



Study of Ductile Fracture Behavior

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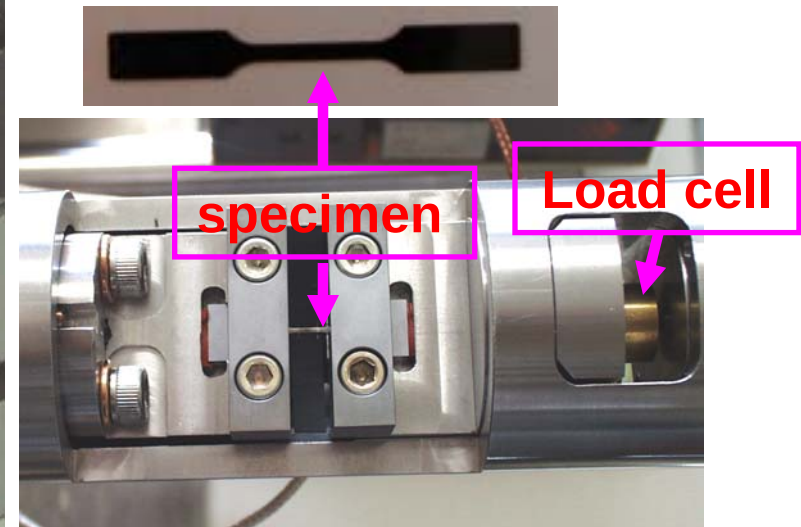
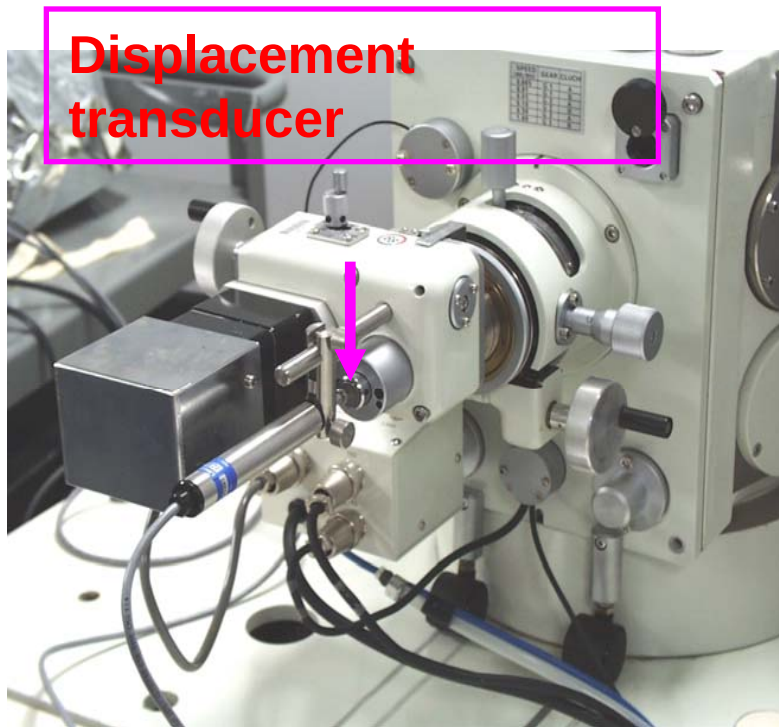
Outline

- Mechanical characterization of LIGA specimen using SEM imaging and DIC technique
- Study of local deformation and strain concentration of ductile fracture
- Pattern generation for the DIC application on the SEM images



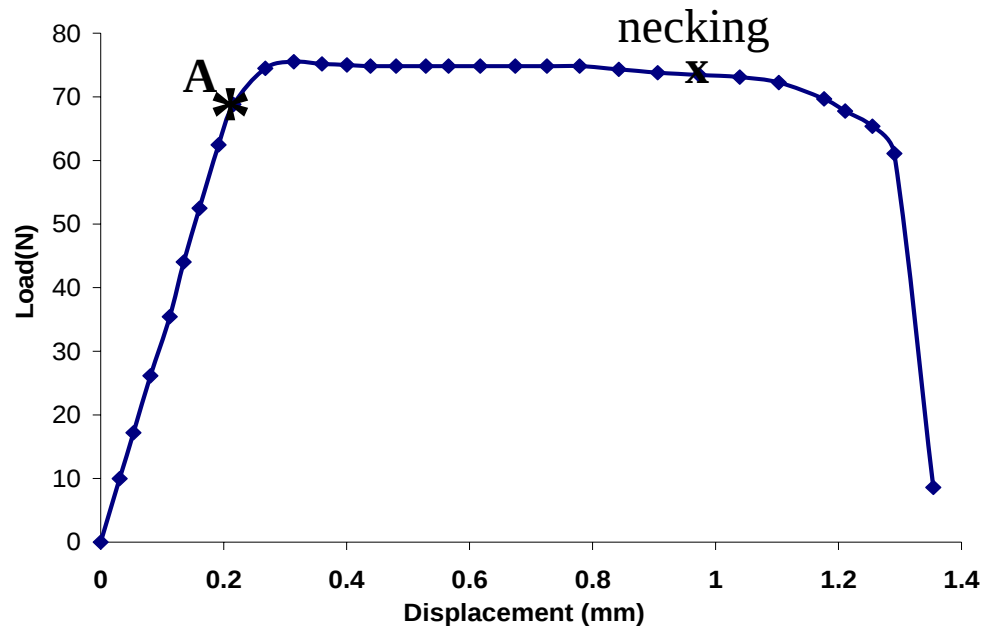
Mechanical Characterization of LIGA Specimen

- LIGA specimen has lateral spacing
- 3-Dimensional high aspect ratio microstructures





Load-Displacement Curves from Loading Stage



- Load is recorded by load cell
- Displacement is recorded by linear displacement sensor at the end of loading stage

- Large error in displacement due to compliance of the loading stage
- Need displacement measurement directly over the specimen

