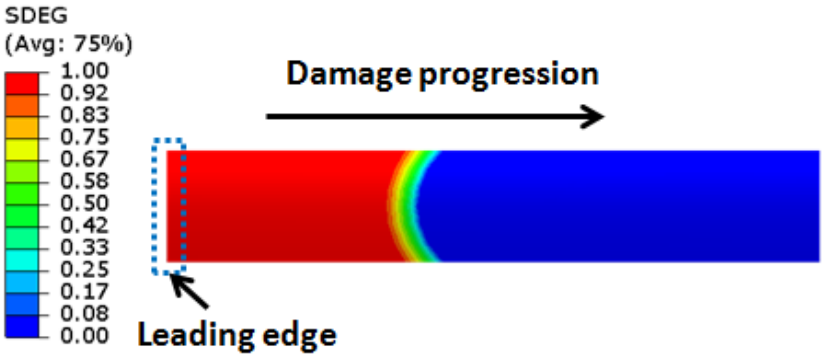
Crack propagation in lever test simulated using CZM



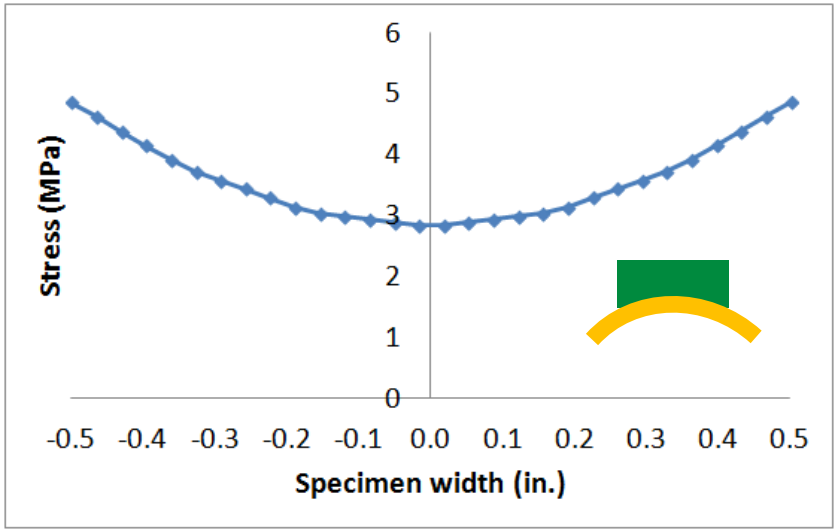
Results-I

- CZM provides insight into possible damage propagation profiles.

