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Effect of Cylindrical Inclusions on the Strength Distributions of Brittle Materials

Rajan Tandon

Materials Reliability Department

Sandia National Laboratories, Albuquerque, NM 87185

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Outline

- Rationale

  Examples of failures from cylindrical inclusions

  - Impact on SCG ?

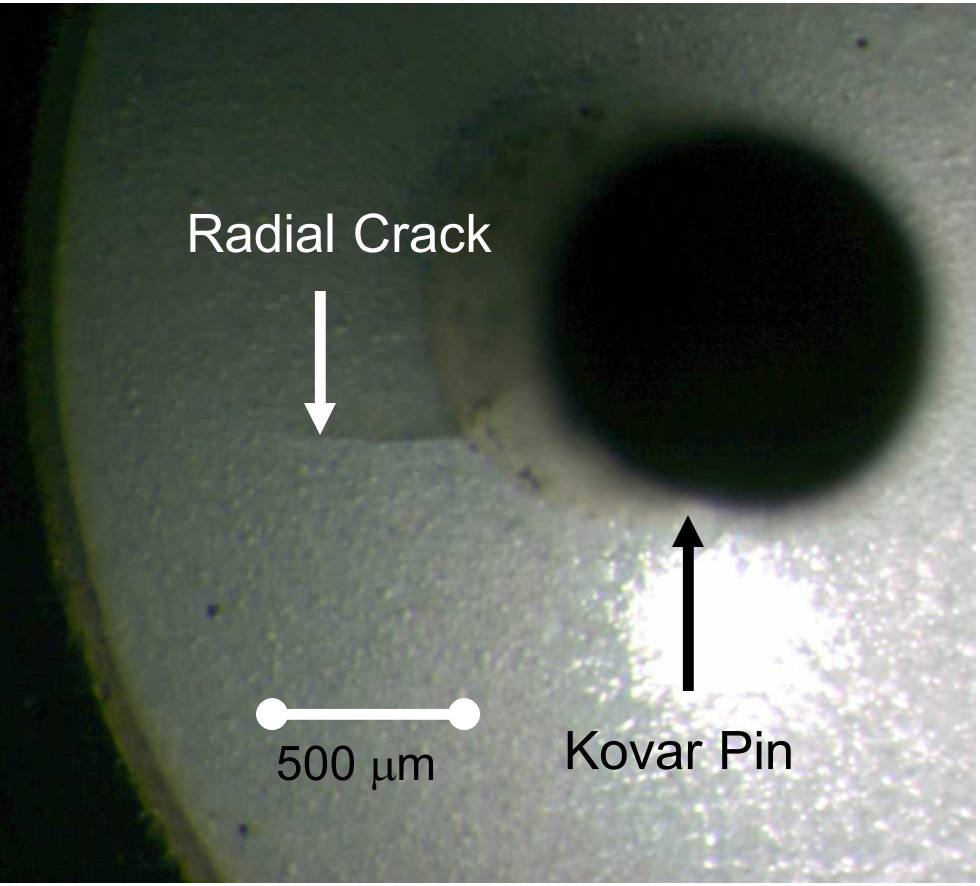