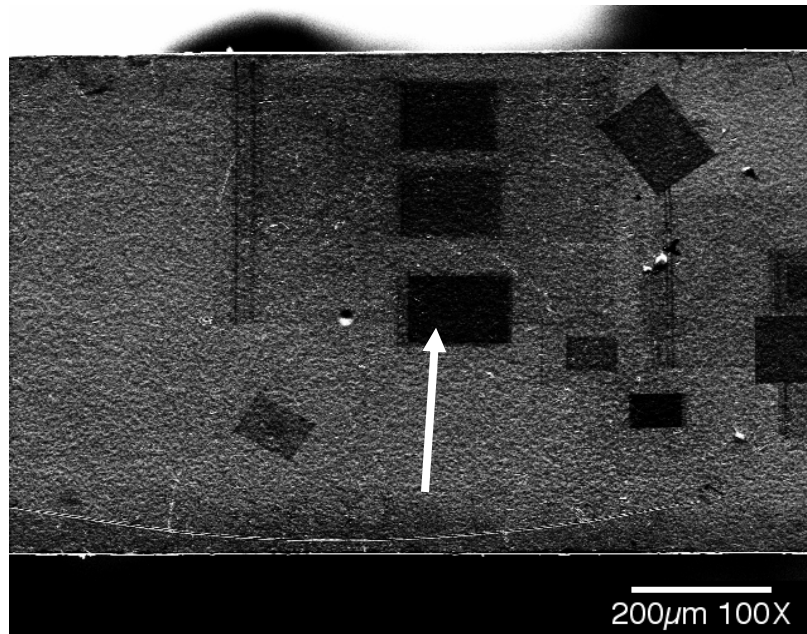


SEM Loading Stage

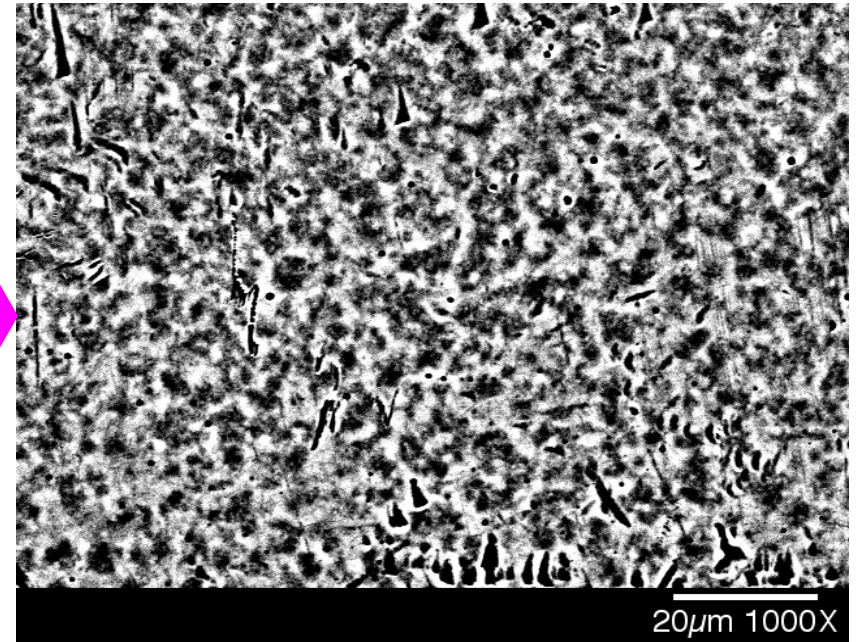




Random Patterns from Microstructural Surface Features



SEM imaging area over specimen

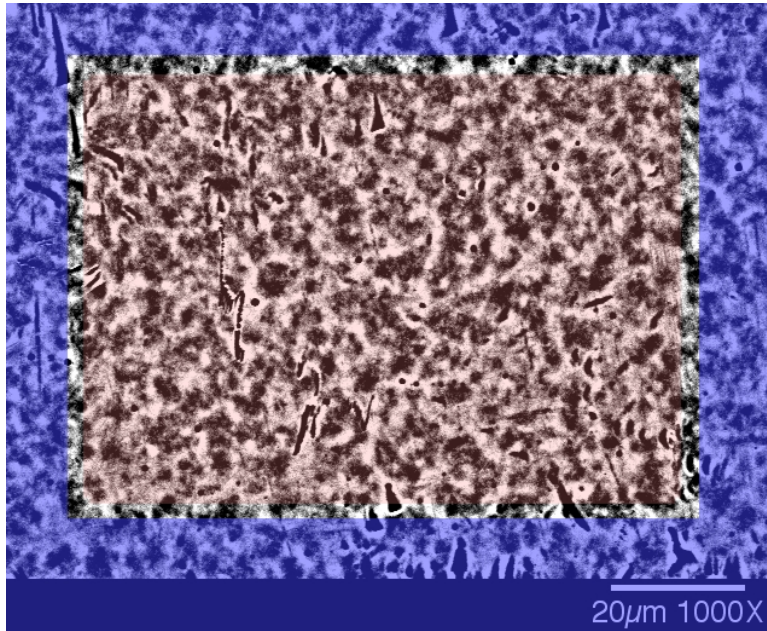


A Typical SEM image for DIC

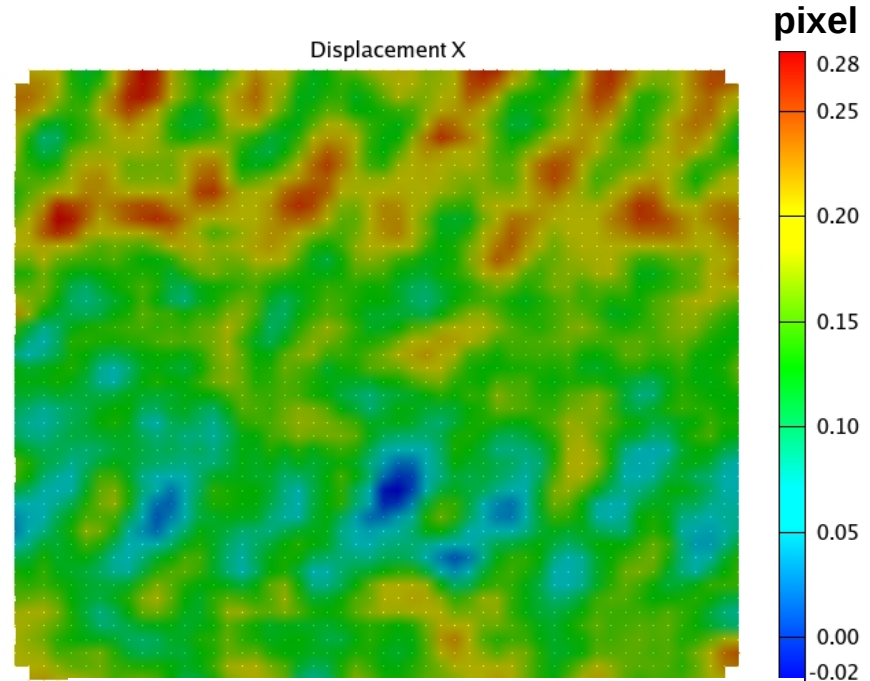
- Proper magnification is chosen for SEM imaging according to microstructure feature
- Brightness and contrast is adjusted to acquire SEM images with even intensity distribution in the histogram



Applying DIC to SEM Images



Area of Interest (AOI) for DIC

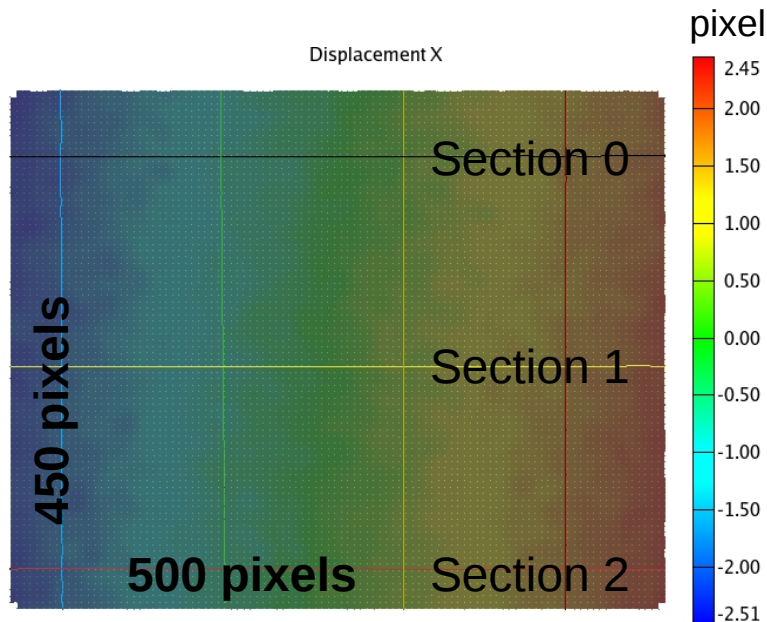


Random error of DIC over AOI

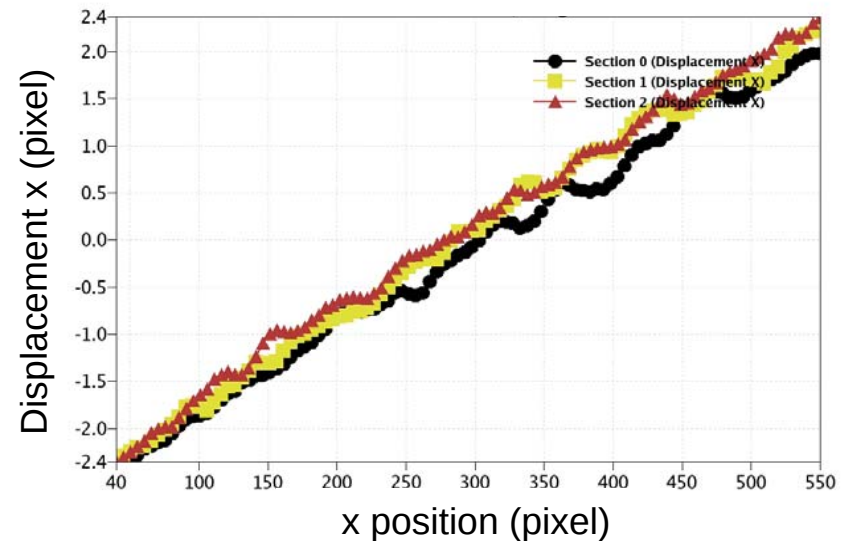
- Random error of DIC is subpixel
- SEM images from microstructural features are suitable for DIC technique



