Rotorcraft Materials
Fatigue Crack Growth Threshold Testing

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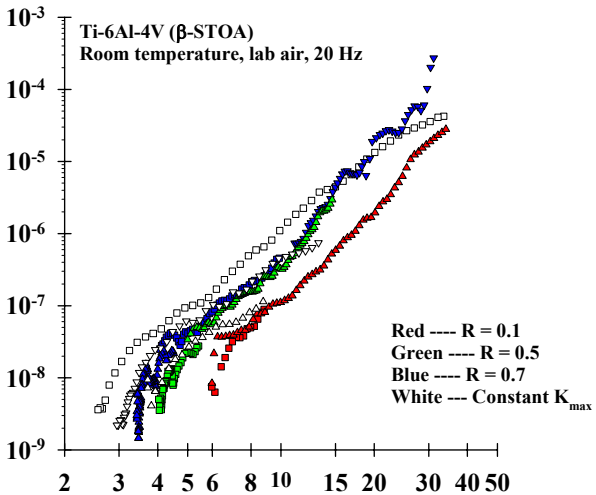
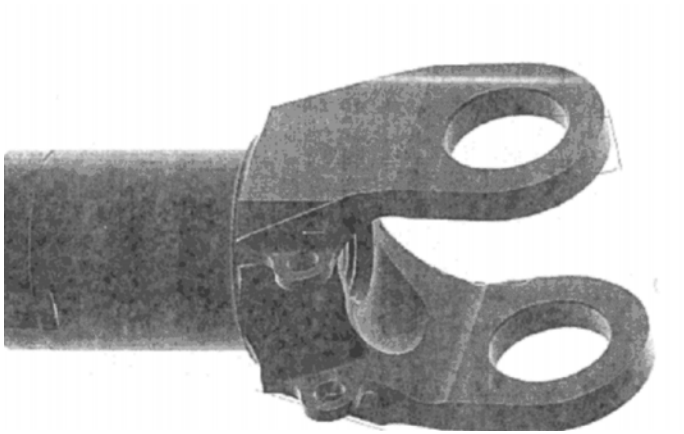
Outline

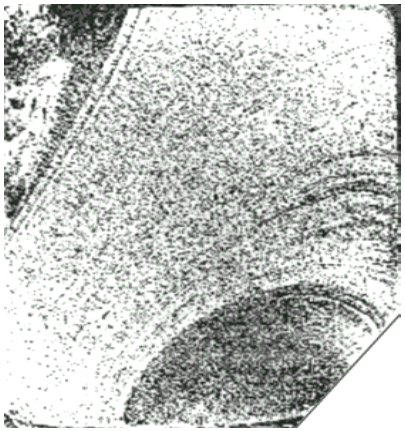
- Motivation and objective
- Status
- Testing procedures overview
- Test results
  - Crack growth rate data
  - Notch geometry effects
- Summary

Motivation





Spindle



Full Scale Test

Status

- Most standard K_{max} and constant load ratio testing is complete
- Compression precracking testing is in progress
- 4340 steel was substituted for 9310 steel
- Budget is 100% costed
- Project delayed due to NASA shuttle priorities

Test Approach

- Automated computer-controlled test machine
  - Tests run continuously
- Crack length monitored during tests using back-face strain gage or clip gage
  - Loads continuously adjusted to achieve programmed stress-intensity factors

Materials

- 7050 Aluminum
- AZ91E Magnesium
- Ti-6Al-4V β-STOA
- 4340 Steel

Environment

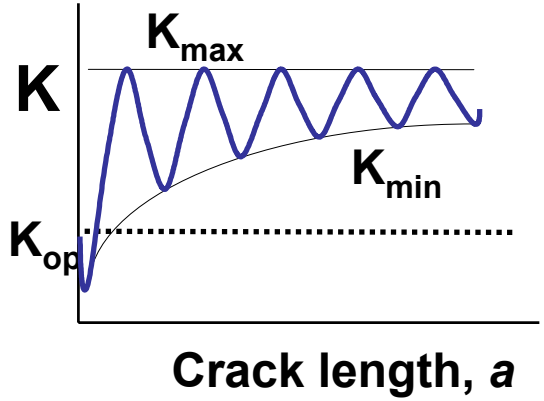
- Lab air / Room Temp
- Dry air / Room Temp

Specimen/Configuration

- Compact Tension, C(T)
- W = 2” B = 0.25”
- W = 3” B = 0.5”

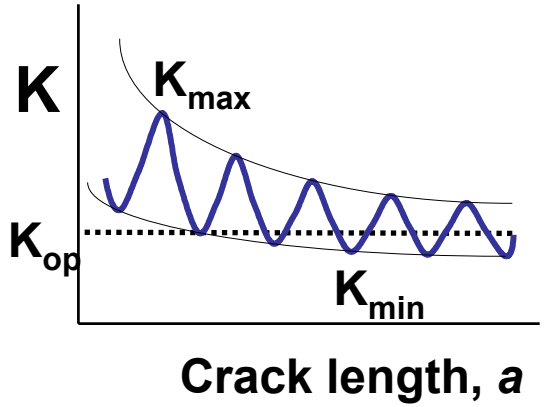
Three Test Methods for Data Generation

1. Constant K_{max} – high mean stress



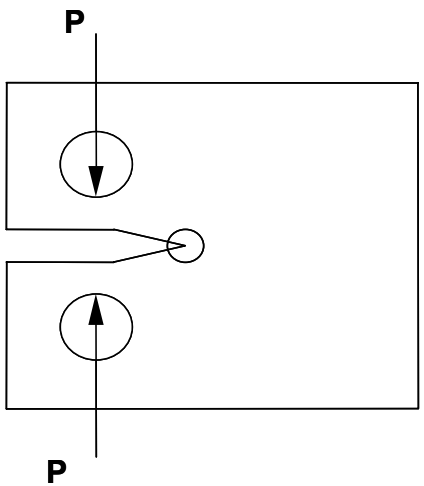
- Constant-K_{max} tests
  - No remote closure concerns
  - Achieves threshold at high R

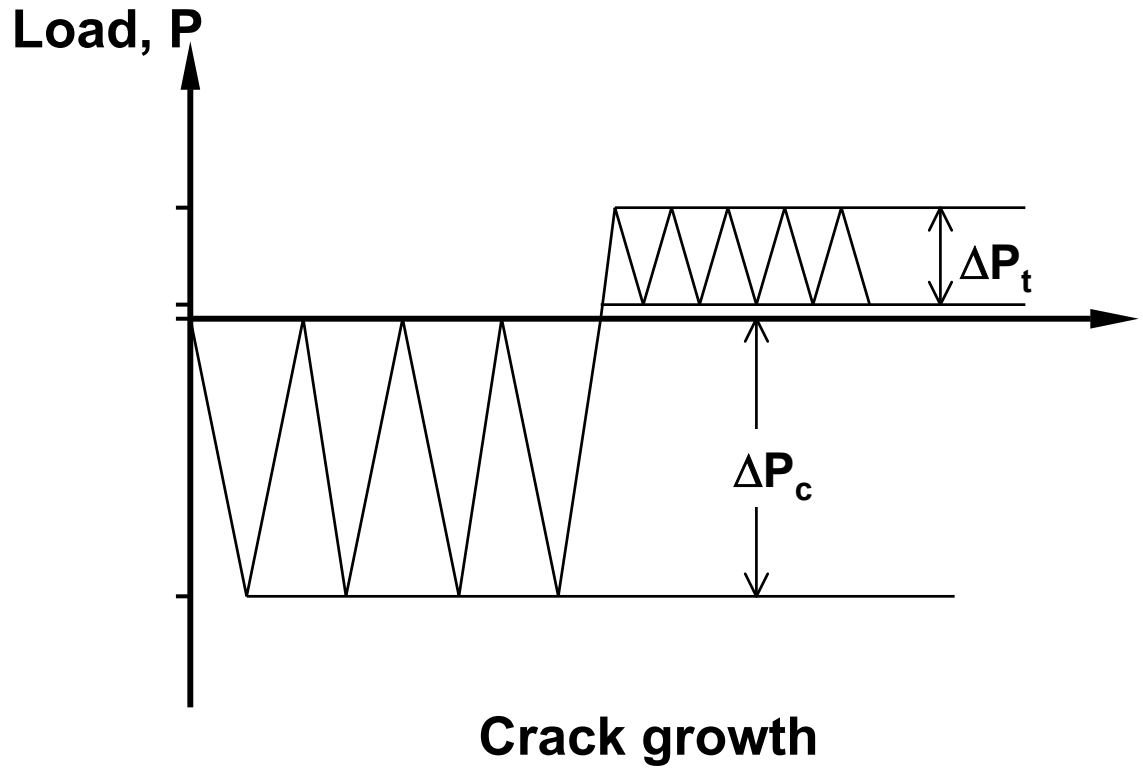
2. Constant R – low mean stress



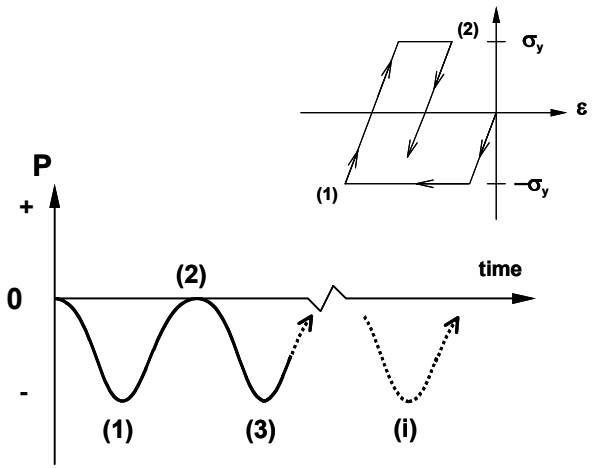
- Constant-R tests
  - Remote closure can occur if starting ΔK is too high
  - Tests will be started at lowest practical ΔK value
  - Data scrutinized for evidence of remote closure

