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

Ti-6Al-4V MA
C(T), W = 2”, B = 0.25”
Room Temp, Lab Air

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**

<table>
<thead>
<tr>
<th>Data ID</th>
<th>R</th>
<th>Thk</th>
<th>Spec Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>P3EA11AB01R3</td>
<td>0.8</td>
<td>0.25</td>
<td>SM(T)</td>
</tr>
<tr>
<td>P3EA11AB01R3</td>
<td>0.4</td>
<td>0.25</td>
<td>SM(T)</td>
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<tr>
<td>P3EA11AB01RT</td>
<td>0.1</td>
<td>0.25</td>
<td>SM(T)</td>
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</tbody>
</table>

**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Forman, R.G., unpublished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

Data ID | R | Thk | Spec Type
---|---|---|---
P3EA11AB01M1 | 0.285 | C(T) | Room Temp, Lab Air
P3EA11AB01P1 | 0.1 | M(D) | Ti-6Al-4V MA
P3EA11AB01Q1 | 0.25 | ESM(T) |
P3EA11AB01R1 | 0.1 | M(T) |
Effect of Specimen Geometry on $R = 0.7$ Threshold

Forman, R.G., unpublished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>
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<tr>
<td></td>
<td>M(T)</td>
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<tr>
<td></td>
<td>ESE(T)</td>
<td>3.9</td>
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<tr>
<td></td>
<td>SM(T)</td>
<td>4.1</td>
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<tr>
<td>0.7</td>
<td>C(T)</td>
<td>2.4 / 2.1</td>
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<tr>
<td></td>
<td>M(T)</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>ESE(T)</td>
<td>2.1</td>
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<tr>
<td></td>
<td>SM(T)</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Specimen Configuration Effects

\[ \frac{da}{dN} \text{ (meter/cycle)} \]

\[ 10^{-7} \]

\[ 10^{-8} \]

\[ 10^{-9} \]

\[ 10^{-10} \]

\[ 10^{-11} \]

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

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

Specimen Configuration Effects at Threshold

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

D6AC Steel
L-T, da/dN ~ 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