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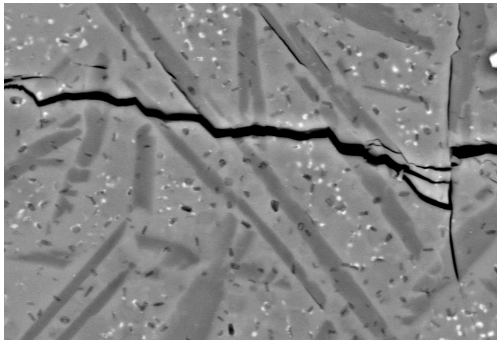

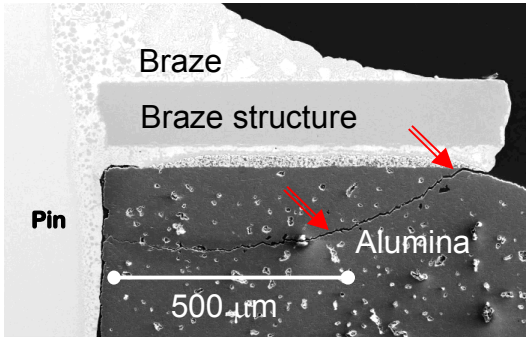

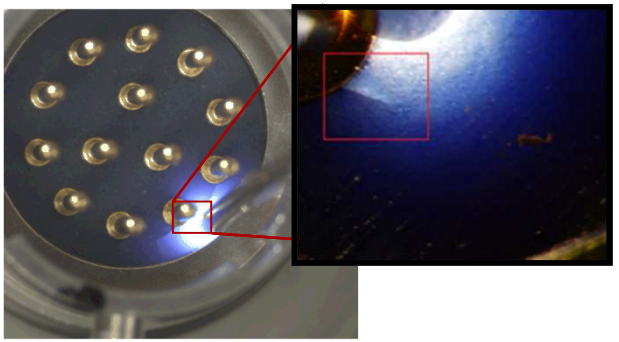

Slow Crack Growth Behavior in Glass-Ceramics

Strong, K.T.; Newton, C.; Wilson, M.; Chandross, M.; and Ewsuk, K.E.

