REPLICA-BASED CRACK INSPECTION

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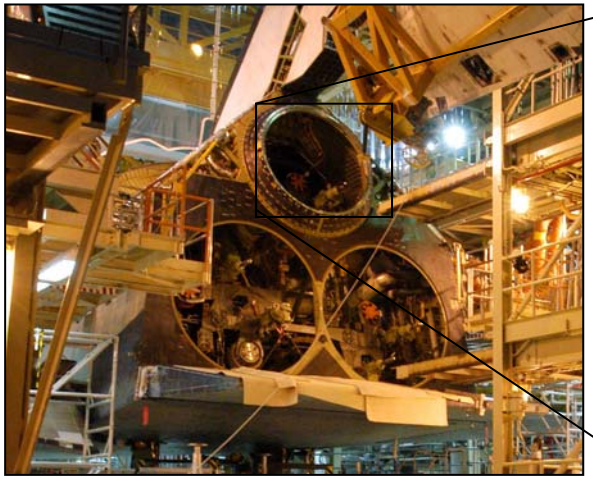
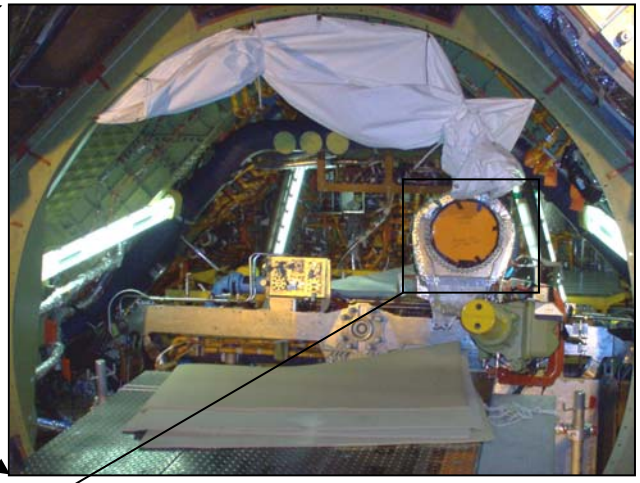
INTRODUCTION

- **Cracks found in Space Shuttle Main Engine LH_2 feedline flowliners (2002)**
  - **Ranged from 0.1 inch to 0.6 inch long**
  - **Weld repaired, polished, and recertified for flight**
  - **NDE: no cracks >0.075 inches long exist**
- **Revisited in 2004**
  - **Unable to show flight rationale with a crack 0.075 inches long**

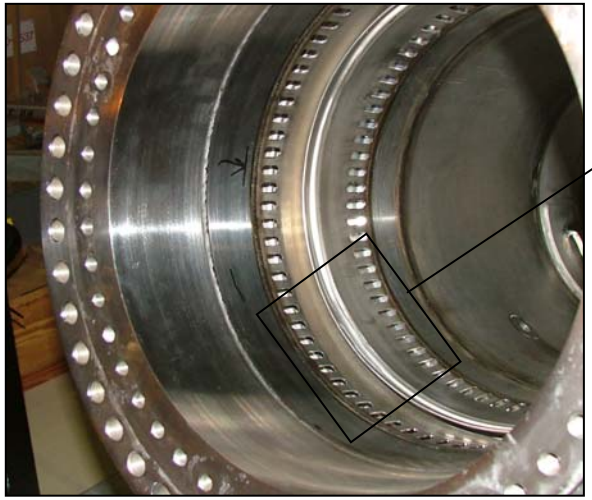
FLOWLINER DESCRIPTION



Orbiter aft



Engine cavity

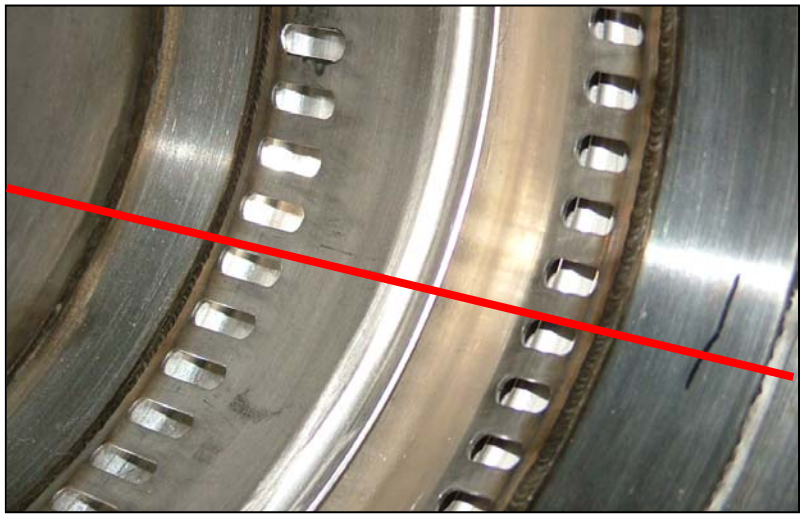


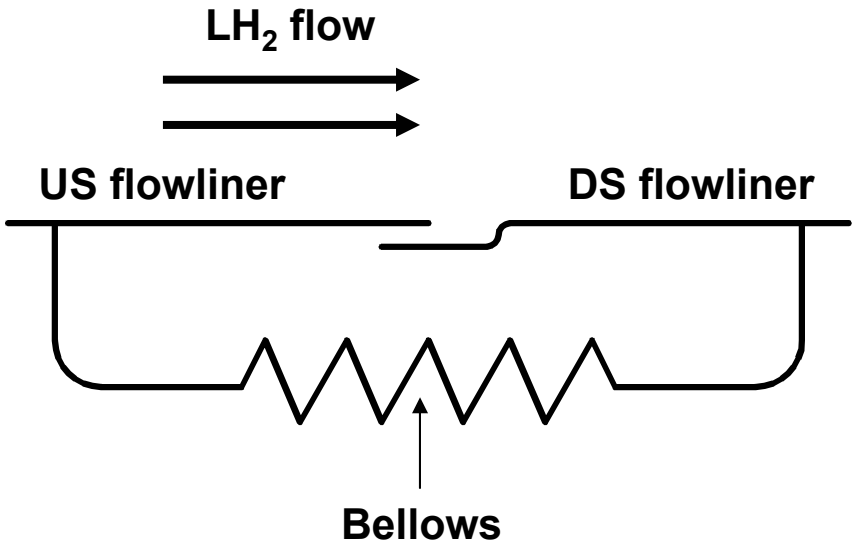
LH_2 feedline

Flowliners

FLOWLINER DESCRIPTION

- LH_2 consumption
  - 385,000 gallons
  - 8.5 minutes
  - Each engine consumes 15,000 gal/min
  - Flow induced stress cycles in kHz range
  - Millions of stress cycles per flight



