# Investigation of Surface Roughness Effects on Additively Manufactured Metals Under Dynamic Loading


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# Background

## *Fatigue Performance in AM*

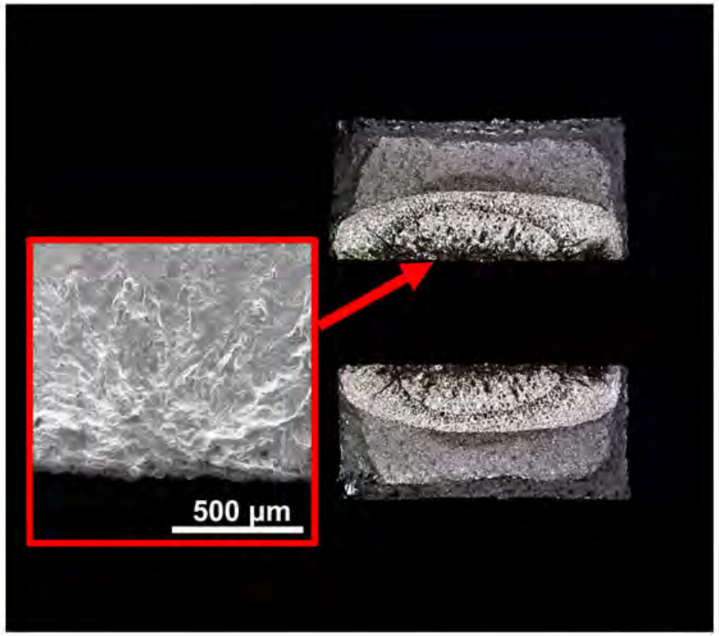
- Additively manufactured (AM) parts often exhibit undesirable fatigue properties
  - Material discontinuities (porosity and surface roughness) act as crack initiation locations and decrease fatigue life
- Surface roughness has been shown to be the **predominant mechanism behind fatigue failure** in as-printed (unmachined) AM parts *[Gretemeier et al., 2016; Gockel et al., 2019]*
  - Surface finishing is not always feasible for complex internal geometries

## *Effects of Cross-Sectional Shape on Fatigue*

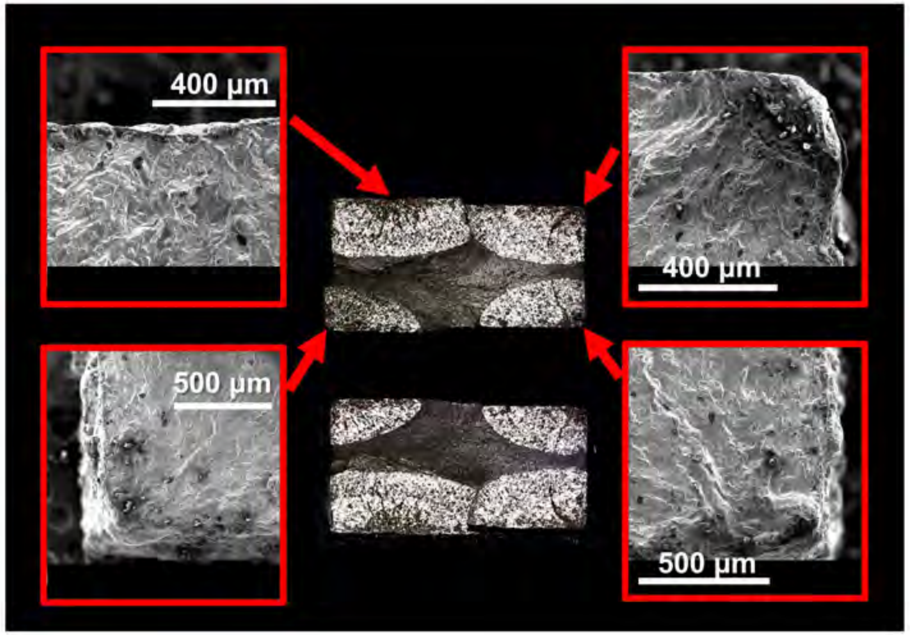
- Early results indicate that geometries containing corners (squares, diamonds) **can exhibit up to a 10% decrease in fatigue life** compared to circular cross-sections *[Dolan et al., 1950]*
- Specimens containing corner flaws have **higher crack propagation rates and SIFs** as compared to embedded surface flaws *[Toribio et al., 2017]*
- Polished AM specimens with a **rectangular hourglass shape tend to fail at the corners** of the cross-section, even when other stress concentrators are introduced to the geometry *[Tullis, 2023; Eidt, 2020]*

