Effect of Crack Opening on Penetrant Crack Detectability

Space Grant Internship
June 8 – August 14

Devin Weaver
Agenda

• Personal Background
• Background Information
• Project Outline
• Project Procedure
• Results
• Conclusion & Future Work
• What I Have Learned
• The Near Future
• Acknowledgements and References
Personal Background

Mechanical Engineering Graduate in May 2010
Background
Non Destructive Evaluation (NDE)

Fluorescent Penetrant Testing
- Penetrant
- Metal
- Crack
- Cleaned Surface
- Developer

Eddy Current Testing
Background
Probability of Detection (POD)

- Quantitative measure of the efficiency of an NDE procedure in finding flaws of specific type and size.
- The goal is to find a crack length for which there is 90% chance of detection with a 95% confidence.
- NASA uses a 29/29 criteria while the Air Force uses regression analyses.
- The JSC NDE lab has several sets of POD specimens.
Background
JSC Titanium POD Specimens

• Semi-circular grooves cut into 4”x18” Ti Bar
• EDM slots placed in rib between grooves
• Fatigue cracks created by bending
• The grooves were machined off after cracking
• Surfaced etched to remove smeared metal that was covering the cracks
• A NASA contractor required to pass POD test to build pressure vessels for Mars Science Laboratory

• Another NASA contractor could not find ultra-tight cracks in shuttle FCV poppets using fluorescent penetrant
  – Rely on eddy current testing to approve poppets for flight
  – Researching root cause of cracks at WSTF
• Assessment of Contractor’s 2008 qualification testing generated several questions about the quality of JSC’s POD specimens
• JSC’s POD specimens have “V” shape from etching
• Do not know how the width of the crack opening affects the crack detectability
• Cracks were contaminated with debris after returned to JSC from the Contractor
How comparable are POD cracks and in-service cracks?

“V” Crack Opening

0.025” Ti POD Set

FCV Poppet Cracks

Are the poppet cracks too tight for penetrant?

How clean and detectable are the POD cracks?
Project Procedure
“V” Investigation

- Cut out 1” square with the crack centered using diamond cut-off saw
- Document initial condition with SEM
- Perform Fluorescent penetrant
  - Spot of penetrant covering crack, P-136E
  - 15 – 30 minute dwell time
  - Dry wipe and solvent wipe
  - Photograph pre-developed state
  - Apply developer from aerosol spray can
  - Photograph post-developed state
  - Dry wipe off developer and repeat development process if necessary
  - Clean specimen
Project Procedure
“V” Investigation Cont’

- Sand off surface in 1 mil increments with grinding wheel
  - 500 grit (18 μm) followed by 800 grit (12 μm)
- Lightly etch Surface – Kroll (2% HF, 4% HNO₃, 96% H₂O)
- Document again with SEM and perform fluorescent penetrant testing at each stage
Project Procedure
0.025” Titanium POD Specimens

- The set consisted of 51 cracks in a total of 19 specimens
- 29 of the cracks were in the test range of 0.023” – 0.027”
- The specimens were cleaned in an ultrasonic cleaner with de-ionized water at 65°C and verified with the SEM
- A similar penetrant procedure was used to give a rating of the indication under the UV light and photograph the indications

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Easily Detectable</td>
</tr>
<tr>
<td>2</td>
<td>Detectable</td>
</tr>
<tr>
<td>3</td>
<td>Barely Detectable</td>
</tr>
<tr>
<td>4</td>
<td>Undetectable</td>
</tr>
</tbody>
</table>

- The specimens were cleaned again in the ultrasonic cleaner
Project Procedure

Poppet Investigation

- Document Langley fatigue cracked and flight FCV poppets in SEM
- Perform penetrant (P-136E & P6F4) tests on Langley fatigue cracked poppets
  - Focused on largest cracks
  - Spot application
  - Solvent wipe
Results

“V” Investigation SEM Photos

As Received

Post 5 mil Removal by Grinding

0.4 mils

0.05 mils
Inverted Light Microscope
Results

“V” Investigation Penetrant Photos

As Received

Pre-developed

Post-developed

Post 5 mil Removal

Pre-developed

Post-developed

Post-developed
**Results**

0.025” Titanium POD Specimens

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Length (inches)</th>
<th>Pre-develop Rating</th>
<th>Post-develop Rating</th>
<th>Pre-develop Photograph</th>
<th>Post-develop Photograph</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Y19-3</td>
<td>0.025</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K703-2</td>
<td>0.026</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Results

0.025” Titanium POD Specimens

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Length (inches)</th>
<th>Pre-develop Rating</th>
<th>Post-develop Rating</th>
<th>Pre-develop Photograph</th>
<th>Post-develop Photograph</th>
</tr>
</thead>
<tbody>
<tr>
<td>52P8-2</td>
<td>0.068</td>
<td>3</td>
<td>1</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>36T4-1</td>
<td>0.013</td>
<td>3</td>
<td>2</td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Results
0.025” Titanium POD Specimens

• From the testing we were able to determine all the cracks within the test range were detectable or better with developer
• Many of the indications after development lost their linearity and gave circular indications
• Our tests were performed in a laboratory and our procedure would be difficult in an industrial setting

<table>
<thead>
<tr>
<th>Ratings</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-develop Cracks</td>
<td>23</td>
<td>14</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Post-develop Cracks</td>
<td>40</td>
<td>8</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
Results
Poppet Investigation

Langley Fatigue Cracked Poppet

POD Specimen
Conclusions & Future Work

• The “V” did not significantly affect our ability to detect the POD cracks with fluorescent penetrant
  – Conduct same experiment with more cracks
• The 0.025 and 0.050 POD specimens are clean and documented with the SEM
  – Conduct water-wash fluorescent penetrant test at EAFB
• The poppet cracks are tighter than the POD specimen cracks
  – Flight FCV poppets: 0.01 mils (0.3 µm)
  – Langley fatigue cracked poppets: 0.02 mils (0.5 µm)
  – POD specimen (post 5 mils): 0.05 mils (1.4 µm)
• We could not detect cracks in Langley fatigue-cracked poppets with fluorescent penetrant
  – Investigate inability of penetrant to wet the poppet surface
What I Have Learned

• Lab procedures and safety
  – Data/procedure documentation
• POD methods and theory
• Fluorescent penetrant testing
  – Hands on and highly influenced by the inspector
• Eddy current testing and bolt inspection device for poppets
• Light Microscope with z-stack
• Metallurgy Camera with UV flash
• Fine grinding and polishing
• Metallurgical etching
• Heat Treatment
The JSC Experience

Lecture by Chris Kraft

Heat Treatment Videos
by: John Figert

STS-127 Crew Return
The Near Future

• After graduation I plan on acquiring a Masters Degree related to Aeronautical Engineering
• I would like to return to JSC or another center as a graduate Co-op
• After graduate school, I hope to start a career working for NASA
Acknowledgements

• Bud Casnter
• Ajay Koshti
• Louis Hulse
• James Martinez
• Glenn Morgan
• Eddie Pompa
• Norman Ruffino
• Veronica Seyl

References

• [http://www.ndt-ed.org](http://www.ndt-ed.org)
• [http://maps.google.com](http://maps.google.com)
• [http://www.nasaimages.org](http://www.nasaimages.org)
• MIL-HDBK-1823, 1999
• Pratt & Whitney Rocketdyne, Inc.