DuraMAT
Durable Module Materials Consortium

Evaluating the Durability of Balance of Systems Components Using C-AST

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The Motivation for the BoS Study

- BoS components include: connectors, cables, **branch connectors**, fuses (discrete), fuse blocks.
- Durability of BoS components has very limited research examination.

- Quantifiable replacement rate for t < 25y! 50y: TBD.

  -2 DOE AOP projects presently examining: components, occurrence, cost.

Example of PV fires in Italy.
Fiorentini et. al., PVRW 2020.

- Consequences of degradation and failure: module offline, string offline, tripped inverter, system shutdown, arc fault, fire!!!
- With limited publicity, latter consequences are BoS-centric.

Goals of the C-AST Project

C-AST chamber during operation (MiMo test sites).

General:

C-AST typically used with MiMos, so:

-Develop characterization methods.

-Identify degradation modes.

-Demonstrate ability to distinguish known bad components using C-AST.

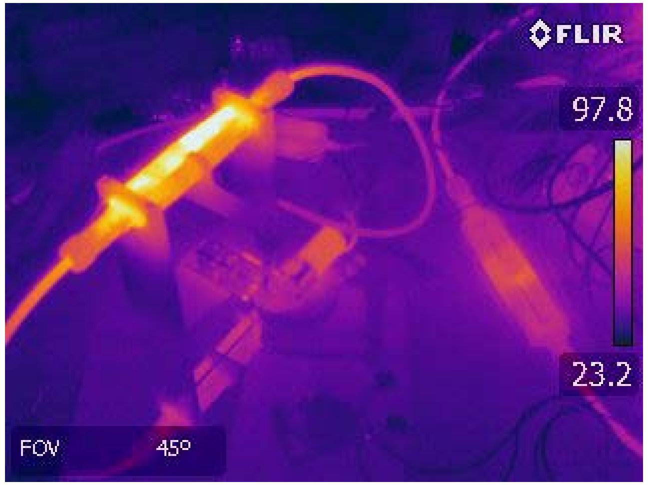
Specific:

-Identify most damaging stressors (environments, from C-AST sequences).

-Can static load or mechanical vibration contribute to failure?

Look For in This Presentation

-External mechanical actuation greatly affected the result.-



- How is examination implemented?
- What component(s) are affected?
- How to further validate the result?

Optional encore slides on j-box adhesives & pottants.

Examples of PV branch connectors.

Branch Connectors: The Scenario

- Utility provider experiencing ~30% failure rate in their power transfer chain, attributed to branch connectors.
  - -“Failure” means overheating, softening, physical distortion.
  - -Observable ΔT in thermographic imaging.
  - -Worst consequence: broken circuit, arc, fire.
- Component makes & models kept confidential in this presentation.

Examples of PV branch connectors.

