SRI International, Menlo Park, CA

CENTER FOR FRACTURE PHYSICS

Observing, Measuring and Modeling Microstructural Failure

D. A. Shockey, J. W. Simons, T. Kobayashi, B. D. Peterson

Predicting Crack Growth in Turbine Disks

Fracture Physics Approach

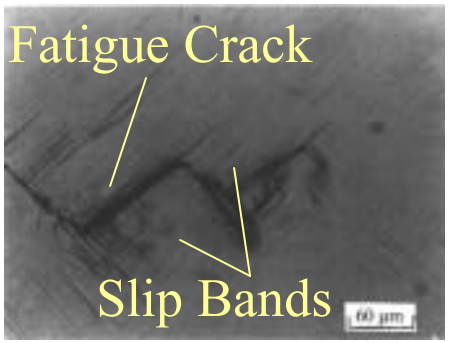
- Determine operative damage mechanisms
  - Examine failed parts
- Perform laboratory tests
  - Control conditions, Isolate each mechanism, Interrupt test
- Quantify damage
  - Count and measure
- Mathematically describe failure evolution
  - Use observations and data
- Simulate lab tests
  - FE code, Iterate
- Simulate field failure
  - Validate, simplify

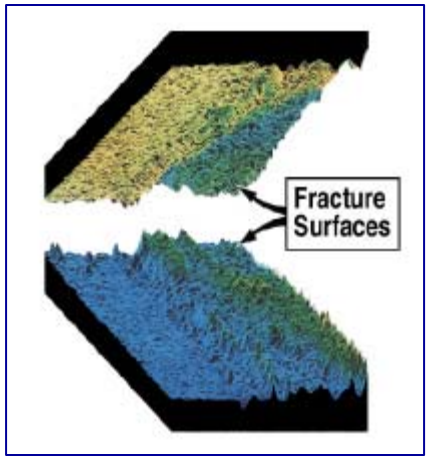
Approach for Fatigue Cracking

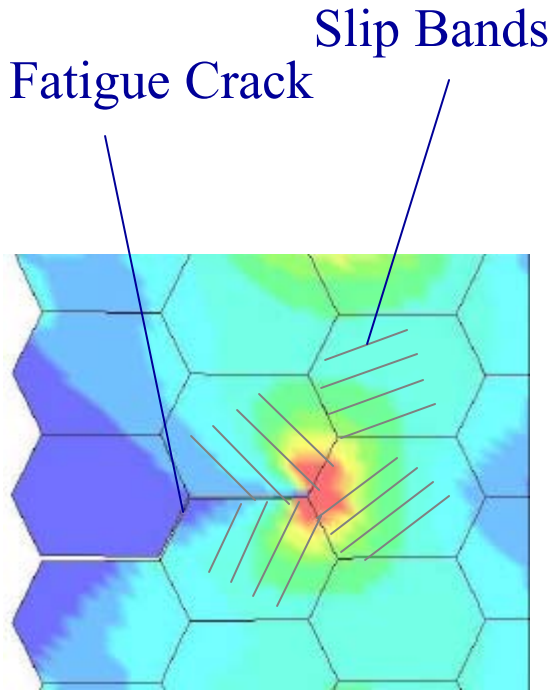
Observe and quantify microstructural deformation and failure through metallography and fractography.

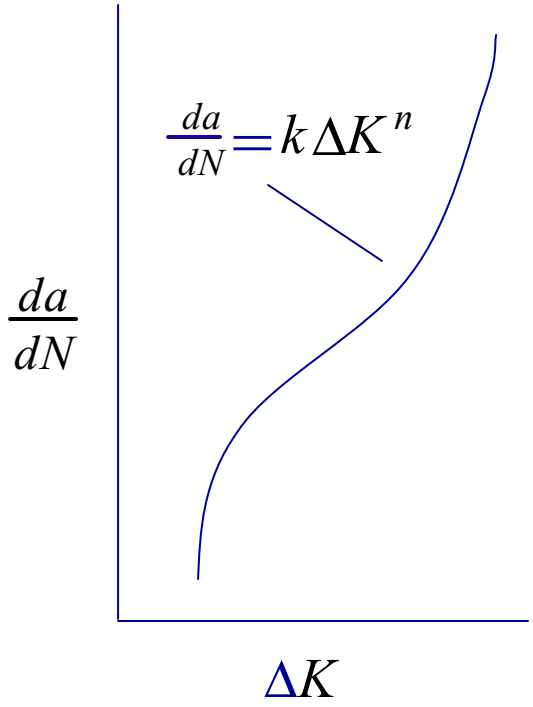
Use experiments to model damage development at fatigue crack front using finite element methods.

