Board Level Failure Analysis of Chip Scale Packages

Nicholas Vickers, Kyle Rauen, Andrew Farris,
Michael Krist, Ronald Sloat, Jianbaio Pan, Ph.D.
California Polytechnic State University at San Luis Obispo

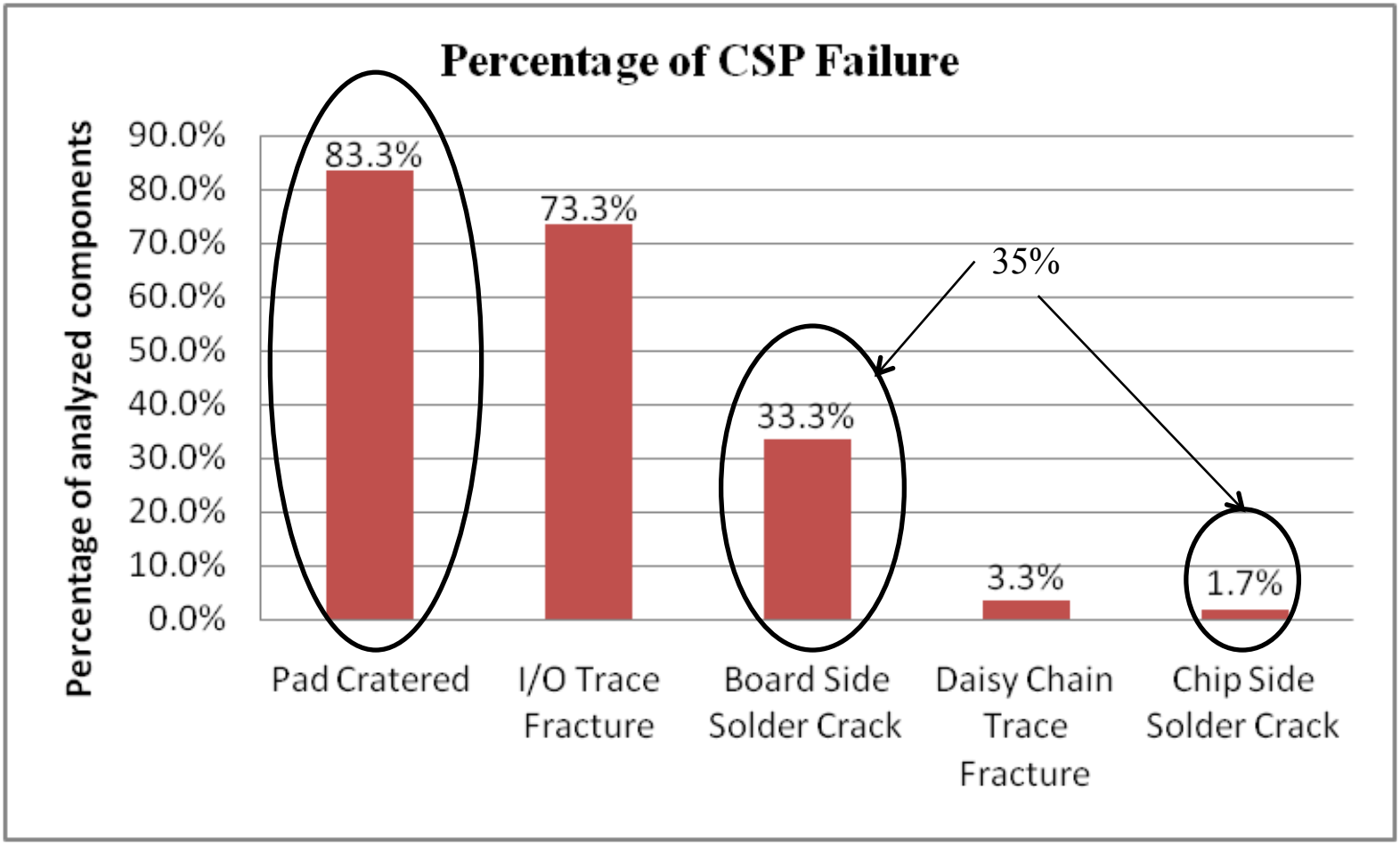
Overview

- Failure analysis Methods
- Failure analysis results
- Mechanical testing
- Conclusions

Failure Analysis Techniques

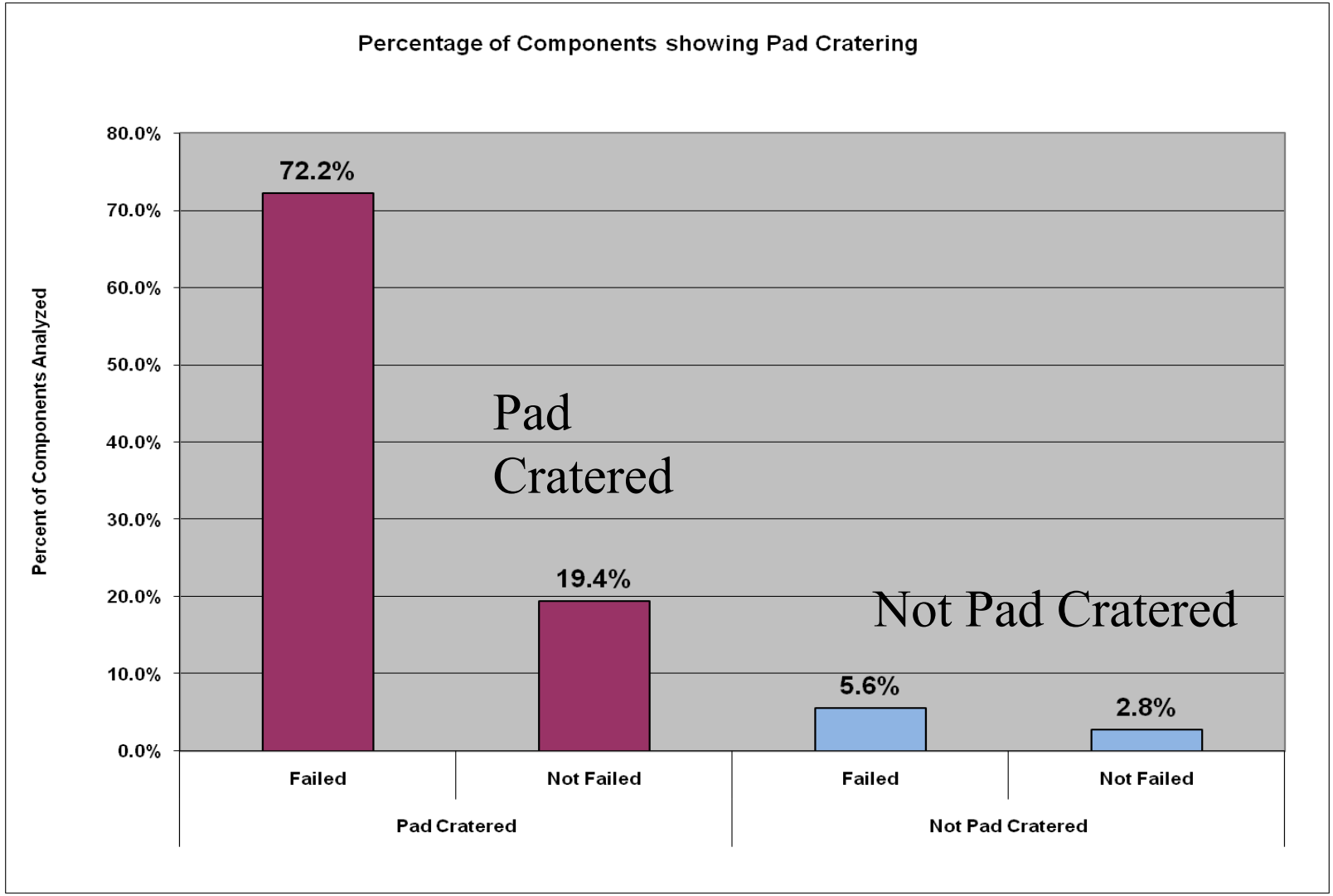
- 2 techniques used:
  - Dye Penetrant
    - Exposes cracks cause by drop testing
    - Crack area, and direction
  - Cross sectioning
    - Locates the layer in which the crack occurs
    - Identifies composition of layer cracks occur

Results



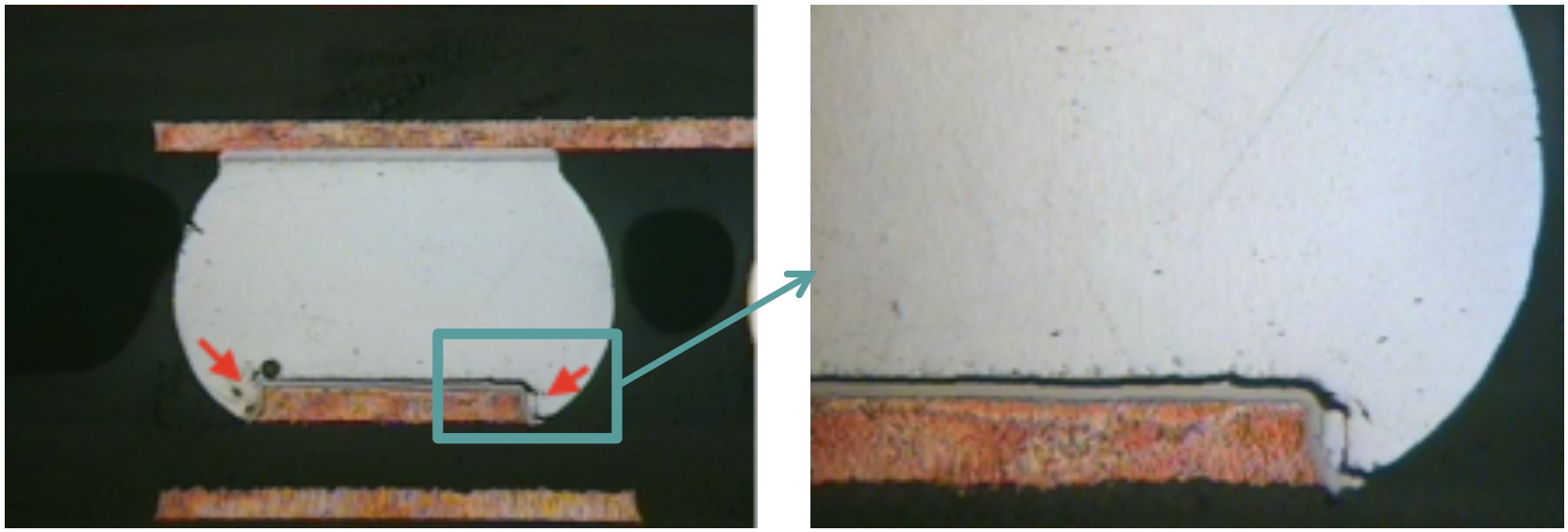
**Note- Some components show more than one failure mode

Pad Cratering and Electrical Failure



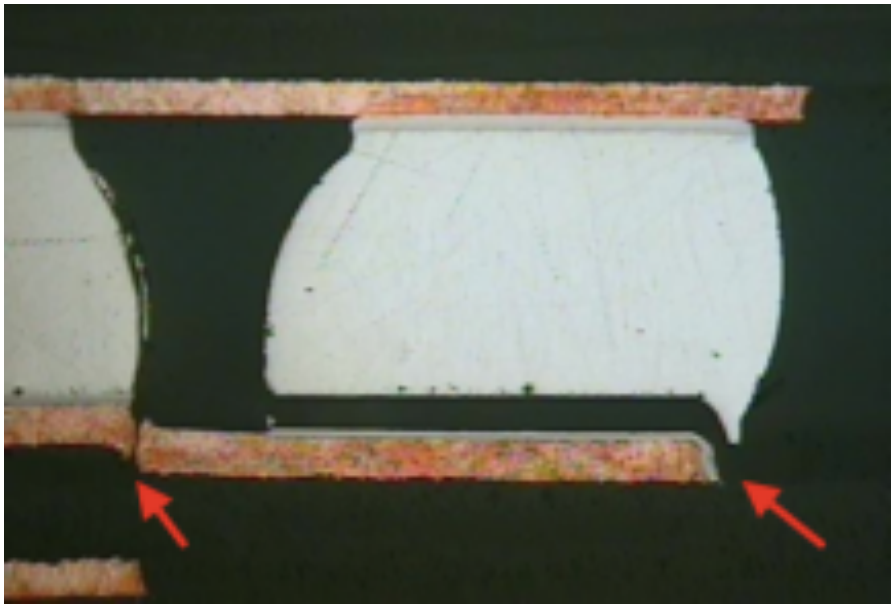
Solder Fracture Failure

- Cross-sectioned solder joint is shown to be cracked near the board side copper pad



