Quantitative relationships between stress distributions, microstructure and high strain rate performance of advanced ceramics: a preliminary report

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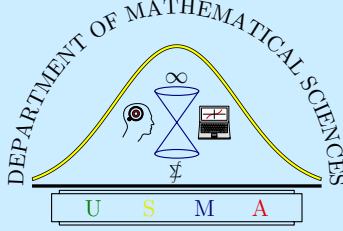
Goal: To better predict fracture under high strain rate, high compressive stress, and large strains in ceramics.

Outline:

- Microstructure
  - Crystallographic texture
  - Misorientation
  - Grain size and shape
- Stress Distributions
  - Three Examples
- Ongoing and Future Work

Questions and comments appreciated



Microstructure

Crystallographic Texture

[Aluminum oxide by
W. E. Lee of Univ. of Sheffield,
in DoITPoMS Micrograph
Library, Univ. of Cambridge]

Crystallographic Texture (con't)

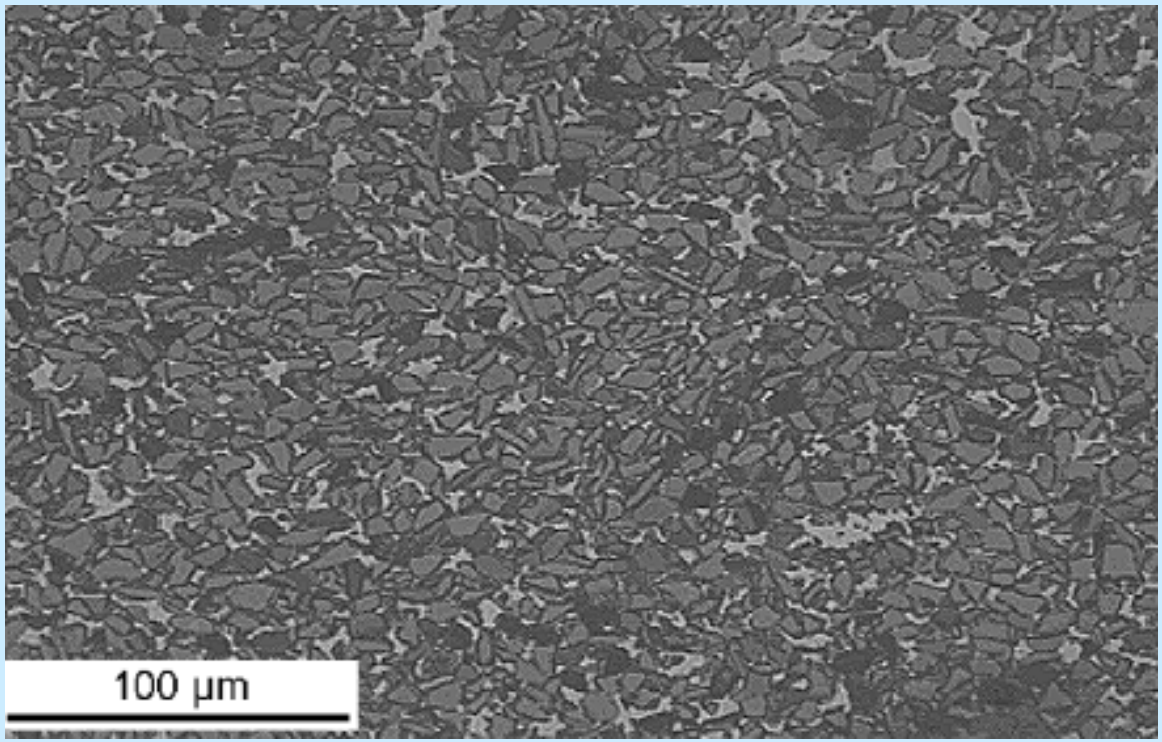
One model: Orientation Distribution Function

$$w(\psi,\theta,\varphi)=\sum_{\ell=0}^{\infty}\sum_{m=-\ell}^{\ell}\sum_{n=-\ell}^{\ell}W_{\ell mn}Z_{\ell mn}(\cos\theta)e^{-im\psi}e^{-in\varphi}$$

- Roe's 1965 notation
- Many coefficients are zero or linearly dependent
- Influence of coefficients decreases with ℓ