- Fracture Mechanics Analysis

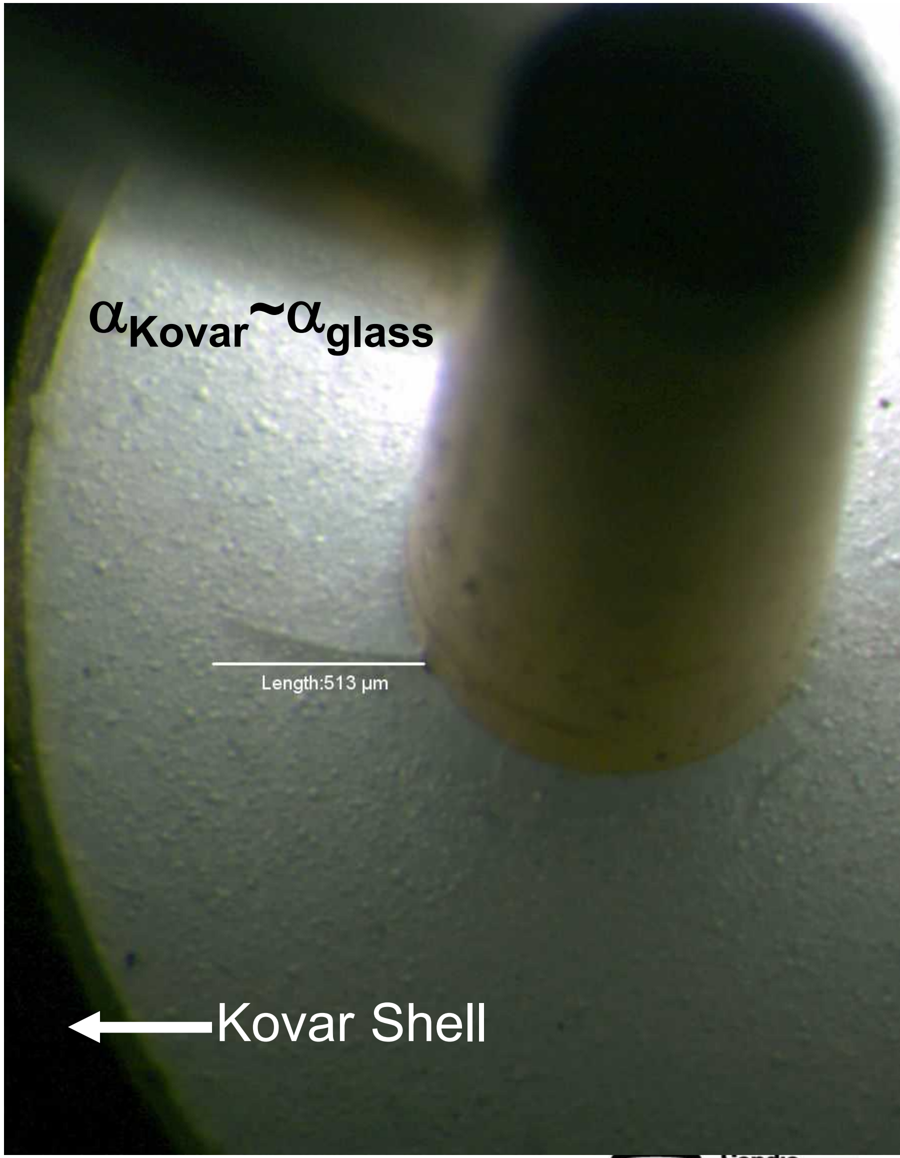
  -Describe behavior of radial cracks

- Effect on Strength Variability

- Considerations for Design of Material Systems

Crack at Pin in a Glass-to-Metal Seal





- Electrical breakdown issue

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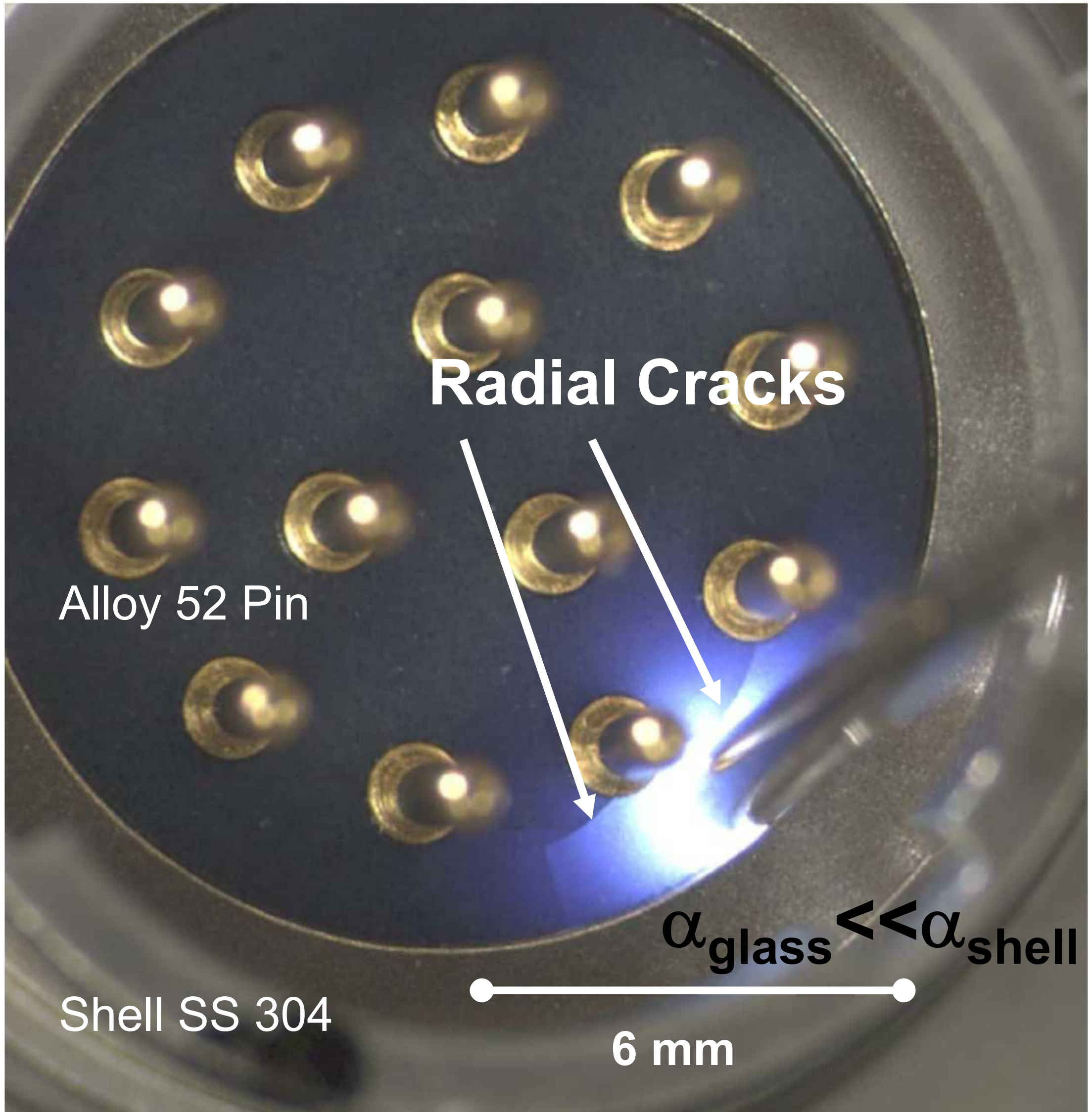
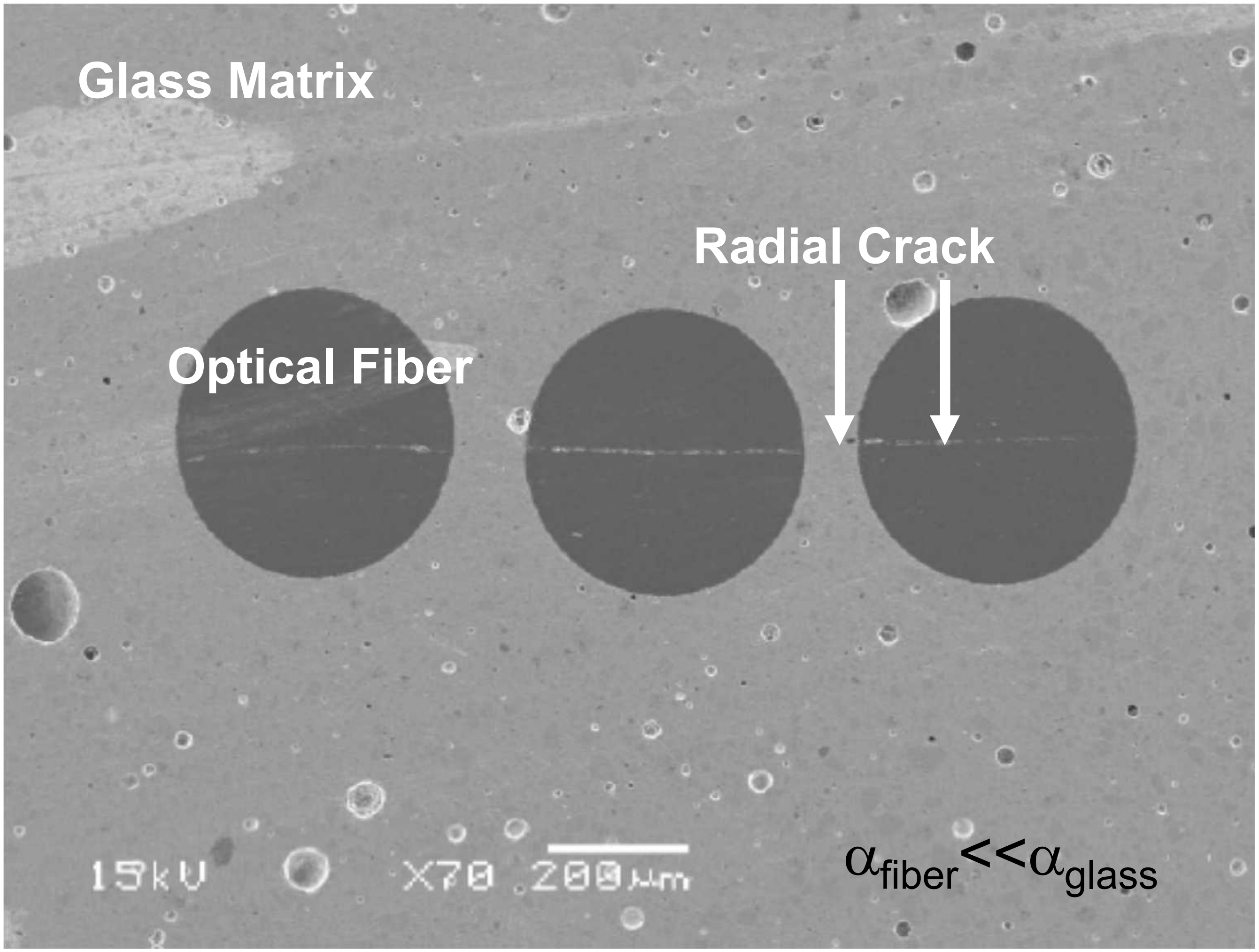
Cracks in Multi-Pin Glass-to-Metal Seal