Use the model to compute crack growth rate, interpret and predict engineering parameters under service spectra.



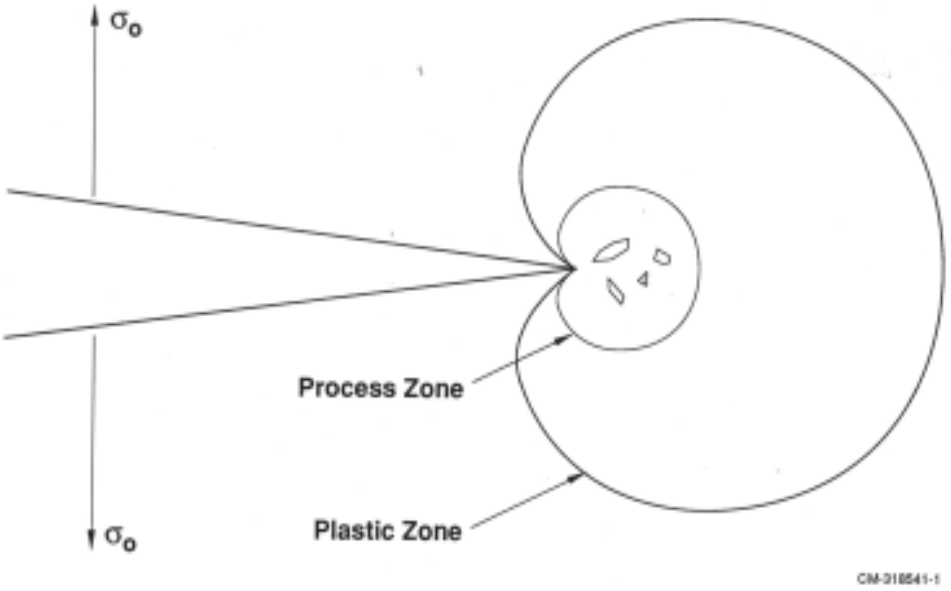




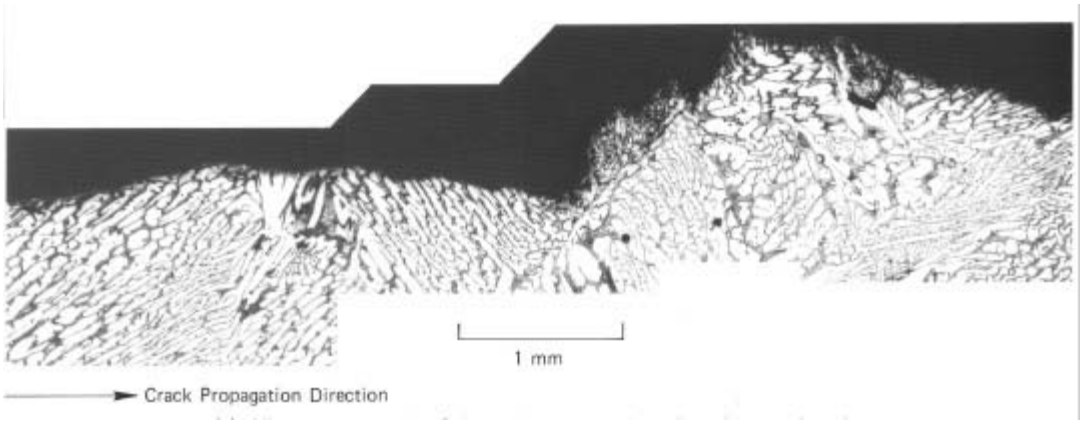


Understanding the Physics of Failure

- Material fails in a small zone at the crack front
- Material elsewhere is unaffected