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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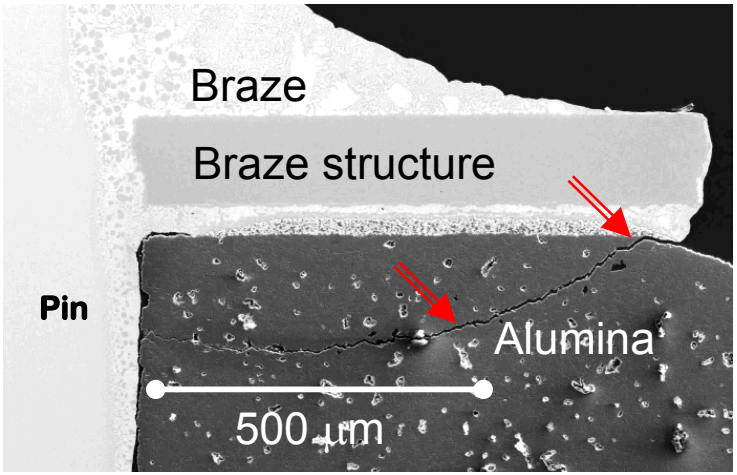
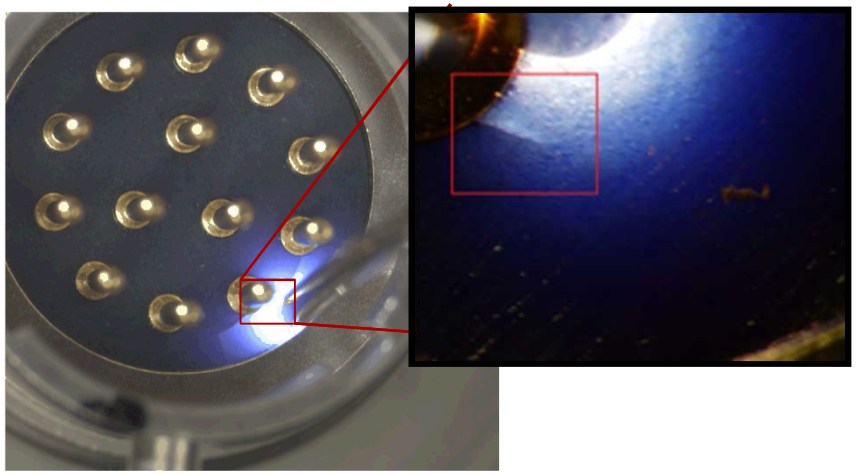
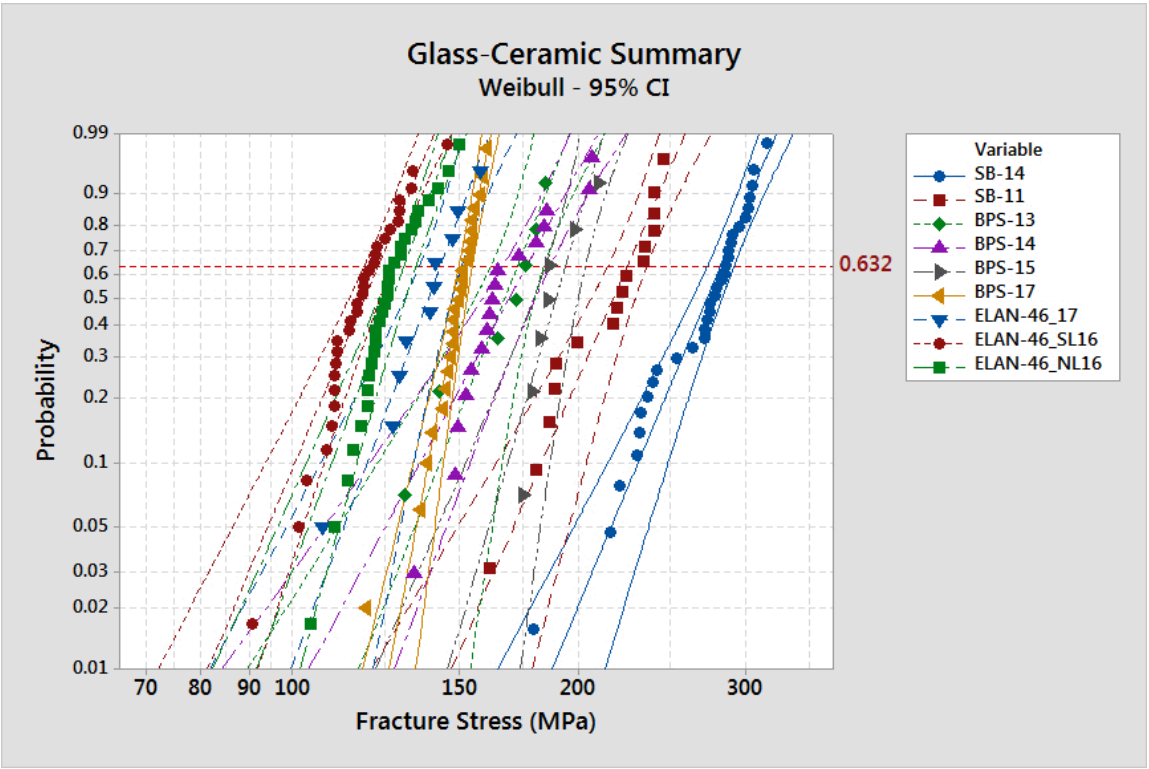
Fracture related problems

- Need predictive mechanistic models to determine
  1) How and where will a crack initiate?
  2) How long until an existing crack causes failure?

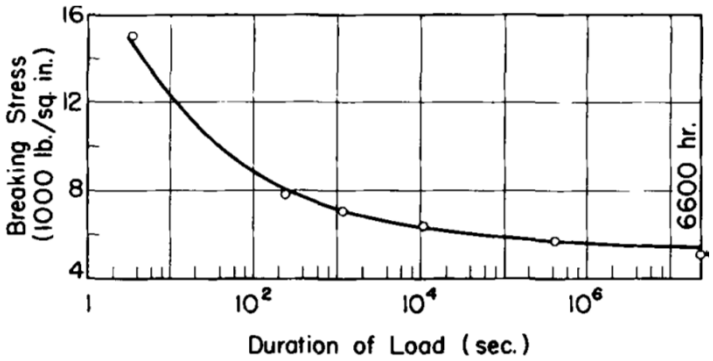




Lifetime Predictions Must Account for Environmental Effects (e.g. Slow Crack Growth)



