Pad Cratering:
Assessing Long Term Reliability Risks

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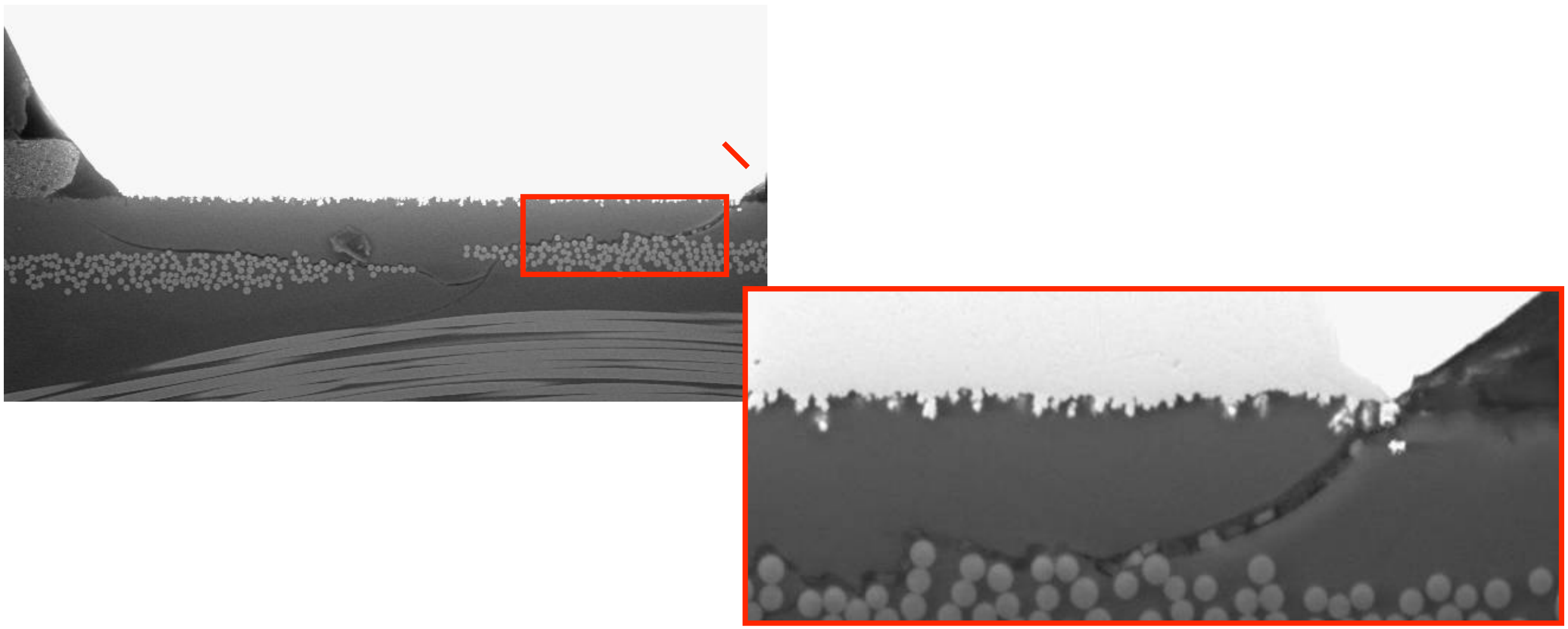
What is Pad Cratering?

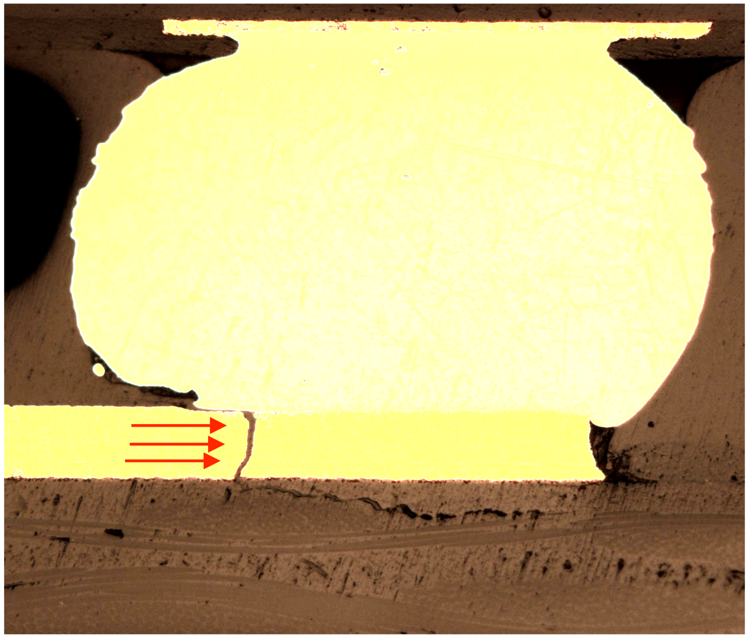
- A pad crater is the mechanical cracking of the PCB laminate under a component connecting pad.
- Cracking most often occurs as a direct result of a mechanical overstress or after mechanical cycling.
- Often occurs during manufacturing (reflow, test, handling, etc) or end use under mechanical stress environments.

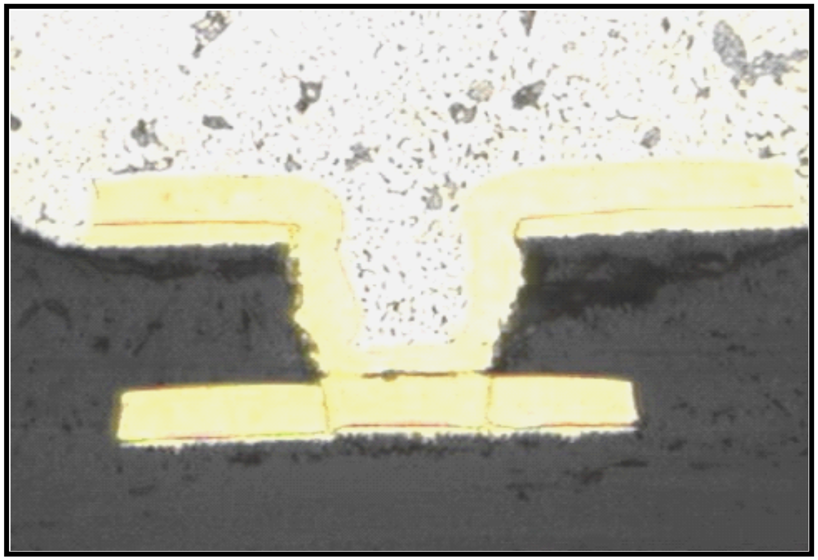


Reliability Issue

Connecting traces, and/or Vias will break, rendering device non-functional.

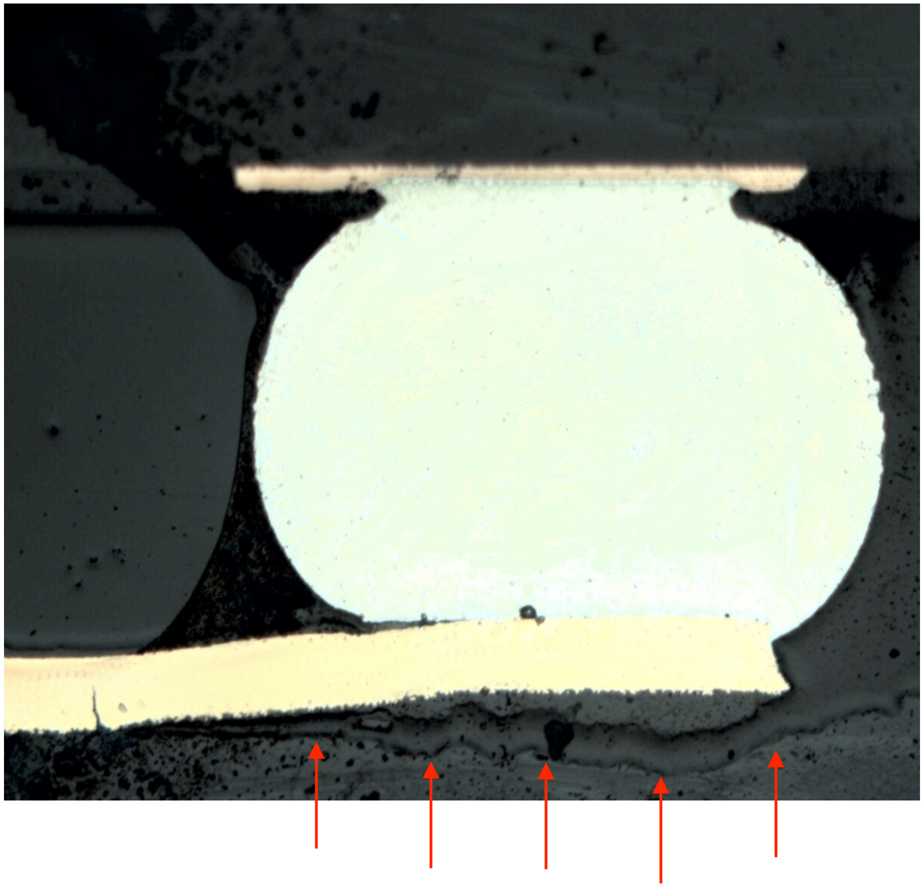
Damage is not easily re-worked, so product is scrapped.





Reliability Issue: Long Term

- Some cracks do not cause immediate electrical failure
- This damage would be missed in functional test
- Potential for early field failure, increased warranty cost, liability, etc.



How do you test?

- The best way to evaluate pad cratering on your product is to test your product.
  - Bend testing (4-point, spherical)
  - Shock (Drop, high-G)
  - Vibration
  - Temp Cycling
- Product/assembly level testing is costly and time consuming and doesn't guarantee pad cratering is the failure mode.

How do you test the pads specifically?

Historical testing may have been done according to:

- **IPC TM-650, Method 2.4.8** **"Peel Strength of Metallic Clad Laminate"**
  - Minimum spec of 0.7 N/mm (4lbs/in) is typical

- **Mil-P-50884D:** **Military Quality and Performance Specification Governing the Manufacture of Flexible and Rigid-Flex Printed Wiring Boards**
  - *"After 5 times soldering and unsoldering Type 1 Flex boards shall have unsupported lands which withstand **5 lbs. pull** or **500 psi**, whichever is less"*

  500 psi on a 20 mil bga pad is equivalent to 70 g force

  In our testing, on a 20 mil bga pad, we observe 1200-1500 g force to cause pad cratering failures.

- **IPC-6013:** **Qualification and Performance Specification for Flexible Printed Boards**
  - *"As per IPC-TM-650, Method 2.4.20, unsupported land shall withstand **1.86kg [4.1lb.] pull** or **35kg/cm² [500 psi]**, whichever is less, after subjection to five cycles of soldering and unsoldering".* (3.6.3)

- **IPC-6012:** **Qualification and Performance Specifications for Rigid Printed Boards**
  - *"The unsupported component hole land shall withstand 23 N [**5lb-f.**] or 3.4x10⁶ Pa **[500 psi]**, whichever is less."* (3.7.3)

How do you test the pads specifically?

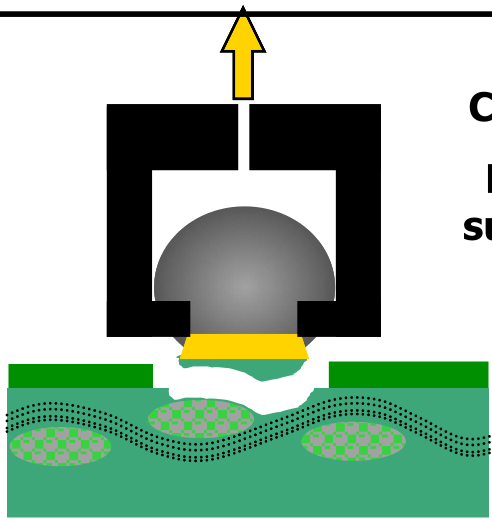
Recently IPC released a specific Pad Cratering test method:

- **IPC-9708**

“Test Methods for Characterizing Printed Circuit Board Assembly Pad Cratering”

  - Provides test method only
  - No Spec limits
    - We do not know what strong enough is
    - Also, stronger does not mean better
      - Stronger may lead to higher stress due to CTE issues.
      - Goal is to reduce stress
  - We need to define spec limits ourselves for our product and service condition

Possible Test Method

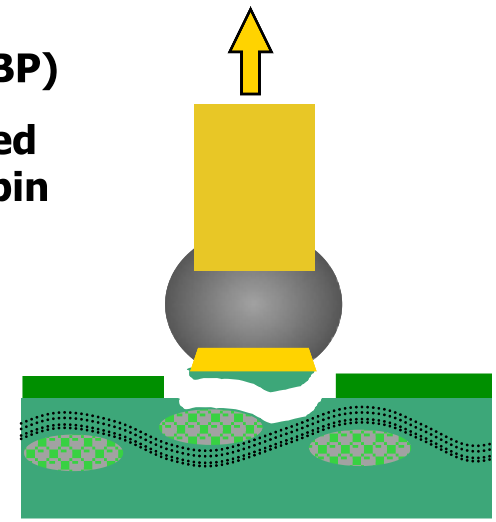


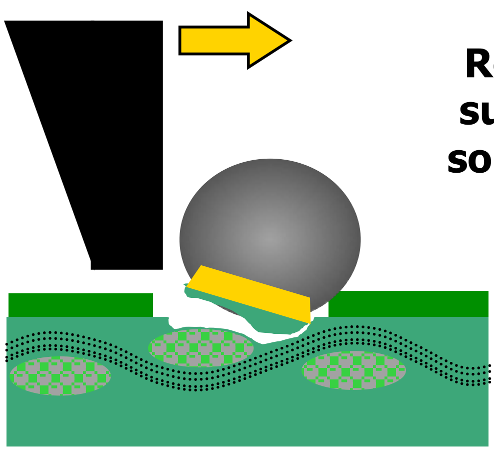
Cold Bump Pull (CBP)

Requires a bumped substrate, Clamp onto solder ball with special jaws.

