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Study Damage Evolution in High Strength Aluminum using X-Ray Tomography

[1]Helena Jin, [1]Wei-Yang Lu, Alejandro Mota, Jay Foulk, Nancy Yang
Sandia National Laboratories, Livermore, CA

George Johnson
University of California, Berkeley, CA

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hjin@sandia.gov

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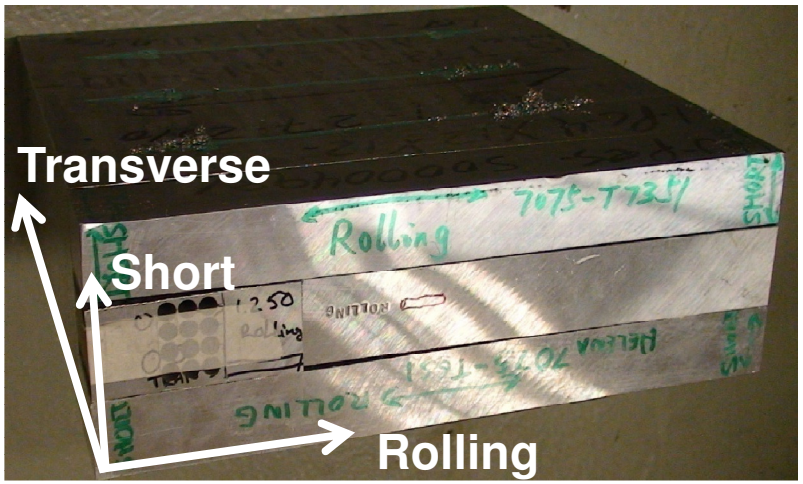
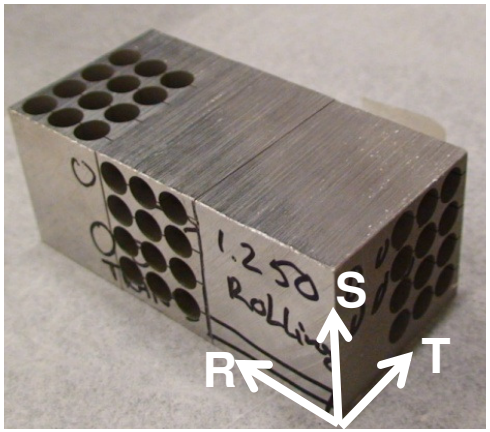
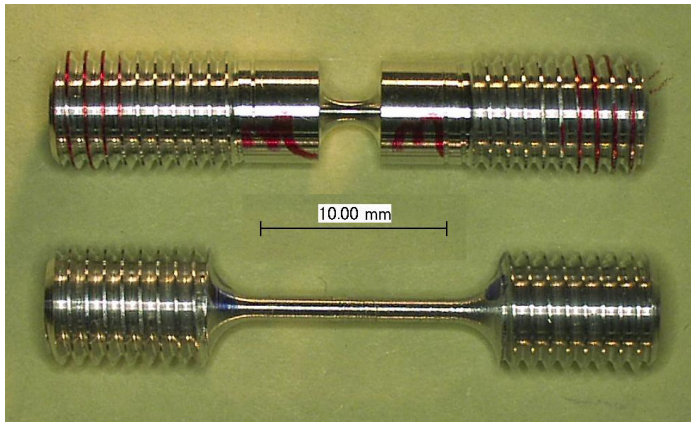
Introduction

- Motivation
  - Develop models for reliable predictions of failure in structural alloys, e.g. high strength rolled aluminum alloys
- Current available models are inadequate to model the evolution of anisotropic damage in rolled aluminum alloys
  - Usually restricted to isotropic material behavior
  - Detailed descriptions of the ductile failure processes based on micro-mechanics are needed, i.e. void nucleation, growth and coalescence
- X-ray computed tomography (CT) could reveal the three-dimensional structure of inclusions and voids
  - Attenuation to X-rays is correlated to the density of the material
- *In-situ* X-ray CT may provide the detailed nature and evolution of the damage and its relationship to the material microstructure

Material of Interest







Specimen	Loading Orientation		
	R	T	S
Smooth	SR	ST	SS
Notch	NR	NT	NS

- Specimens were machined from the center layer of a certified 4” rolled Al 7075-T7351 plate.
- Uniform tension and notched tension with notch width of 3.05 mm (0.120 in)
- Same minimal diameter of 1.5 mm and same overall specimen length
- The geometry of the notch affects the stress triaxiality which is known to promote void growth

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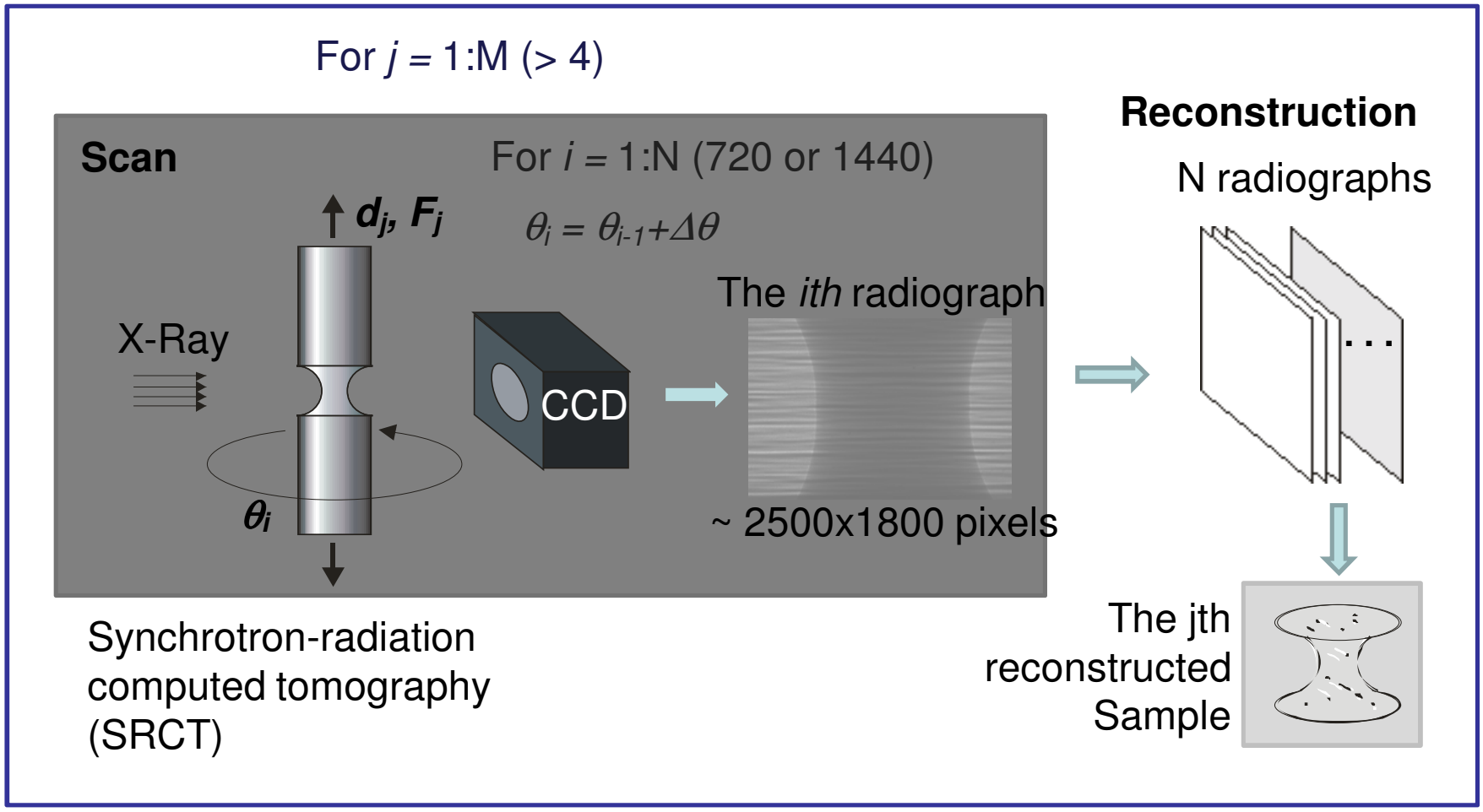
In-situ X-Ray CT Experiment



