ASME
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INTERNATIONAL DESIGN ENGINEERING TECHNICAL CONFERENCES & COMPUTERS AND INFORMATION IN ENGINEERING CONFERENCE

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INTERNATIONAL DESIGN ENGINEERING TECHNICAL CONFERENCES & COMPUTERS AND INFORMATION IN ENGINEERING CONFERENCE

End-Of-Life Prediction For Solder Joints In Electronic Systems Experiencing Low-Cycle Fatigue Under Impact Loading

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Outline

- Background and Introduction
- Methodology
- Experimental approach
- Results
- Conclusions and future work

High-Rate Dynamics

- Mechanical Shock
  - Sudden change in force, position, velocity, or acceleration[1]
  - Induces transient states in the system [1]
  - Can excite system frequencies [1]
  - Can lead to unpredictable responses within the structural integrity of components

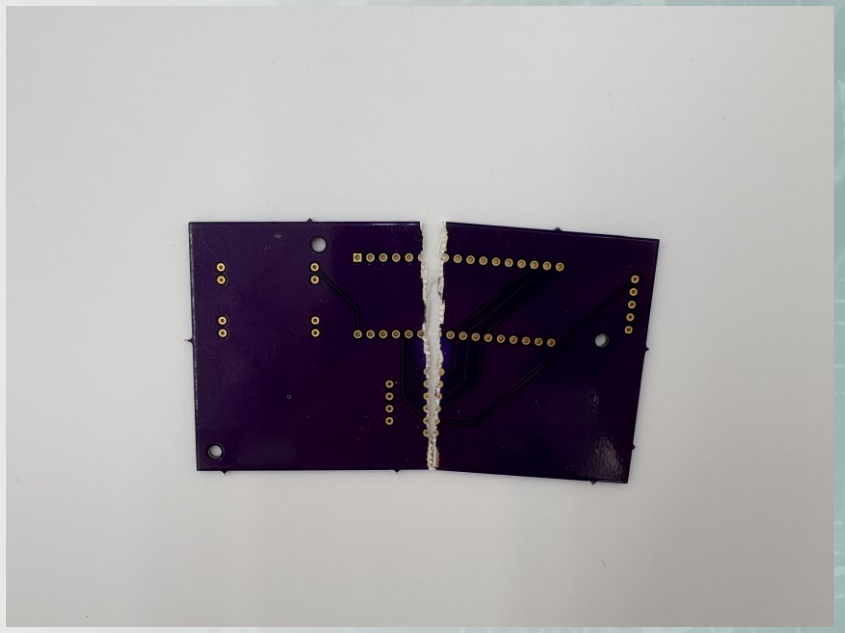
Blast against civil structures

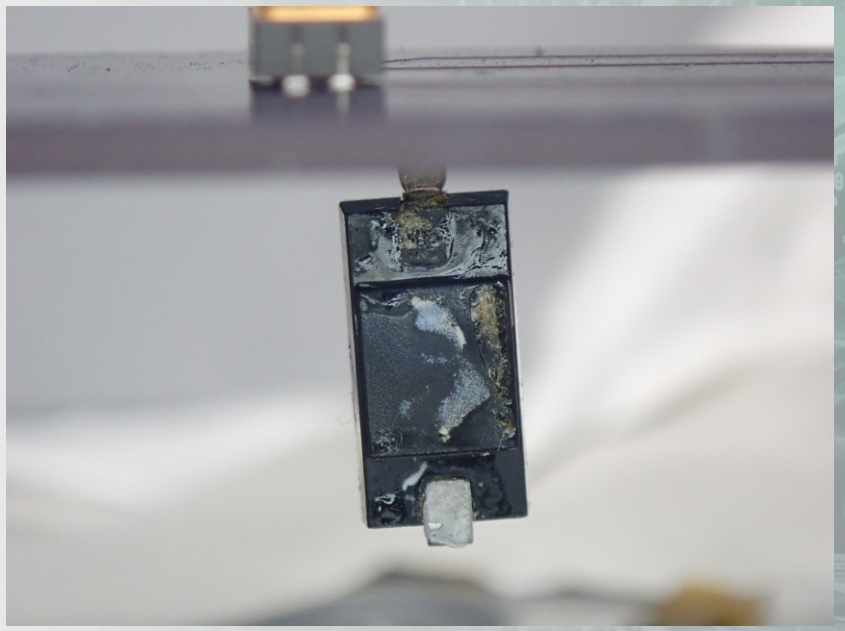
Automotive impact and crashes

High-speed aircraft and airframes

Introduction

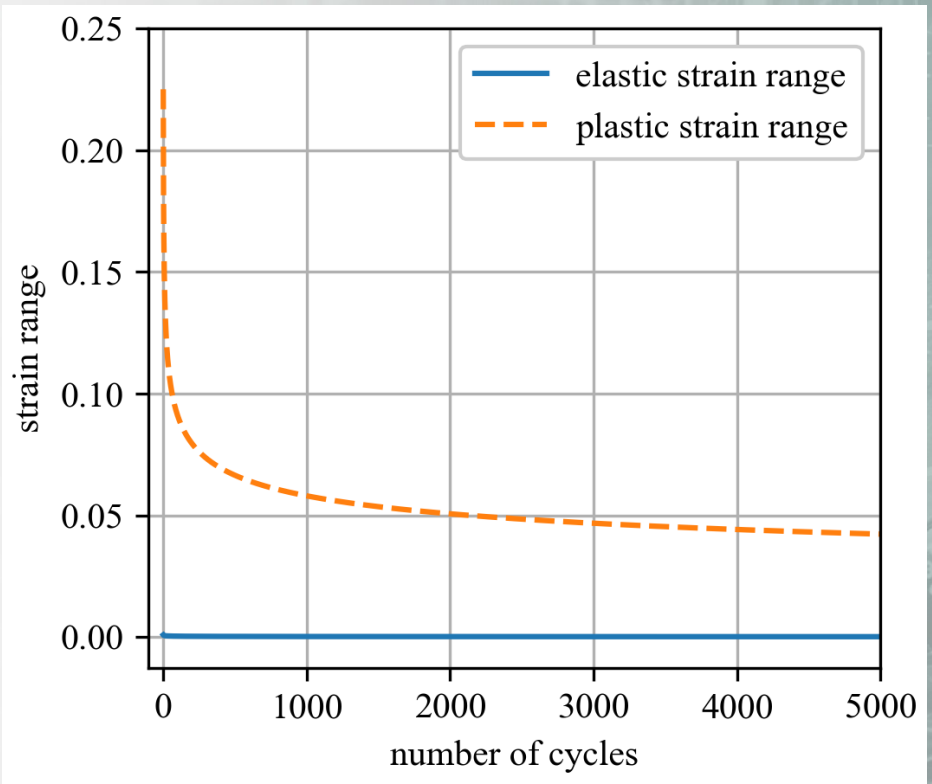
- Importance:
  - Systems subject to fatigue can experience sudden failure
- Problem:
  - Repeat inspection is not always practical
- Proposal:
  - Construct an algorithm to estimate remaining useful life of system
- Objective:
  - Track remaining useful life of system across intermittent impacts





