

Microscale Characterization of Plastic Deformation at the Crack Tip

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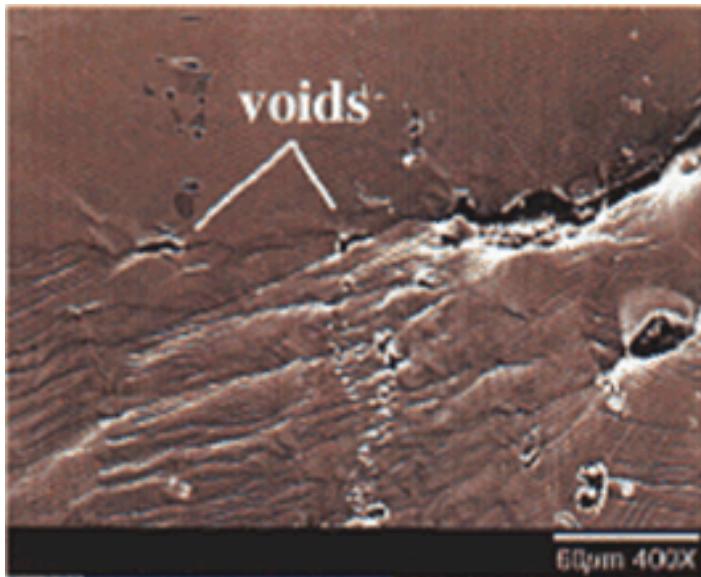
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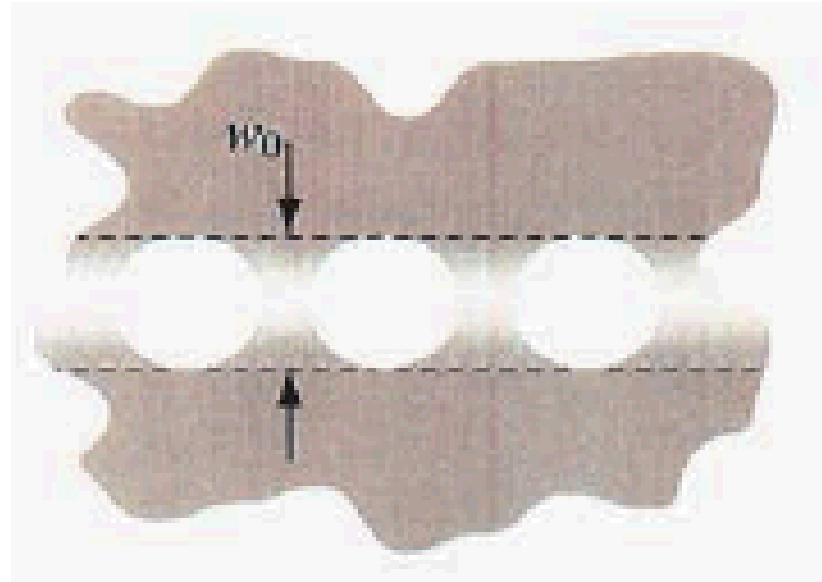
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Mechanism-based cohesive modeling of ductile fracture were developed



(a)



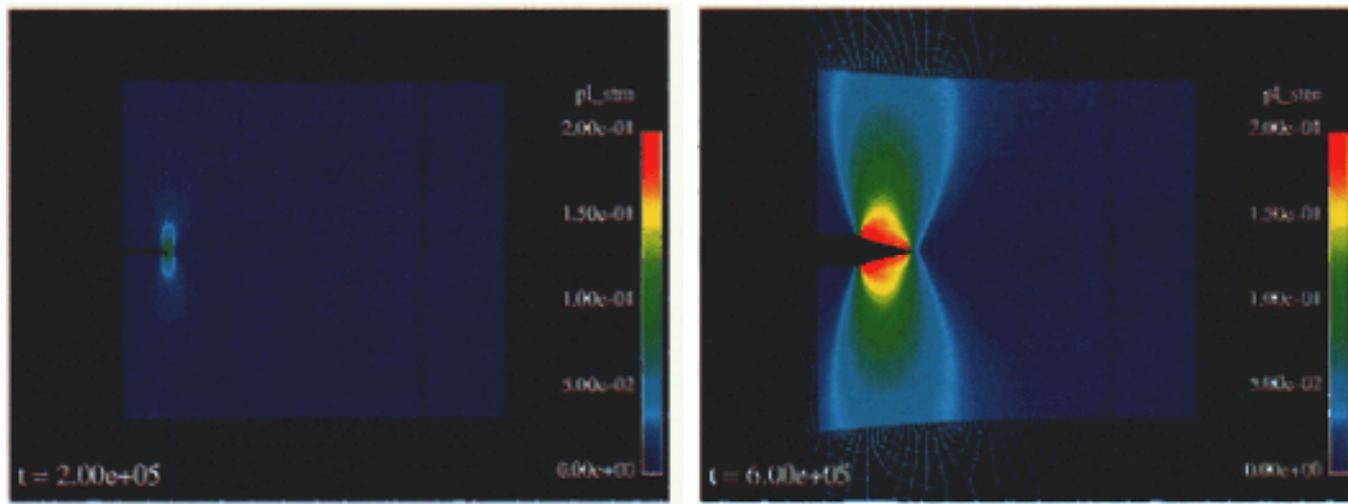
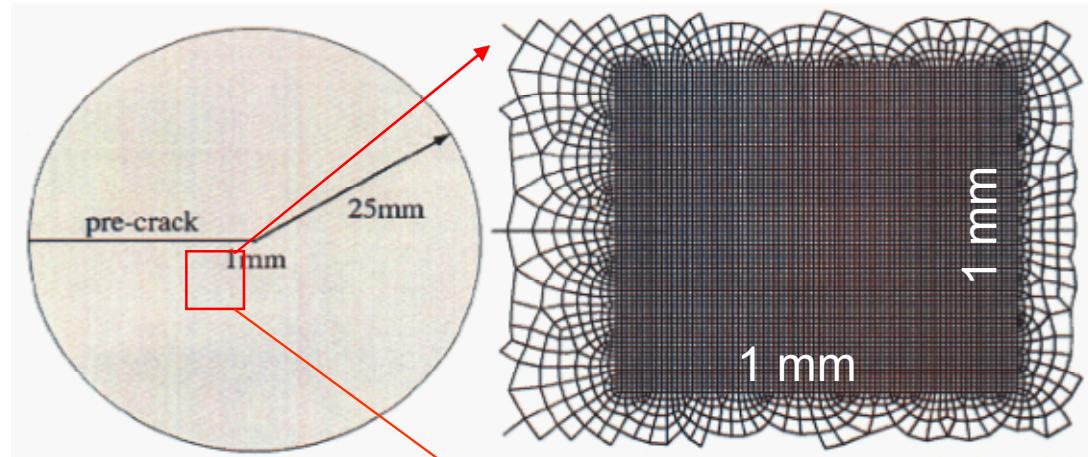
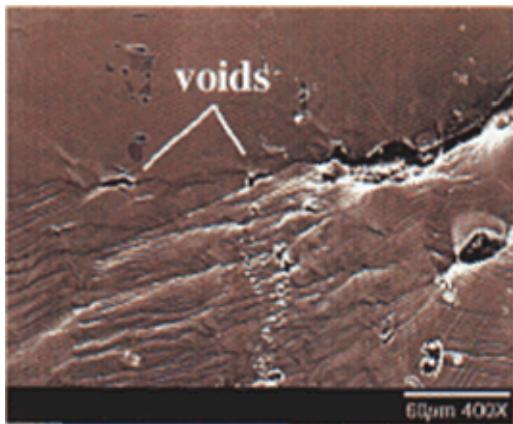
(b)