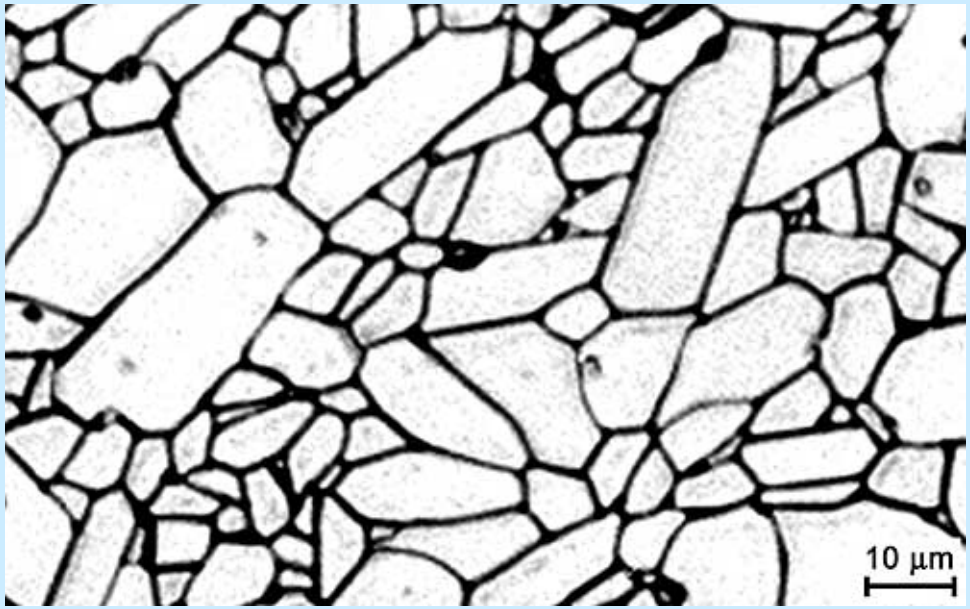
Misorientation

aka Grain Boundary Texture

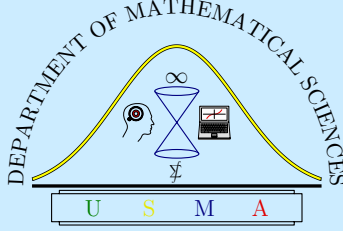


[Silicon carbide by J. Marrow of Univ. of Manchester and UMIST, in DoITPoMS Micrograph Library, Univ. of Cambridge]

Grain Size and Shape



[Aluminum oxide from Technical Ceramics Brevier at
http://www.keramverband.de/brevier_engl/brevier.htm
accessed 10/17/2005]

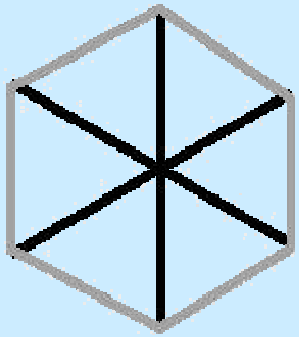


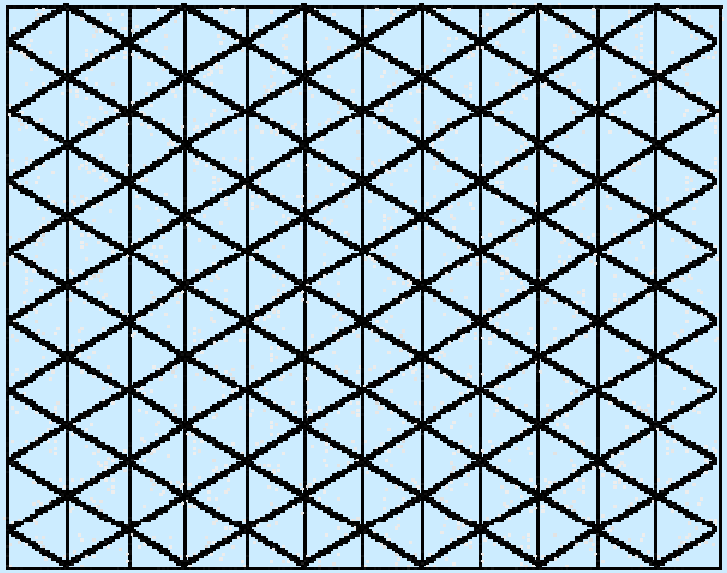
Stress Distributions

Network Model

Work by X. H. Zhang, et al. published 2004

[Coupling effects of heterogeneity and stress fluctuation on rupture. Theoretical and Applied Fracture Mechanics, 41:381-389, 2004.]