Background - Fatigue

- Fatigue
  - Load applied over time
  - Can cause sudden structural failure



Example strain-life curve

Background - Modeling Fatigue

Initiation Life Estimation

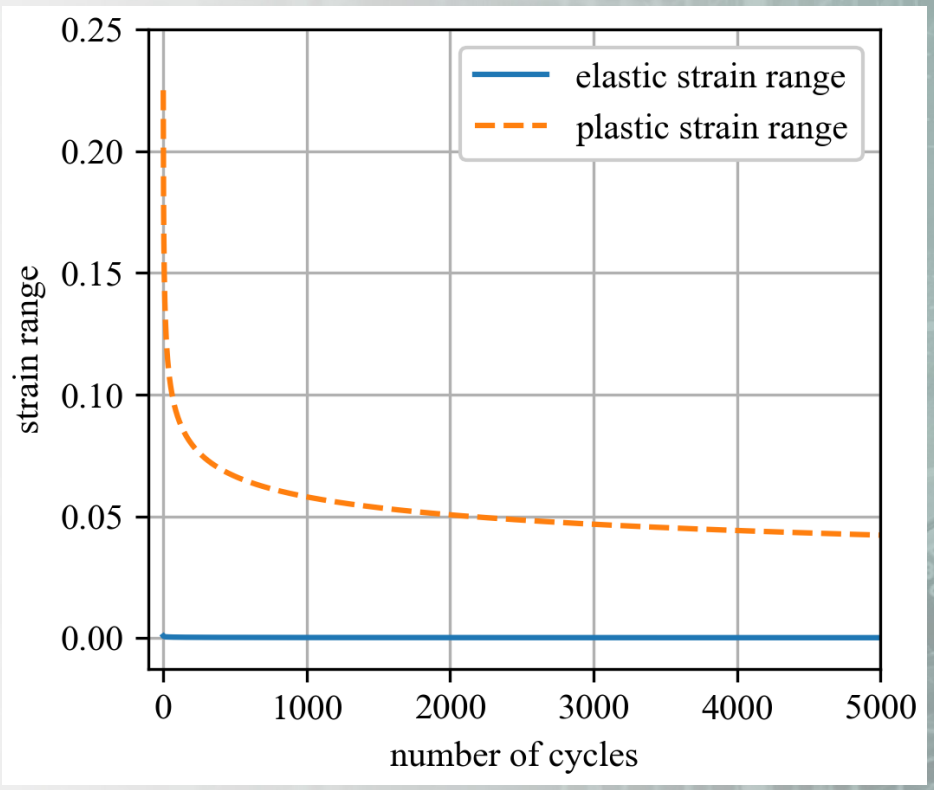
- Simulates fatigue damage at points of stress concentration
- Models when a crack occurs
- Modeled through stress-life or strain-life

Propagation Life Estimation

- Tracks length of crack in material
- Models when crack grows beyond critical length
- Modeled through fracture mechanics

Background - Fatigue

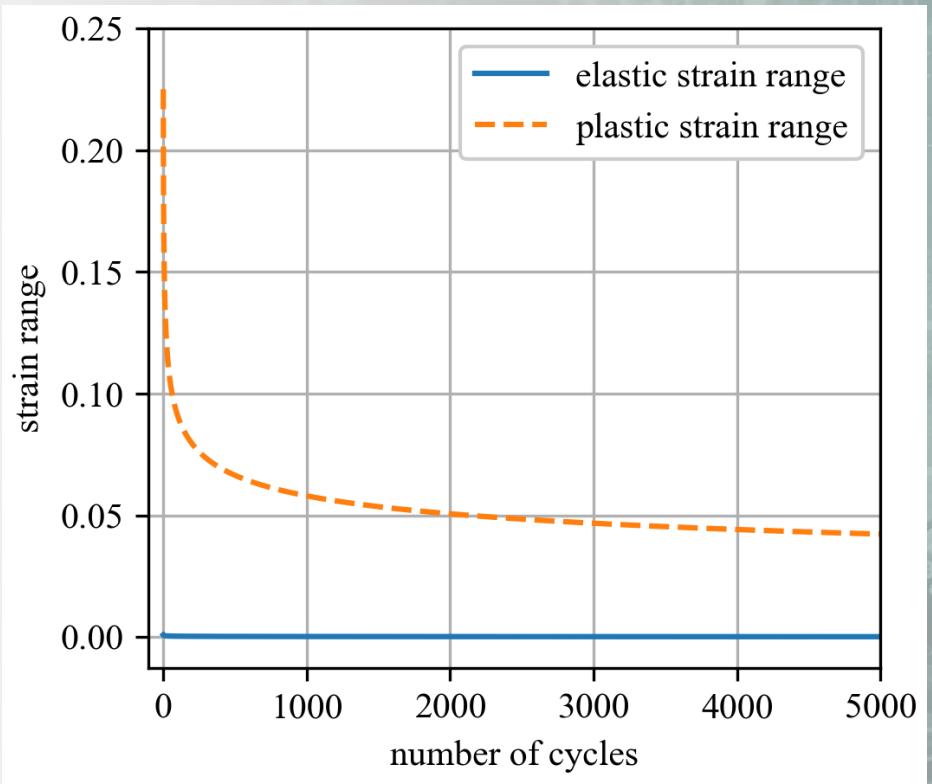
- Strain-life method
  - Estimates damage from strain amplitude
  - Better for low-cycle fatigue
- Elastic strain
  - $\frac{\Delta\varepsilon_e}{2} = \frac{K}{E} \cdot (2N)^{-B_0}$
- Plastic strain
  - $\frac{\Delta\varepsilon_p}{2} = \epsilon_f \cdot (2N)^{-\beta_0}$
- Coffin-Manson Relation
  - $\frac{\Delta\varepsilon}{2} = \frac{\Delta\varepsilon_e}{2} + \frac{\Delta\varepsilon_p}{2}$