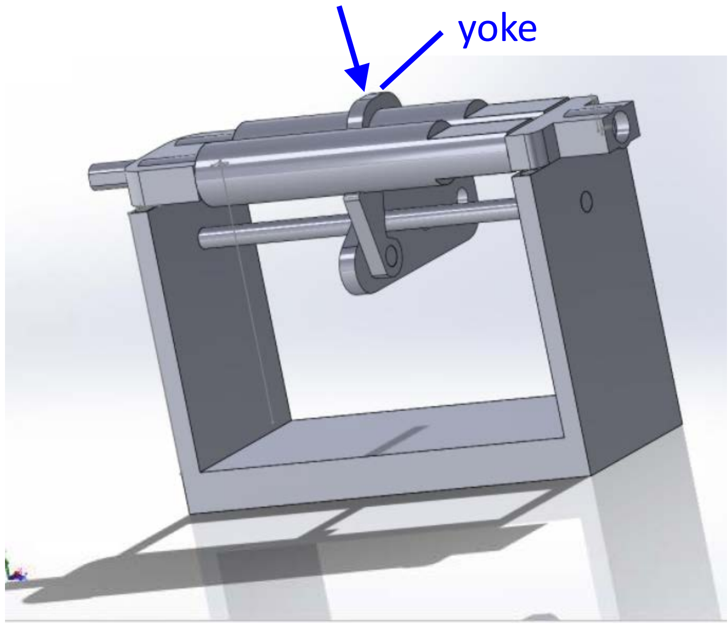
Branch Connectors: The Approach

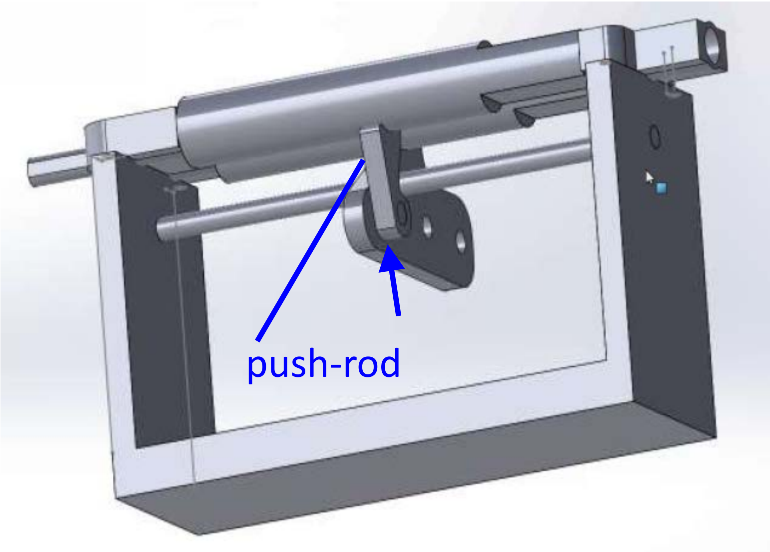
- Compare **C-AST** to UL standard tests.
- # and contribution of bad components unknown.
  Evaluate proximate system components: cable connectors, fuse, branch connectors.

- **Develop fixture and software using benchtop experiments (1 replicate).**
- Use custom C-AST fixture for mechanical actuation (6 replicates).

A Benchtop, Sample Integrated Push/Pull Mechanical Fixture Was Used

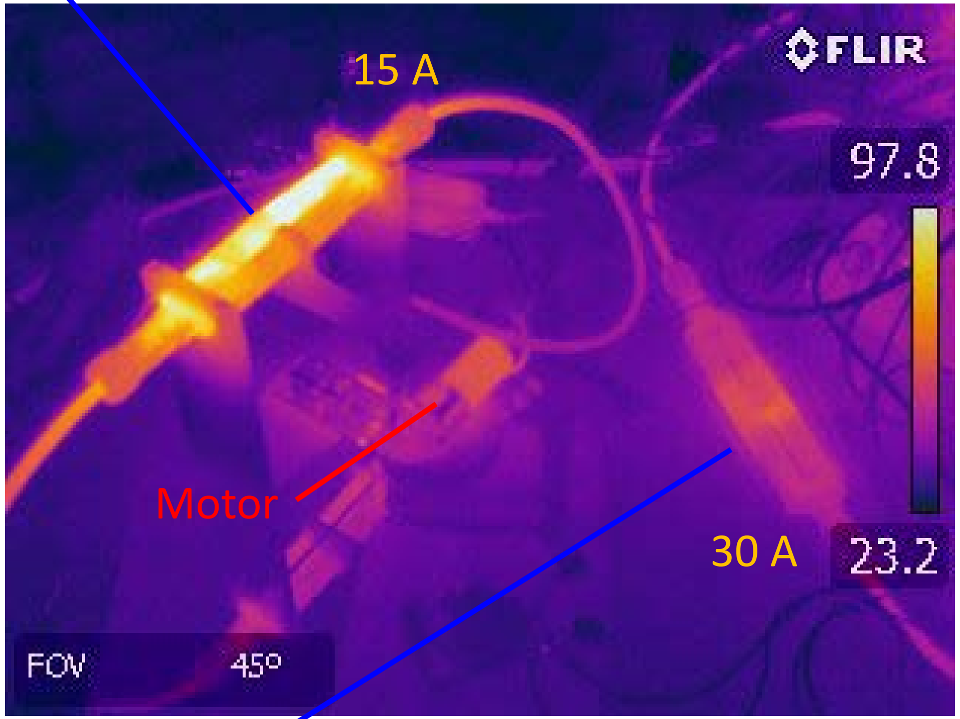
- "Yoke and push-rod" concept design concept was selected. (vs. "wedge").
- Specimen assembly is part of the actuation mechanism.
- Deflection used: 3 mm (initial) $\rightarrow$ 1 mm $\rightarrow$ 0.5 mm (C-AST).
- Benchtop version run with 16 rpm DC motor.
- C-AST version uses hydraulic actuators, 1/8 – 10 Hz.