- Hermeticity and electrical breakdown issues

Radial Cracks Within and Outside fiber



- Loss of power-transmission functionality

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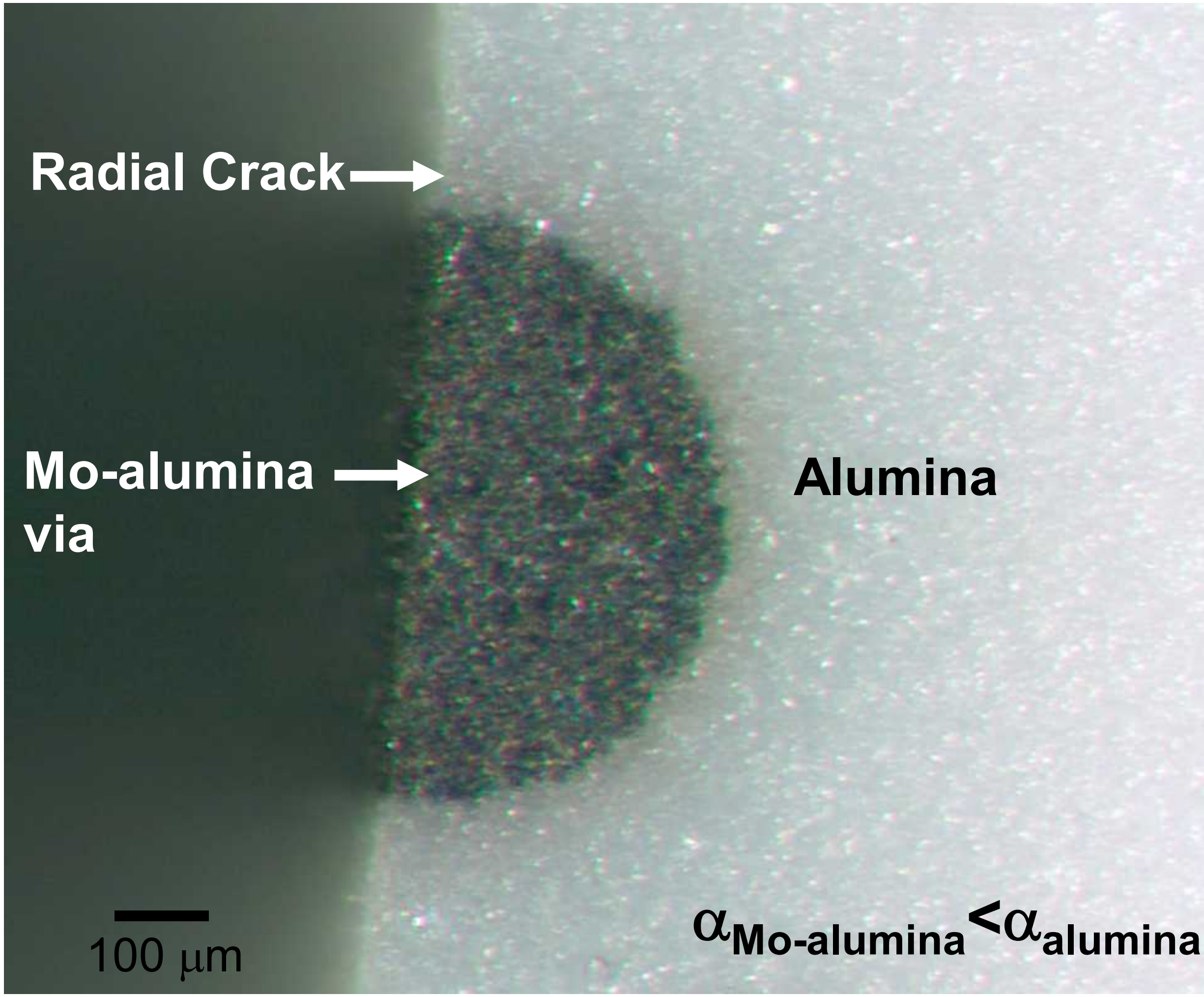
Radial Crack at Via in Packaging Material



- Strength testing reveals radial cracking at via to be failure mechanism

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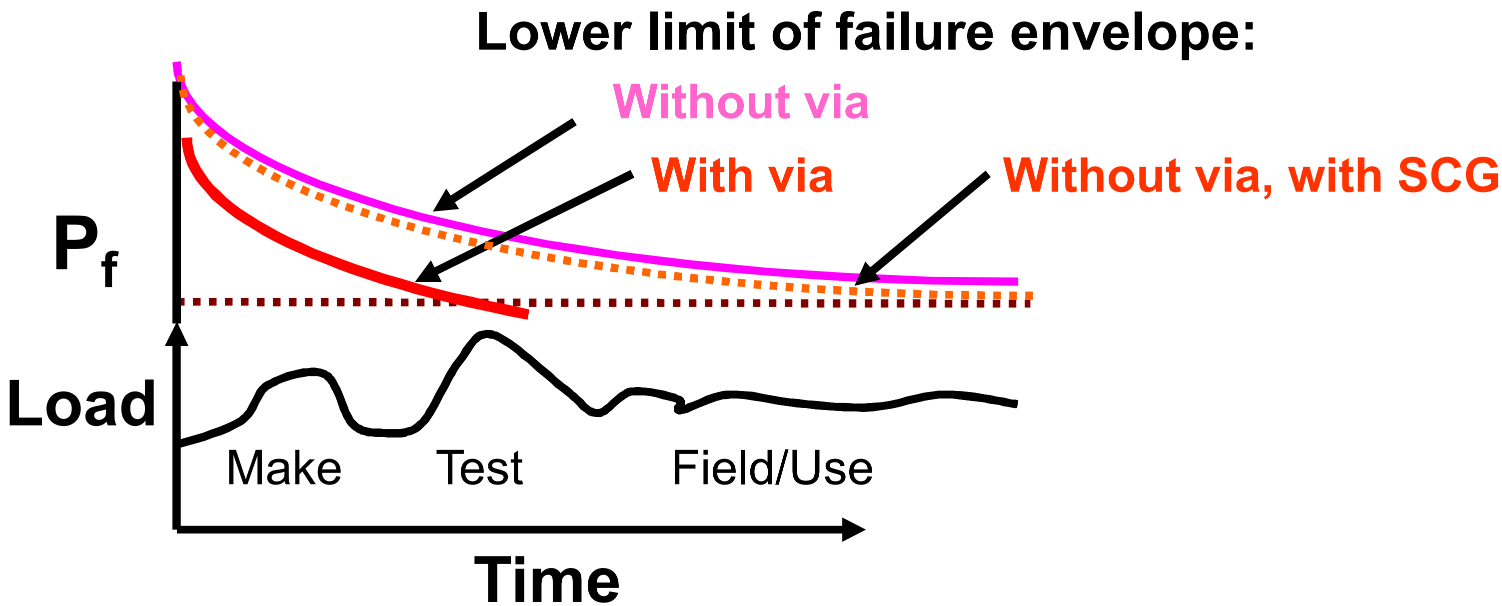
Stress Fields Around Vias Influence Fracture Behavior

A. Effect on strength variability of components ?



B. Failure envelopes degrade with time due to SCG . How does this stress field impact lifetime predictions of components ?