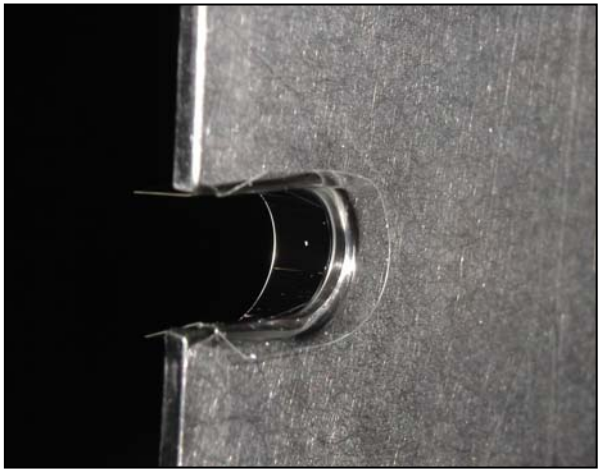


PROBLEM

- **Analysis: unsafe conditions may occur for multiple cracks > 0.005 inch long**
- **Improved eddy current unable to detect 0.005-inch-long cracks**
- **Need an NDE method able to find cracks down to 0.005 inch long**

PROPOSED SOLUTION

- Use surface replicas as an NDE method
- Surface replicas used for decades to monitor small cracks (<0.005 inch)
- Recently-developed silicone-based replicas better suited for inspection



Acetate tape replica

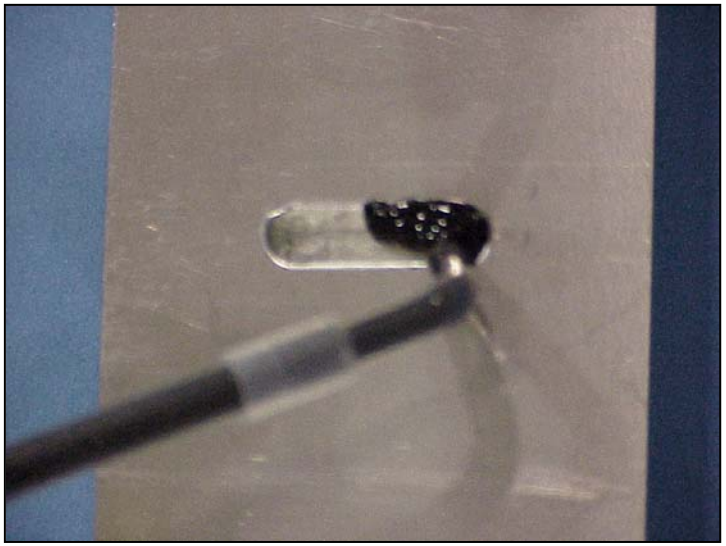
Silicone-based replica dispenser

EXPERIMENTAL PLAN

- **Feasibility study:**
  - **Generate fatigue cracks in laboratory specimens**
  - **Compare crack lengths from**
    - **Silicone-based replicas (zero load)**
    - **Acetate-tape replicas (maximum load)**
    - **Destructive exam (zero load)**
- **Determine reliability of silicone-based replicas relative to acetate-tape replicas**

FATIGUE TESTING

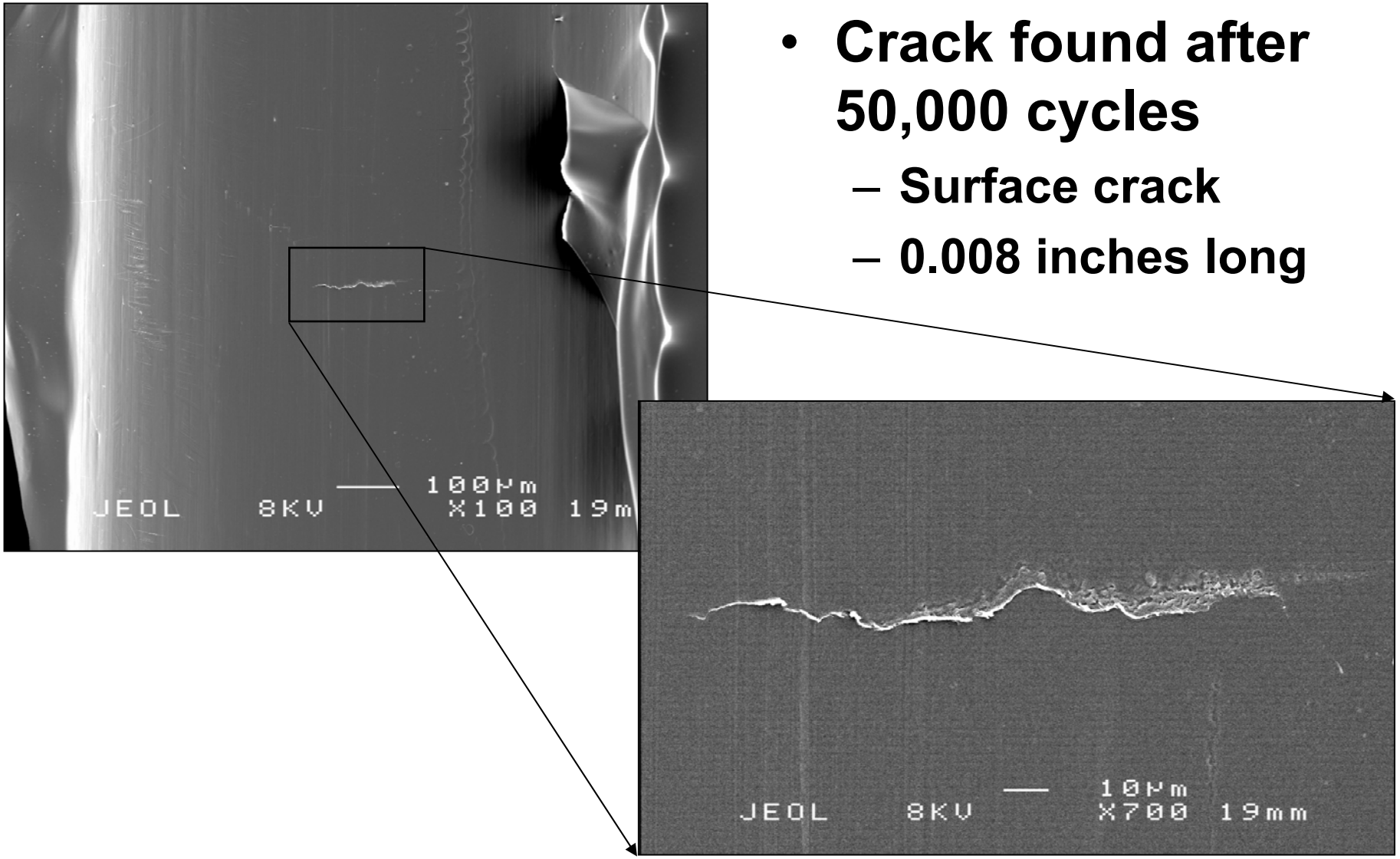
- Specimens used to simulate flowliner slot geometry and stress state
  - Pmax = 3.4 kips, R = 0.1
- Testing interrupted periodically for slot surface replication
  - Acetate-tape replicas
  - Silicone-based replicas