SolidWorks model of mechanical fixture

Mechanical Actuation Readily Affected Test Results



Operation:

- Start at 10 A / 20 A applied DC current.
- Current incremented 1 A each day to failure.

Observed limits:

- Static assembly: fails at 35 A (equiv. labels for 30 A).
- Dynamic assembly: fails at 15 A. $T_{external}$ > 130° C.
- UL connector test: no failure BC @ 37.5 A. $T_{external}$ 44° C.

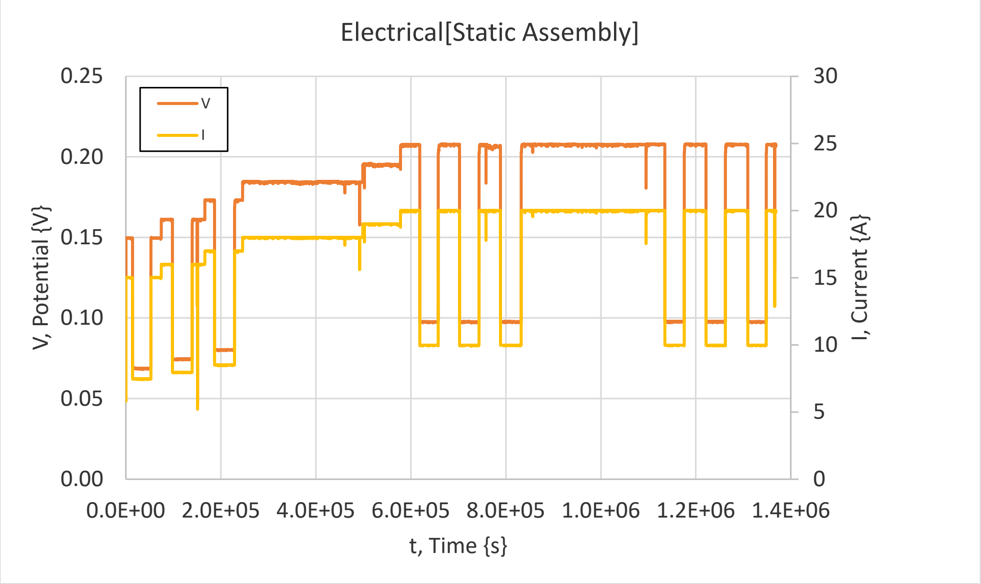
Failure modes:

- Static assembly: fails at fuse (open circuit).
- Dynamic assembly: fails at fuse/branch.

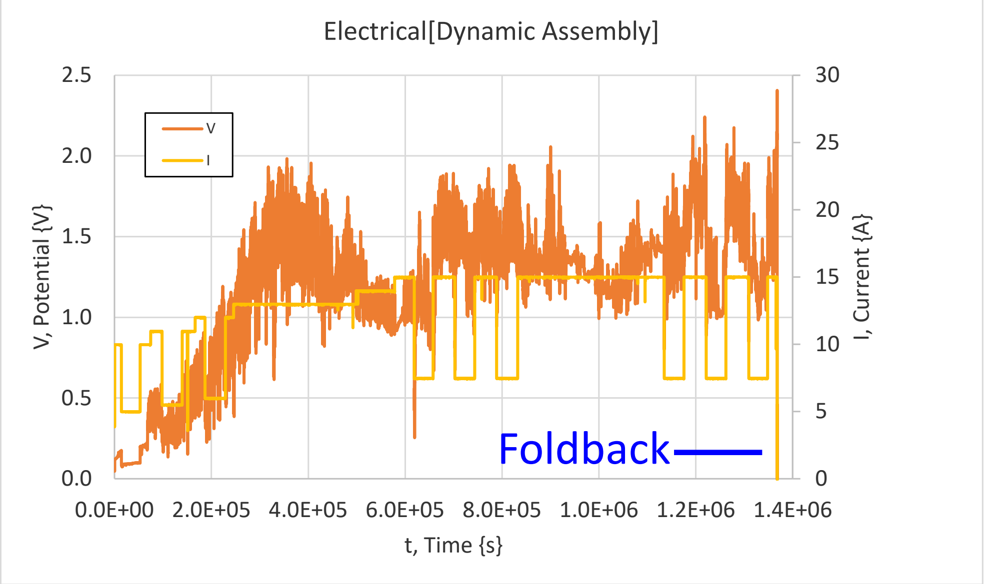
-Local arcing suspected from: smoke, local melting of plastic, discolored metal pins, increased fuse resistance.