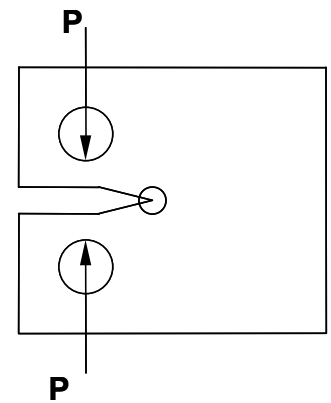
3. Compression Precracking Test Method

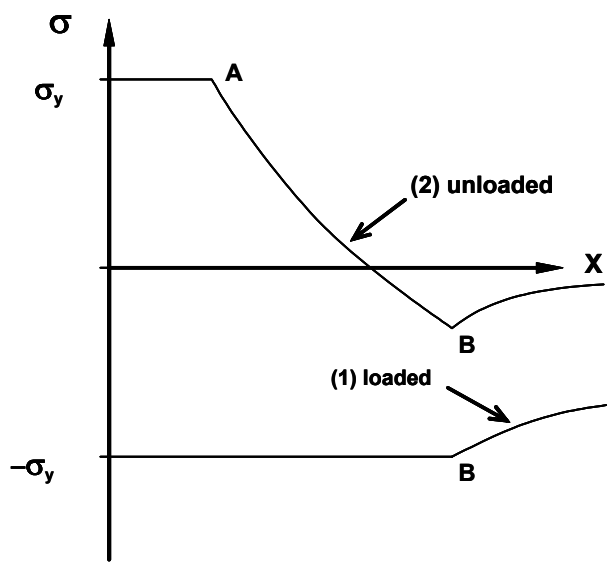


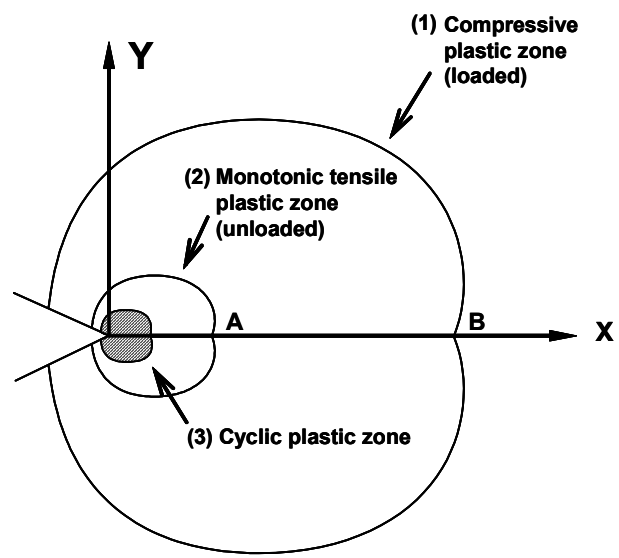


Schematic of Specimen Response to Compression Loading

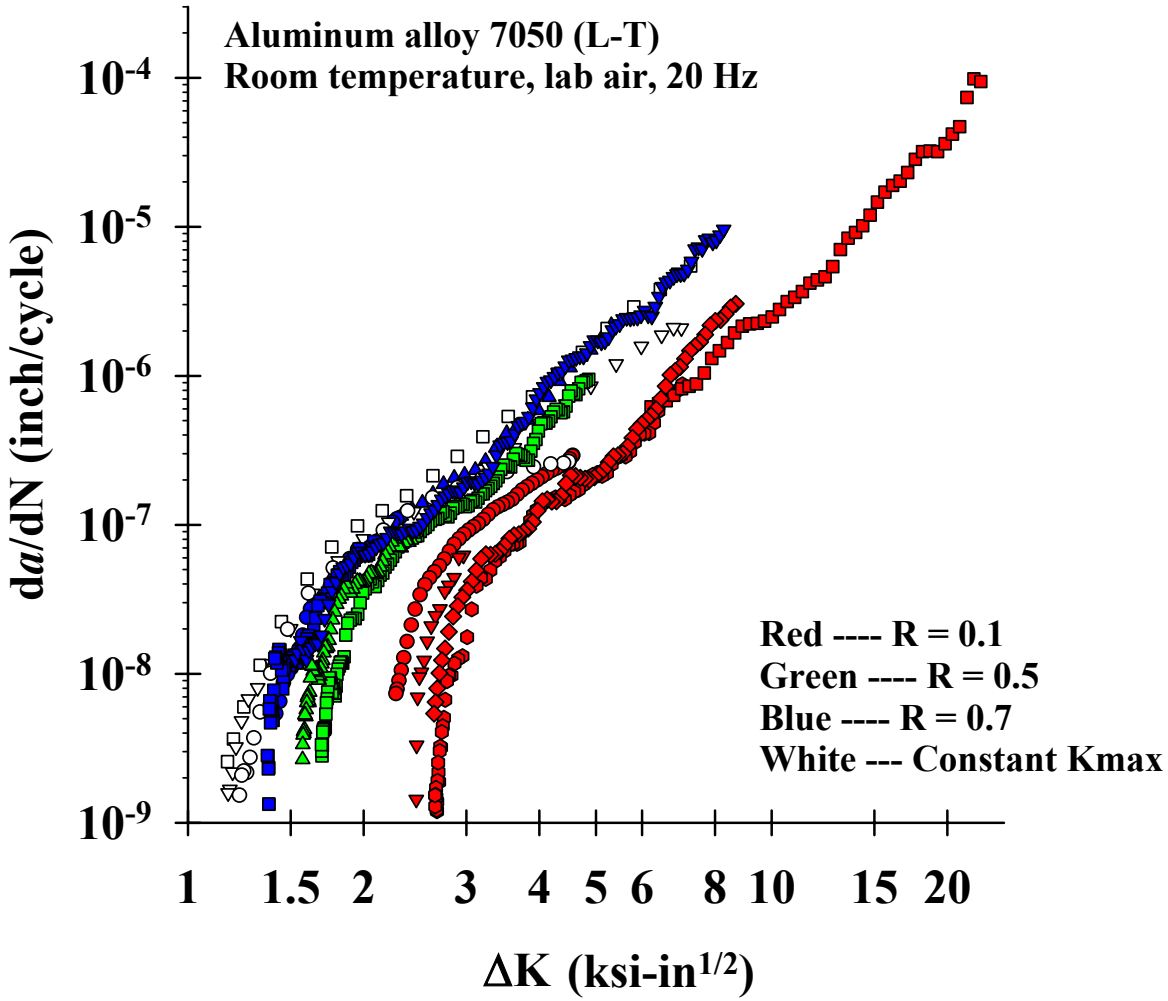




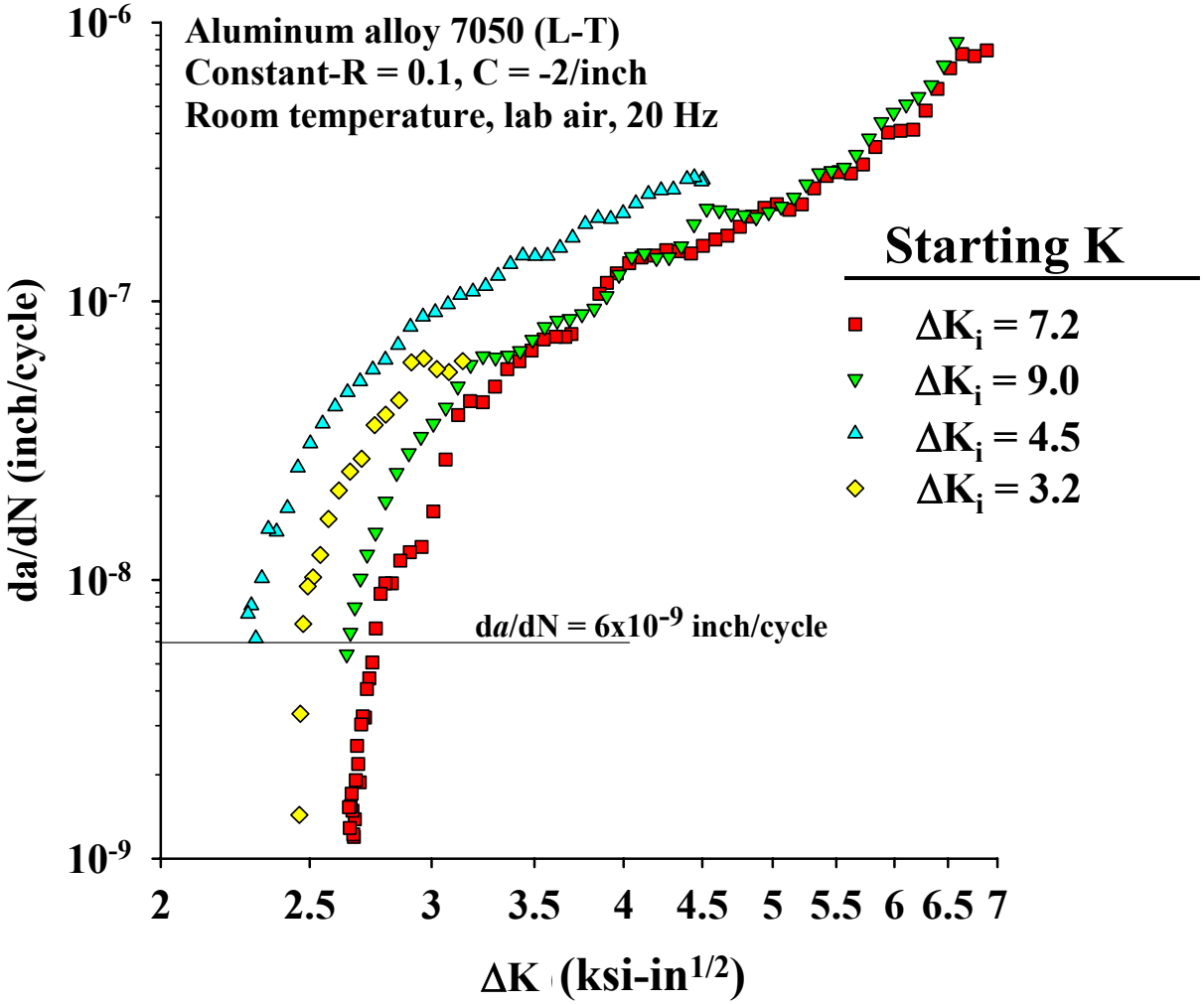




Comparison of all Standard Precracking 7050 Aluminum Data