Example strain-life curve

Background - Fatigue Summary

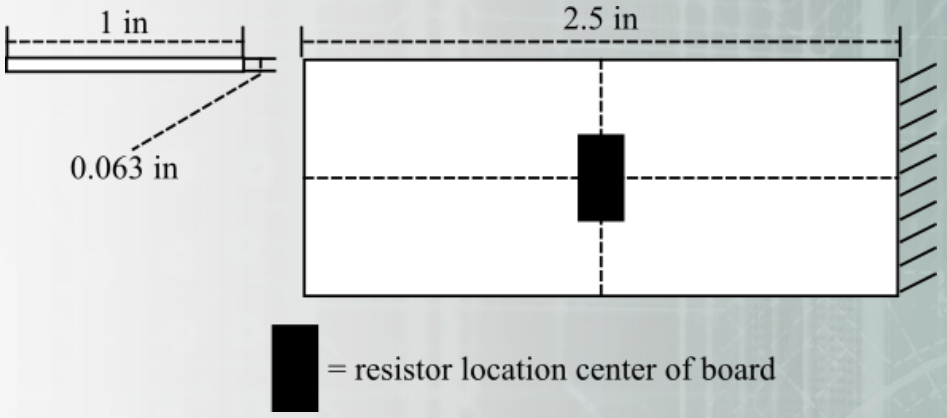
- Fatigue is damage over time
- Strain splits into plastic and elastic component
- Both represented by exponential decay functions

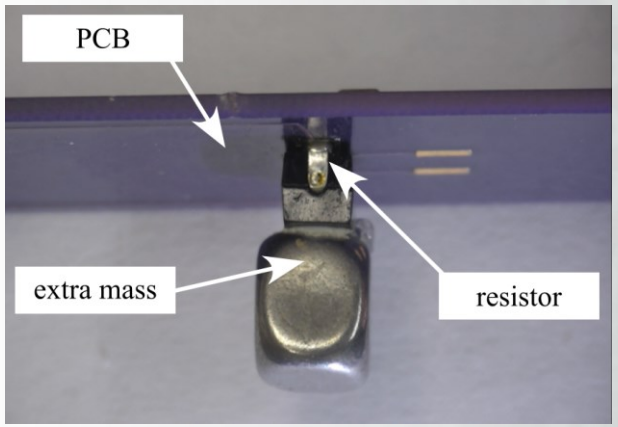


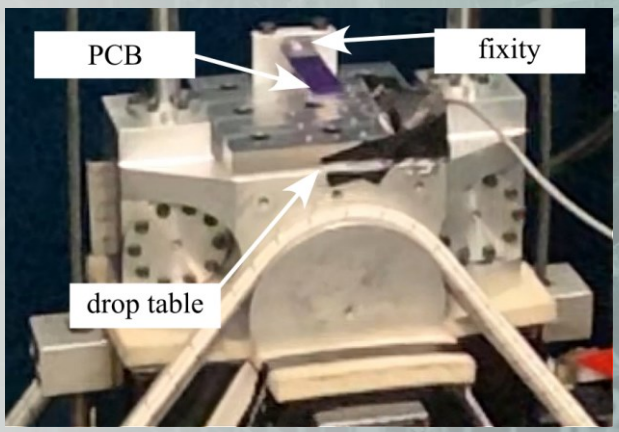
Example strain-life curve

Methodology

- Sensor breakdown:
  - Piezoresistive accelerometer
  - 2 strain gauges
  - Resistor/mass
    - Voltage divider circuit
- High-speed camera