I-V: Mechanical Actuation Gave an Immediate, On-going Affect

- LabView software for C-AST developed in benchtop experiments.
- I, V are logged per sample assembly.
- Data binned & analyzed in 1 minute intervals.
- Optional “burst” mode to log @ 100 kHz.



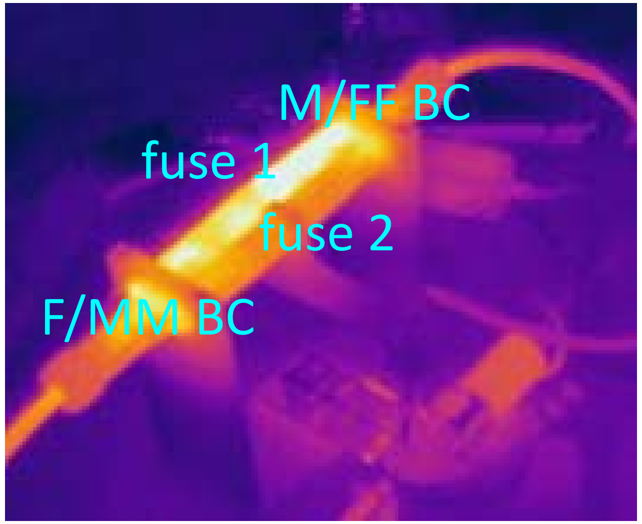
- Example (δ=1 mm) compares I, V for static & dynamic assemblies.
  -I, V scales (y-axis) are different, static vs. dynamic.
  -V quickly becomes more variable for dynamic.