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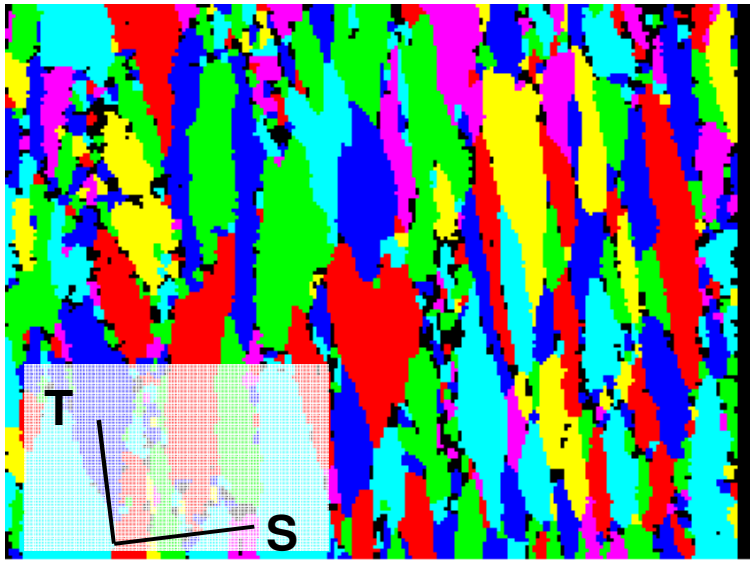
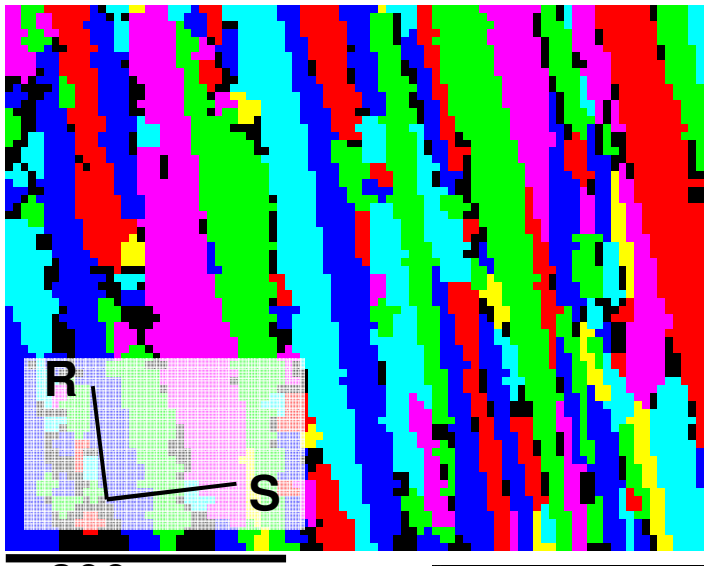
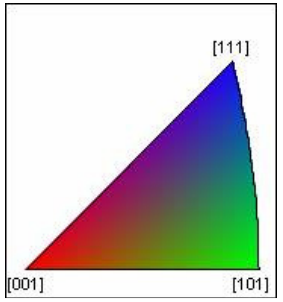
Grain Analysis Using EBSD







- The grain is about
  - 300 um long in R-direction,
  - 100 um in T- direction,
  - 50 um in S-direction
- Grain boundary is defined by 5° angle difference in EBSD

Component	Al	Mg	Si	Cu	Zn	Fe	Cr	Mn
Wt.%	87-91	2.1-2.9	<0.4	1.2-2	5-6	< 0.5	0.18-0.28	<0.3

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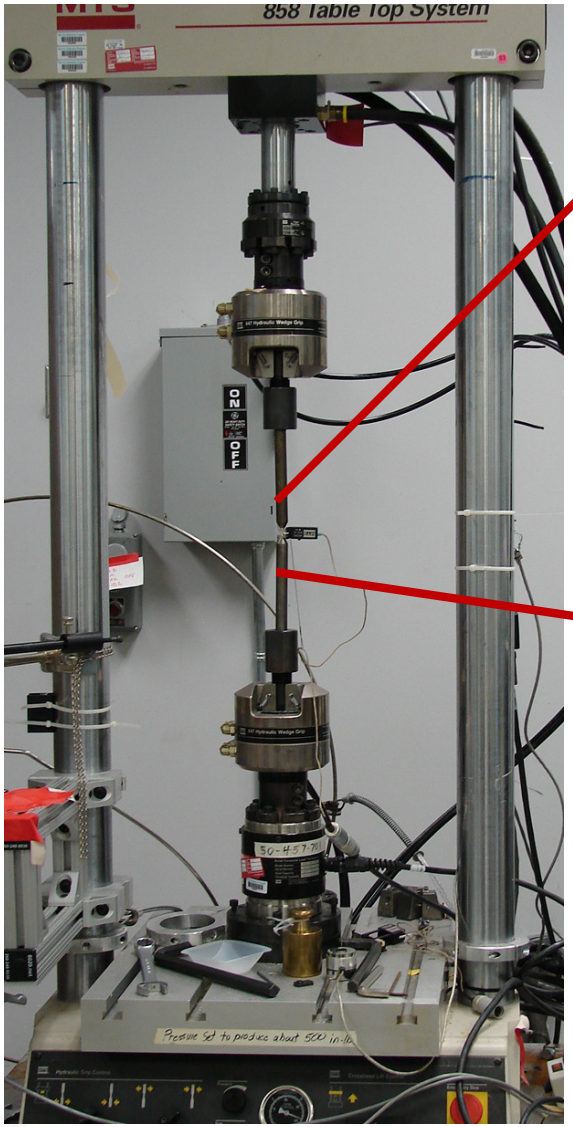
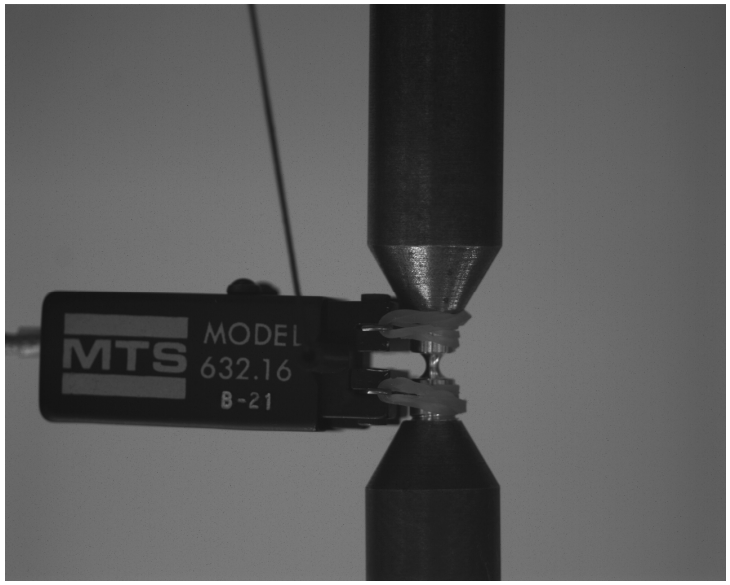
Conventional mechanical characterization of the material





- MTS 858 table top system;
- Ball joint for better alignment;
- Extensometer gage length is 0.3 inch;
- Displacement controlled test.