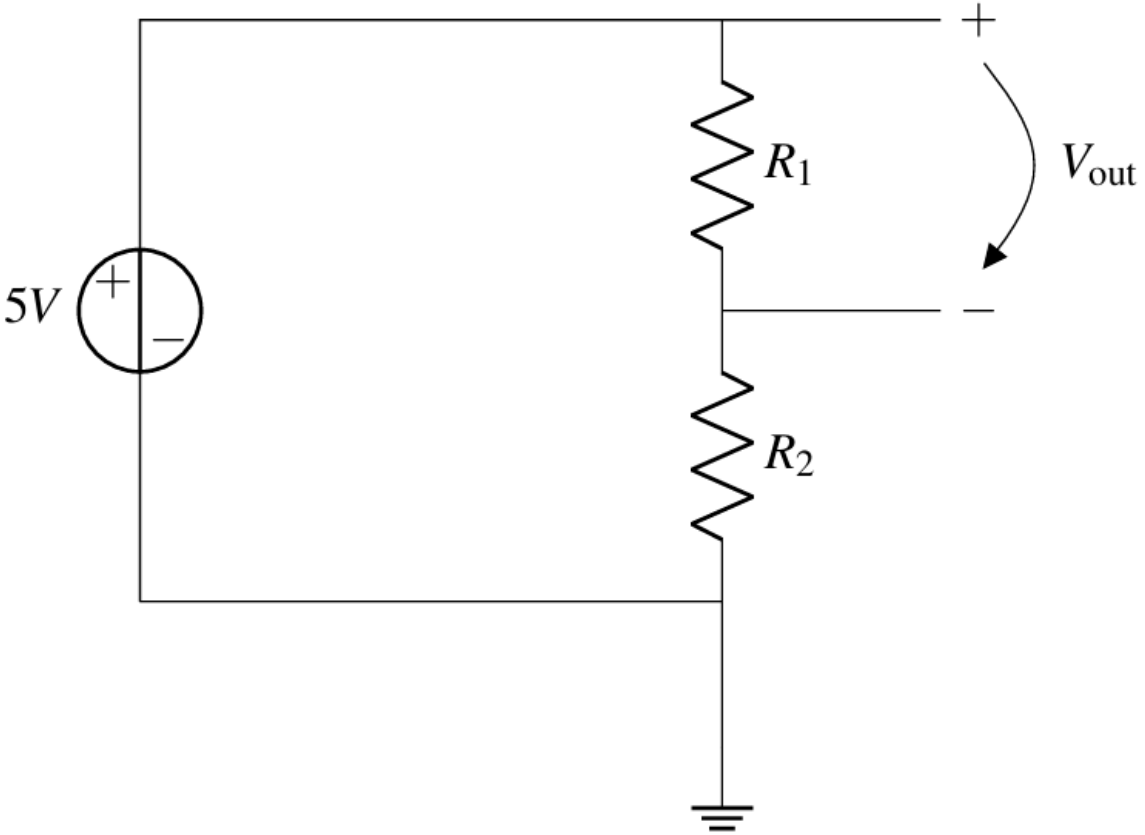






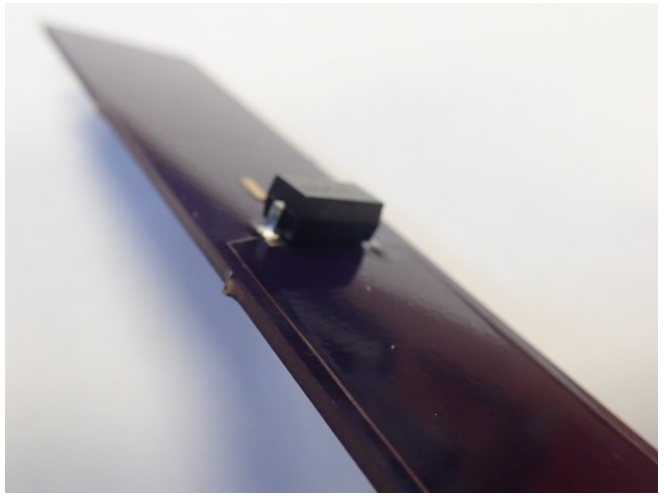
Methodology

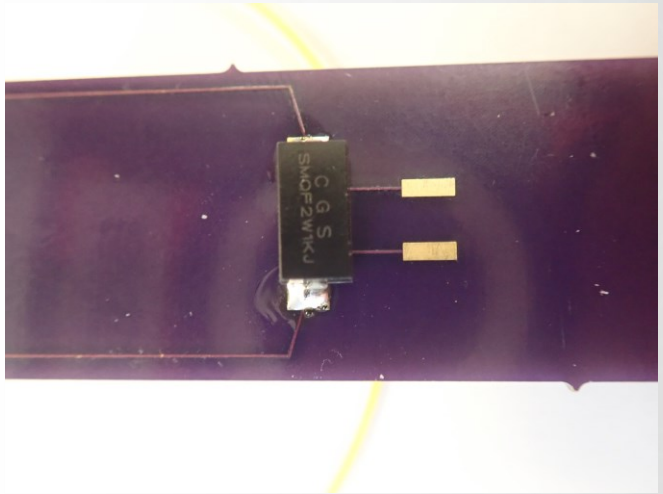
- Resistor circuit used to get a time reference on the exact moment of failure
  - Voltage divider keeps a 2.5 V signal until failure, which then drops to 0 V

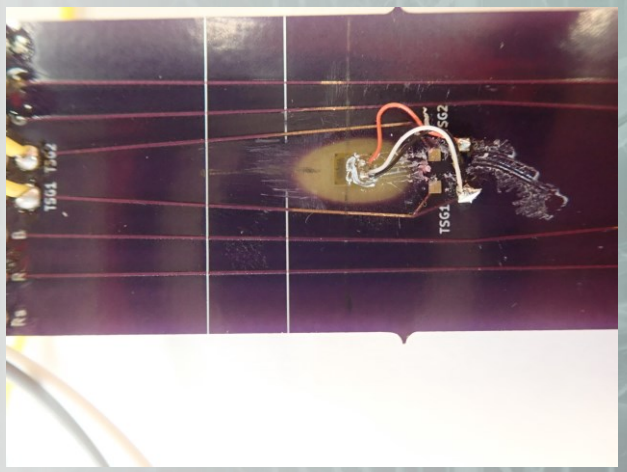


Methodology

Material	Density (lb/ft^3)	Young's Modulus (psi)	Poisson ratio
FR4	118.64	2,697,707	0.2







