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Microstructure Clones

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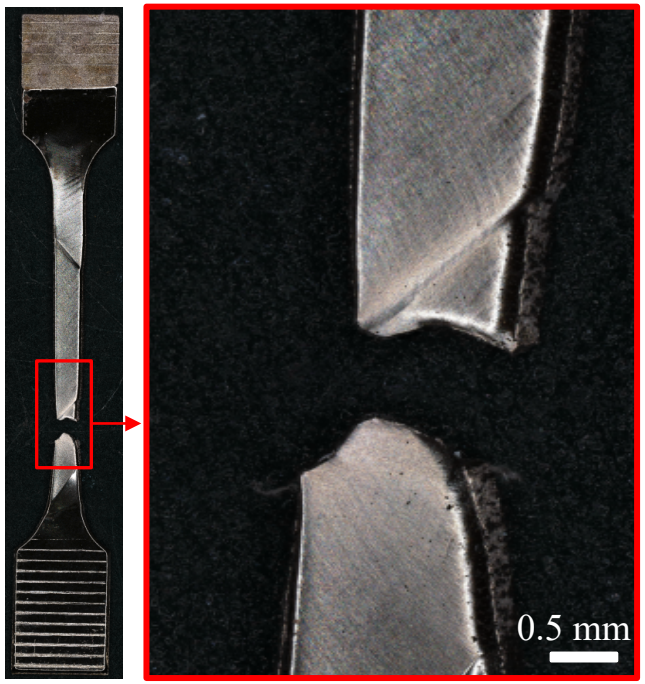
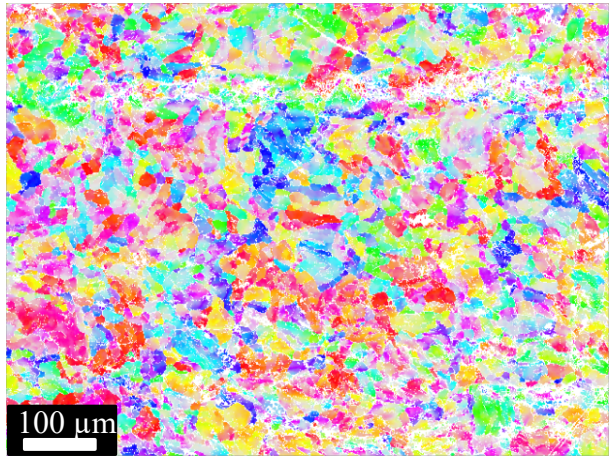
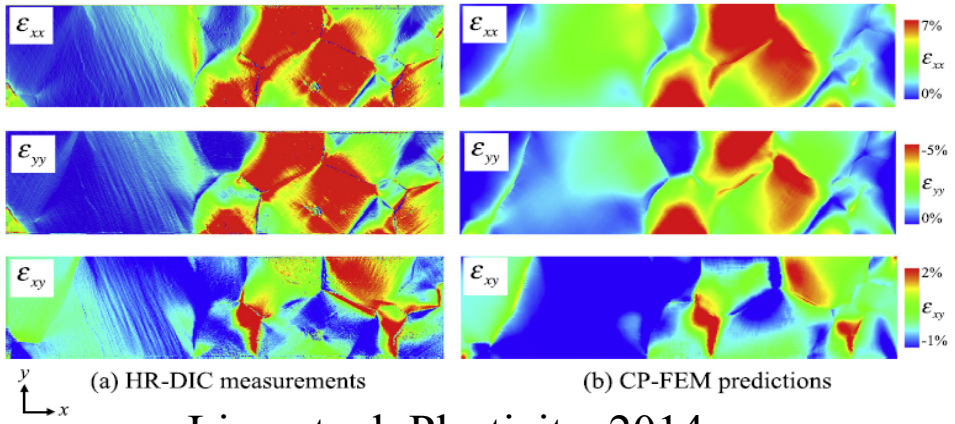
Microstructure Clones

The Challenge of Evaluating Microstructure Reponses in Experimental Mechanics

- How do you perform all of the tests you want on the same specimen?
- Will a unique microstructure always behave the same?
- How do you know where to look for high resolution tests?