REPLICA ANALYSIS

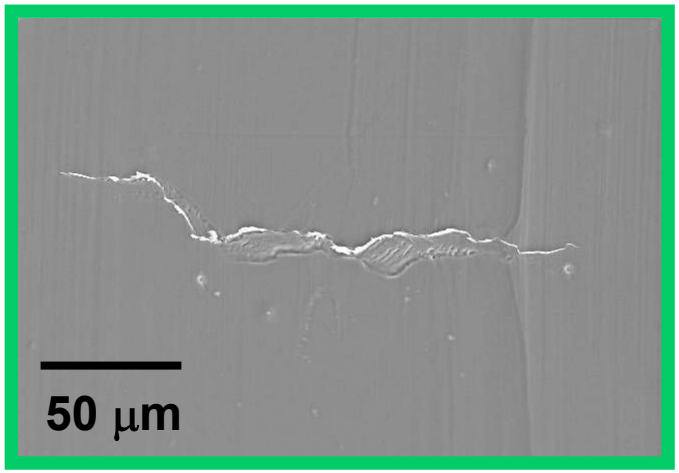
- Replica preparation
  - Sectioned in 4 pieces
  - Grounded on metallic slide
  - Coated with metallic material
- Examined in an SEM
- Initial scan at 50-100X
  - Surface finish, scratches, etc.
- Crack scan at 400-700X

EXPERIMENTAL RESULTS

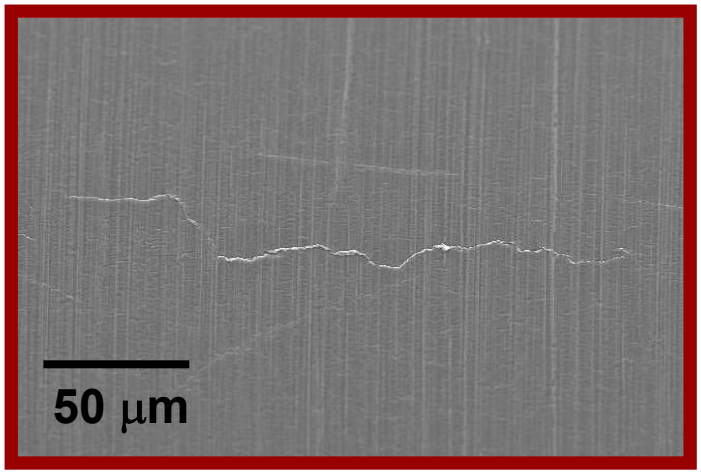


- **Crack found after 50,000 cycles**
  - **Surface crack**
  - **0.008 inches long**