Delayed Failure

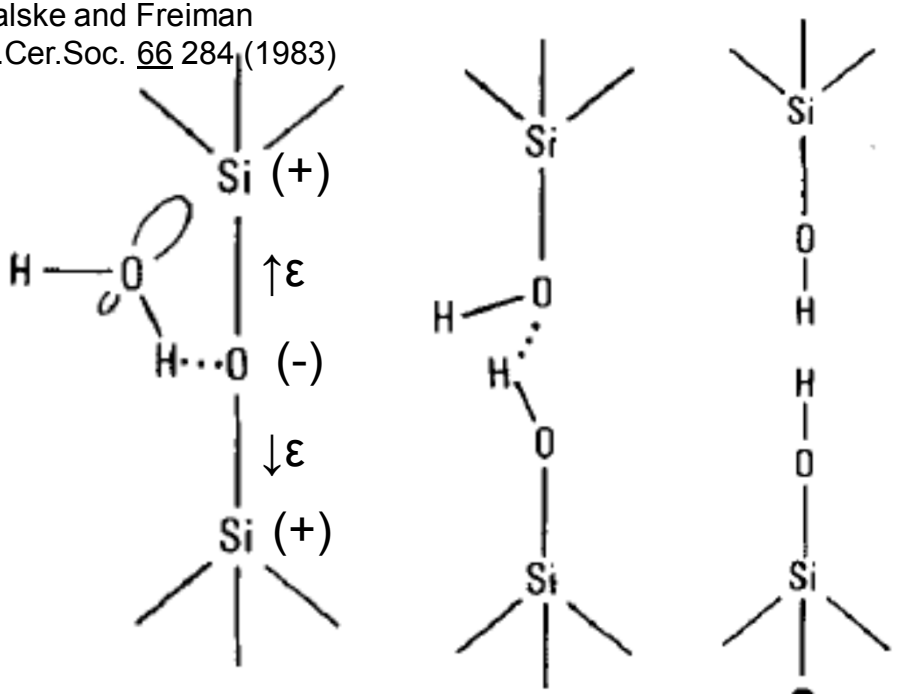


Shand, J. Am. Ceram. Soc. (1954)

Need to account for environmental effects.
Slow Crack Growth

Molecular Mechanisms for Slow Crack Growth Effects

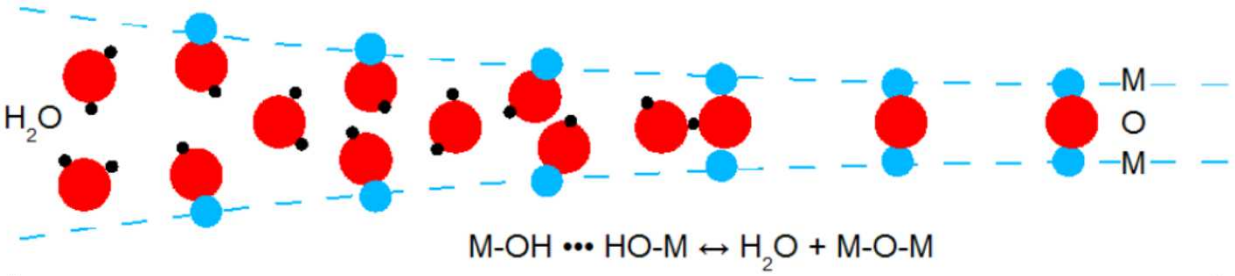
Michalske and Freiman
J.Am.Cer.Soc. 66 284 (1983)