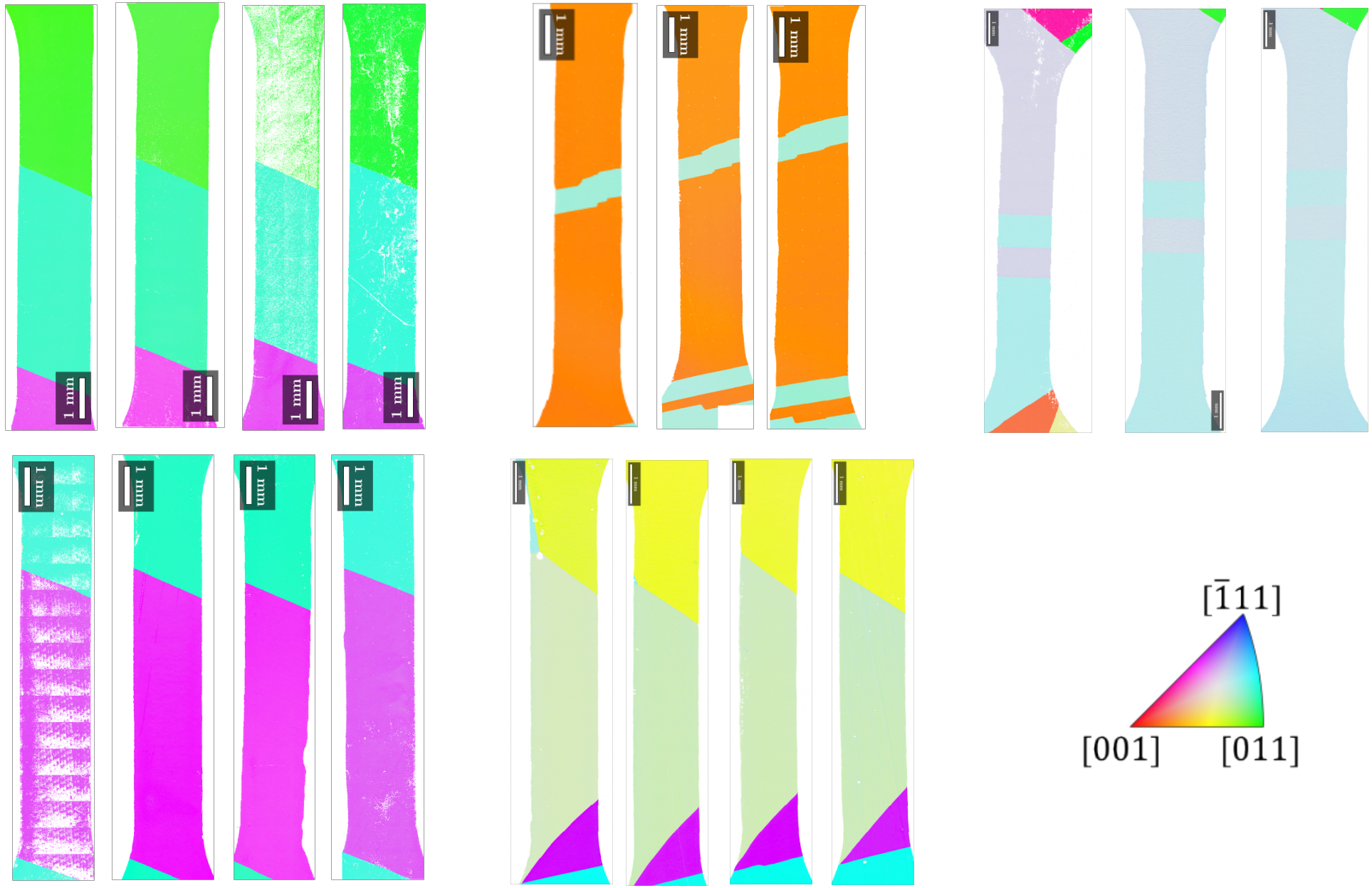




Lim, et. al, Plasticity, 2014

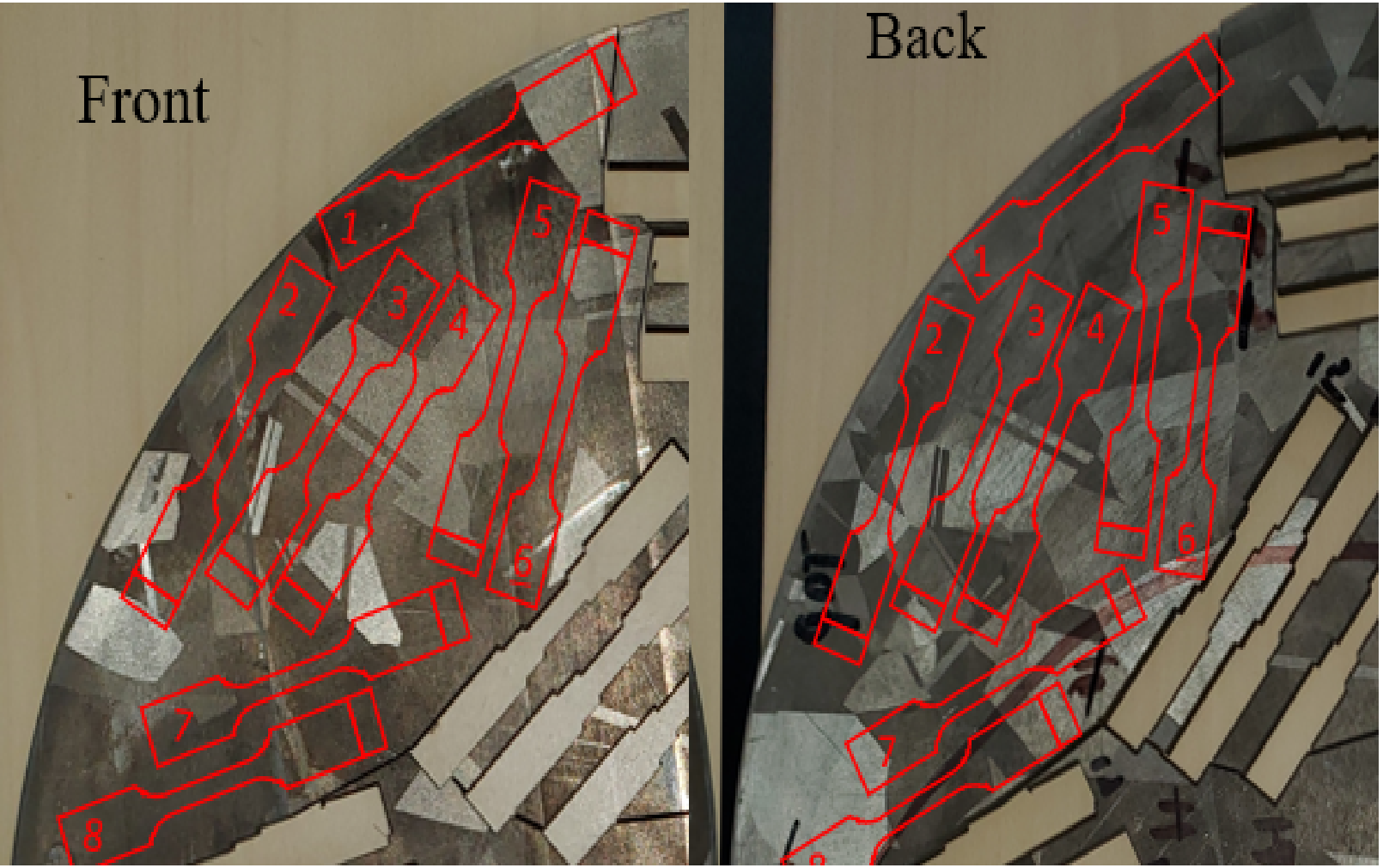
Microstructure Clones

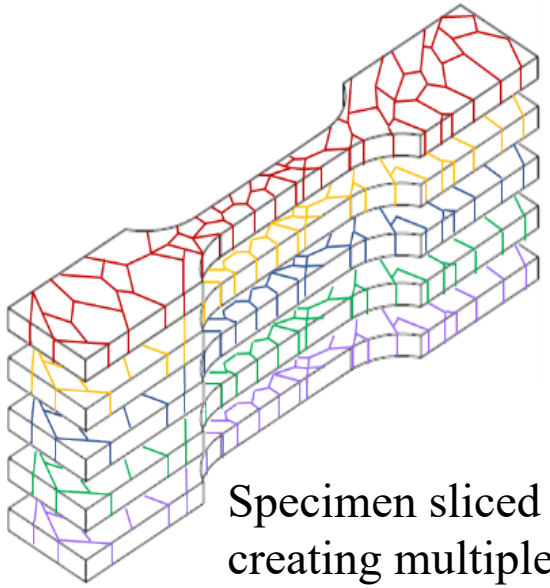
Multiple specimens in a set with nearly identical microstructures



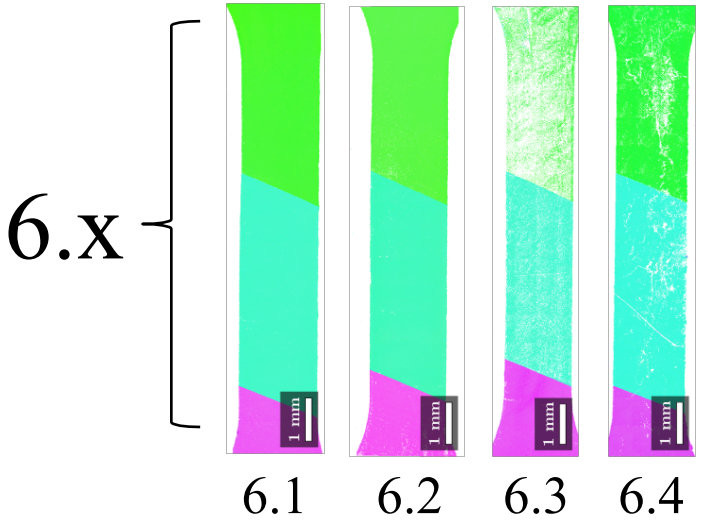
Microstructure Clones

99.999% Nickel 0.25 in thick plate
Heat treated to grow grains 10-20 mm in diameter
Tensile specimens cut from locations with similar microstructure front and back



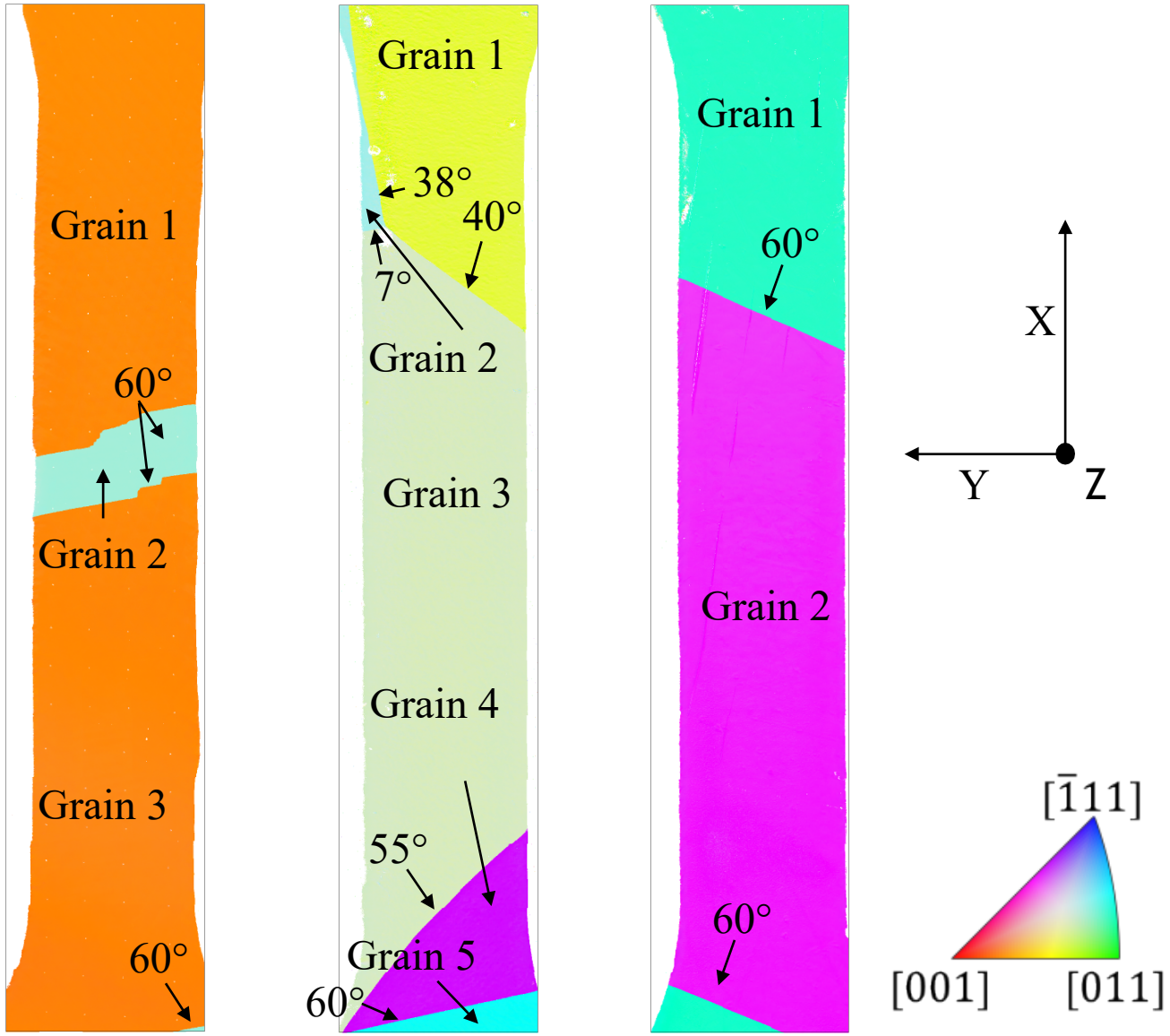


Specimen sliced horizontally creating multiple specimens with nearly identical microstructures



Three Clone Sets Chosen for Study

(a) Clone Set 1.x (b) Clone Set 2.x (c) Clone Set 5.x



Clone Set 1.x

- Parent grain (orange) with jagged horizontal twin (blue)

Clone Set 2.x

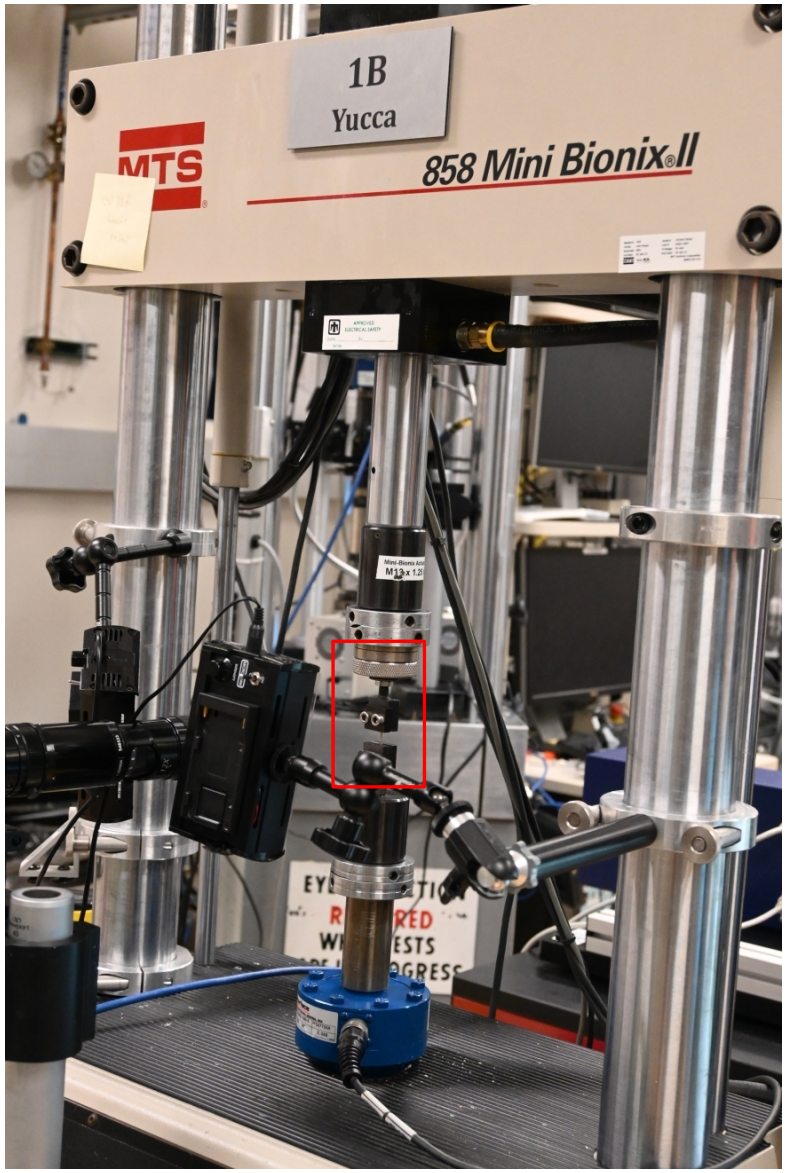
- Five main grains
- High and low angle grain boundaries

Clone Set 5.x

- Parent grain (teal) with large angled twin (purple)