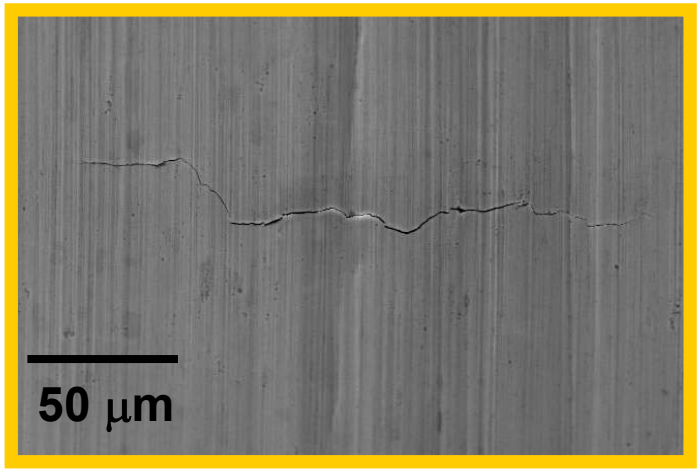
CRACK LENGTH COMPARISON



Acetate replica (loaded) – 163 μm

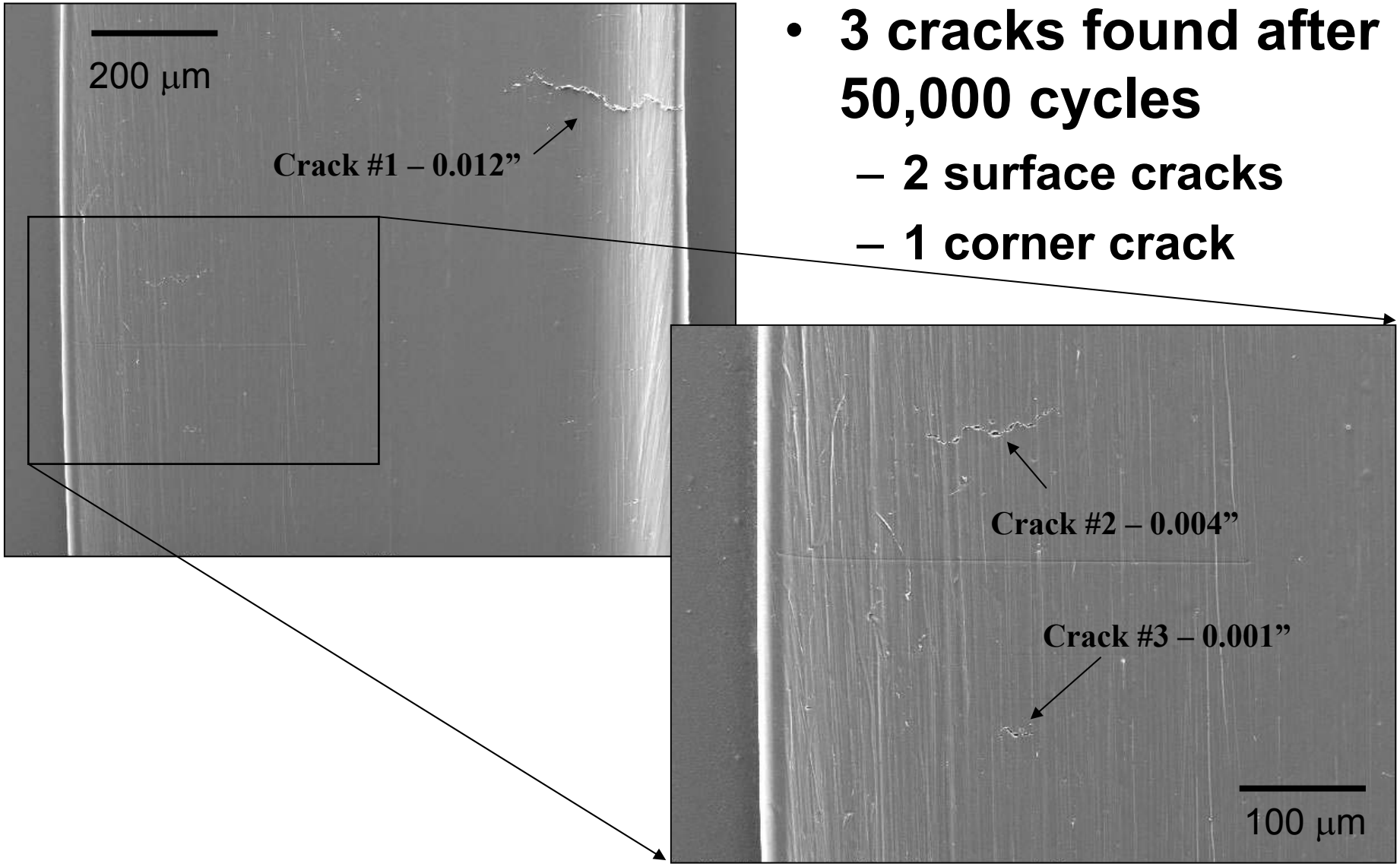


Silicone replica (no load) – 199 μm



Specimen (no load) – 194 μm

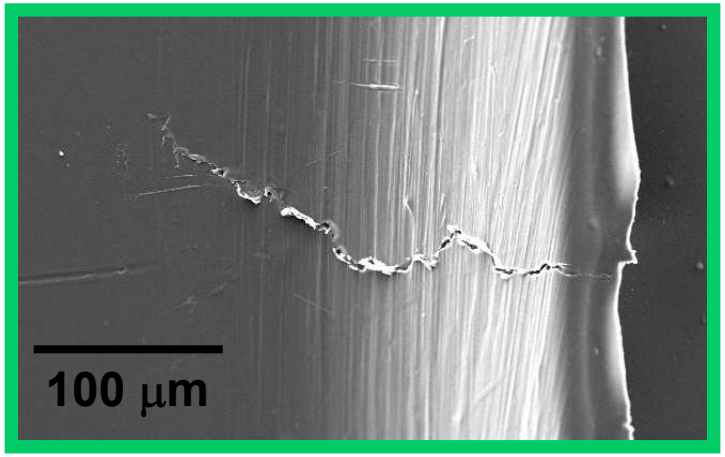
EXPERIMENTAL RESULTS



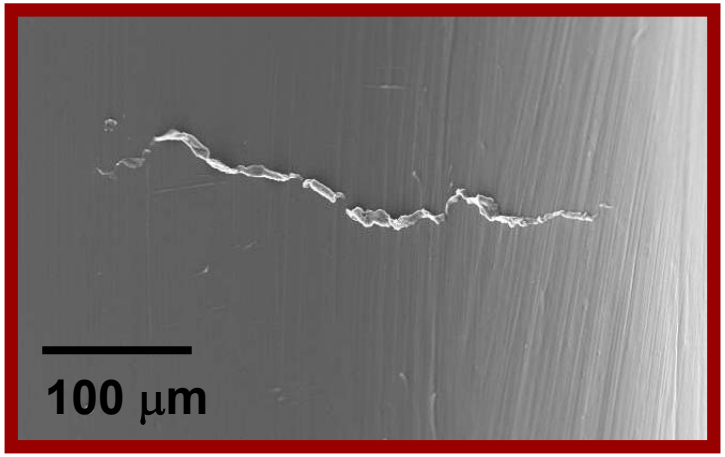
- 3 cracks found after 50,000 cycles
  - 2 surface cracks
  - 1 corner crack

CRACK LENGTH COMPARISON

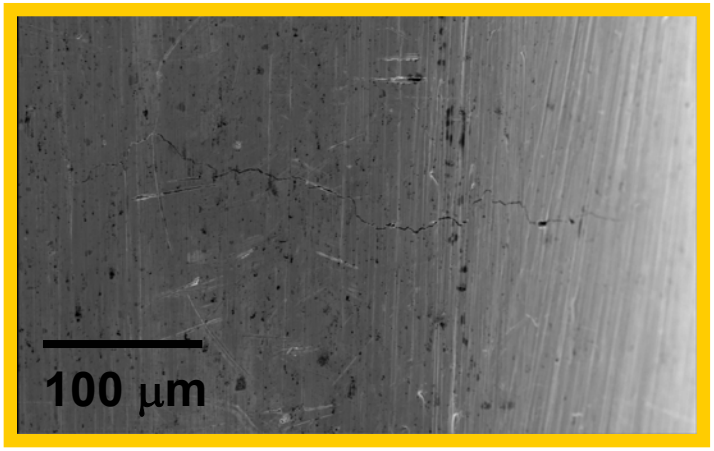
(Crack #1)