Methodology

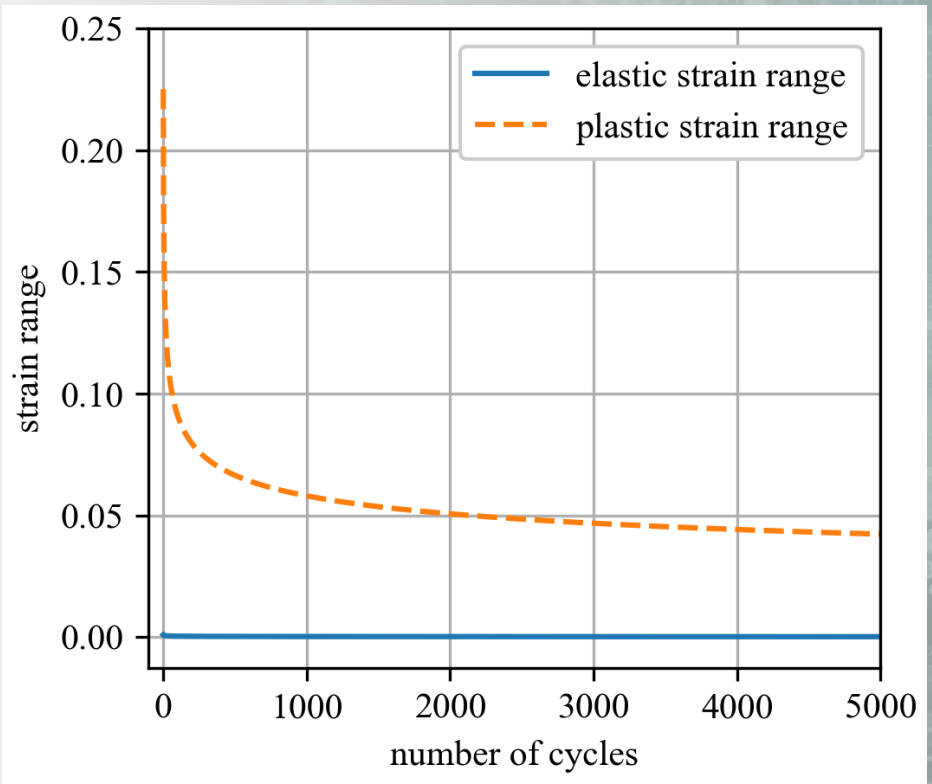
Solder Properties

- Methods to collect data:
  - Find in public data 1
  - Calculated 2
  - Find in research paper 3
- Morrow's assumption
  - Relationship between:
    - Cyclic strain hardening index
    - Ductility exponent
    - Strength exponent

Property	Value	Difficulty
Modulus of elasticity	5.1×10^{10} Pa	Easy [1]
Strength coefficient	4.9×10^{7}	Easy [1]
Strength exponent	1.608×10^{-1}	Medium [2,3]
Ductility coefficient	2.25×10^{-1}	Hard [3]
Ductility exponent	1.96×10^{-1}	Medium [2,3]

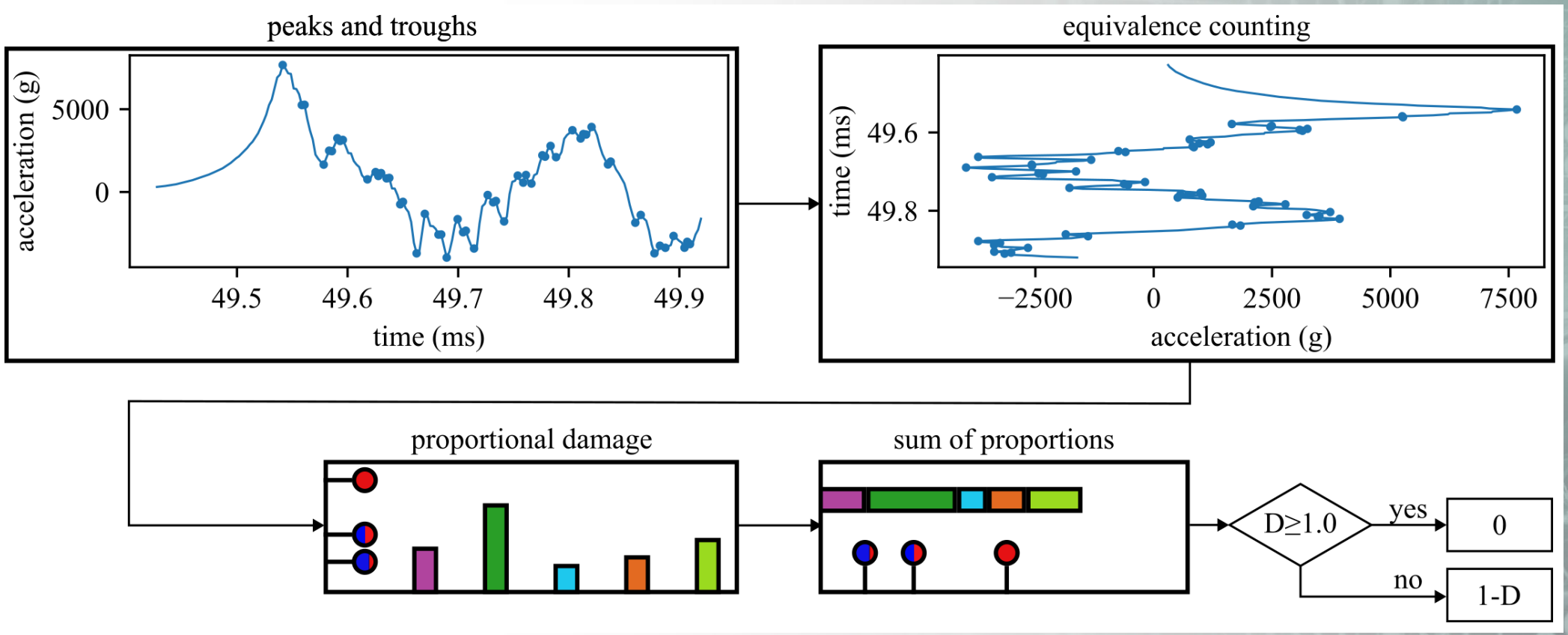
Methodology

- Assumes constant strain amplitude
- Miner's rule[2]
  - Damage from strain cycles are independent
  - Order of strain cycles does not matter