Hot Bump Pull (HBP)

Requires a bumped substrate, solder pin into the bump.



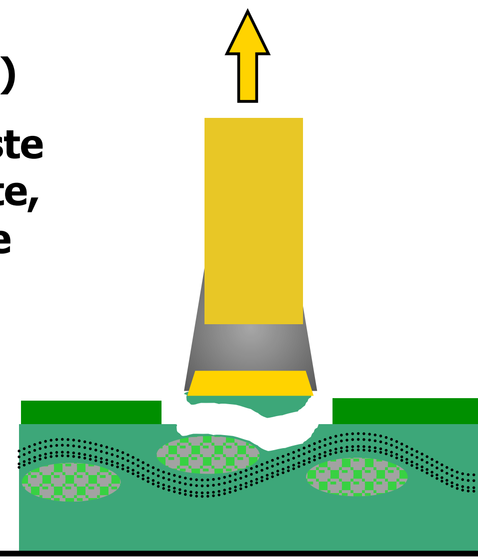


Shear

Requires a bumped substrate, Standard solder ball shear test.

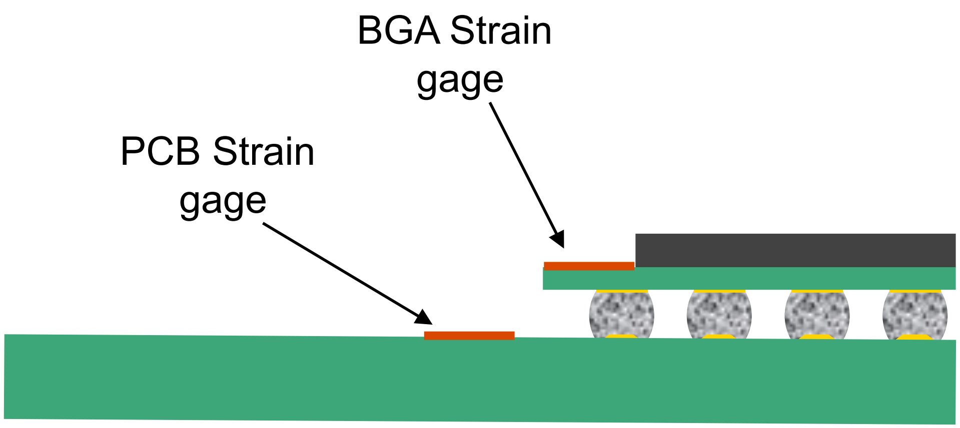
Hot Pin Pull (HPP)

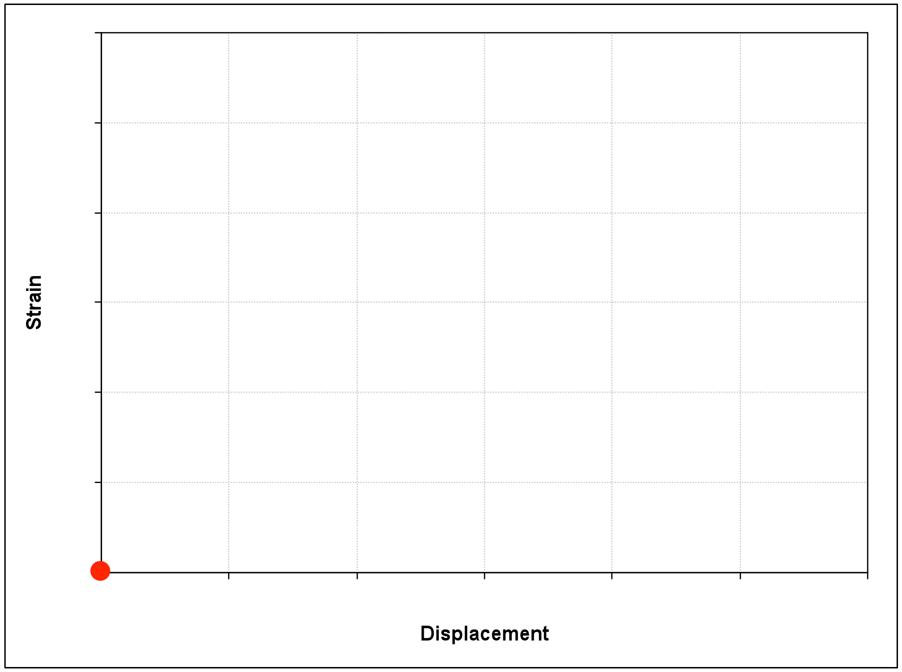
Requires only a paste deposit on substrate, solder pin into the solder.



Board Flexure Drives Failures

- Measure both PCB and Component bending strain at the same time





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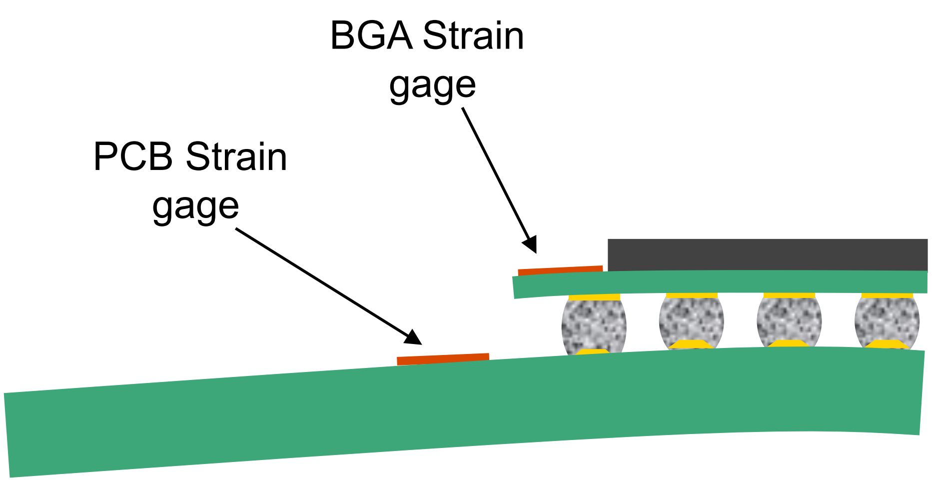

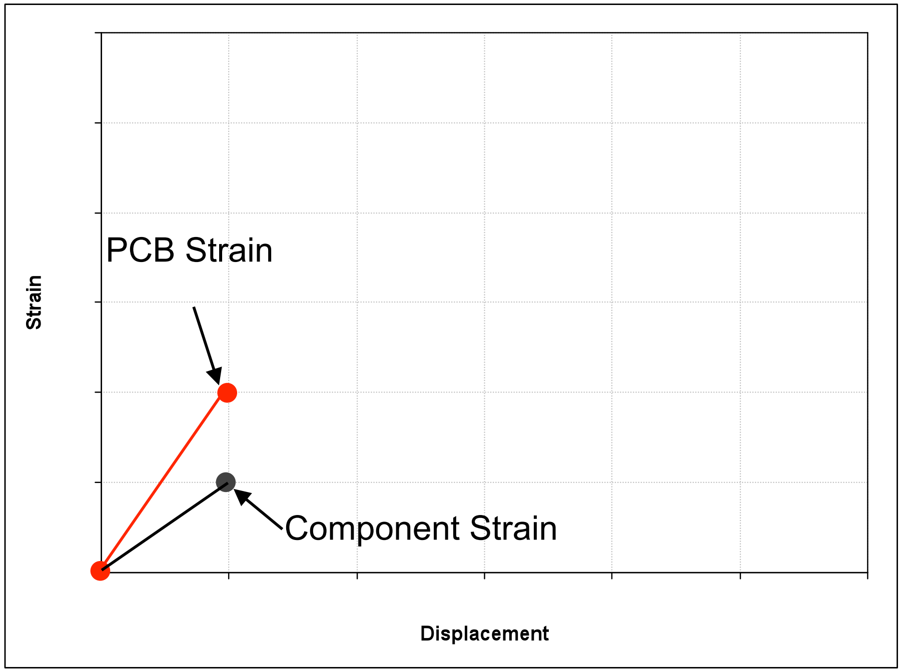

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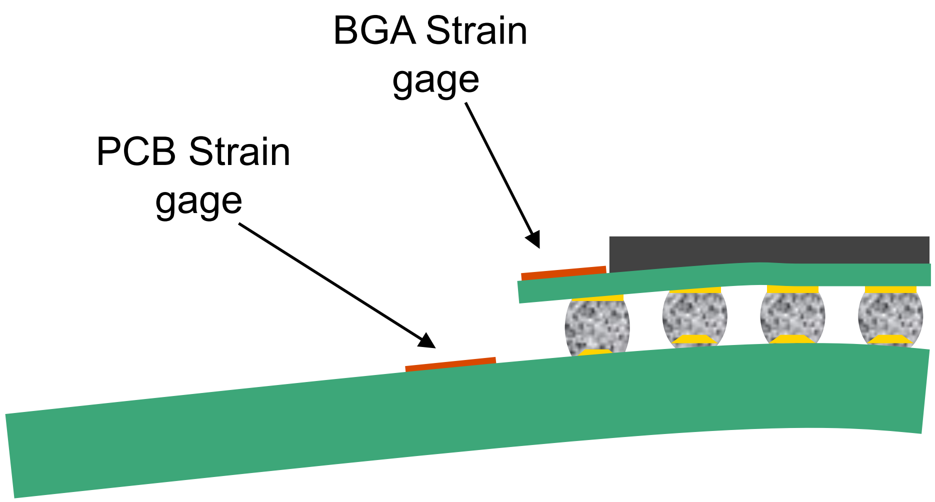

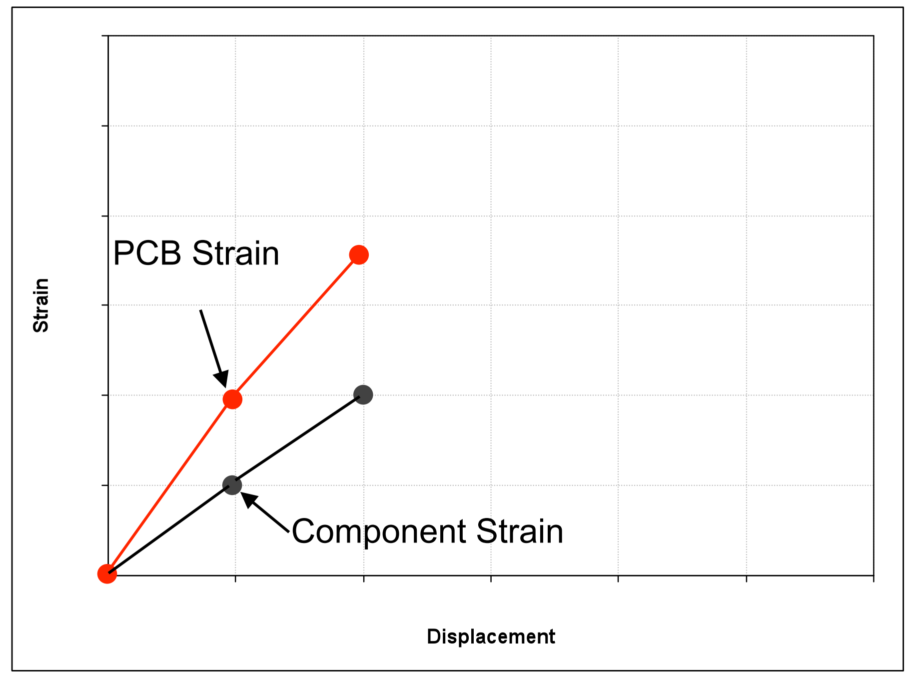

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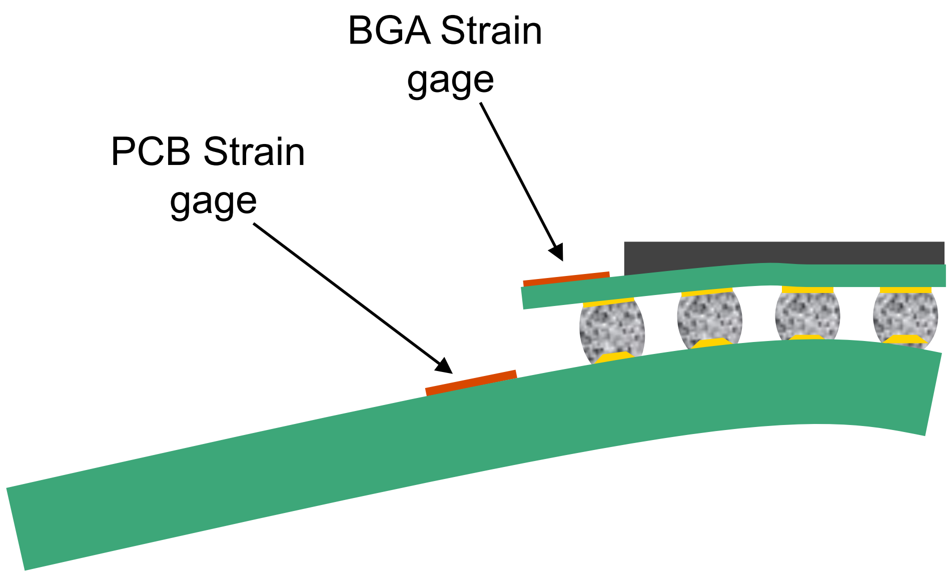