Acetate replica (loaded) – 280 μm



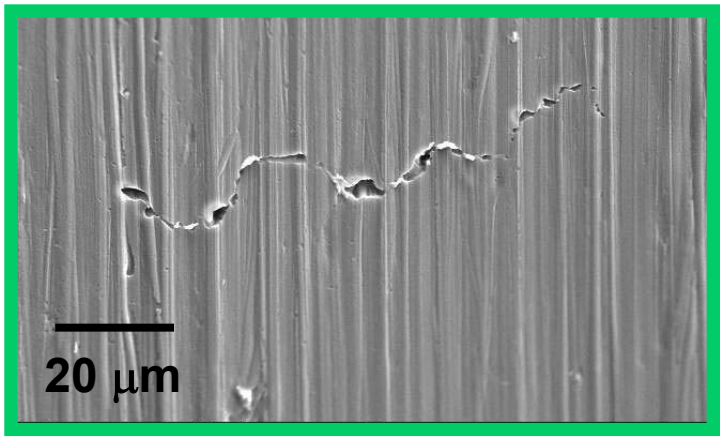
Silicone replica (no load) – 343 μm



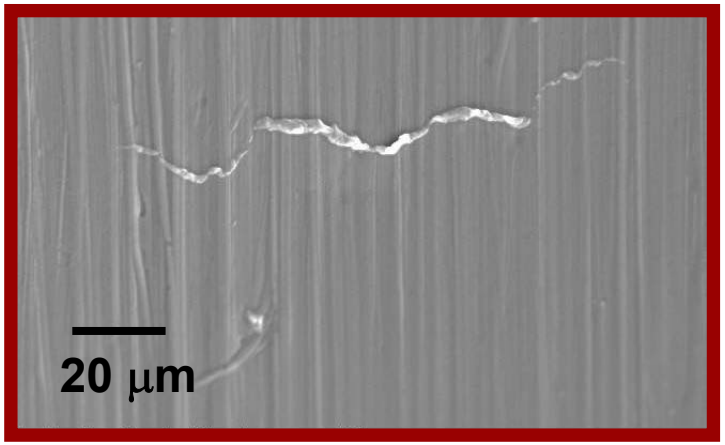
Specimen (no load) – 350 μm

CRACK LENGTH COMPARISON

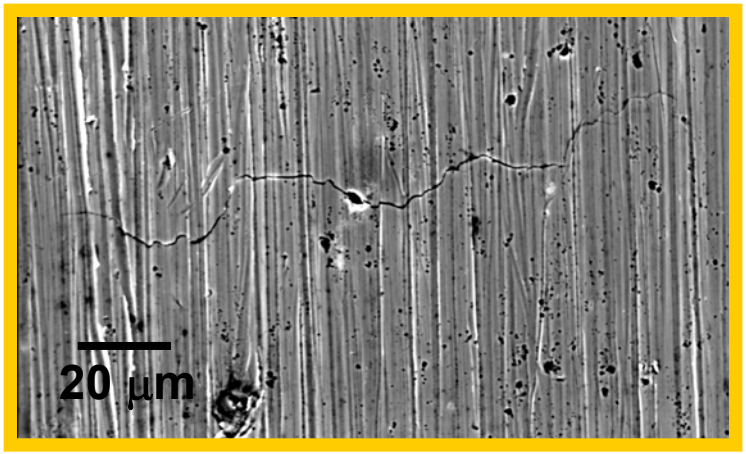
(Crack #2)



Acetate replica (loaded) – 81 μm



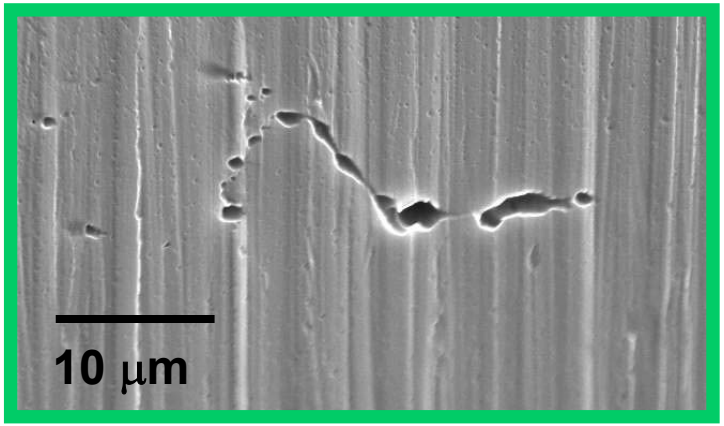
Silicone replica (no load) – 104 μm



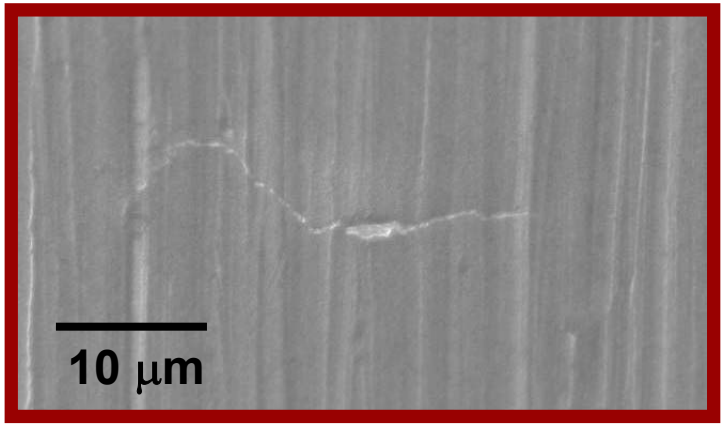
Specimen (no load) – 110 μm

CRACK LENGTH COMPARISON

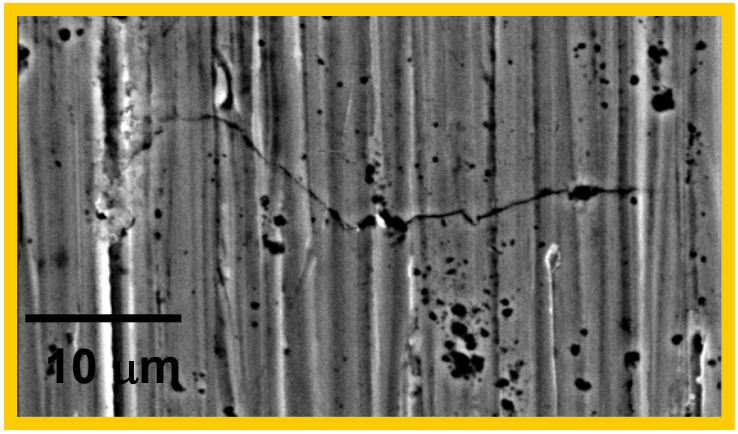
(Crack #3)