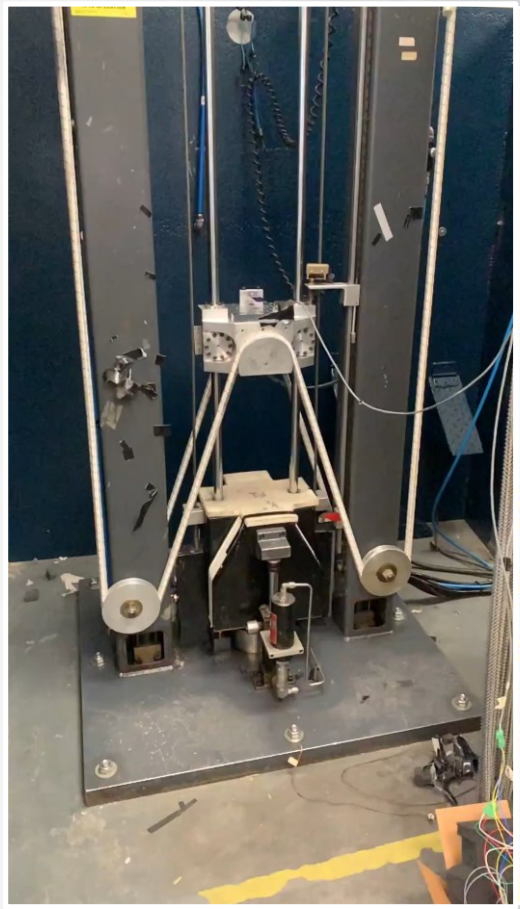
Example strain-life curve

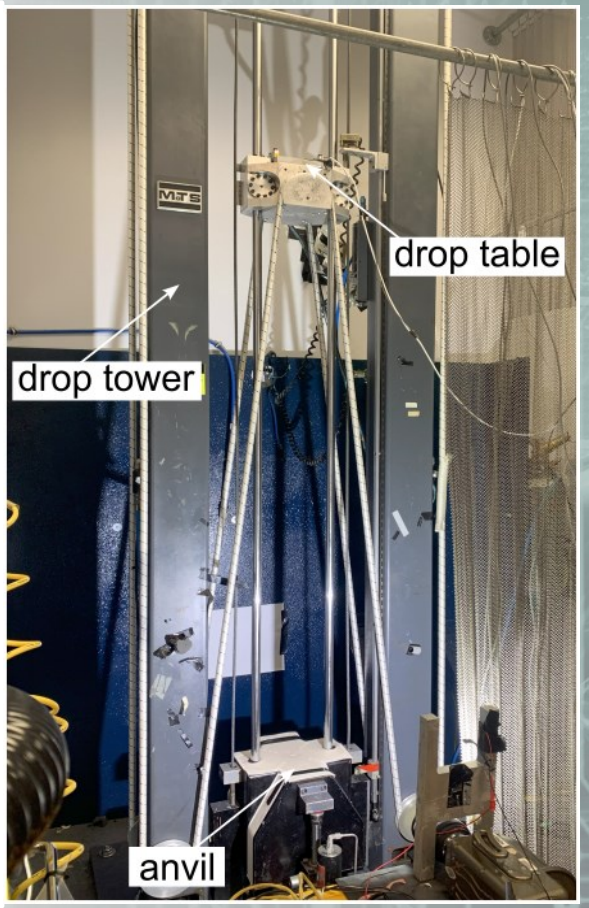
Methodology



Experimental Approach

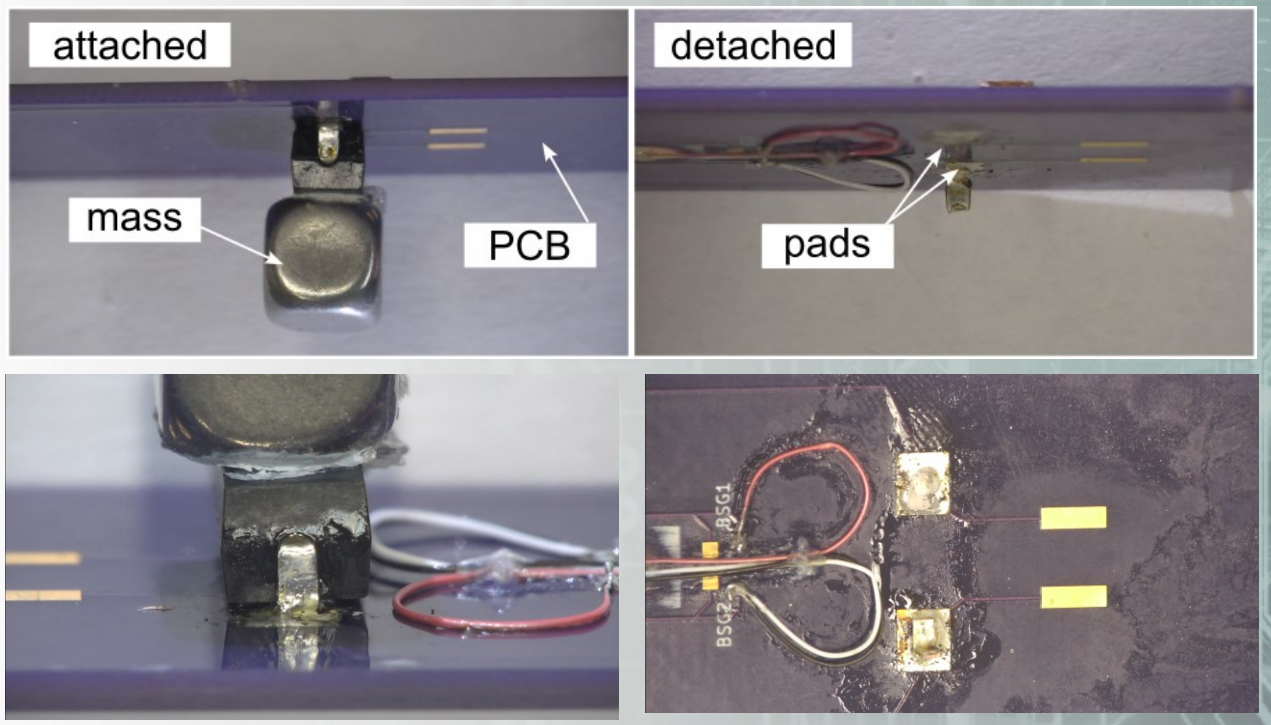
- Drop tower (simulates high-rate impacts)
- Cantilever printed circuit board with sensors
- Resistor/mass component meant to exaggerate the change in dynamics
- Several impacts at varying heights
- Intended to fail the resistor/mass and measure the differences in the response