# Motivation

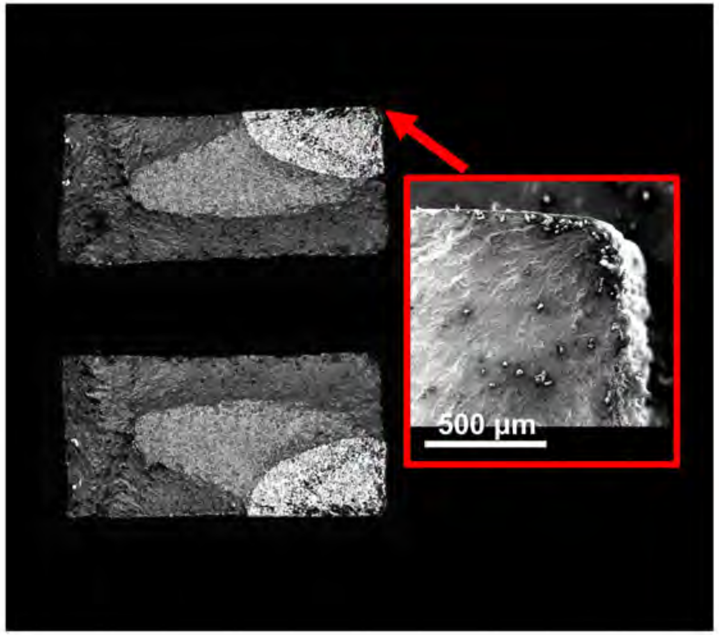
- Three failure behaviors seen in prior fatigue study [Tullis et al., 2023]
- Fatigue failures **tend to initiate on corners** in rectangular specimens
  - For similarly-sized flaws, the stress intensity factor is much higher at corner locations
  - ***Varying the cross-sectional geometry is expected to influence fatigue due to changes in corners***




Face Initiation




Multiple Cracks




Corner Initiation

*>75% of failures*

# Methods

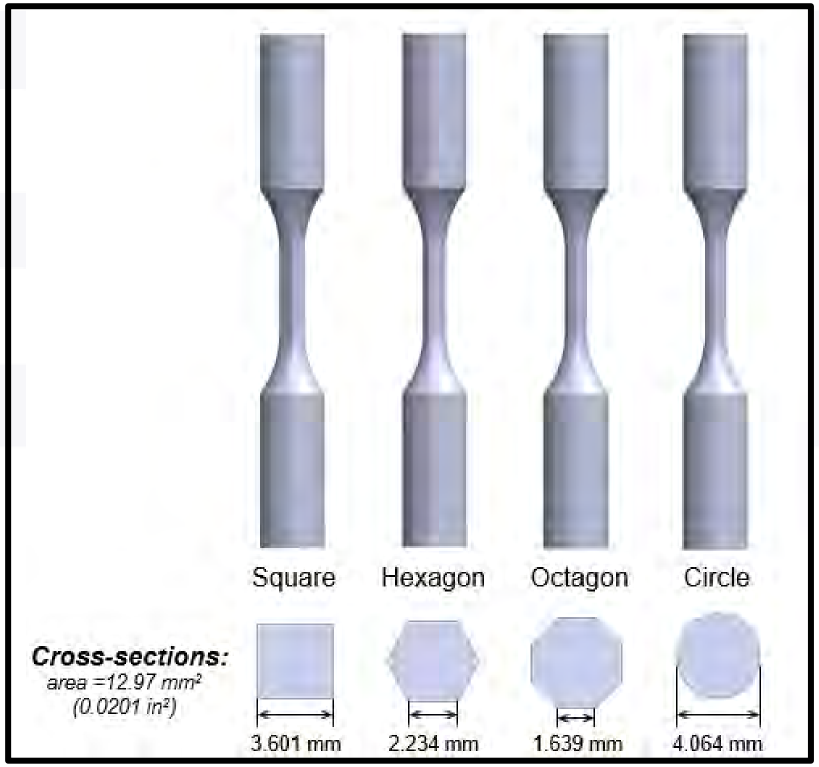
### *Specimen Geometry*

- Four specimen sets with variable cross-sectional shapes throughout the gage section
  - Square (Four 90° corners)
  - Hexagon (Six 120° corners)
  - Octagon (Eight 135° corners)
  - Circle (No corners; baseline)
- Cross-sectional areas are constant, regardless of shape