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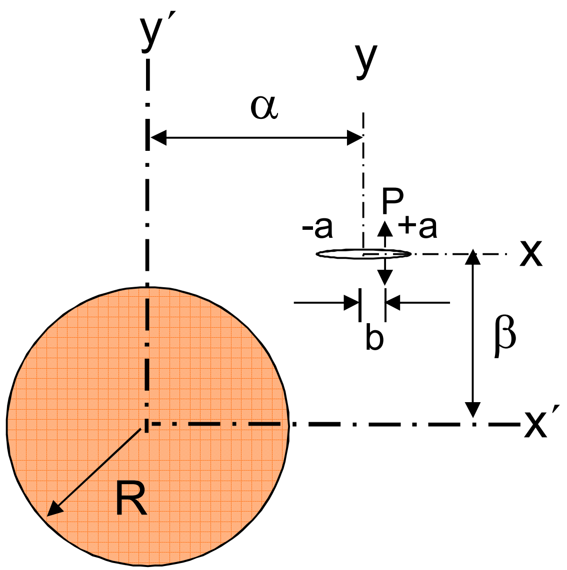
Fracture Mechanics Description



Stress due to inclusion acting on crack

$$\sigma_{\theta\theta} = -\sigma_{rr} = \Lambda T_{diff}\left(\frac{R}{r}\right)^2$$

where

$$\Lambda = \frac{E_m E_i\left[\eta_m\left(1+\nu_m\right)-\eta_i\left(1+\nu_i\right)\right]}{E_i\left(1+\nu_m\right)+E_m\left(1-\nu_i-2\nu_i^{\,2}\right)}, \text{ and } \Lambda = \frac{E_m E_i\left(\eta_m-\eta_i\right)}{E_i\left(1+\nu_m\right)+E_m\left(1-\nu_i\right)}$$

for plane strain, and plane stress respectively.

Point force solution acting on crack

$$K_{Res.}\Big|_{\pm a} = \frac{1}{\sqrt{\pi a}}\int_{-a}^{+a}\left(\Lambda T_{diff} R^2 \frac{\left[\left(x+\alpha\right)^2-\left(y+\beta\right)^2\right]}{\left[\left(x+\alpha\right)^2+\left(y+\beta\right)^2\right]^2}\right)\sqrt{\frac{a\pm x}{a\mp x}}dx$$

Does not include effect of crack on the inclusion
Does not include stresses due to elastic mismatch

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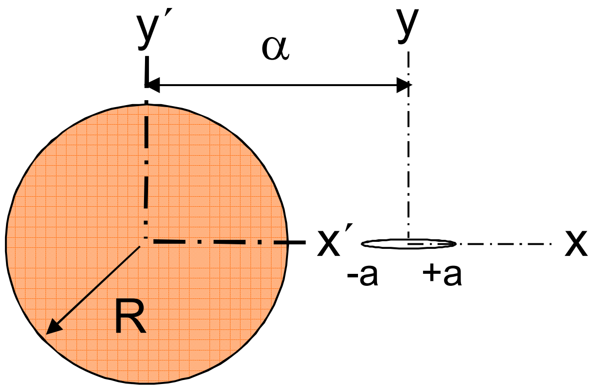
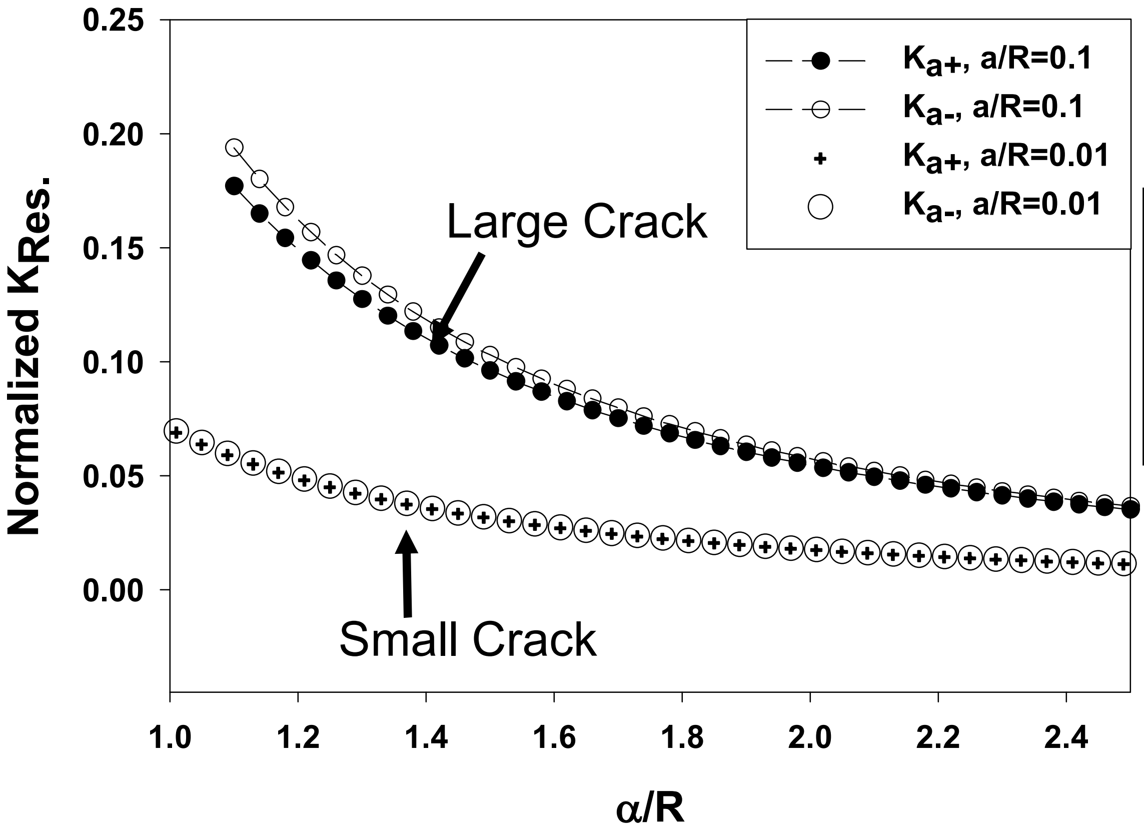
Simplification: β=0



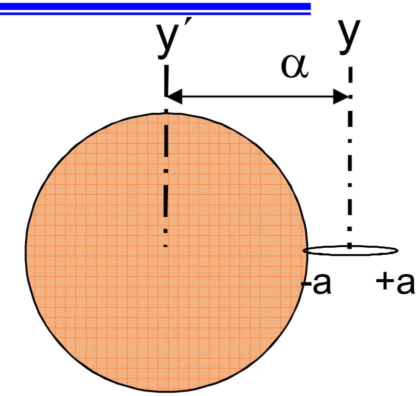
$$K_{Res.}\Big|_{\pm a} = \frac{\Lambda T_{diff} R^2 \sqrt{\pi a}}{(\alpha \pm a)\sqrt{\alpha^2 - a^2}}$$