Void volume fraction: $\Phi = \frac{V_{void}}{V_{total}}$

Evolution of void volume fraction: $\dot{\Phi} = \beta \left[\frac{1}{(1-\Phi)^n} - (1-\Phi) \right] \|D^p\|$



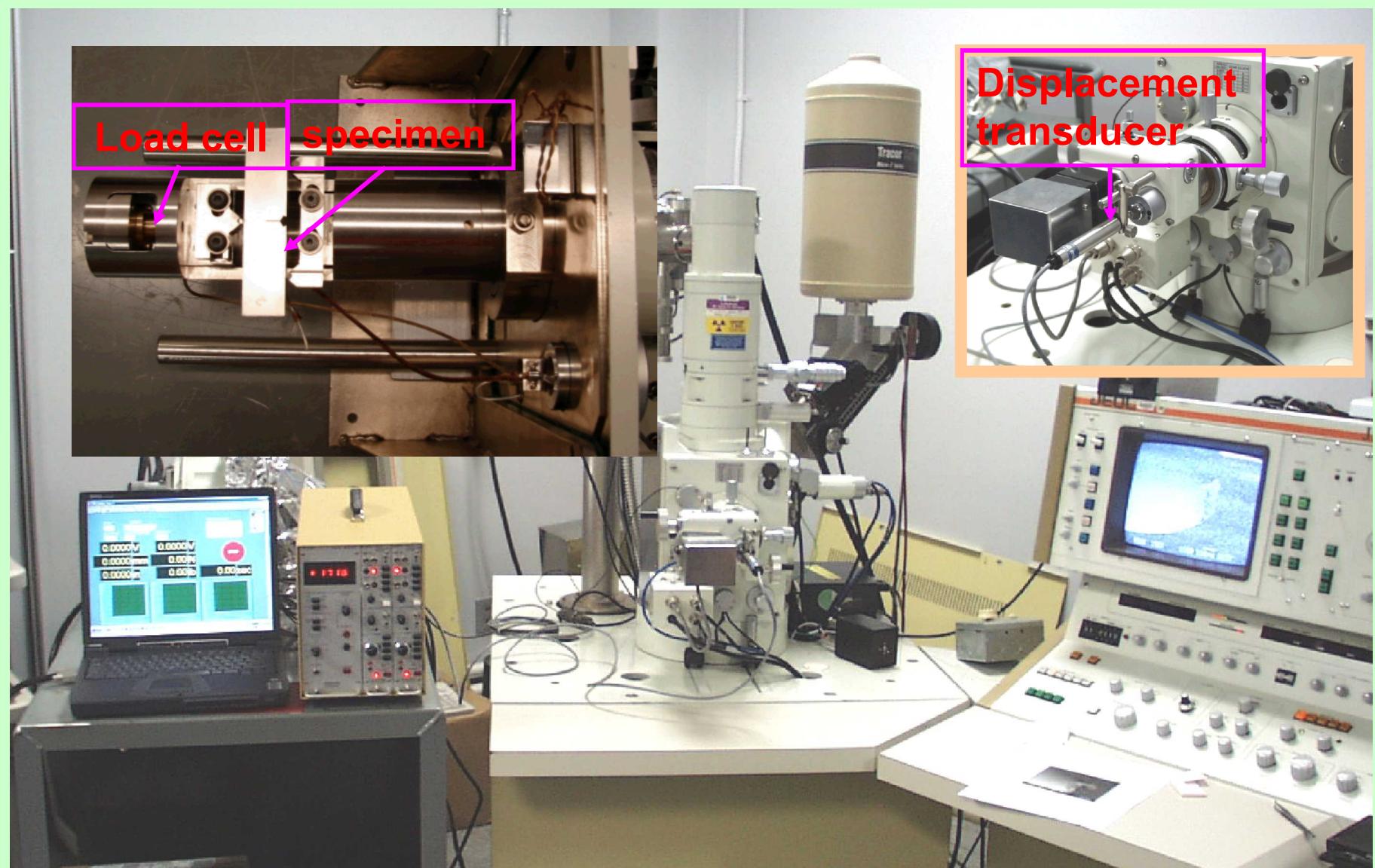
Cohesive Zone Modeling and Mapping



Research Approach: Combine SEM imaging with DIC technique to study ductile fracture behavior