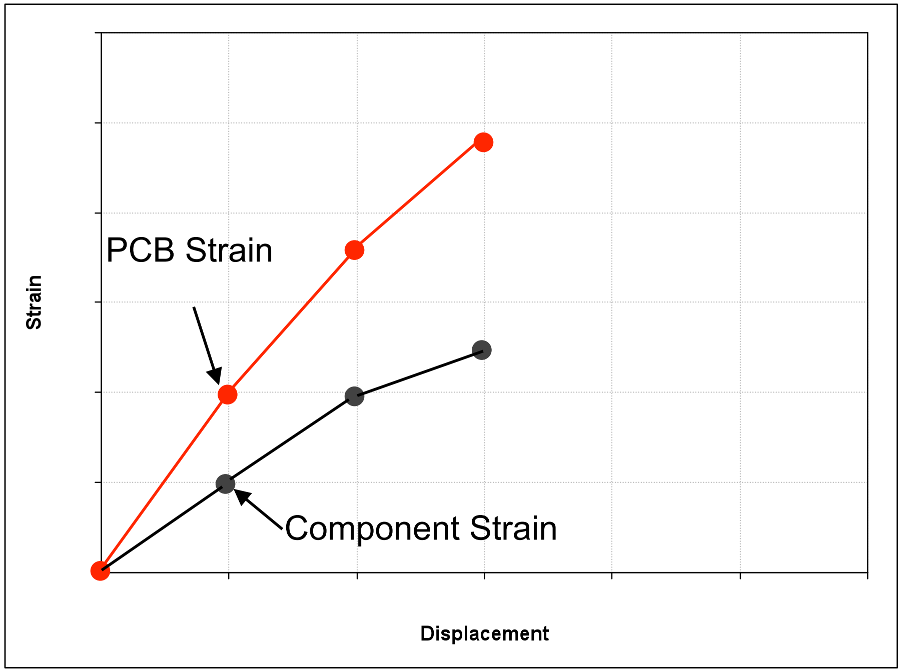

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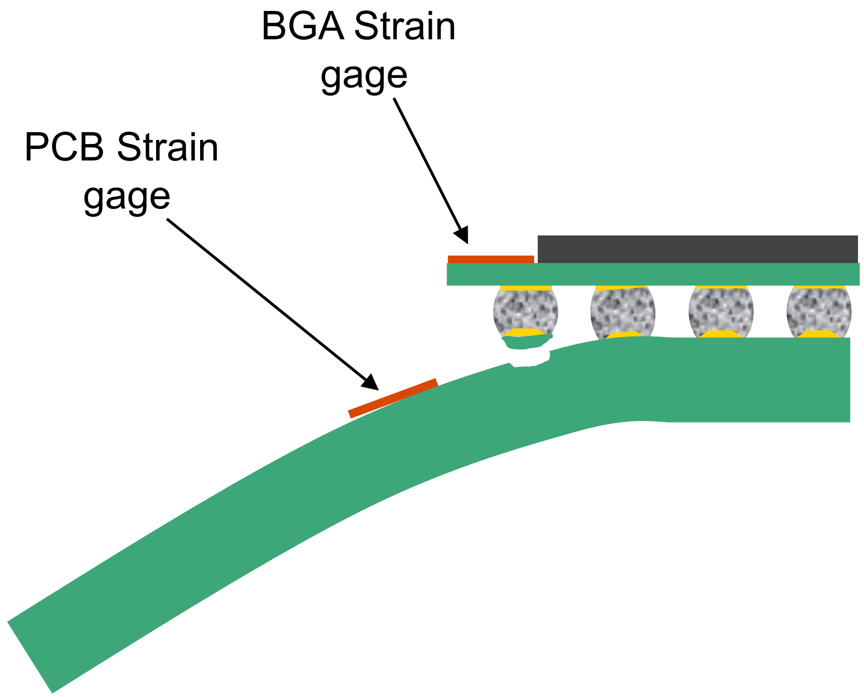
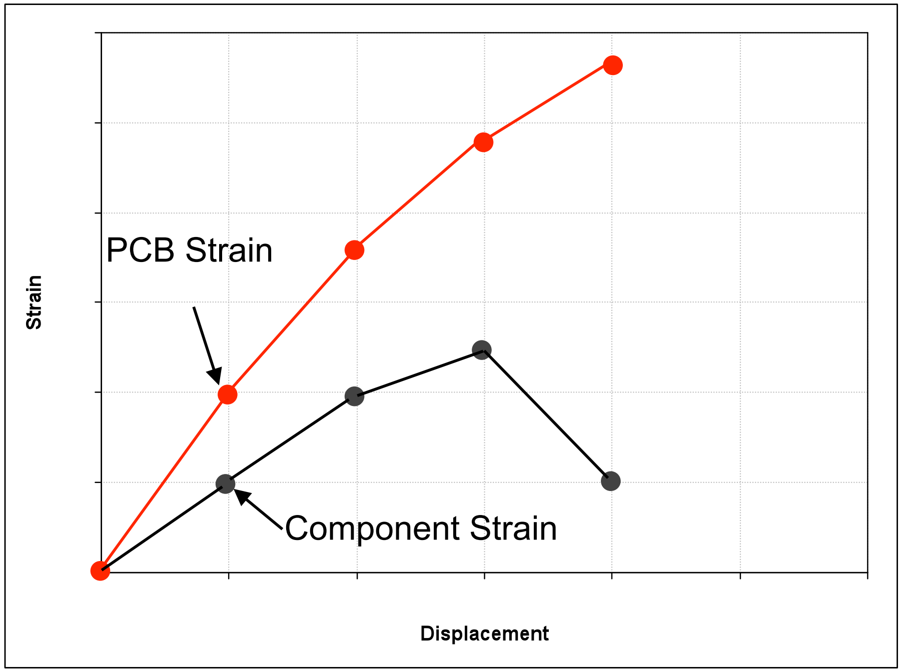
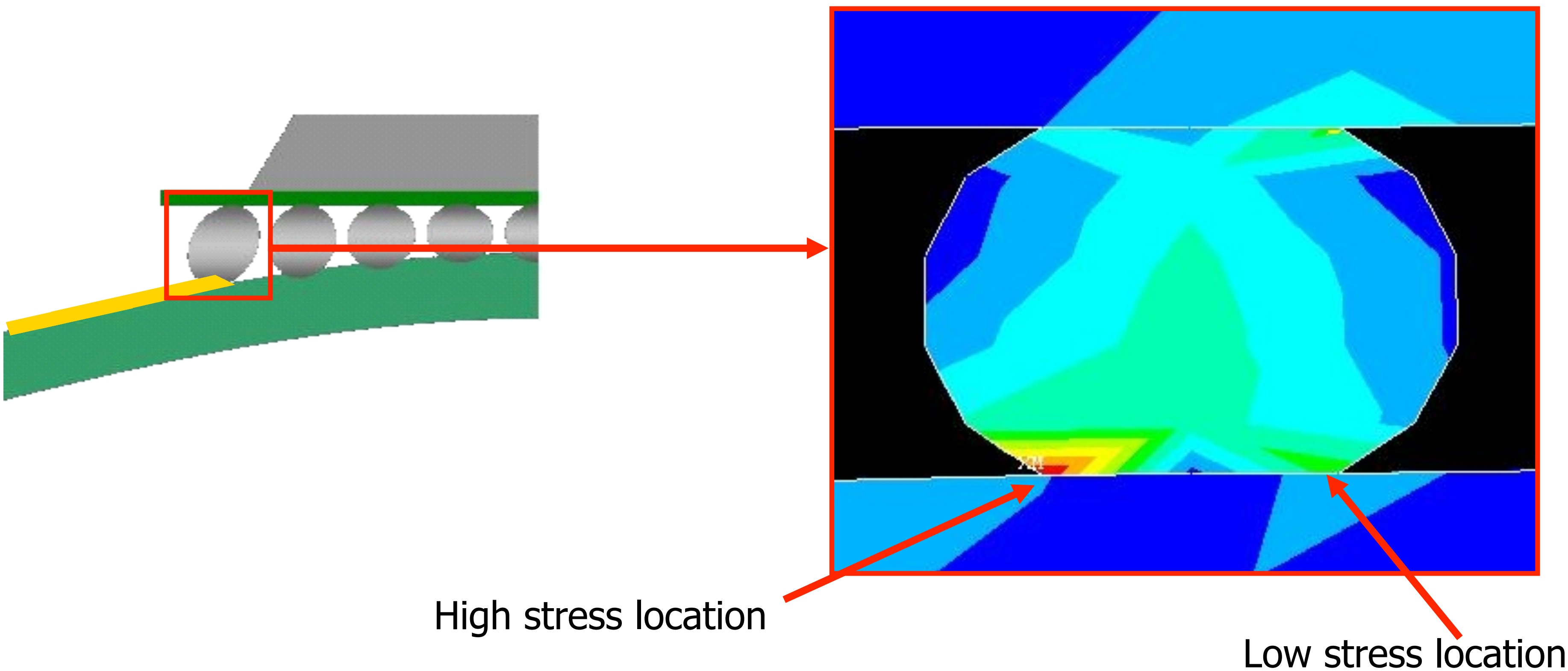




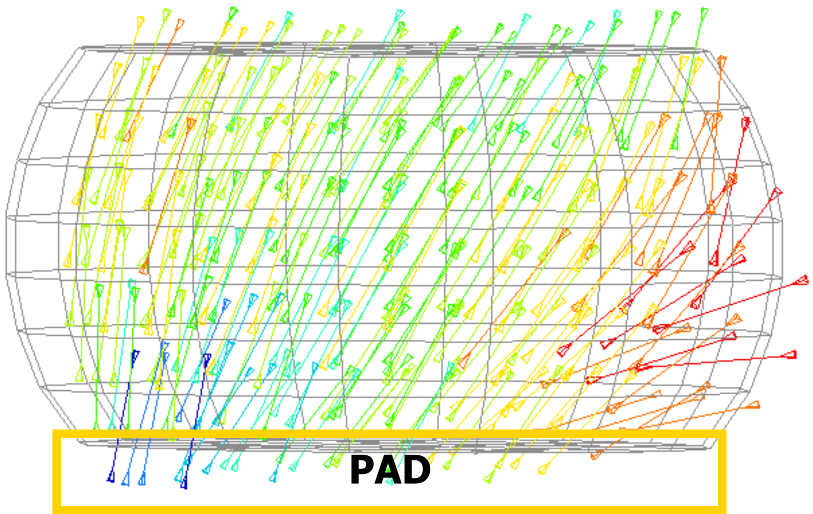
Board Flexure

- Board Flexure is a large driver of pad cratering after assembly.
- The resultant Von-Mises stress distribution shows a preferential loading at one side of the pad, suggesting a principal stress angle ≠ 0°

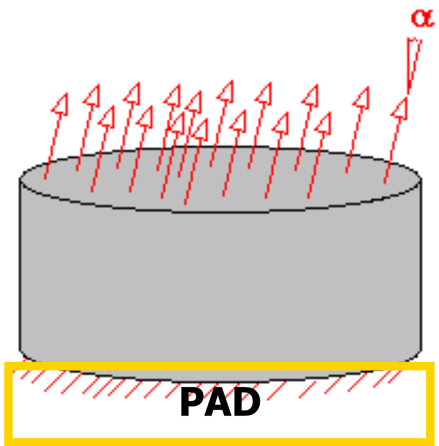


Angle of Pull

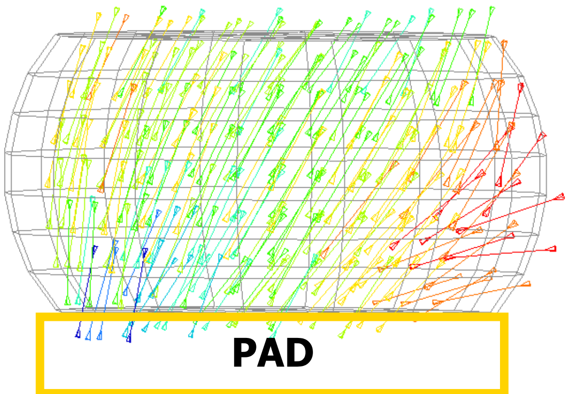
Board level loading creates principal stresses within the joint at some angle. How do we simulate this in joint level (pad level) test?