Acetate replica (loaded) – 20 μm



Silicone replica (no load) – 26 μm



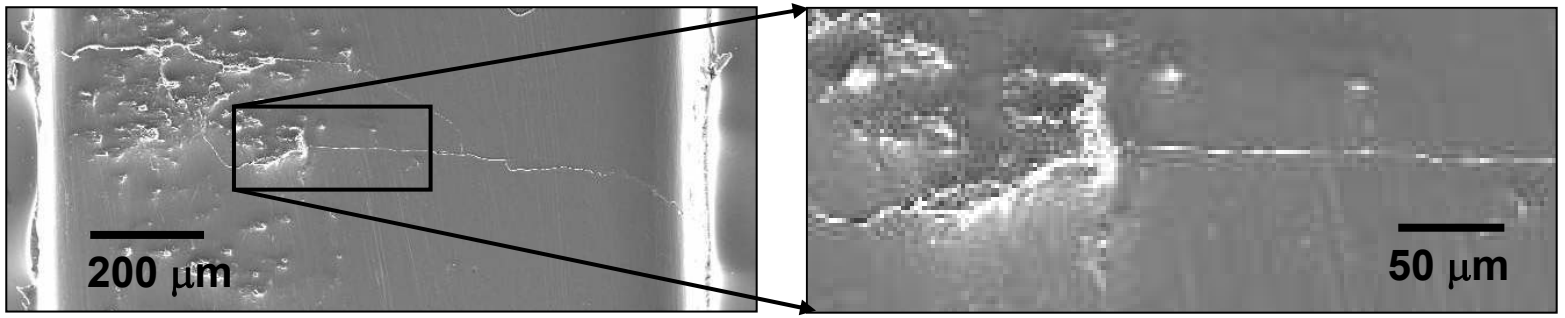
Specimen (no load) – 27 μm

CRACK DETECTION AFTER POLISHING

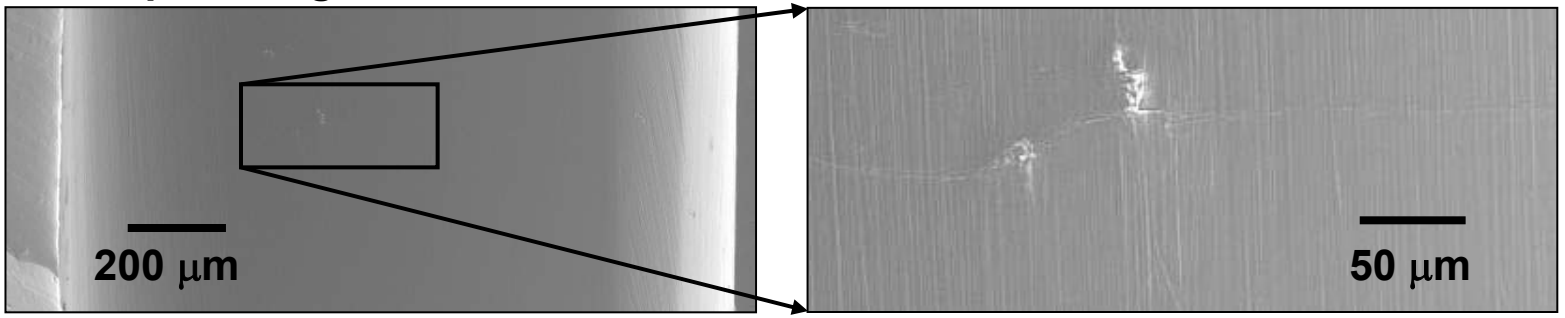
- Flowliner slots were polished after cracks detected in 2002
- One orbiter has not flown since flowliner slot polishing
- Concern about post-polishing crack detection
  - Crack mouth potentially filled with material