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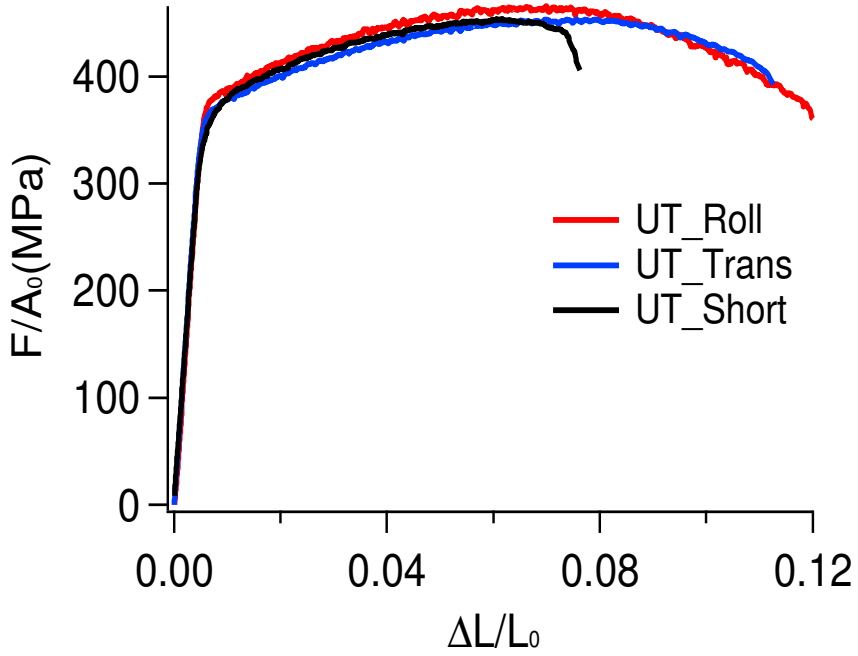
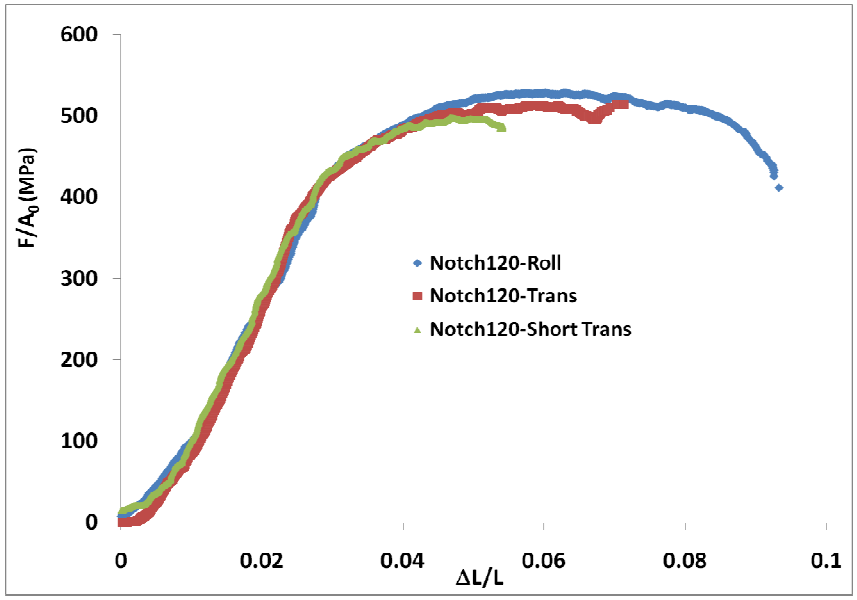
Anisotropy of ductility was found in rolled material



Uniform Tension



Notched tension with notch length of 0.120 inch

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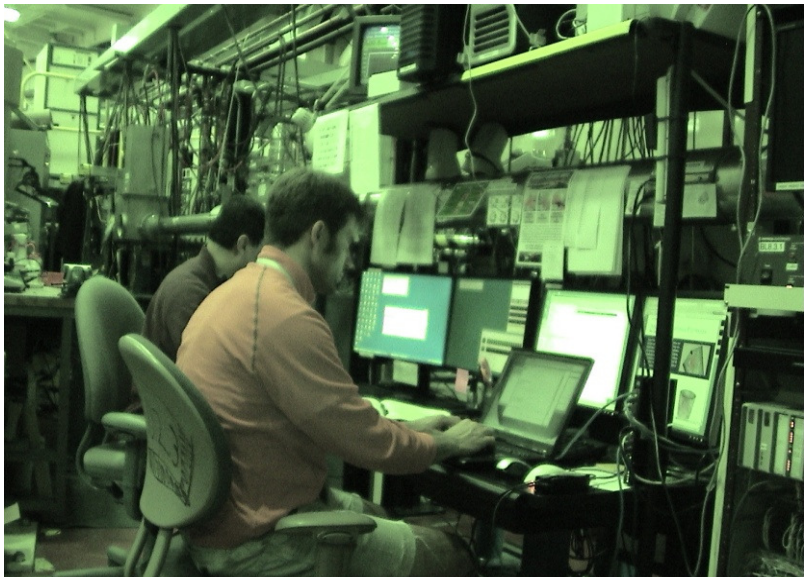
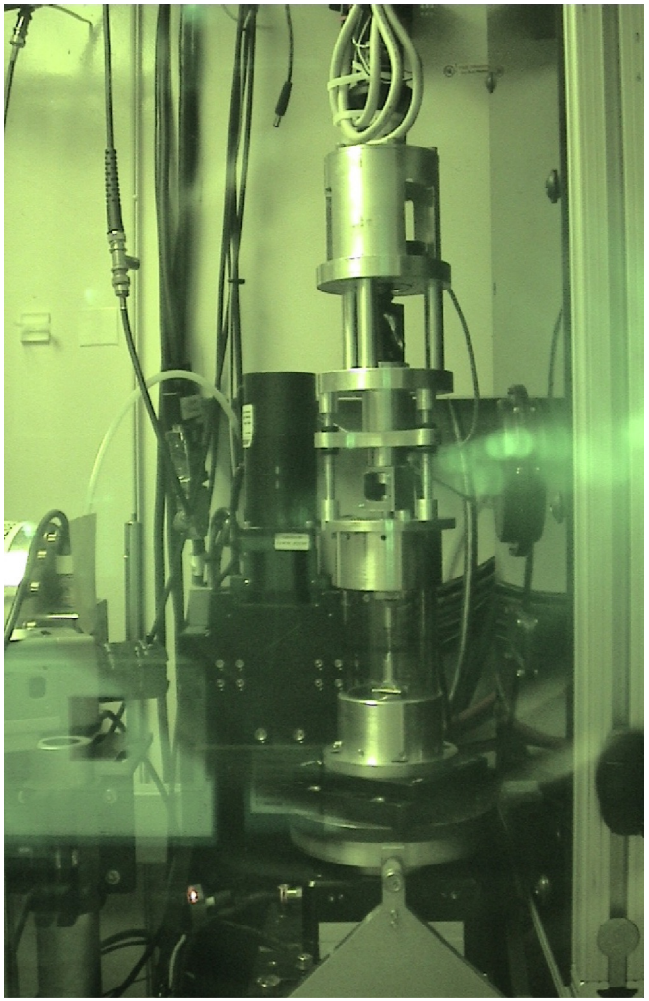
In-Situ XCT Experiment





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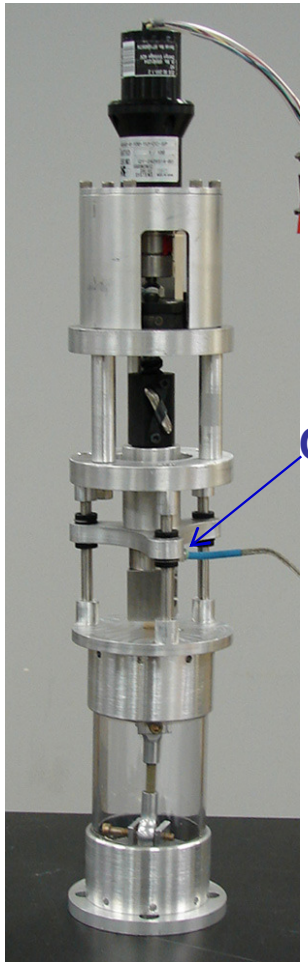
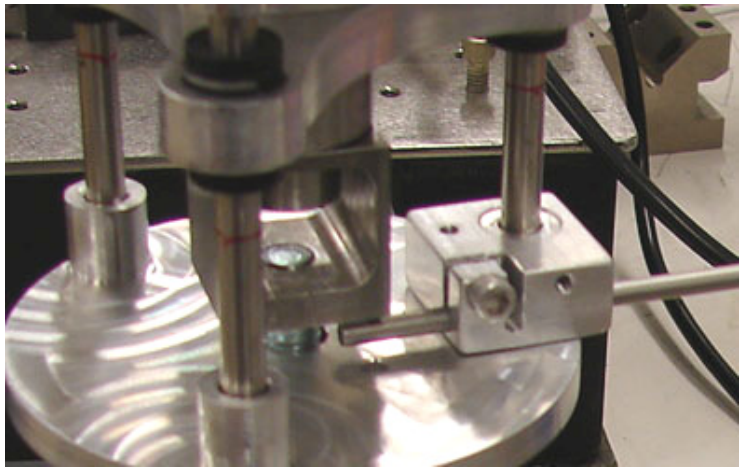
In-Situ Loading Stage