Clone Sets 1.x and 5.x loaded to 3% strain
Clone Set 2.x loaded to failure

Test Plan and Experimental Setup



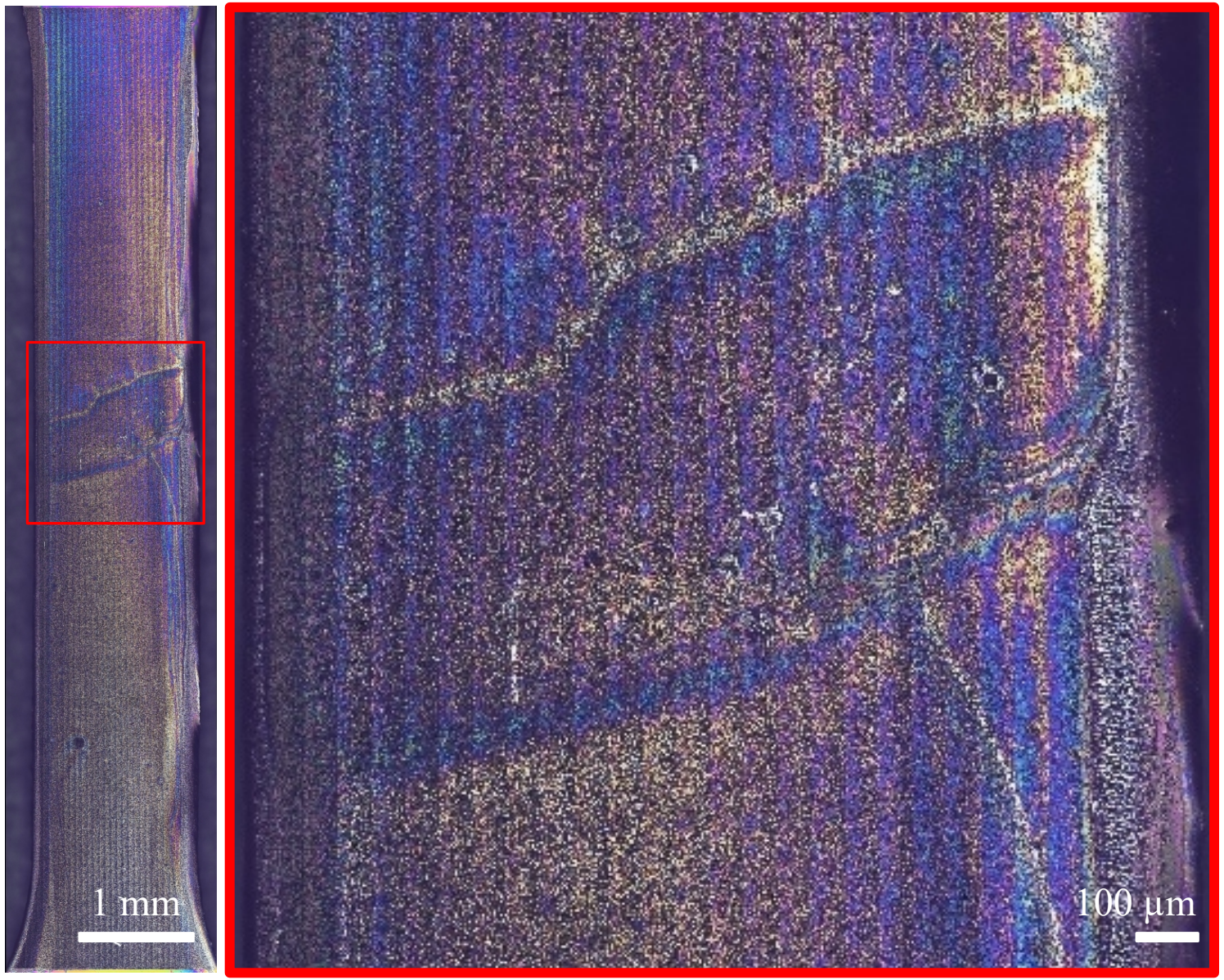
Two sets of clones (1.x and 5.x) tested to 3% strain