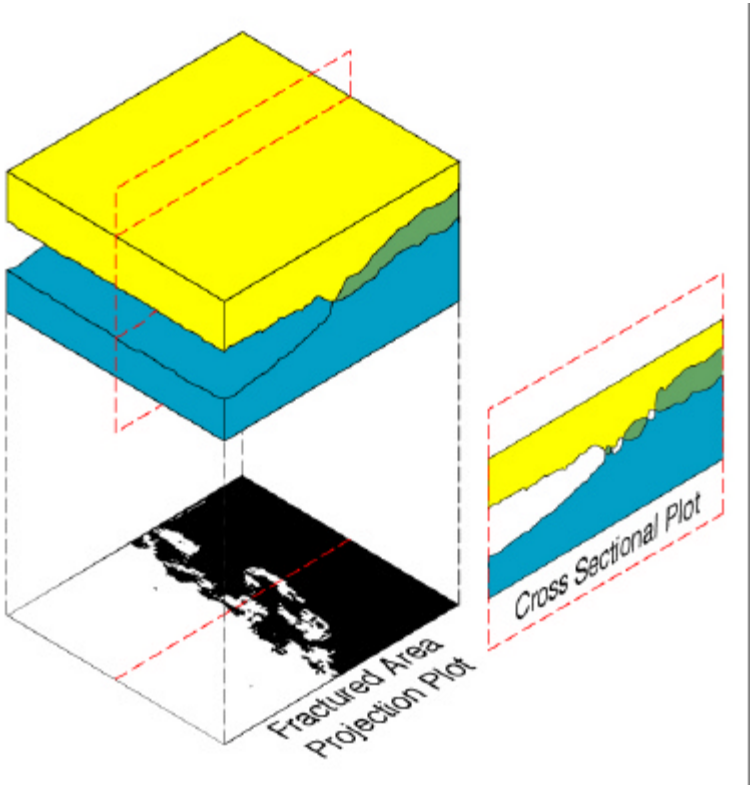


- Fracture surfaces hold critical failure information