### *AM Builds*

- 40 alloy 718 specimens printed vertically on Open Additive PANDA printer
  - 10 replicates of each geometry
  - 2 separate builds
  - Constant parameters throughout
- Stress relieved and precipitation heat treated in accordance with current standards for AM alloy 718 *[ASTM F3055; AMS 5662]*

| | Bulk | Contour |
|---|---|---|
| Laser Power (W) | 230 | 150 |
| Scan Speed (mm/s) | 800 | 560 |
| Hatch Spacing (µm) | 70 | N/A |
| Layer Thickness (µm) | 30 | |



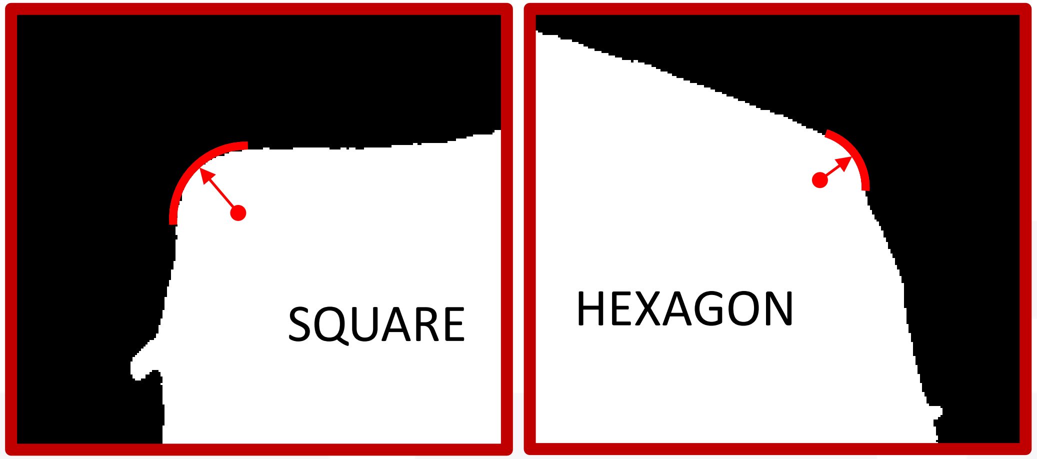
# Methods

## *Surface Characterization*

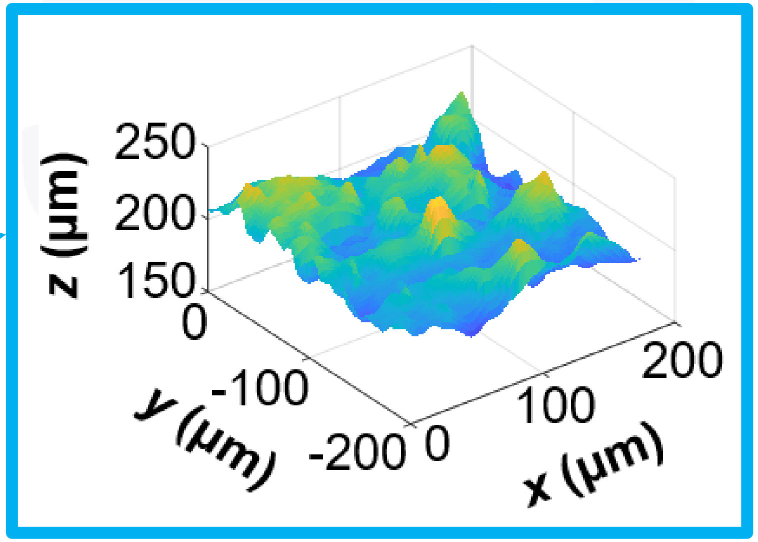
- Area measurements are used rather than line measurements *[ISO 25178-2:2021]*
  - Height data obtained from a large surface area on the specimen
  - Captures more of the surface data

- **Computed Tomography (CT) Scans**
  - Used to quantify the printer accuracy (corner radius) and analyze porosity
  - *Initial results:* More acute corners have larger radius due to manufacturing
  - *Future work:* Obtain porosity distributions and more comprehensive 3D surface roughness data, and evaluate crack initiation sites post-fracture