Two potential kinetic processes

1) Reaction Kinetics between environmental species and crack tip

2) Transport Kinetics of the environmental species to the crack tip



R. Cook, BrittMAPP Review 2015

Dynamic Slow Crack Growth (SCG) Parameters Are Being Determined Empirically

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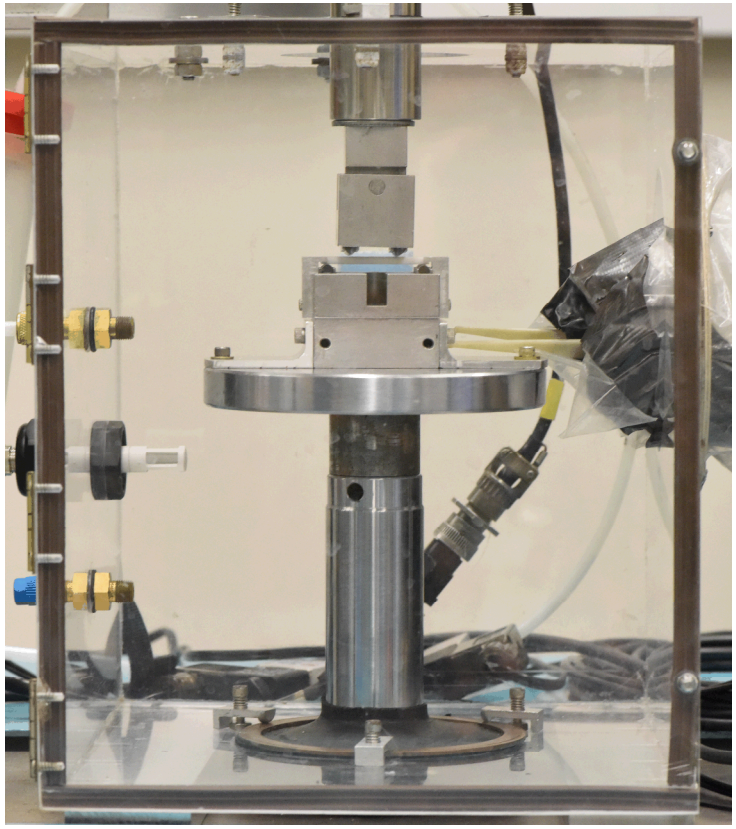
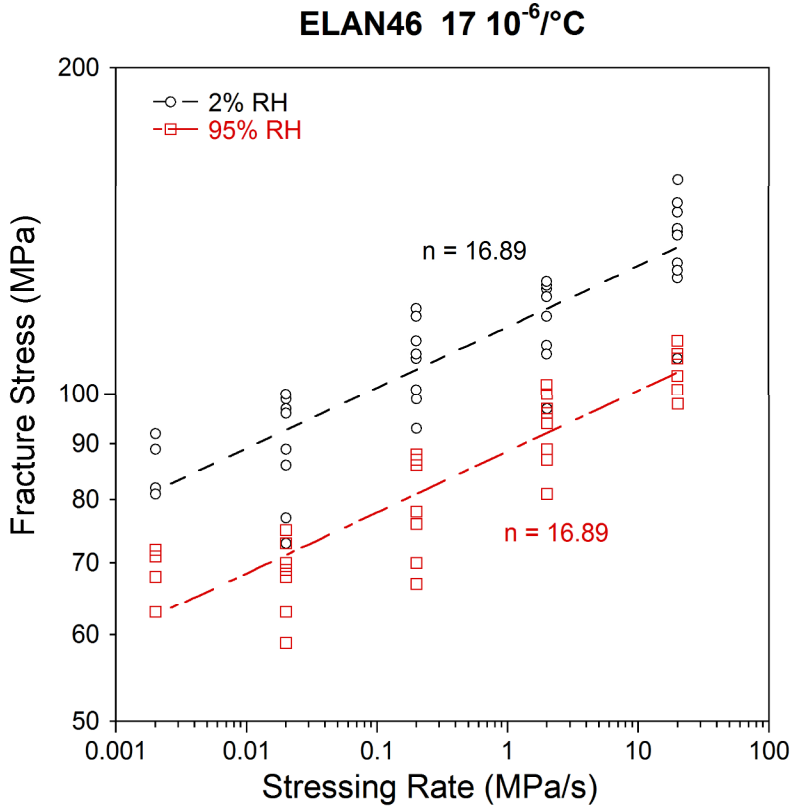
ASTM C1368