$K_{-a} > K_{+a}$

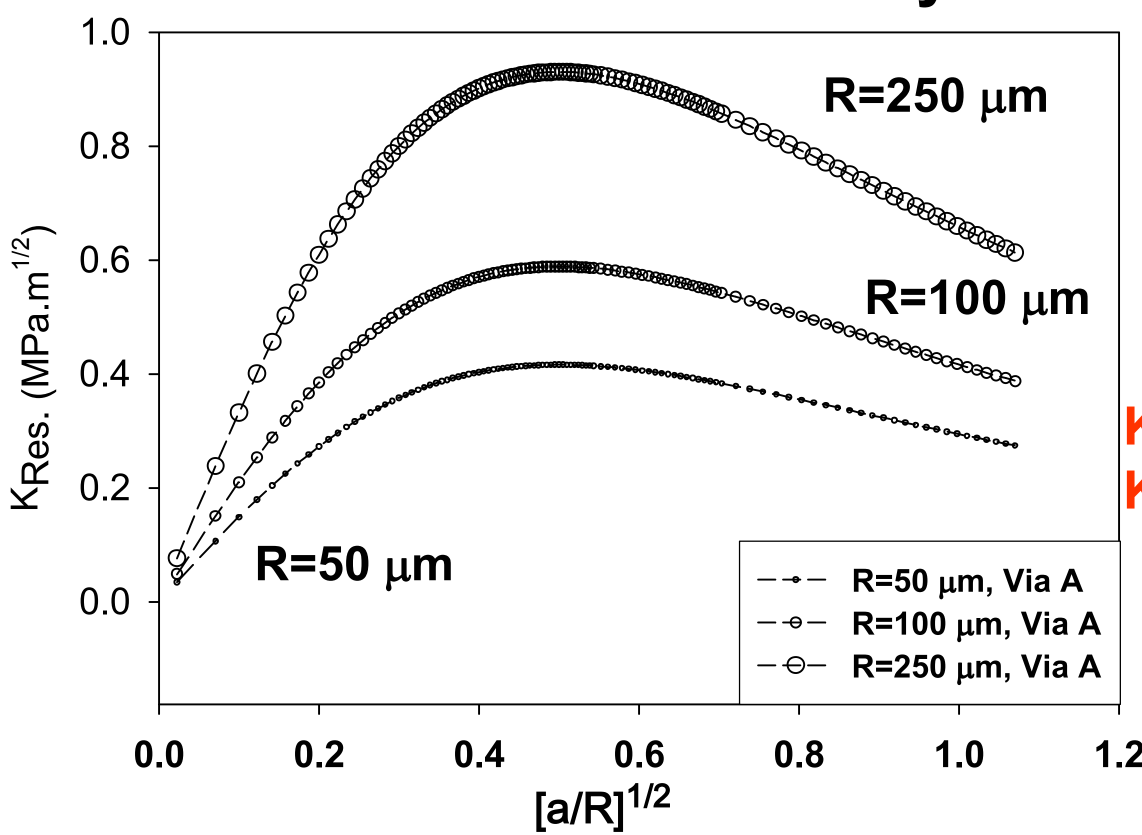
ΔK increases as $\alpha \rightarrow R$

Simplification: α=R+a



If $K_{-a} > K_{1c}$, –a tip jumps to inclusion; arrests
Jump likely on external stress application