- Modified beamline 8.3.2 loading stage for tensile loading
  - Step motor open-loop control
  - New fixture design for easy specimen mounting
  - New grips with ball joint for precision alignment
  - New confocal displacement sensor



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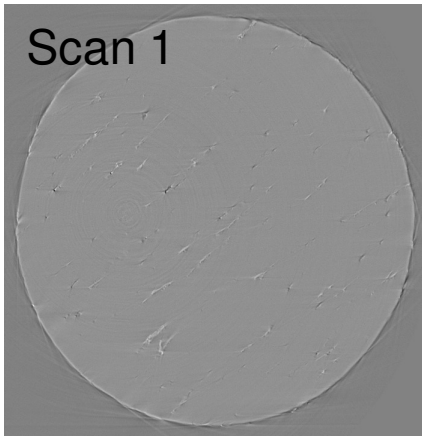
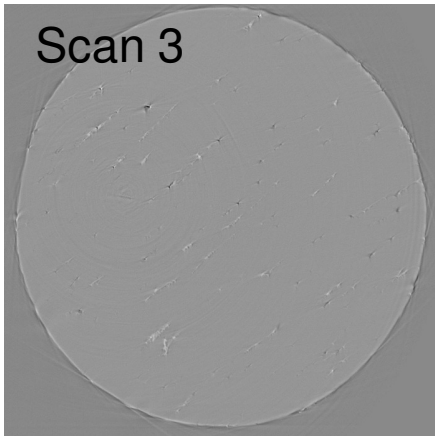
Data of a Horizontal Slice

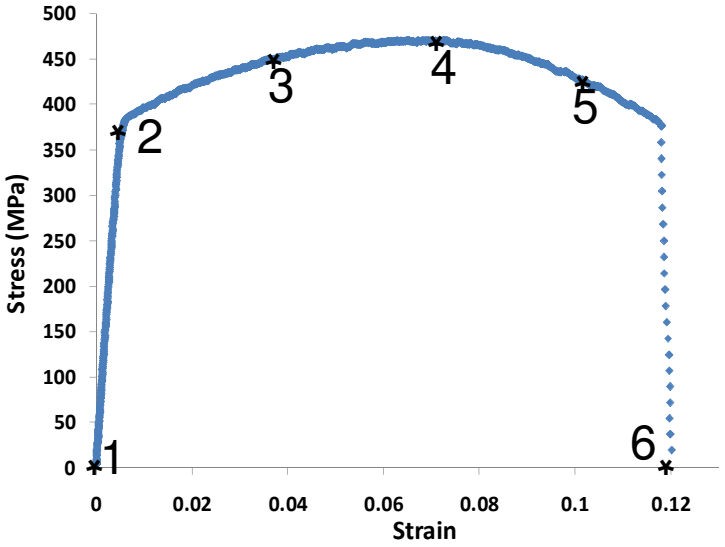
ST Specimen



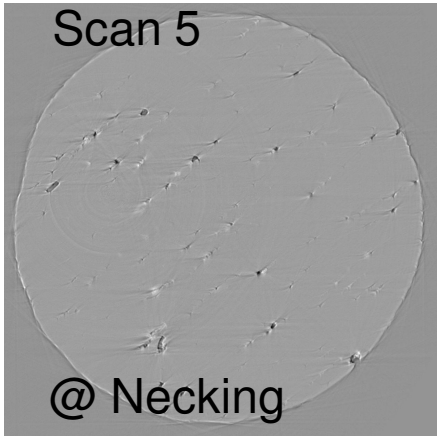
@ Original state



@ Hardening

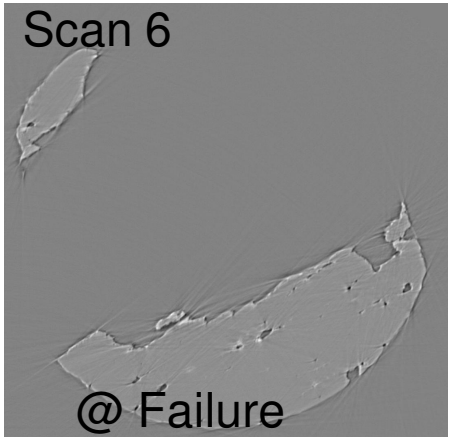


@ Maximum stress



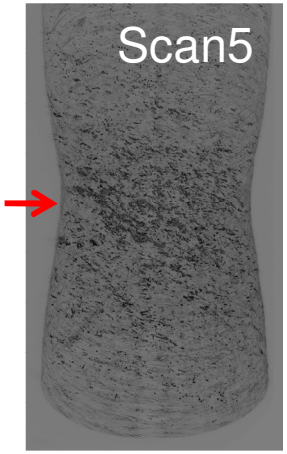
@ Necking

Void growth



@ Failure

Coalescence



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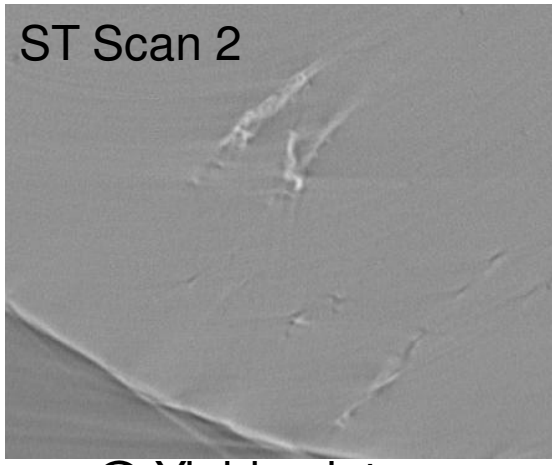
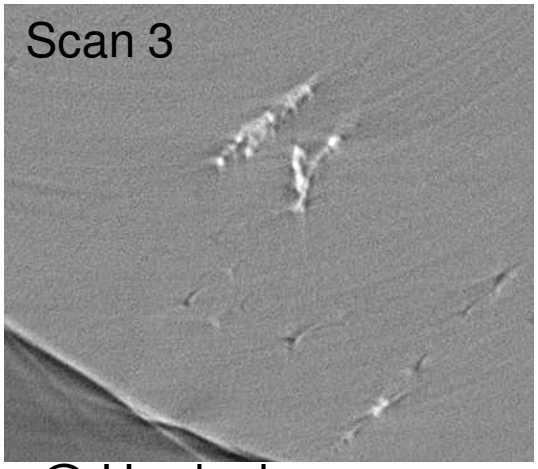
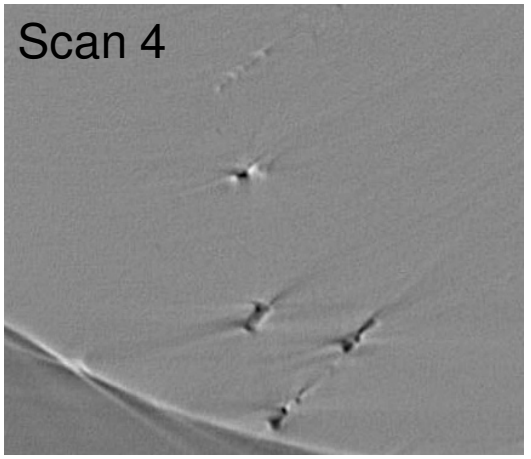
Voids Evolution



