Precision Threshold Testing Using the Flat Bottom Hole (FBH) Specimen

Rick Pettit

rgp@fracturelab.com

January 2012

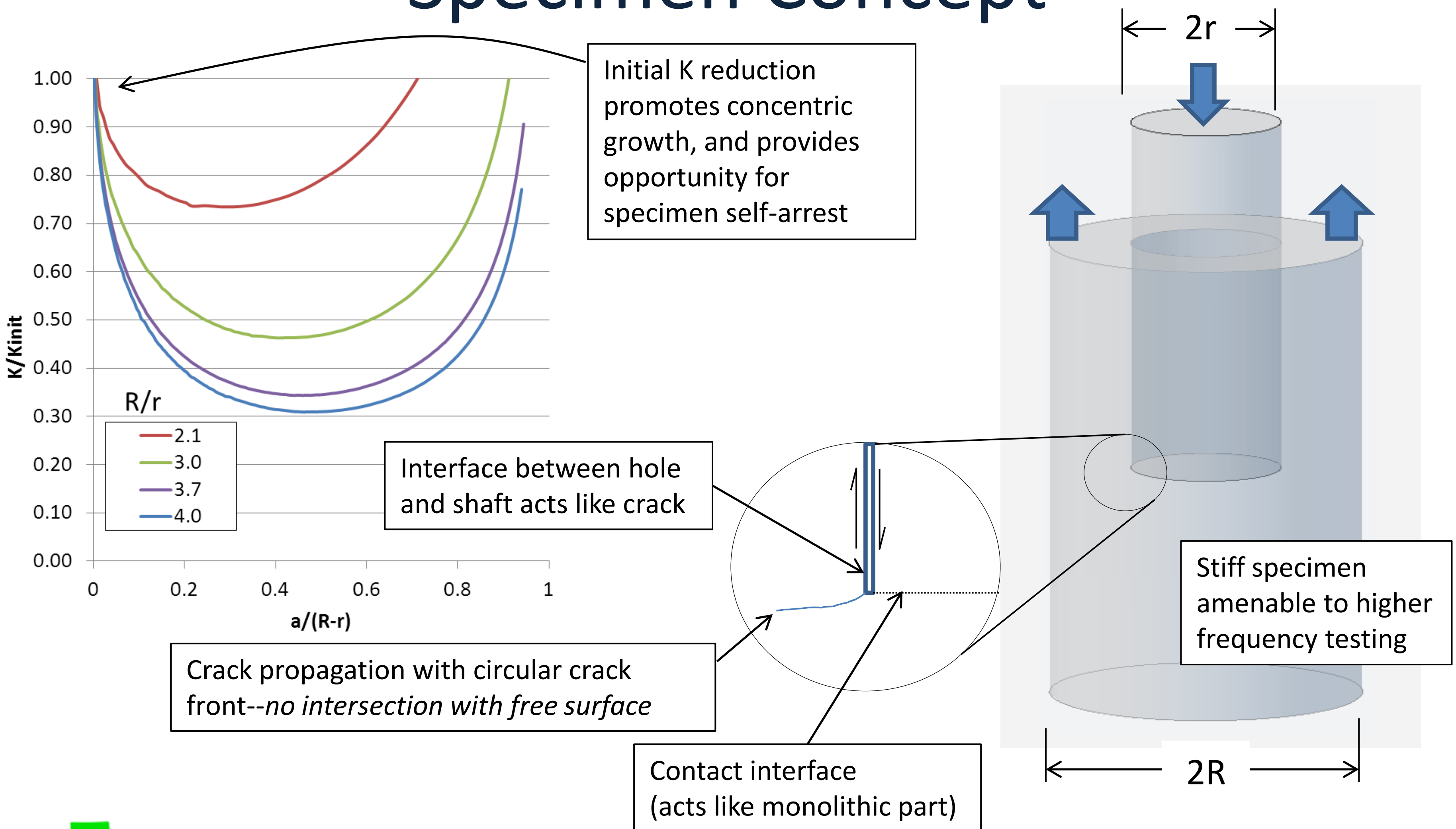
FractureLab

Background

- Crack growth threshold historically prone to overestimation
- New FBH specimen geometry with following advantges
  - No preflaw required
  - K reduces naturally as crack grows
  - Small specimen size (.63 DIA x 1.75 blank)
  - Uniform crack closure state across crack front
    (no free surface intersection)
  - Crack front shape precisely known (circular & self-centering)
  - Stiff specimen loading set-up; enables high testing at high frequency
- Over a year in development
- Initial data looks promising