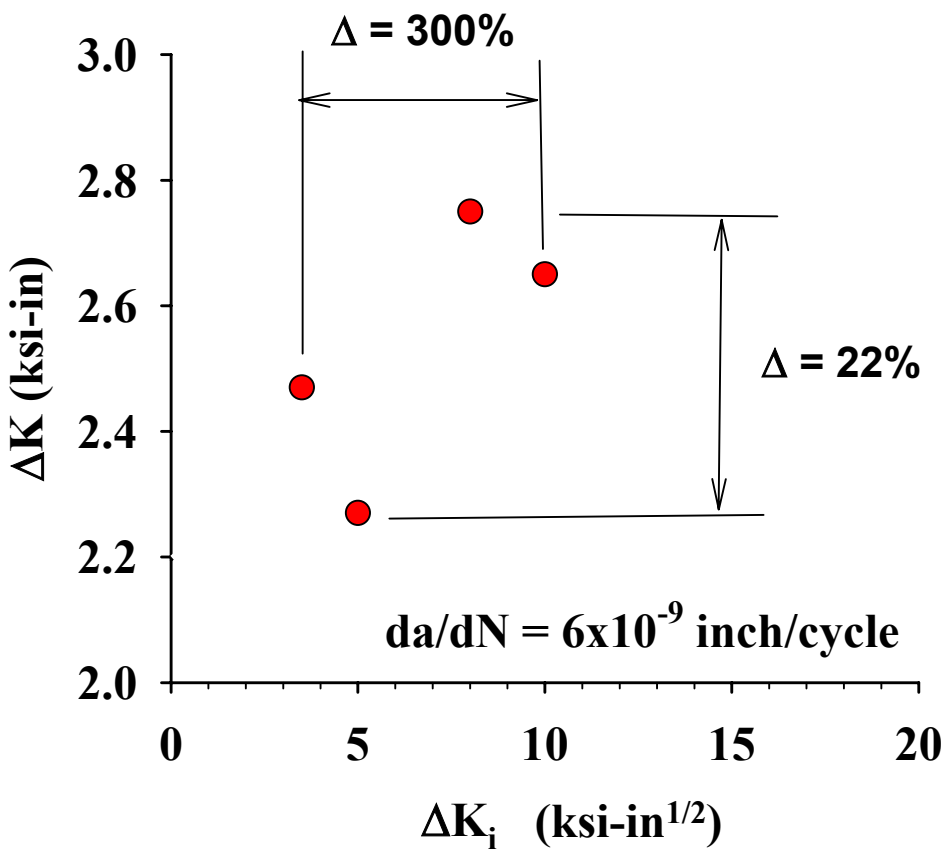


Effect of Load Reduction Starting K on the R = 0.1 Threshold

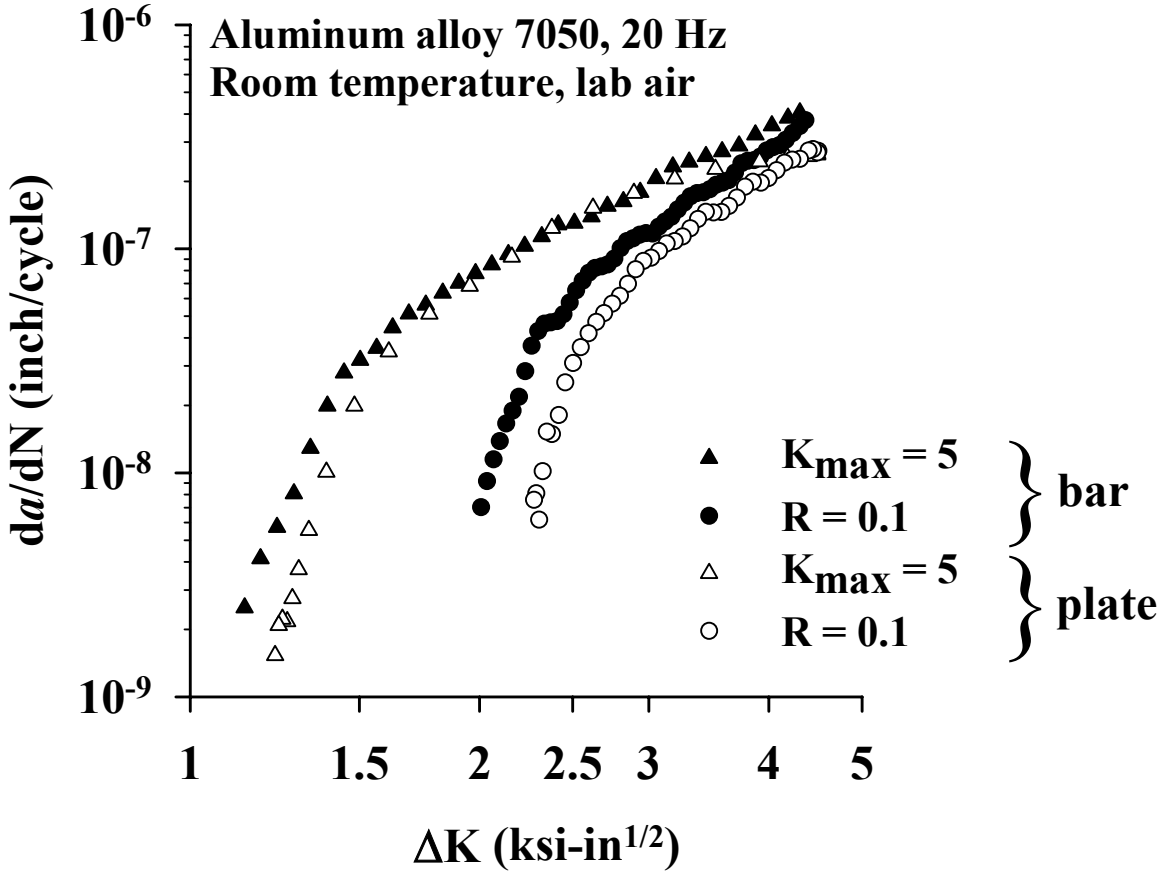


Effect of Load Reduction Starting K on the R = 0.1 Threshold

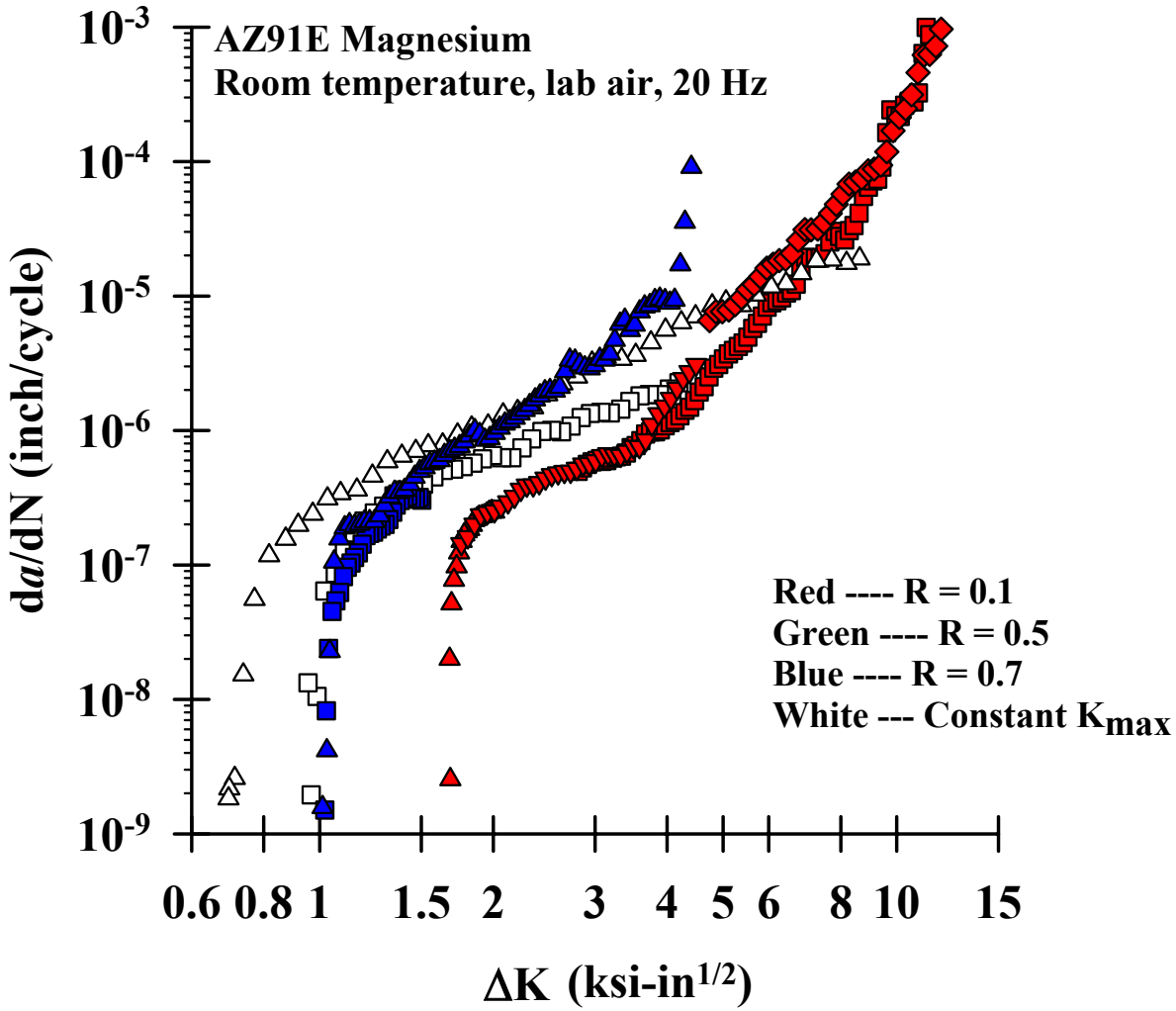
7050 Aluminum Data



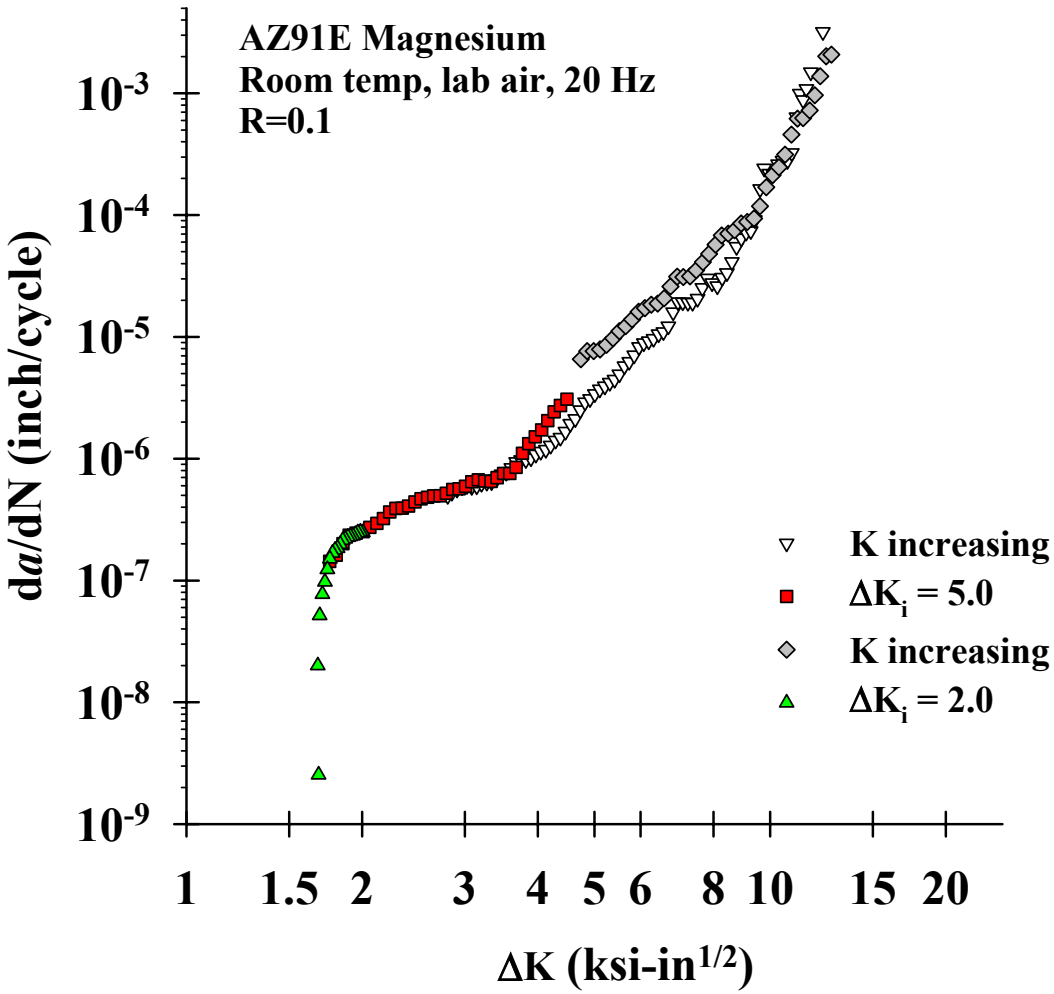
Comparison of Bar Data with Plate Data