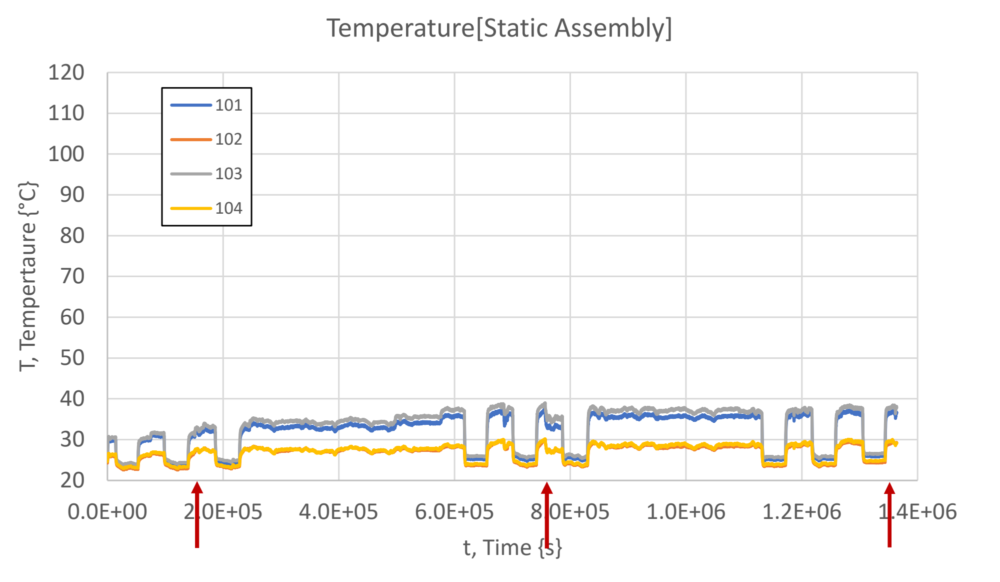


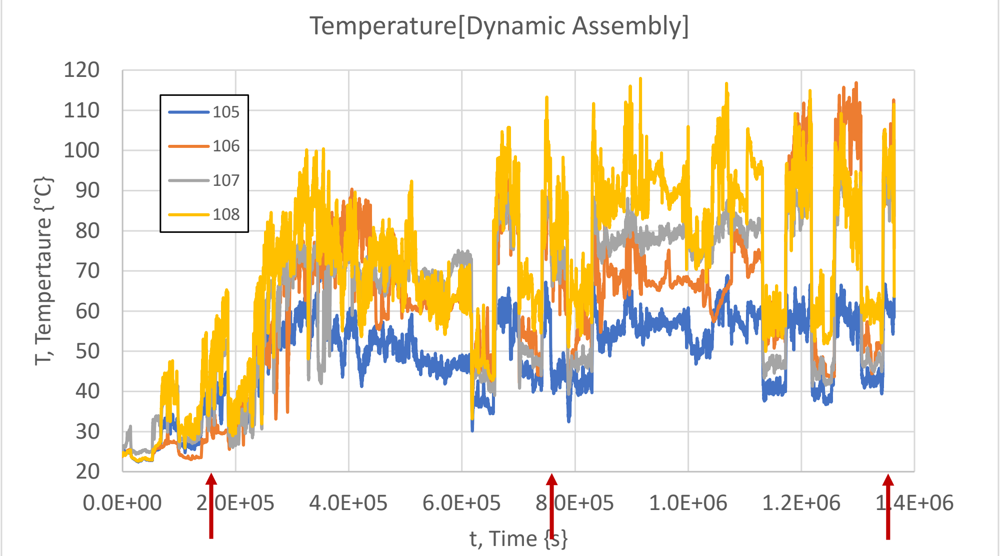
- Foldback protection (> V_{fb}) was extended from 1 to 5 to 25 s.
- Q: what would you use to simulate an inverter?

T: Mechanical Actuation Gave an Immediate, On-going Affect

- T is logged per site (F/MM BC, fuse 1, fuse 2, M/FF BC).
  -Discrete T-type thermocouples in sheet package.





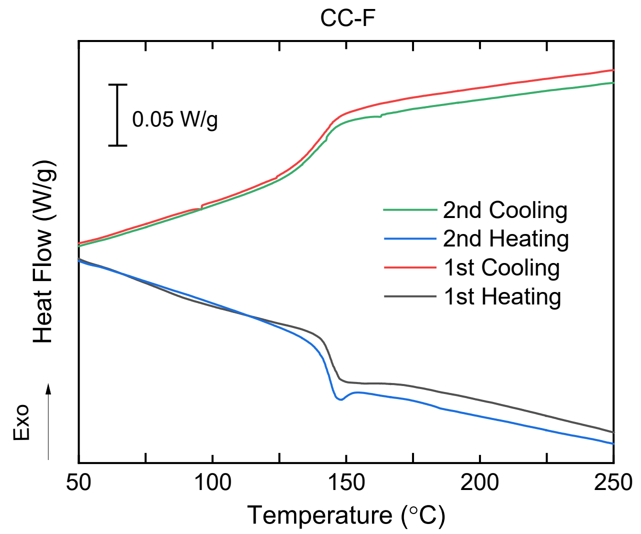


- Example (δ=1 mm) compares T for static & dynamic assemblies.
  -Scale (y-axis) same for static & dynamic.
  -FLIR vs. TC: exact hottest spot difficult to predict.
  -Helpful to know: t_{onset}, what components affected.

Data from experiment 4. Red arrows indicate approximate read point for FLIR imaging.

DSC & FTIR Identify Connector Ends Are Polycarbonate

Q: What is the phase transition temperature, what material is implied for black deformed plastic?
→DSC and FTIR examination of unaged samples.