Results for Materials Systems of Interest



Matrix: Alumina
Via A: Cermet =
Mo + alumina

K_{Res} has a maximum
K_{Res} increases with radius

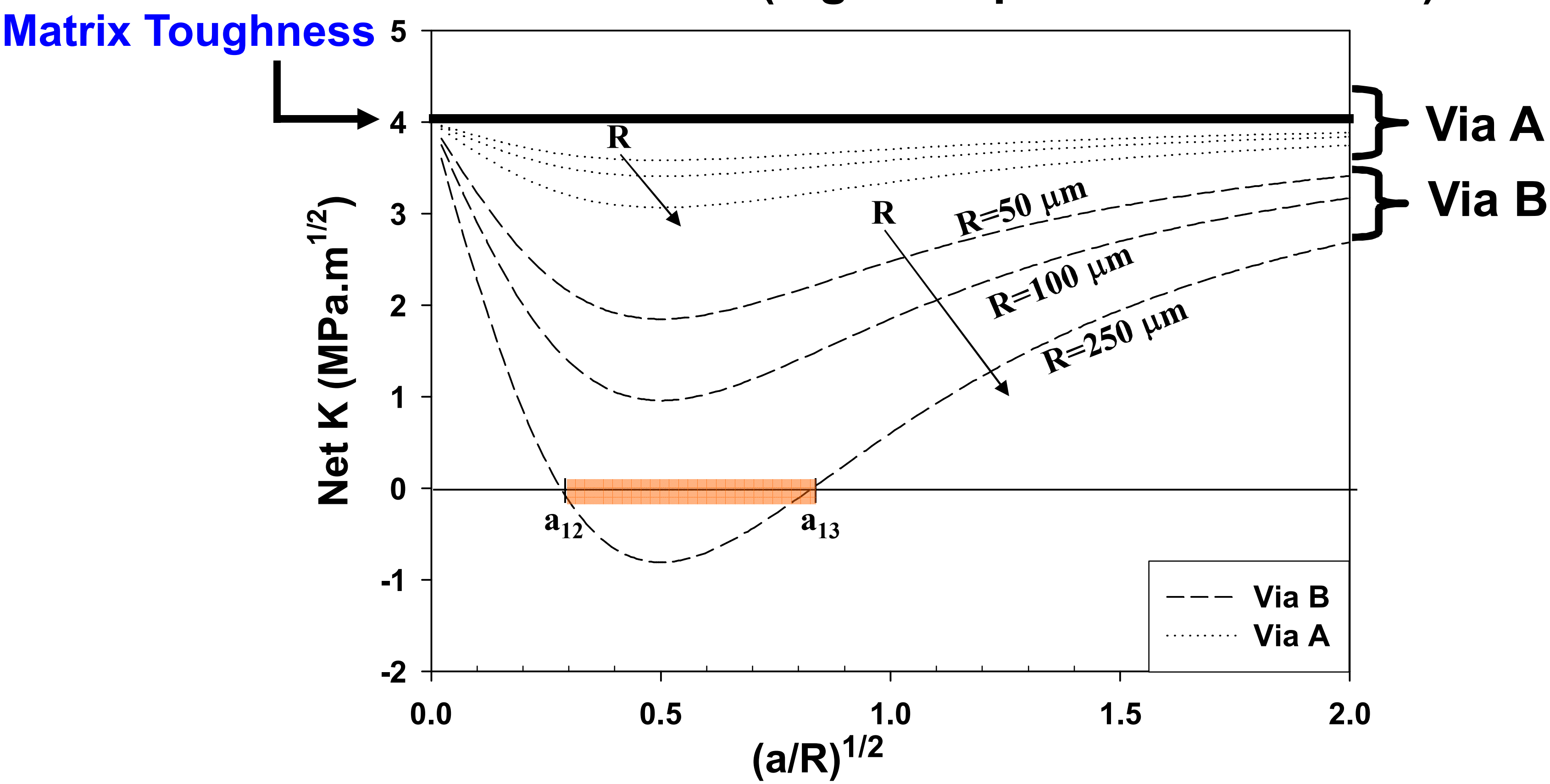
Destabilizing-Stabilizing Fields

Net K= Matrix Toughness- $K_{Res.}$ due to inclusion

RESULTS FOR TWO VIA MATERIALS

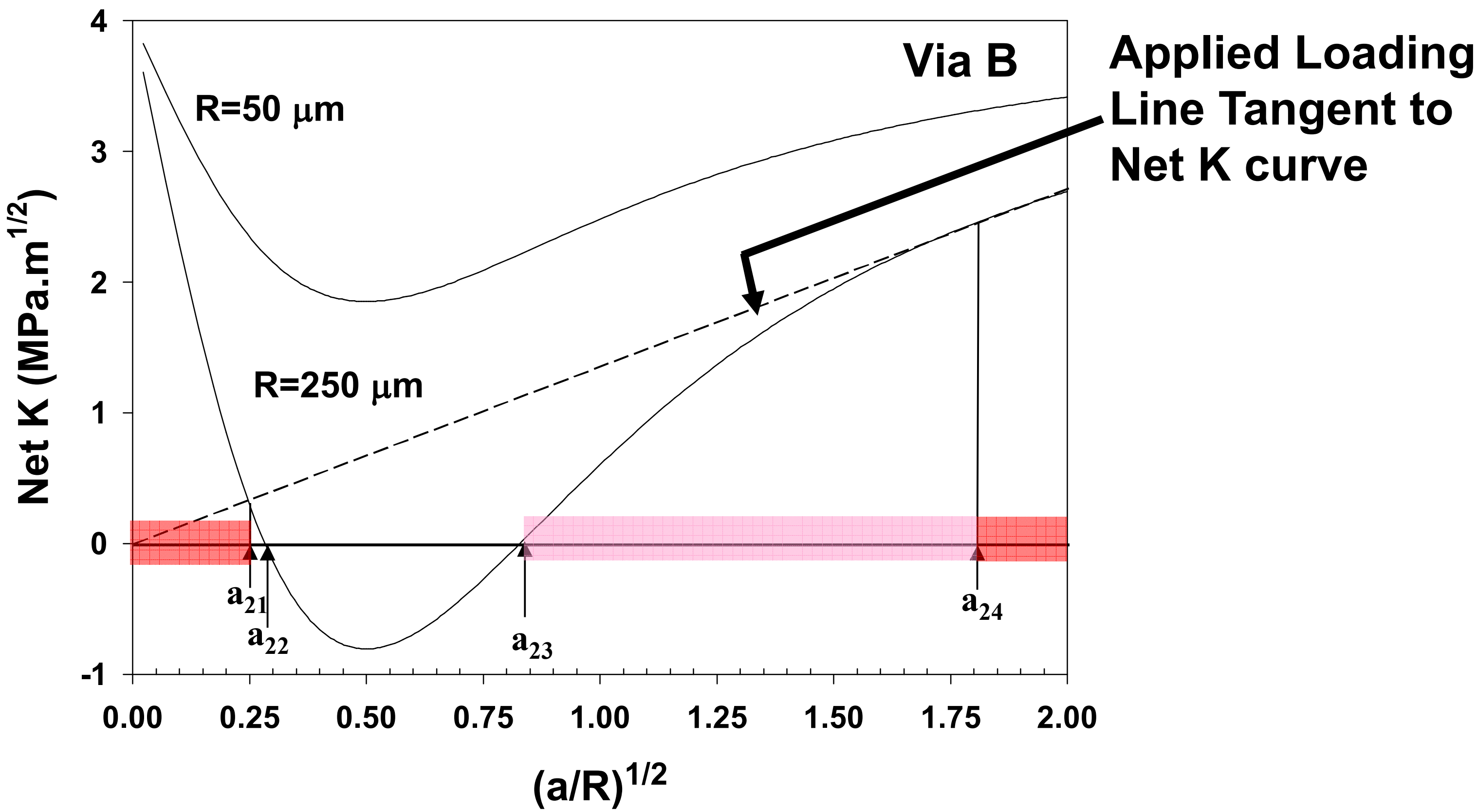
Via A: Mo-alumina

Via B: Pure Mo (higher expansion mismatch)



