ASIP2011 PRESENTATION

Crack Growth Behavior in the Threshold Region for High Cyclic Loading

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Fatigue Crack Threshold Investigations at JSC

- CY 2006 – 2010: Two concurrent FAA sponsored projects
  1. Development of analysis tools to assess the damage tolerance of rotorcraft.
  2. Improve damage tolerance analysis of propeller systems, (a) for crack initiation from sharp surface flaws, (b) for crack initiation and growth from corrosion pits.

- CY 2011: In-house project - Improved characterization of fatigue crack growth thresholds
What is the cause of “fanning” of $\frac{da}{dN}$ data in the threshold region for some materials?

(1) Is fanning caused by the ASTM load shedding test method (as some believe), and the resulting data is not valid for use in damage tolerance analysis?

(2) Or is sometimes the cause of fanning a result of inherent characteristics of the material and the data is valid and acceptable for use in damage tolerance analysis?
EXAMPLE OF THE THRESHOLD FITTING PROBLEM

NASGRO FITS: 6061-T6 AL Extr, L-T & T-L, LA

With Fanning Fit

Without Fanning Fit
Known Test Conditions That Cause Fanning

(1) Crack tunneling – i.e., specimen thickness

(2) Moist environment - i.e., fretting corrosion
 Crack Tunneling Example

- For 0.5” thick specimens, crack front tunneling occurred just before final threshold and caused elevated threshold values.

- Thus, all remaining specimens were re-machined to a thickness of 0.2”, and the tunneling was eliminated.
(a) Macroscopic appearance of oxide deposits on near-threshold fatigue fracture surfaces in a 2\frac{1}{4}Cr–1Mo bainitic steel fatigue tested in moist air at $R = 0.05$ and 0.75. (b) Corresponding Auger measurements of oxide layer thickness as a function of crack length and crack growth rates. (From Suresh, Zamiski & Ritchie, 1981)
Example of Significant Fanning that Occurred in Lab Air Testing

AerMet 100 Lab Air Data Fit – Cth = 2.25

![Graph showing data fit for AerMet 100 lab air testing with Cth = 2.25.](image-url)
Example of Decreased Fanning in Dry Air Testing

AerMet 100 Dry Air Data Fit – Cth = 0

NASGRO Eqn fit:AerMet100; 280 UTS 6in Rnd Bar; L-R;ESE(T) in Dry Air

SOME POINTS OFF SCALE!
Other Causes of Fanning

Causes that result from inherent material characteristics which affect crack surface morphology in the threshold region:

- When ratio of crack tip yield zone size/grain size is $< 1$ and crack surface changes from striated to a faceted morphology in threshold region.
- When the material dislocation property results in multiple crack bifurcations and branching in threshold $da/dN$ region ($< 1E-8$ inches/cycle).
Example of Faceted (Cleavage Like) Fatigue Crack Growth in Threshold $da/dN$ Regime

Hertzberg 1976: Micromorphology in the Ultra-Low Growth Rate Regime

2024-T3 Aluminum

305 Stainless Steel

FIG. 2—Electron fractographs showing fatigue fracture surface micromorphology at various points on the $da/dN$ versus $\Delta K$ plot for 2024-T3 aluminum alloy.
Variation in Crack Surface Morphology for 7050-T7451 Tests

Basic Fit for M7GJ12AC1
7050-T7451 3/8in Plt; T-L; Dry Air

- Ductile growth
- All striated
- Faceted & striated
- Faceted

- $a = 0.360$
- $\Delta = 0.33''$
- $a = 0.691''$
- $\Delta = 0.029''$
- $a = 0.7196''$
Load Shedding Test of 6156-T6 ESE(T) Specimen

For plane strain:

\[ r_p = \frac{1}{6\pi} \left( \frac{K_{\text{max}}}{YS} \right)^2 \]

Grain diameter, \( d = 1.5 \times 10^{-3} \)

\[ \Delta a = 0.128'' \quad r_p/d = 0.806 \]
\[ \Delta a = 0.135'' \quad r_p/d = 0.29 \]
\[ \Delta a = 0.030'' \quad r_p/d = 0.1 \]
\[ \Delta a = 0.0065'' \quad r_p/d = 0.067 \]

Threshold:

\[ a = 0.6615'' \]
Al 6156-T6, R=0.1: Threshold Main Crack Tip
Al 6156-T6, R = 0.1: Close to Threshold Tip
AI 6156-T6: Load Shedding Crack (etched to show grains)
Al 6156-T6 Specimen, R = 0.7: Midway to Threshold Tip
Fatigue Crack Sample: 2524 ESE-LT-3
Fatigue Crack Sample: 2524 ESE-LT-3

20 μm
EHT = 20.00 kV
WD = 8.2 mm
Mag = 461 X

Signal A = SE2
Width = 620.8 μm
Reference Mag = Out Dev.

Date: 5 Apr 2011
Chamber = 6.79e-004 Pa
Vacuum Mode = High Vacuum

a=0.79"
IMI 685 Ti Specimen Showing a Crack Closure Point

MA Hicks, Fatigue of Engineering Materials, & Structures
Vol. 6, No. 1, pg 59
Summary

- The present studies show that fanning in the threshold regime is likely caused by other factors than a plastic wake developed during load shedding.

- The cause of fanning at low R-values is a result of localized roughness, mainly formation of a faceted crack surface morphology, plus crack bifurcations which alters the crack closure at low R-values.

- The crack growth behavior in the threshold regime involves both crack closure theory and the dislocation theory of metals.

- Research will continue in studying numerous other metal alloys and performing more extensive analysis, such as the variation in dislocation properties (e.g., stacking fault energy) and its effects in different materials.