Damage propagation



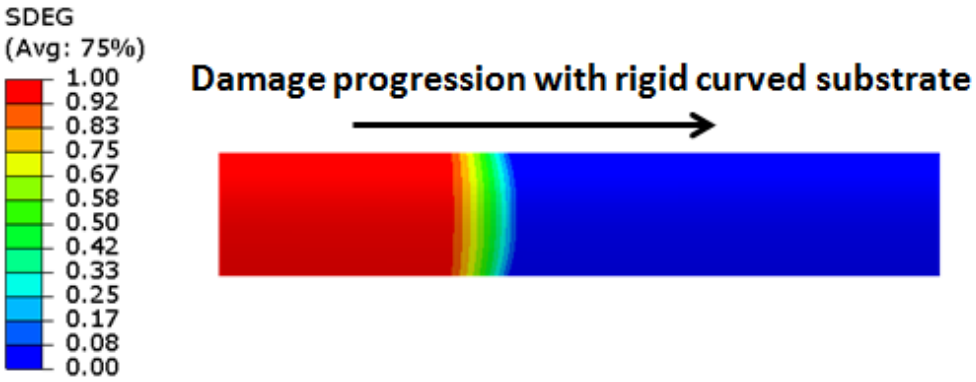
Stress Concentration at leading edge

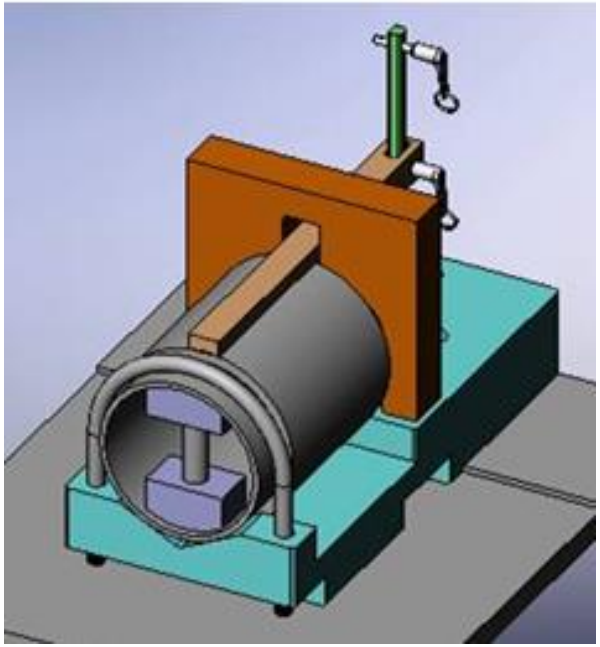


Results-I

- Simulations suggest that the compliance of the backing tube affects the crack propagation.
- It is desired to have rigid substrate for uniformity of crack propagation.