Fracture Test Inside SEM

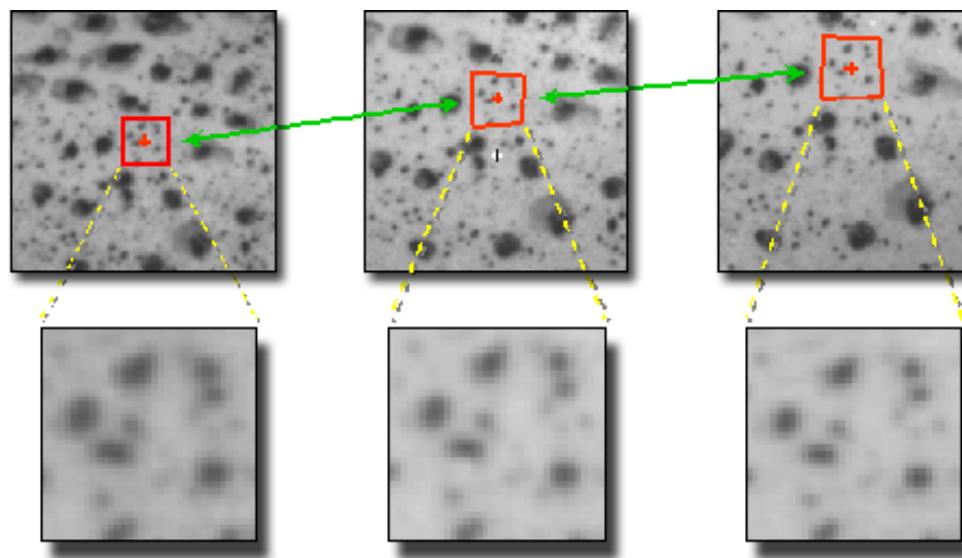




Principle of Digital Image Correlation (DIC)

- An optical method to measure displacement and strain
- Tracks the gray scale patterns during deformation
- Full-field, non-contact

An example from Correlated Solutions:



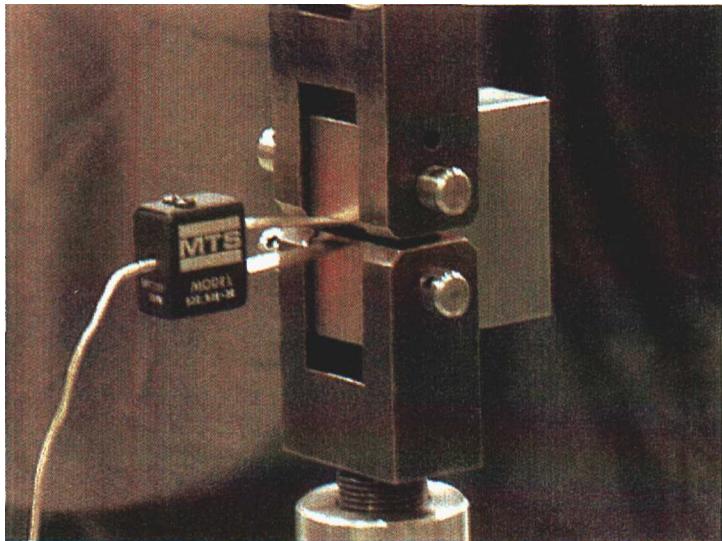
$$s(x, y, u, v, \frac{\partial u}{\partial x}, \frac{\partial v}{\partial y}, \frac{\partial u}{\partial y}, \frac{\partial v}{\partial x}) = 1 - \frac{\sum F(x, y) * G(x^*, y^*)}{\sqrt{\sum F(x, y)^2 * \sum G(x^*, y^*)^2}}$$

where, $x^* = x + u + \frac{\partial u}{\partial x} \cdot \Delta x + \frac{\partial u}{\partial y} \cdot \Delta y$

$$y^* = y + v + \frac{\partial v}{\partial y} \cdot \Delta y + \frac{\partial v}{\partial x} \cdot \Delta x$$



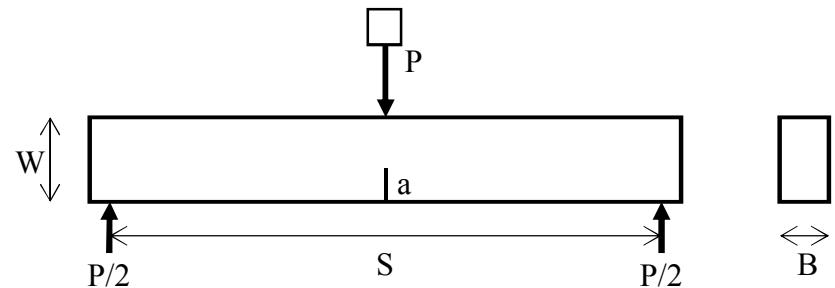
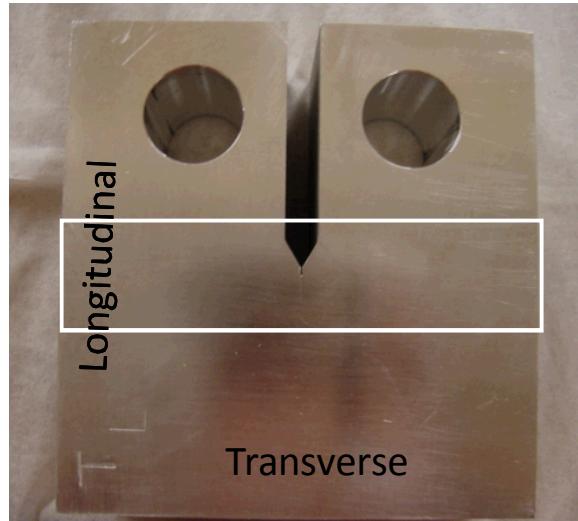
Pre-crack and Sample Preparation