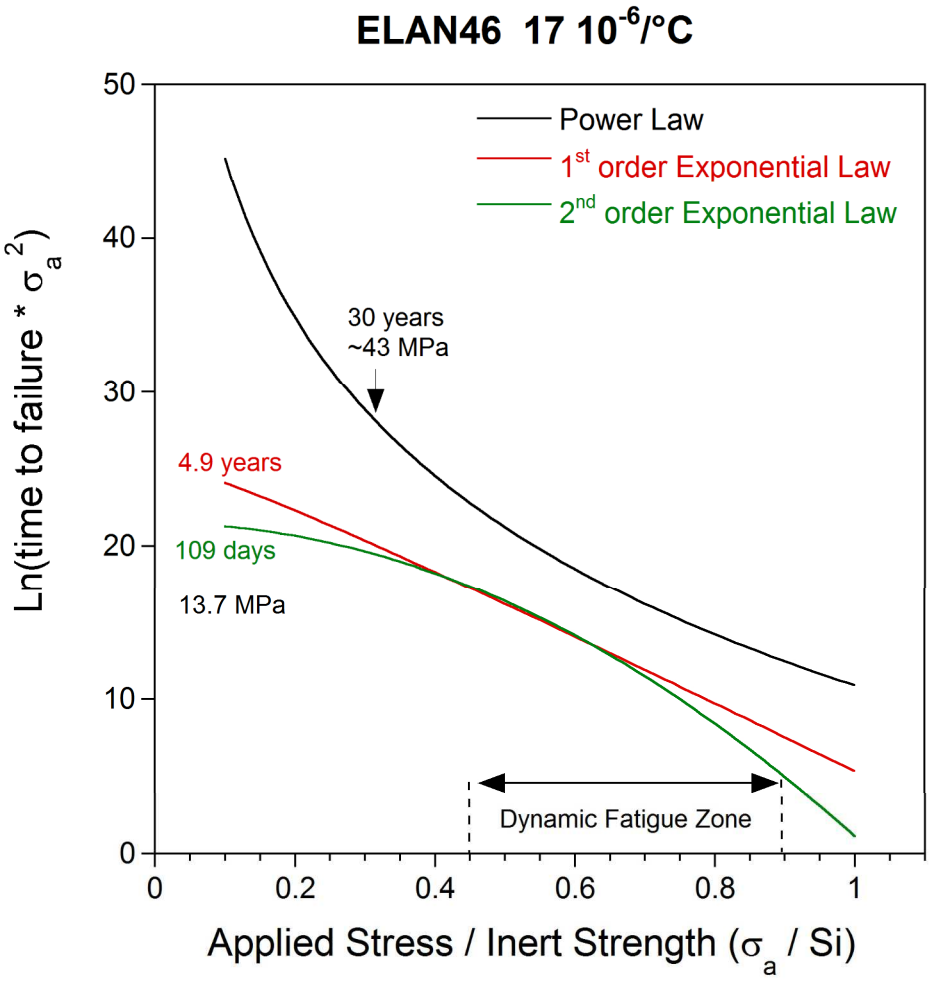




$$v = \frac{da}{dt} = AK_I^n = A^* \left[\frac{K_I}{K_{IC}}\right]^n$$

$$\log \sigma_f = \frac{1}{n+1} \log \dot{\sigma} + \log D$$

A Representative Crack Velocity Model is Required For Reliable Lifetime Predictions



Crack Velocity Formulas

Power Law

$$v = A_1 \left(\frac{K_I}{K_{IC}} \right)^{n_1}$$

1st order Exponential Law

$$v = A_2 \exp\left[n_2 \left(\frac{K_I}{K_{IC}} \right) \right]$$

2nd order Exponential Law

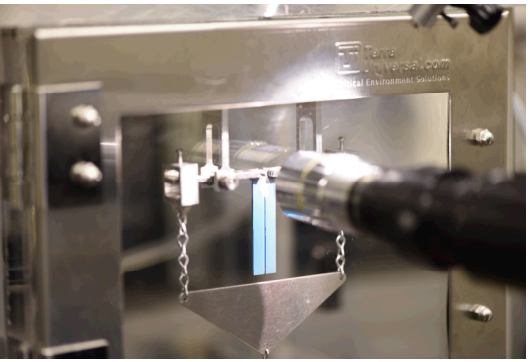
$$v = A_3 \exp\left[n_3 \left(\frac{K_I}{K_{IC}} \right)^2 \right]$$