Comparison of all Standard Precracking AZ91E Magnesium Data

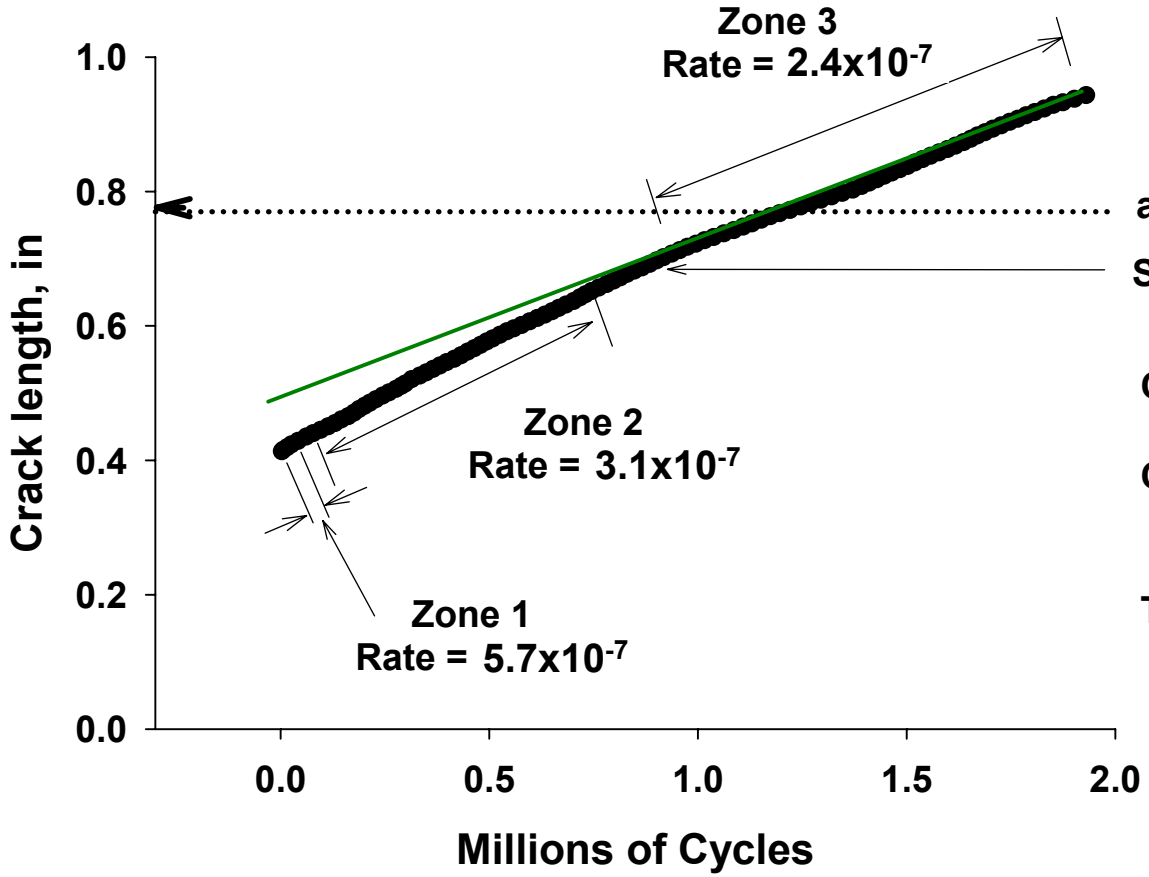


Effect of Load Reduction Starting K on the R = 0.1 Threshold



Constant ΔK after Compression Precracking

AZ91E Magnesium Data



$a_n + 3*r_p = 0.77"$

Steady rate begins?

C(T) W = 2" B = 0.25"

CPC:

P_{min} = -1 kip

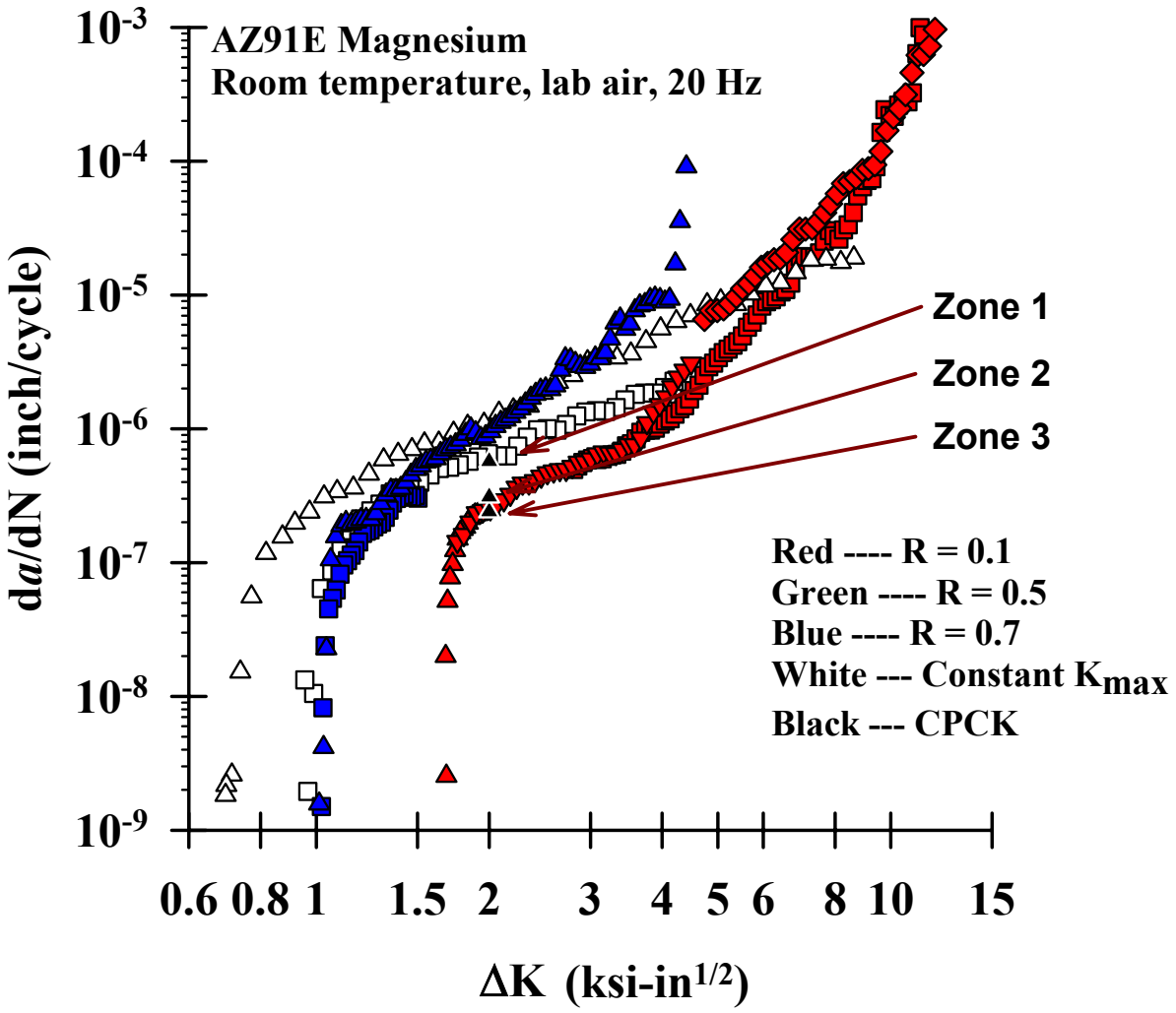
Δa_{cpc} = 0.016"

