The Purpose of Generating Fatigue Crack Growth Threshold Data

Scott Forth
NASA Johnson Space Center
Overview

- NASA Applications
- Laboratory Data
- Summary
NASA Applications

- Space Shuttle Main Engine Thrust Structure
- Ti-6Al-4V Titanium
- High Cycle Fatigue
  - Launch Vibration
- Threshold used as design allowable
  - All $\Delta K$ values below $\Delta K_{th}$
High Cycle Fatigue (HCF) Components. Fracture critical components operating in a potential HCF environment...

The metallic component is acceptable if the calculated HCF stress intensity is below the stress intensity factor threshold for the metallic material.
Design Threshold Data

Recent Threshold Testing

- Threshold testing completed on Ti-6-4 MA specimens to compare threshold values between C(T), ESE(T), M(T) & SM(T) designs.
**Short Middle Through Crack Specimen**

**SM(T)**

- Crack has less tendency to turn compared to the C(T) specimen
- Specimen has high stiffness - allowing high cyclic frequency
- Requires much less material than for an M(T) specimen.

Comparison of $W = 3''$ C(T) specimen with $W = 3.4''$ SM(T) specimen.
SM(T) Threshold Data

Ti-6Al-4V MA
SM(T), W = 3.4”, B = 0.25”
Room Temp, Lab Air

Forman, R.G., unpublished
Effect of Specimen Geometry on $R = 0.1$ Threshold

Ti-6Al-4V MA
Room Temp, Lab Air

Forman, R.G., unpublished
Effect of Specimen Geometry on $R = 0.7$ Threshold

Ti-6Al-4V MA
Room Temp, Lab Air

Forman, R.G., unpublished
## Ti-6Al-4V MA Thresholds

<table>
<thead>
<tr>
<th>R Value</th>
<th>Specimen Type</th>
<th>( \Delta K_{th} ) (ksi in( ^{1/2} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>C(T)</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>M(T)</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>ESE(T)</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>SM(T)</td>
<td>4.1</td>
</tr>
<tr>
<td>0.7</td>
<td>C(T)</td>
<td>2.4 / 2.1</td>
</tr>
<tr>
<td></td>
<td>M(T)</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>ESE(T)</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>SM(T)</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Specimen Configuration Effects

Constant $K_{\text{max}}$ Data

Specimen Configuration Effects at Threshold

\[ \Delta K_{th} (\text{MPa m}^{1/2}) \]

- \( C(T), W = 76.2 \text{ mm}, B = 12.7 \text{ mm} \)
- \( C(T), W = 76.2 \text{ mm}, B = 5.08 \text{ mm} \)
- \( C(T), W = 50.8 \text{ mm}, B = 5.08 \text{ mm} \)
- \( C(T), W = 25.4 \text{ mm}, B = 5.08 \text{ mm} \)
- \( \text{ESE}(T), W = 38.1 \text{ mm}, B = 5.08 \text{ mm} \)
- \( M(T), W = 76.2 \text{ mm}, B = 12.7 \text{ mm} \)
- \( M(T), W = 76.2 \text{ mm}, B = 5.08 \text{ mm} \)

D6AC Steel
L-T, \( da/dN \sim 10^{-10} \) meters/cycle
Room Temp, Lab Air

Specimen Configuration Effects at Threshold

Low Carbon Steel

R = 0.1

Summary

- Test data shows that different width and thickness C(T), M(T) and ESE(T) specimens generate different thresholds.
- Structures designed for “infinite life” are being re-evaluated:
  - Threshold changes from 6 to 3 ksi in$^{1/2}$
  - Computational life changes from infinite to 4 missions
- Multi-million dollar test programs required to substantiate operation.
- Using ASTM E647 as standard guidance to generate threshold data is not practical.

- A threshold test approach needs to be standardized that will provide positive margin for high cycle fatigue applications.