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

LH₂ feedline

Flowliners
FLOWLINER DESCRIPTION

- **LH₂ 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

![Diagram of LH₂ flow and bellows](image)
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
  - $P_{\text{max}} = 3.4$ 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 #1 – 0.012”

Crack #2 – 0.004”

Crack #3 – 0.001”
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