Tension:

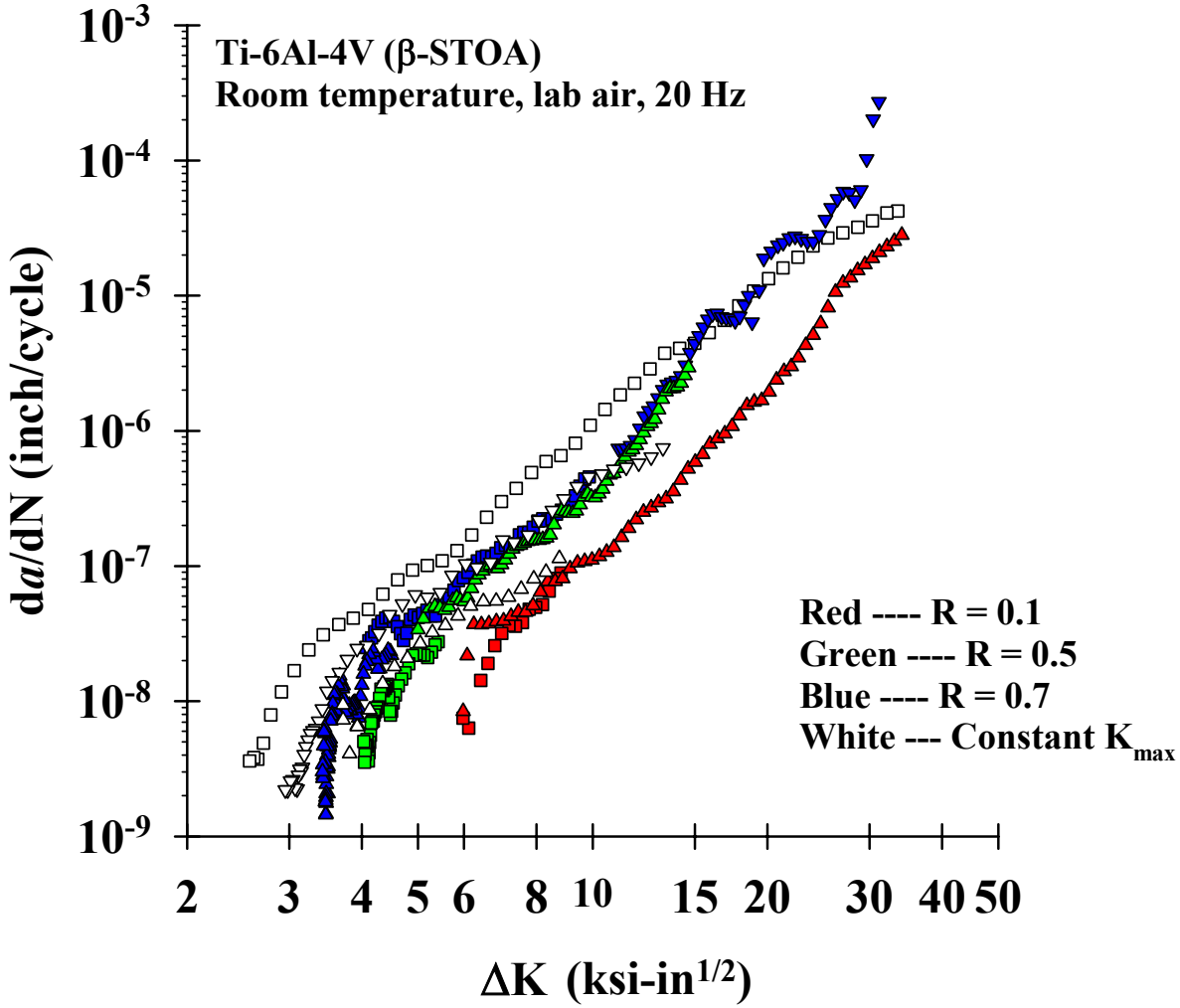
ΔK = 2.0 ksi $in^{1/2}$

R = 0.1

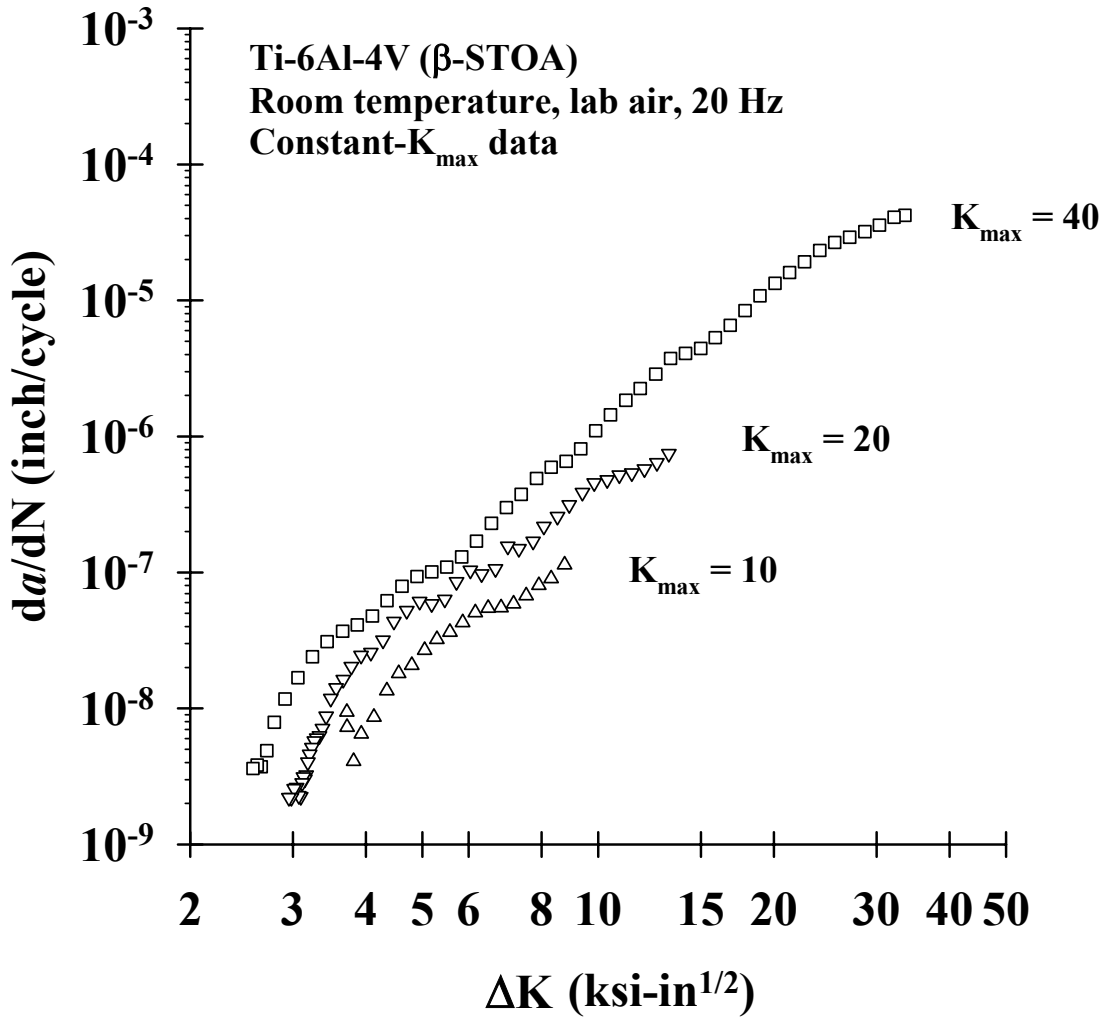
Comparison of Compression Precracking Data with Standard Precracking Data



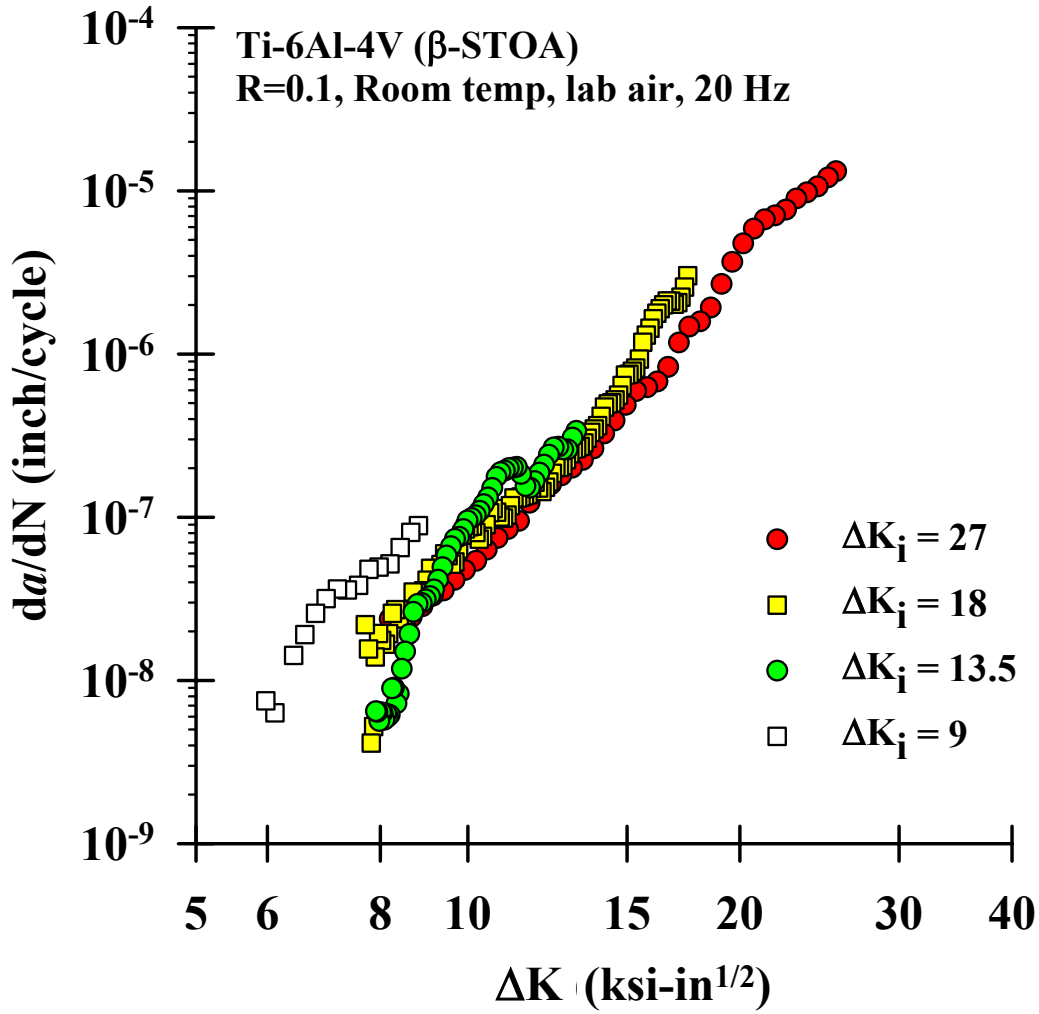
Comparison of all Standard Precracking Ti-6Al-4V β–STOA Titanium Data