- Crack history and load history



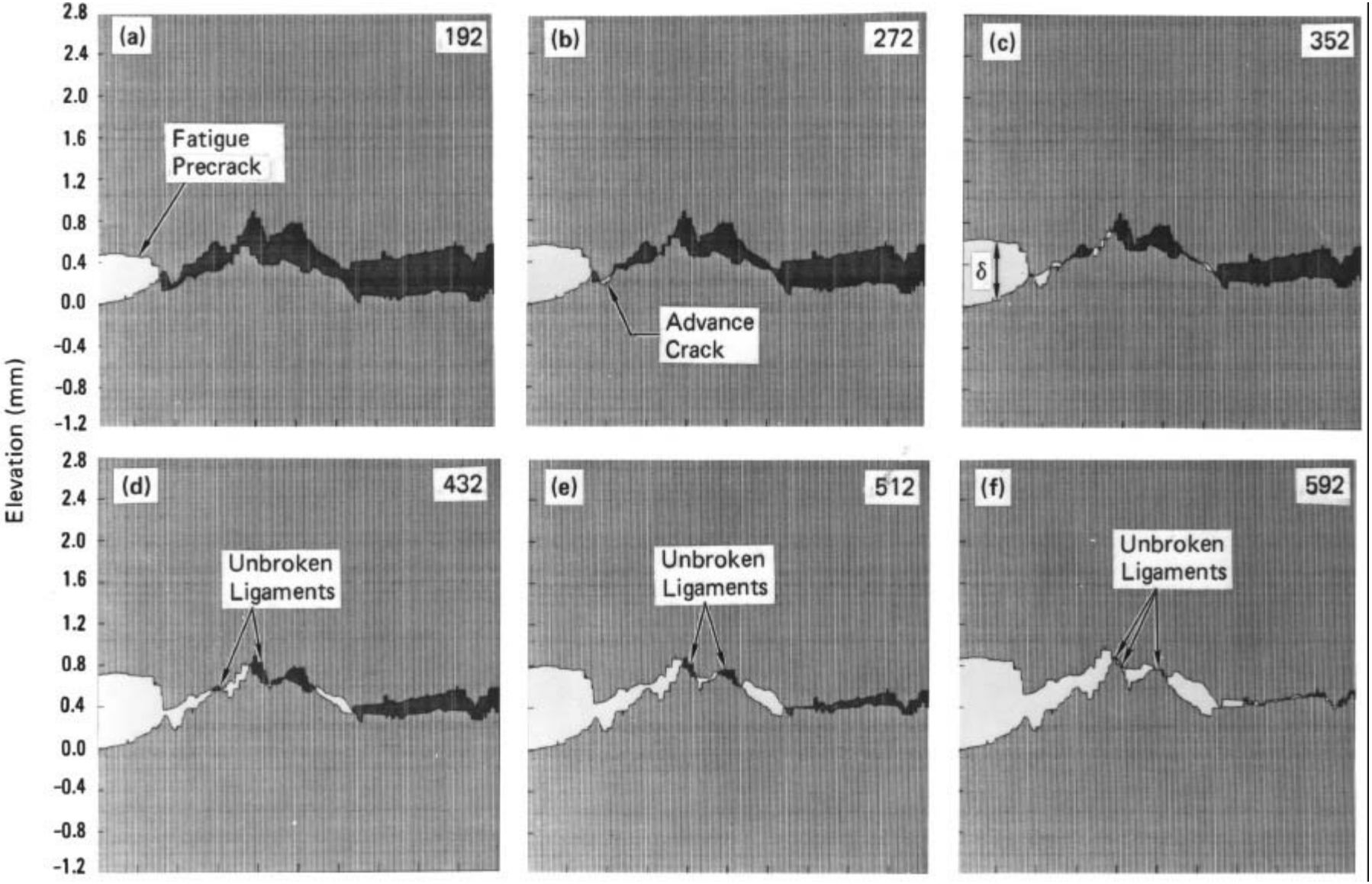
FRASTA (FRActure Surface Topography Analysis)