FractureLab

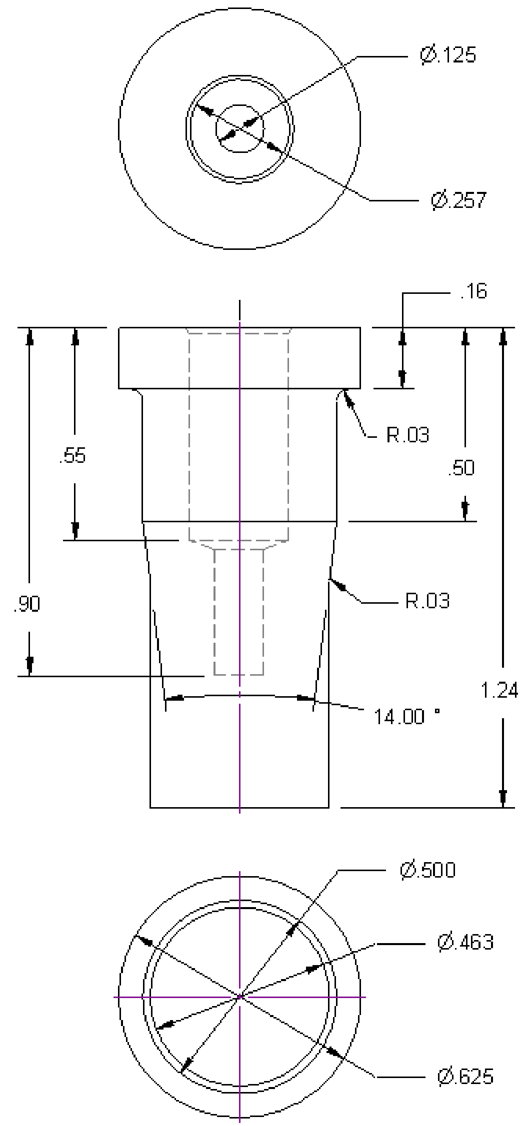
Flat Bottomed Hole (FBH) Specimen Concept