- **Structured Light (SL) Scans**
  - Allows for calculation of standardized surface metrics
    - Average roughness (Sa) and maximum valley depth (Sv)



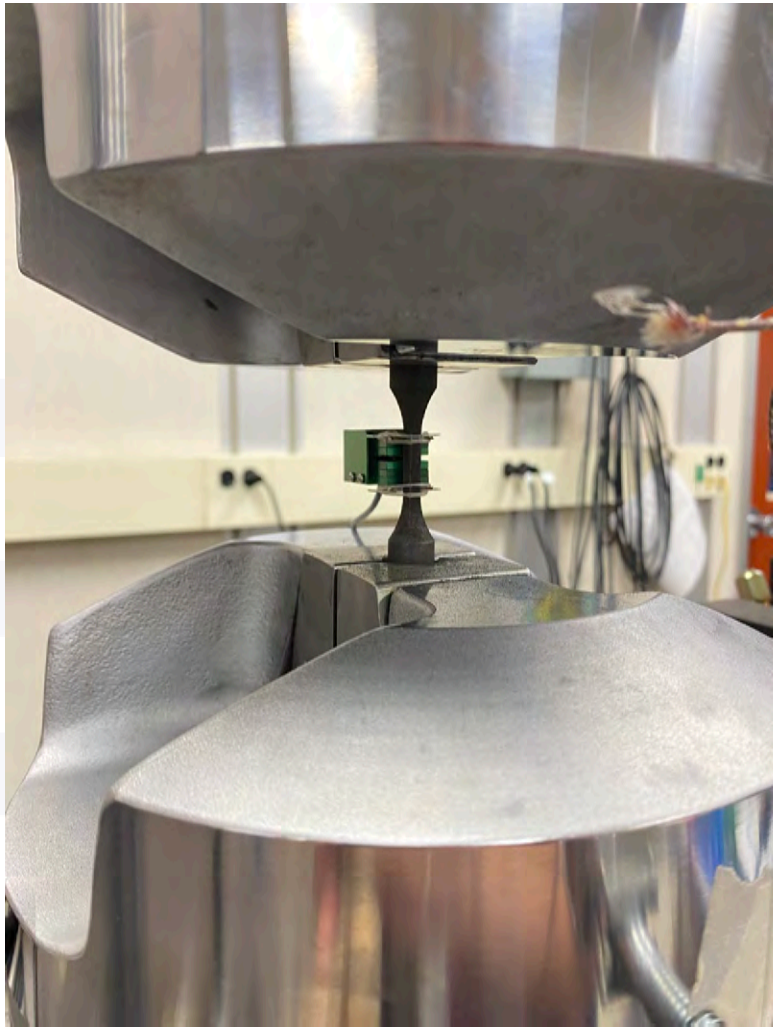




# Methods

***Fatigue Tests***

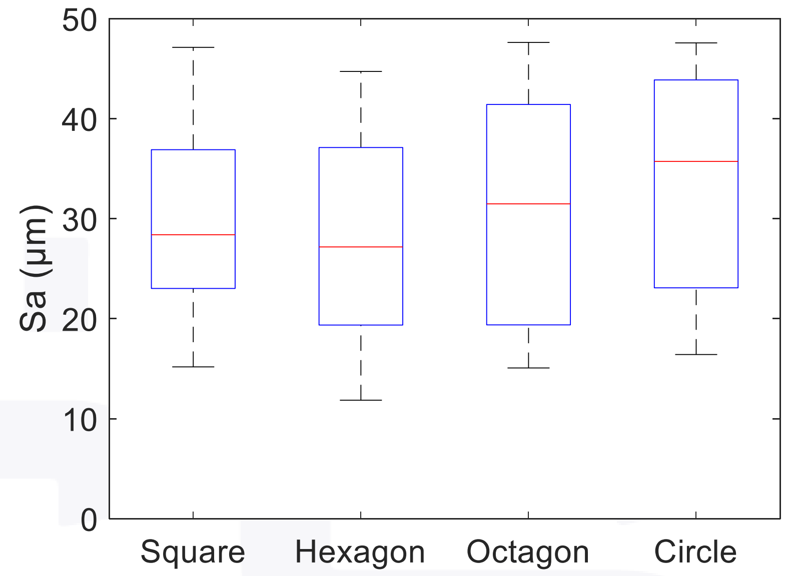
- Fatigue testing performed on an MTS servo-hydraulic load frame at the AFRL Turbine Engine Fatigue Facility (TEFF)
  - Load ratio, R = 0.1
  - Frequency = 20 Hz
  - Four stress levels (100 ksi, 80 ksi, 70 ksi, and 60 ksi)
- Specimens tested to failure
- Compliance monitored to determine initiation and growth lives