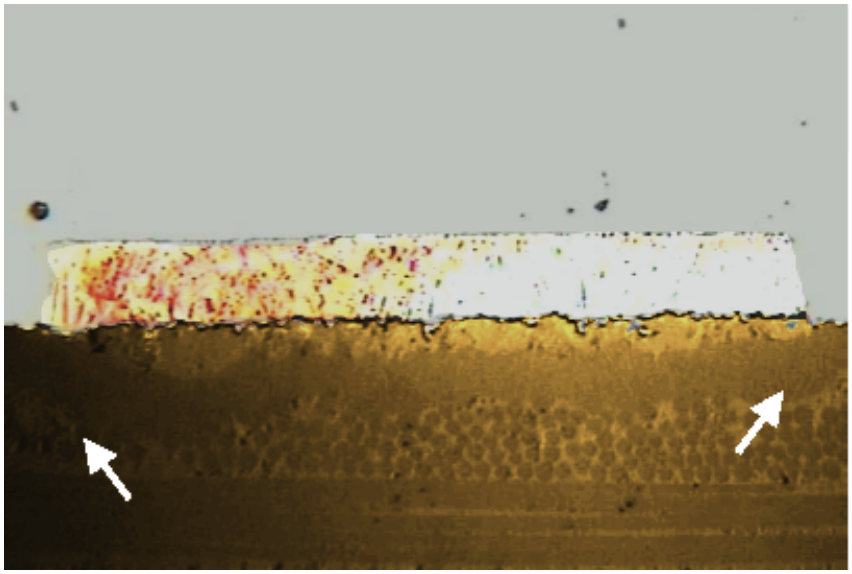
Solder Fracture Failure

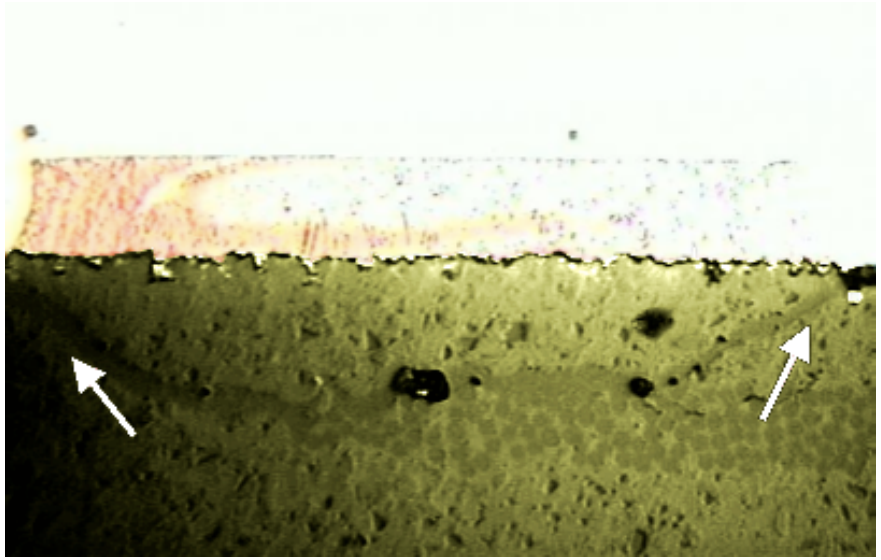
- Cross-sectioned solder joint is shown to be cracked near the board side copper pad
- Copper trace failure also shown (left side)



Cracking Under Pads (Cratering)

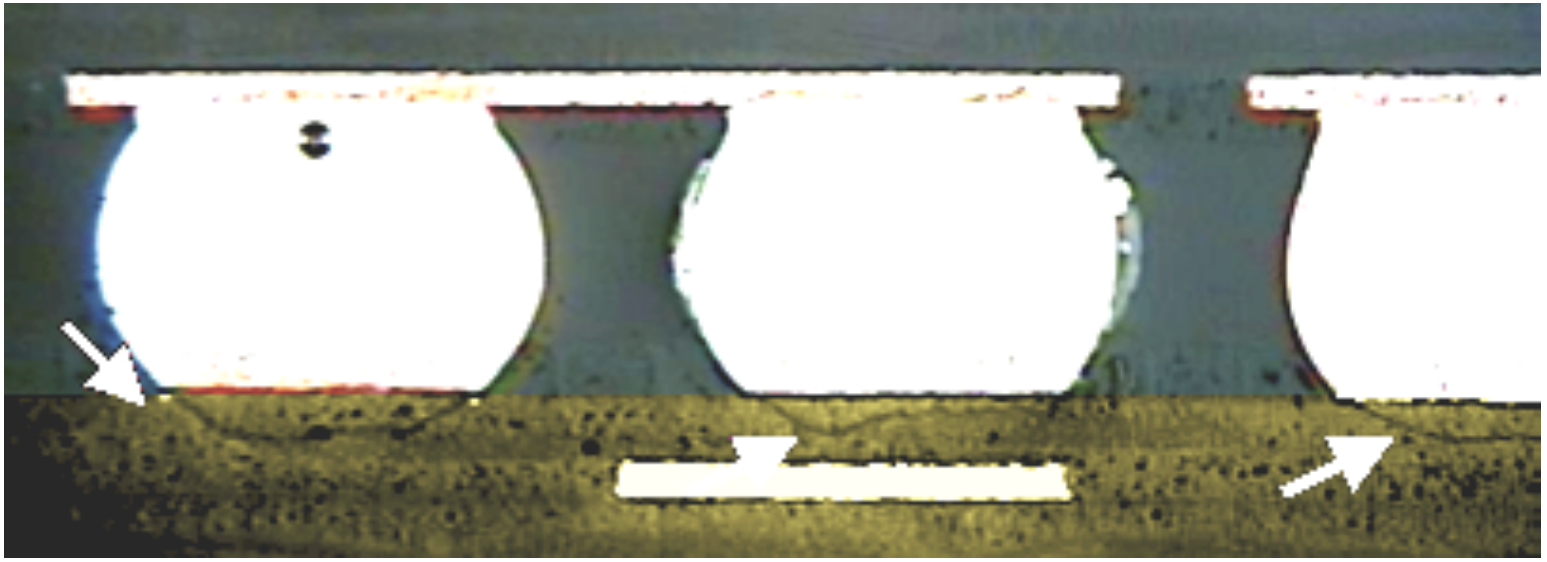
- Epoxy on the PWB board surface cracked away from the fibers within the board, allowing the copper pad to lift away from the board





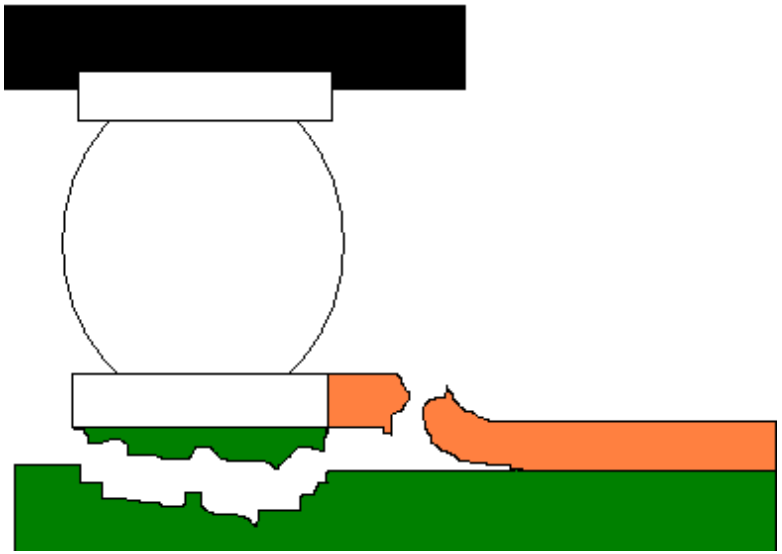
Cracking Under Pads (Cratering)

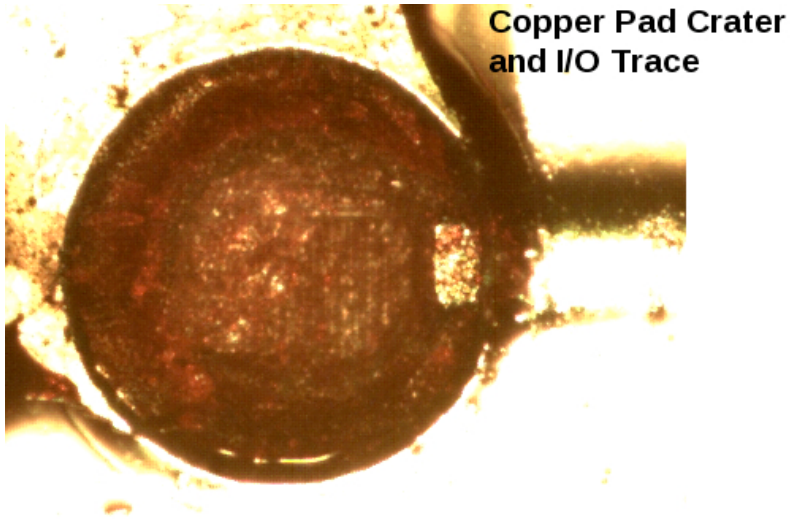
- Epoxy on the PWB board surface cracked away from the fibers within the board, allowing the copper pad to lift away from the board



Input/Output Trace Failure

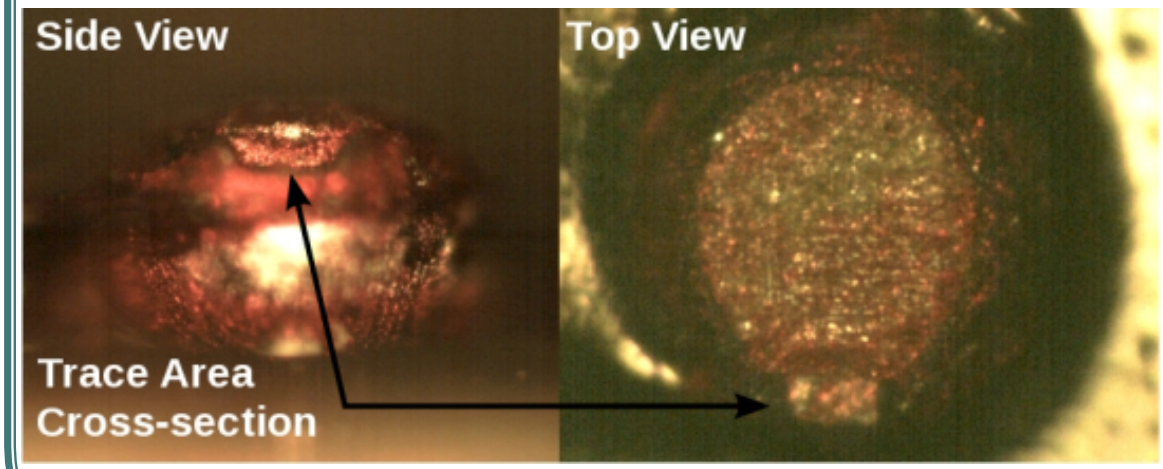
- I/O trace gets stretched when the copper pad lifts away from the PWB
- If the copper pad lifts far enough away, then ductile failure occurs in the copper trace



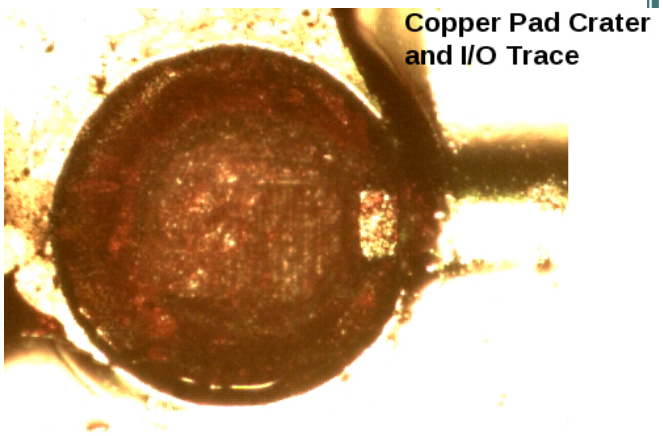


I/O Trace Failure

- Input/Output (I/O) traces that connect to the daisy-chain ‘resistor’ were often broken
- Many components had this broken trace and no other identifiable failure