FractureLab

FBH Specimen, R/r=3.7

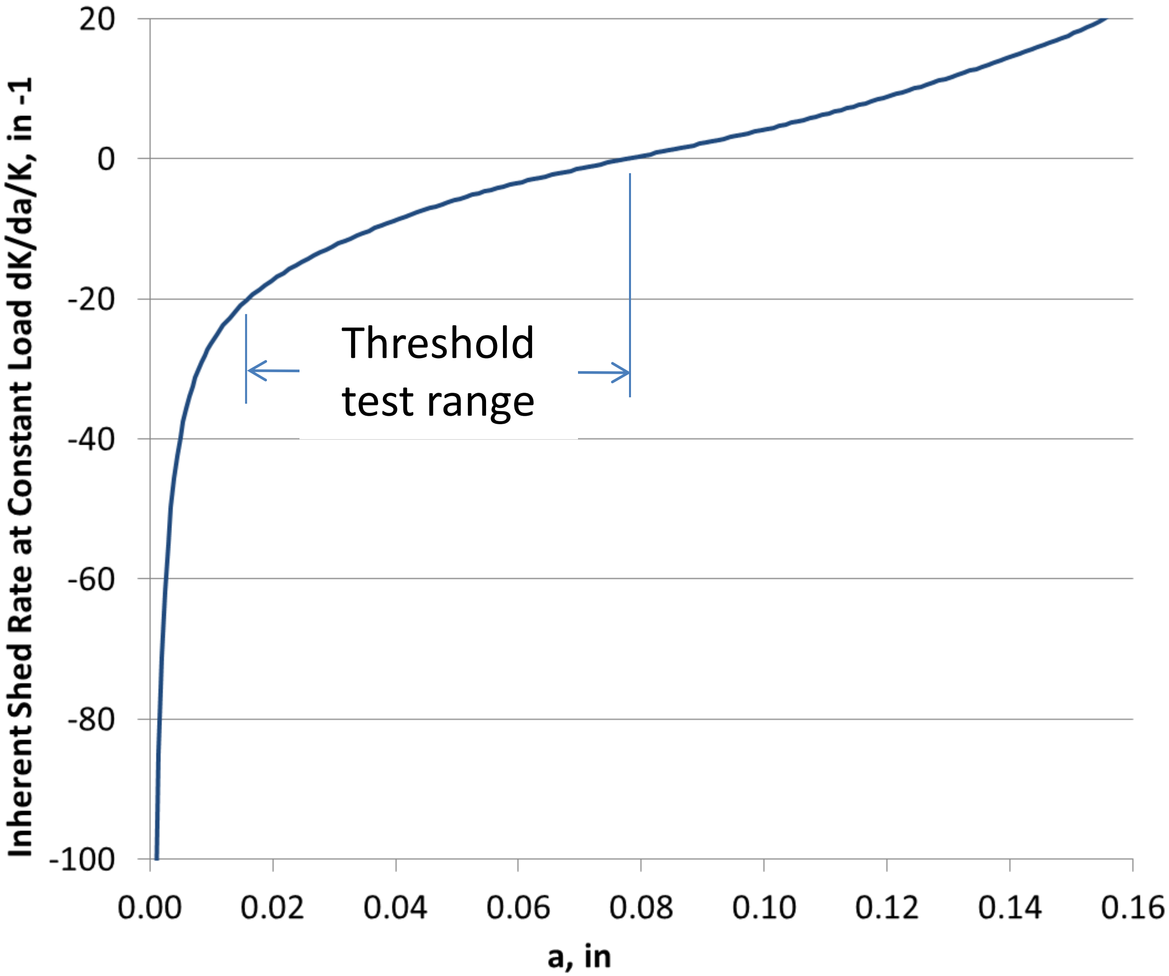
- Small sample size (0.63 DIA x 1.75 blank)
- .34x drop in K
- Can produce 2-3 thresholds/test
- Includes furnace retention shoulder
- K-solution within 0.5%