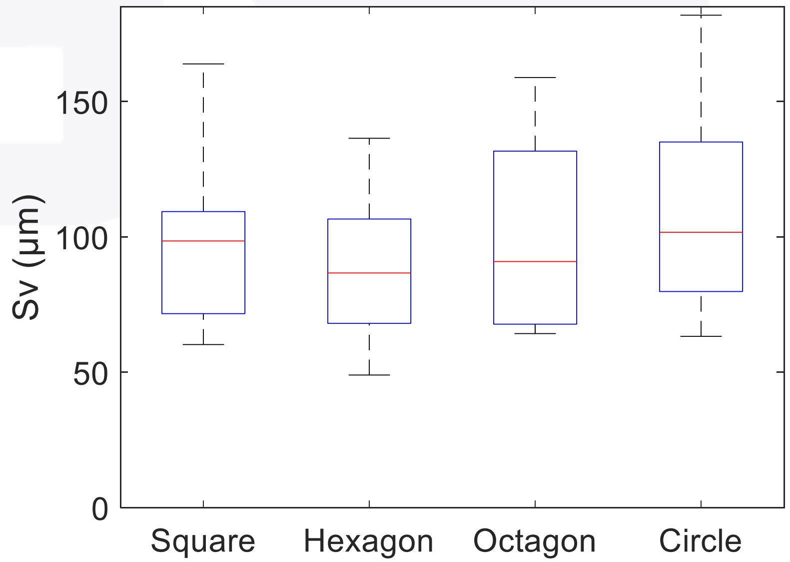


# Results

***Surface Roughness Characterization***

- Surface metrics calculated using data from SL surface scans
  - Boxplots indicate Sa and Sv for each of the geometries
- Specimen geometry does not appear to significantly affect surface roughness
  - This is expected due to the constant AM processing parameters
- Wide spread of data