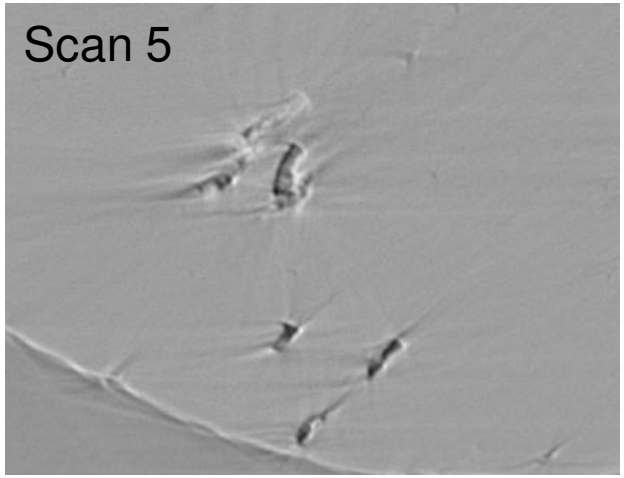
@ Yield point,
- nearly intact



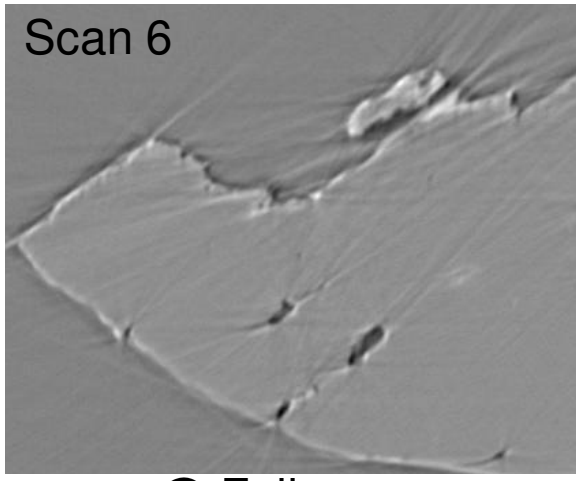
@ Hardening



@ Maximum stress



@ Necking
- Void growth



@ Failure
- Coalescence

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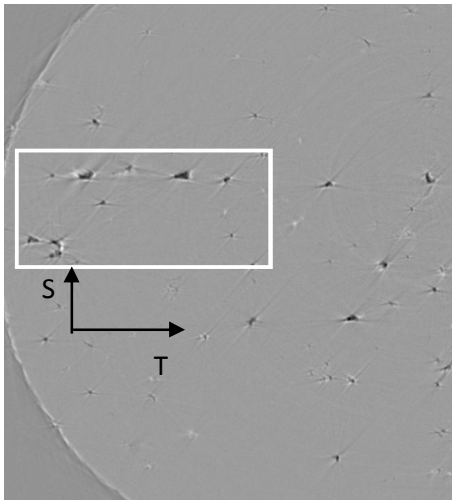
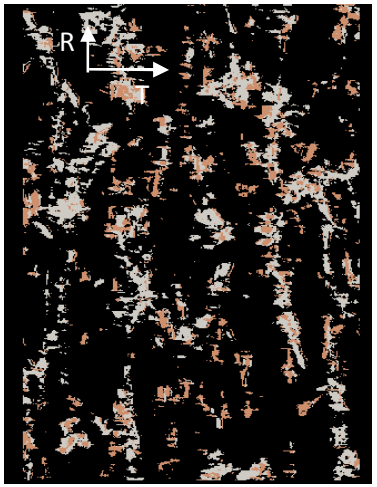
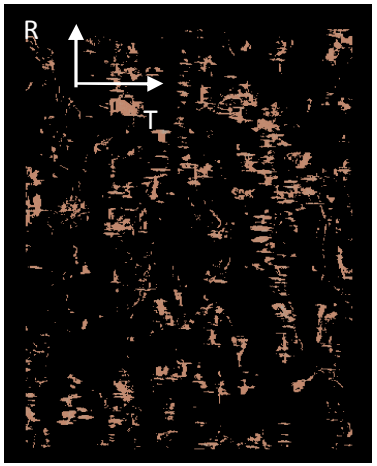
Voids Evolution for the Specimen in Rolling Direction



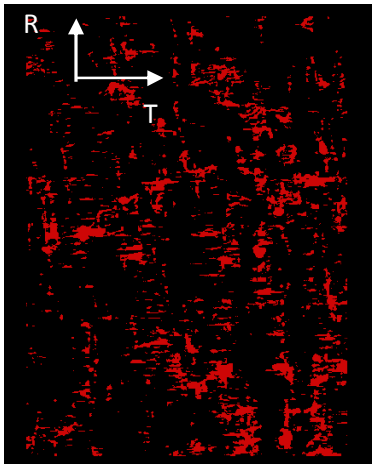
(a) area used for projections in R-T plane



(b) 3D rendered image of voids (orange color) and constituent particles (white color) at the original unloaded state



(c) 3D rendered image of voids at the original state



(d) 3D rendered image of voids at failure state

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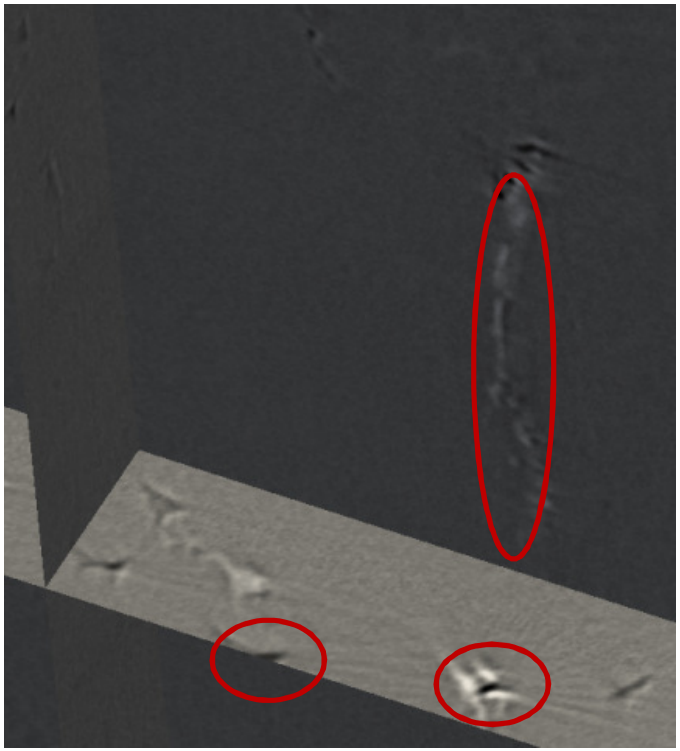
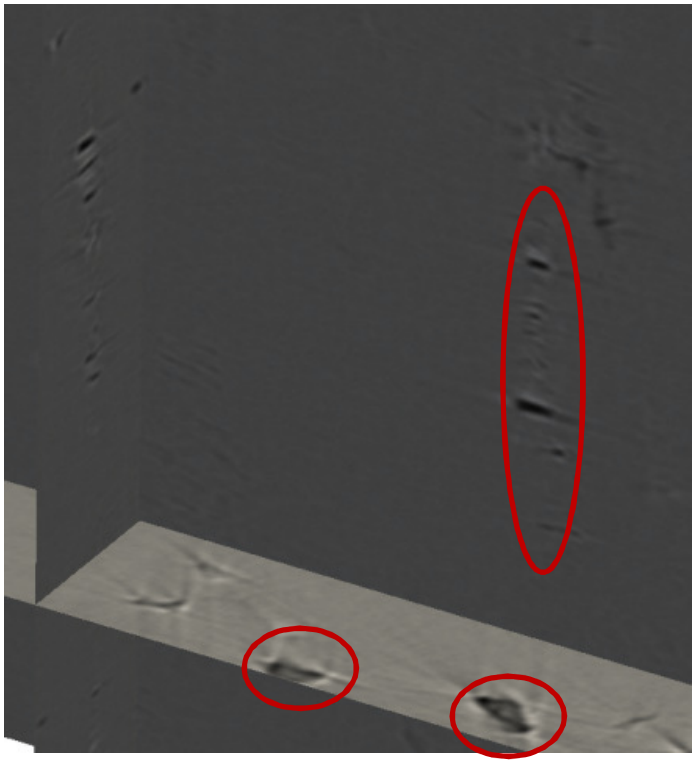
Voids Evolution for the Specimen in the Rolling Direction (cont'd)