FractureLab

Inherent K Shed Rate for FBH 3.7

Constant Load

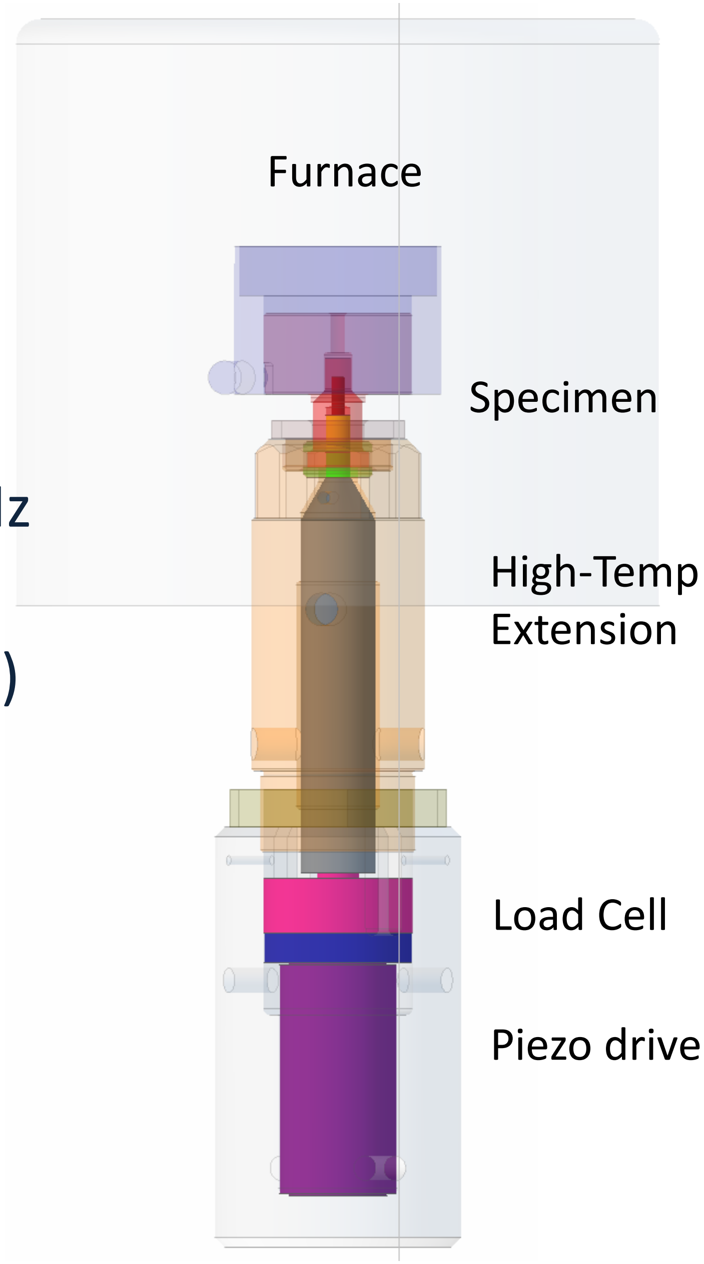


- Fast shed rate when crack is small during precracking
- Specimens with inherent shed rates expected to be more resistant to remote closure
- Thresholds taken at shed rates slower than -20 in^{-1}

FractureLab

Test Rig

- Piezoelectric drive
- High frequency, low load amplitude
  - Test frequencies approaching 300 Hz demonstrated (for highest R-ratios)
  - 3 Kips max load (~1300 P-P variable)
- Integrated heating chamber
  - Up to 1400F
  - Shorter assembly for Room Temp
- Patent pending on rig/specimen



FractureLab

ΔK_{th} Test Procedure Summary

1. Precrack at P_{max}, low R, RT
2. Begin test at P_{max}, highest R, test temperature
3. Run to arrest (crack progress monitored using strain gage metrology on piezo drive)
4. Lower min load to next R
5. Run to arrest

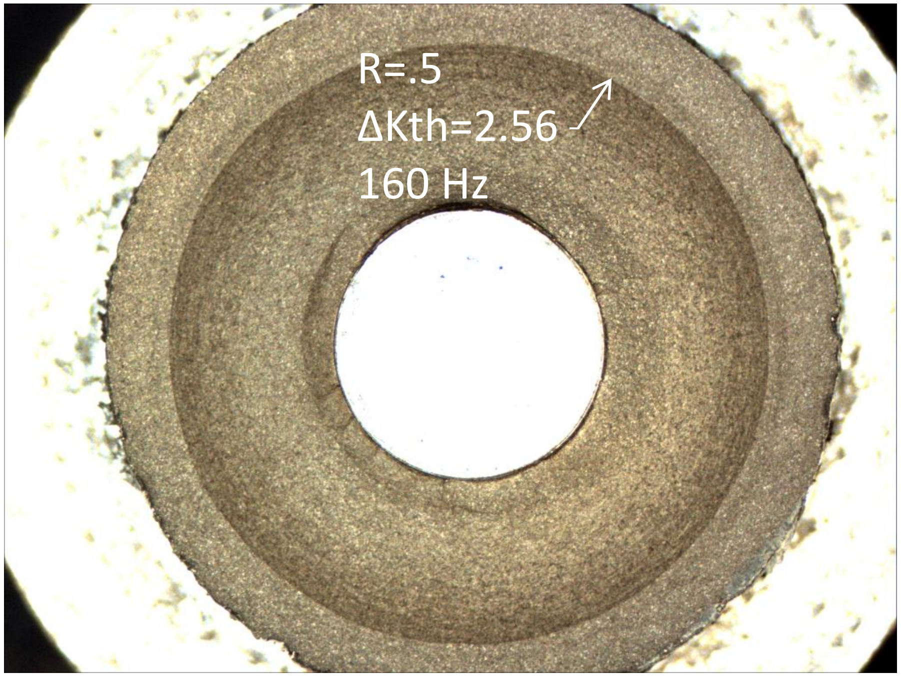
⋮

Test concludes when crack passes min K point on specimen. Increase ΔK and grow to failure.