Damage propagation

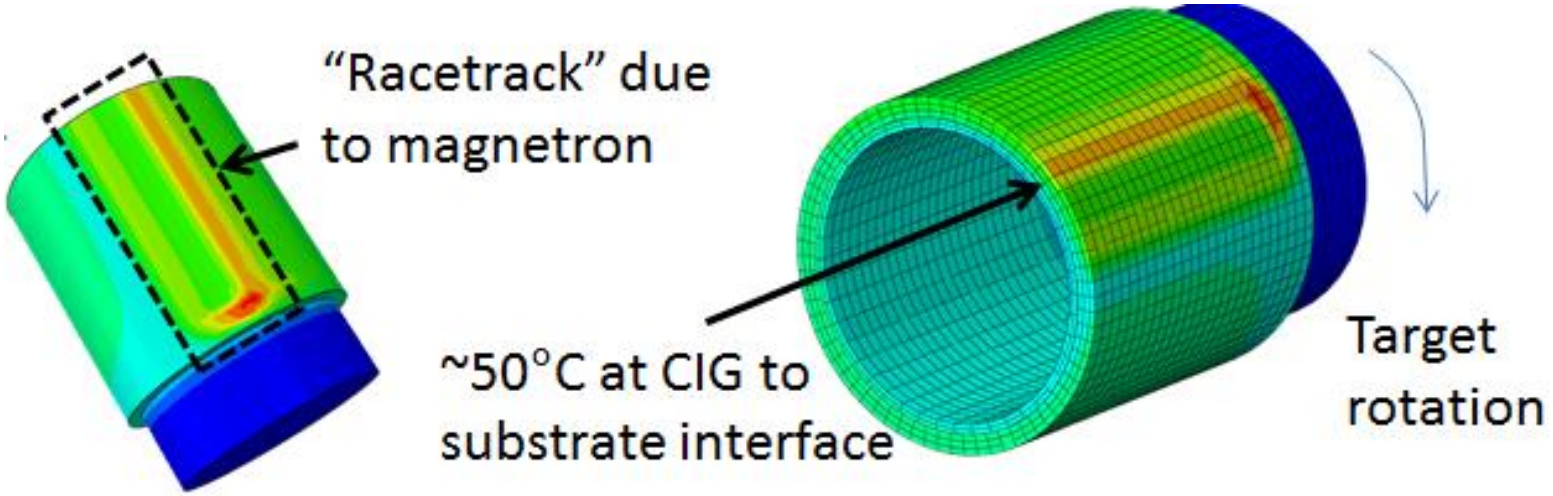




Extra support and clamping for enhanced rigidity of substrate

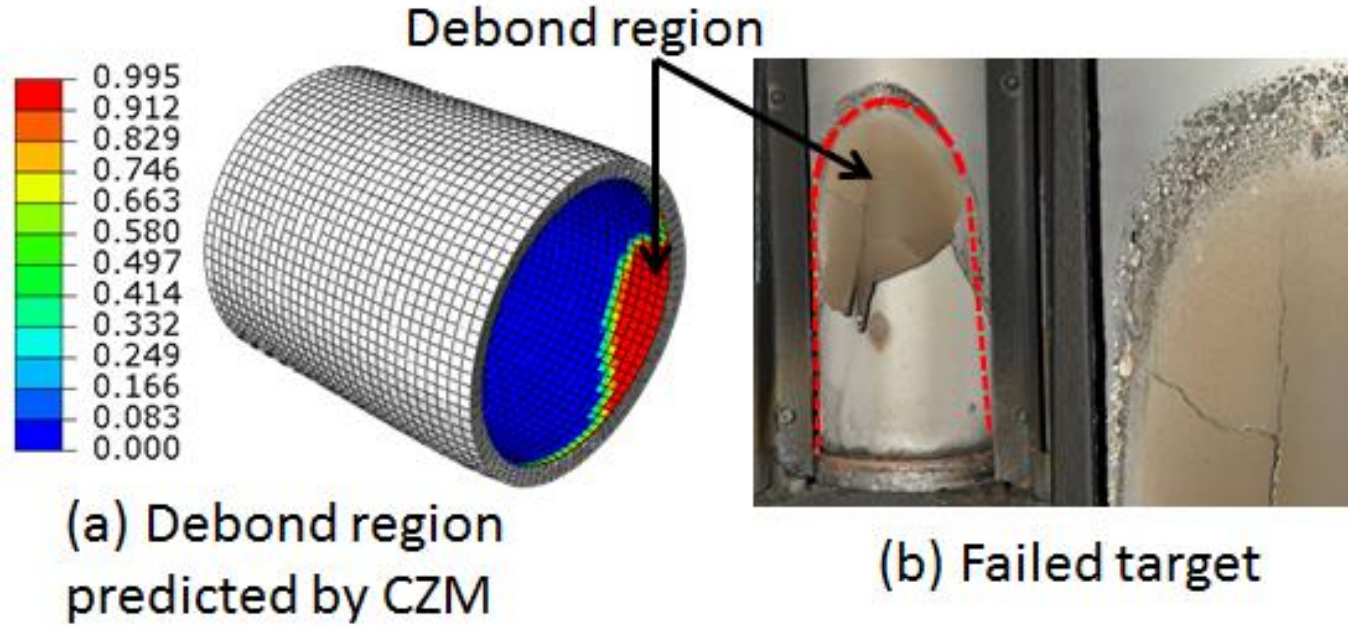
Results - II

- Heat transfer simulation results justify room temperature characterization of interface fracture resistance.



Results - II

- CZM simulation captures the approx. parabolic debond zone satisfactorily.



Ref: K. Hardikar, J. Vlcek, V. Bheemreddy and D. Juliano, "Assessing Reliability of Cold Spray Sputter Targets in Photovoltaic Manufacturing," JTST, v26, 2017.

Conclusions

- Simulation based reliability assessment approach is developed for CIG based rotary sputter targets.
- Custom lever test is developed for adhesion characterization in as-deposited condition for CIG alloy on cylindrical substrate.
- Lever test data in conjunction with cohesive zone model development is shown to enable engineering of target bond coat successfully.
- More than 800 CIG sputter targets with up to 50 lb. deposit per target have been manufactured to date using cold spray with no production failures to date by adapting the framework presented here.

Acknowledgements

- This work was a result of collaboration between Advanced Development Group and RISC (Reliability Integration Simulation and Certification) Group at MiaSolé.
  - Jack McInerney (CFD simulations)
  - Bao Nguyen (test fixture design)
  - Eric Cowart (machining)

Thank you

NCCAVS Thin Film User Group

Questions?