One set of clones (2.x) tested to failure

Quasi-static displacement controlled test

Dual Resolution DIC Technique

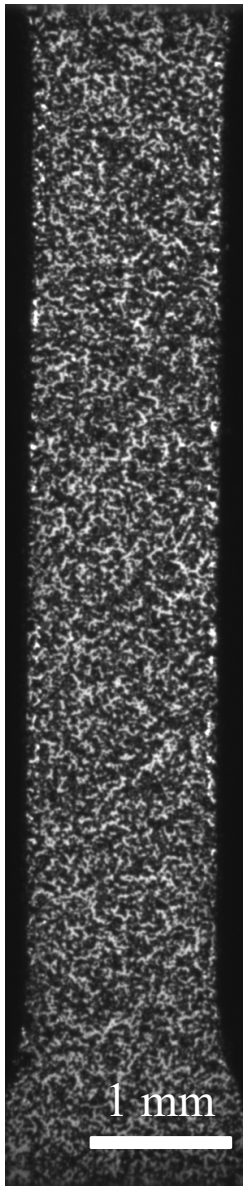
High Resolution DIC



HR-DIC
- Speckle size 500 nm
- Imaged before and after deformation
-

Low Resolution DIC
- Speckle size 50 µm
- Imaged throughout test

Low Resolution DIC

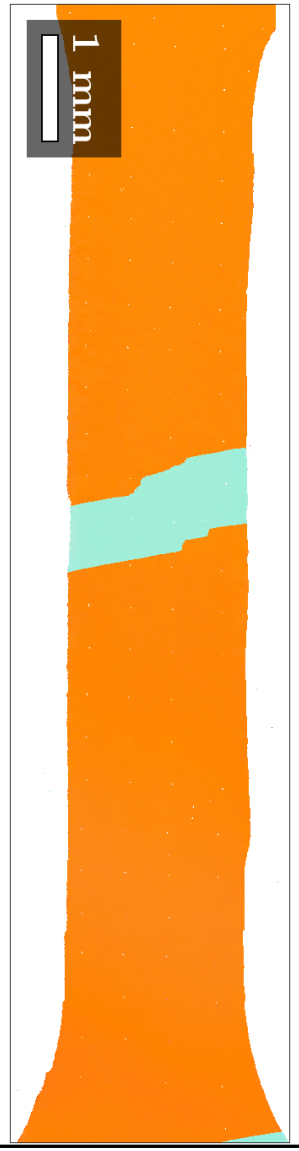


Specimen Imaging

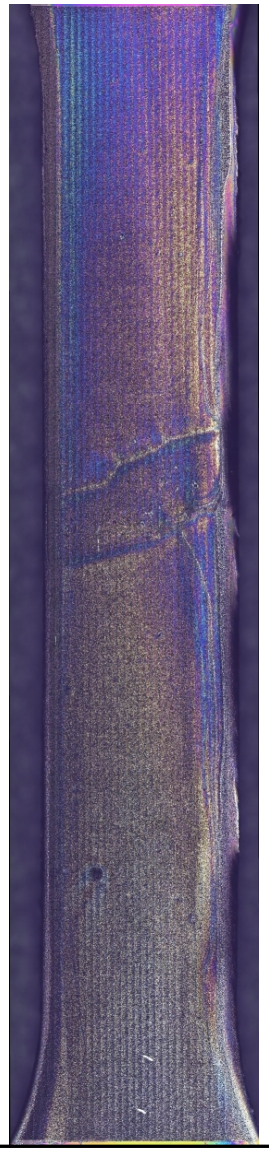
Front of Specimen – Mirror Finish

Laser Fiducials

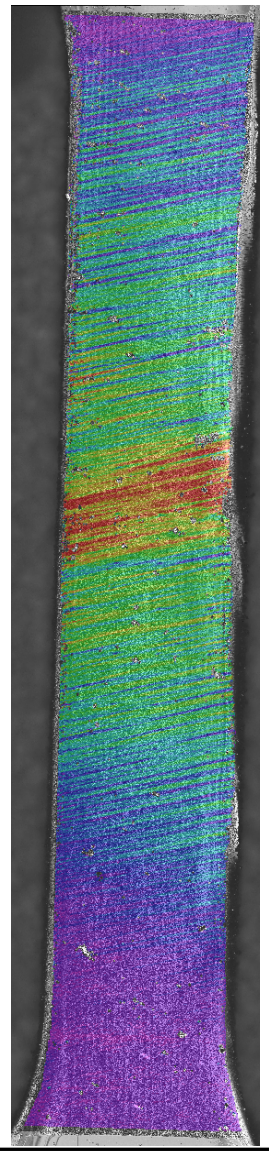
EBSD Pretest



HR DIC

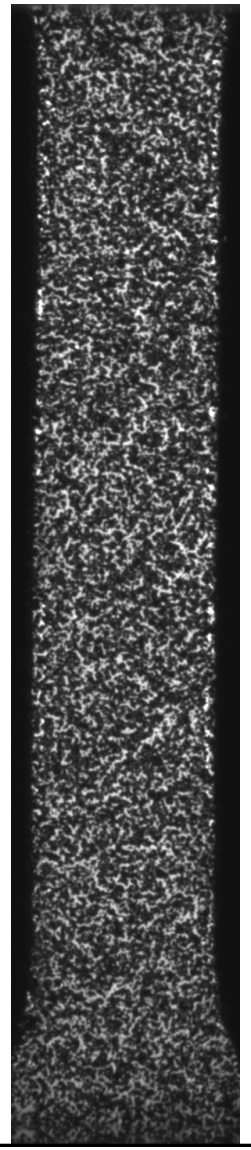


HR DIC

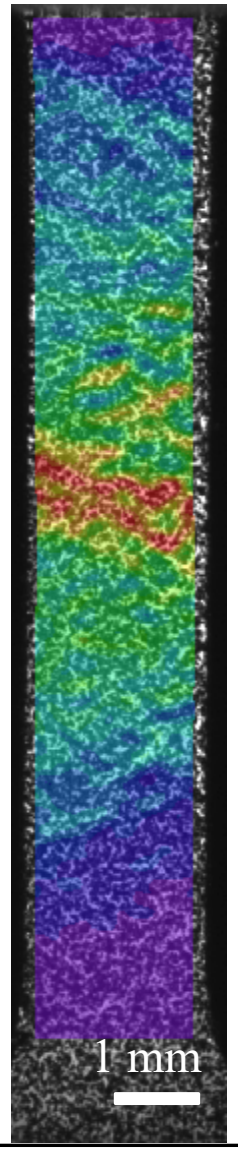


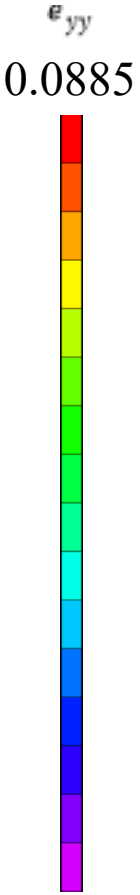
Back of Specimen – EDM Finish

LR DIC

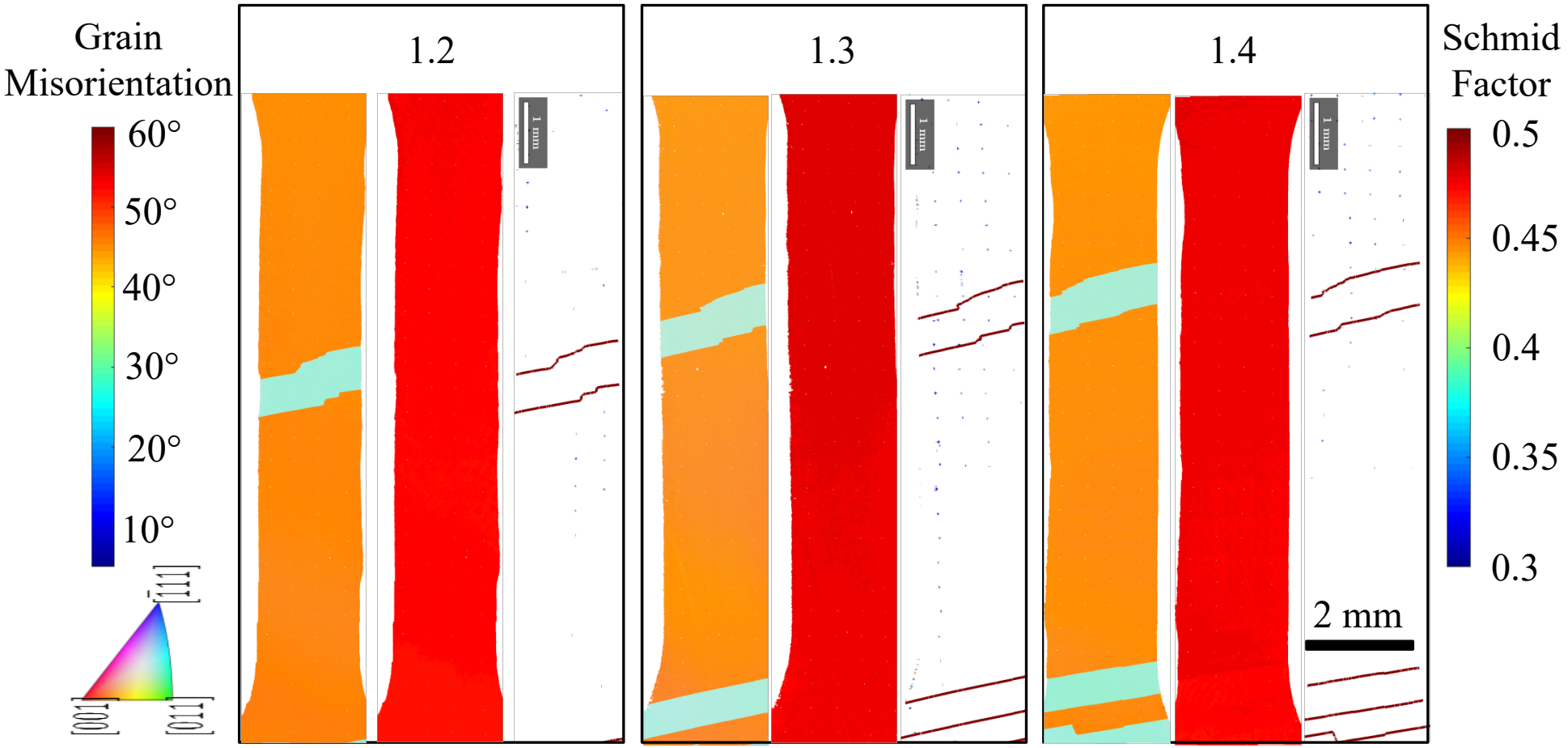


LR DIC

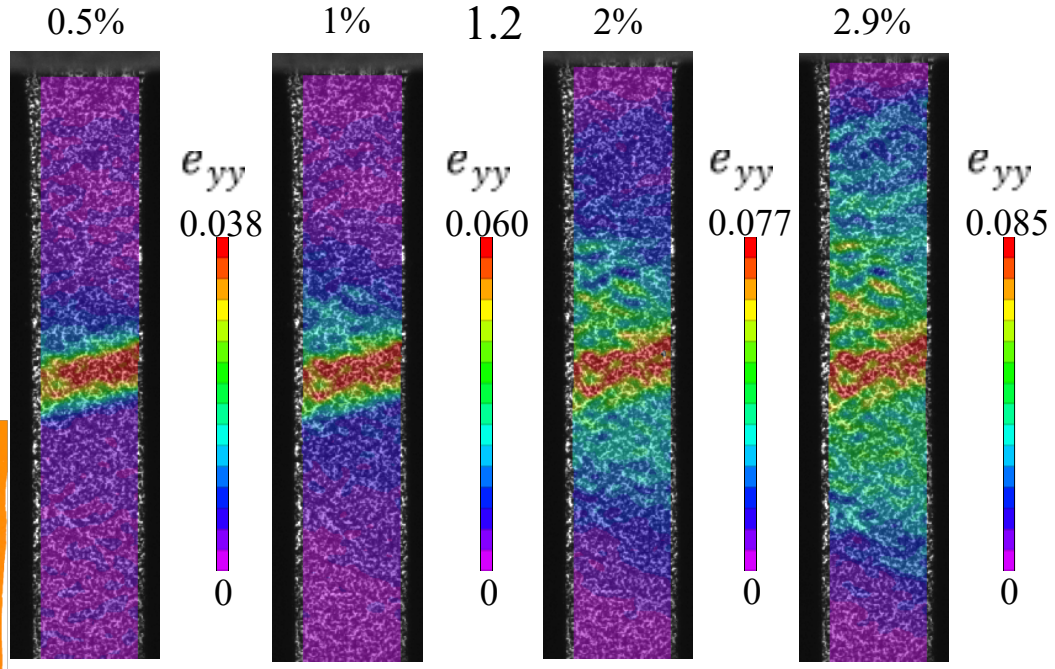




1.x – Microstructure

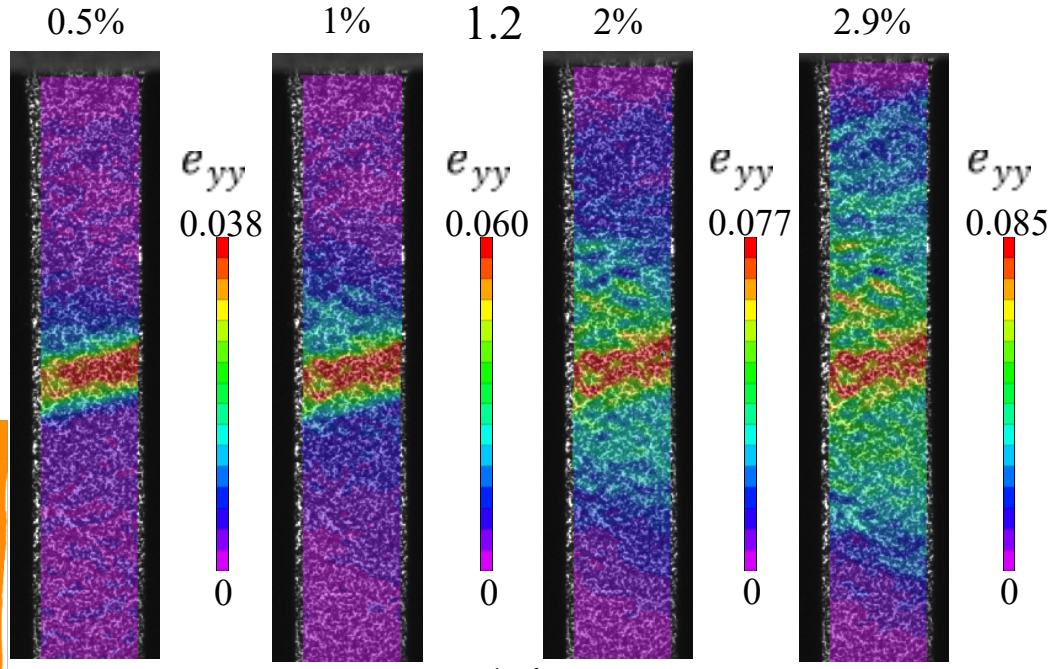


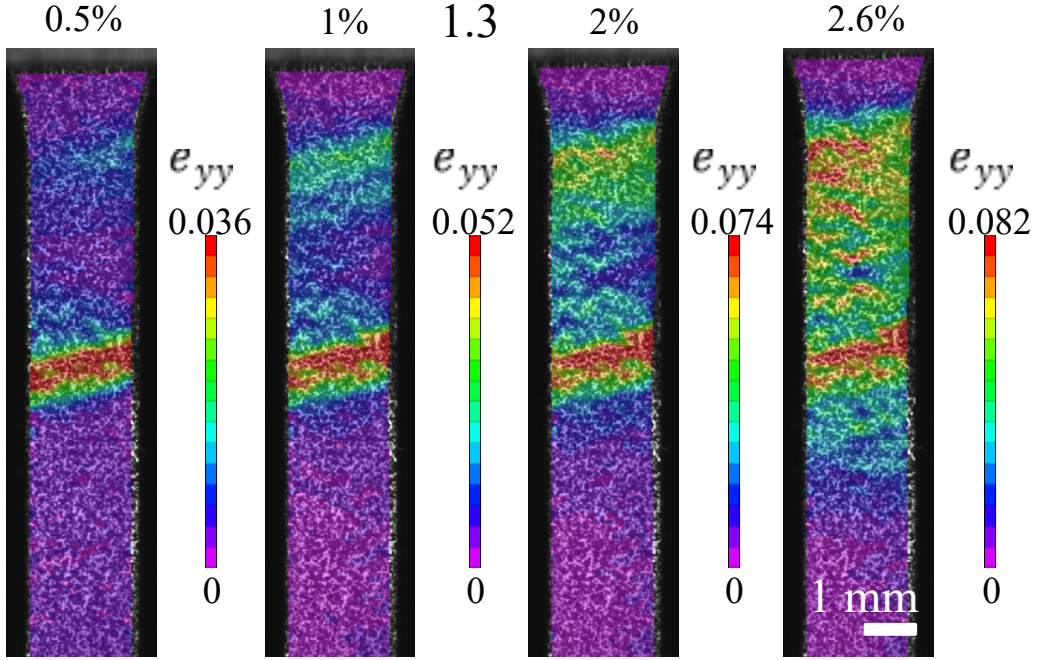
1.x – Loaded to 3% Strain

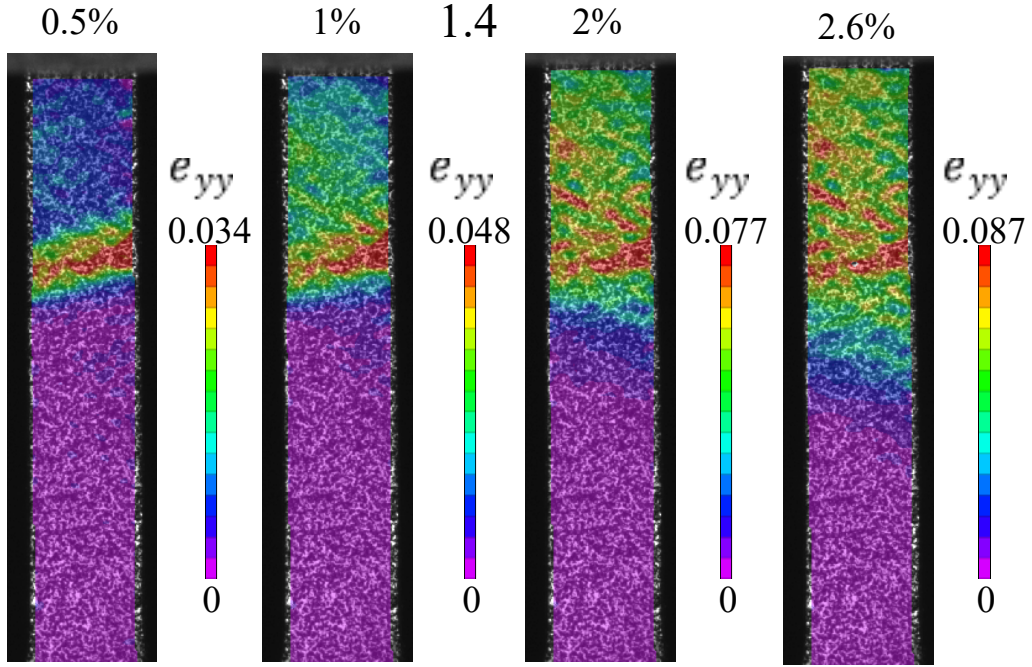


- Strain localizes in twin first
- Strain spreads to parent grain with further loading
- Strains in parent grains not even