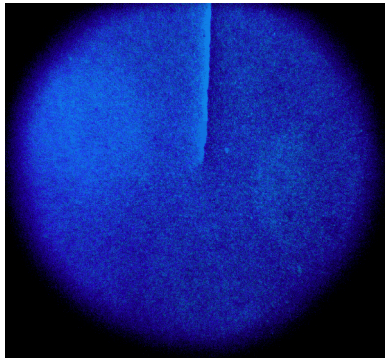
Lifetime Prediction Formula

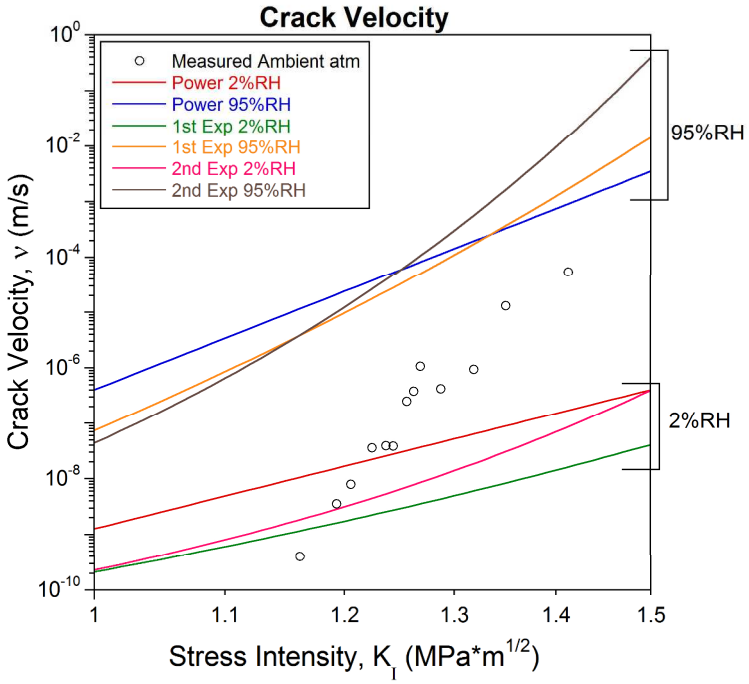
$$t_f = \frac{2}{\psi^2 \sigma_a^{\,2}} \int_{K_{1i}}^{K_{1C}} \frac{K_1}{v(K_1)} dK_1$$

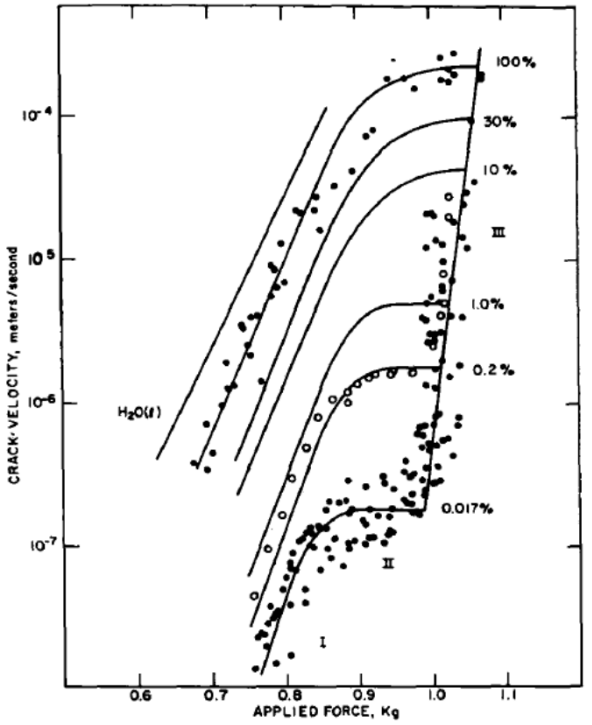
Significantly different lifetimes are predicted with different crack models

Crack Velocity Measurements Will Help Determine Appropriate Crack Velocity Model







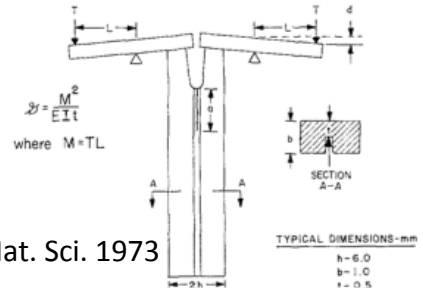


Wiederhorn, J.Am.Cer.Soc., **50** 407 (1967)

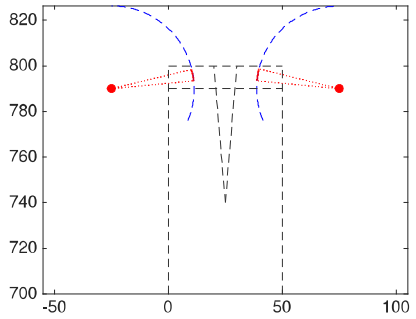
Need a better mathematical representation of crack velocity.