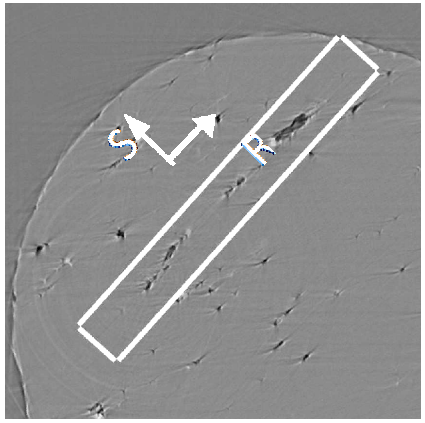
(a) Voids at the original state



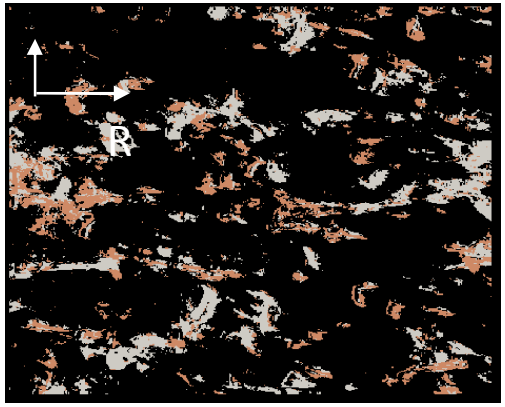
(b) Voids at the failure state

➡ Voids were nucleated at the second particle location and voids growth were observed. The voids growth was nearly isotropic.

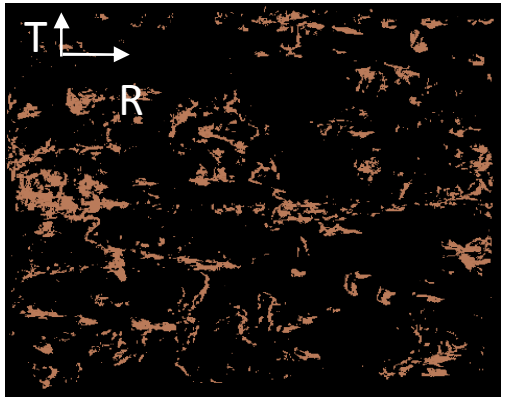
Voids Evolution for the Specimen Loaded in Transverse Direction



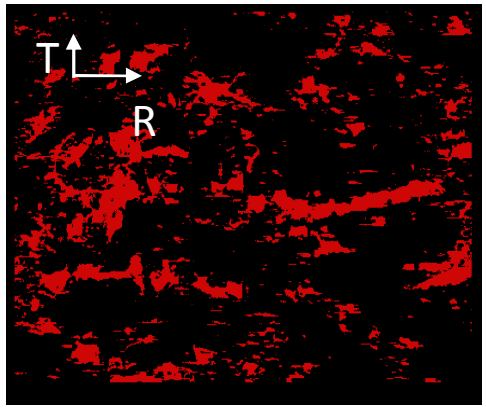
(a) area used for projections in T-R plane



(b) 3D rendered image of voids (orange color) and constituent particles (white color) at the original unloaded state



(c) 3D rendered image of voids at the original state



(d) 3D rendered image of voids at failure state

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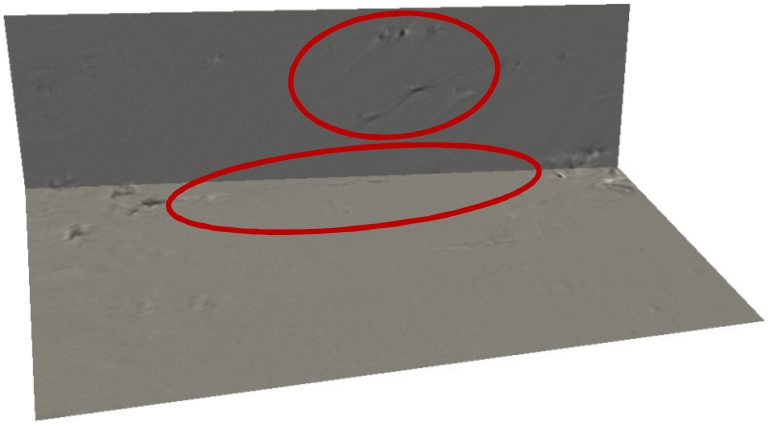
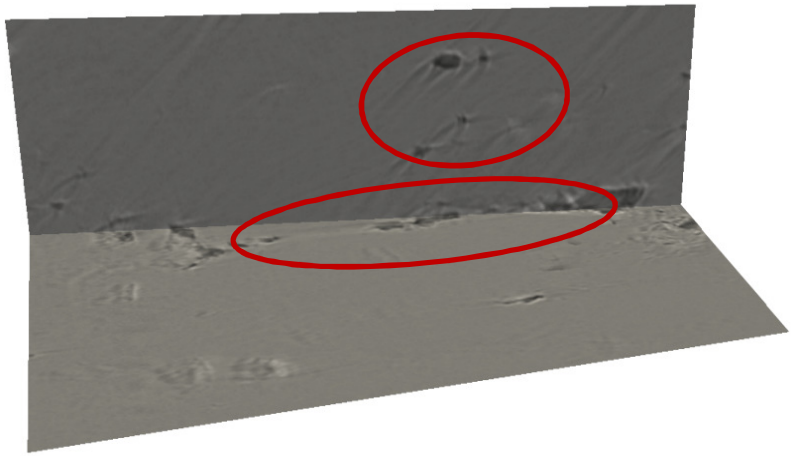
Voids Evolution for the Specimen Loaded in Transverse Direction (cont'd)



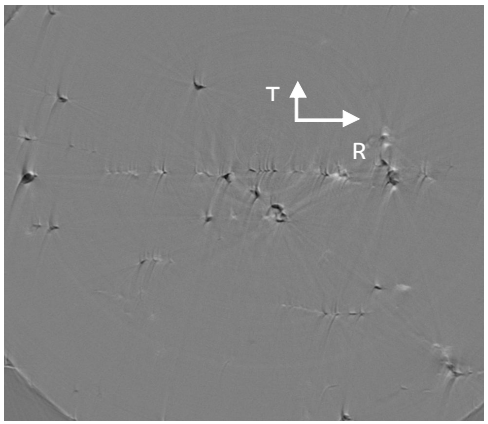
(a) Voids at the original state



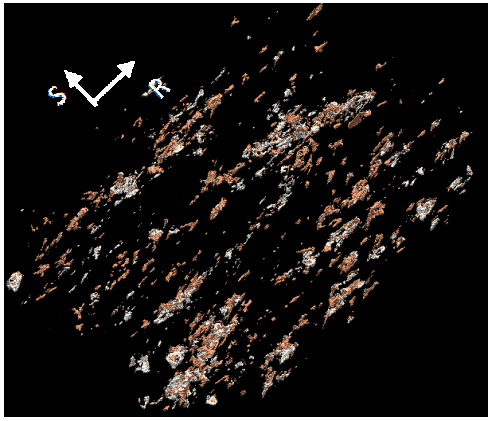
(b) Voids at the failure state

➡ Voids nucleation, growth and coalescence were observed. The voids growth and coalescence had one dimensional preference along "stringers" in the rolling direction.