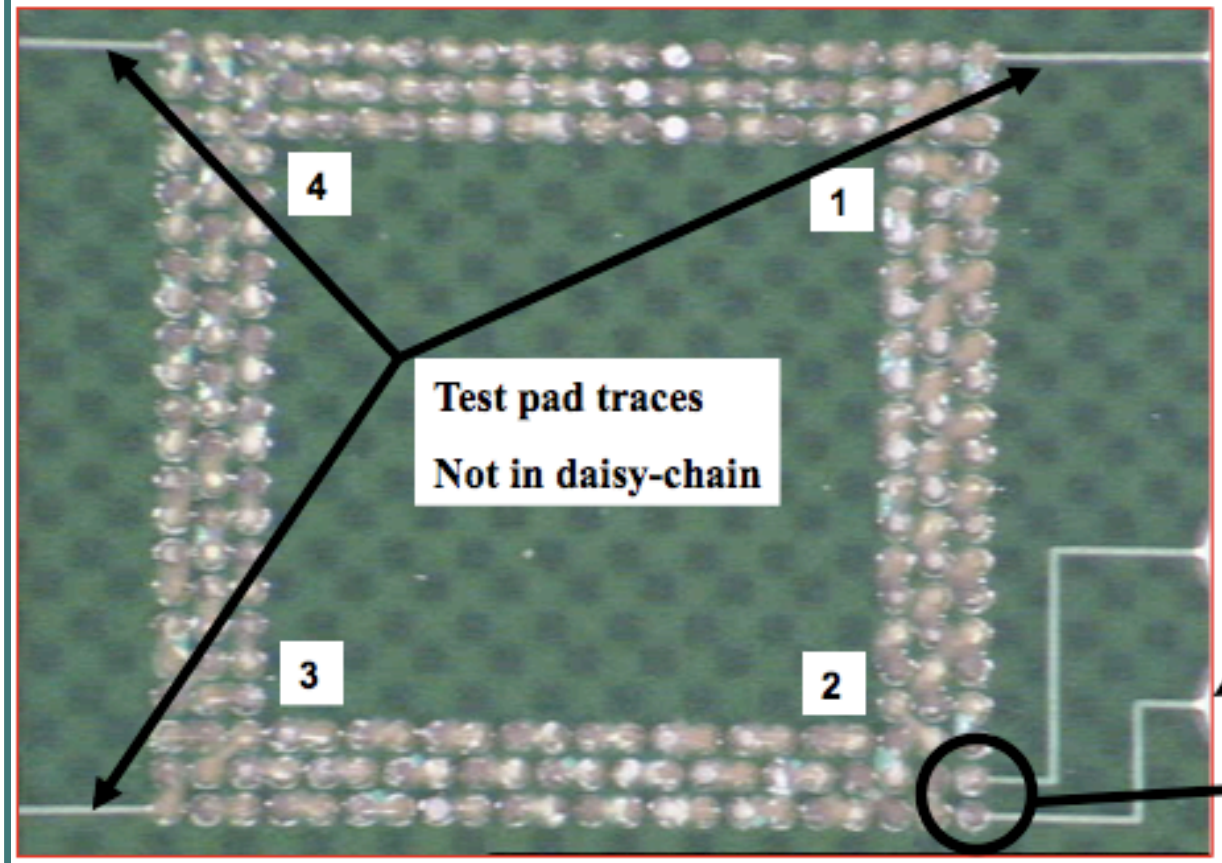


Component side

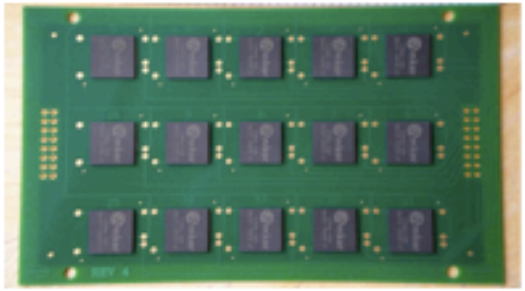


Board side

I/O Trace Failure Location



Solder pad layout for the CSP used in the test vehicle, orientation as board below



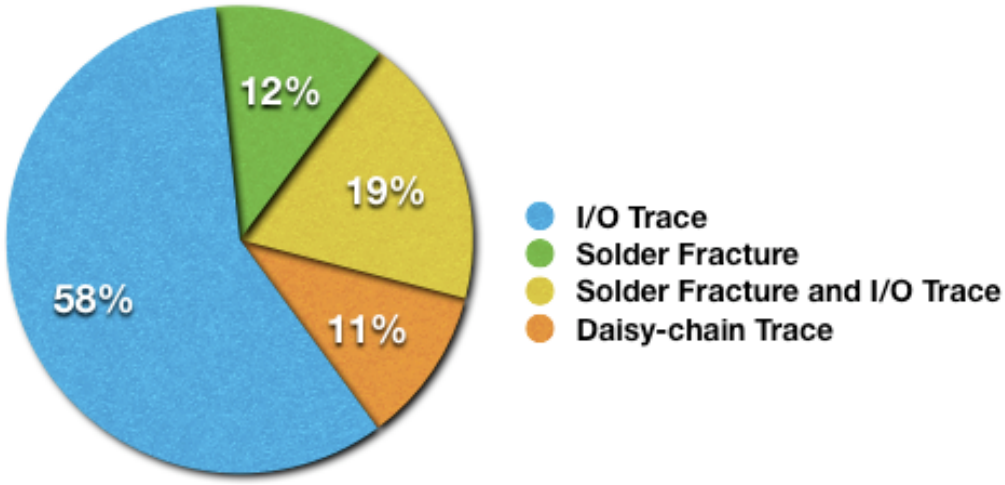
Cable located to the right

Critical Signal Traces

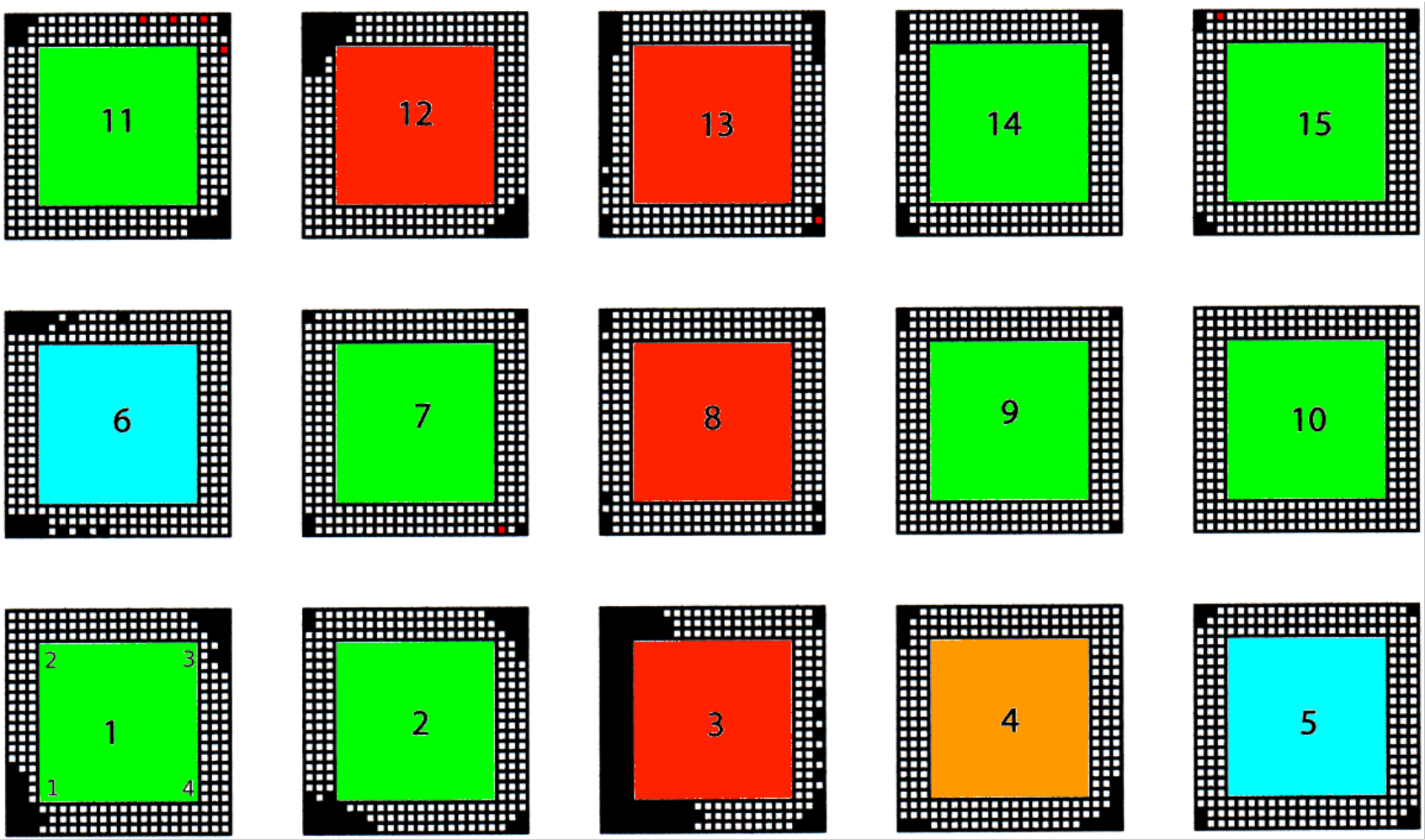
Area where I/O failure occurs most often

Failure Mode Comparison

- I/O Trace and Daisy-chain Trace failures are both caused by pad cratering
- Pad cratering was present on 88% of electrically failed components, and is directly responsible for 69% of electrical failures

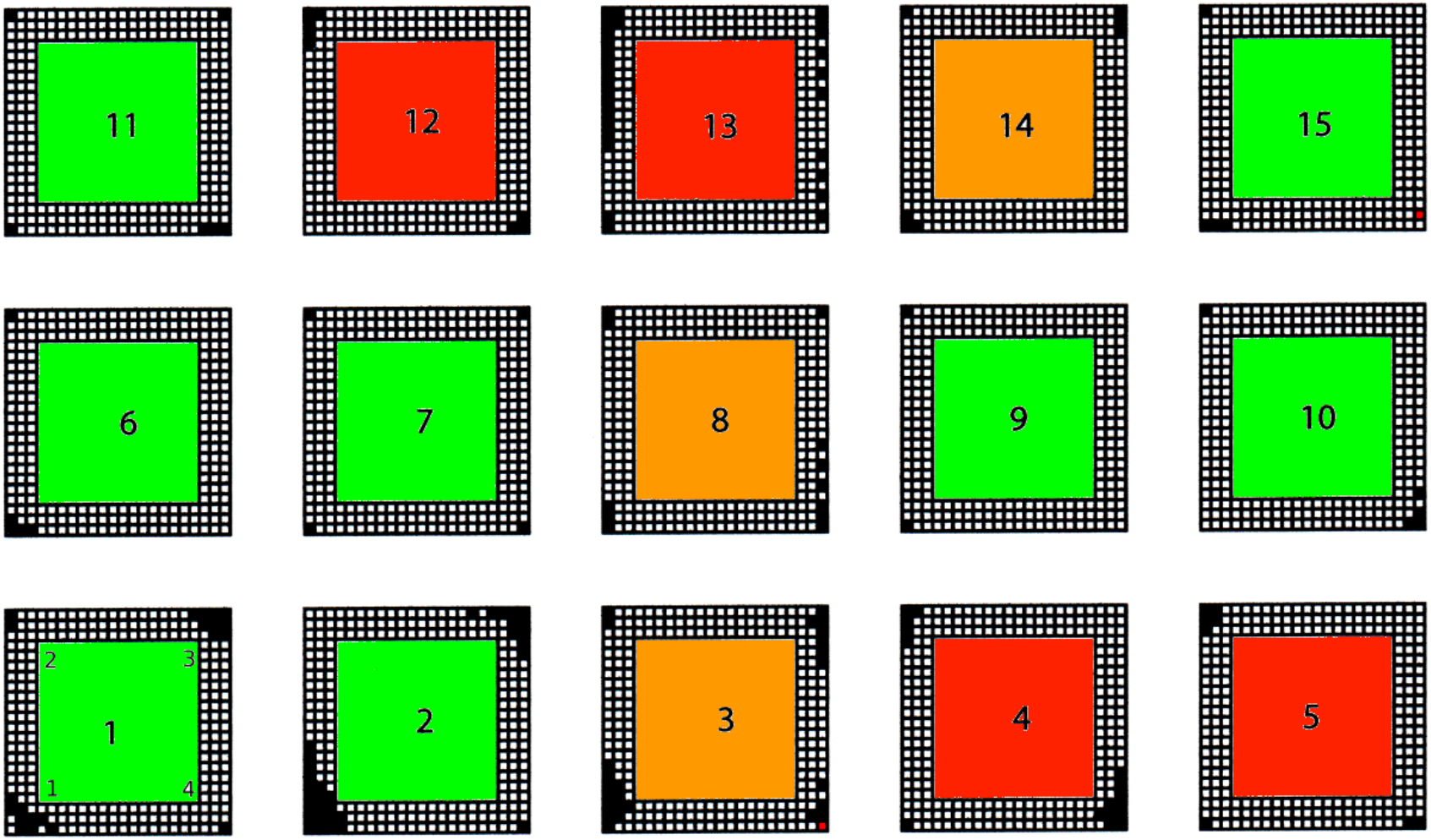


Failures After 10 Drops (No EB)