POLISHED CRACK DETECTION

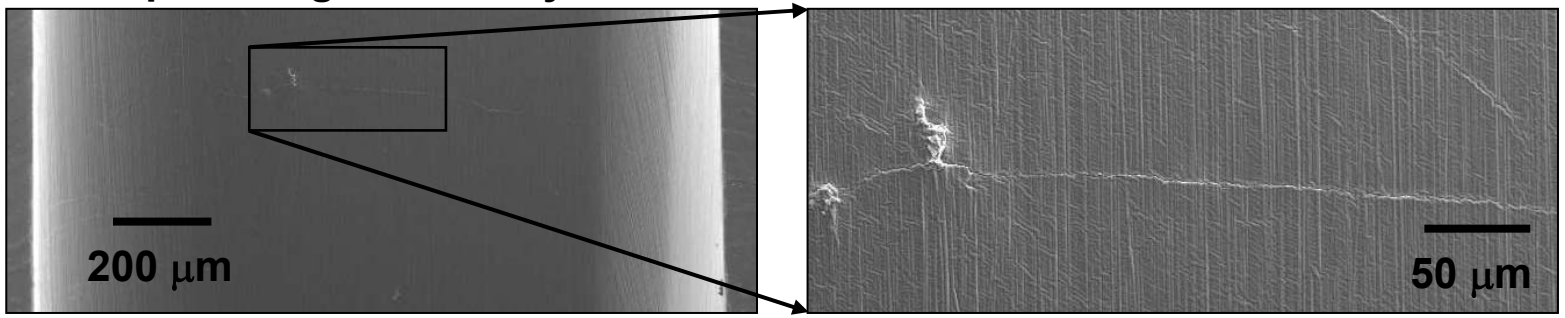
Initial crack



After polishing

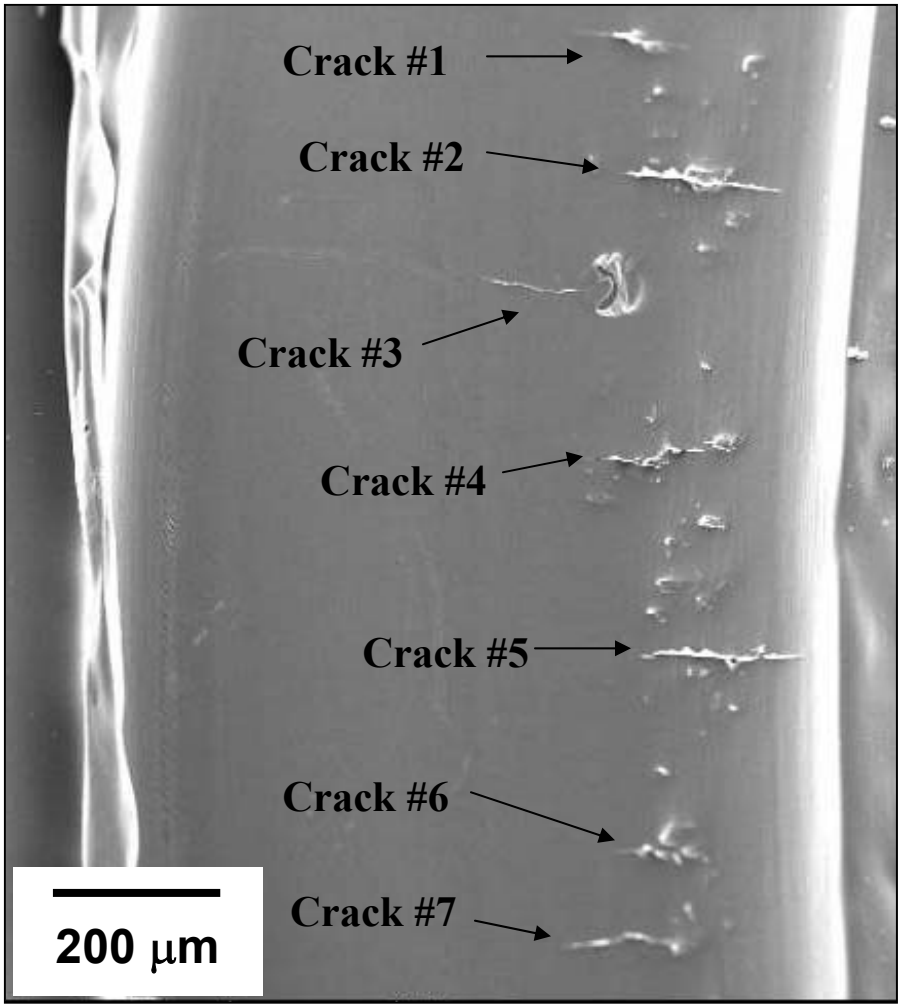


After polishing + 1 load cycle

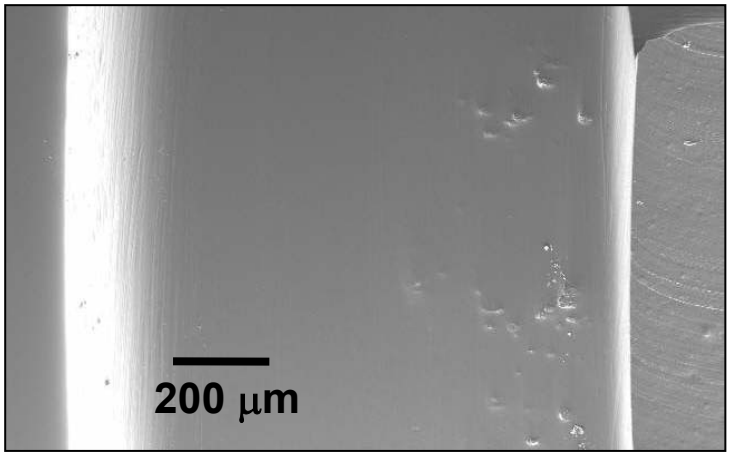


SURFACE FINISH QUALITY

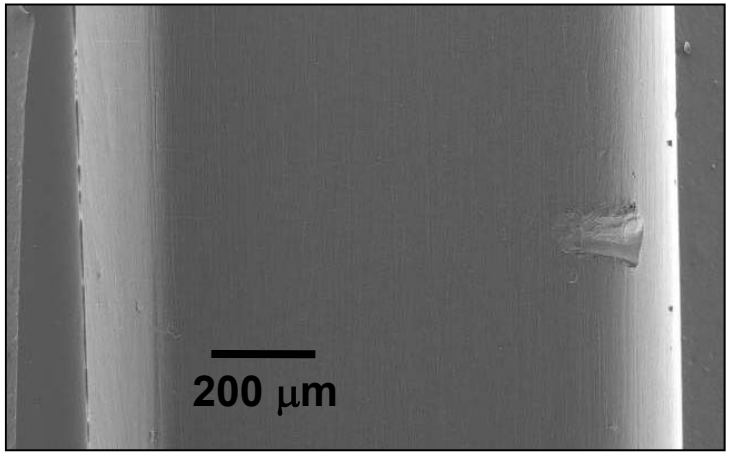
- Pit-like damage from punching not completely removed by polishing
- At least 7 fatigue cracks initiated by 50,000 cycles
- Quality of surface finish is important