Full-field Displacement from DIC at Yielding Point A



Displacement at yielding point A

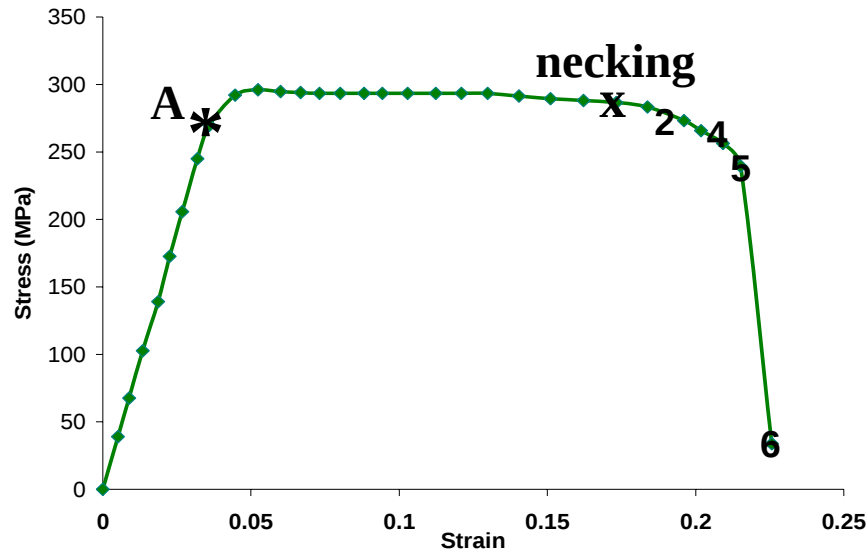


Displacement along the defined sections

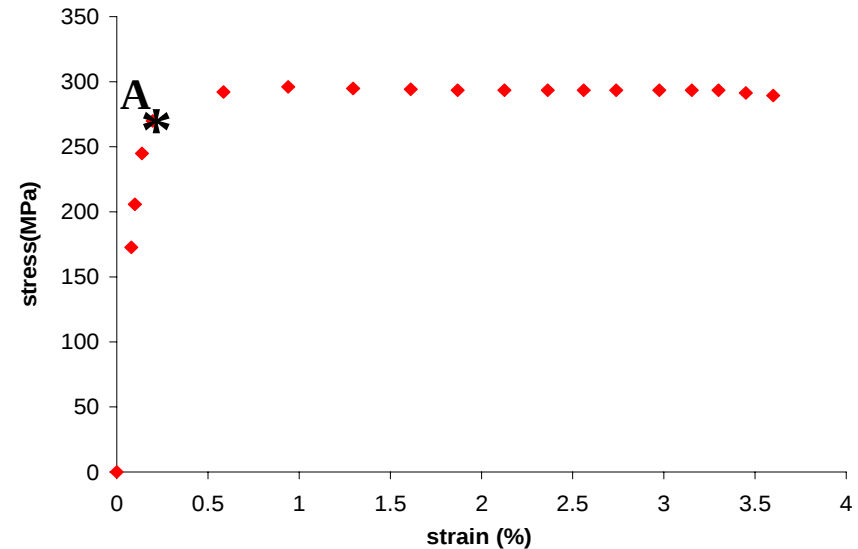
- Displacement can be acquired from the SEM images for each step of loading
- Strain can be calculated from displacement



Stress-strain Curves



Stress-strain curves recorded from transducers

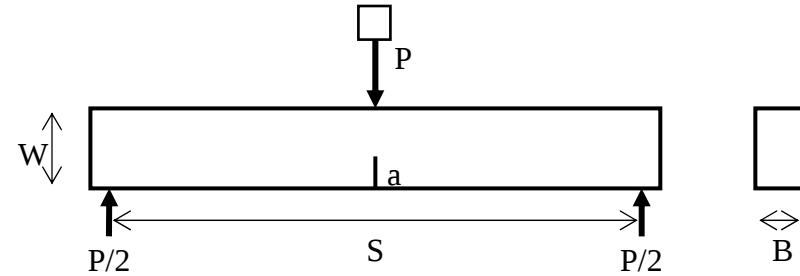
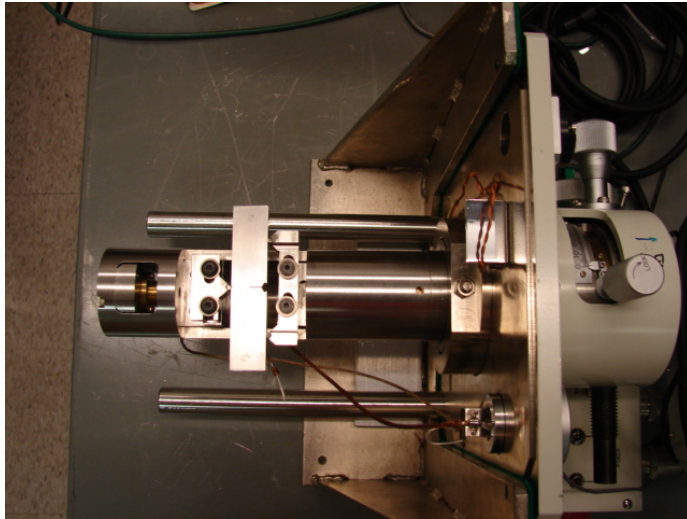


Stress-strain curves calculated using DIC

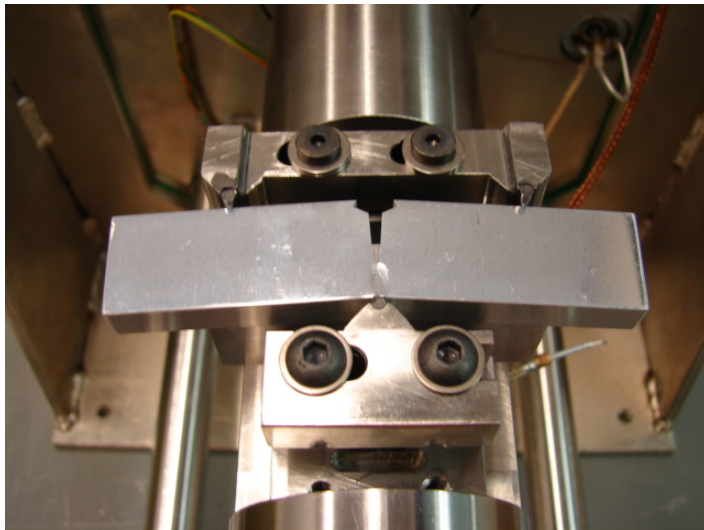
- Yield stress ~275MPa
- Ultimate stress ~300MPa
- Young's modulus ~155GPa