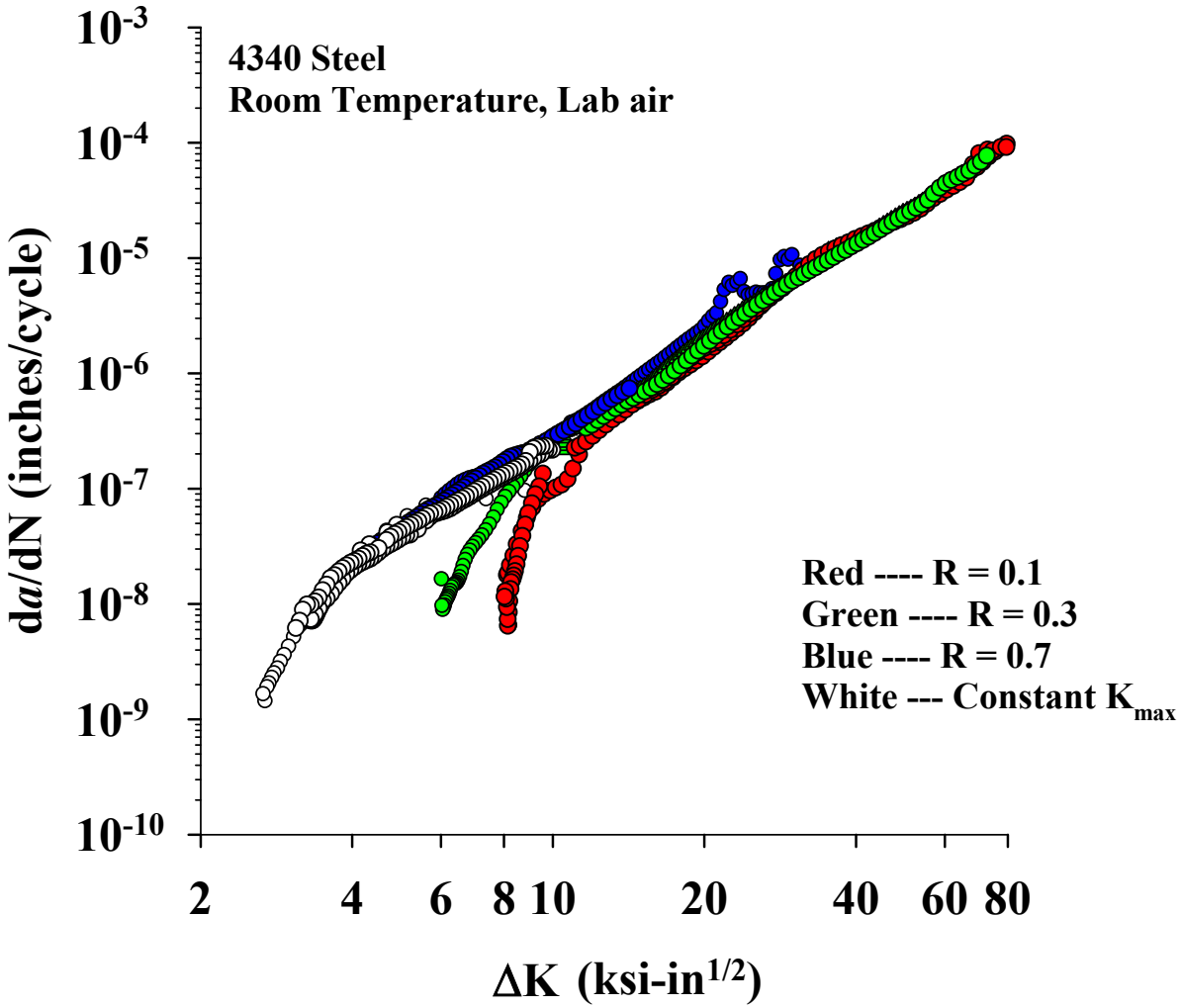
Effect of K_{max} on Threshold
Ti-6Al-4V β–STOA Titanium Data



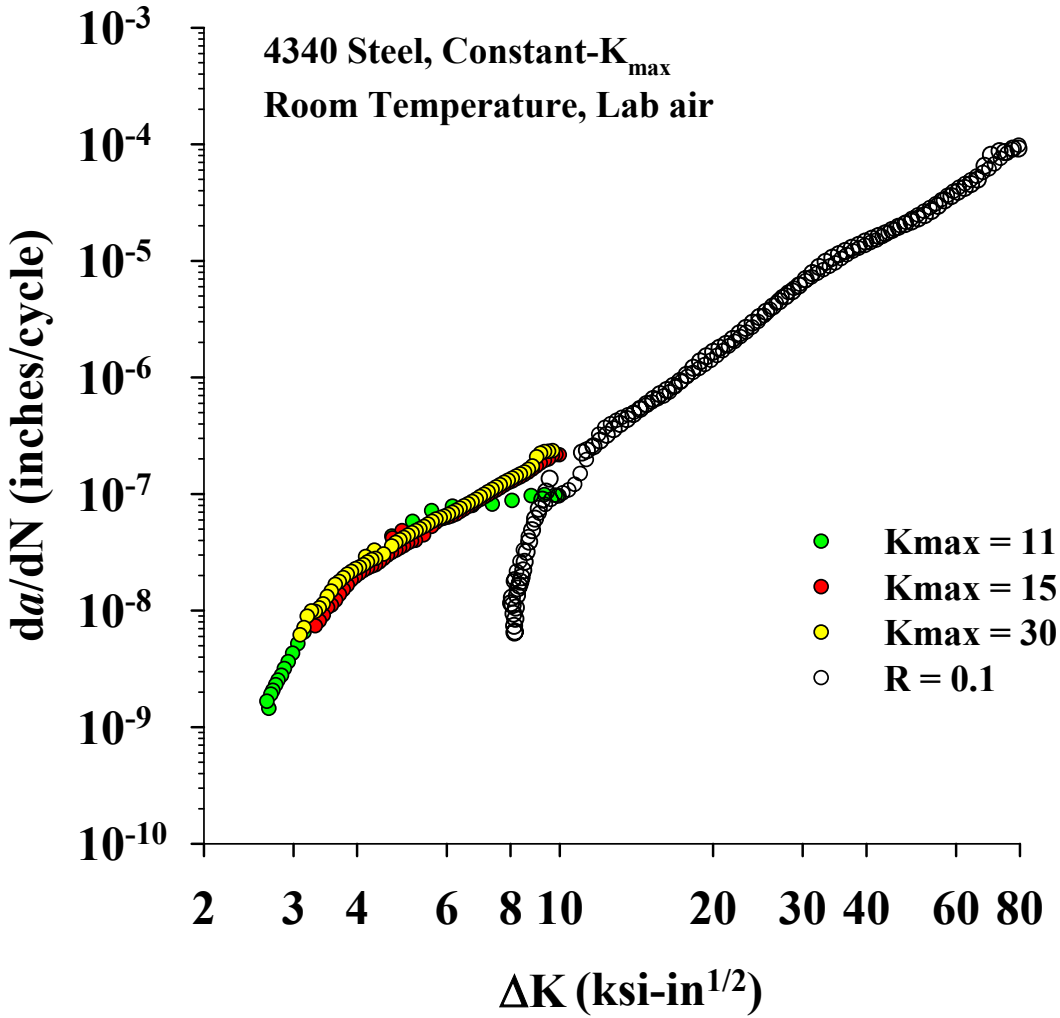
Effect of Load Reduction Starting K on the R = 0.1 Threshold