SCG: First-principles calculations for mechanistic investigation

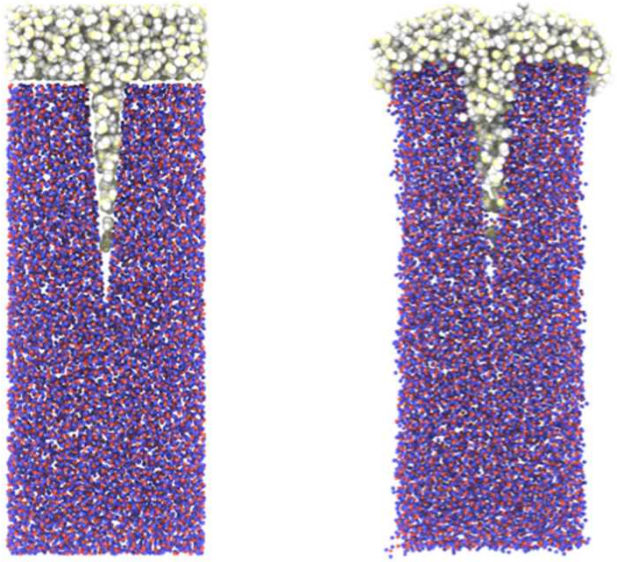
- Developing capability to simulation constant moment crack propagation experiments
- Constant moment implies constant stress intensity factor (K_I) at crack tip
- Measure crack velocity versus K_I and compare to experiment (quartz, amorphous silica, glass ceramics)



Frieman et al, J. Mat. Sci. 1973



Measured forces from MD simulation



Simulations of constant moment applied to amorphous SiO_2 with existing crack and water layer

Developed Crack Growth Models That Are Experimentally Validated

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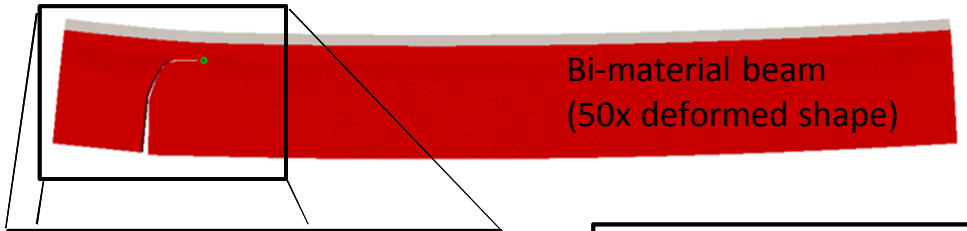
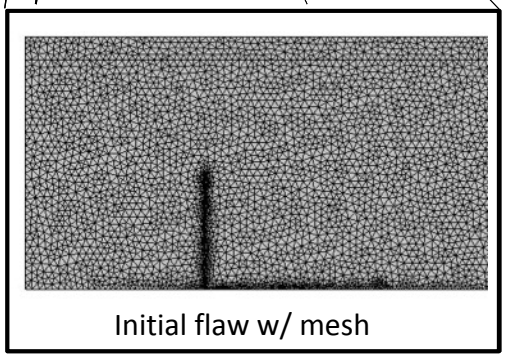
Bimaterial Beam