Three-Point Bending Test

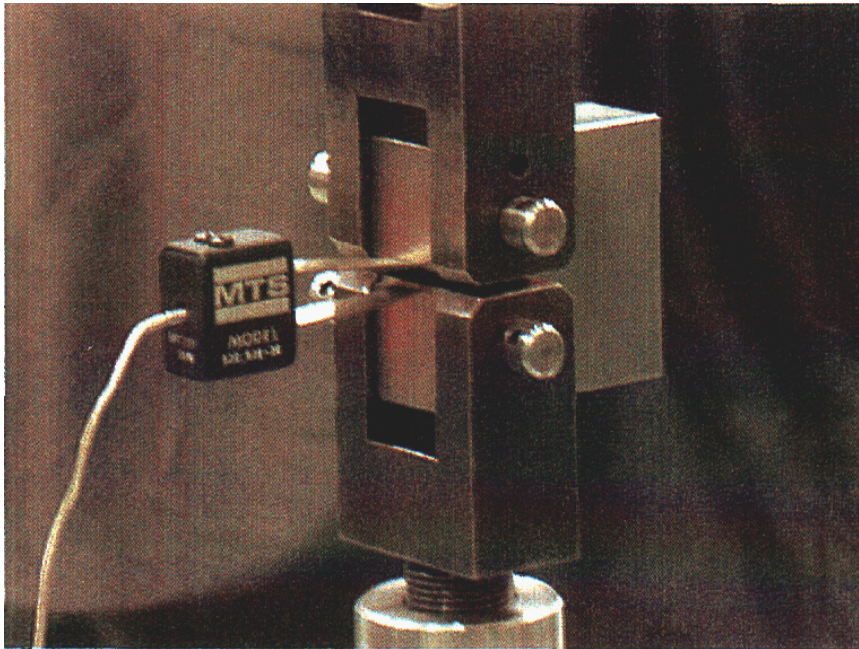


W (mm)	a (mm)	S (mm)	L (mm)	B (mm)
6.35	3.175	50.8	63.5	6.35

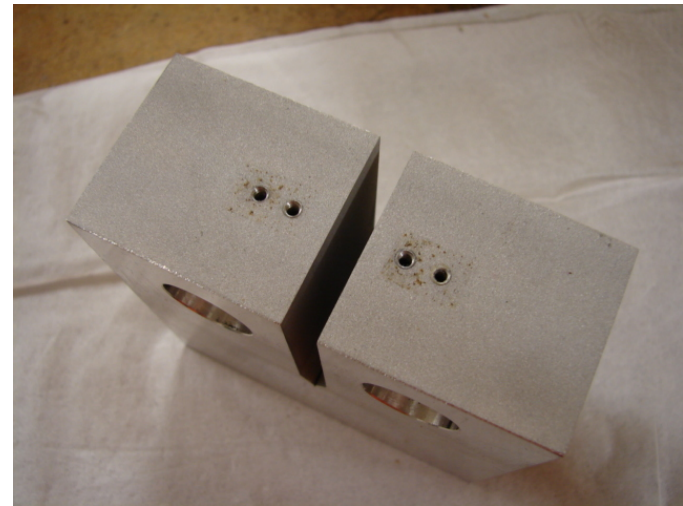
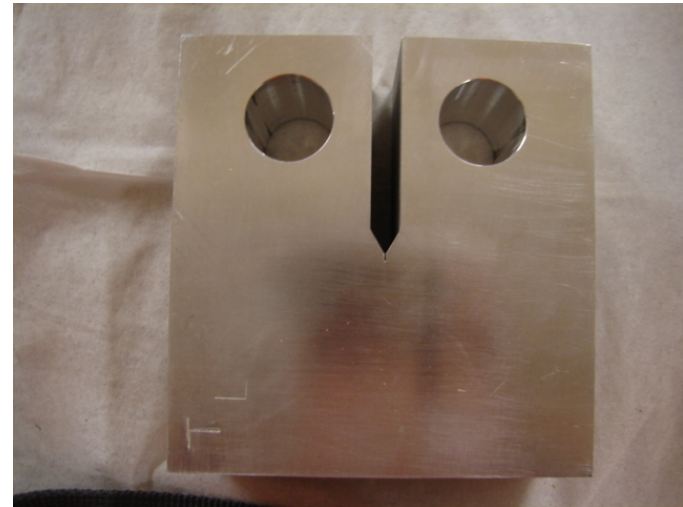


Three-point bending inside SEM:
 ➤ Plastic Zone Mapping;

Pre-crack



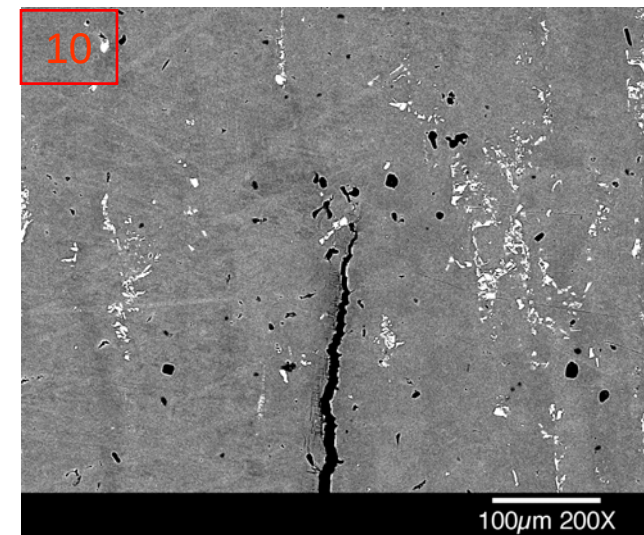
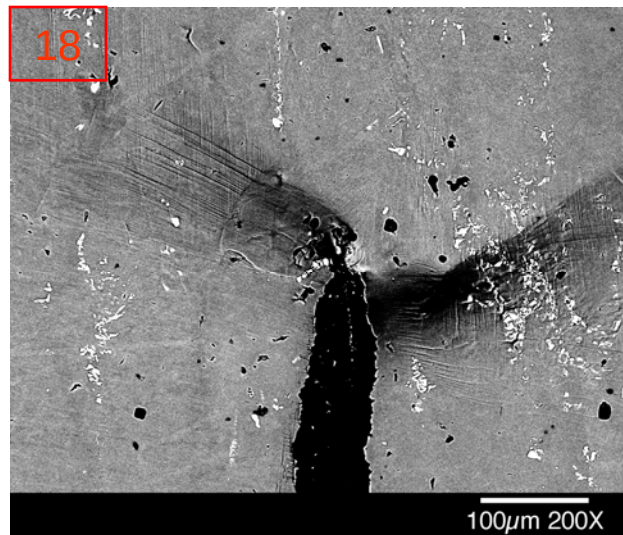
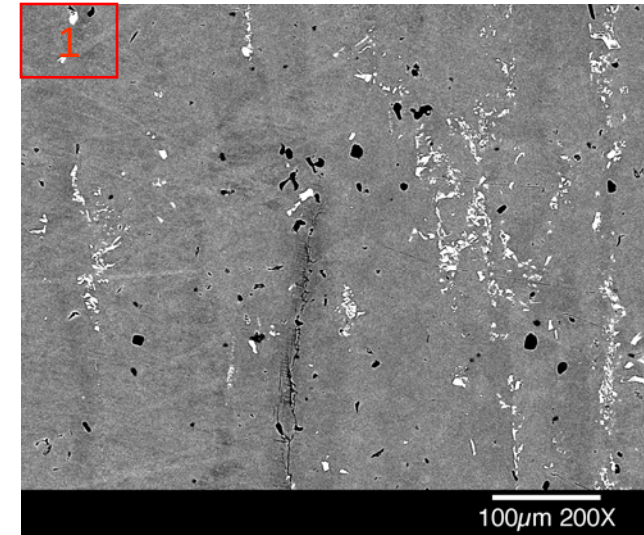
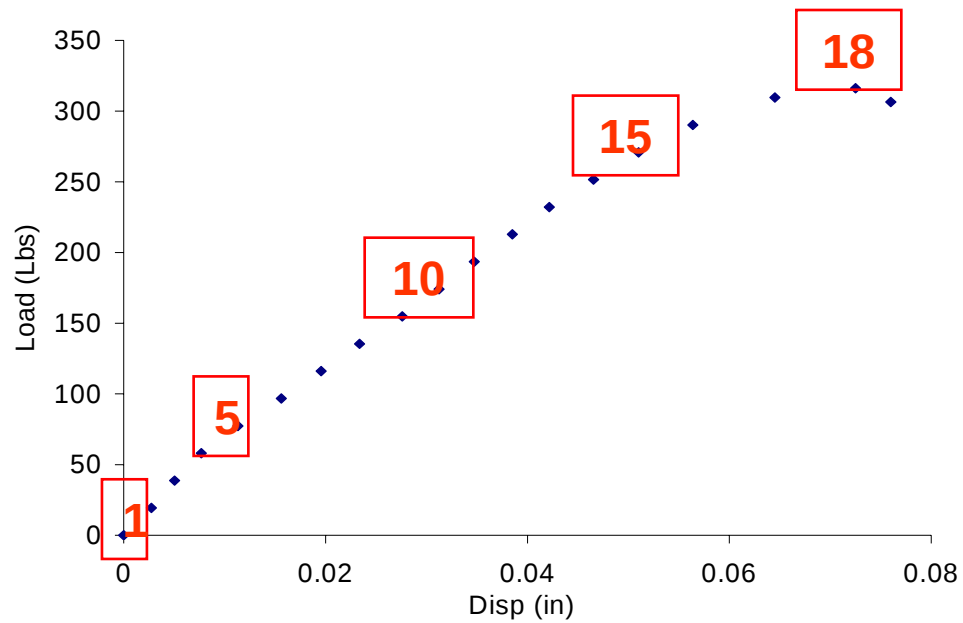
Compact tension sample set up for precracking