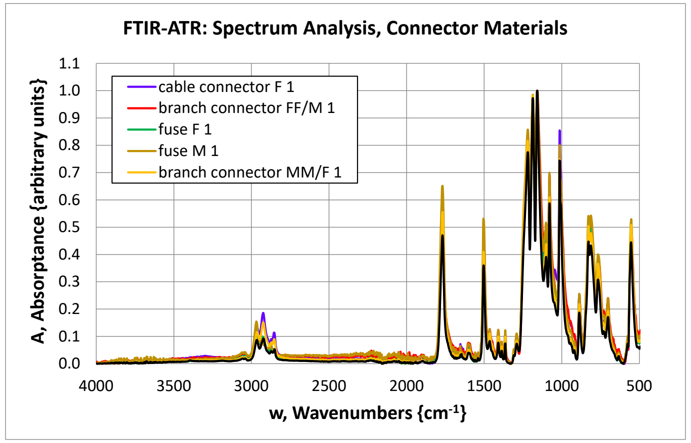


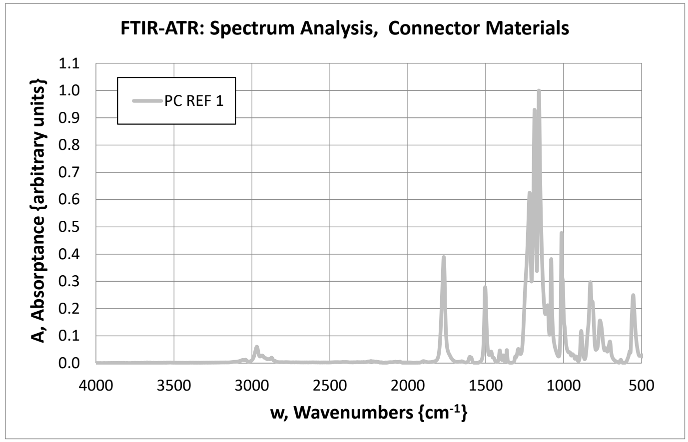
DSC for cable connector, female end (plastic).

- Suspect hard structural polymer (PC, ABS, etc) from handling samples.
- T_{glass} of 142±5°C (AVG ± 2 S.D.) suggests material is amorphous PC.
- All samples gave similar response (scans from -90 – 200 °C), including: cable connector, branch connector, fuse connector ends.

- Cable-, branch-, fuse- connectors have same FTIR spectra.
  - -Similar to polycarbonate reference sample.
  - -2 measurements from separate pieces each component.
  - -FTIR spectra verified on both F and M connector ends.

⇒Suspect PC containing carbon black.

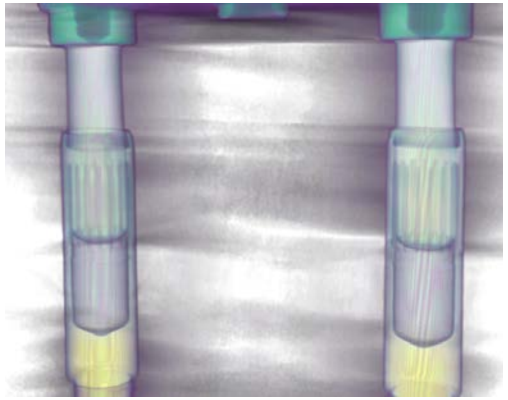




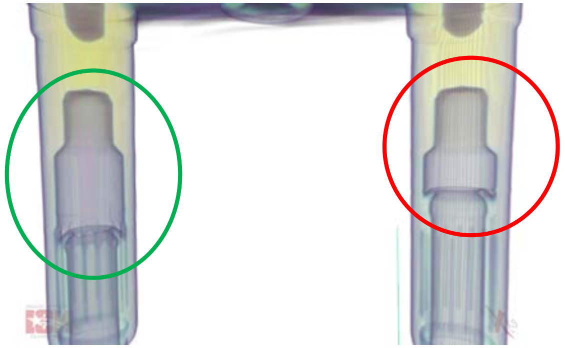
FTIR (left) for all component ends and (right) PC reference.