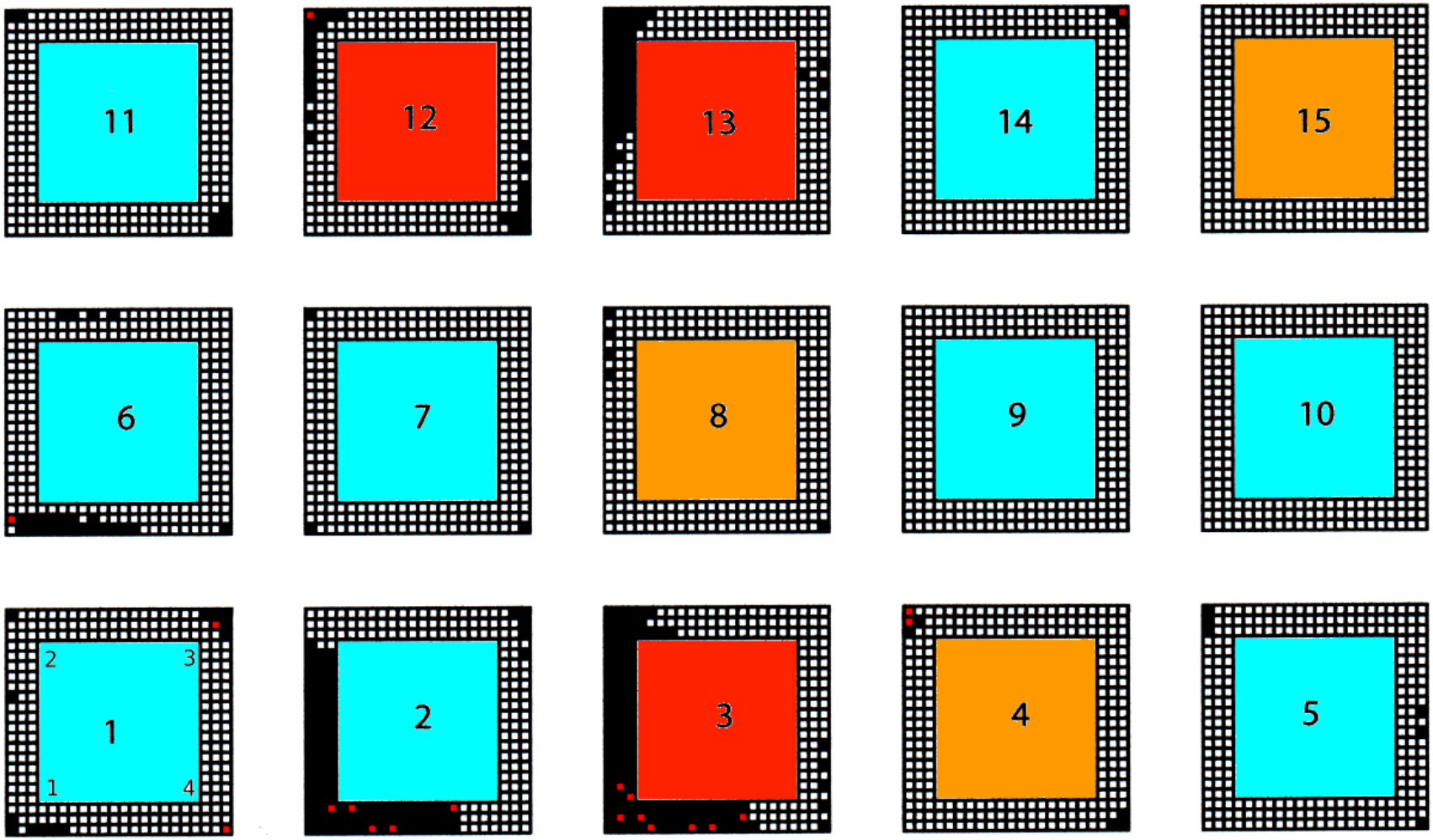
Component: Green – no failure, Blue – transitional failure, Orange – full failure, Red – complete failure
Solder Joints: Black – pad crater, Red – solder fracture (board side), Yellow – solder fracture (csp side)

Failures After 14 Drops (No EB)



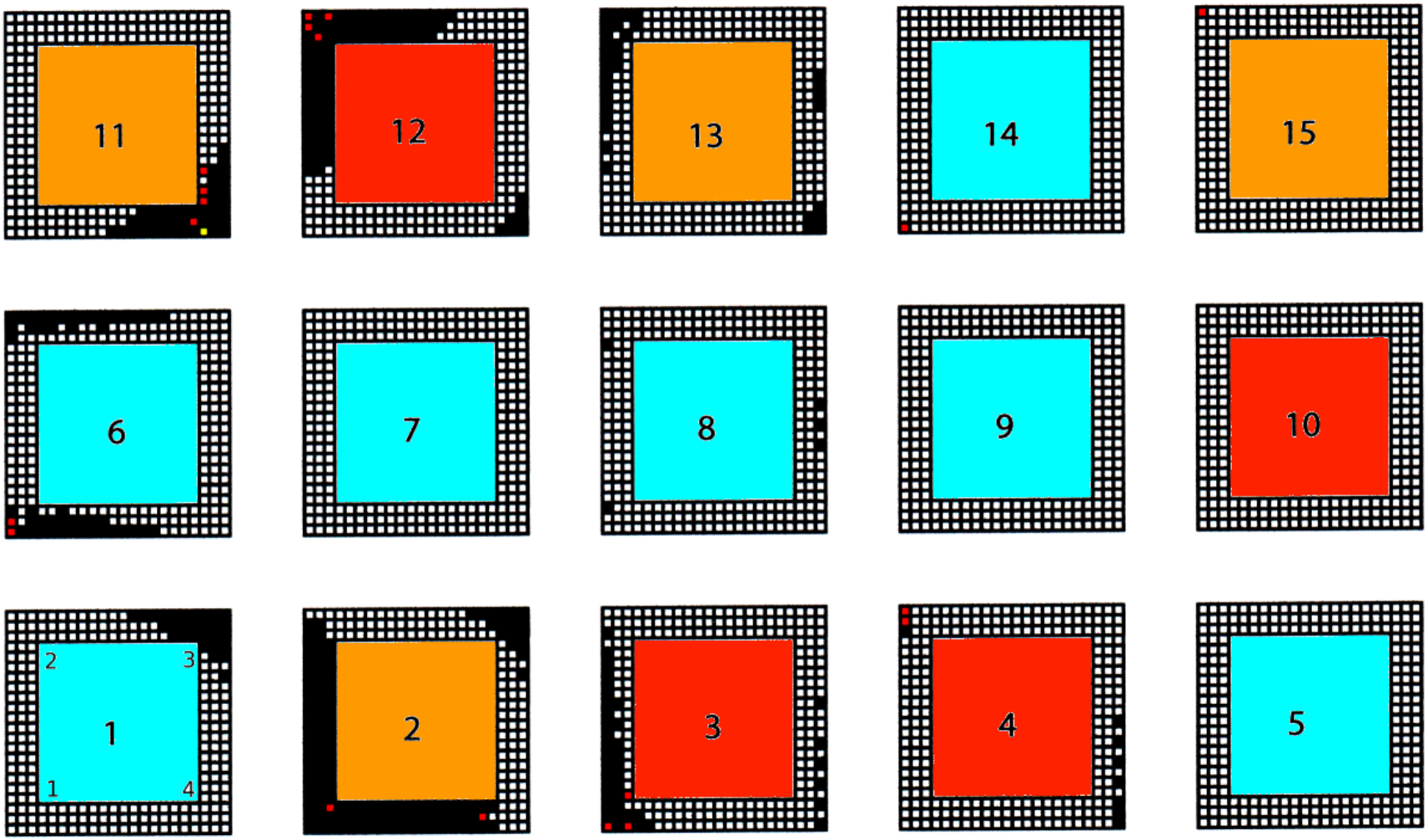
Component: Green – no failure, Blue – transitional failure, Orange – full failure, Red – complete failure
Solder Joints: Black – pad crater, Red – solder fracture (board side), Yellow – solder fracture (csp side)

Failures After 325 Drops (Epoxy EB)



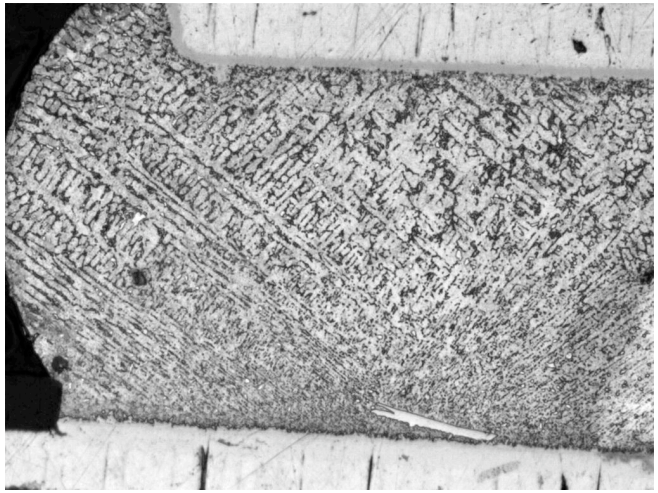
Component: Green – no failure, Blue – transitional failure, Orange – full failure, Red – complete failure
Solder Joints: Black – pad crater, Red – solder fracture (board side), Yellow – solder fracture (csp side)

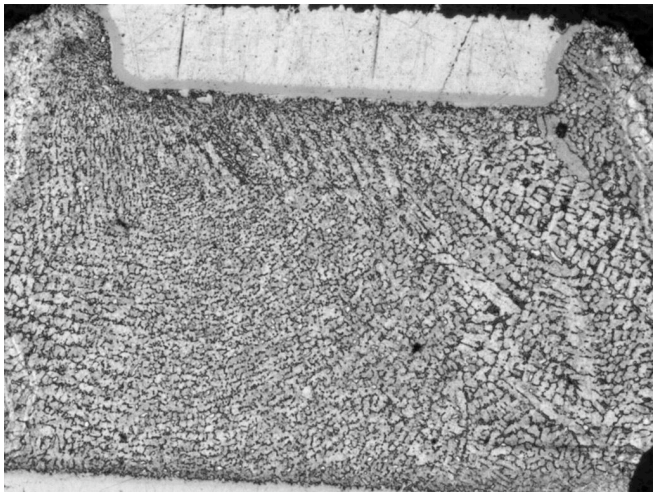
Failures After 279 Drops (Acrylic EB)

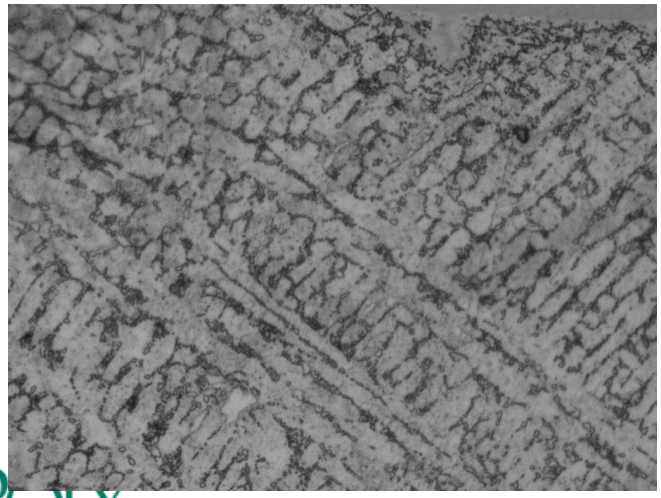


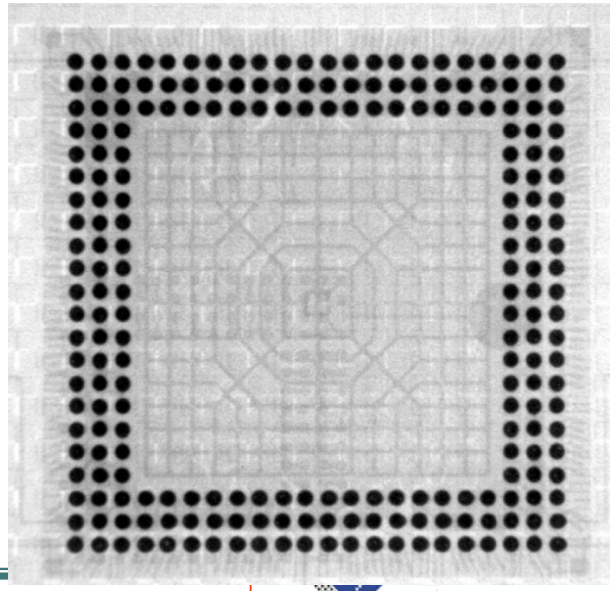
Component: Green – no failure, Blue – transitional failure, Orange – full failure, Red – complete failure
Solder Joints: Black – pad crater, Red – solder fracture (board side), Yellow – solder fracture (csp side)