CT specimen

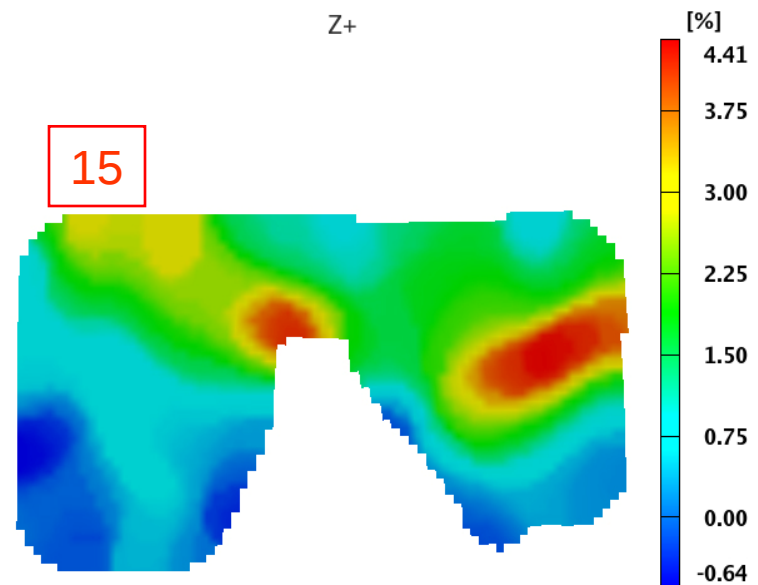
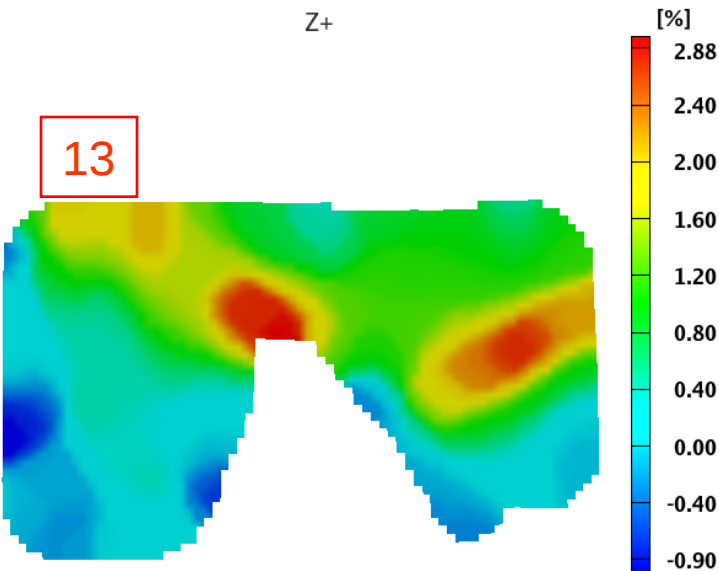
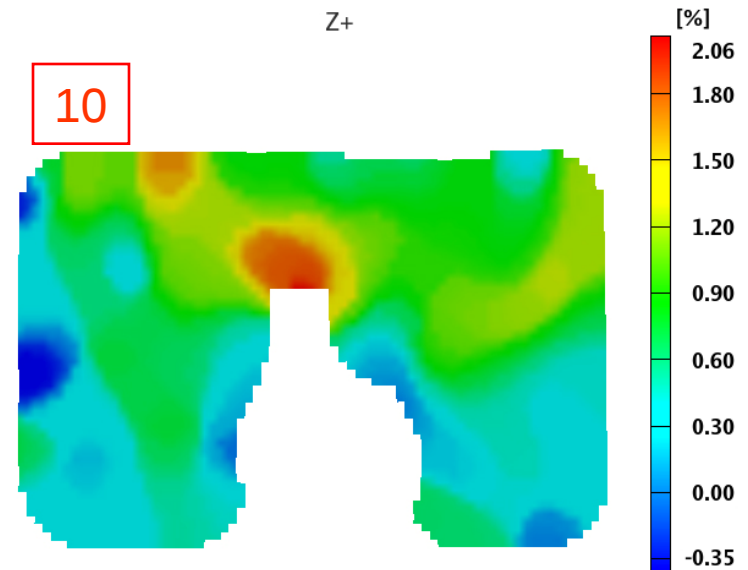
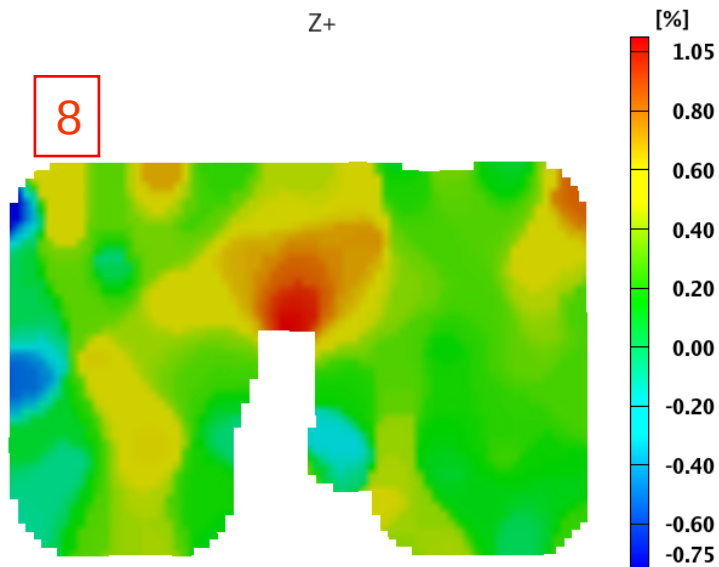