- A major advance in fractography
- Allows a failure event to be replayed in detail
- Provides often unobtainable mechanistic information
- Can detail the history of a crack
- Estimate load parameters



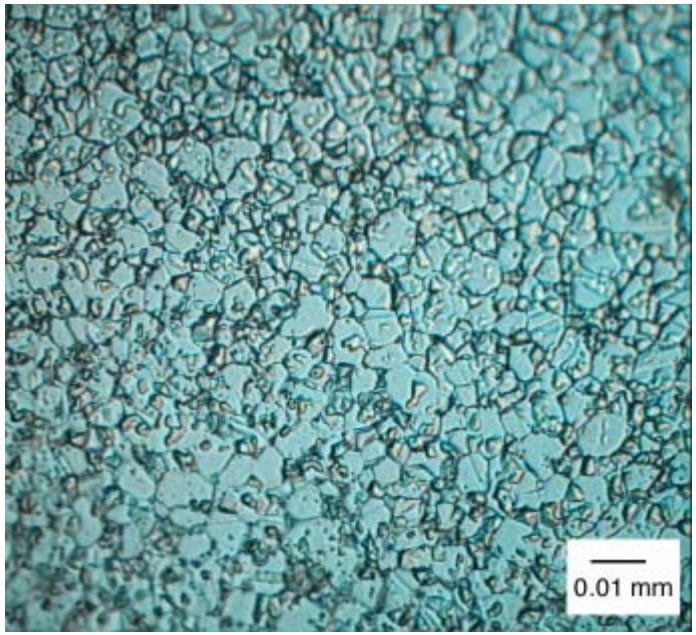
FRASTASCOPE

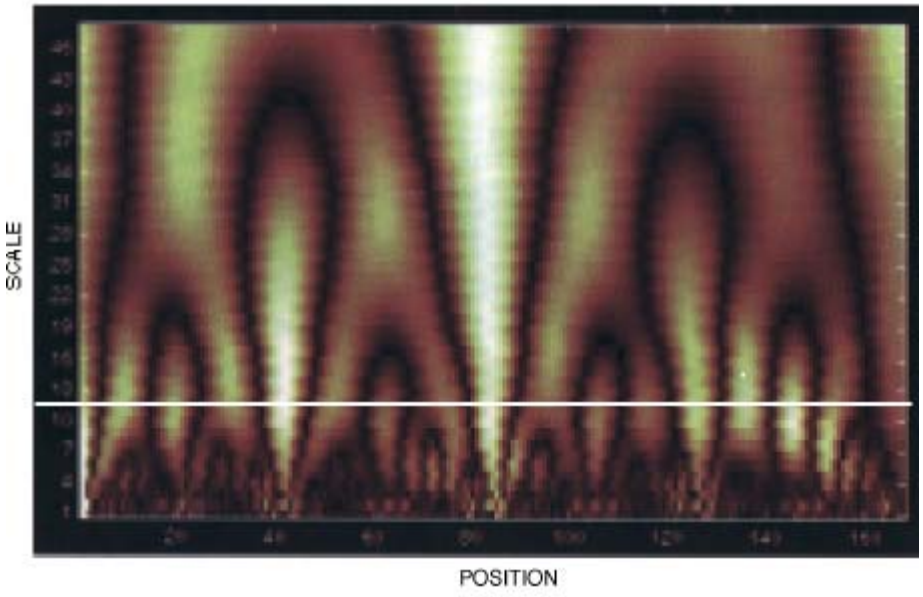
Computer reconstruction of crack tip damage development

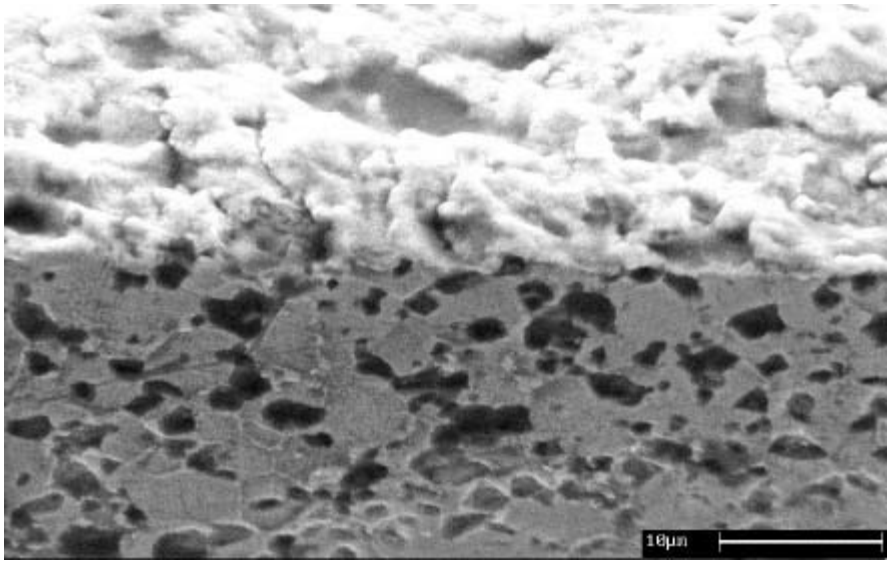


Microstructure and Fractography

- Grain shape and size
- Crystal orientation
- 2nd phase particles
  - different sizes
- Chemical composition
- Wavelet analysis of fracture surface