SAC305 Solder Microstructure

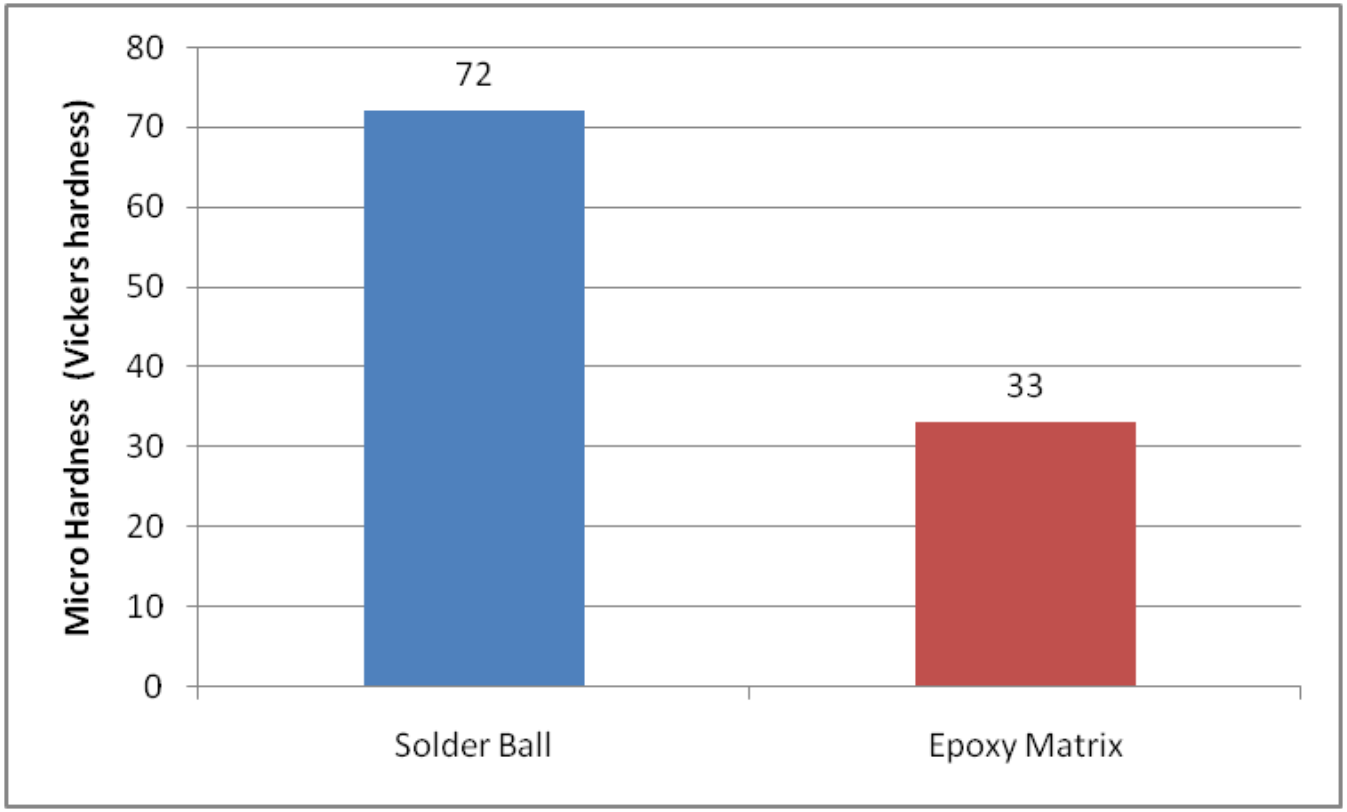






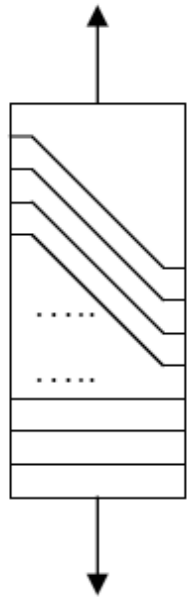


Microhardness Testing

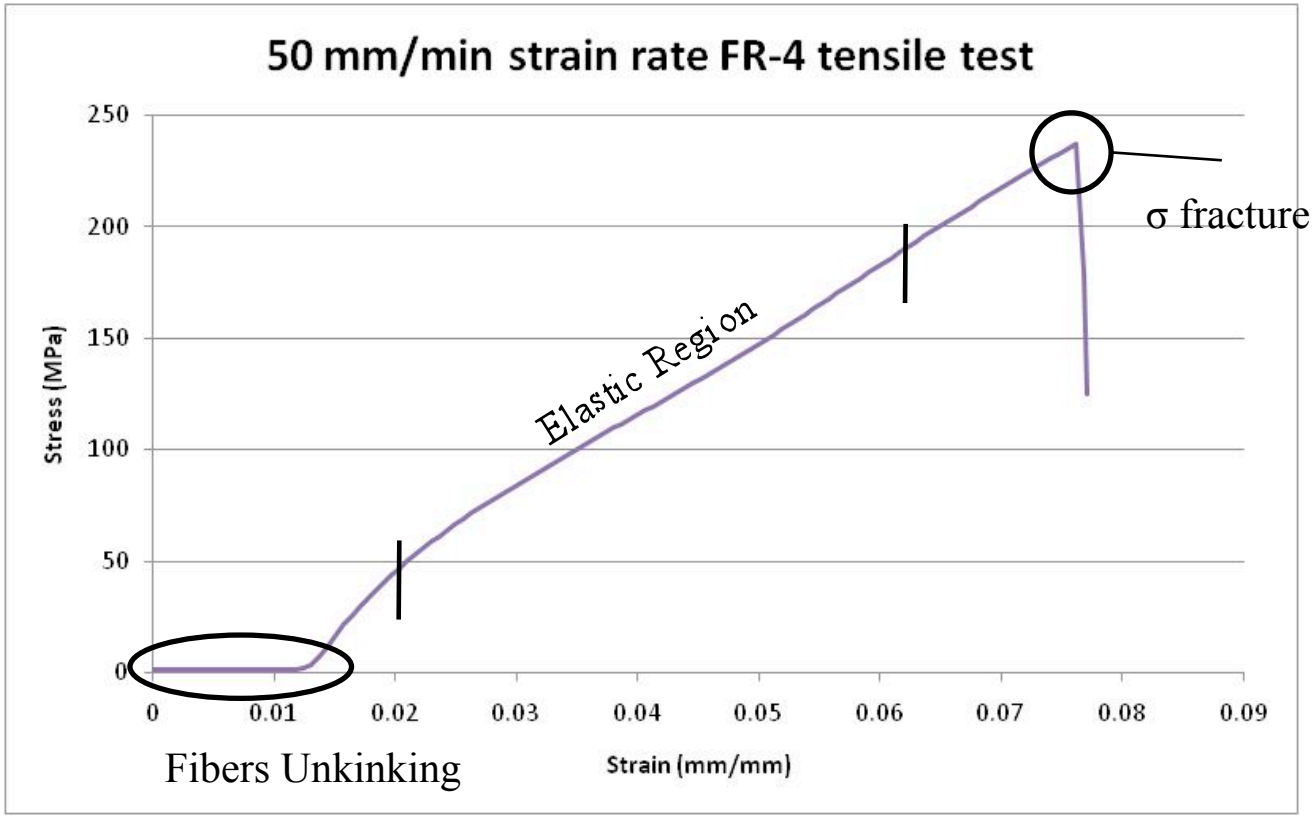


Mechanical Testing of Boards

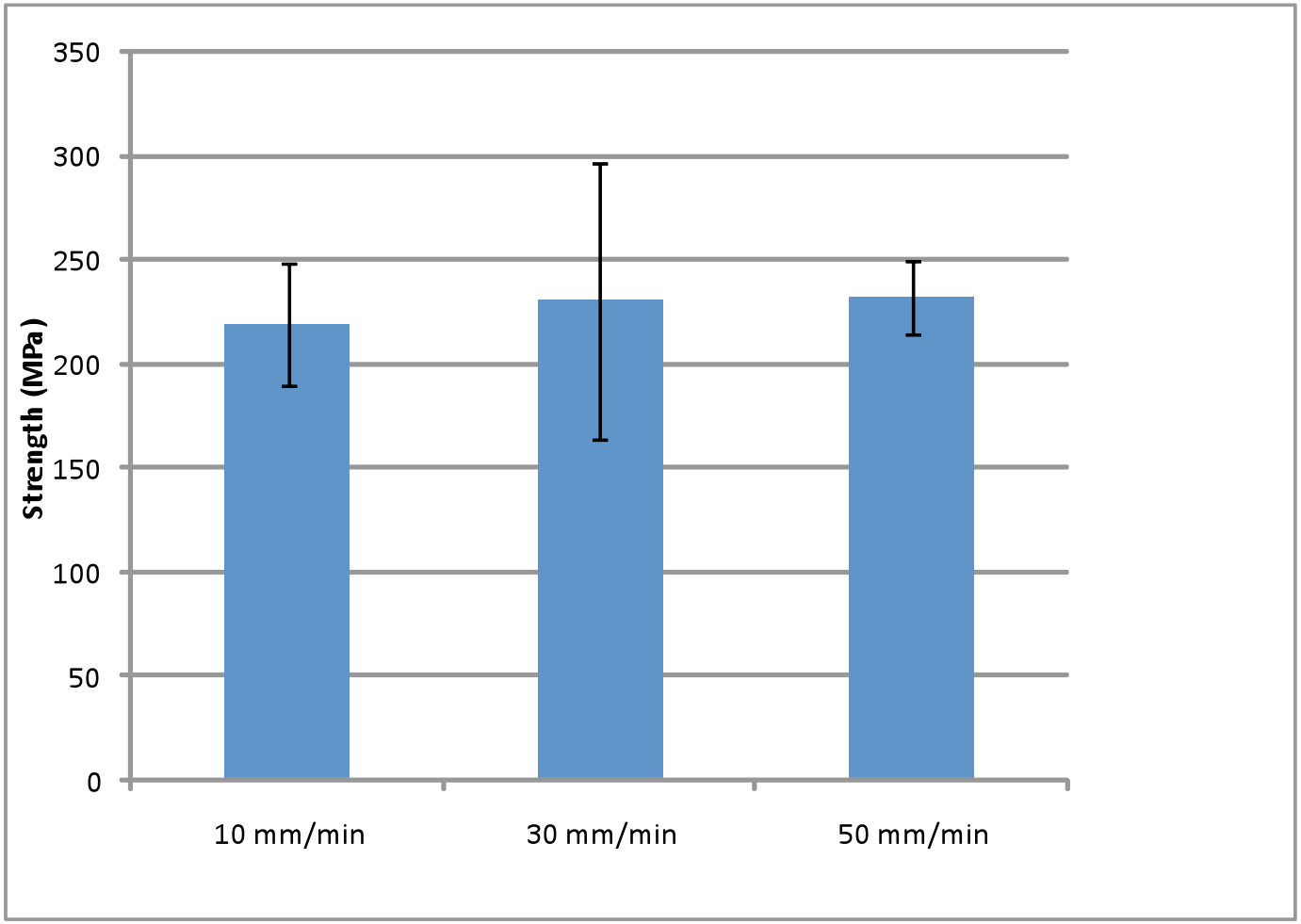
- Need to know material properties of the board to simulate using FEA methods.
- Tested along fiber direction using an Instron tensile tester.



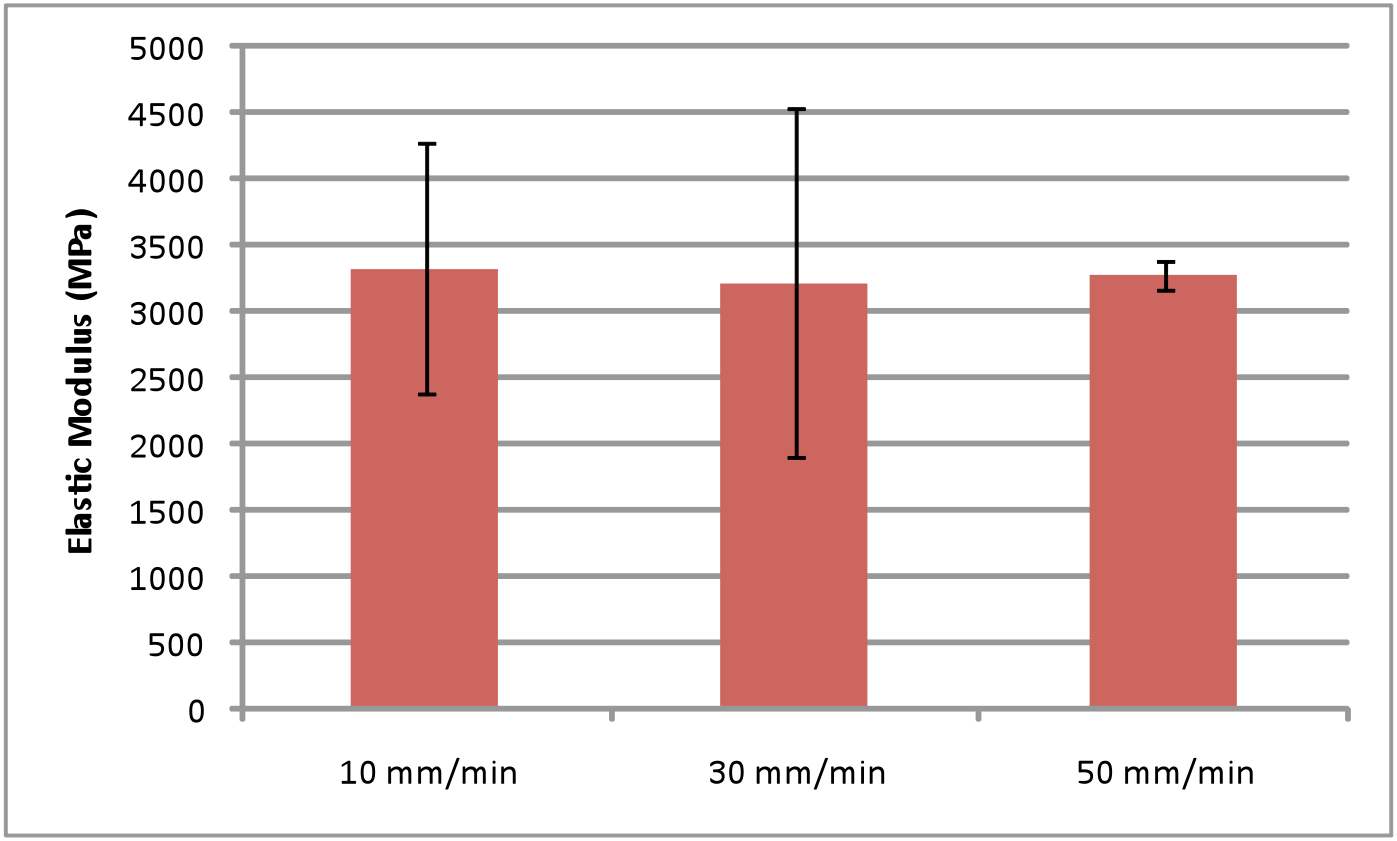
Along Fiber Results



Along Fiber Strength



Along Fiber Modulus



Conclusions

- Pad cratering is the most common failure mode
- Pad cratering does not necessarily cause electrical failure, but can cause electrical failure by introducing other failure modes
- Dominance of pad cratering indicates that solder joints are not the weakest part of this lead-free assembly

Conclusions (Cont.)