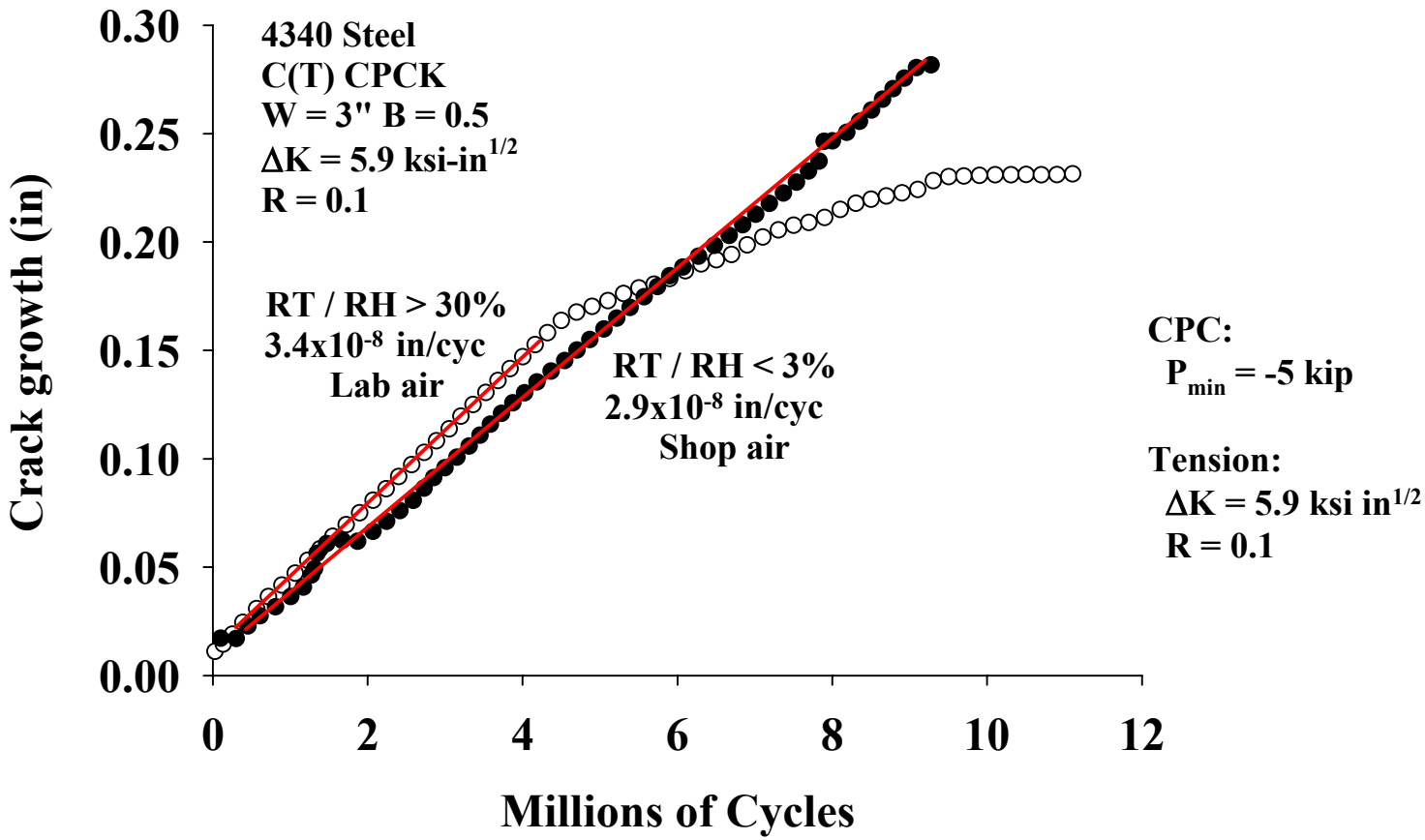
4340 Steel Data



Effect of K_{max} on Threshold

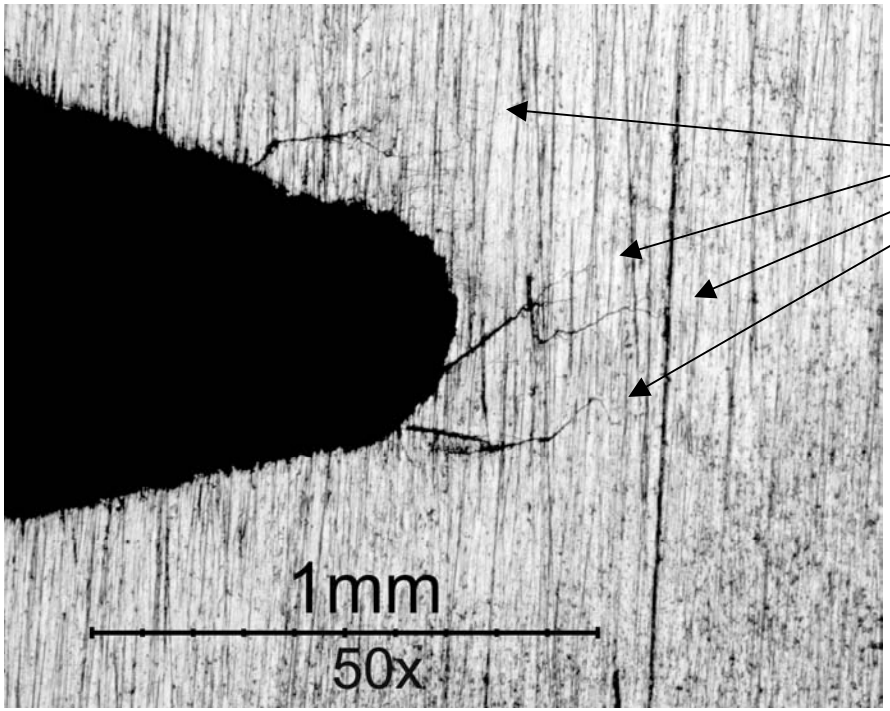


Effect of Humidity on the Crack Growth Rate



Example of Multiple Cracks from Compression Precracking in Ti-6Al-4V β–STOA

- **Testing revealed that multiple cracks can start at a notch**
- **Precracking is a function of the notch geometry and loading level**



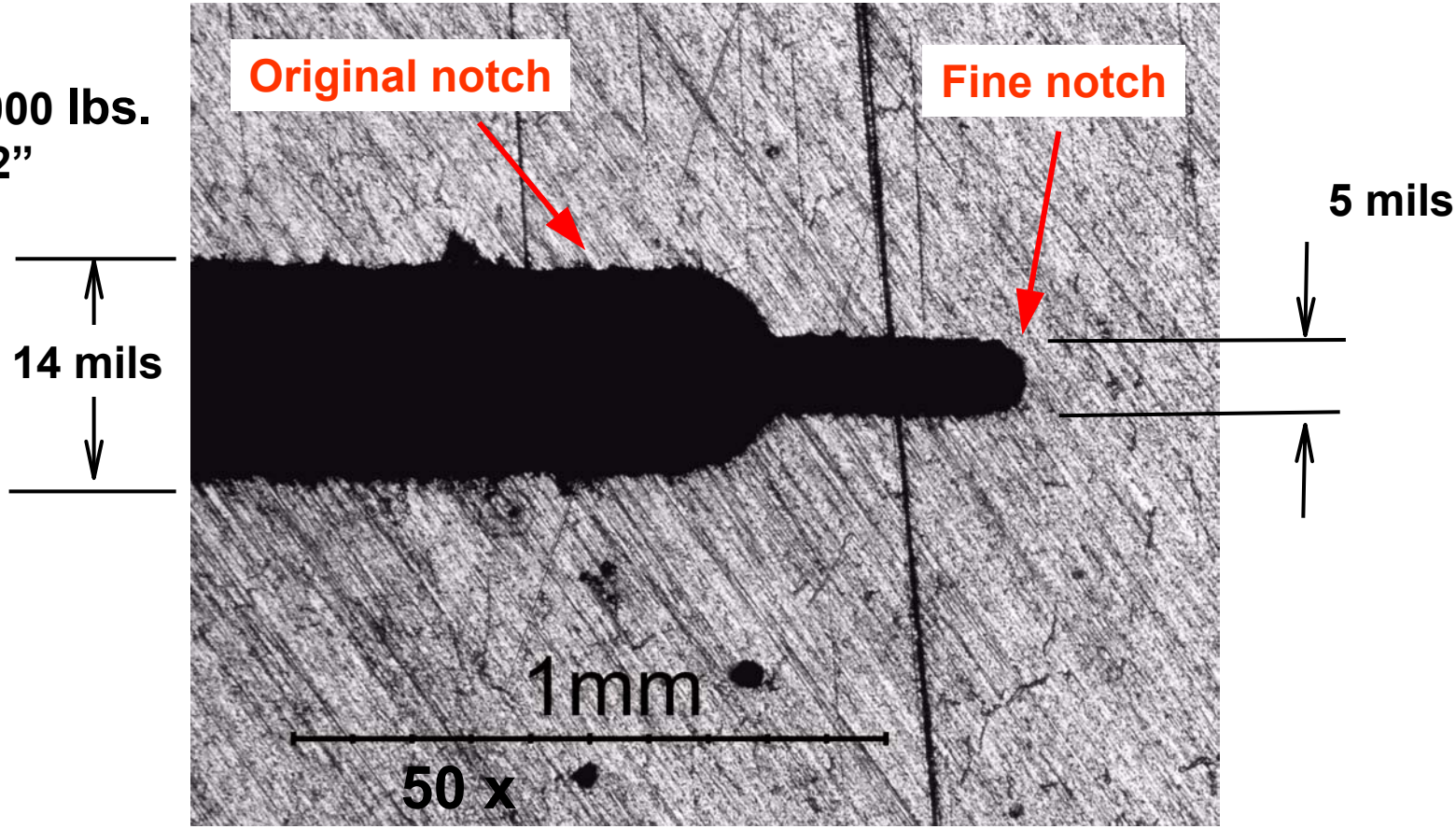
Cracks

Ti-4-H2-SideB-50x-002.jpg

Example of a Fine EDM Notch to Reduce Multi-cracking Problems

P_{min} = -2150 lbs.
r_p =0.05”

P_{min} = -1000 lbs.
r_p =0.012”