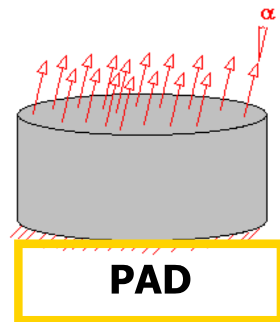


Simulated Joint, small volume of solder with a uniform force at some angle to the pad-normal

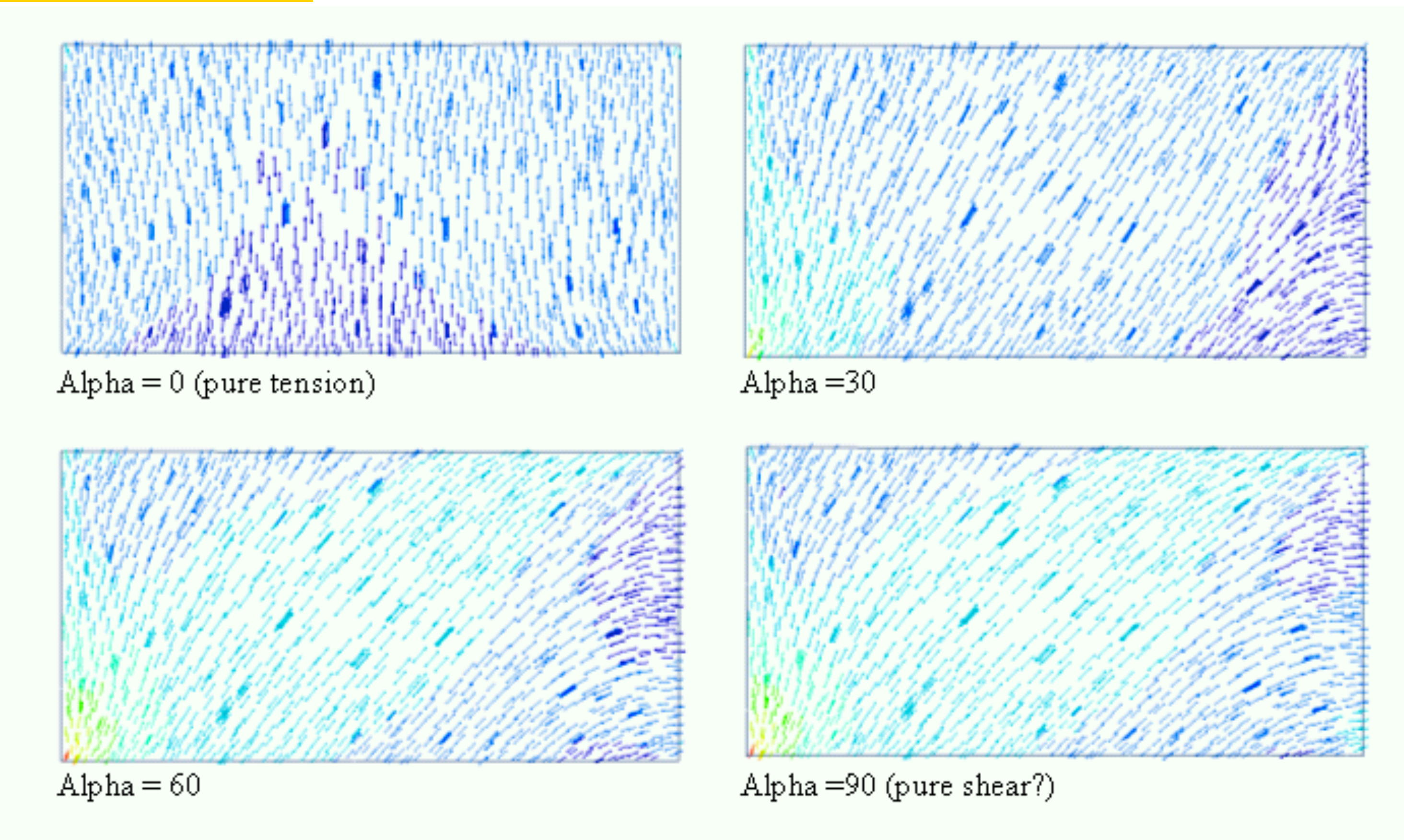


Angle of Pull



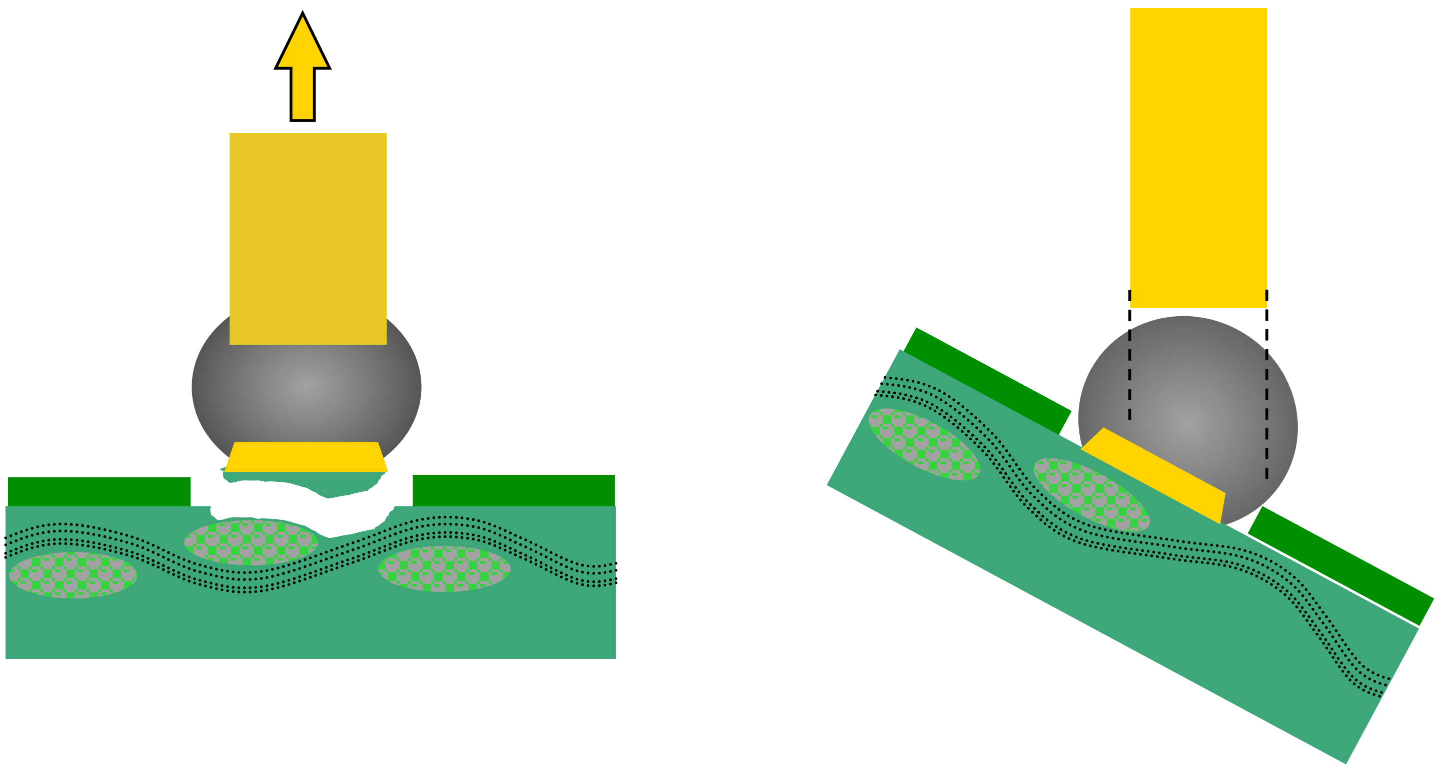


Pure Tension does not properly simulate the P1 stresses. Alpha = 30° gives the best representation of the actual joint.

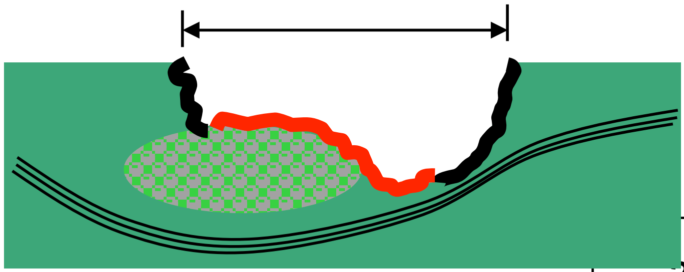


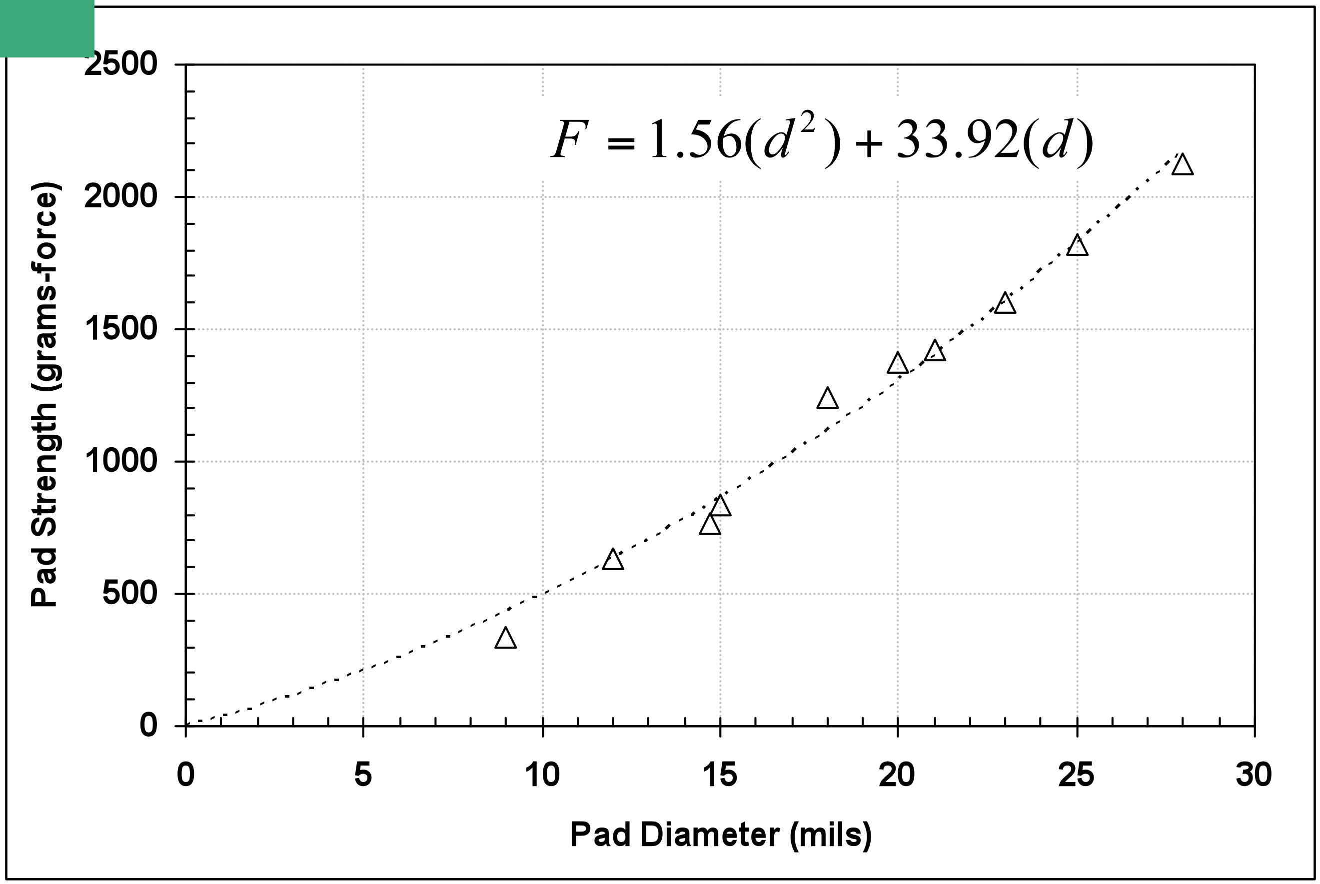
Pull testing of Pads

Due to principal stress tensors determined from FEM analysis, we suggest pull testing of pads at an angle of 30° to the pad normal.