Compact tension sample set up for precracking



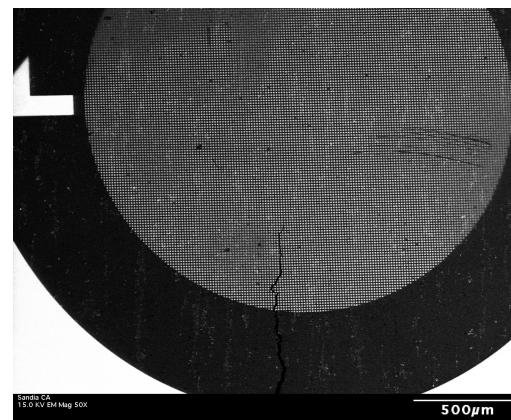
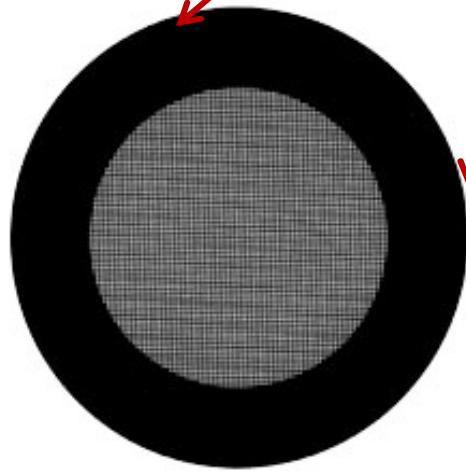
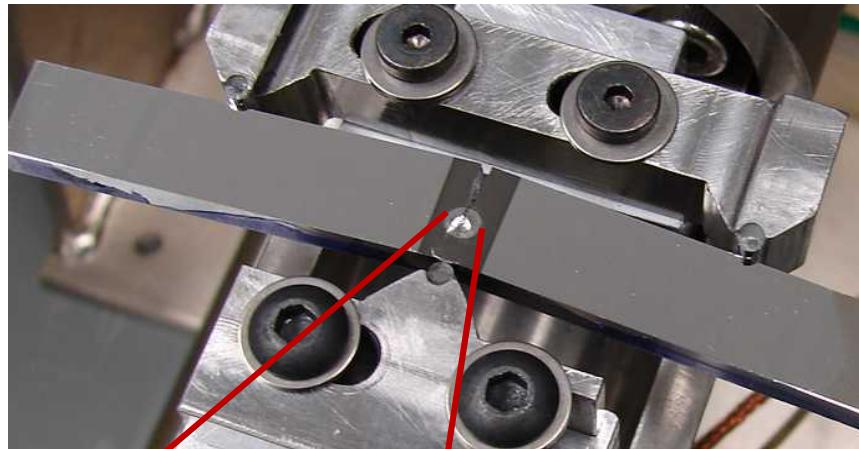
- Pre-crack is along the longitudinal (extrusion) direction
- Surface is polished up to $3\mu\text{m}$ finish



W (in)	a (in)	B (in)	L (in)	S (in)
0.75	0.375	0.3	2.5	2.0



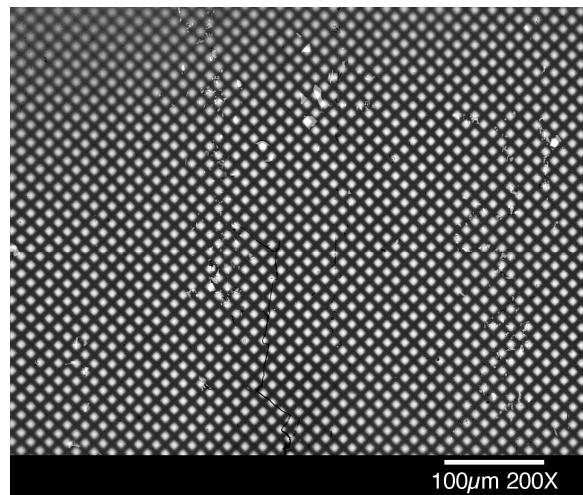
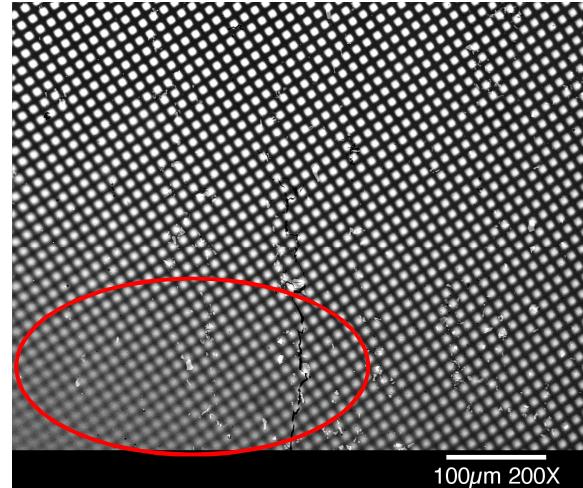
Microscale Pattern Generation for DIC



2000 mesh grid from Ted Pella:

Pitch 12.5 μ m

Hole Width 7.5 μ m



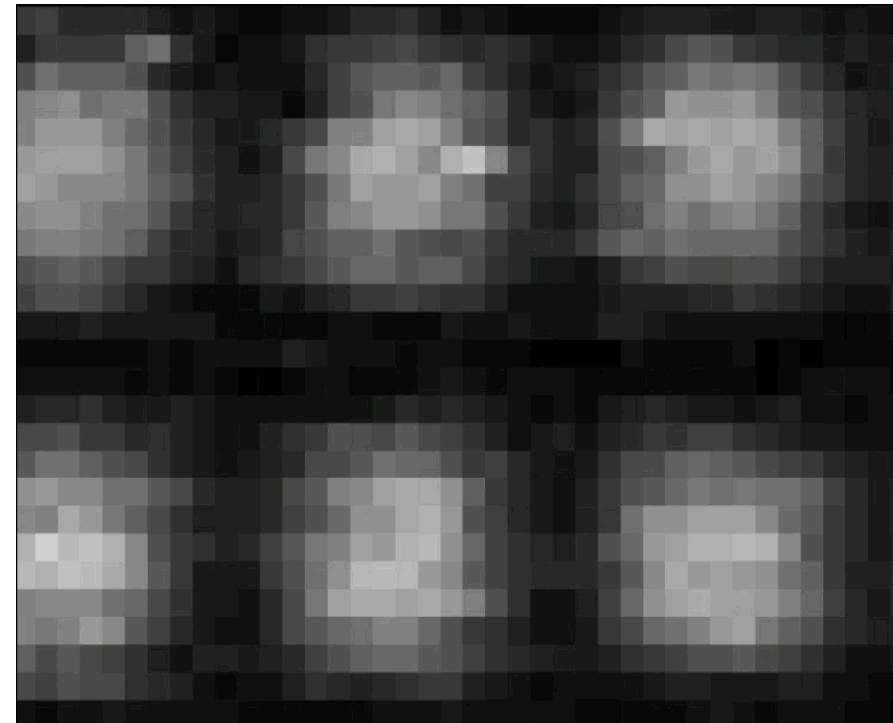
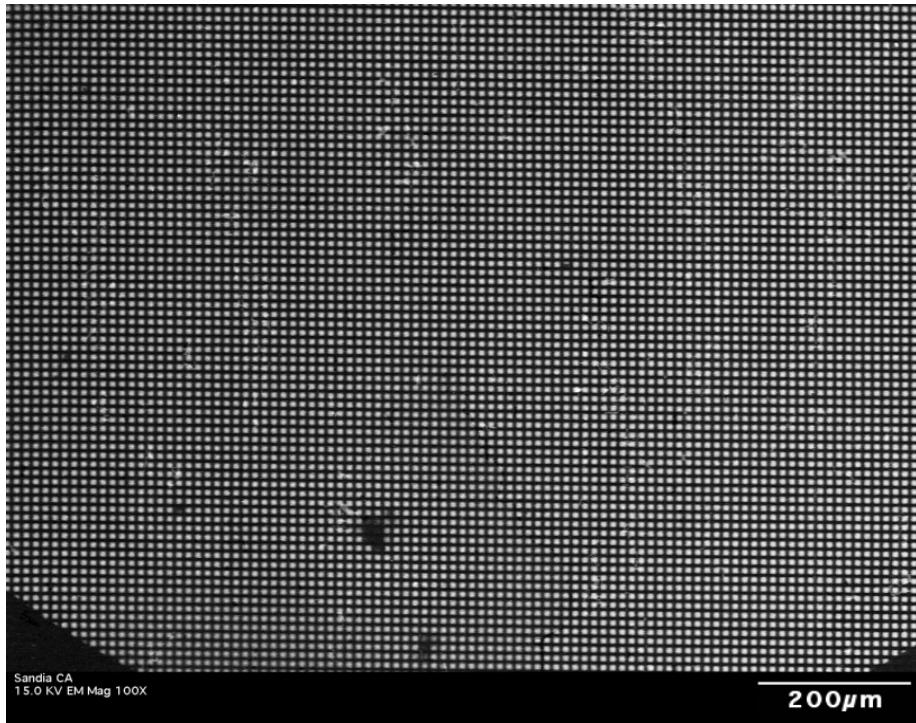
Key: Assure uniform flat contact between the grid and specimen surface.



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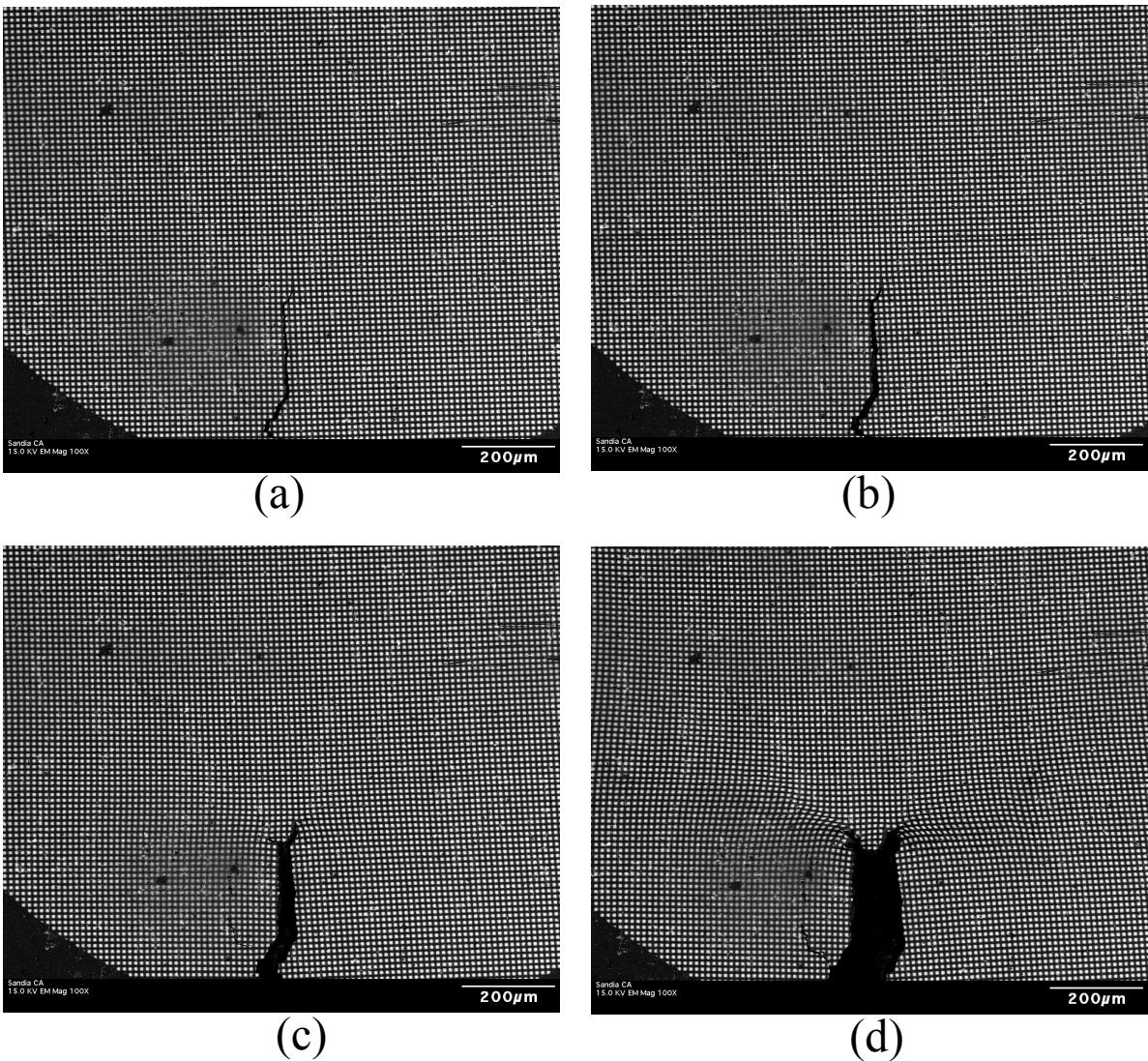
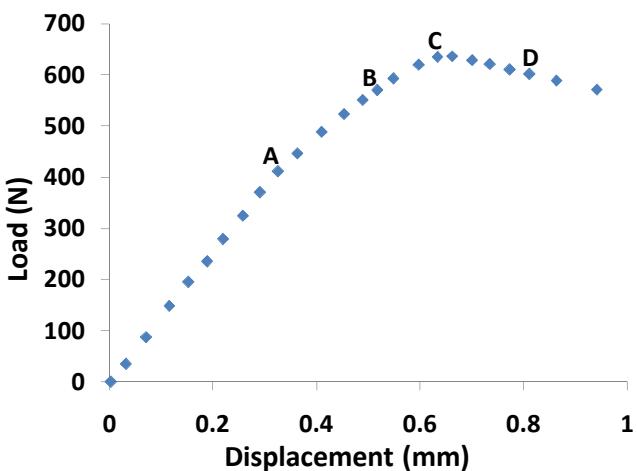
SEM Imaging of the Sputtered Pattern