For largest via, Via B, cracks $a_{12}<a<a_{13}$ grow spontaneously to a_{13}

Behavior of crack at R=250 μm, Via B under Applied Tension

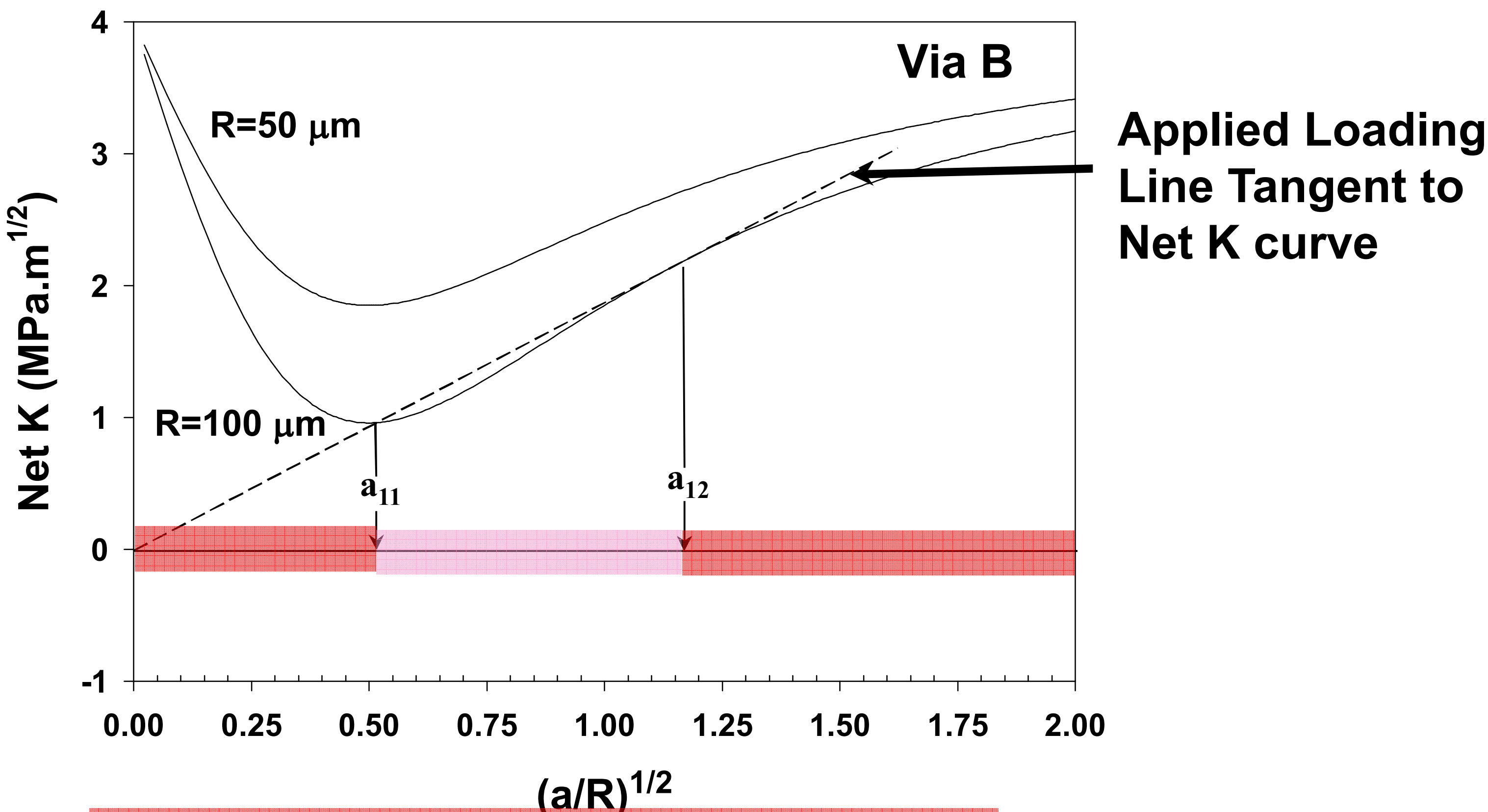


a_{21}<a: Unstable fracture; failure at a

a_{23}<a<a_{24}: Stable crack growth, failure at a_{24}

a>a_{24}: Unstable fracture; failure at a

Behavior of crack at R=100 μm, Via B under Applied Tension

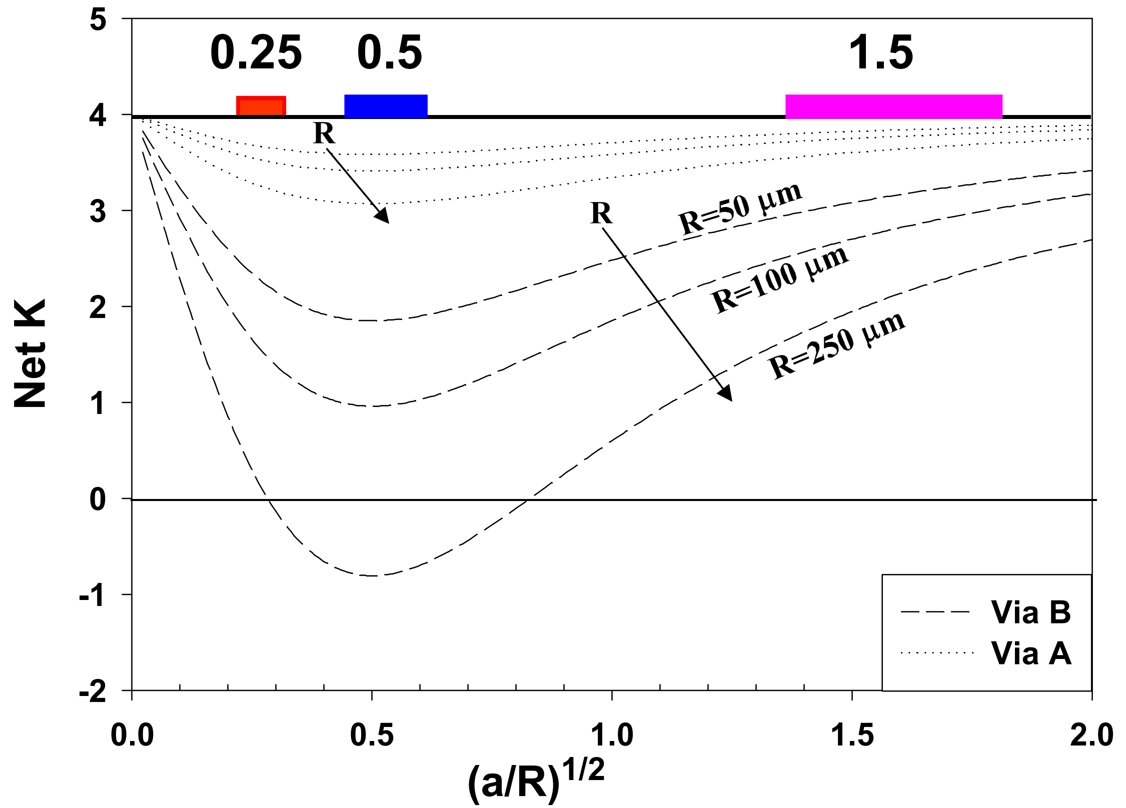


a_{11}<a: Unstable fracture; failure at a

a_{11}<a<a_{12}: Stable crack growth, failure at a_{12}

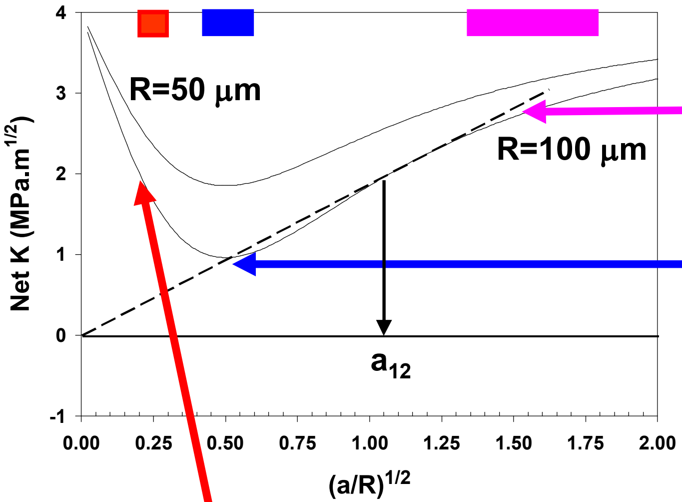
a>a_{12}: Unstable fracture; failure at a

Effect on Strength Variability



Generated crack size distributions centered at various a/R locations such that the Weibull moduli=20 for each distribution on the base material