Strength Scaling





Strength scales with pad area, using both a quadratic and linear term

Quadratic term is related to pad area.

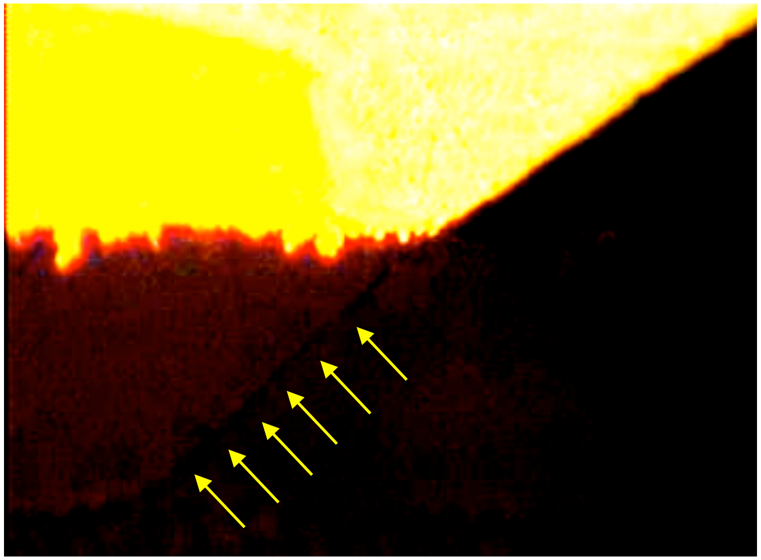
Linear term is related to crack depth.

Latent Pad Damage

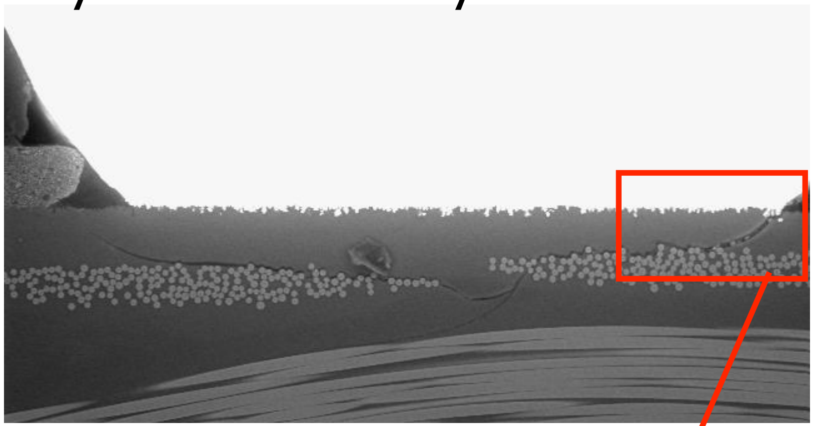
Risk:

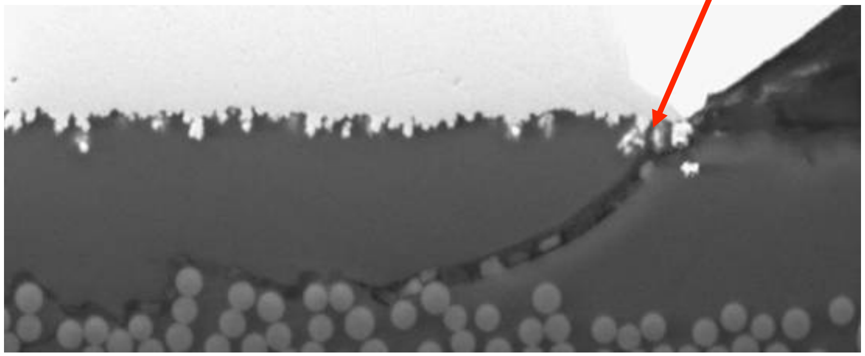
- **Small cracks under the pad may be initiated during manufacturing and test**
- **These cracks are not generally electrically detectable**
  - Usually requires destructive techniques to find them
- **What is the ultimate reliability risk?**
- **Or, will my product survive through warranty period with a pre-existing crack?**

Latent Damage



- Small cracks observed just after reflow
- Changed failure mode from Solder Fatigue to Pad cratering
- Reduction in Lifetime from >9500 Cycles to 2500 Cycles





Pad Level Test

Measure medium/high cycle fatigue life of individual pads

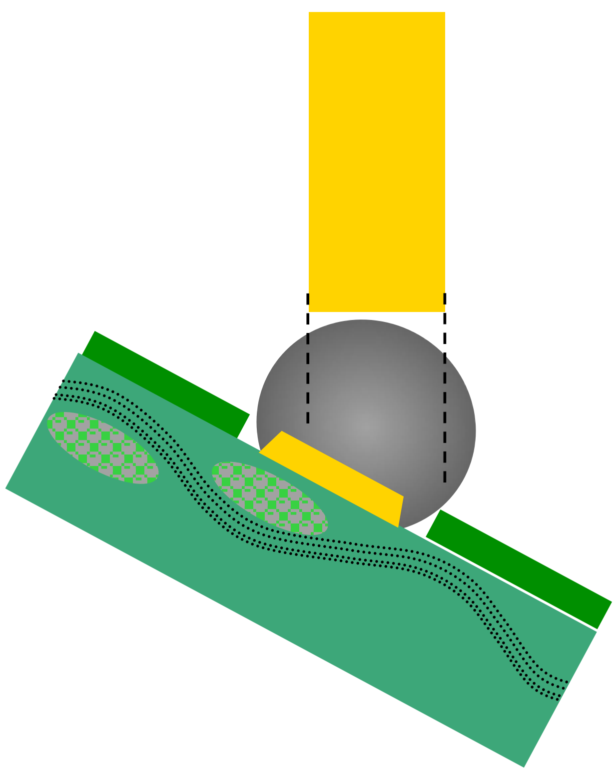
Simulate manufacturing stress to induce damage

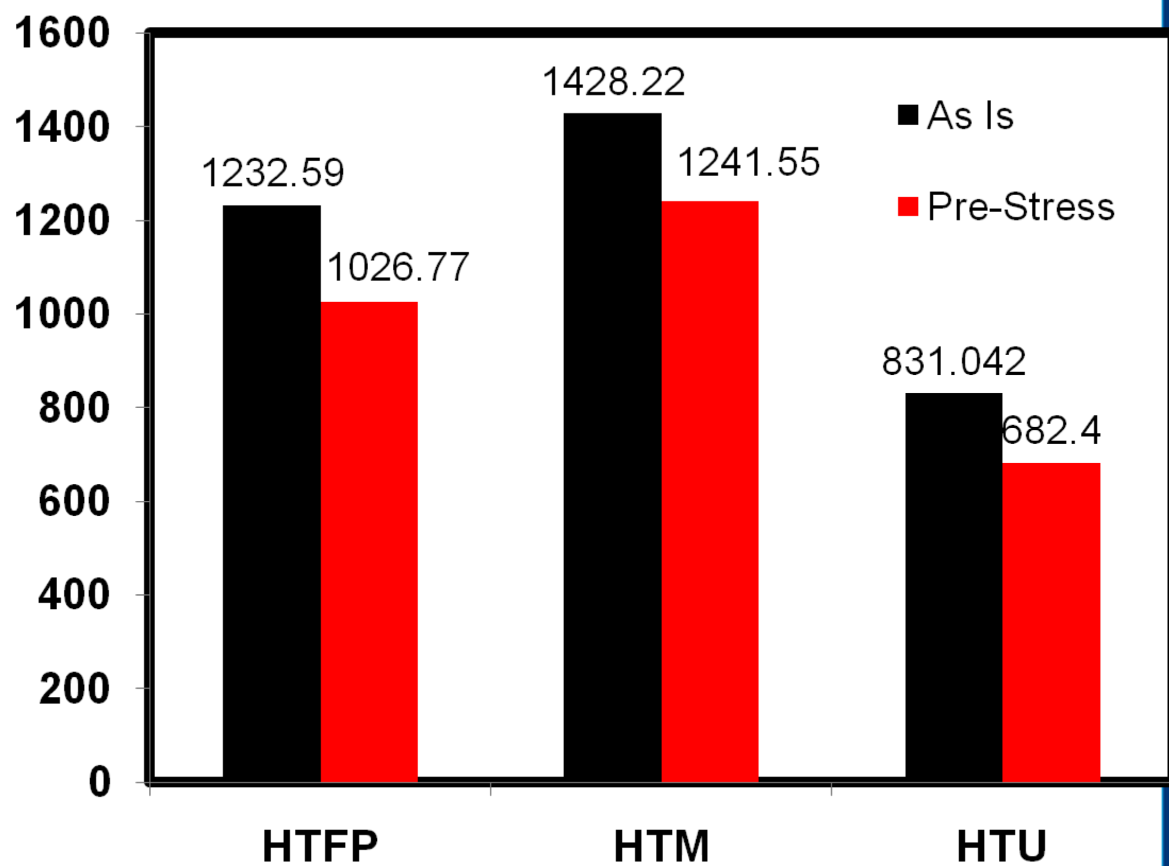
Re-measure medium/high cycle fatigue life of individual pads

- Determine degradation in lifetime as a function of simulated manufacturing defect
- Develop predictive extrapolation to determine risks in “service conditions”

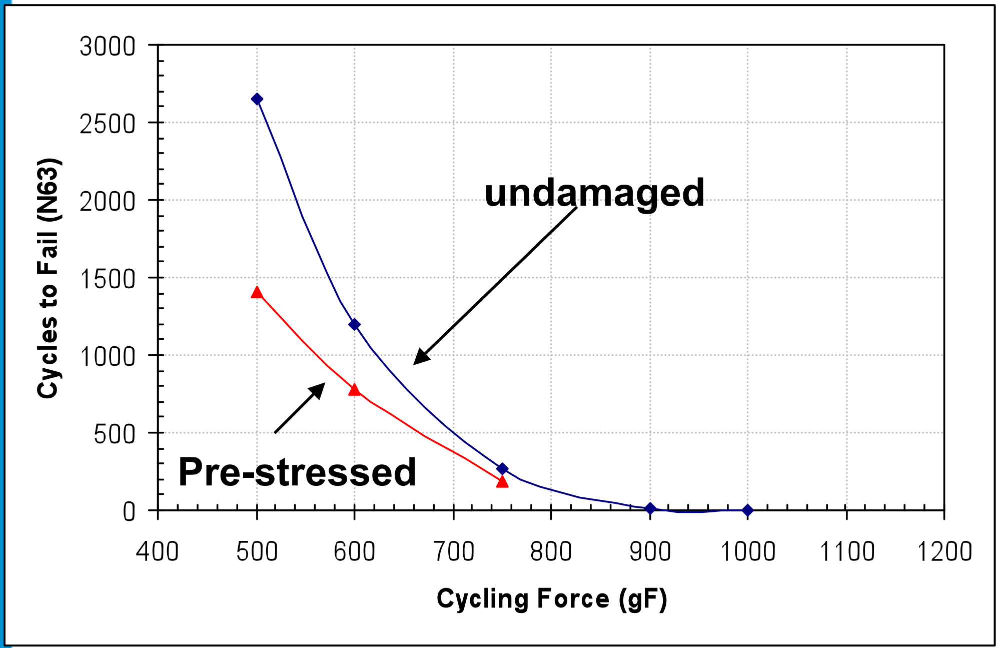
Pad Level Test: Strength Degradation

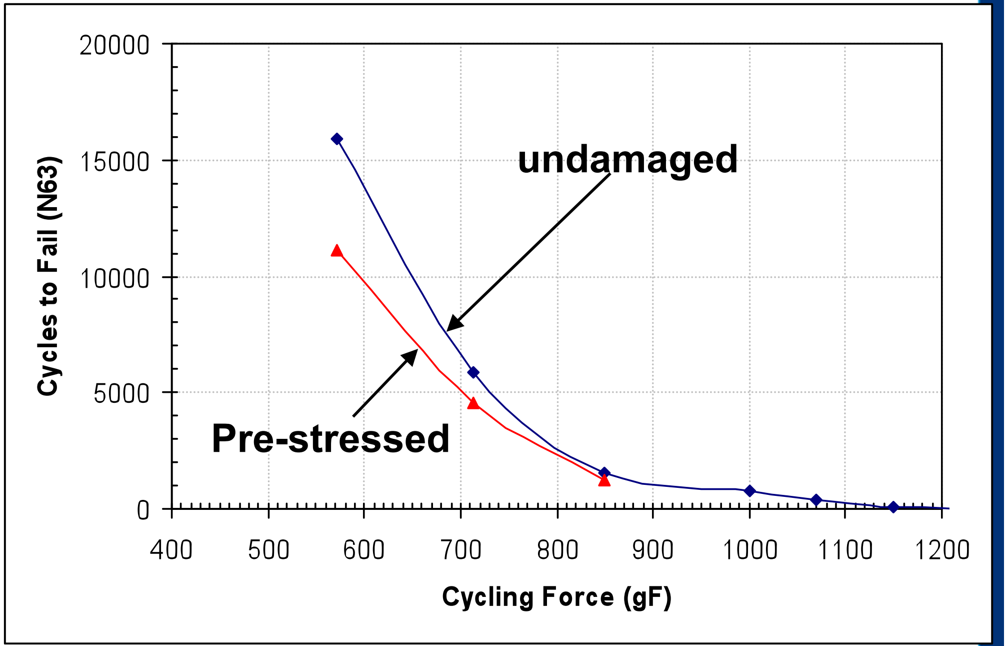
3 laminate systems exhibit approximately 20% strength decrease when pre-stressed with a simulated manufacturing stress.