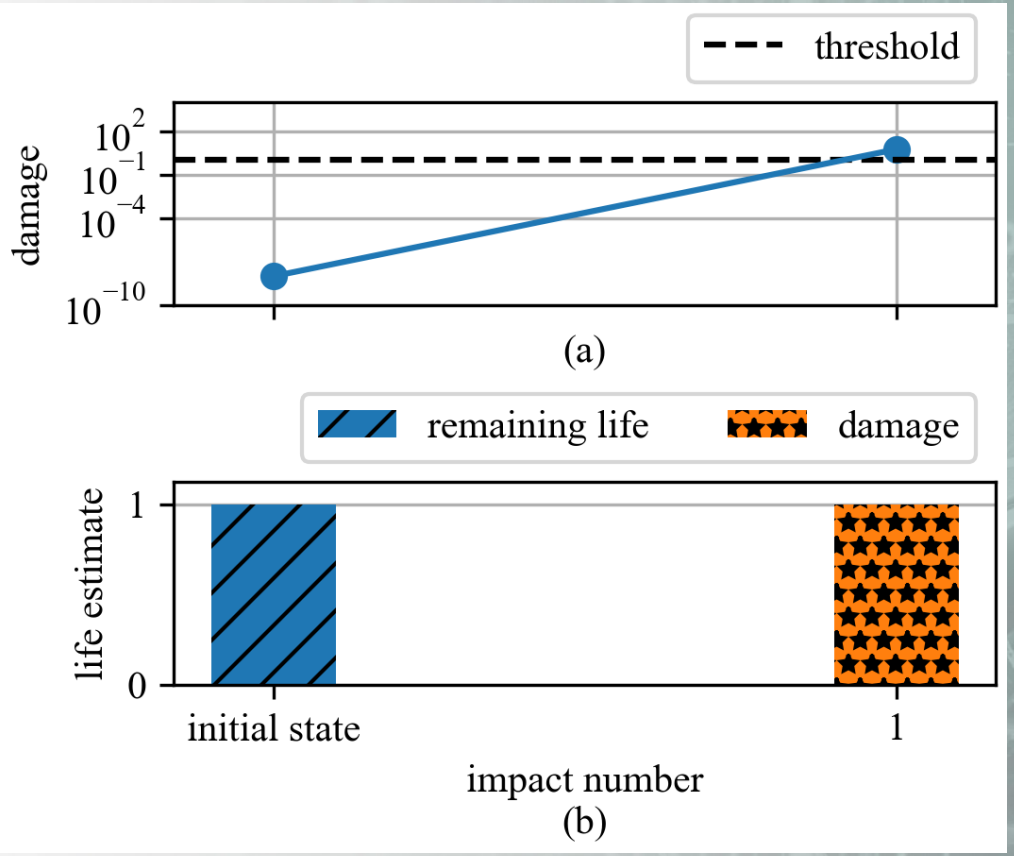
Experimental Approach

- Close-up of PCB and resistor
- Measured voltage for duration of impact
- If voltage was 0
  - device failed
  - replace resistor
- Otherwise
  - inflict another impact
- Impact set: impacts until device failure



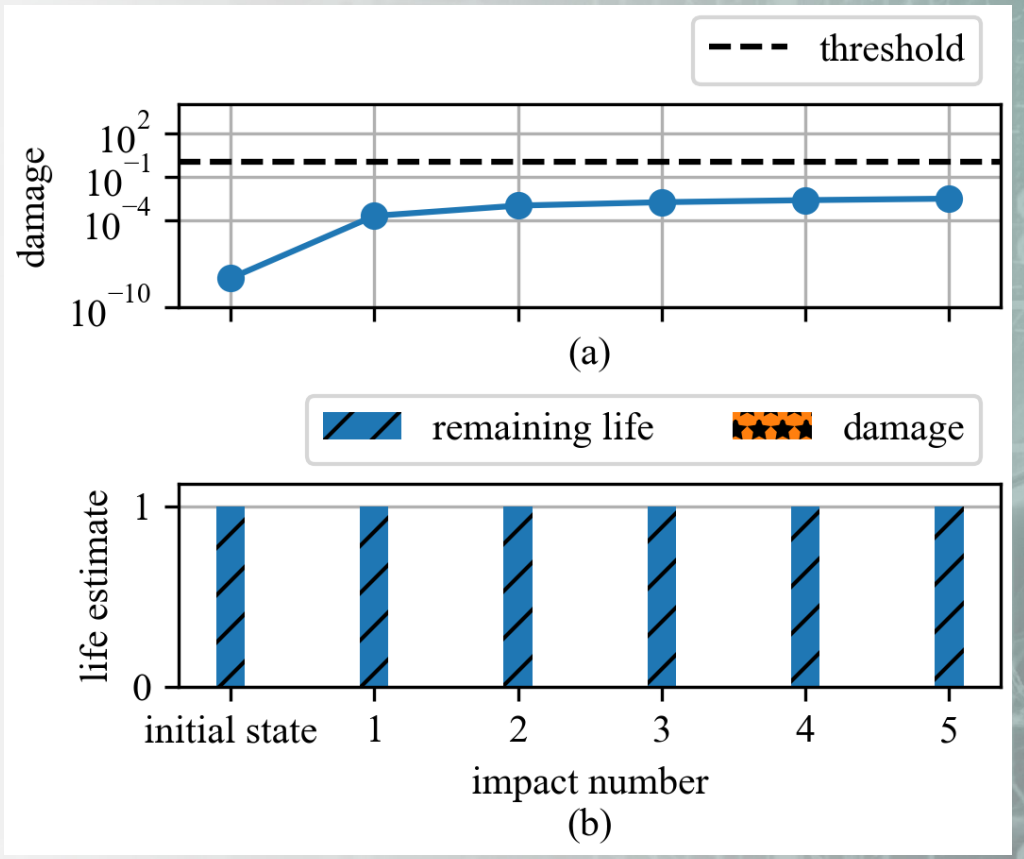
Results - Set 1

- First impact set
  - Failed after one impact
  - Damage estimate changed 0->100%