- Bars have same elastic modulus
- Bars have individual yield points
- 40x40 and 60x60 models
- Uniaxial *tension*

Network Model (con't)

- *Pure* model
- As bars break, stresses are redistributed throughout solid
- Like flow of electricity through network of fuses

Stages Leading to Damage:

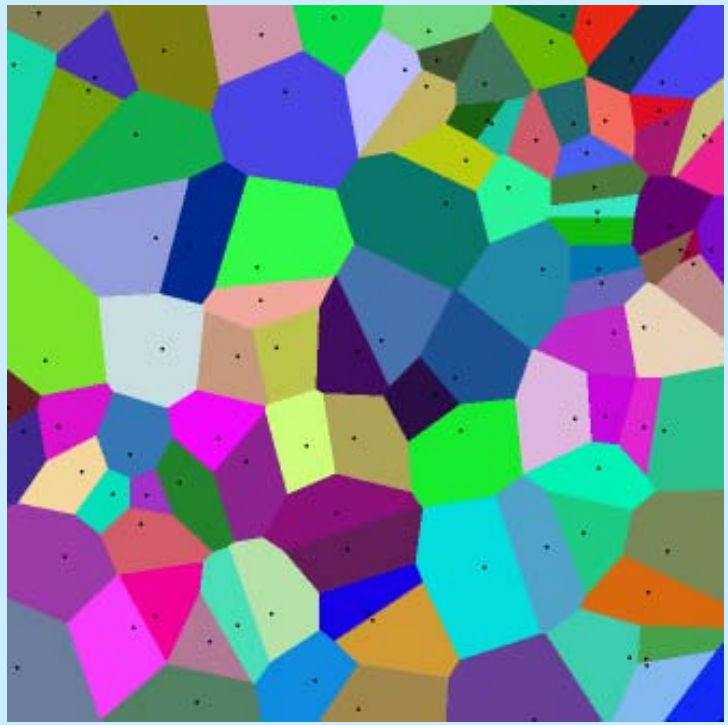
1) Microcracking
2) High stresses rapidly shift from one location to another
3) Large cracks form

Microplasticity Simulation

Work by D. Zhang, et al. published 2005

[Micromechanical investigation of heterogeneous microplasticity in ceramics deformed under high confining stresses. Mechanics of Materials, 37:95-112, 2005.]

- 100 Voronoi Cells
- Hexagonal grains
- 2 slip systems
- Uniaxial strain compression past Hugoniot elastic limit



[Anonymous, from wikipedia.org, under GNU Free Documentation License, accessed 10/17/2005]

Microplasticity Simulation (con't)

- Standard deviation of longitudinal and lateral stresses increased as compression increased

  (i.e. Heterogeneity of stress states increased)

- Consistent with Network Model

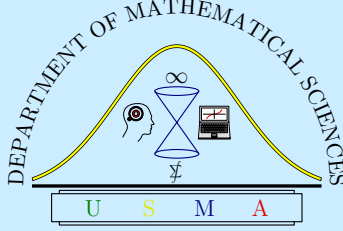
FEM & SHPB Experiments

Work by Tasdemici and Hall published 2005

[Experimental and modeling studies of stress wave propagation in multilayer composite materials: Low modulus interlayer effects. Journal of Composite Materials, 39(11):981-1005, 2005.]

- Impact Loading
- Multiple layers (ceramic/interlayer/glass composite)
- FEM model compared to Split Hopkinson Pressure Bar Data

Stress heterogeneity important – not just maximum stress



Ongoing Work and Related Topics

Ongoing Work

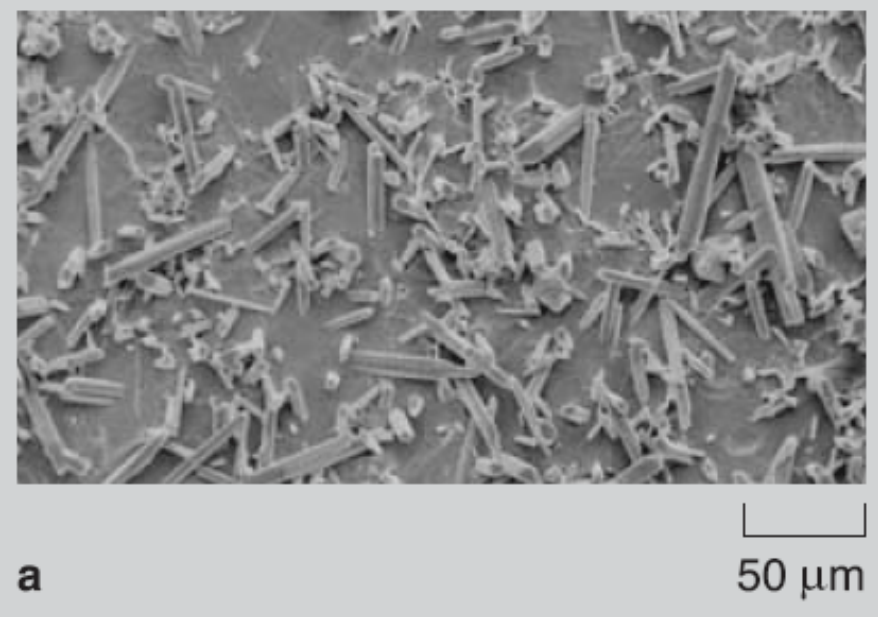
- Better understand the relationship between Slip, Local Stress, and Fracture