- SEI is more sensitive to the surface topography than BEI
- BEI gives more contrast based on the atomic number
- Brightness and contrast is adjusted to acquire SEM images with best even distribution in the intensity histogram



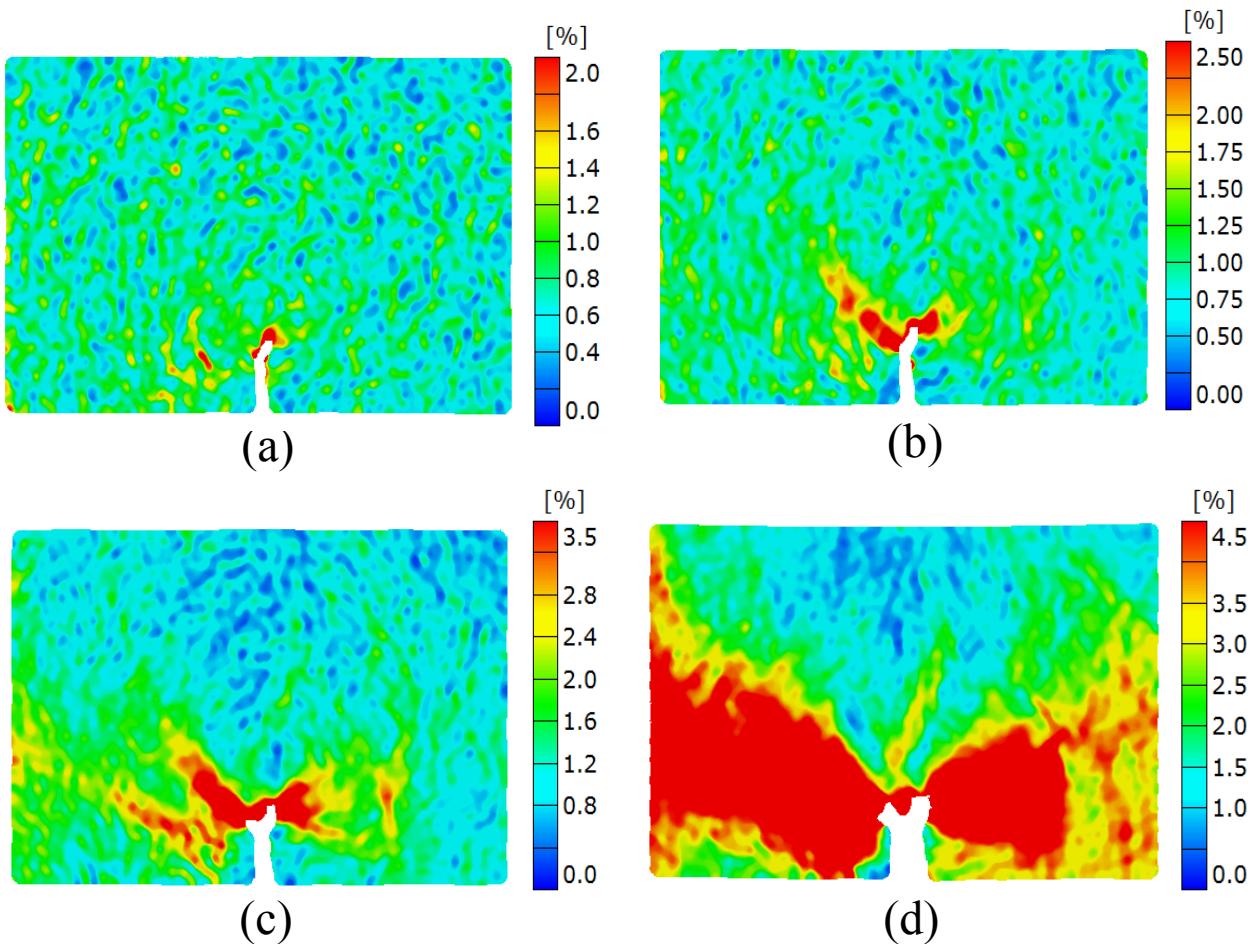
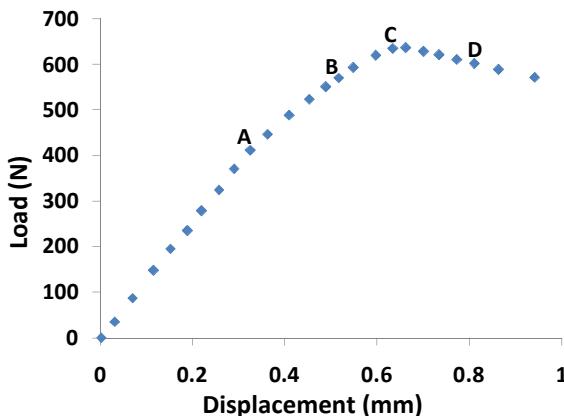
In-Situ SEM Imaging of Fracture Specimens