Crack Opening during Bending



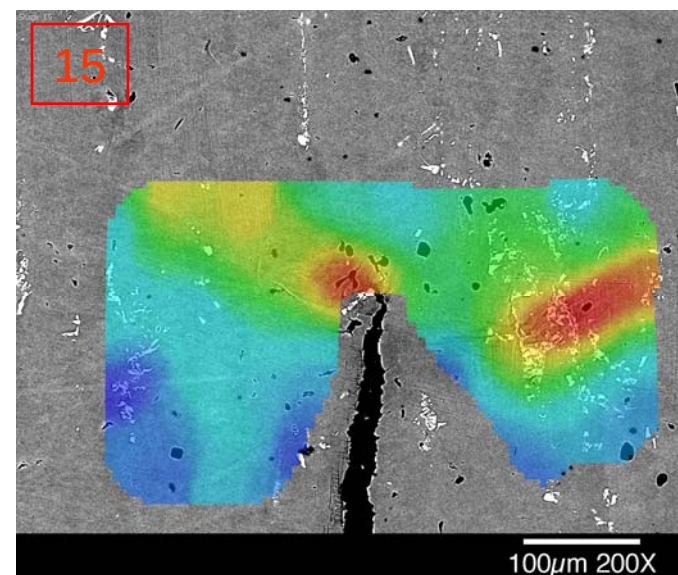
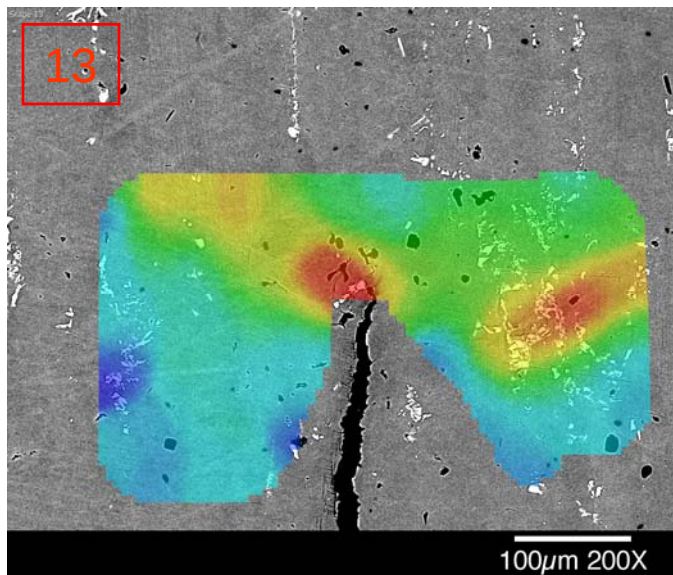
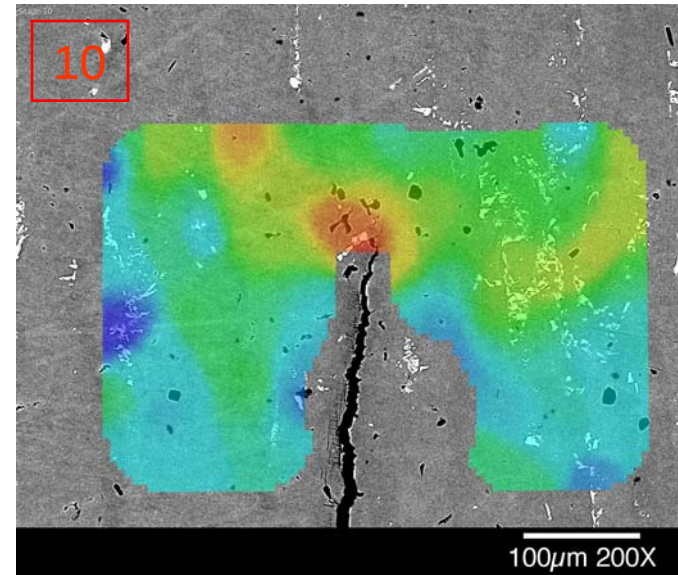
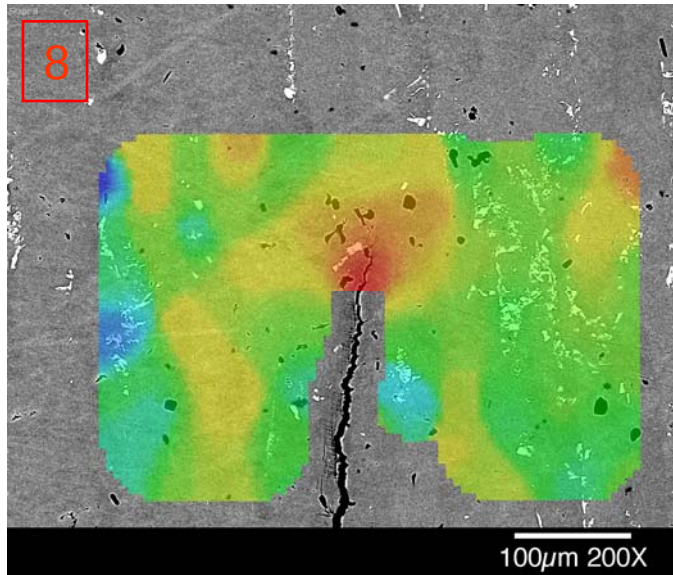