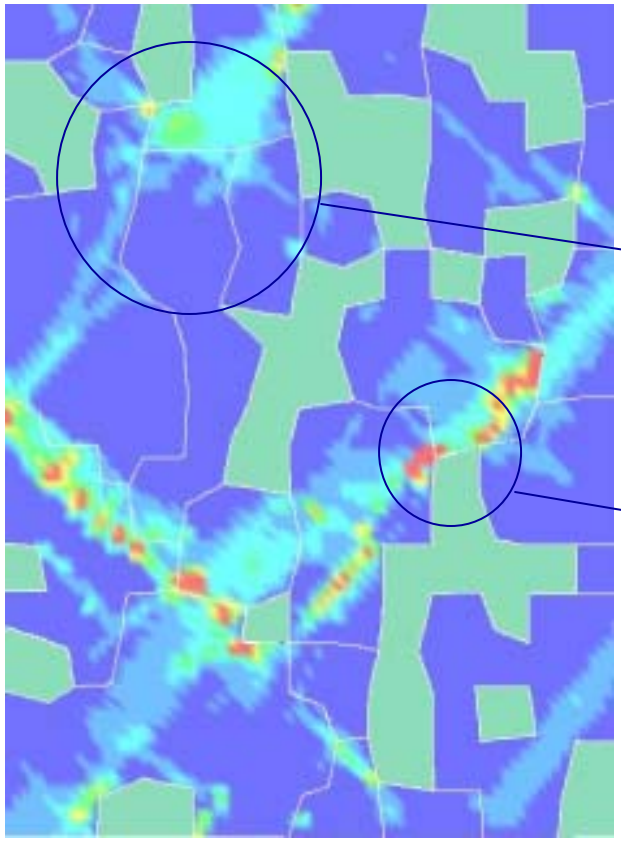


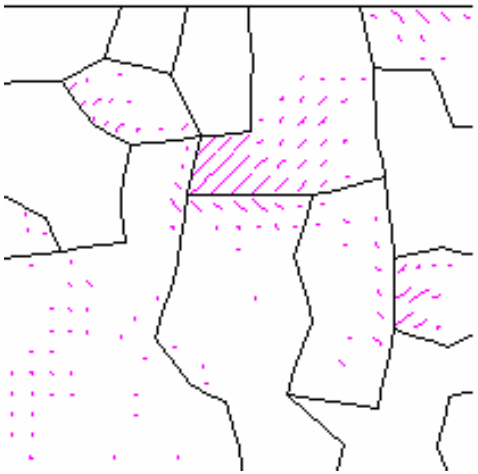
Advanced Finite Element Analysis of

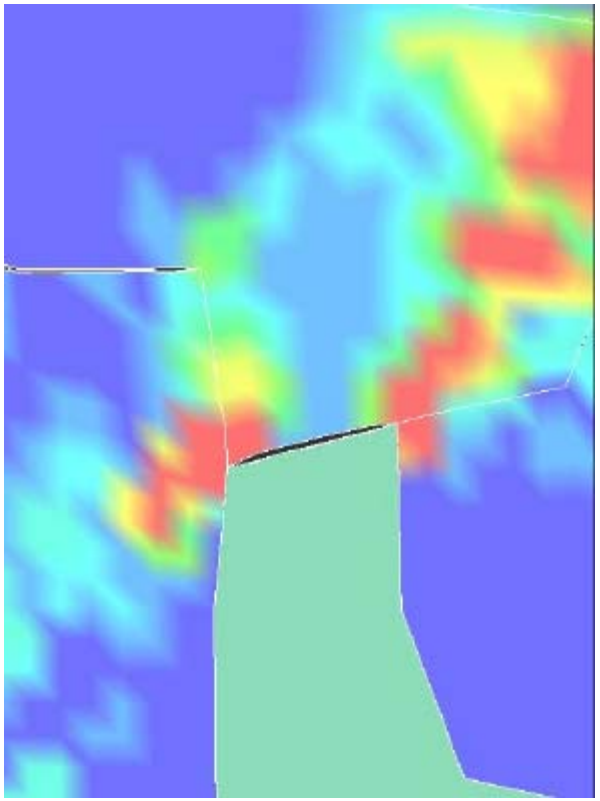
Calculated strains in microstructure

Calculated slip bands in grains

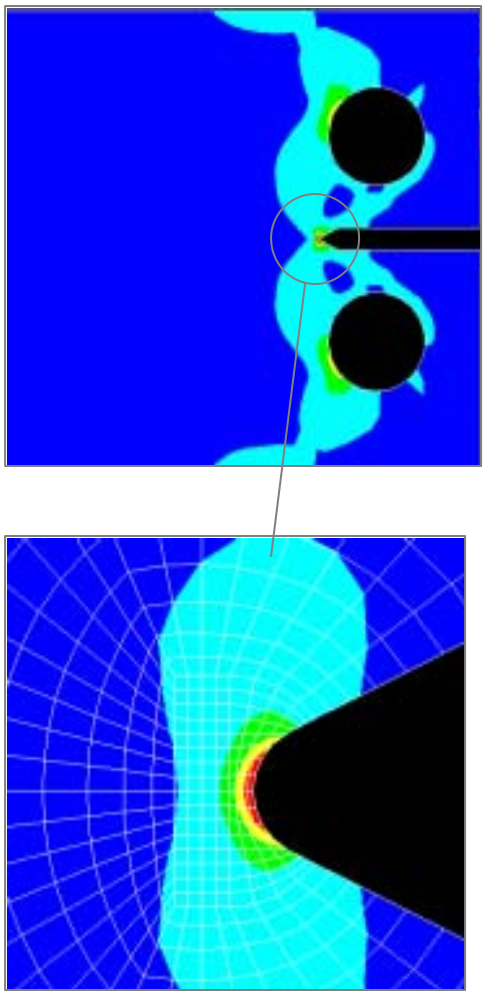
Microstructural failure; fatigue crack growth