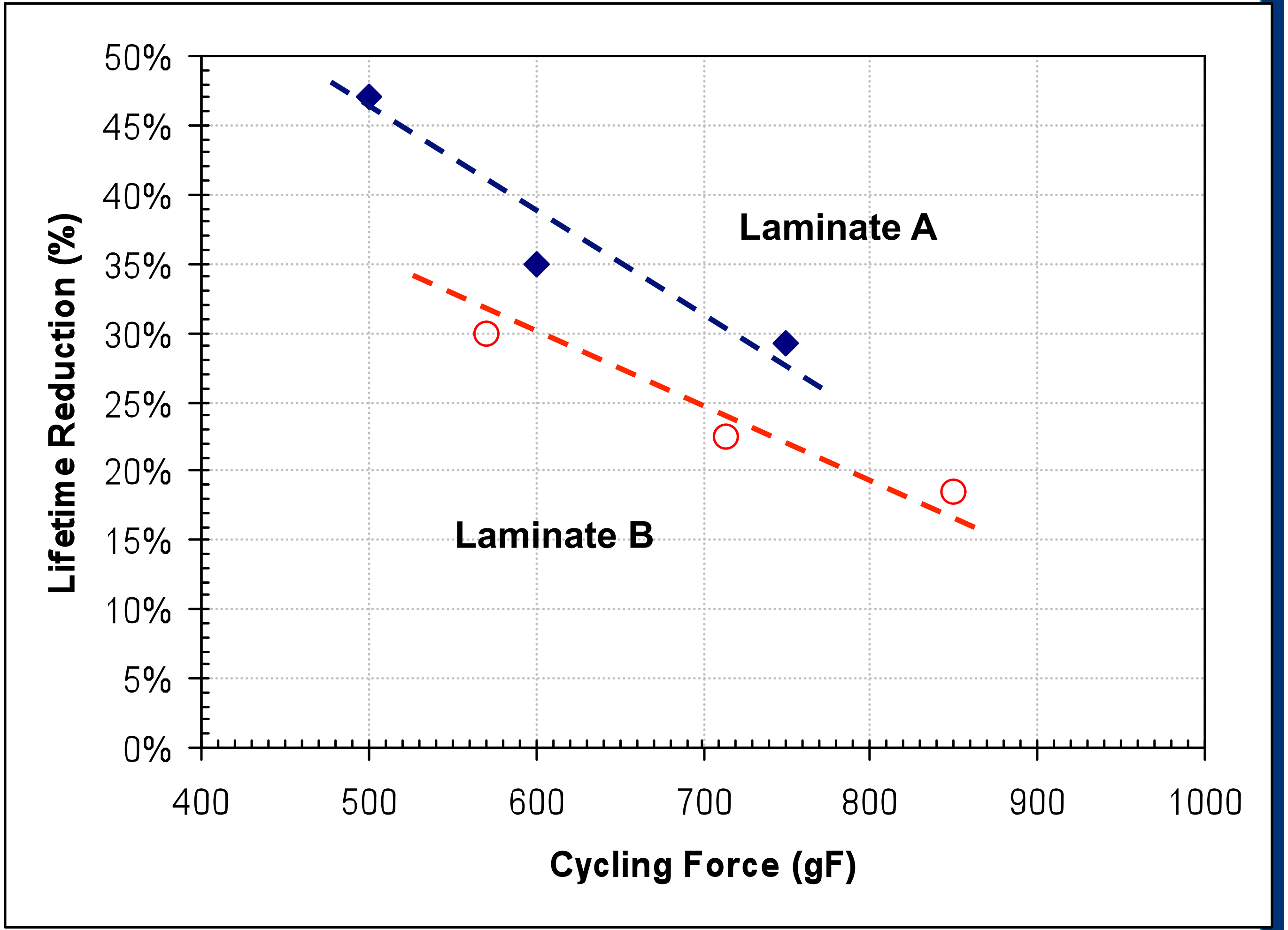
Lifetime Analysis: Undamaged Assemblies





Lifetime Reduction

- Note that service conditions are generally mild compared to test conditions.
- Lifetime reductions are greater at milder cycling conditions.



Assembly Level Analysis

Simulate a manufacturing defect

- **PCB bending to known strain levels, below failure strain**

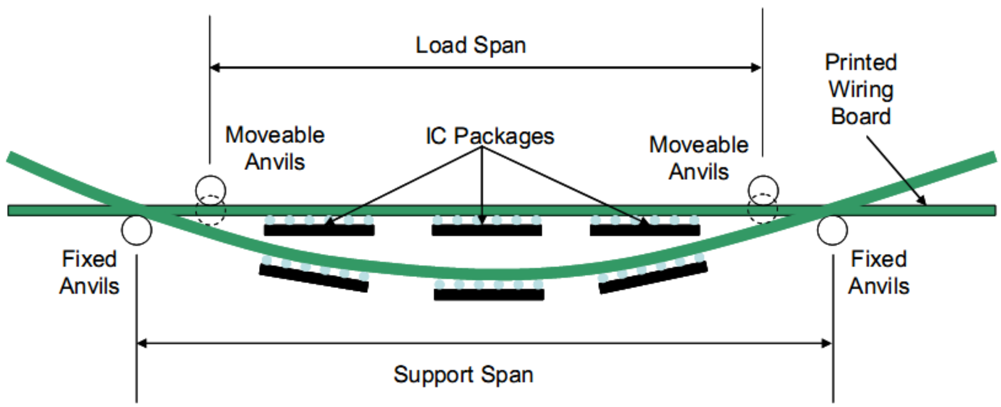
Determine amount of cratering by area %

- **Requires destructive FA.**
- **No known methods of determining crack area otherwise**

Perform Lifetime assessment

- **drop/shock testing**
  - Virgin boards
  - Boards pre-stressed at levels above

4-Point Bend Approach



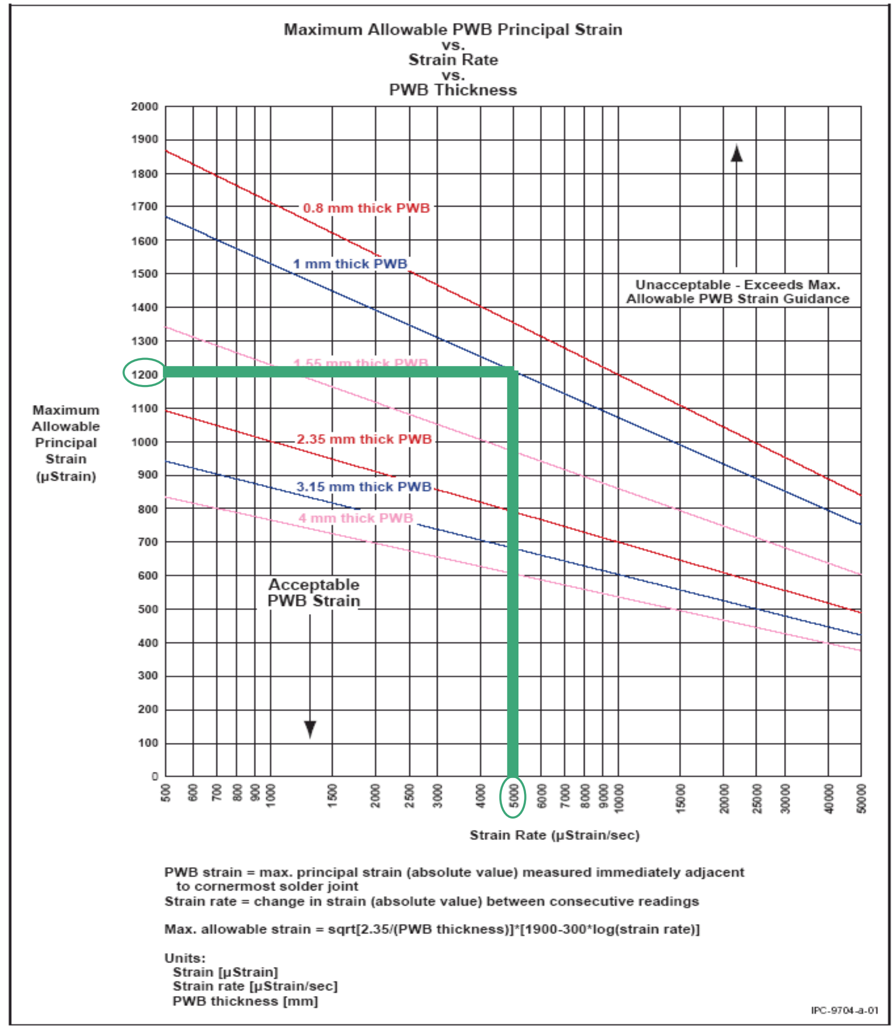
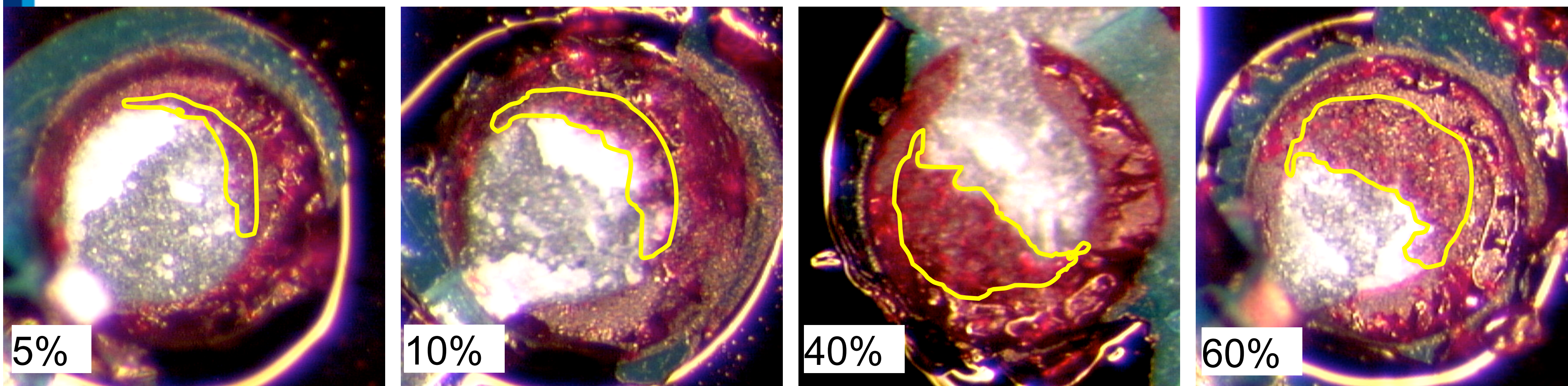


Figure A-1 Typical Example of Allowable Strain as a Function of Strain Rate and Board Thickness
Note: The limits do not serve as strict guidance and need to be verified for the specific application.