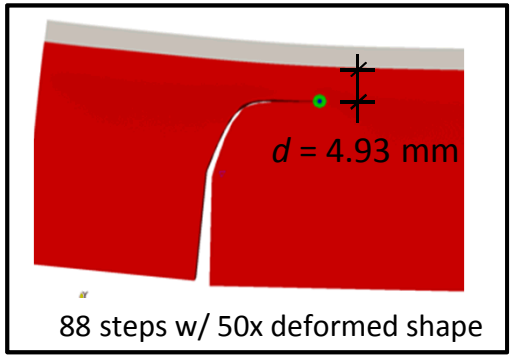
Initial crack normal to bottom edge



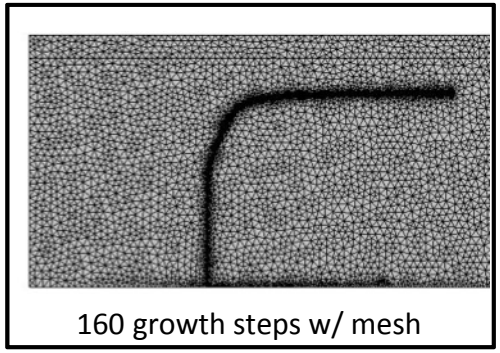
experiment



Initial flaw w/ mesh



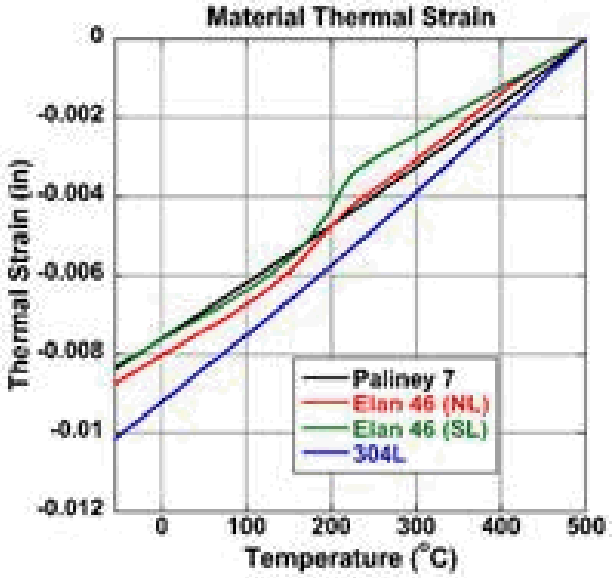
88 steps w/ 50x deformed shape

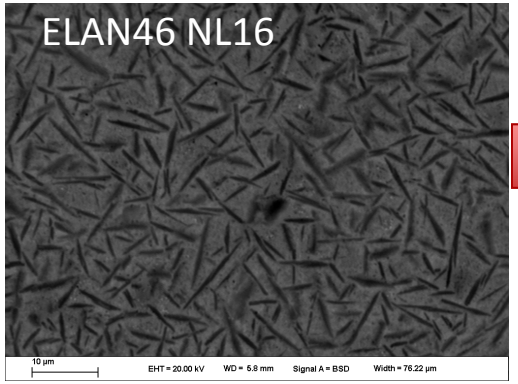


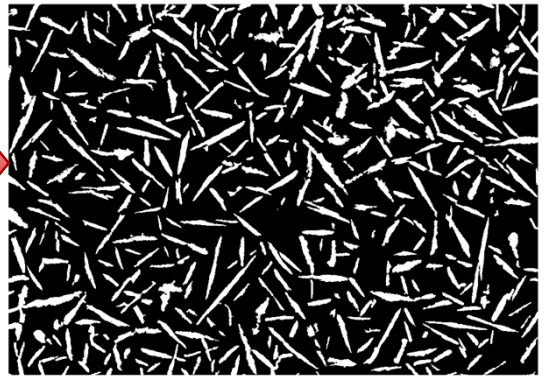
160 growth steps w/ mesh

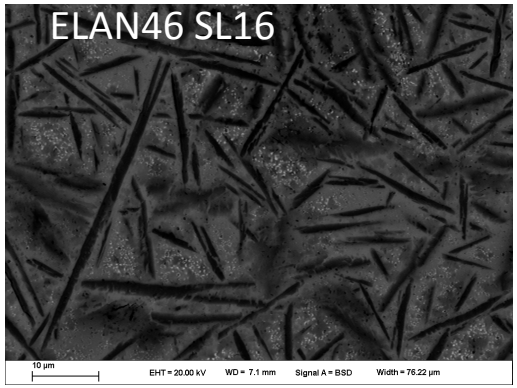
We need to incorporate environmental parameters into crack models.

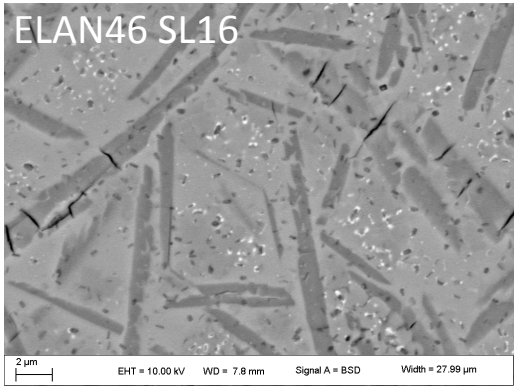
We Also Need to Determine How Microstructure Affects Properties & Crack Velocity











Glass-Ceramic microstructure/variability can affect failure/predictions

Summary

- Environmental effects have a significant impact for lifetime prediction of components
- Need to determine appropriate crack velocity formula for lifetime predictions
- Need to incorporate environmental parameters into modeling efforts
  - Possibly NASA'S MCARES?