Strain Concentration



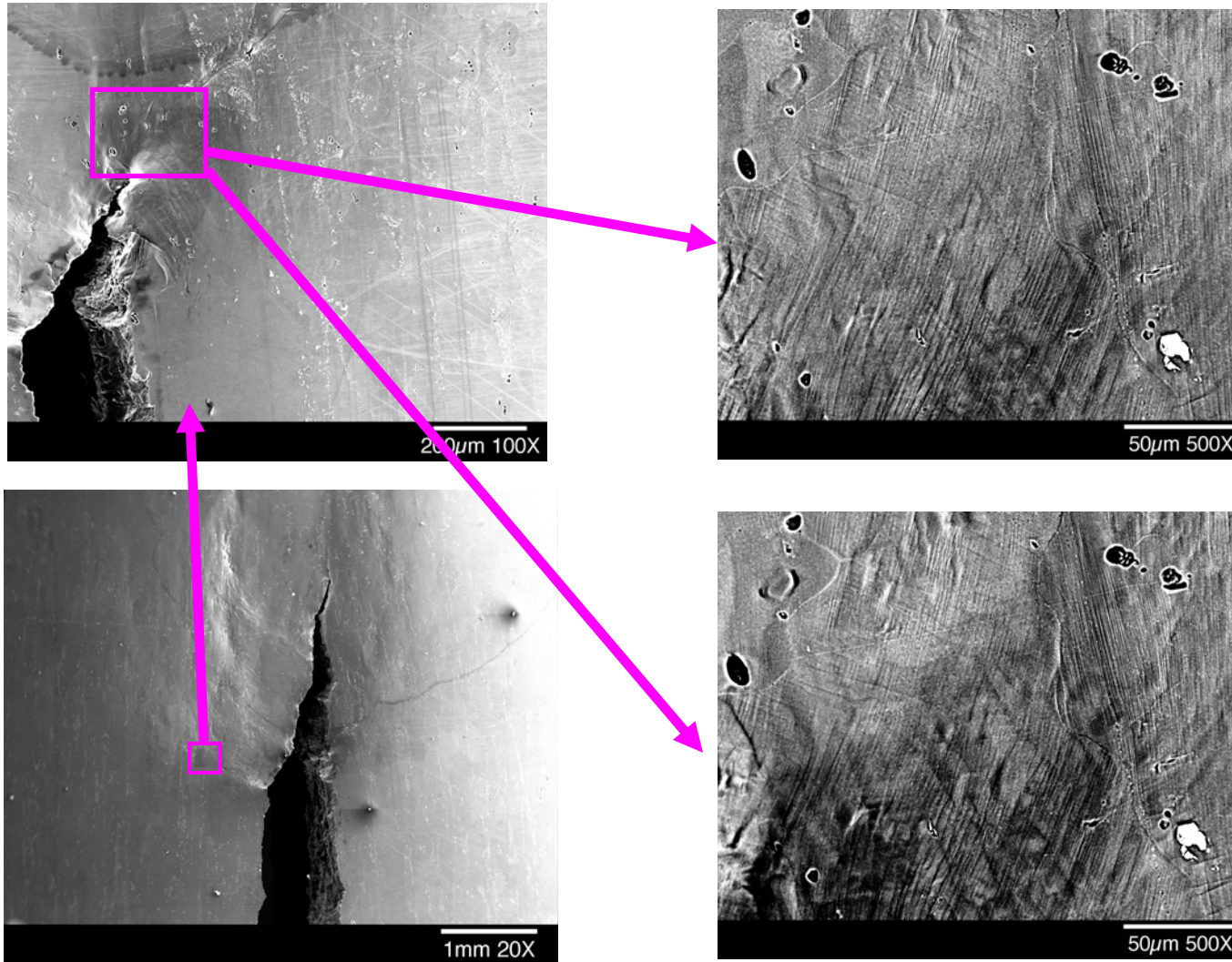


Local Deformation during Bending





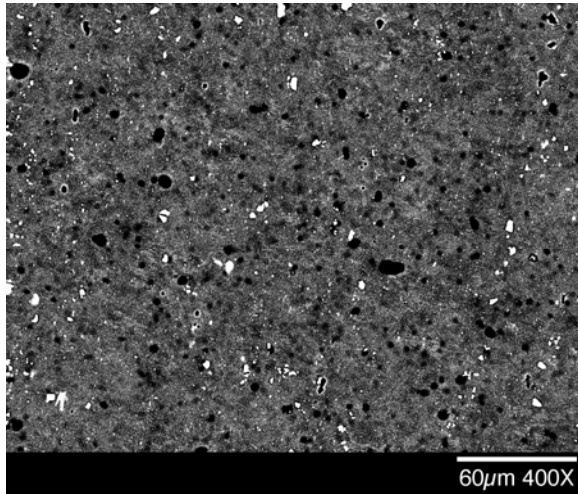
SEM Observation of Microstructure Evolution



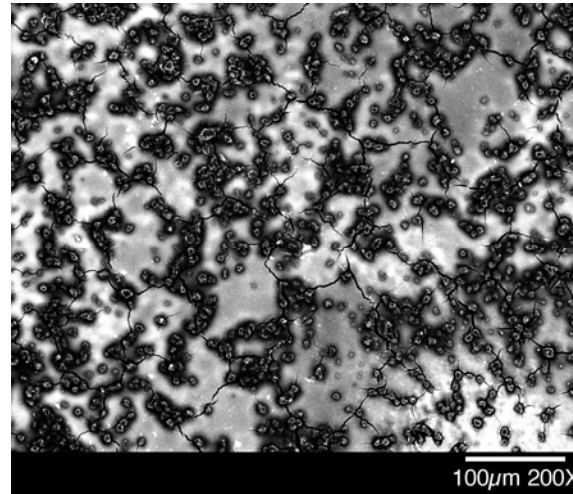
Microstructural evolution makes correlation of patterns from surface features impossible



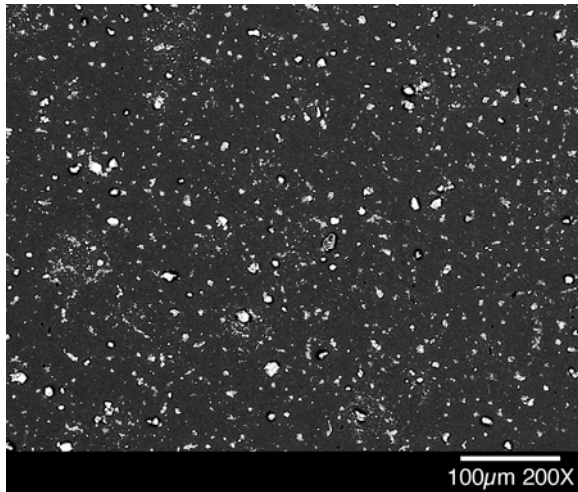
Air Brush Painting



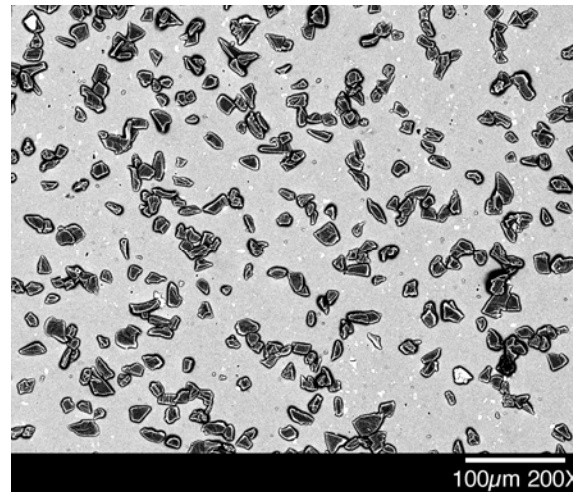
Carbon



Diamond



Iron

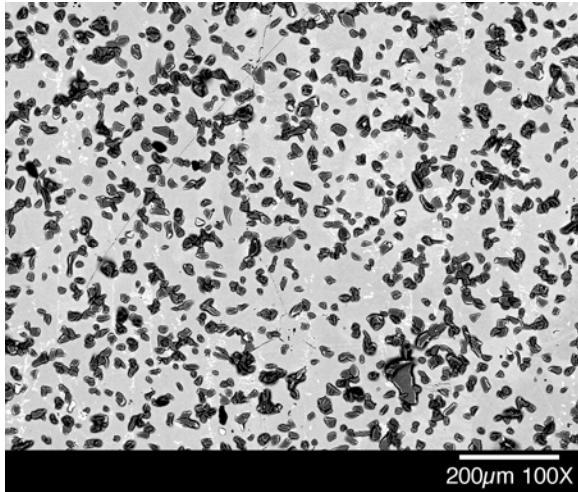


SiC

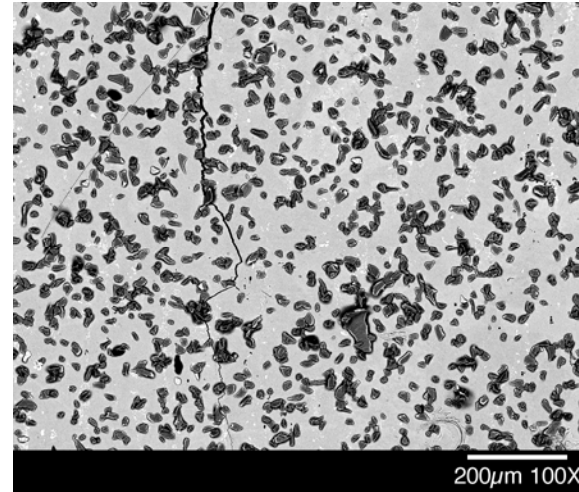
Air brush painting with different particle solutions