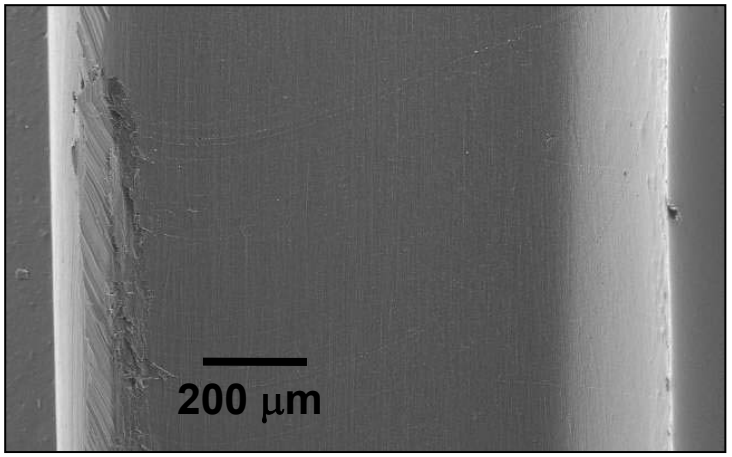
OTHER TYPES OF DAMAGE



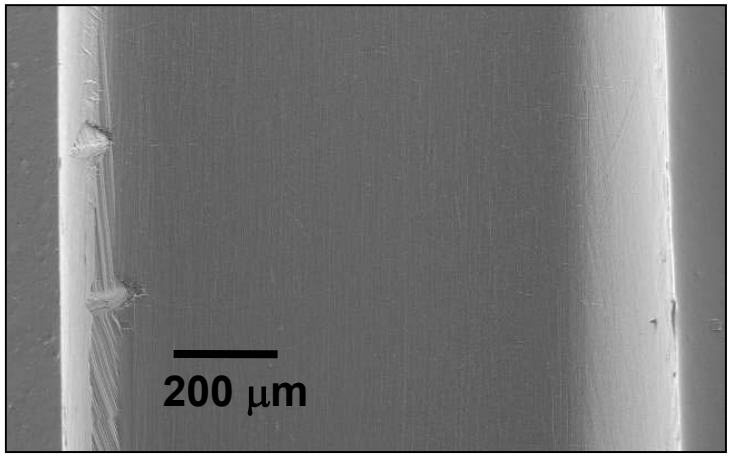
Pit damage



Tool mark



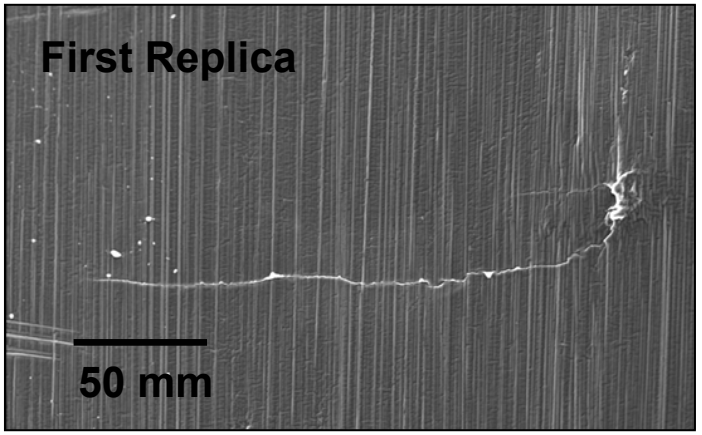
Abrasion and scratches

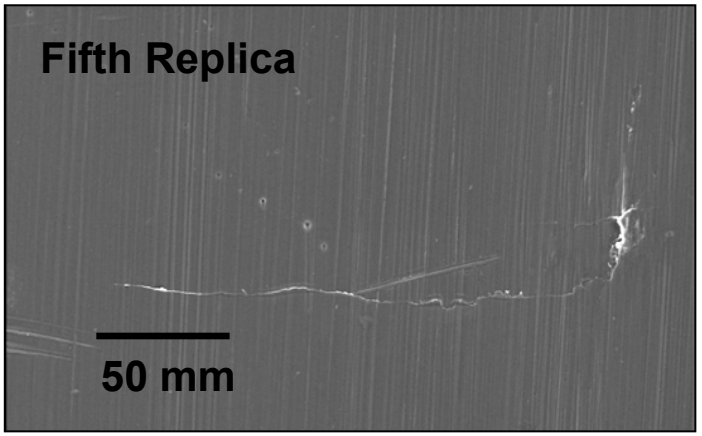


Tool marks/dents

REPRODUCIBILITY

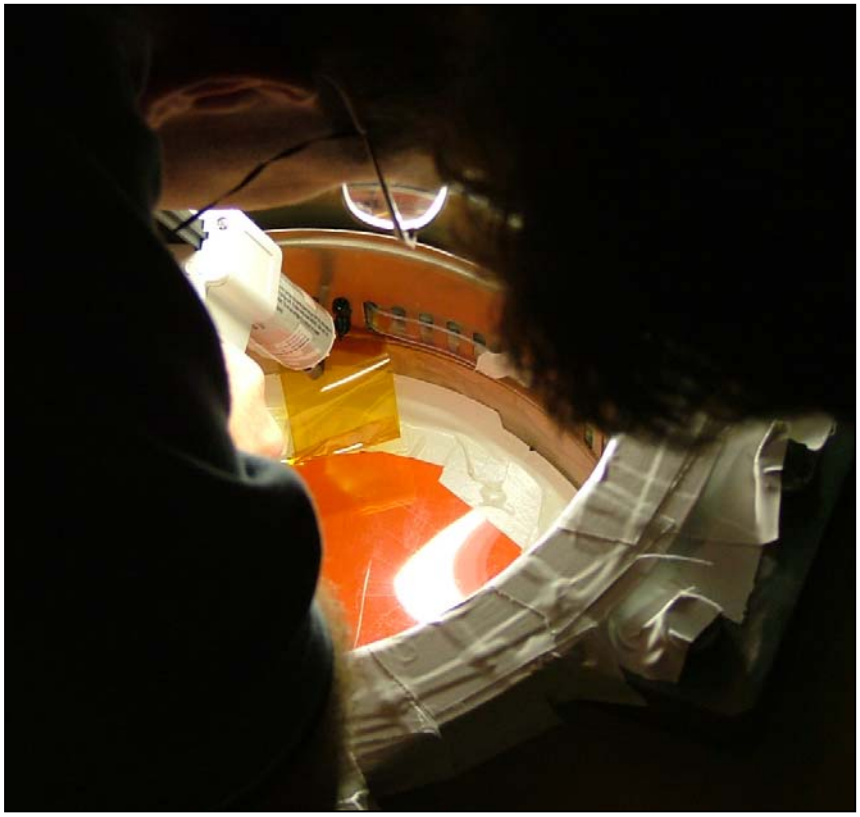
- Concern: Repeated replication may fill crack mouth
- Repeated replicas taken on several cracked specimens
  - Example: 0.006-inch-long surface crack
- No degradation in crack detection





APPLICATION

- Replica-based inspection method approved for use on flight hardware
- Found 55 cracks in 3 orbiters
  - Ranging from 0.004 to 0.040 inches
- Confirmed repair by second round of replicas



OTHER APPLICATIONS

- **Replica-based crack inspection may be well-suited for other applications**
  - **Improved crack detection could make damage tolerance life management practical for additional components**
    - **Rotorcraft ?**
    - **Propellers ?**
    - **HCF engine components?**

PROS AND CONS

PROS

- Much better resolution than traditional NDE
- Little training required to make replicas
- Limited equipment needed in field

CONS

- More labor intensive than traditional NDE
- Limited to surface flaws
- Dependent on surface condition
- Limited to small areas
- No immediate feedback

SUMMARY

- Analysis of silicone-based replicas
  - Find cracks below 0.005 inches
  - Find pits/defects down to 0.001 inches
- Method approved for use on flight hardware
  - Found 55 cracks in 3 orbiters (684 slots)
  - Identified unacceptable levels of damage
  - Repair confirmed by second round of replicas