Partial Craters



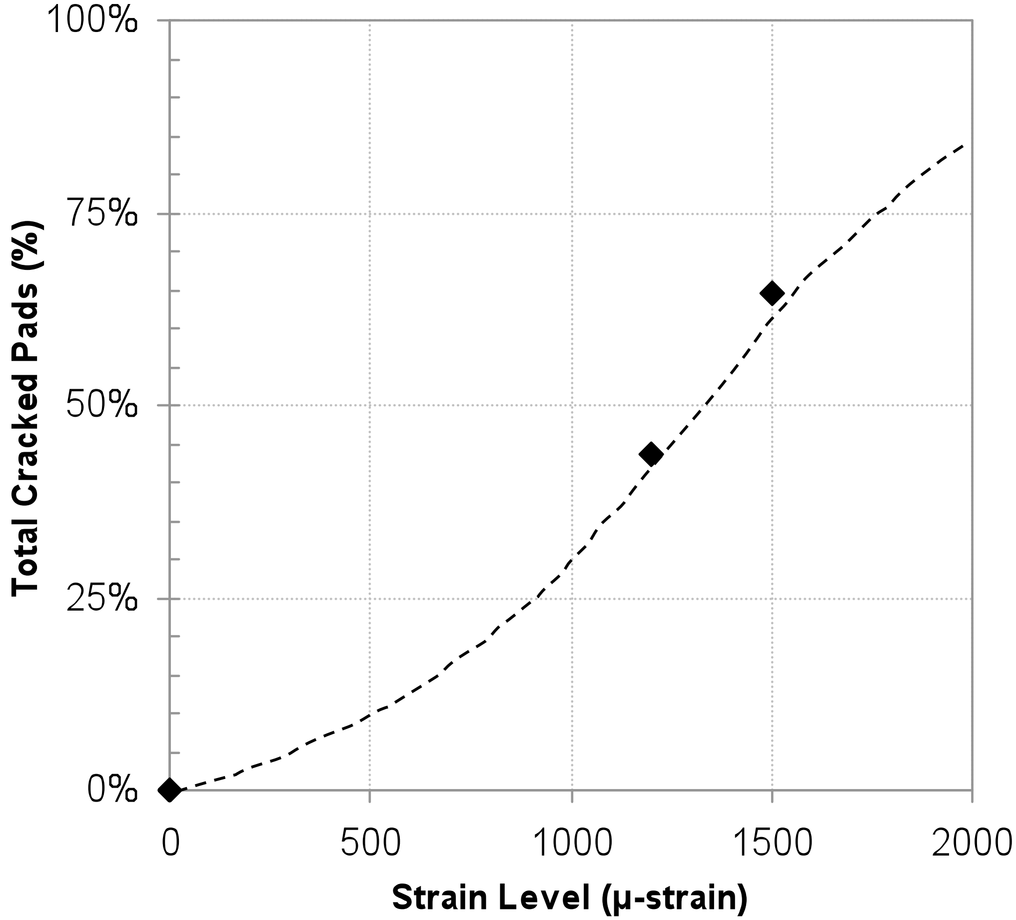
Crack area considers only the pad area, not the trace.

Quantitative measurements by visual approximation

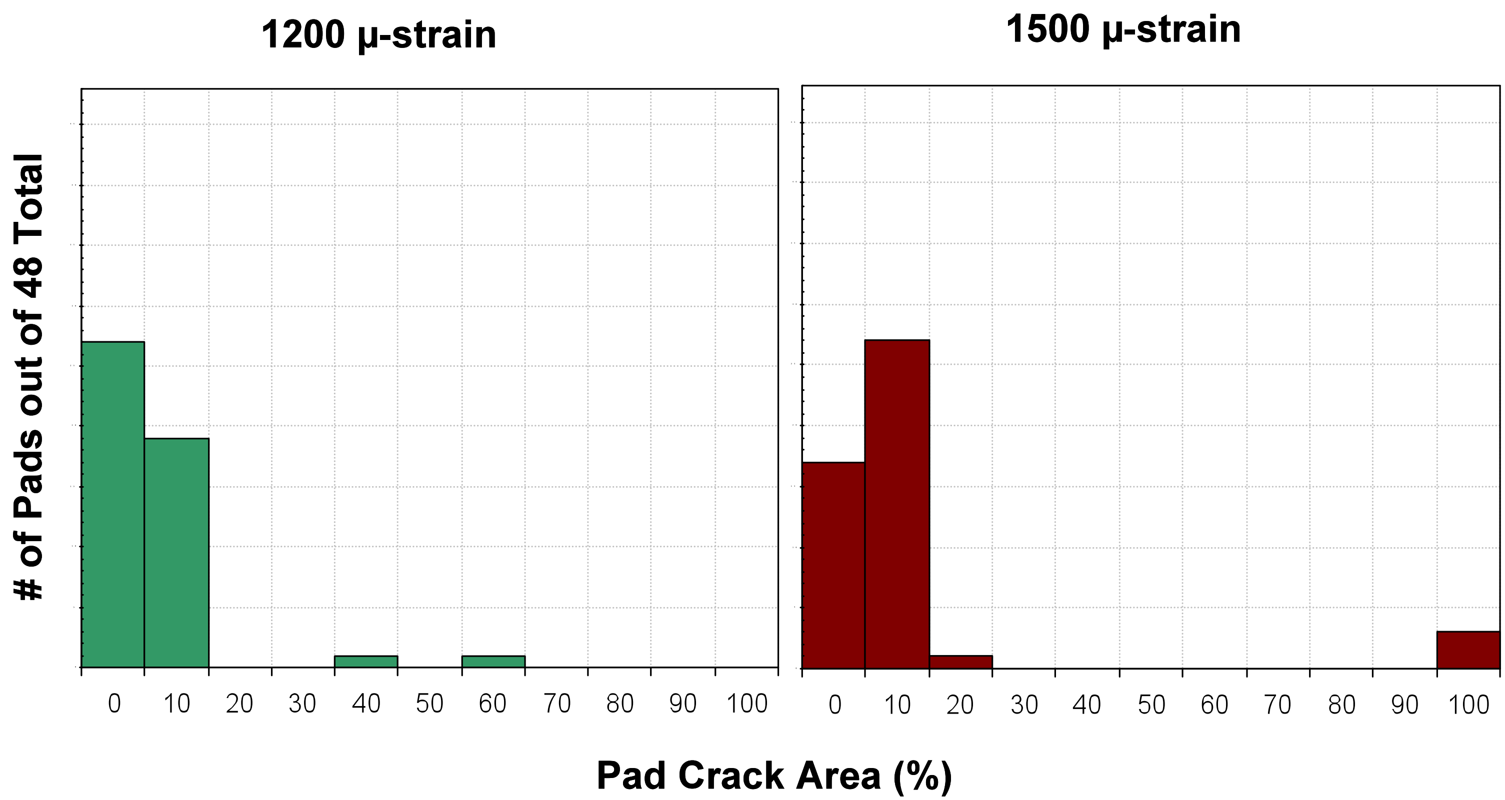
1% cracking was assigned to those that showed crack initiation, but little to no crack progression.

Damaged Pads

Total number of pads exhibited some level of damage due to simulated manufacturing stresses.



Partial Crater Distribution



Examined 48 pads for each strain level

Cracks areas range from 0%-100%

More non-cracked pads at 1200 μ-strain.

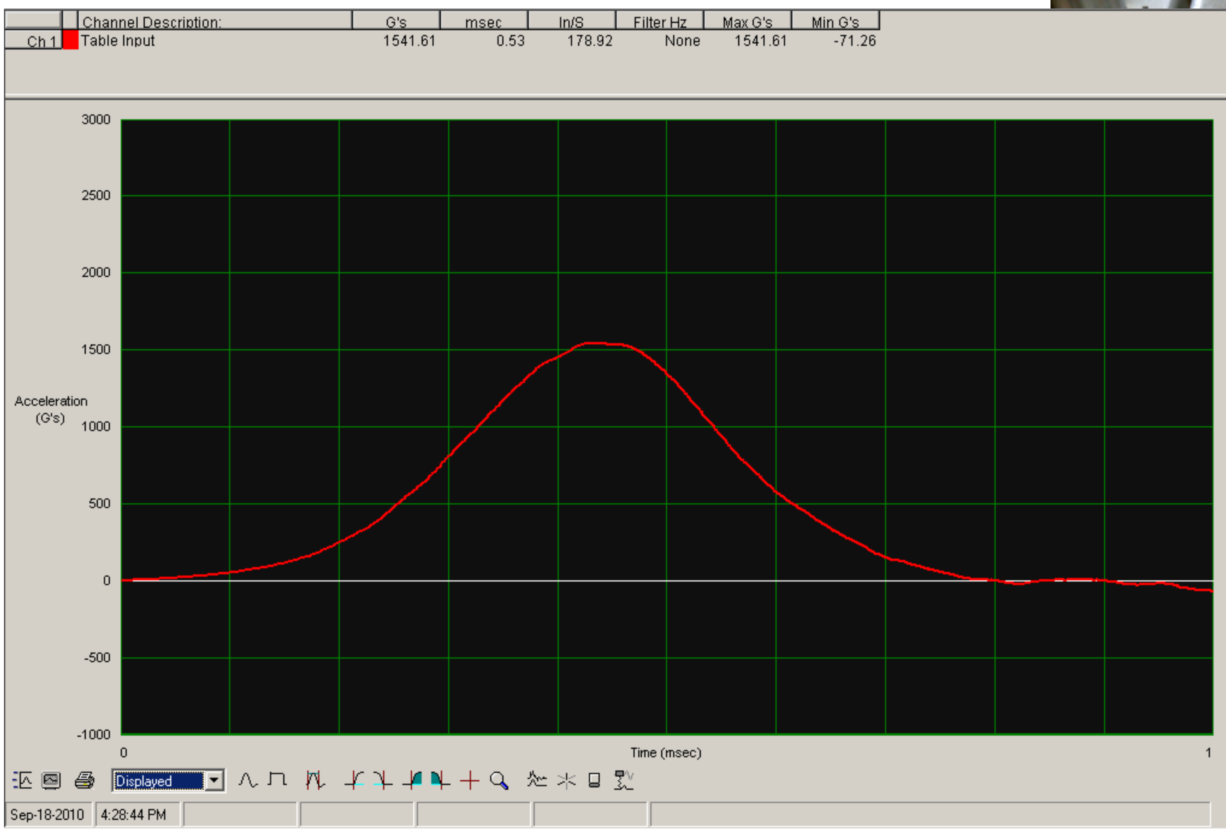
Greater amount of cracked pads at 1500 μ-strain

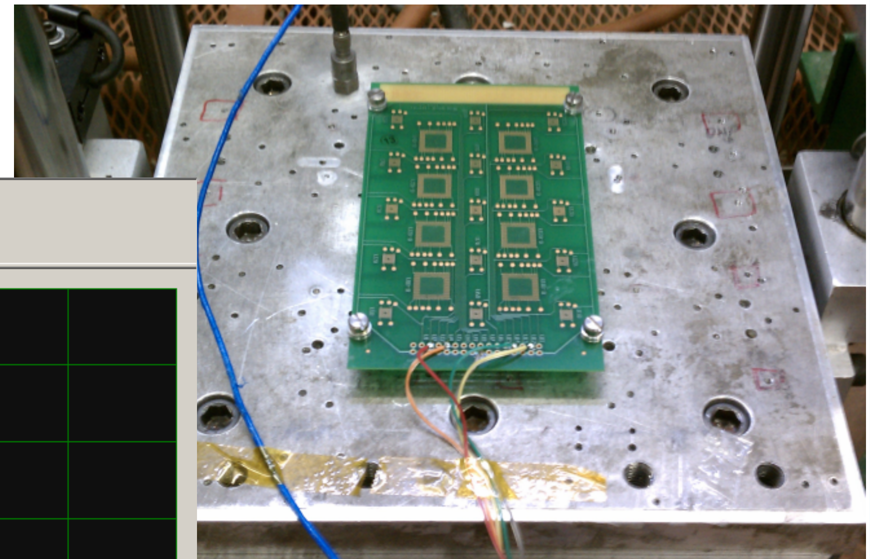
- 3 pads were fully cracked, but electrically good.

Additional boards were bent to these levels and then drop/shock tested.