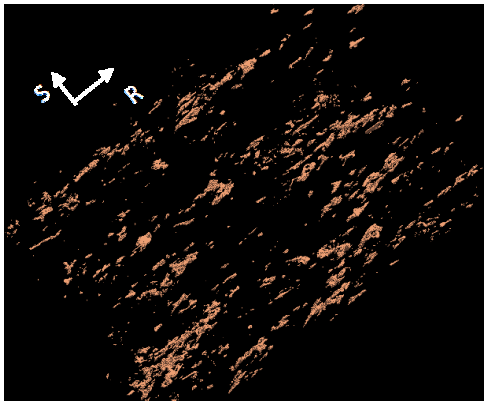
Voids Evolution for the Specimen Loaded in the Short Transverse Direction



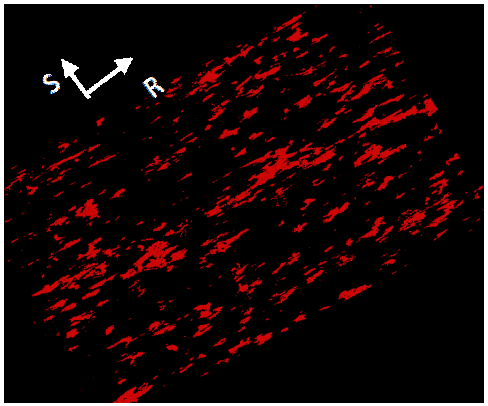
(a) area used for projections in S-R plane



(b) 3D rendered image of voids (orange color) and constituent particles (white color) at the original unloaded state



(c) 3D rendered image of voids at the original state



(d) 3D rendered image of voids at failure state

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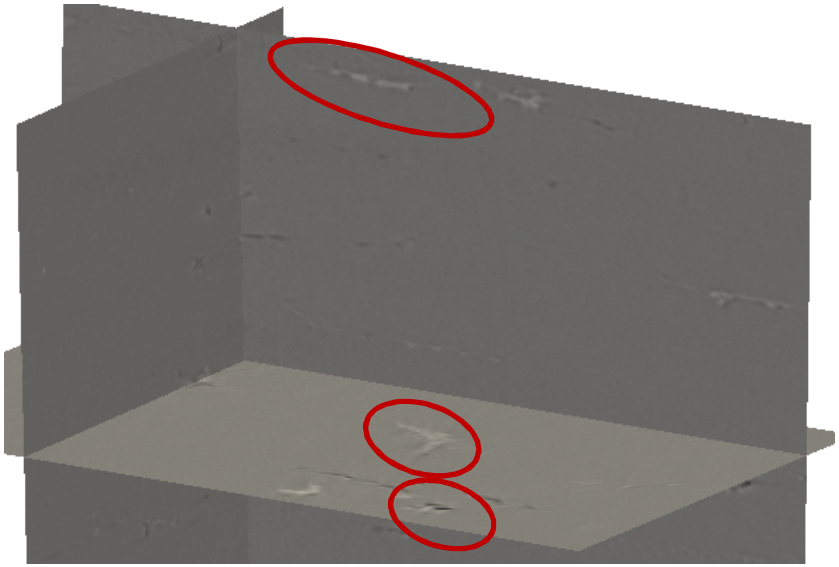
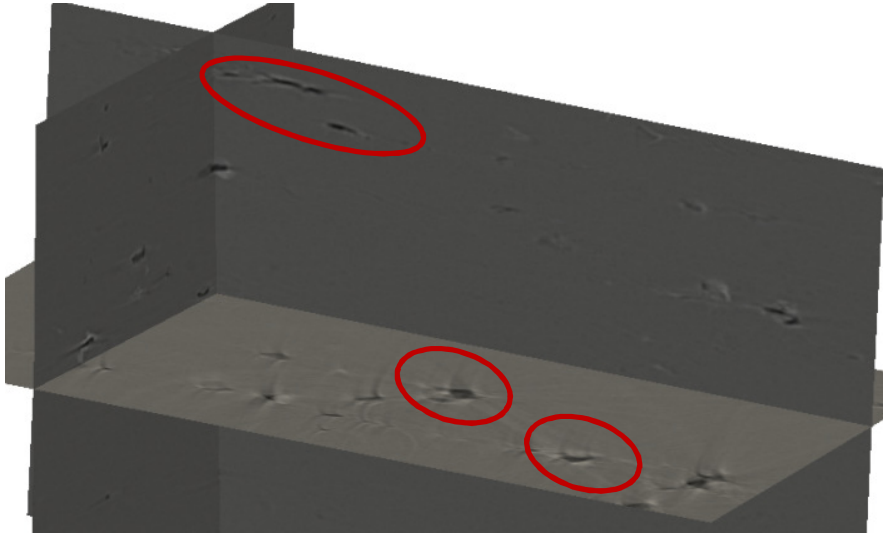
Voids Evolution for the Specimen Loaded in the Short Transverse Direction (cont'd)



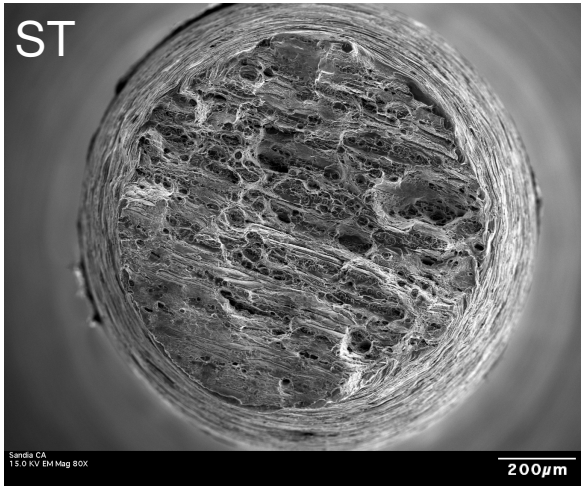
(a) Voids at the original state

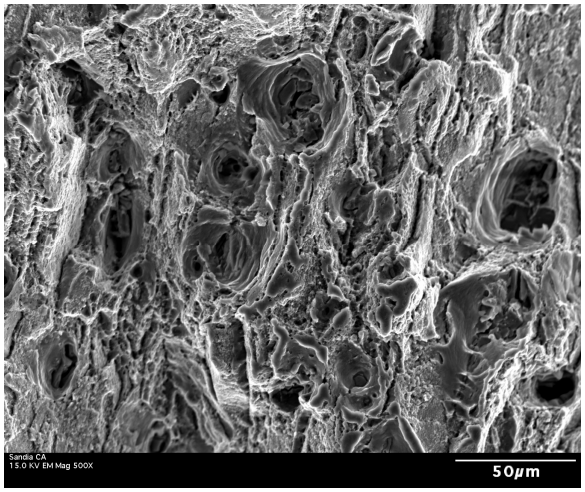


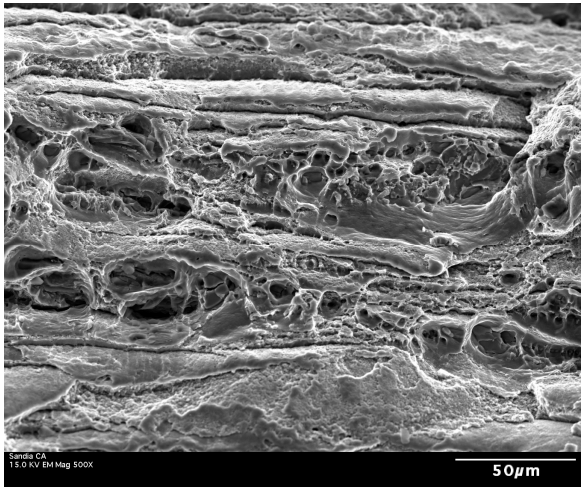
(b) Voids at the failure state

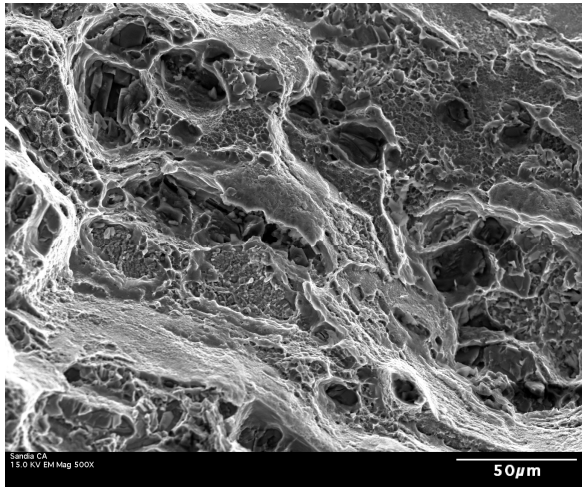
➡ Voids nucleation, growth and coalescence were observed. The voids growth and coalescence had planar preference in the R-T plane.