Strength Variability: R=100 µm

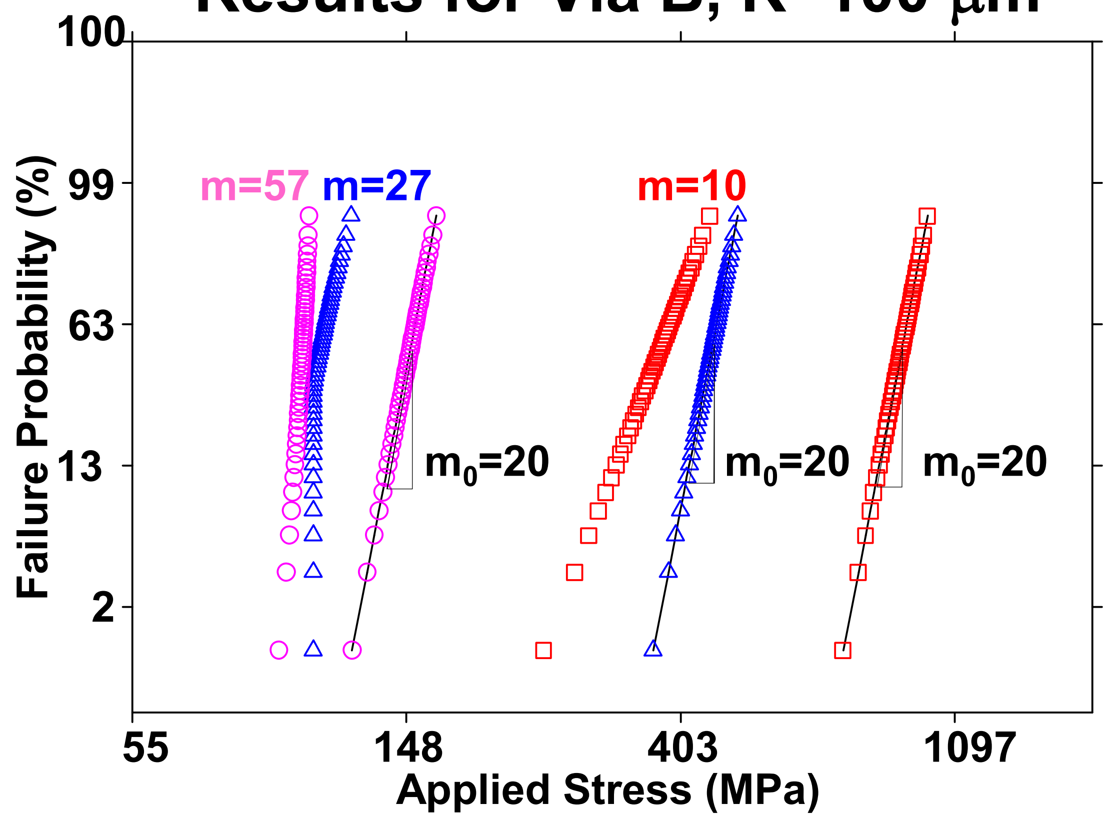


All Cracks in this set: Stabilizing Field

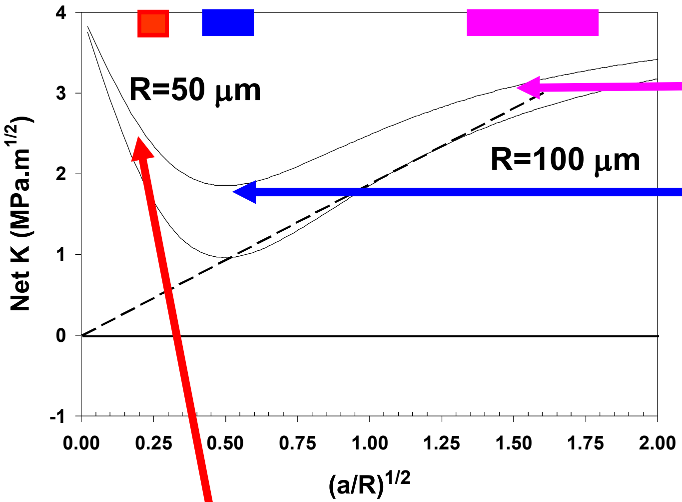
Smaller Cracks in this set: Destabilizing Field
Larger Cracks: Stable growth; failure at a_{12}

All cracks in this set:
Destabilizing Field; no stability

Results for Via B, R=100 µm



Strength Variability: R=50 μm

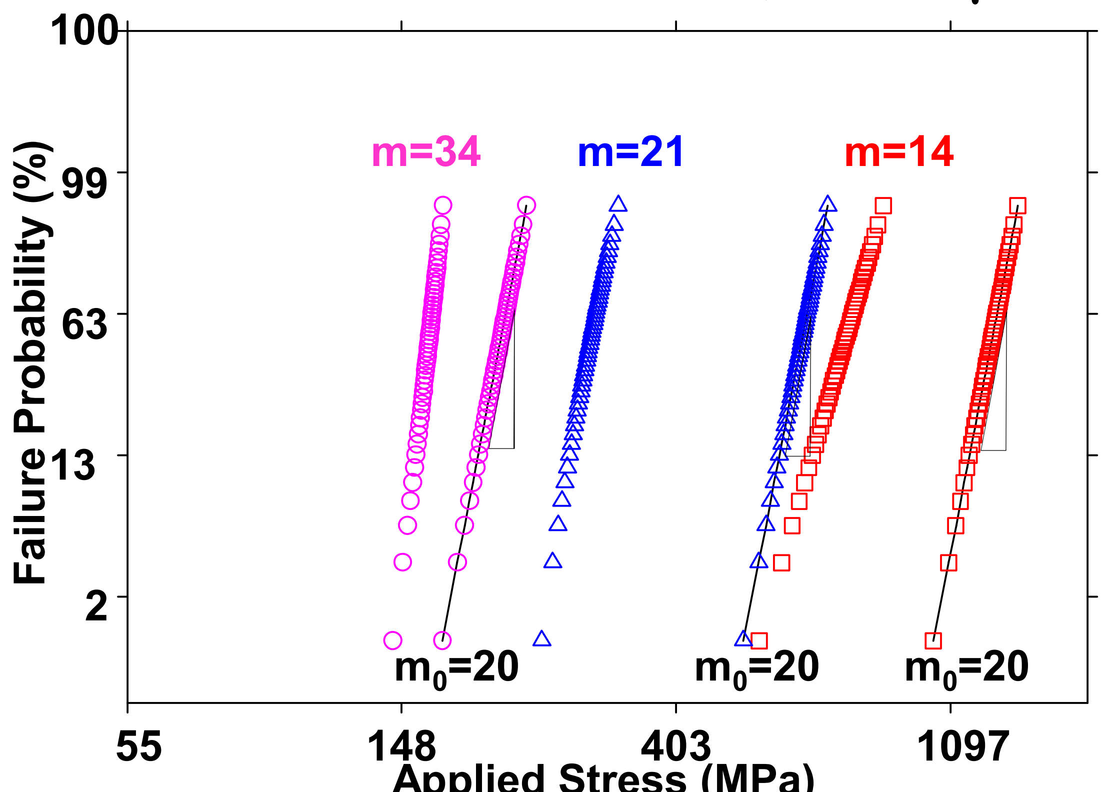


All Cracks in this set: Stabilizing Field

Smaller Cracks: Destabilizing Field
Larger Cracks: Stabilizing Field

All cracks in this set:
Destabilizing Field

Results for Via B, R=50 μm



Conclusions

Choose smallest inclusion size possible

-Retain most of the strength

-Possibly reduce variability

For High Retained Strength +Reduced Variability

If crack size is ~ microstructure feature size (*g*), then choosing R < 4a~4*g* ensures that most cracks lie on the stabilizing branch.

Fracture Mechanics Vs. Strength of Materials