A series of BEI images at the selected loading steps as marked in the left figure

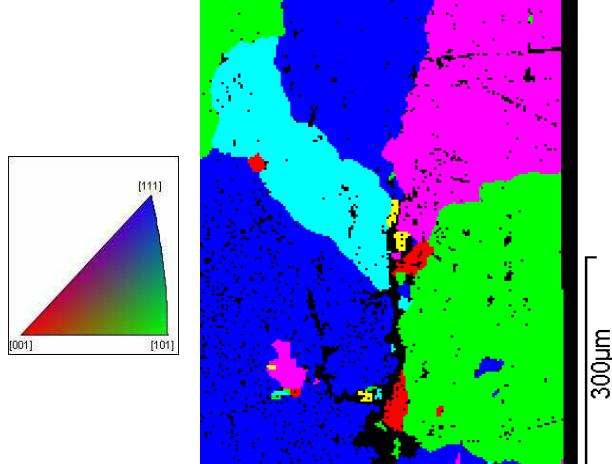
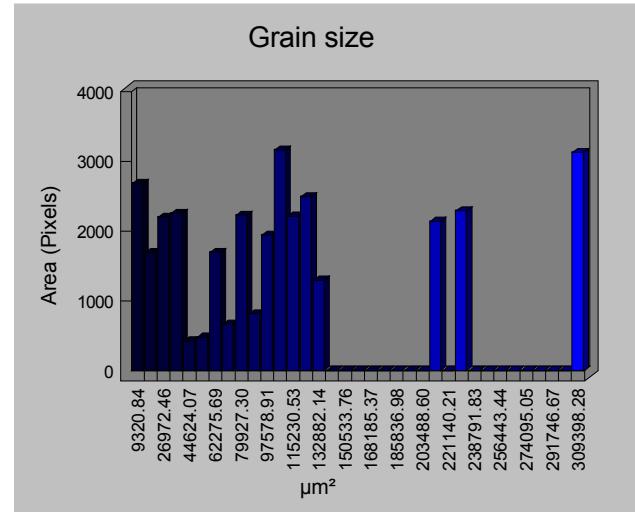
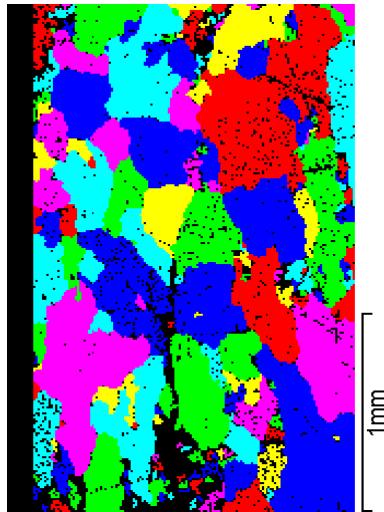