- Apply existing literature on ceramics and microstructure– much work already done on metals should be applicable

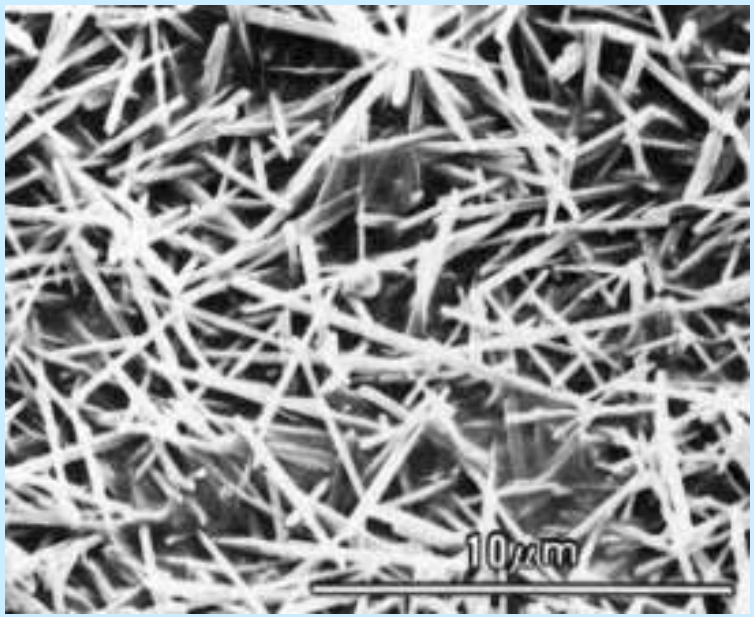
- How best to predict crack behavior? Multifractal Formalism?

Related Topics

- **Whiskers**



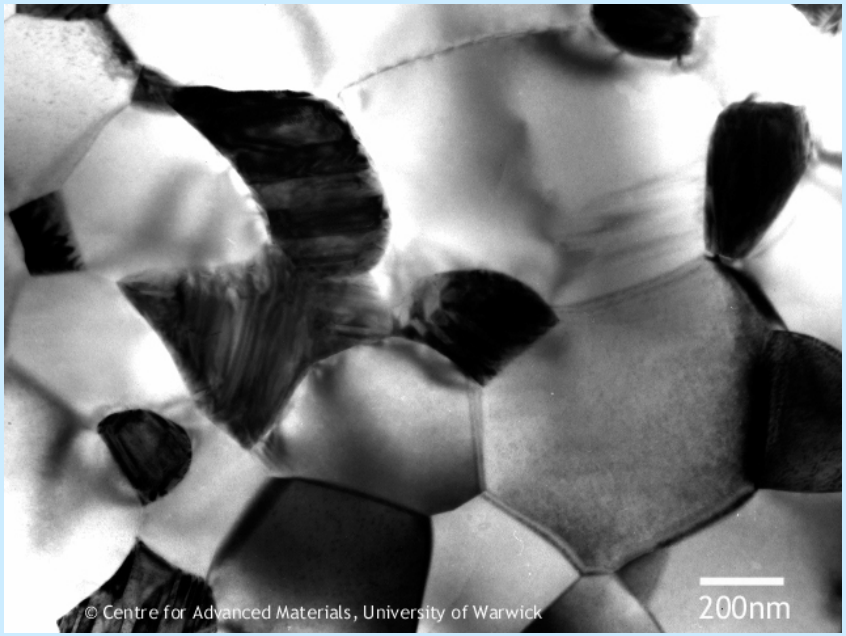
[Chandran, et al., TiB_w-reinforced Ti composites: Processing, properties, and application prospects and research needs. JOM, May 2004, online]