1.x – Loaded to 3% Strain







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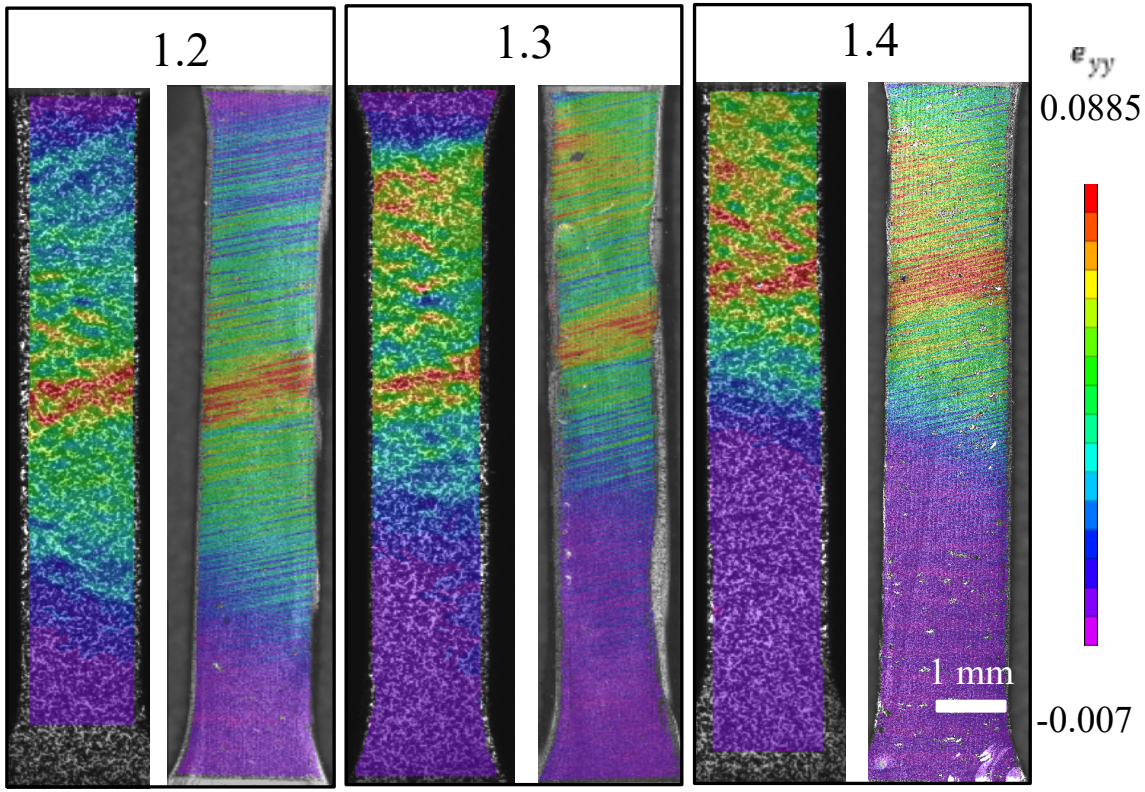
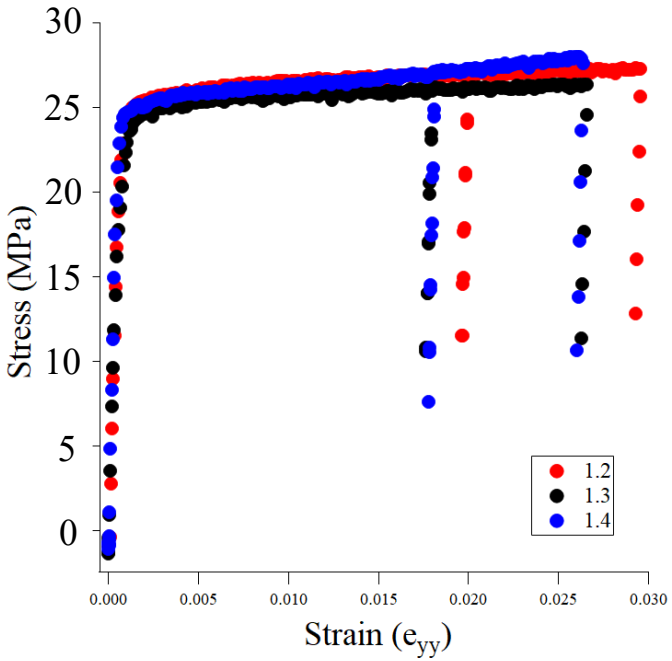
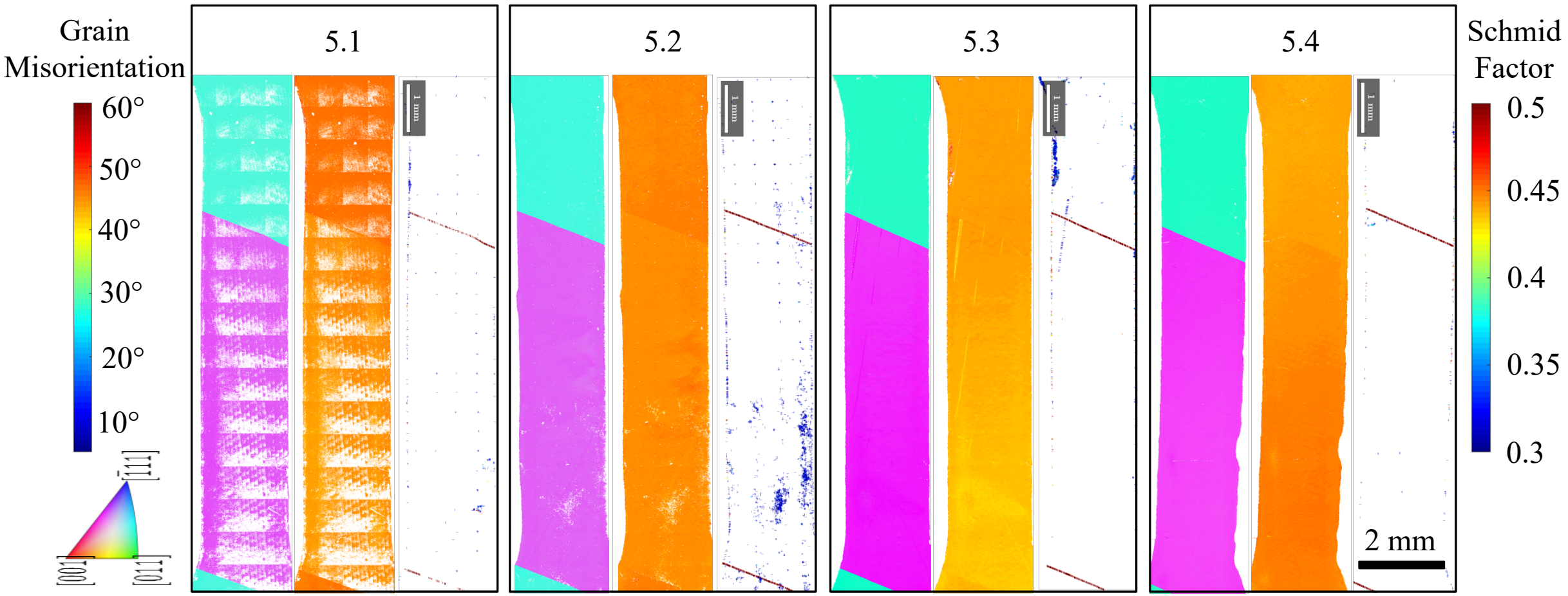
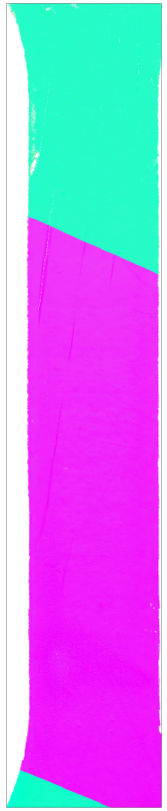