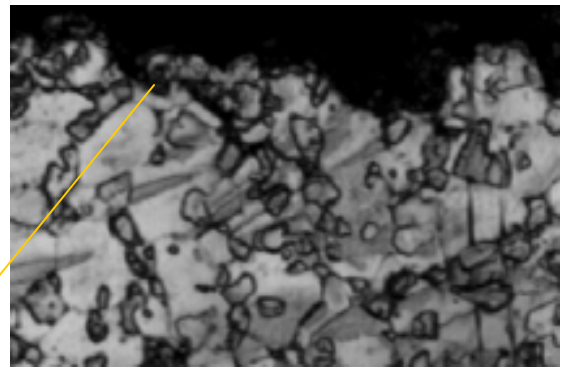
Material Damage and Failure

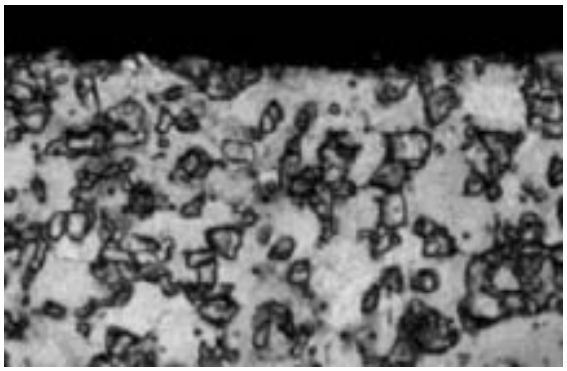


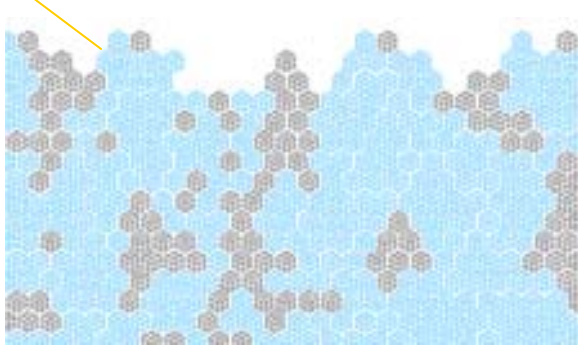
Compact Tension Specimen

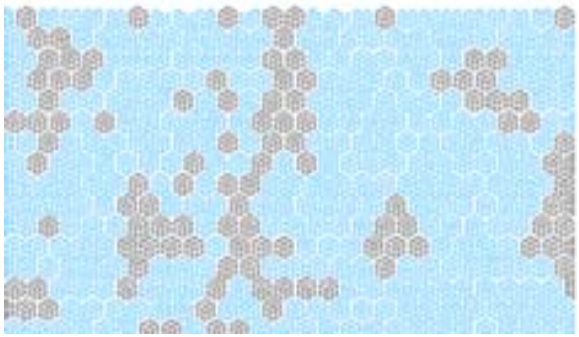
Modeling of fracture surface formation

Fracture surface









Low frequency cycles:
crack follows grain boundaries

High frequency cycles:
crack cuts through grains

Summary

- Failure is a gradual process
  - Failure EVOLVES over time
  - By the NUCLEATION, GROWTH, AND COALESCENCE of DAMAGE FEATURES in the microstructure
  - Such as MICROCRACKS, PITS, SHEAR BANDS, etc
- There is time to act to prevent failure
  - Asset readiness can be assessed
- Physics-based models are needed
  - Treat operative damage mechanisms
  - Quantify damage features
  - Compute evolution kinetics
  - Merge with conventional predictive methods