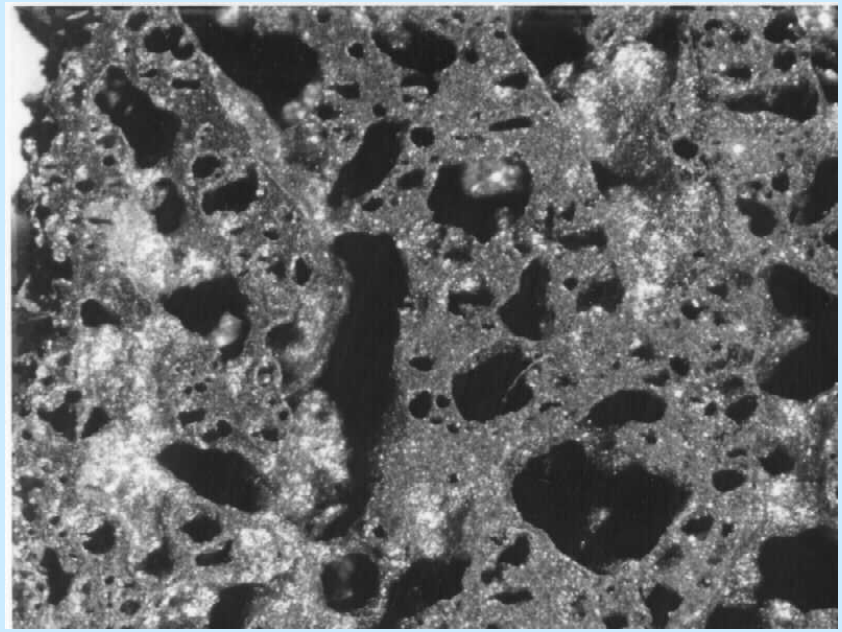


[Aluminum borate from Shikoku Nat'l Industrial Research Institute accessed online 10/18/2005 at http://www.aist.go.jp/SNIRI/research/muki.html]

Related Topics (con't)

- **Voids, Biologically-useful Ceramics**





[Left: α-alumina from Center for Advanced Materials, Univ. of Warwick, UK. Right: TiB, X. Zhang and M. Castillo, CCACS, Colorado School of Mines at http://www.mines.edu/research/ccacs/Porous_Ceramics/Porous_Ceramics.html]

- **Microcracking**

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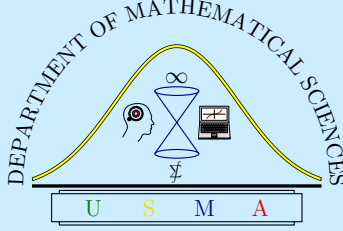
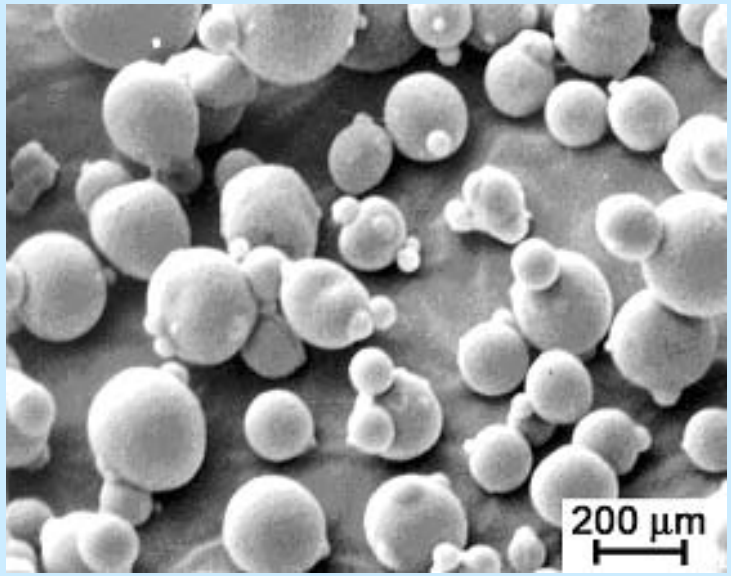
- ARL Sponsors: James W. McCauley and Thomas W. Wright
- National Research Council: This research was done while holding a NRC Research Associateship Award at USMA and ARL.



Extra Slides

Pre-Sintered Powders



[Top Left: Boron carbide from http://www.abrasive-kaidacn.com/BoronCarbide.htm, Right: Aluminum oxide spheres from Technical Ceramics Brevier at http://www.keramverband.de/brevier_engl/brevier.htm, Bottom Left: Boron/silicon carbide from http://www.isucon.de/Projekte/industrial/index_industrial.htm]