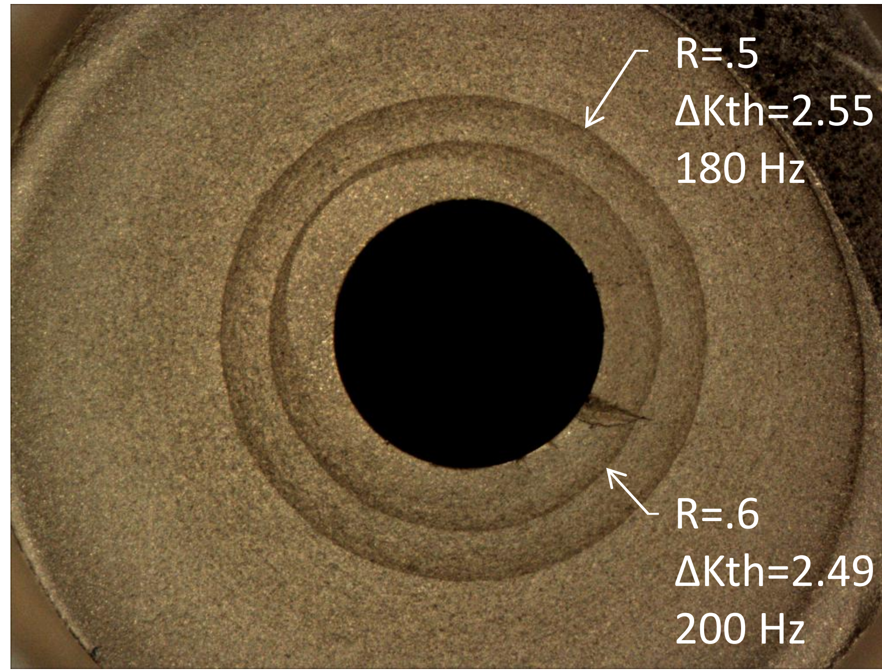
FractureLab

High R-Ratio Test Results

4140 Steel, 132 ksi yield, RT



Specimen #28, 1300 lb. max



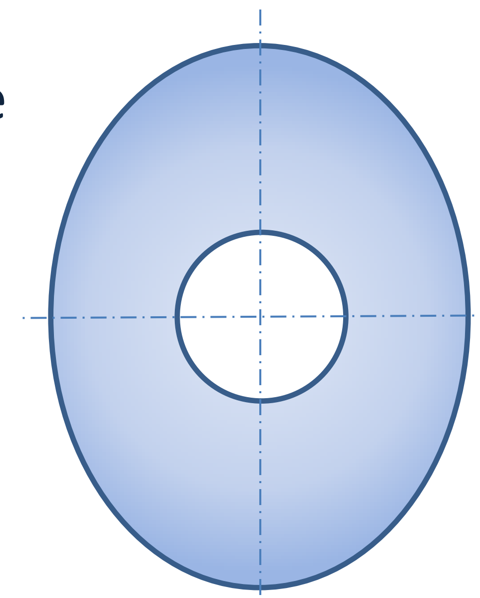
Specimen #29, 1200 lb. max

- ΔK_{th} determined from final crack size
- Highly concentric , circular propagation yields precision results

FractureLab

The FPB and Anisotropic Materials

- Arrested crack at threshold will not in general be circular for anisotropic materials
- ΔK_{th} determined from final crack size and shape can be a function of orientation, producing results for **all orientations within the plane of the crack**
- The stress intensity distribution can be determined for the crack shape using a 3D fracture code such as Franc3D