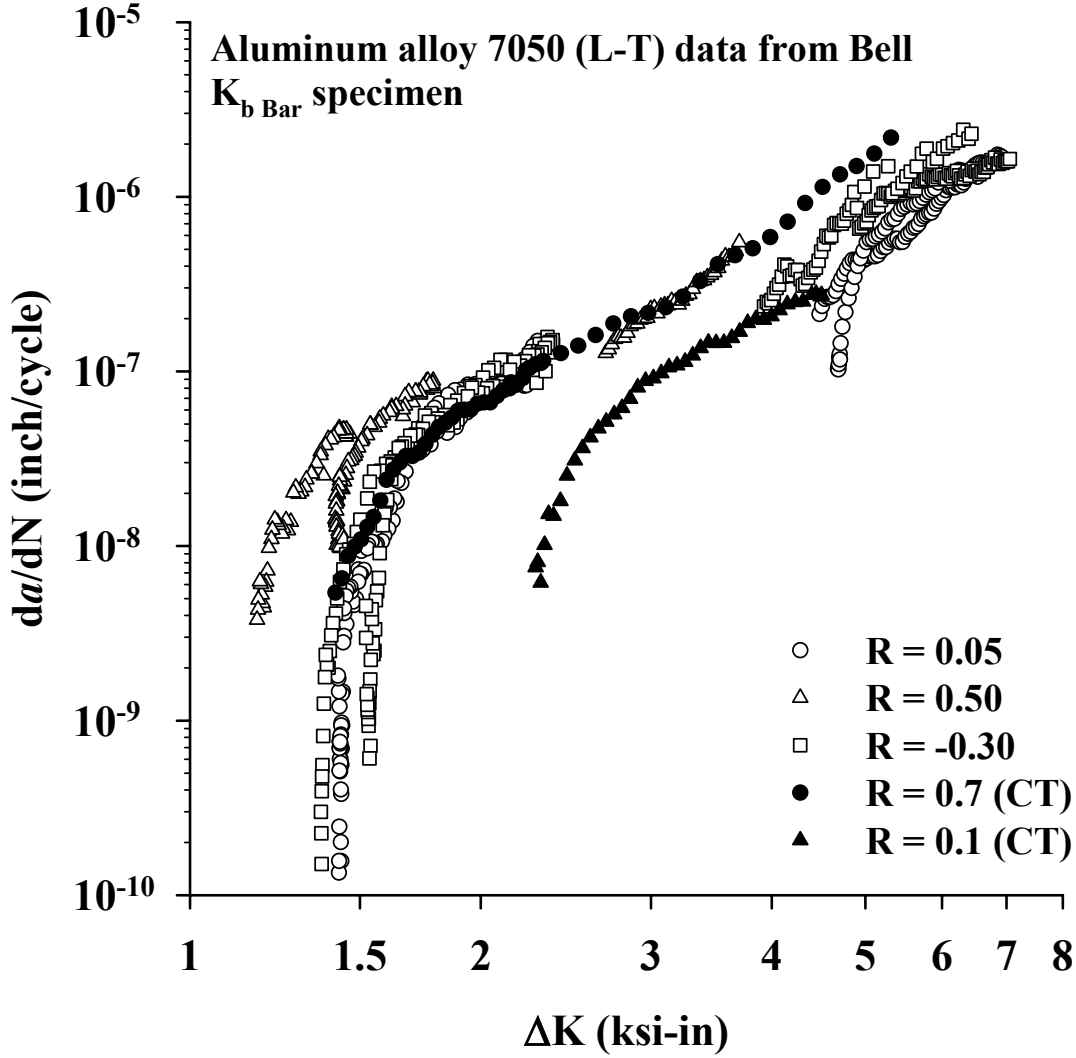


Summary

- Standard testing is essentially complete for all four alloys
- Compression precracking testing is underway
- Increasing threshold with load reduction starting K
  - 7050 Aluminum
  - Ti-6Al-4V Titanium
- K_{max} effect
  - AZ91 Magnesium
  - Ti-6Al-4V Titanium
- 7050 Aluminum bar and plate product forms have about the same growth rates
- Environmental effects as demonstrated for the 4340 should be investigated more
- Notch geometry effects on precrack quality
  - "Large" EDM notch (0.015") often leads to multiple cracks
  - "Small" EDM notch (0.005") seems better (preliminary)
  - Plastic zone size (estimated) of two times the notch size typically results in a single crack

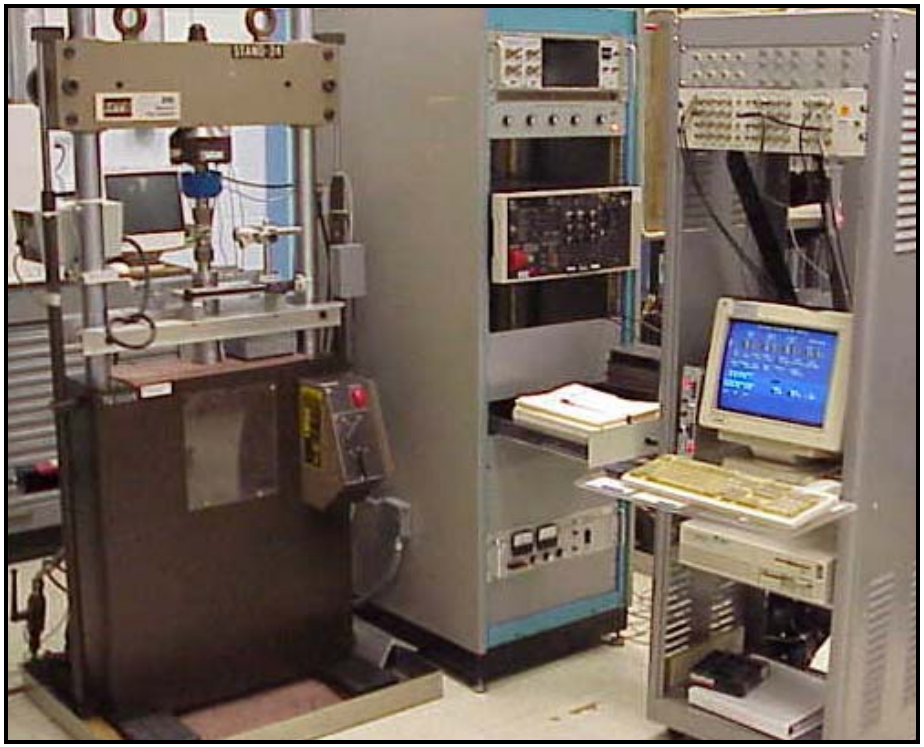
Backup

Comparison of C(T) Data with $K_{b\ Bar}$ Data



Photograph of a Typical Test Setup

- Automated computer-controlled test machine
  - Tests run continuously
- Crack length monitored during tests using back-face strain gage or clip gage
  - Loads continuously adjusted to achieve programmed stress-intensity factors

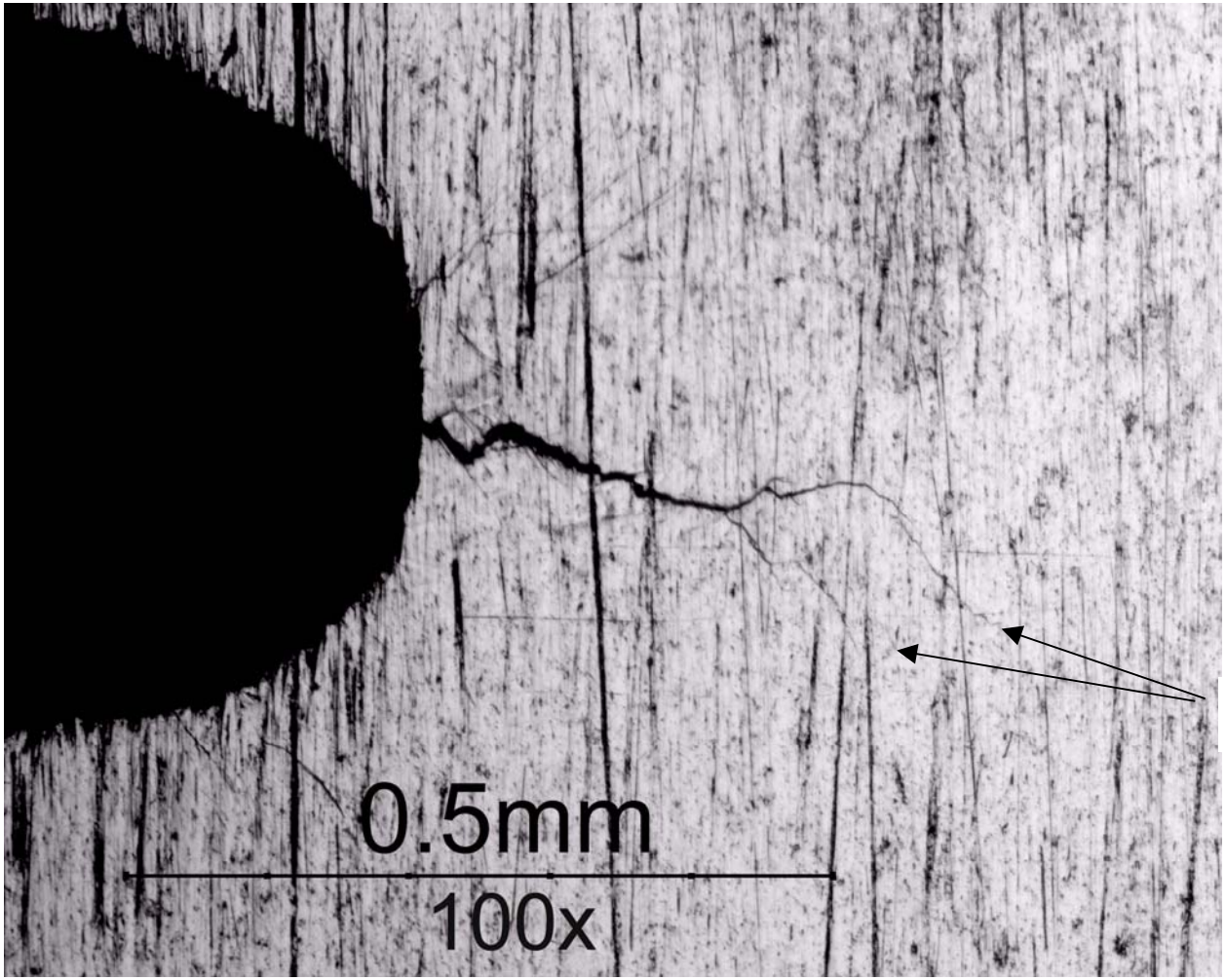


Motivation and Objectives

- **Motivation – Rotorcraft industries:**
  - **Manufacture products and components that must endure a high number of load cycles (high-cycle fatigue)**
  - **Majority of fatigue life spent initiating/propagating small cracks**
  - **Damage-tolerance fatigue life management difficult**
  - **Accurate fatigue crack growth threshold data are essential**

- **Objectives**
  - **To develop fatigue crack growth data needed for damage-tolerance analysis of rotorcraft materials. Special emphasis is given to accurately determining the fatigue crack growth threshold behavior.**
  - **To develop and evaluate compression precracking as an alternative to standard precracking for generating near threshold data**

Typical/Expected Crack Branching in Ti-6Al-4V



Cracks

Ti-4-H2-SideA-100x-001.jpg