Local Deformation at the Crack Tip during Loading

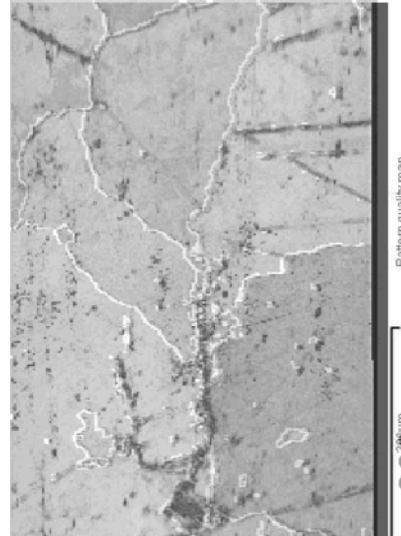




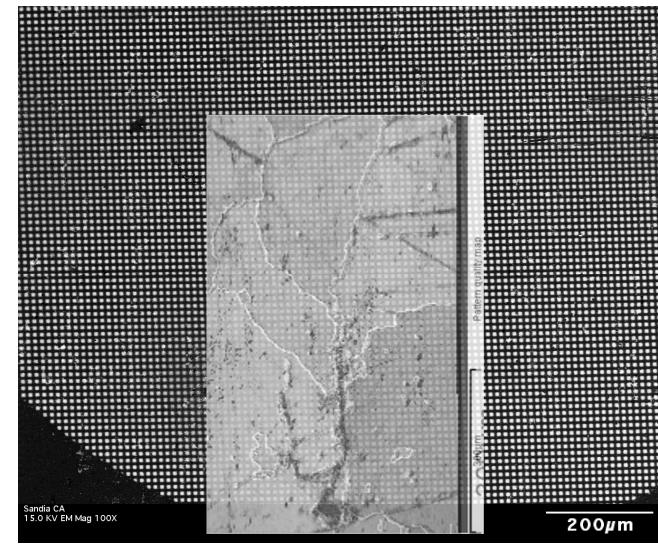
Microanalysis at the Crack Tip



Grain Orientation Mapping



Pattern Quality Map



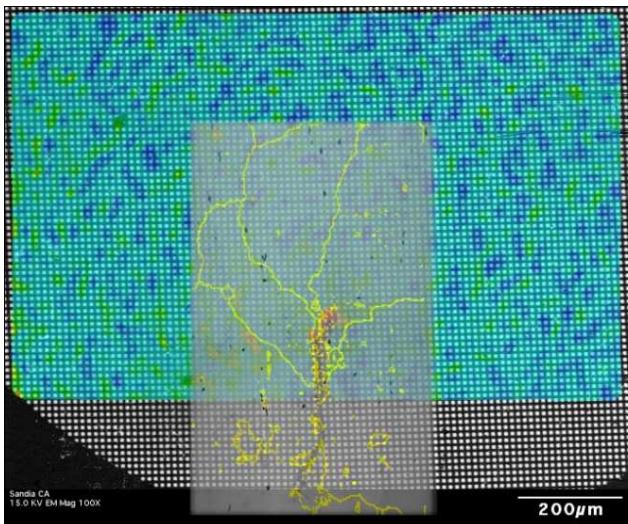
Grain map overlap with BEI



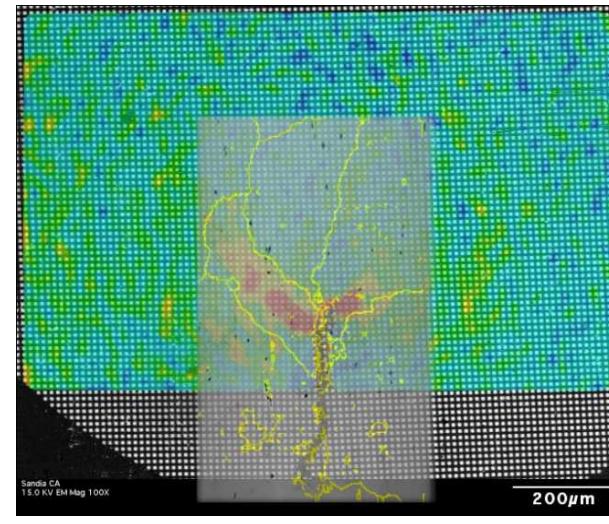
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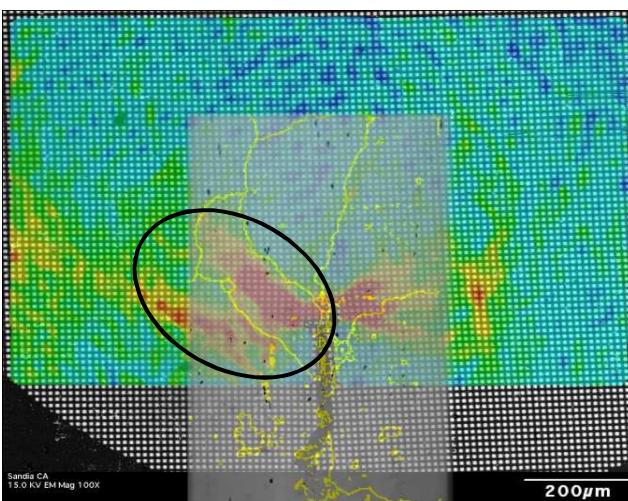
Effects of Microstructure on the Strain Localization at the Crack Tip



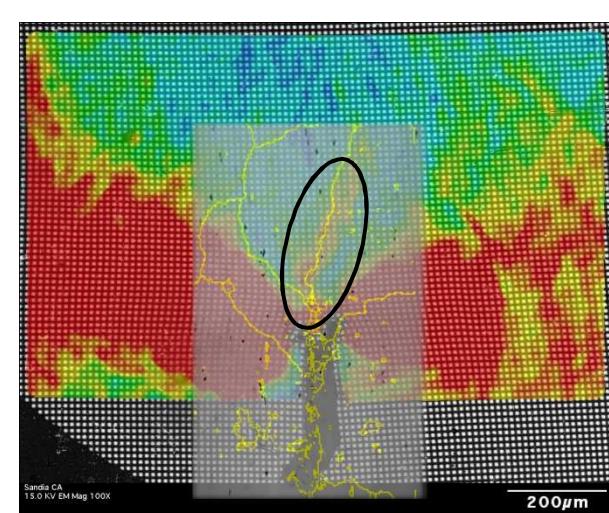
(a)



(b)



(c)



(d)



Conclusions

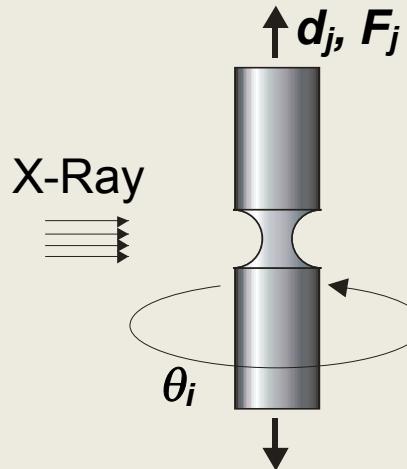
- A new method combining SEM imaging with DIC was successfully applied to study microscale plastic deformations at the crack tip during fracture testing of Al specimens.
- The BEI mode was able to acquire consistent images which are suitable for the DIC technique during three-point bending fracture testing.
- The local grain maps obtained from EBSD were carefully overlayed onto the strain fields.
- There is a mixture of effects in the fracture process zone at the crack tip where the weaker aspects of the grain boundary controls the growth of the crack and the more ductile aspects of the grains dissipate the energy.



Future Work–3D Imaging

For $j = 1:M$ (> 4)

Scan



For $i = 1:N$ (720 or 1440)

$$\theta_i = \theta_{i-1} + \Delta\theta$$

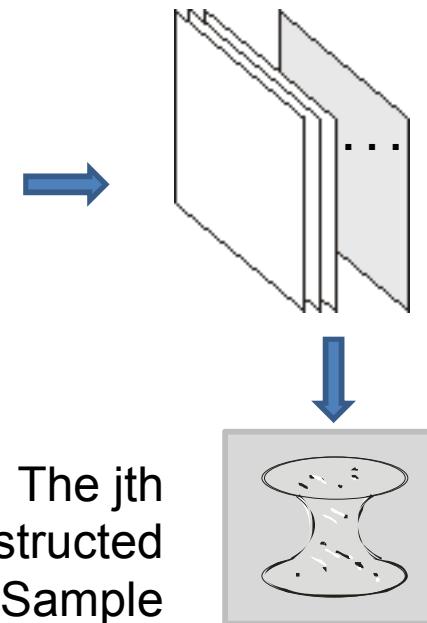
The i th
radiograph

~ 2500x1800
pixels

Synchrotron-radiation
computed tomography
(SRCT)

Reconstruction

N radiographs



The j th
reconstructed
Sample