XCT: Different Sample Locations, Temperatures May Dominate Between Field & "C-AST"

- Figures: X-ray Computed Tomography imaging of field- and accelerated tested-samples.
- Field samples show asymmetry not present on unaged samples.
- Accelerated samples: bulge + contrast proximate to solder.



Unaged metal pins, utility provider (opposite end)



Metal pins, utility provider.

- Convolute spring component shape unchanged.
  - T_{forge} Cu ~900°C. T_{melt} Cu 1085°C.
- Aluminum bronze fuse holder shape unchanged.
  - $T_{softening}$ Al/Cu ~315°C. T_{melt} Al/Cu >550°C.
- Solder may contribute to failure.
  - T_{melt} Sn/Ag/?Cu? ~220°C.

Unaged metal pins, utility provider.

Metal pins, benchtop δ = 3 mm.

plastic $\Rightarrow$142 °C realized in field.
solder $\Rightarrow$220 °C realized in accelerated test.

The Destructive Failure Analysis Procedure Following XCT

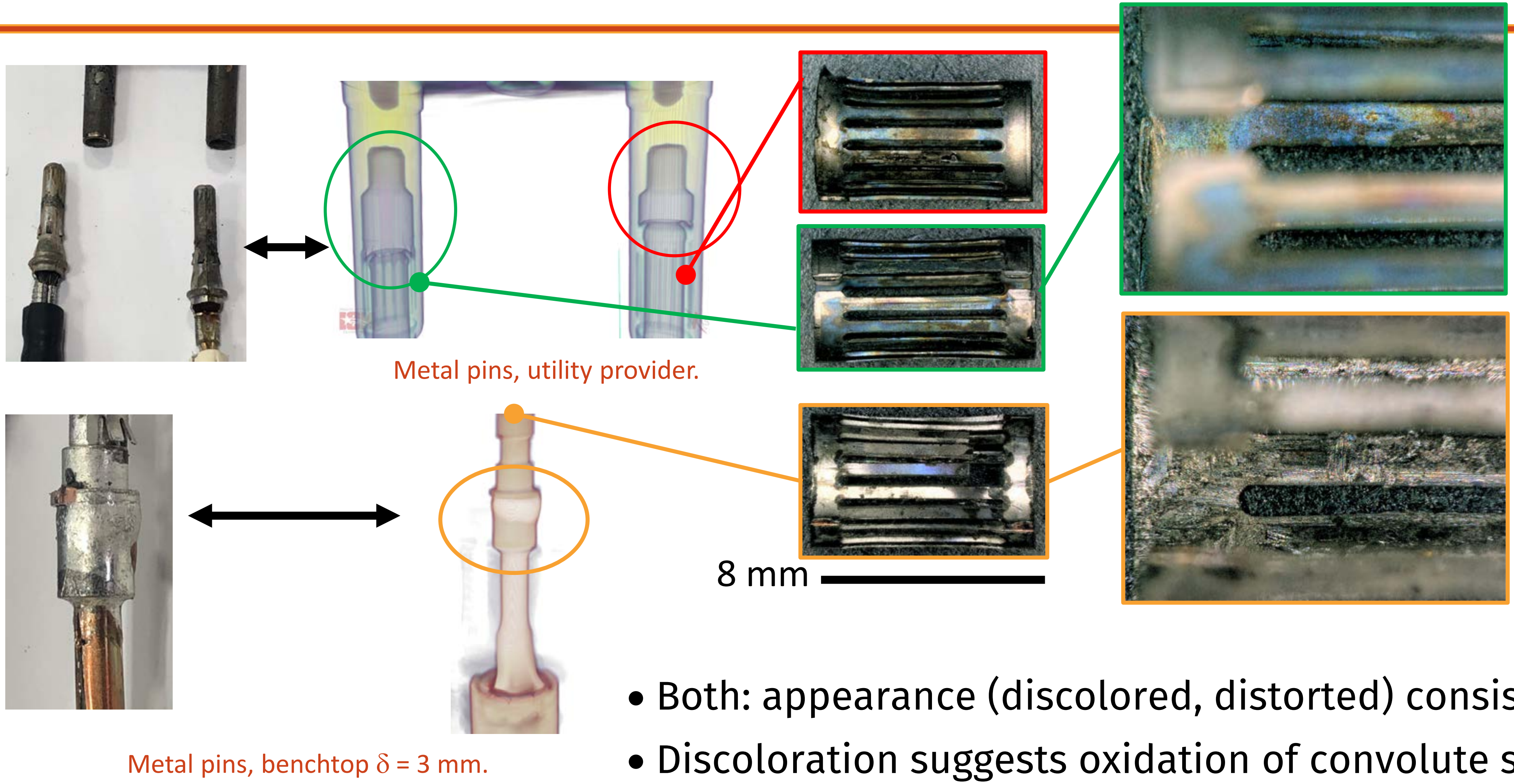
1. Remove (mill) external plastic.
   - -Retain plastic for F/A (FTIR, DSC).
   - -Inspect internal metal components relative to XCT.
   - -Methods: camera, optical microscopy, SEM/EDX.