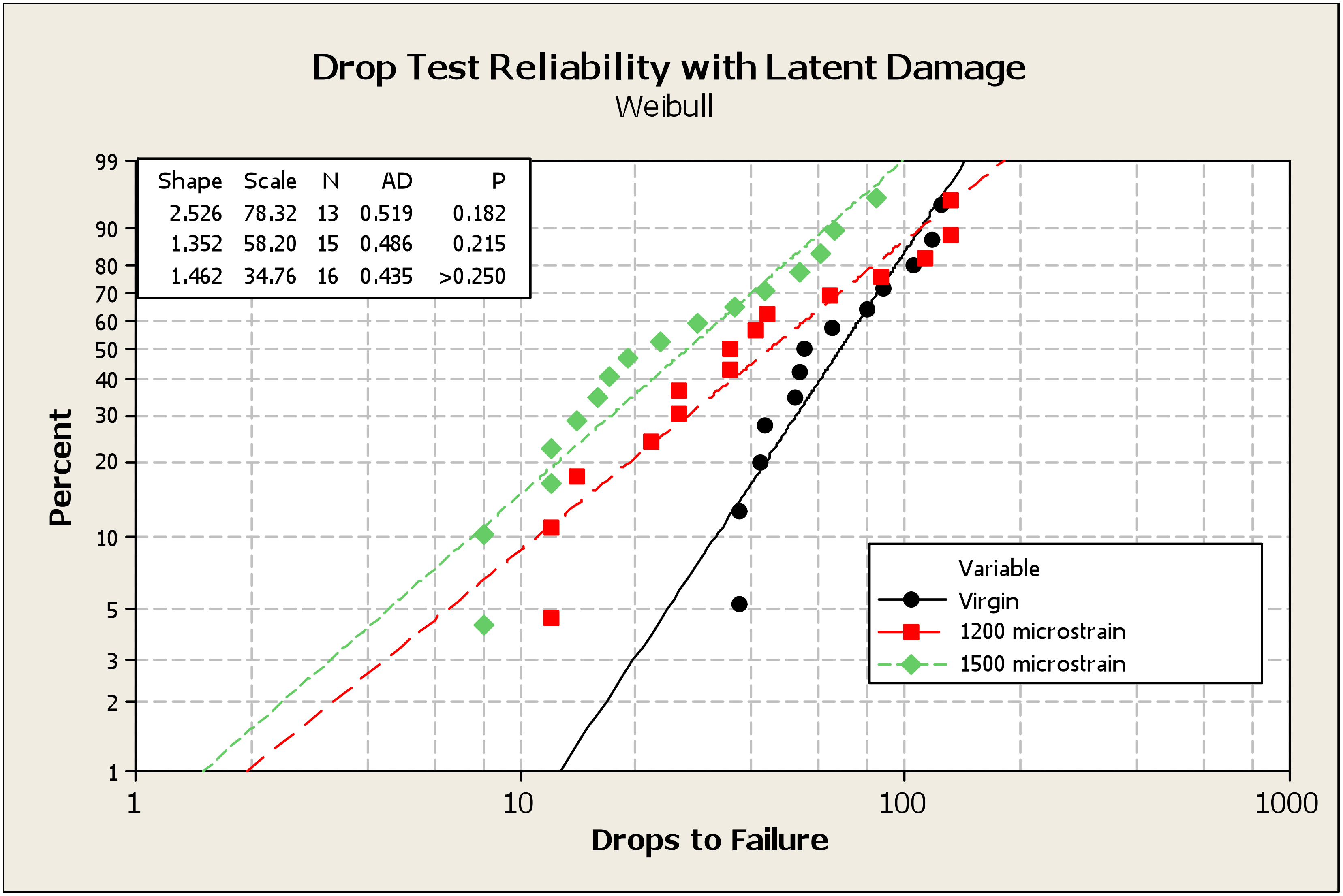
Reliability Test: Drop/Shock

Standard JEDEC 1500-G, 0.5ms pulse





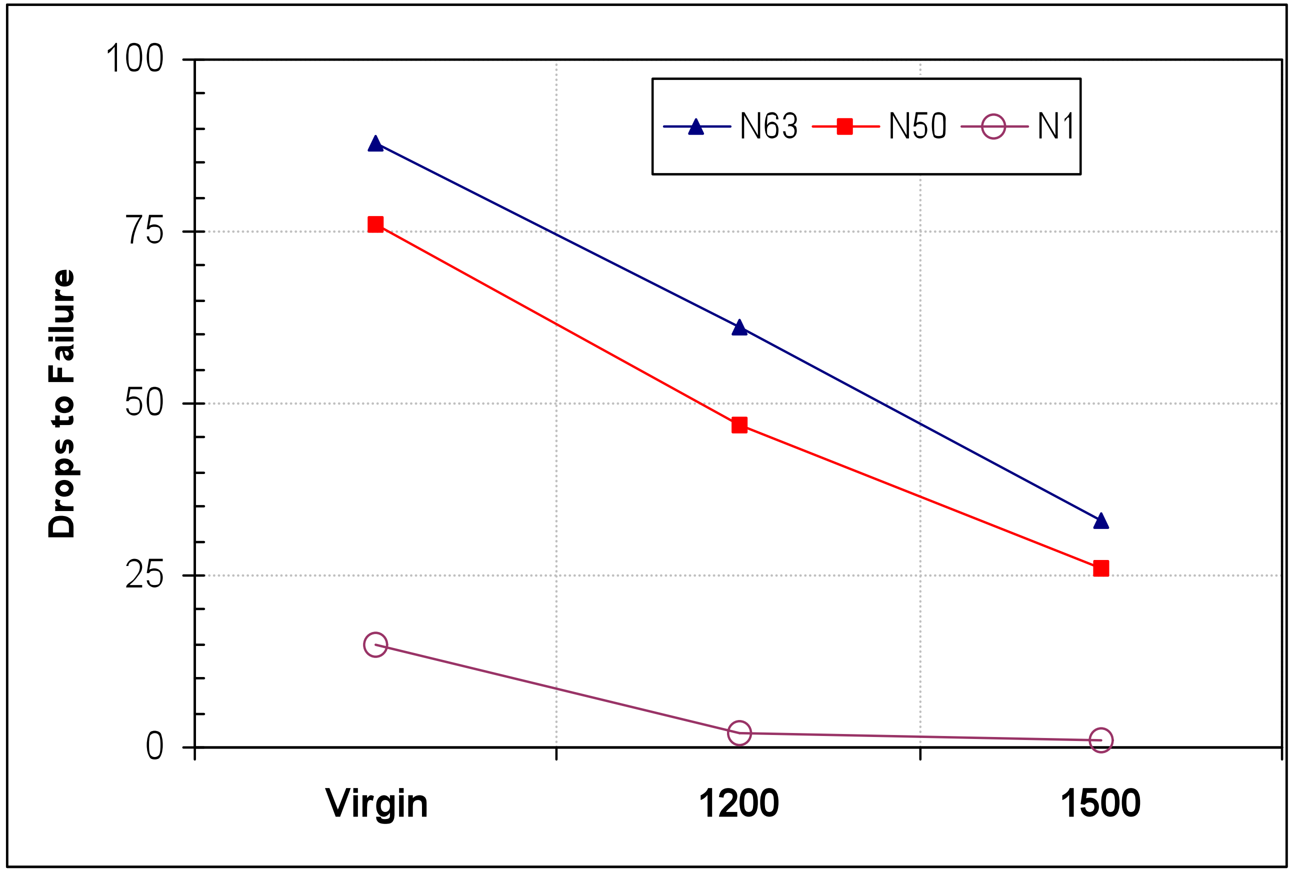
Reliability Data



Reliability Data

Reliability Reductions.

- **N63 drops by 30-60%**
- **N50 drops by 40-65%**
- **N01 drops by 87-93%**



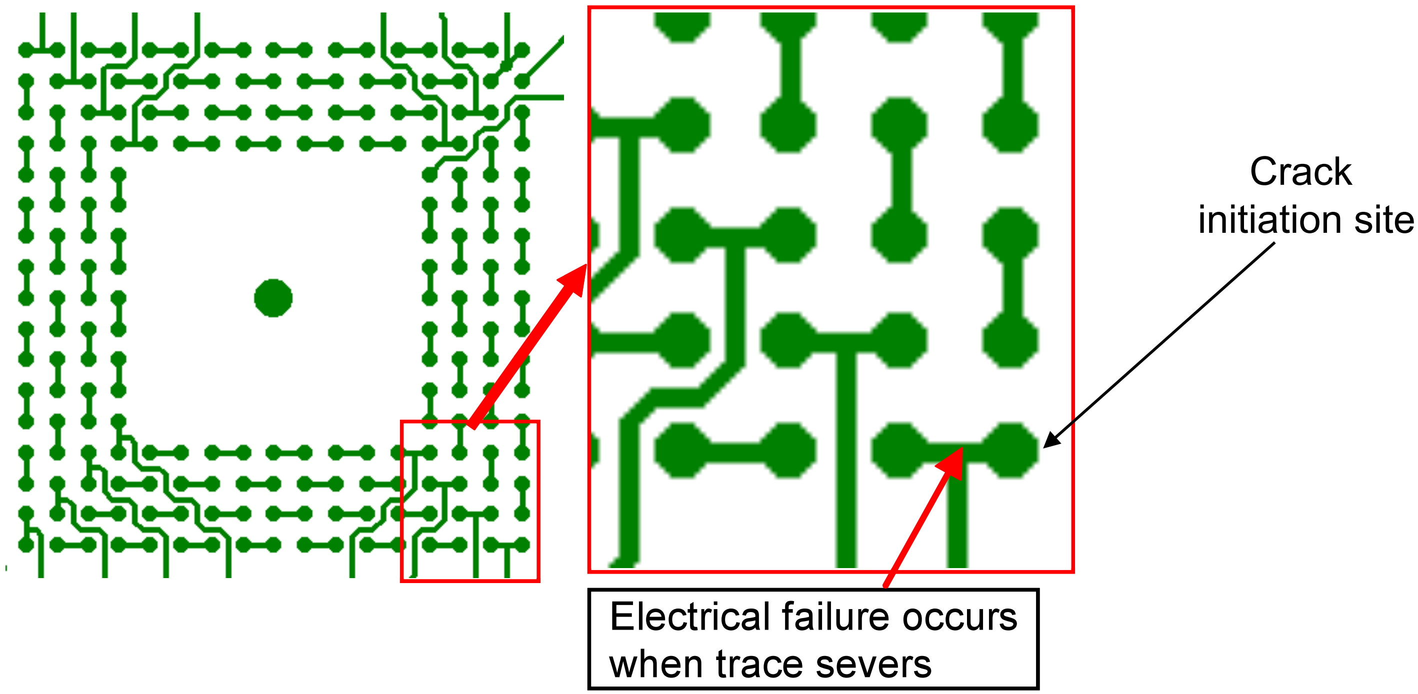
Consequence: Later failures have a significant degradation, but degradation of early failures is catastrophic.

First Measured Failures: Effects of Board Design

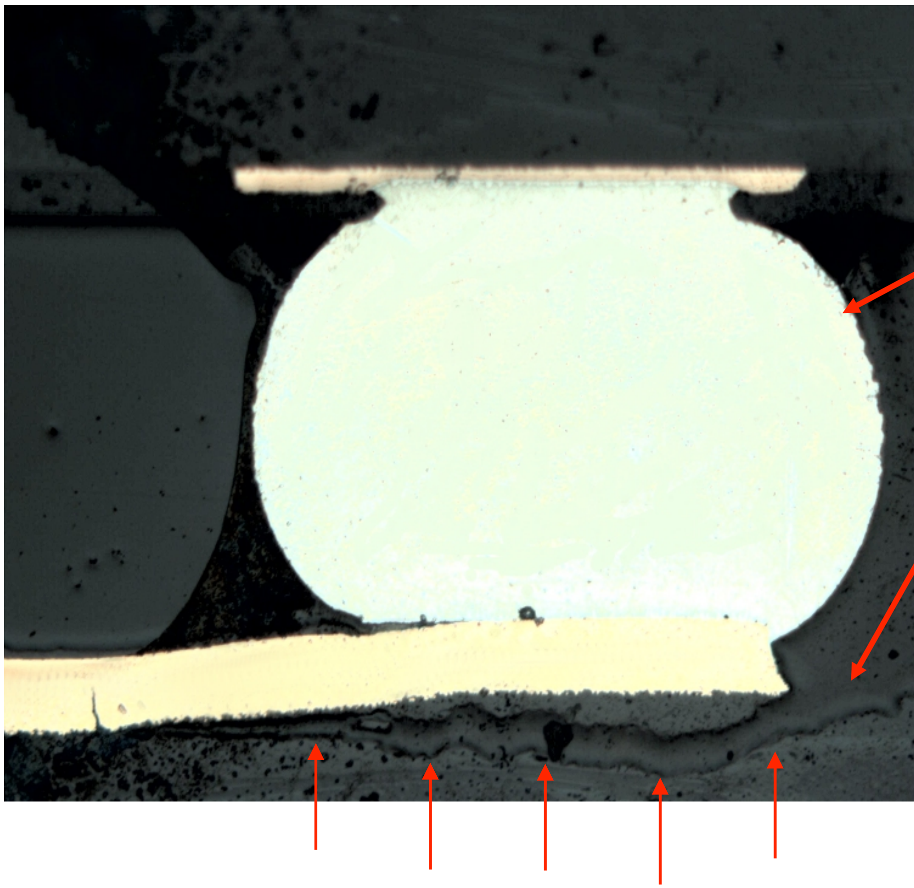
We expect earliest failures in pre-stressed conditions to relate to an existing crack length of 100%.

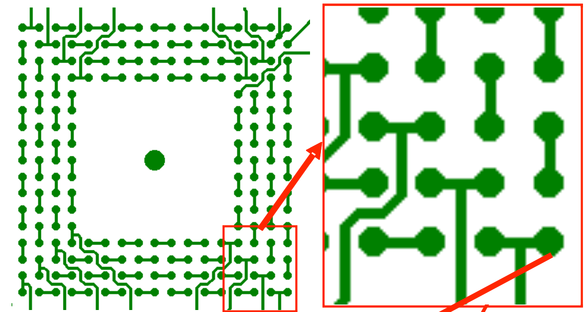
Yet failure was still delayed until 8 drops.

Pad cratering is a mechanical failure, we measure electrical failure, so our signal is delayed until the trace cracks,



Effect of Board Design





Crack starts at outer edge of pad.

Electrical failure occurs AFTER pad has mechanically failed.

Trace failure is delayed and electrical functionality is maintained.

Universal Instruments

Summary

- At least one EMS has described pad cratering as the most prevalent failure mode, more common than solder fatigue.
- Cratering in not reworkable…at least not easily like solder failure
- Catastrophic failures can be addressed with simple strength testing of your laminate and stress analysis of your product.
- Long term reliability risks are more critical for partial cracks that are not detectable.
- Long term reliability degradation is greater for mild cycling conditions, such as seen in service.
  - Most lab testing is ‘accelerated’ and therefore higher stress than service.
- Many mitigation strategies exist, but they can be costly and often require re-design or material re-specification/qualification.

Thank You

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