- Tougher board material is needed to increase reliability
- Majority of failures occurred on the cable side of the board when DAQ cable is attached
- First failures usually occur in the corners of the CSPs
- Edge-bonding is effective at reducing pad cratering problems

Acknowledgements

- Cal Poly: Michael Krist, Kyle Rauen, Micah Denecour, Andrew Farris, Ron Sloat, and Jianbaio Pan, Ph.D.
- Flextronics: Dongkai Shangguan, Ph.D., Jasbir Bath, David Geiger, Dennis Willie
- Henkel: Brian Toleno, Ph.D., Dan Maslyk

Acknowledgements

- Project Sponsors:

FLEXTRONICS

- Office of Naval Research (ONR)

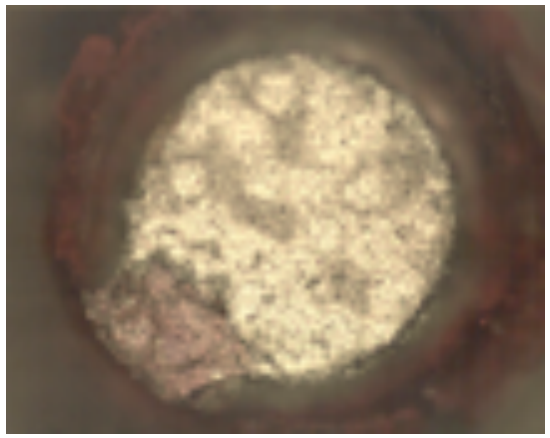
  Through California Central Coast Research Park (C^3RP)
- Society of Manufacturing Engineers Education Foundation
- Surface Mount Technology Association Silicon Valley

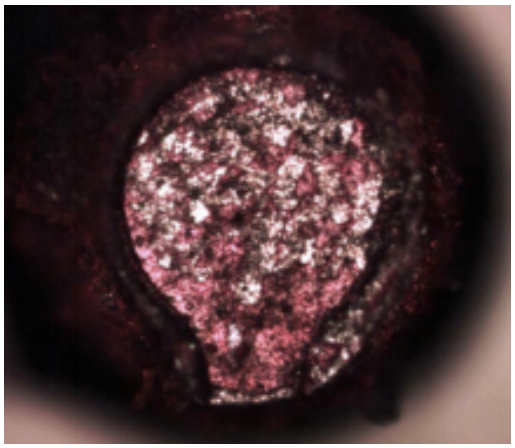
Thank You.
Any Questions?

Supplementary Slides

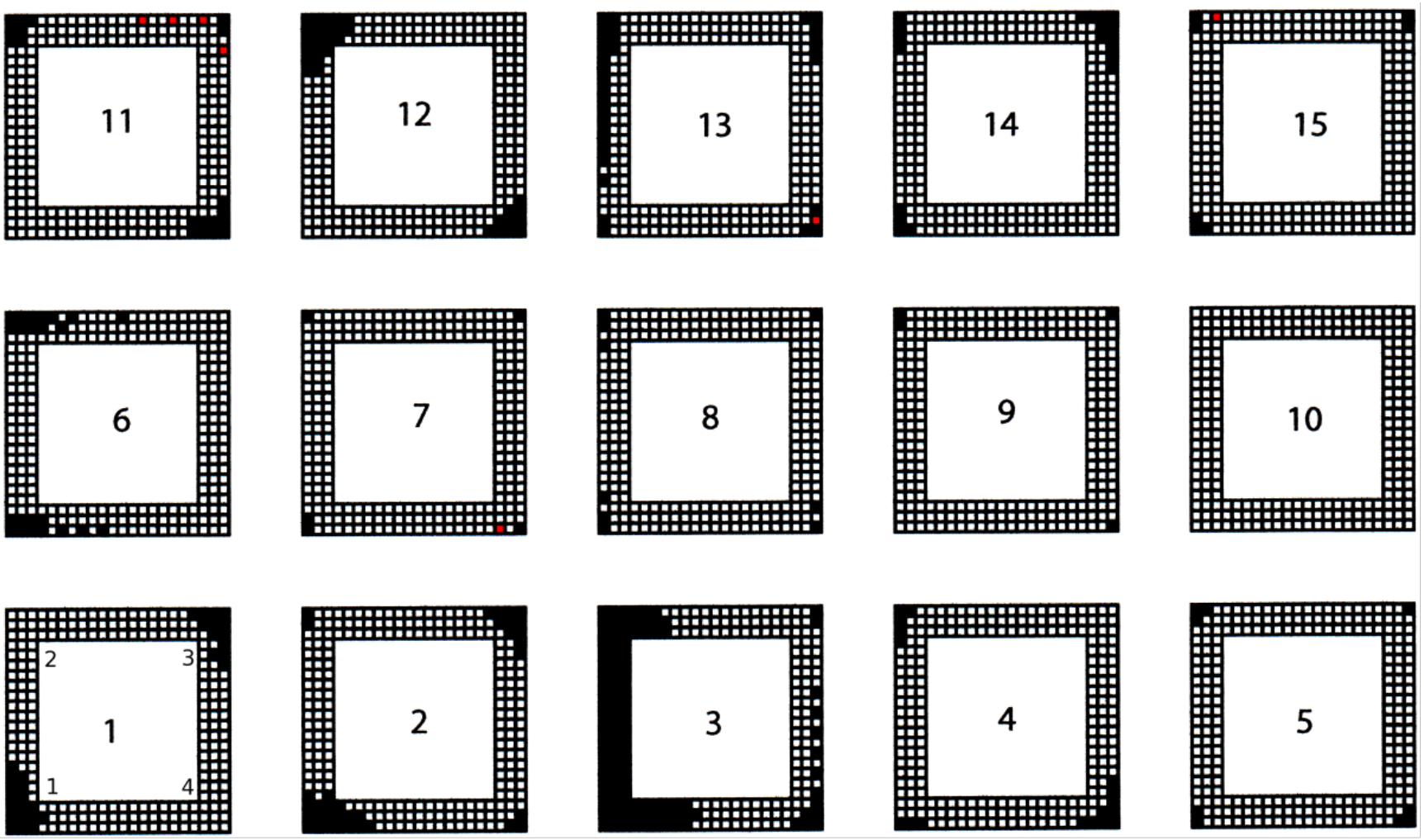
Dye Stained Solder Fractures

- Dye stained solder fractures were found
  - Partial solder fracture (left) was not completely fractured before the component was removed
  - Complete solder fracture (right) was fully fractured before the component was removed