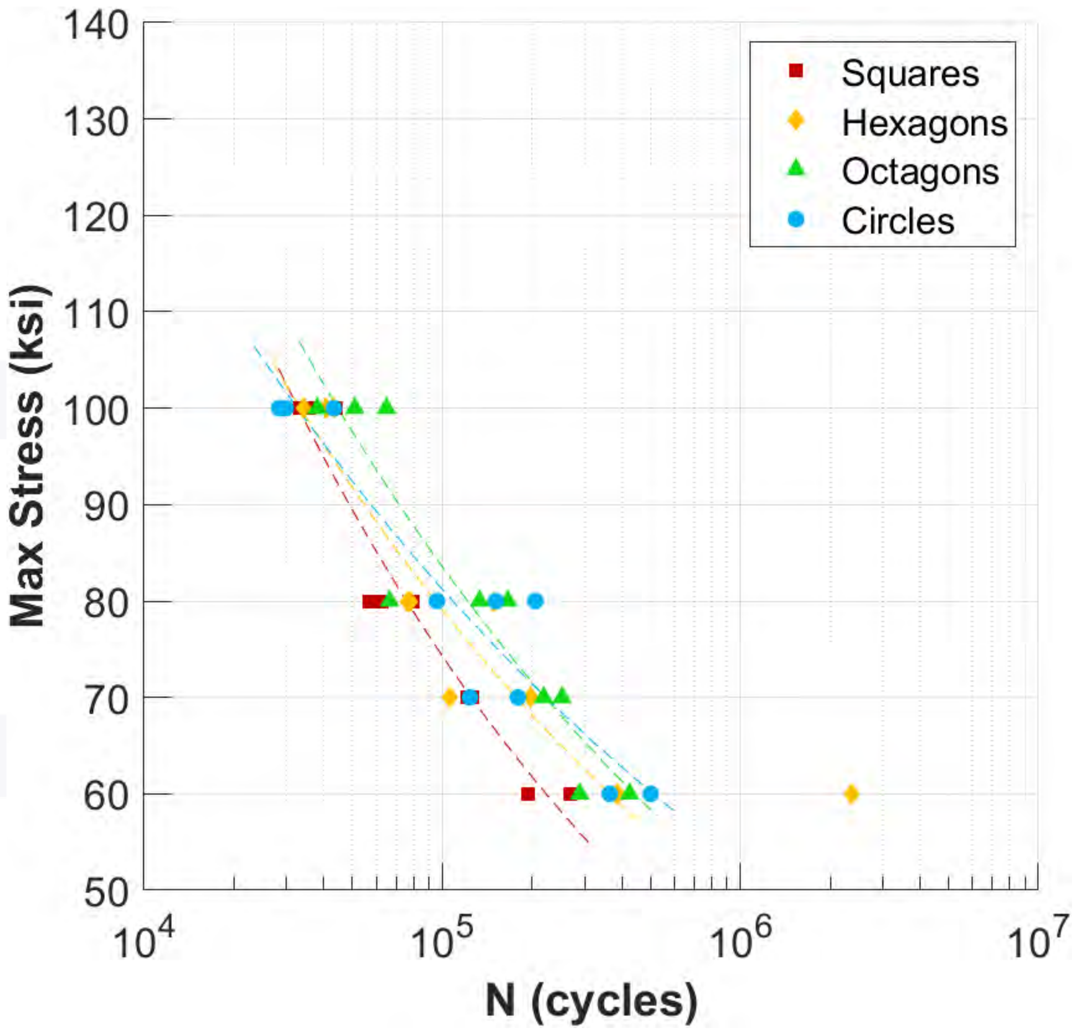


# Results

### *Total Fatigue Life*

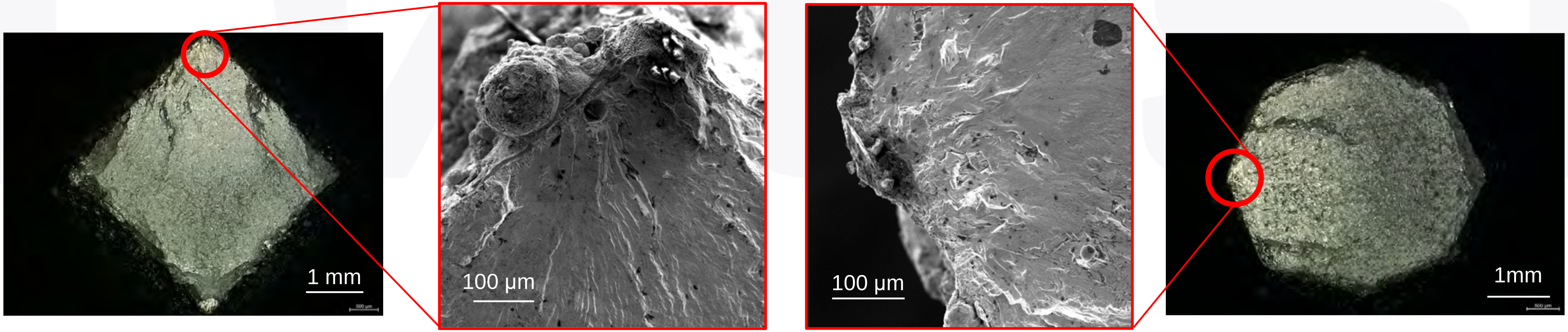
- 4 completed stress levels: 100, 80, 70, and 60 ksi (689, 552, 483, and 414 MPa)
- Cross-sectional geometry appears to slightly affect fatigue performance
  - Slope of trendlines appear to vary due to cross-sectional geometry
  - Weak trend: Sharper corners → lower life
- A more detailed analysis is expected to further explain and collapse the data
  - Compliance analysis can separate initiation and growth life components
  - SIF (rather than stress alone) is expected to affect fatigue life



# Results

## *Fractography*

- Optical microscopy and scanning electron microscopy (SEM) are used to determine crack origins
- Most samples appear to initiate cracks near the specimen corners
  - For similarly-sized flaws, the stress intensity factor is much higher at corner locations



# Conclusions

- Specimen geometry was not shown to significantly influence surface roughness
  - Large amount of scatter in data
- Cross sectional geometry appears to slightly affect fatigue life
  - Slope of trendline (stress sensitivity) appears to be affected by cross-sectional geometry
  - SIFs, rather than stress alone, are expected to have stronger relationships
  - Compliance analysis and determination of initiation life may also provide further explanations
- Many specimens appeared to initiate cracks near the corners
- *Future work:*
  - Further utilize CT scans to evaluate crack initiation sites
  - Analyze SIFs for further explanation of data