Failure Surfaces









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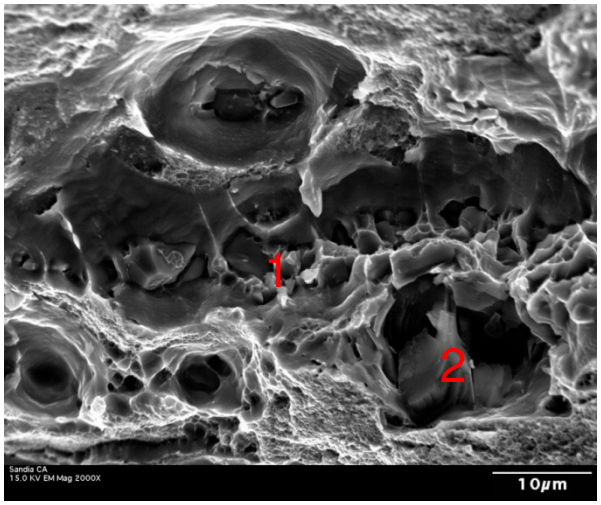
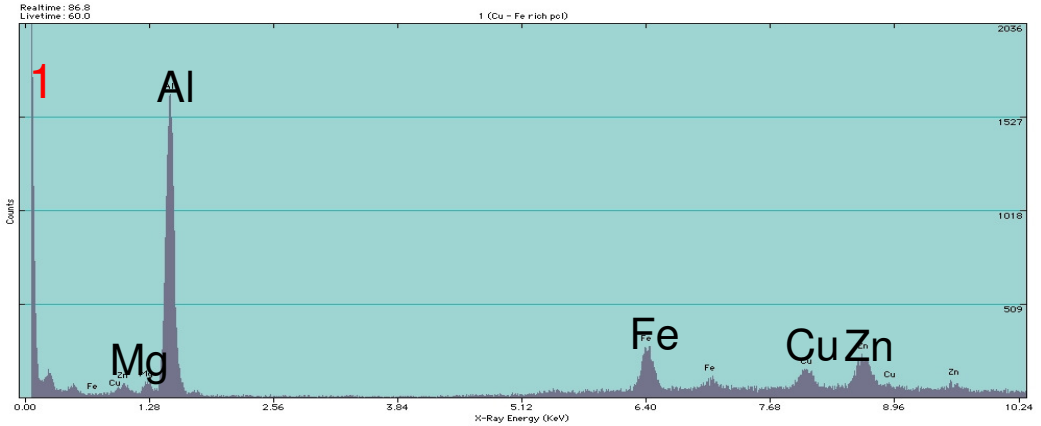
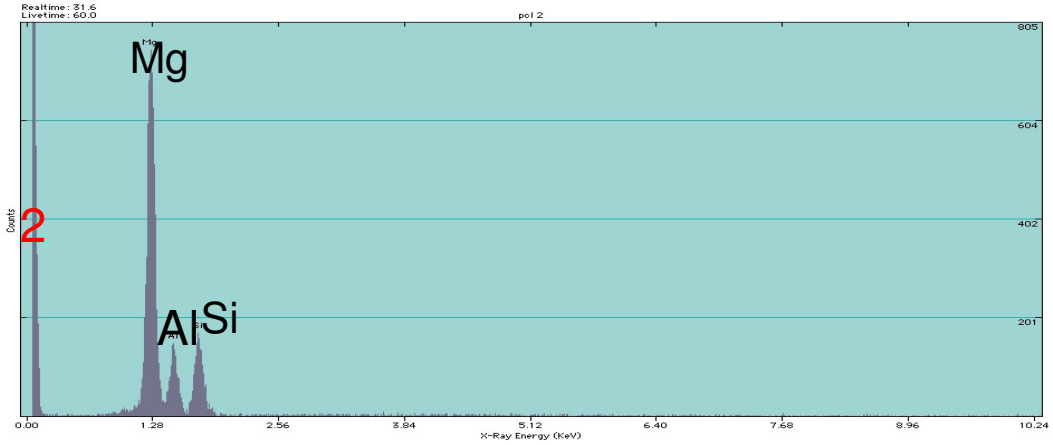
Second Phase Particles







- Both Iron-rich and Magnesium-rich second phase particle were identified
- Voids were initiated at the locations of the second phase particle

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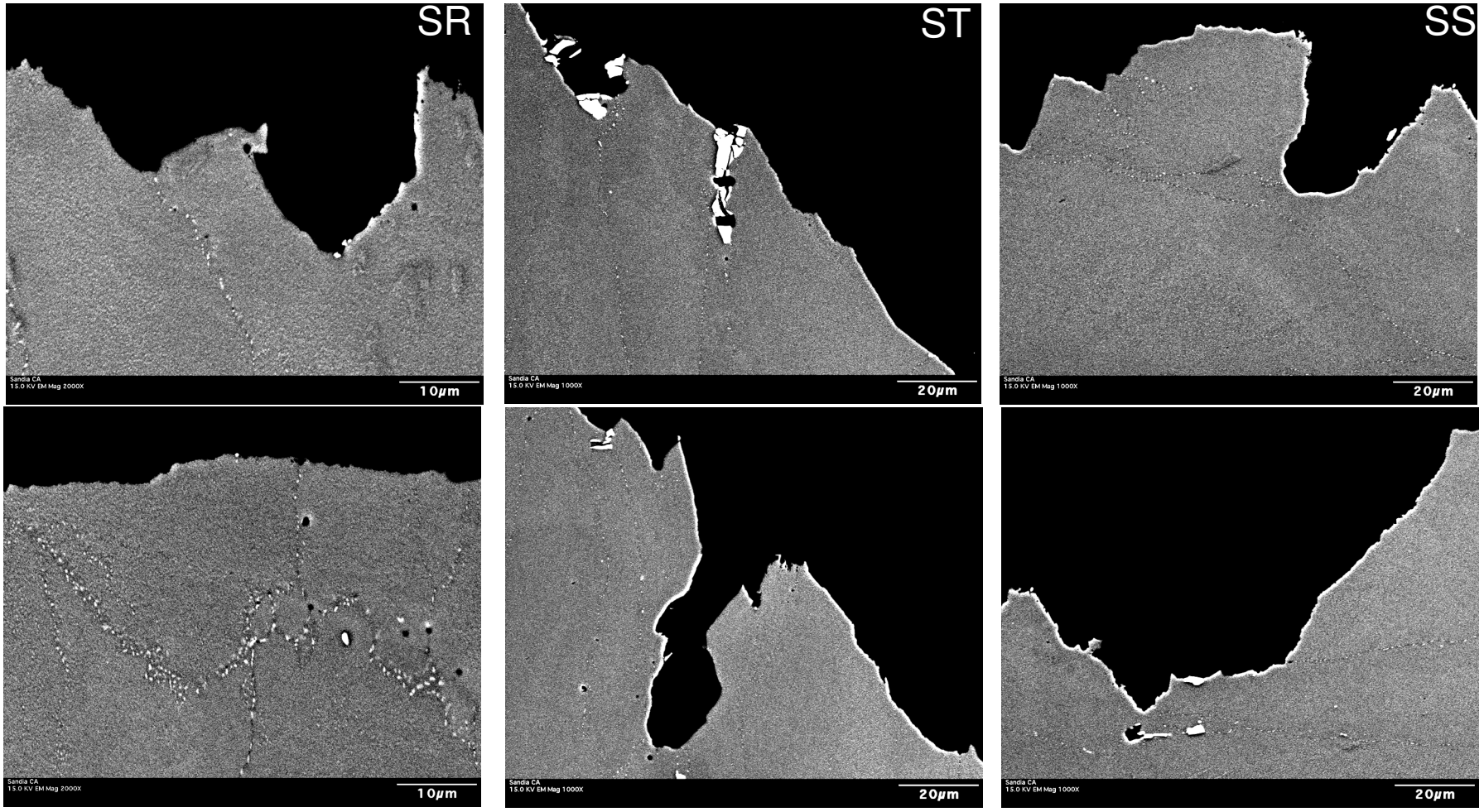
Failure Modes



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Summary

- XCT data were obtained at incremental loading steps for 7075-T7351 aluminum specimens loaded in three principal material directions
- The resolution of SRCT data is 900nm, which allows elucidation of the mechanisms governing void growth and coalescence. The resolution may be not fine enough for nucleation
- SEM imaging and EDS confirmed that the voids were initiated at the locations with second phase particle
- The constituent particles tend to align with the rolling direction in the form of stringers
- The voids and anisotropic failure are closely associated with these strings of particles
- Void growth and coalescence show anisotropy in three loading directions

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Thank you!

Questions?

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