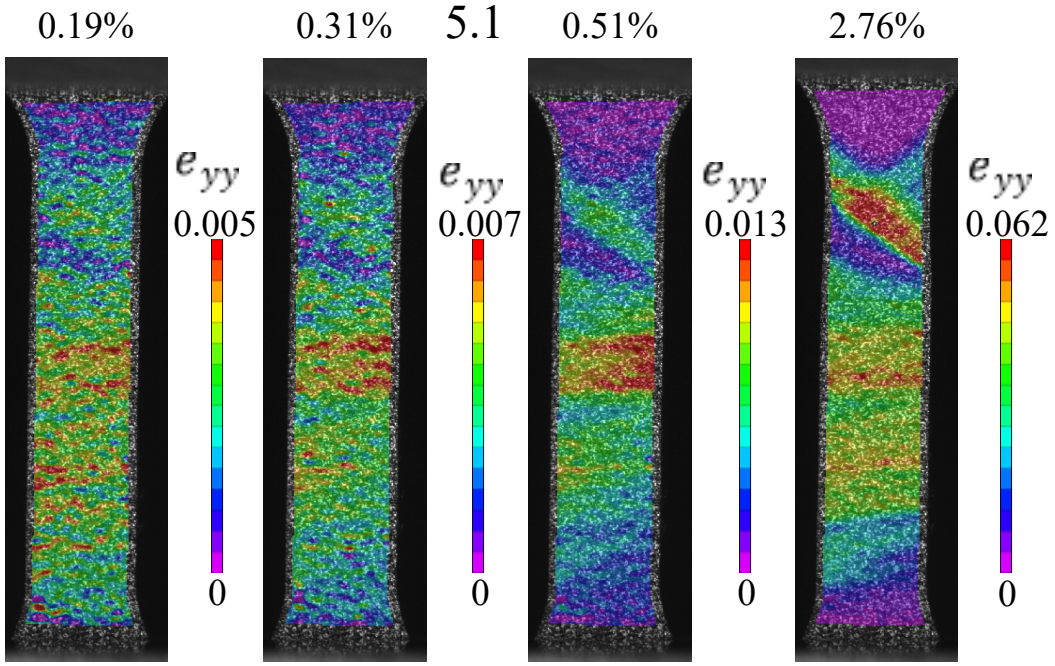


5.x – Loaded to 3% Strain

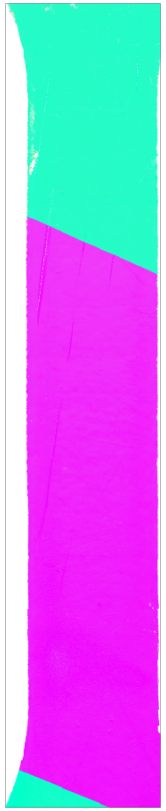


5.x – Loaded to 3% Strain

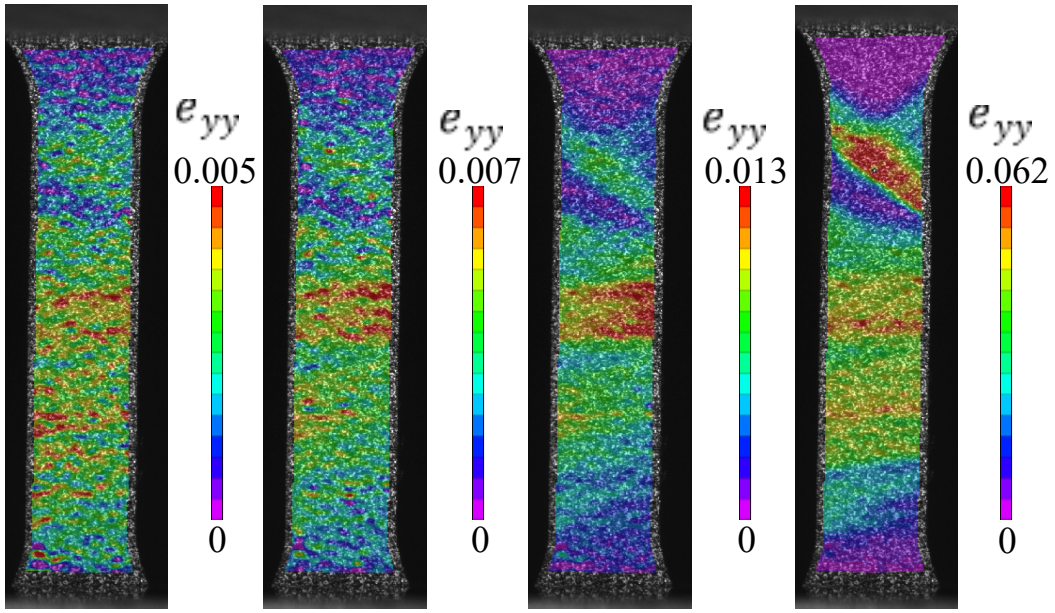




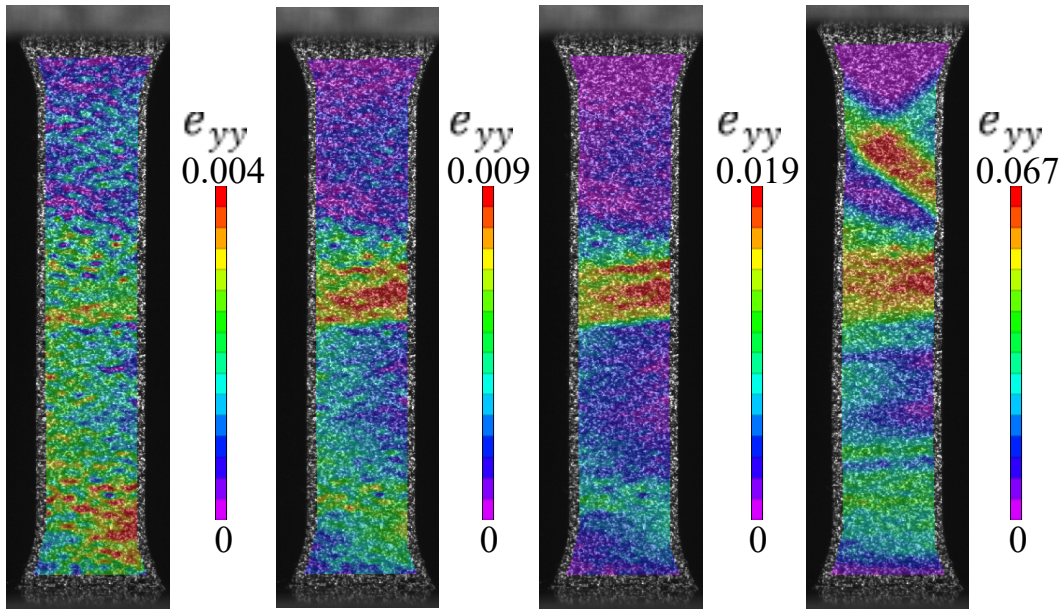
5.x – Loaded to 3% Strain



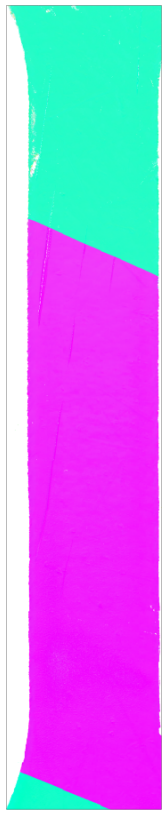
0.19% 0.31% 5.1 0.51% 2.76%

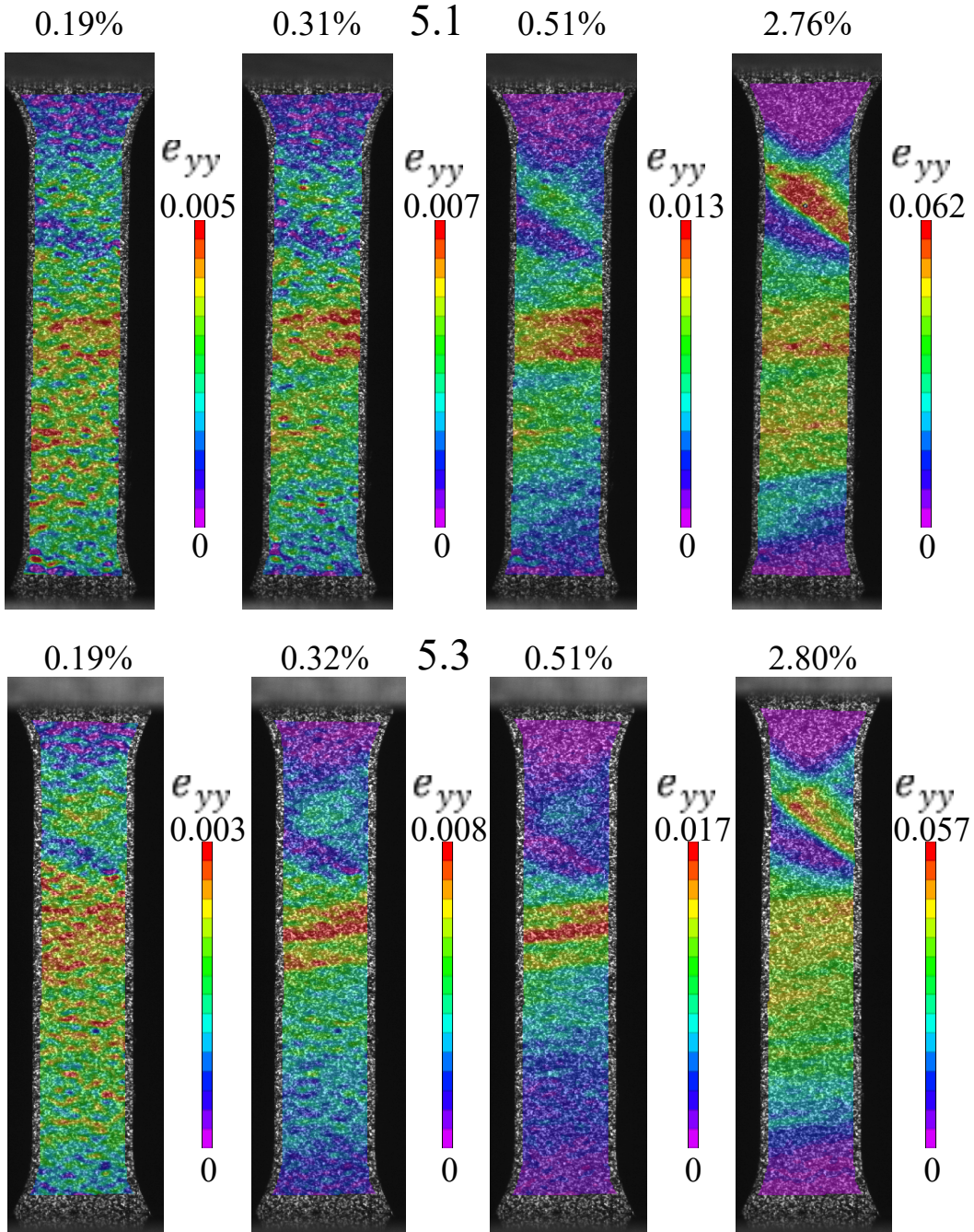


0.19% 0.31% 5.2 0.51% 2.78%