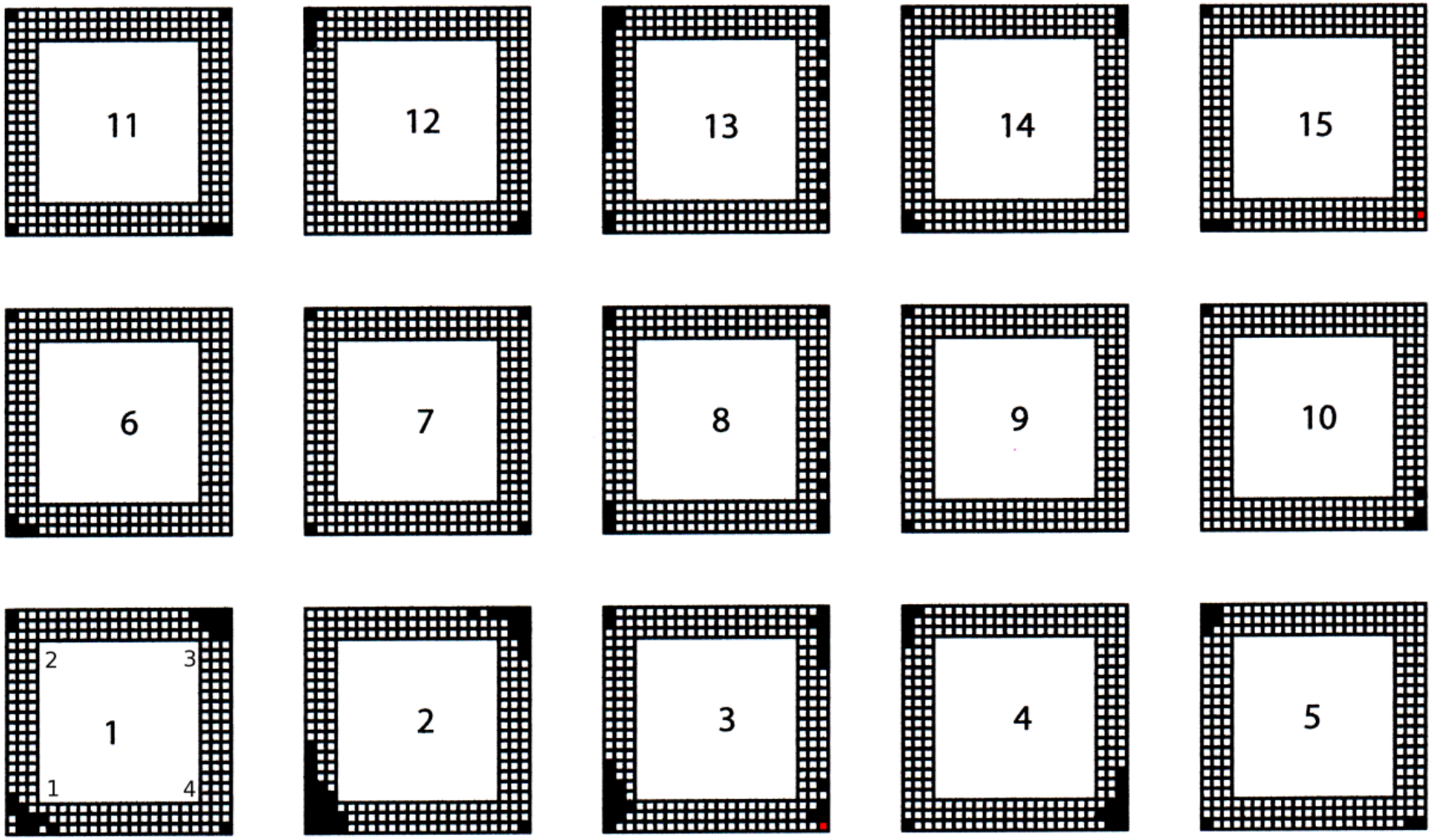




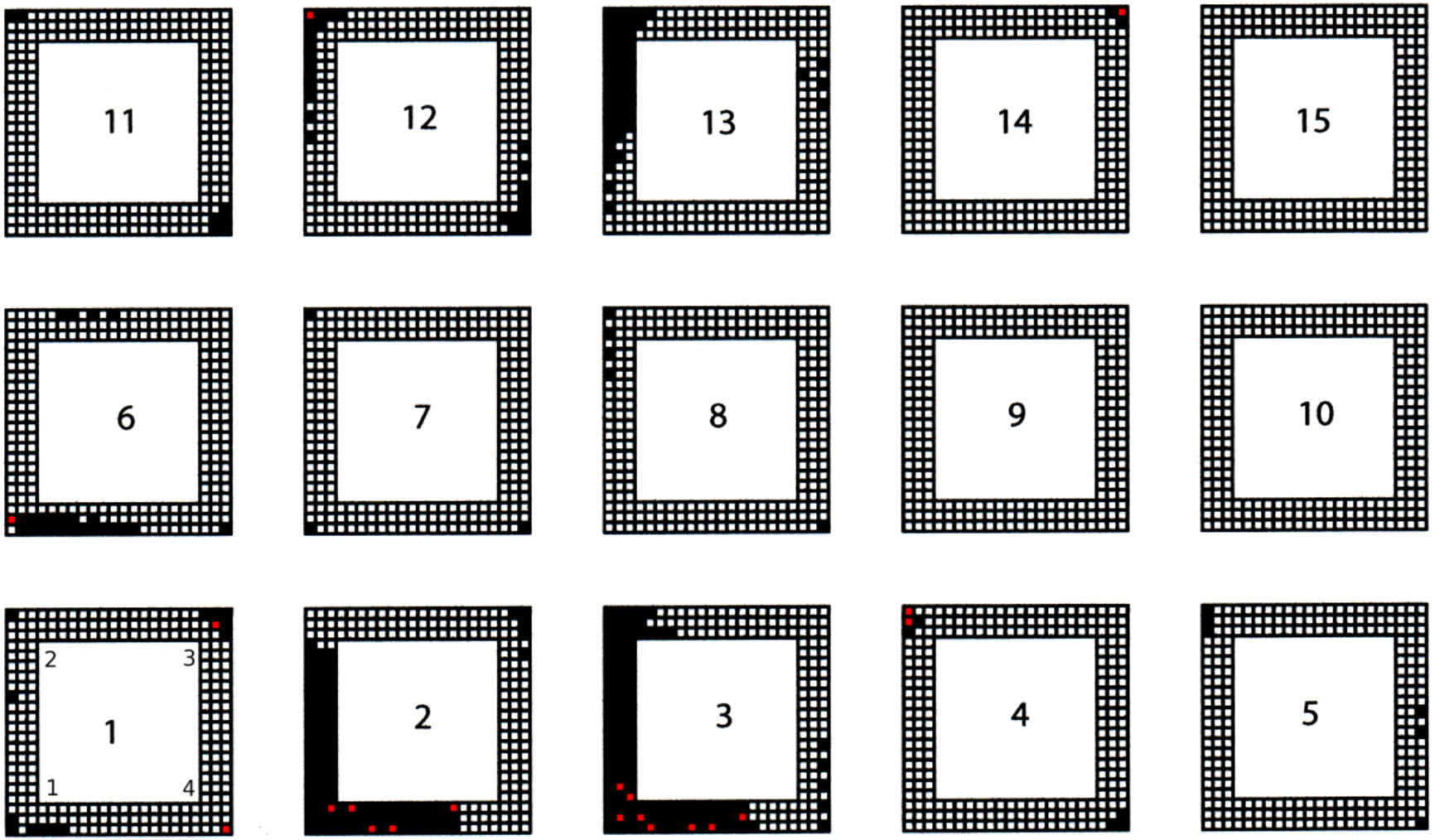
Failures After 10 Drops (No EB)



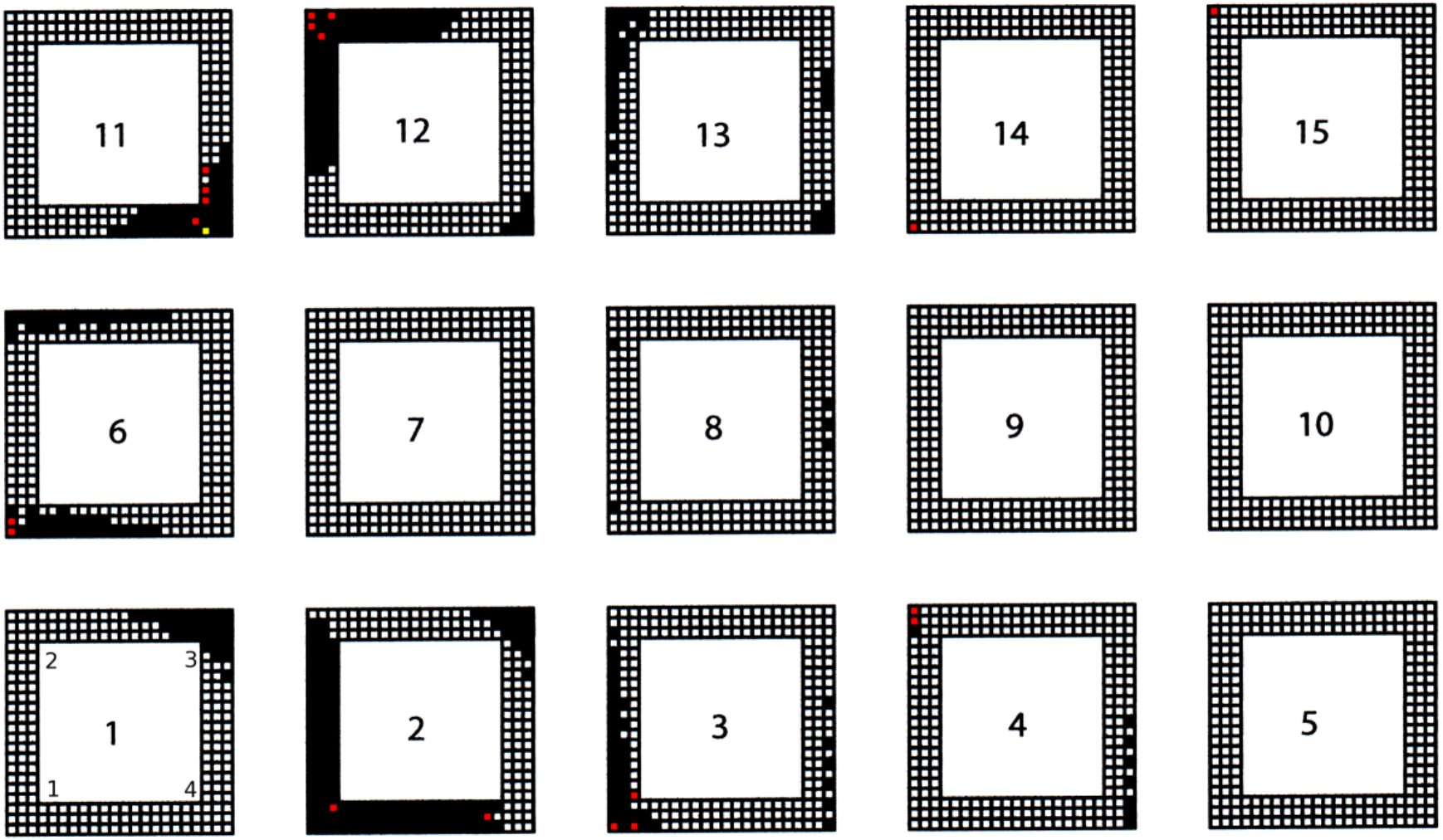
Failures After 14 Drops (No EB)



Failures After 325 Drops (Epoxy EB)

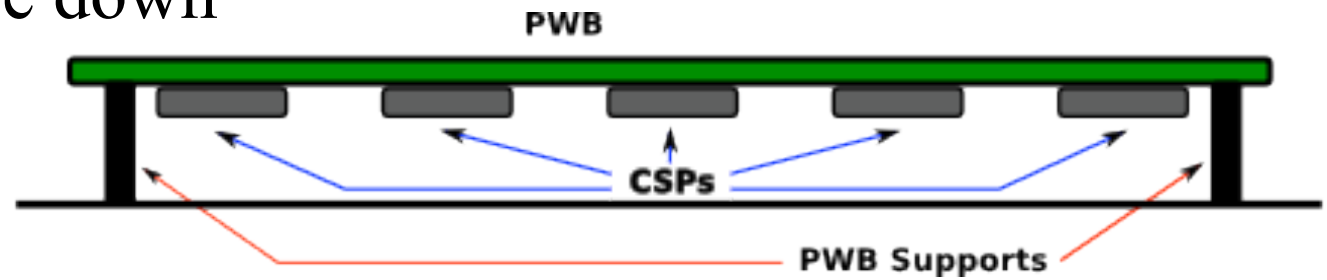


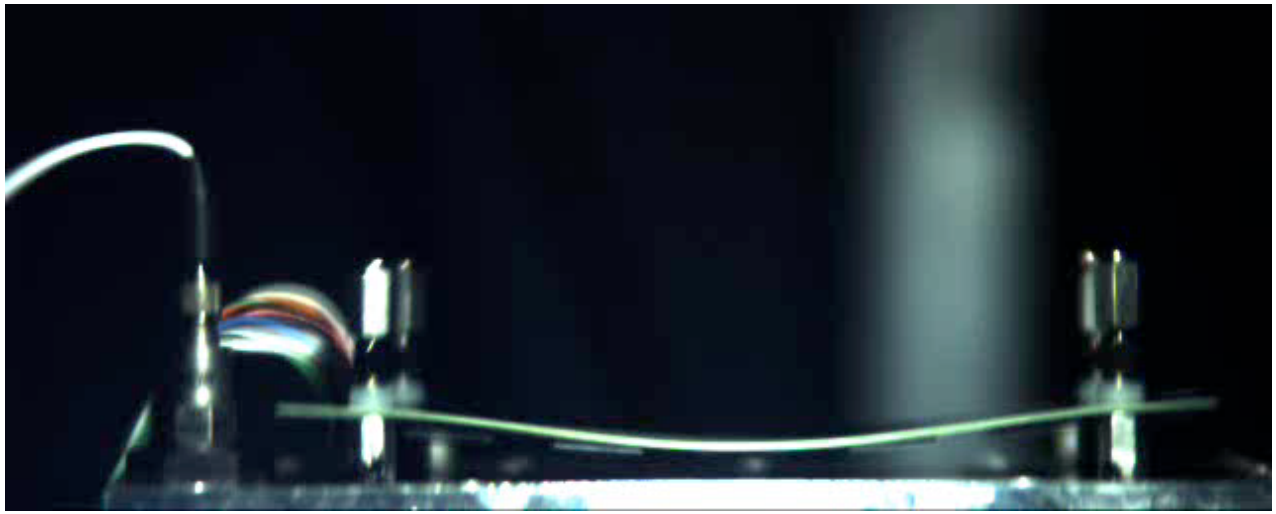
Failures After 279 Drops (Acrylic EB)



Test Vehicle Drop Orientation

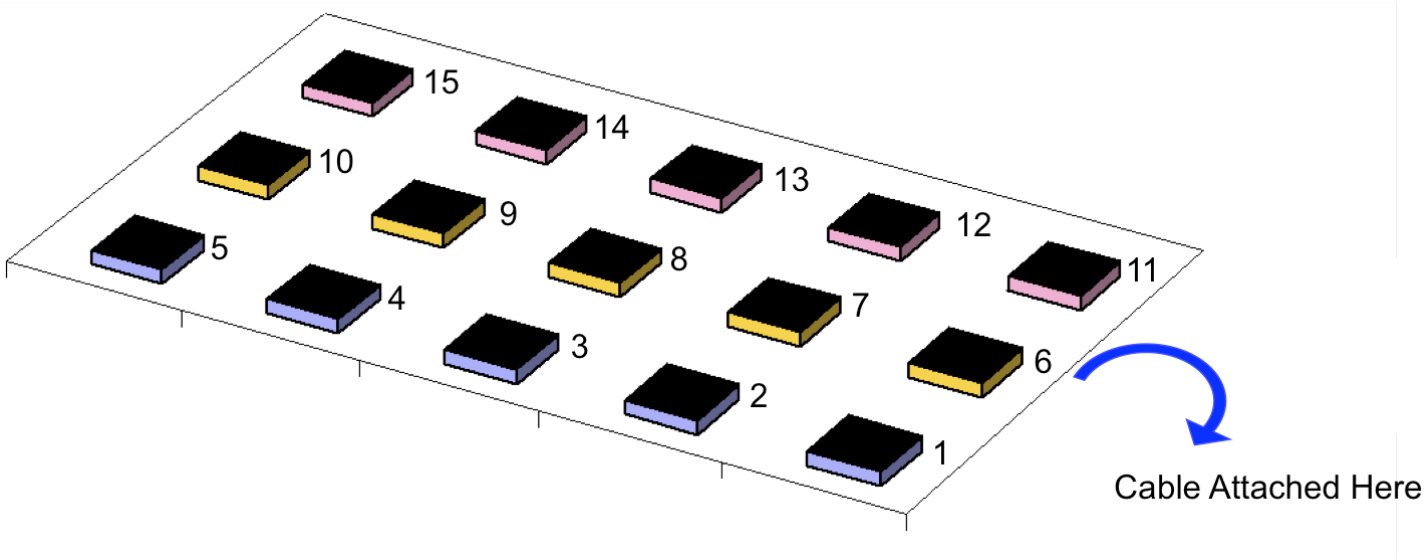
- Test vehicle is always mounted with components face down