FractureLab

Summary

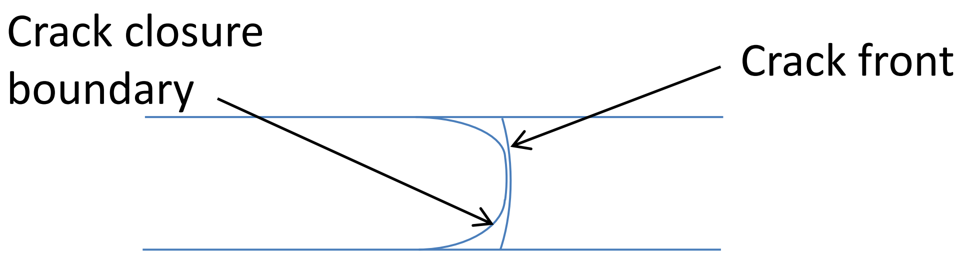
- FBH testing provides high precision, reproducible crack growth threshold data at >100 Hz
  - Small specimen size (.63 DIA x 1.75 blank)
  - Uniform crack closure state across crack front
    (no free surface intersection)
  - Crack front shape precisely known (circular & self-centering) for isotropic materials
  - Crack shape for anisotropic materials can be used to characterize anisotropy

FractureLab

Backup Slides

Free Surface Effect on Closure

- Schijve* and others have observed that crack closure is concentrated near where the crack front intersects a free surface.



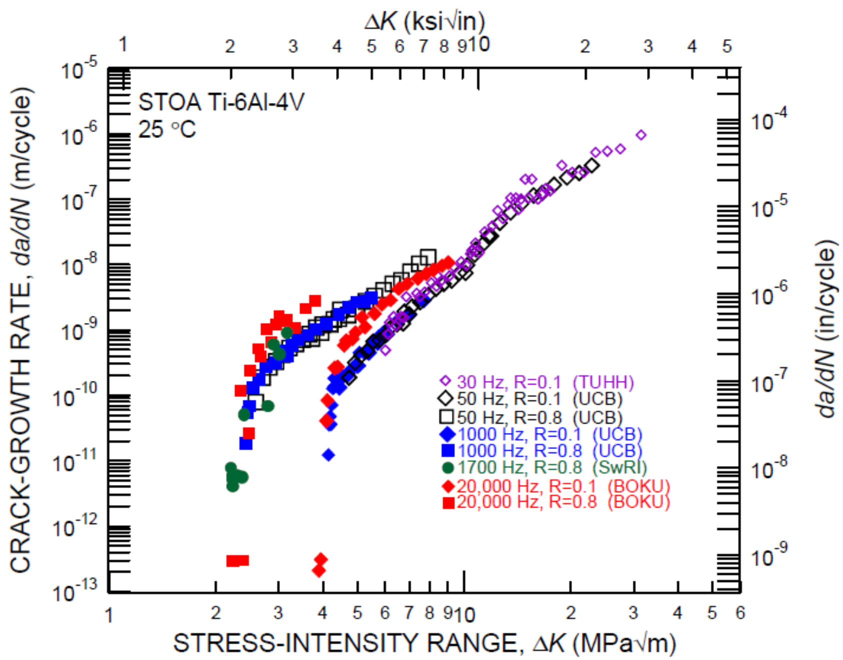
- A specimen configuration without a free surface intersection would have a uniform closure state, eliminating a potential source of specimen dependence, and better simulate cracks in thick structures

*ASTM STP 982, pp. 5-34, 1988

FractureLab

Frequency Effect on Threshold

- ΔK_{th} typically drops as test frequency is increased, often approaching a limiting value.
- "High frequency" threshold data is commonly run at 10-30 Hz.
- Higher test frequencies would be more cost effective, closer to HCF conditions, and perhaps slightly more conservative.



Ritchie, R. et al, *High-cycle Fatigue And Time-dependent Failure In Metallic Alloys For Propulsion Systems,* UCB/R/99/A1167, 1999. (see *www.lbl.gov/ritchie/Programs/URI/PDFs/99AnnualRep.pdf)*

FractureLab