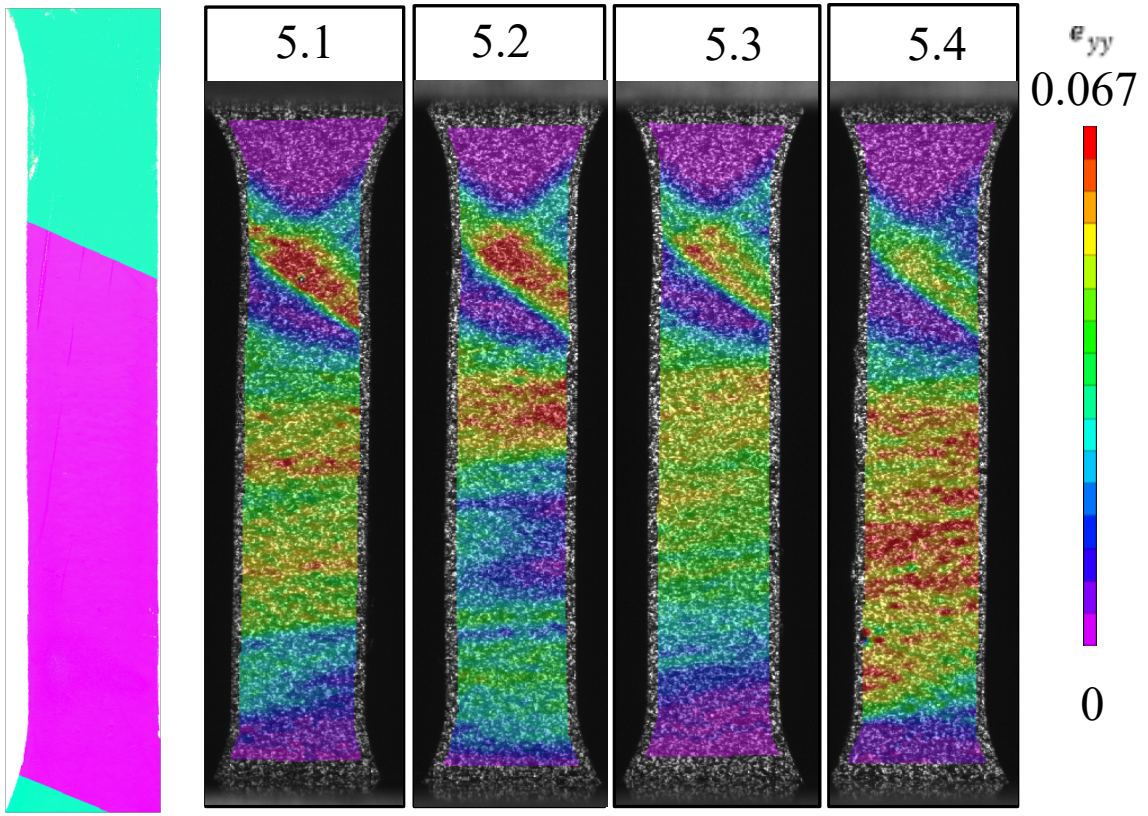


5.x – Loaded to 3% Strain

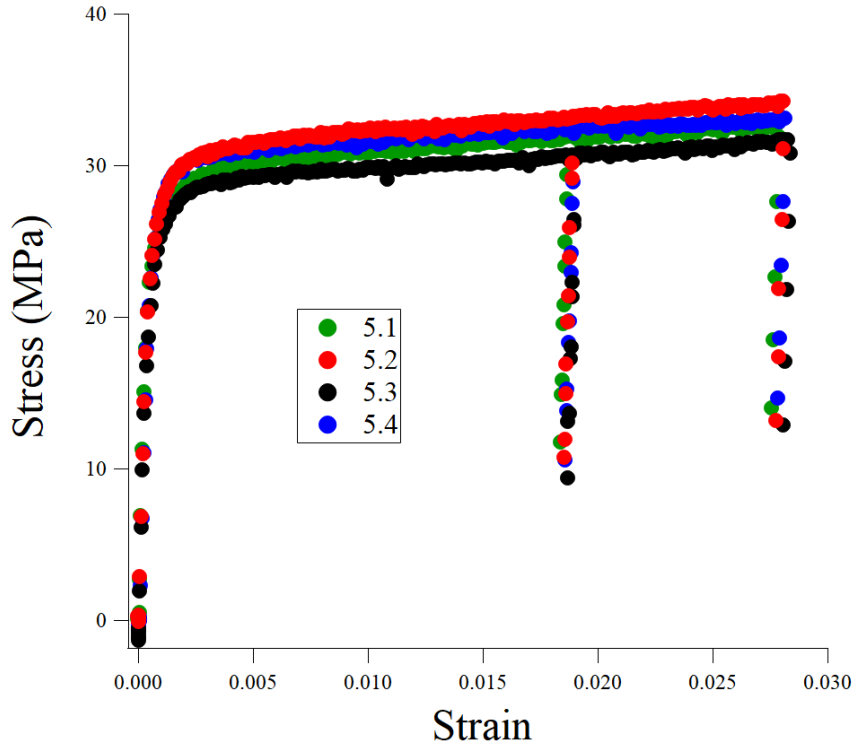




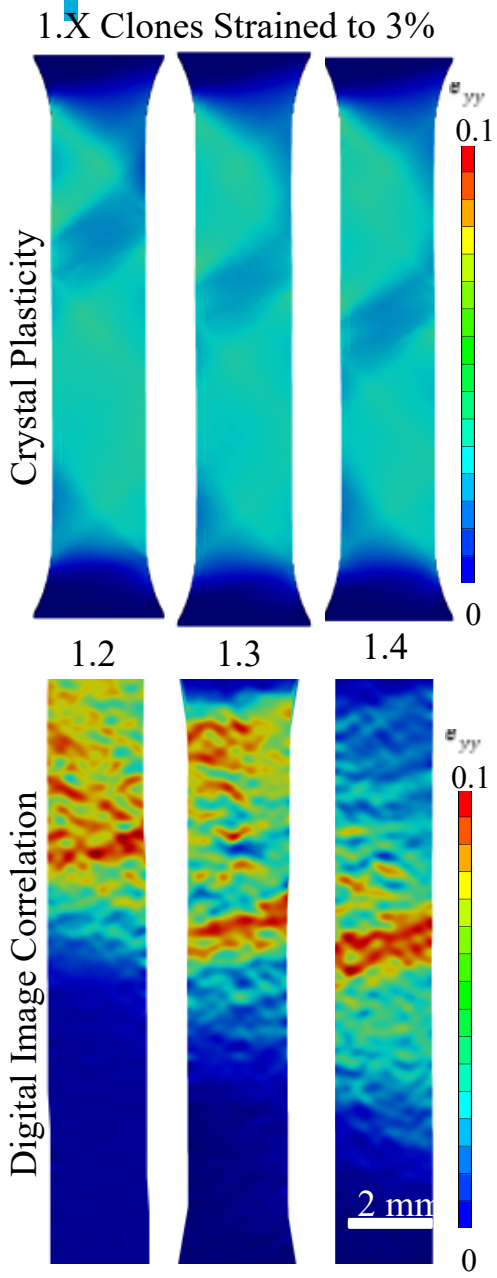
5.x – Loaded to 3% Strain

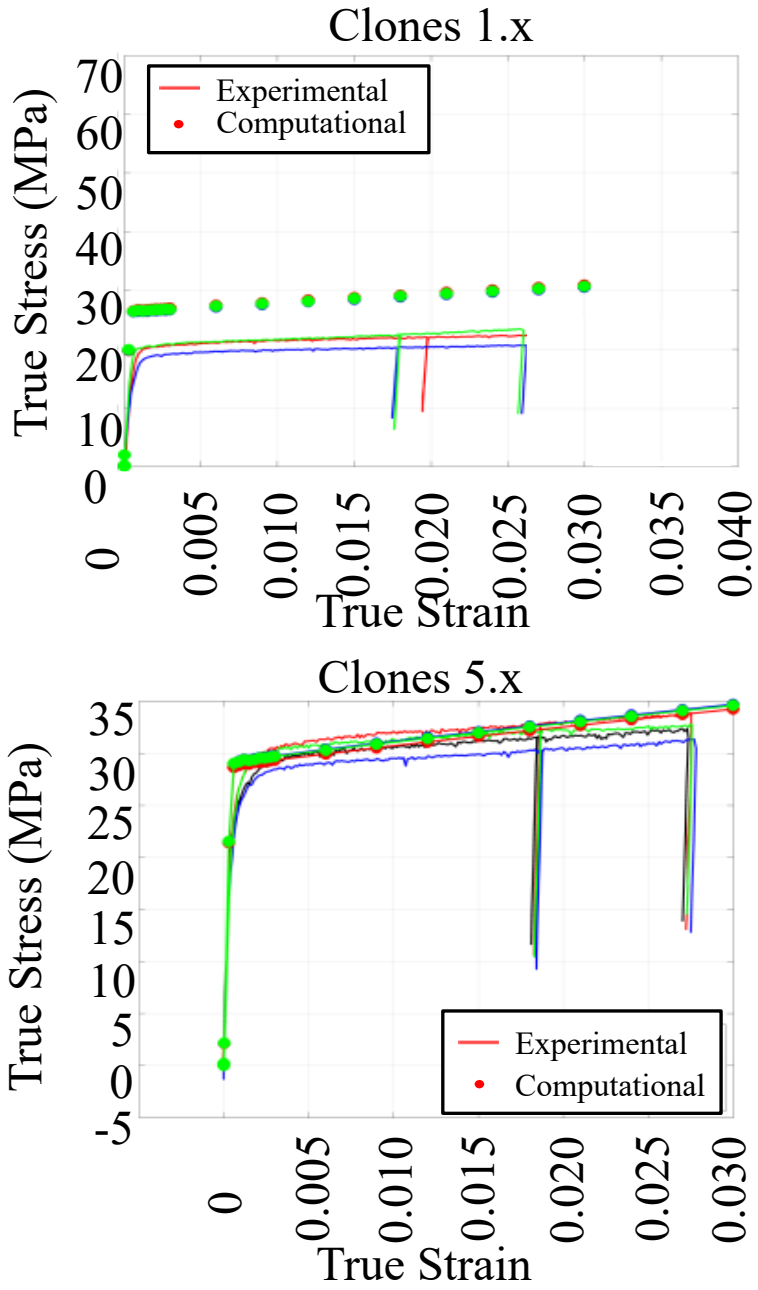


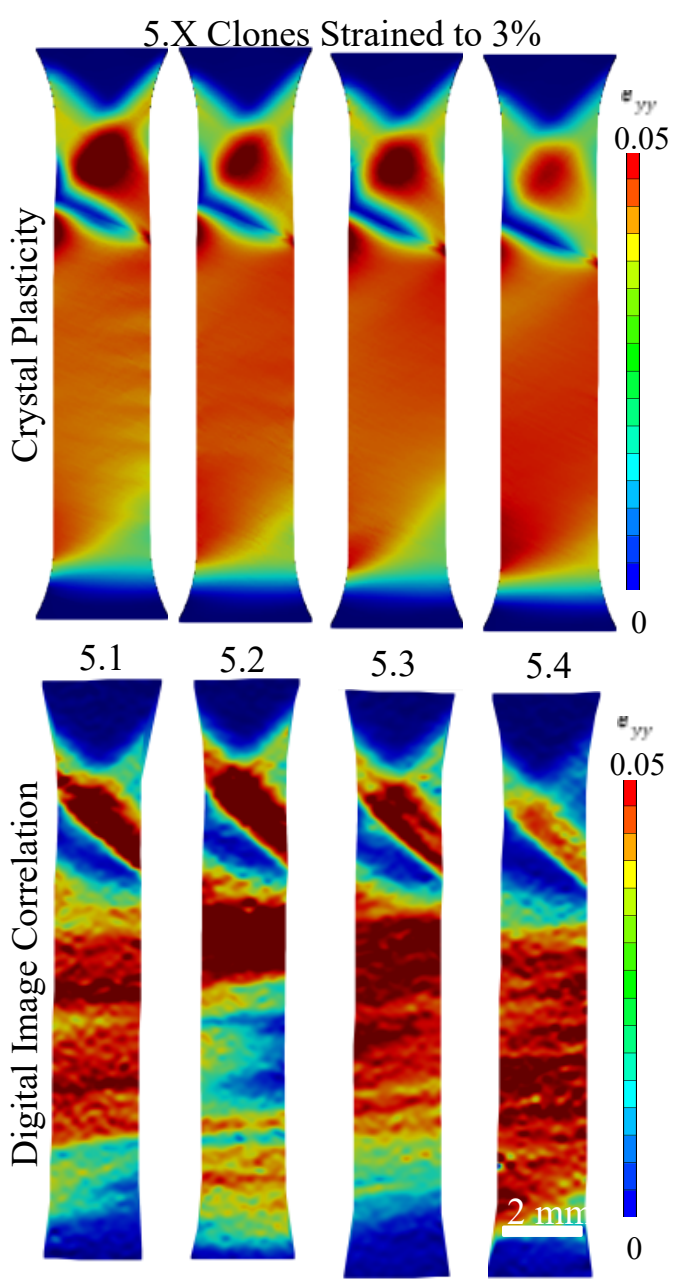
- Strain dispersed across lower grain
- Shear band develops in top grain at same location for all four specimens