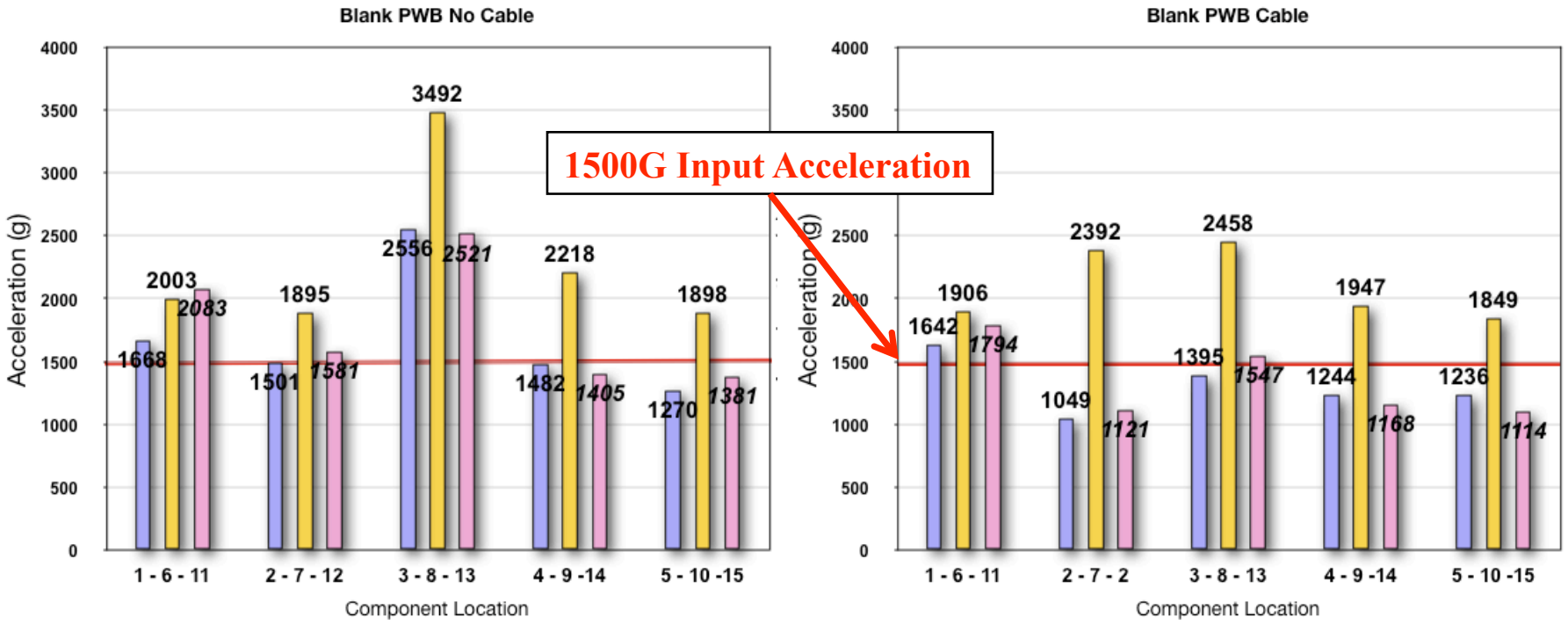


Component Locations

- JEDEC defined component numbering
  - The DAQ cable attaches near component C6 (in between components C1 and C11)

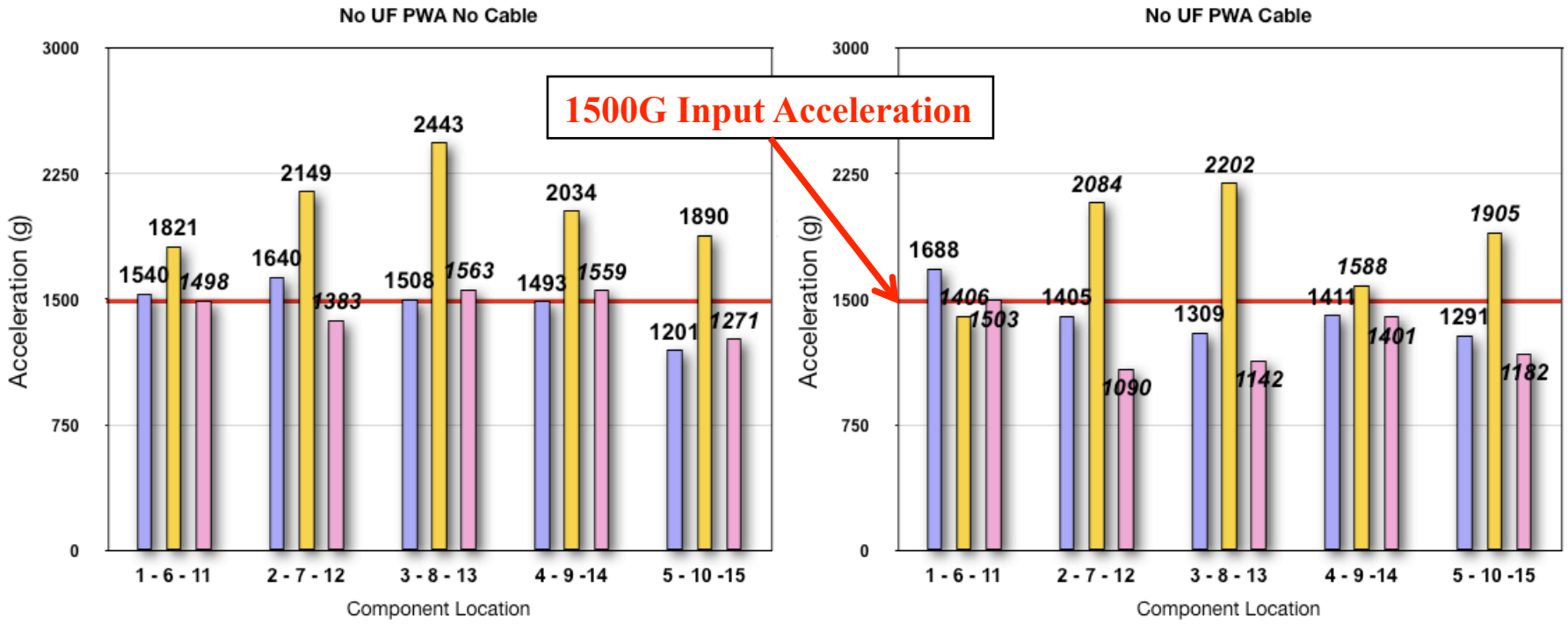


Blank PWB – No Cable vs Cable



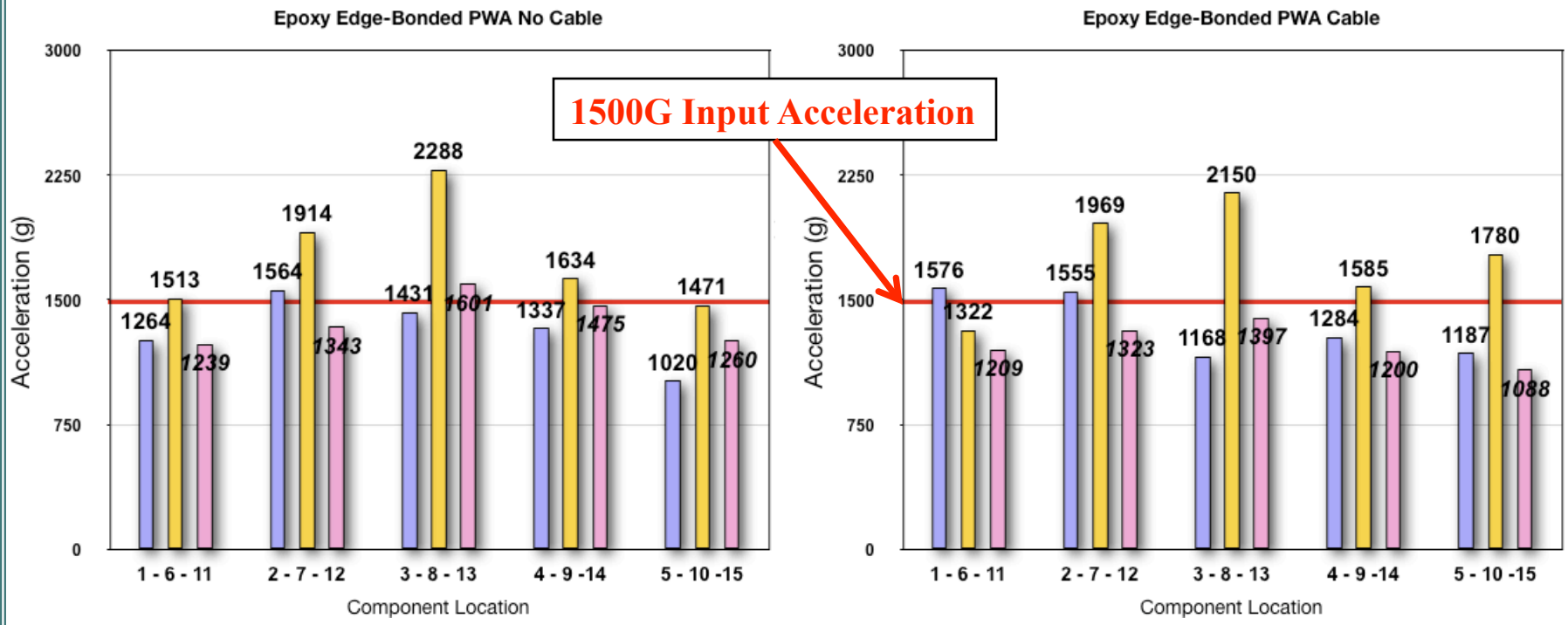
- Symmetry of acceleration peaks has shifted (C7 vs C9)
- Maximums greatly reduced by cable (C3, C13, C8)

Populated PWB – No Edge Bond



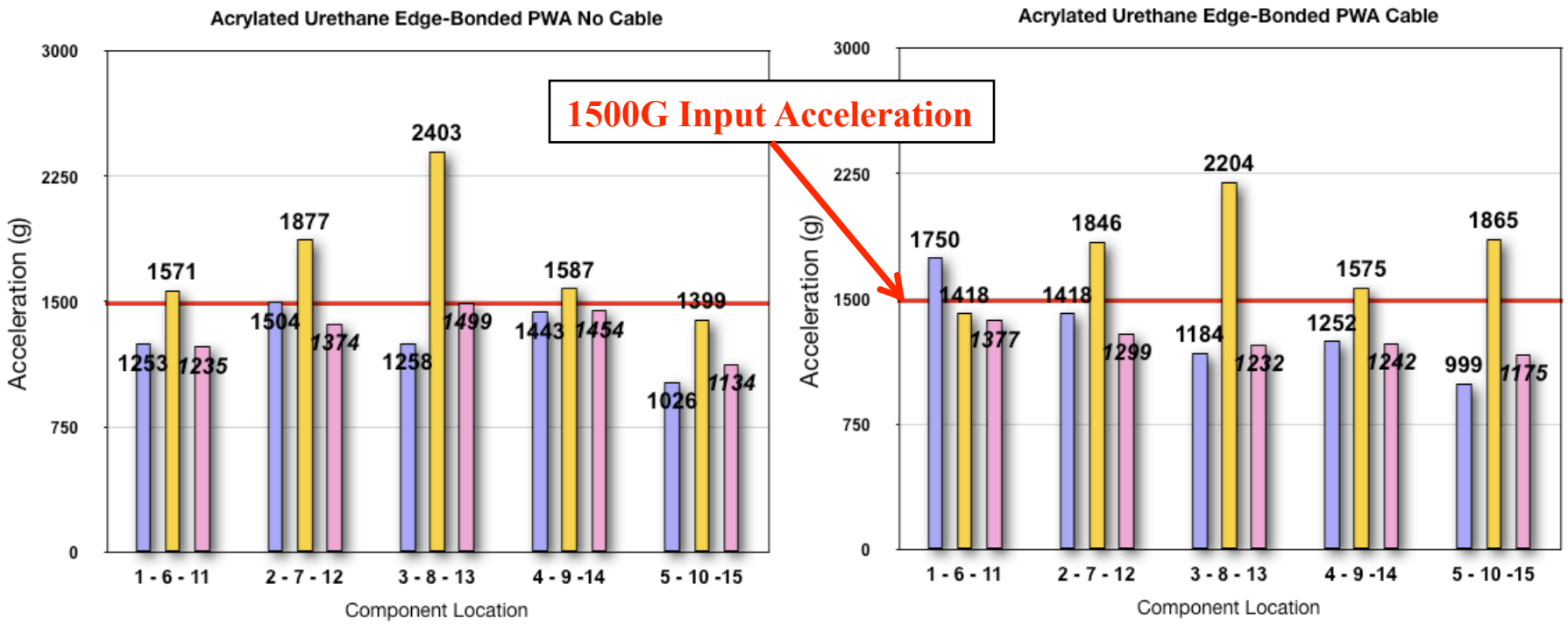
- Dampening due to the cable seems less significant than with blank PWB (both graphs are more similar)

Epoxy Edge Bonded CSPs



- Stiffer board with edge bonding has less symmetry disturbance
- Overall accelerations are significantly reduced vs no edge-bond

Acrylic Edge Bonded CSPs



- Stiffer board with edge bonding has less symmetry disturbance
- Overall accelerations are significantly reduced vs no edge-bond