2. Extract (cut, unfold) convolute spring from F metal pins.
   - -Inspection, methods as above.

convolute spring, extracted from unaged metal pin

~8 mm

Optical Micrscopy: Oxidation of Spring, with Mechanical Wear for δ = 3 mm



- Both: appearance (discolored, distorted) consistent with XCT.
- Discoloration suggests oxidation of convolute springs. (ΔT).
  - -More localized discoloration in benchtop specimen.
- Scuff marks (ends, interior) suggest wear during accelerated test.

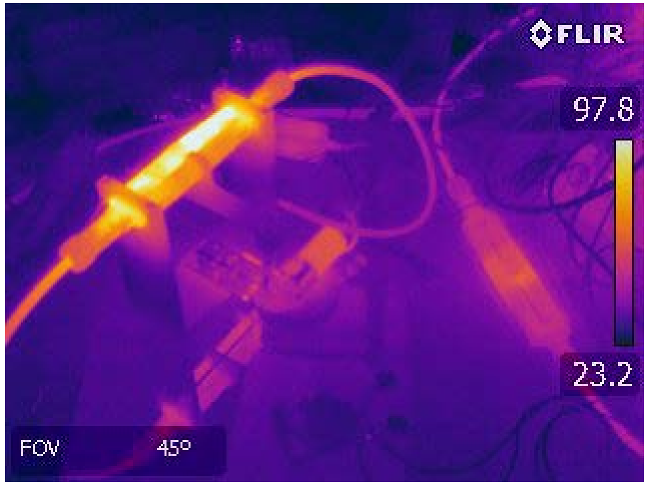
Present Status

Branch Connectors:

- On-going failure analysis: solder vs. spring, δ = 1 mm.
  - -Do we still see wear?
- Static assembly branch connectors through round 1 of C-AST (10 A).
- Dynamic C-AST branch connector assembly pending.
  - -Will effect of mechanical actuation be observed as in benchtop experiments?
  - -Will effect of weathering be observed?
- May apply second round of C-AST (increased current).
- Final comparison at IEEE PVSC 2022.

Remember From This Presentation

-External mechanical actuation greatly affected the result.-



- How is examination implemented?

  -sample integrated push/pull mechanical fixture

- What component(s) are affected?

  -static: fuse (internal).

  -with actuation: BC/fuse (observed for field).

- How to further validate the result?

  -mechanical wear observed for δ = 3mm.

  -pending C-AST @ δ = 0.5mm.

Acknowledgements

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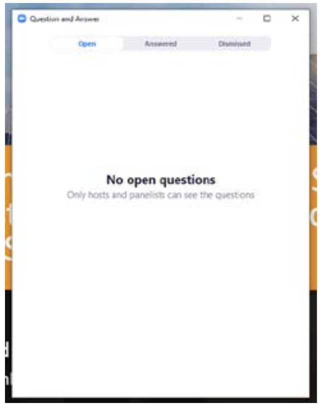
NREL STM campus (Dennis Schroeder)



☞ Please add to the ”Questions and Answers” or contact: David.Miller@nrel.gov

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