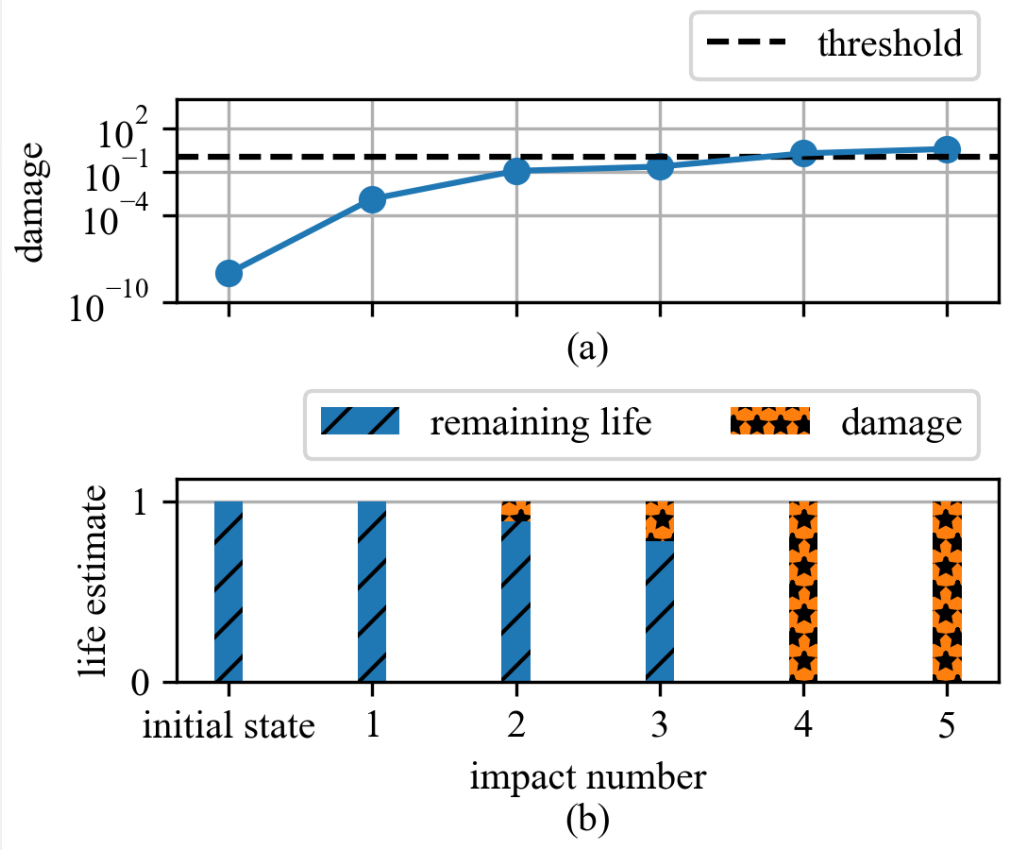
Results - Set 2

- Second impact set
  - Failed after five impacts
  - Damage estimate remained near 0%
  - Why?
  - Failure occurred at solder-pad interface
  - Our prediction is for solder failure



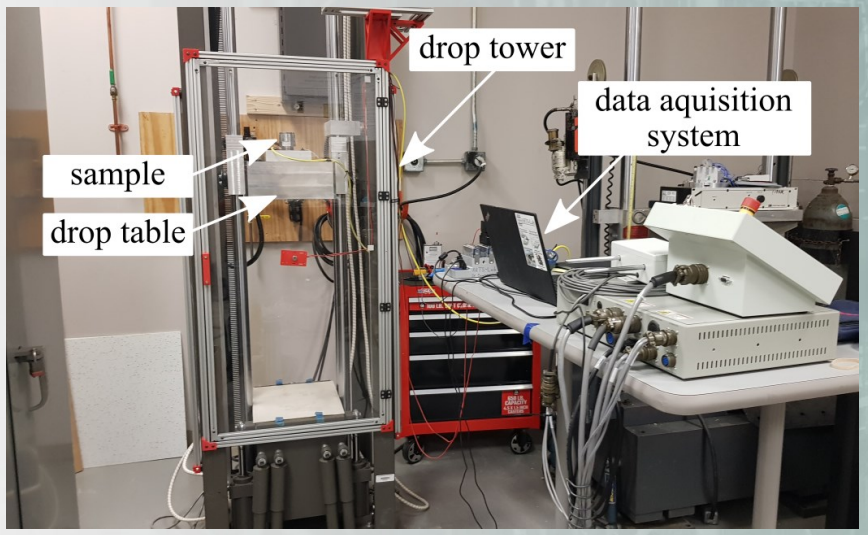
Results - Set 3

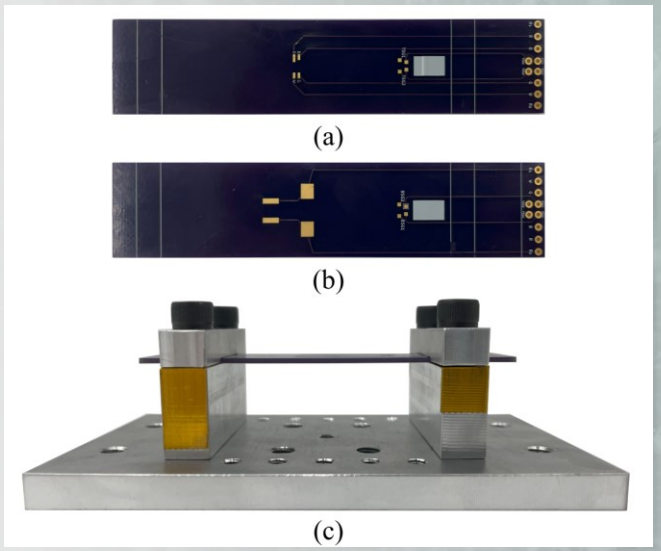
- Third impact set
  - Failed after five impacts
  - Damage estimate changed 0->100%
  - Survived one more impact than expected



Conclusions and Future Work

- Algorithm for predicting remaining useful life in solder joints
- Future work
  - Incorporating fatigue from creep[3]
  - Verifying algorithm predictions
  - Generating with varying structural configurations





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Thanks!

Open-source Data Set

https://github.com/High-Rate-SHM-Working-Group/Dataset-9-repeated-impact-testing-of-rectangular-electronic-assembly [4]

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