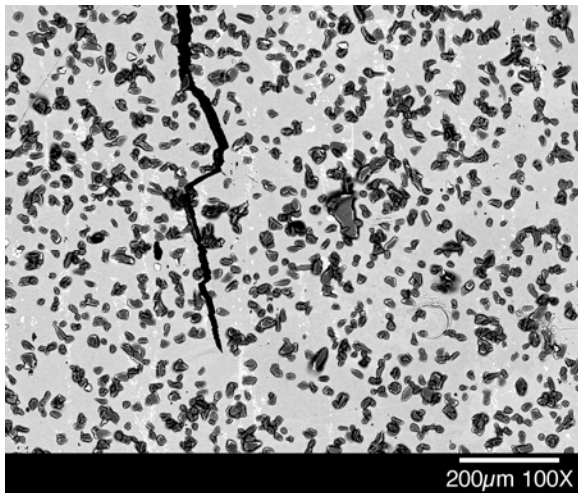
Patterns from Diamond IPA Solution



Stage 0



Stage 35

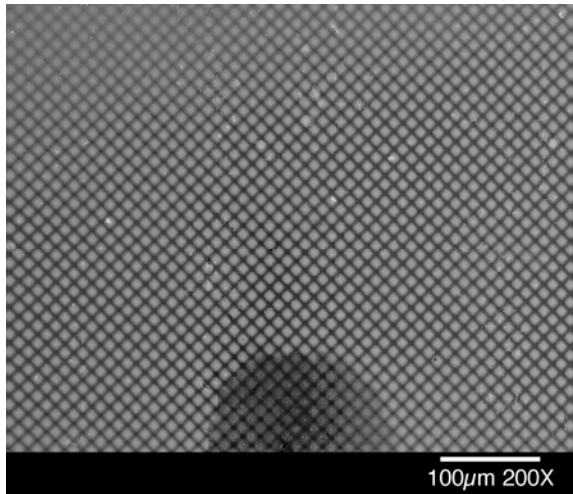


Stage 50

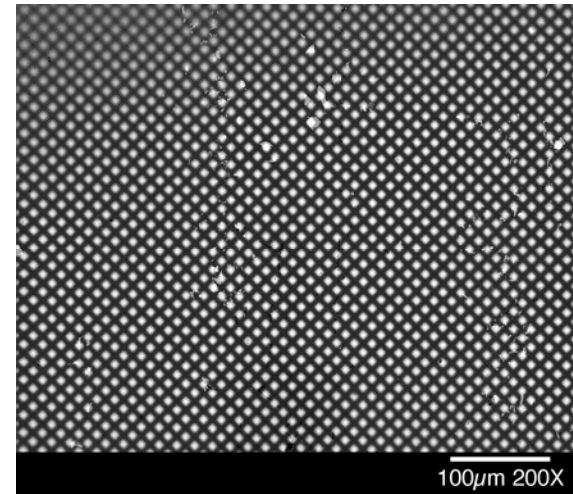
The motion of the particle does not represent the motion of the specimen surface around the crack



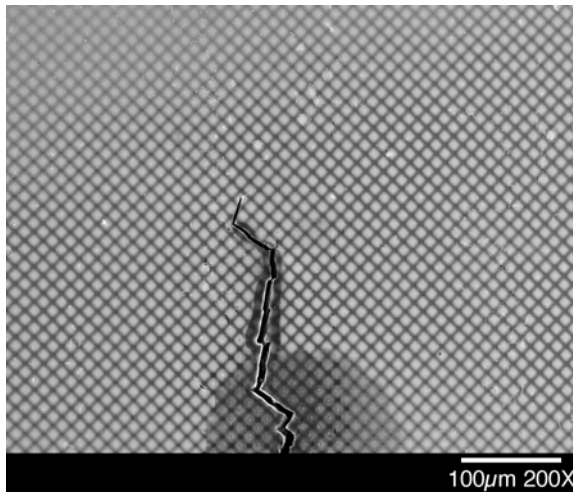
Sputter Coating using Cu Mesh



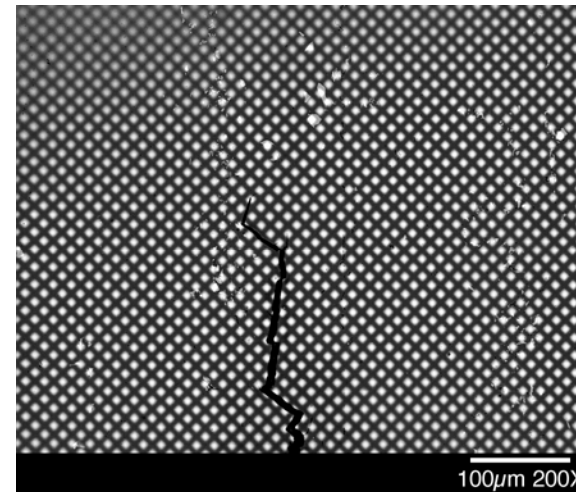
Step0 SEI



Step0 BEI



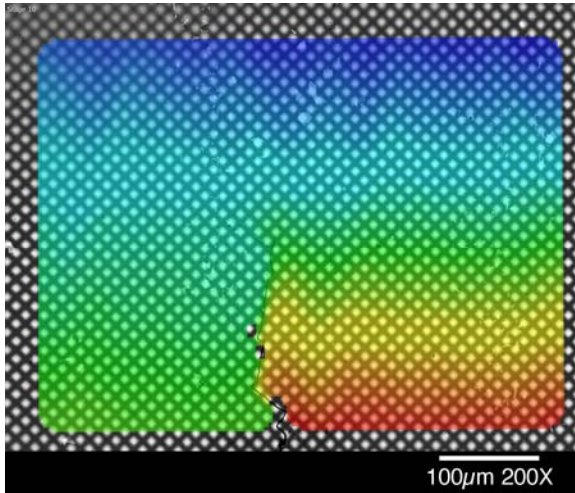
Step36 SEI



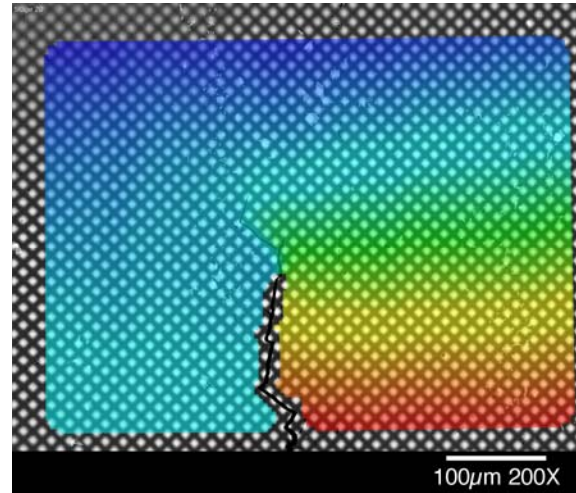
Step36 BEI



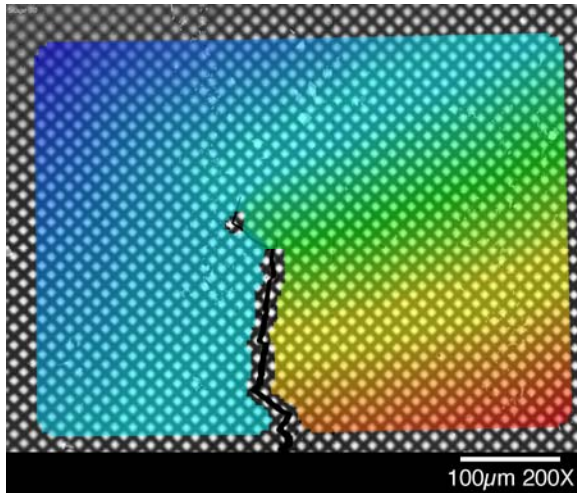
Displacement Field during Bending



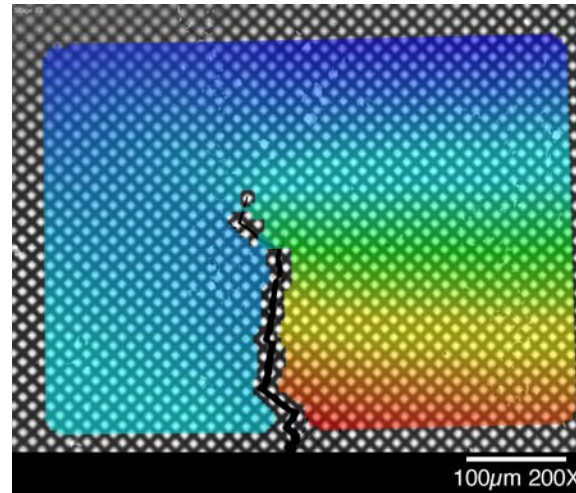
Step 10



Step 20



Step 30



Step 36



Summary

- DIC technique is applied to the SEM images to obtain full-field displacement to characterize the mechanical behavior of LIGA specimens;
- DIC technique is used to study the local deformation and strain concentration during the fracture of ductile materials;
- Different techniques were used to generate patterns for DIC application to the SEM images;



Thank you!

Questions?