Crystal Plasticity – DIC Comparison



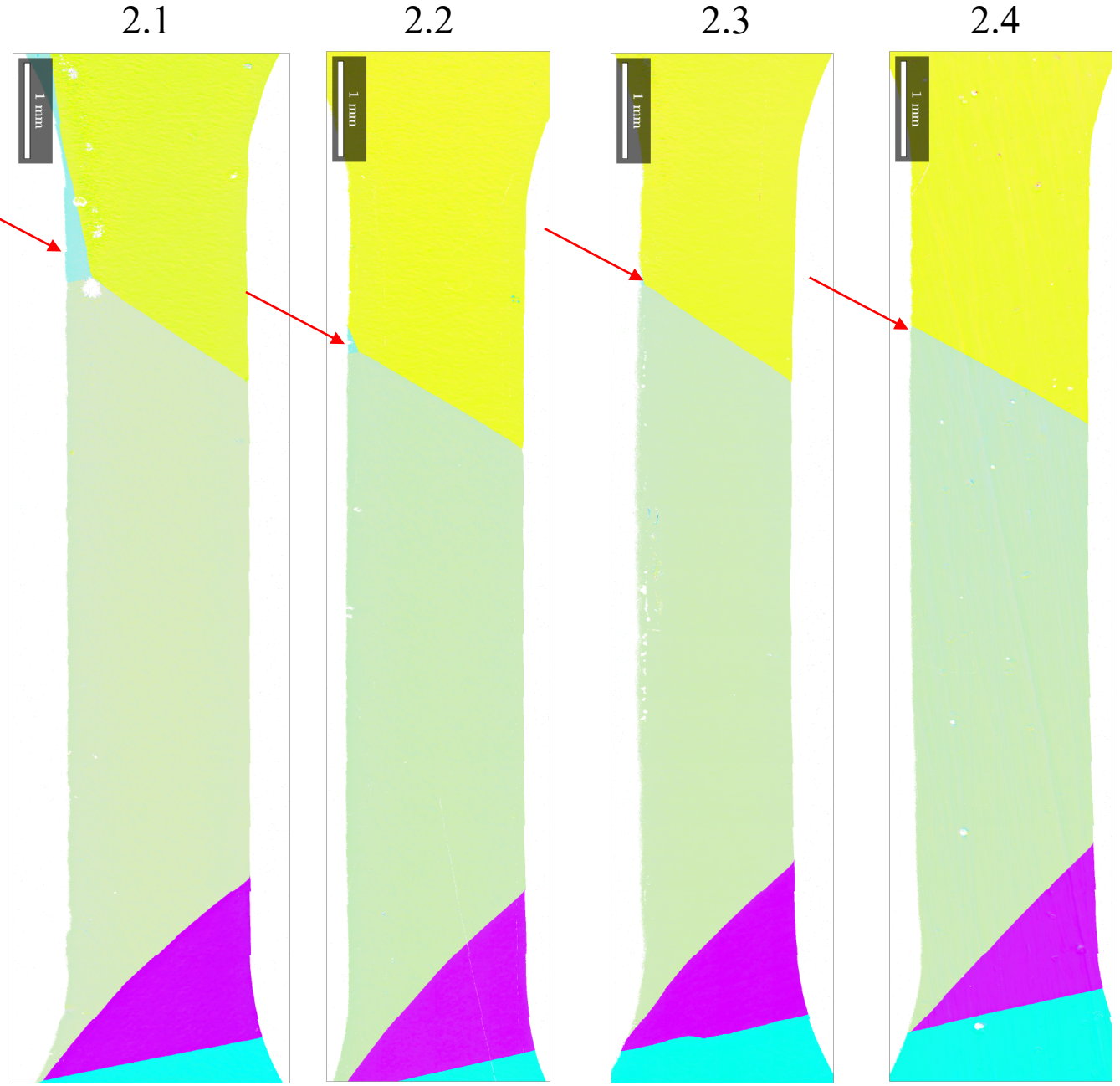


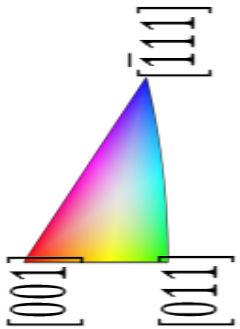


- Crystal plasticity over estimates the yield strength of the 1.x clone – Does not have strong match to DIC data
- 5.x has good agreement on yield and hardening behavior as well as DIC strain locations and magnitudes

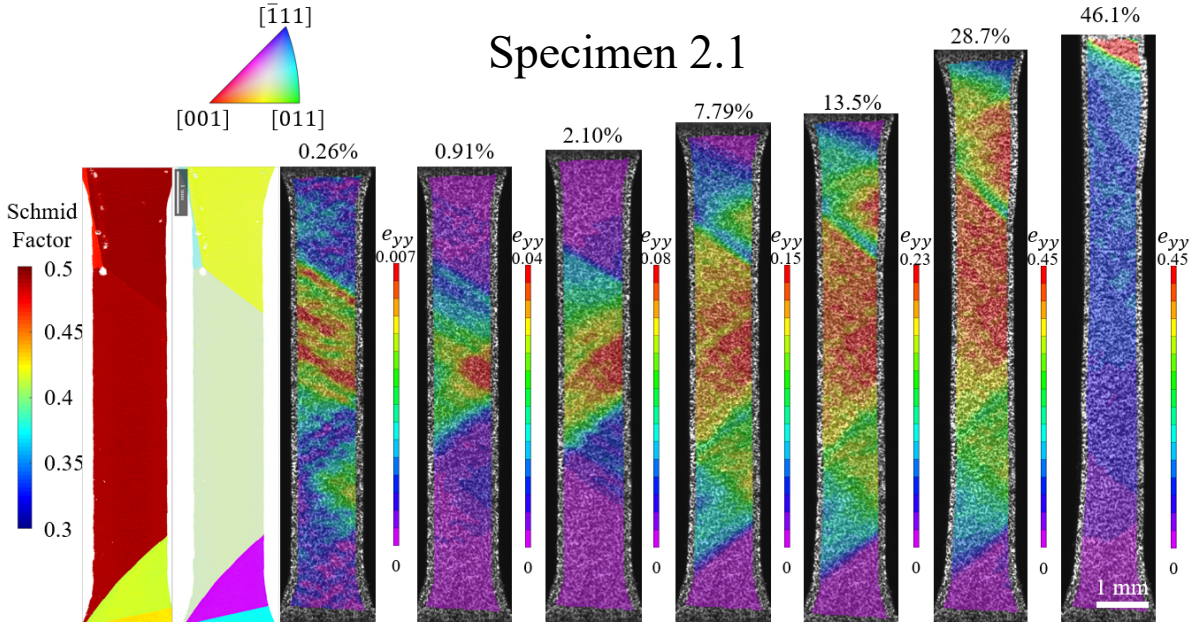
2.x – Loaded to Failure

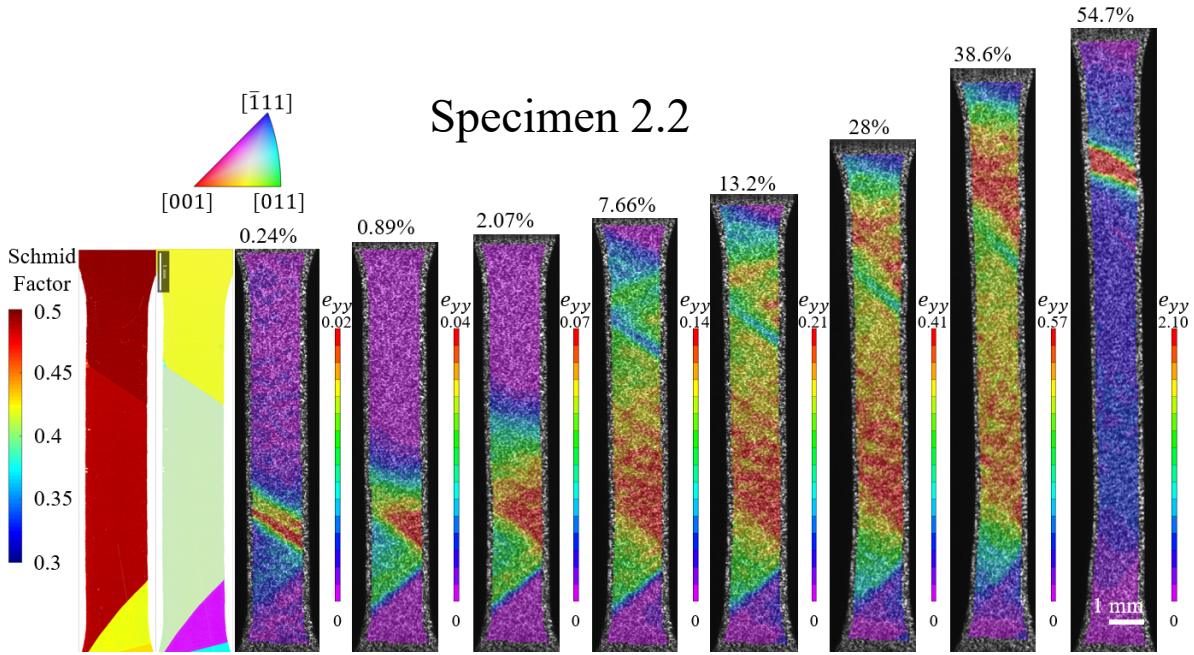
Effect of a disappearing grain

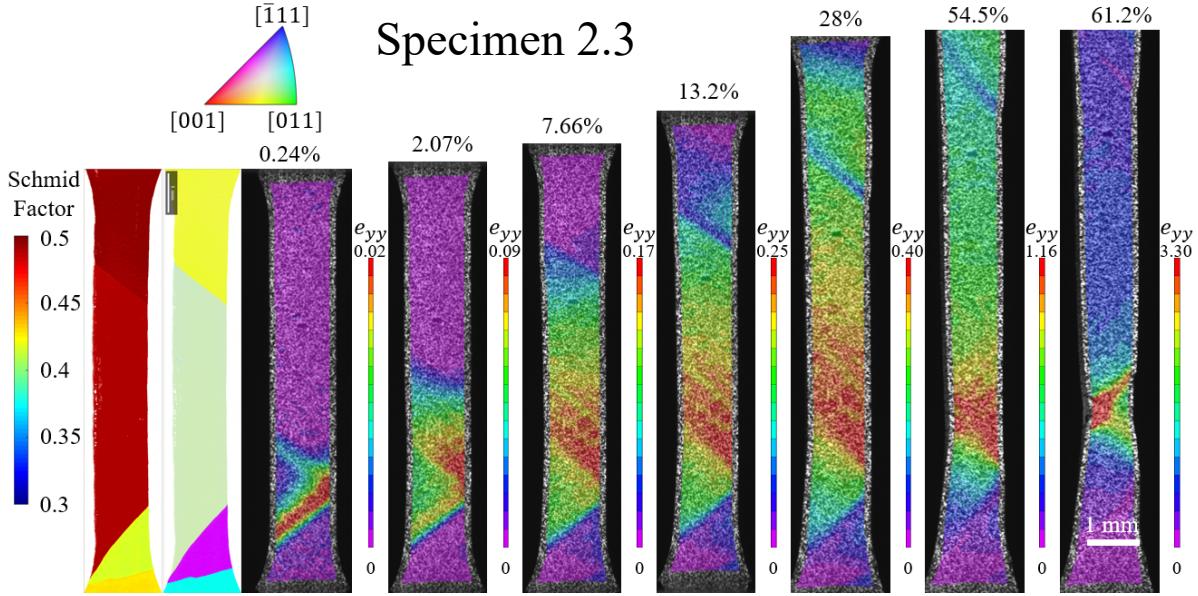


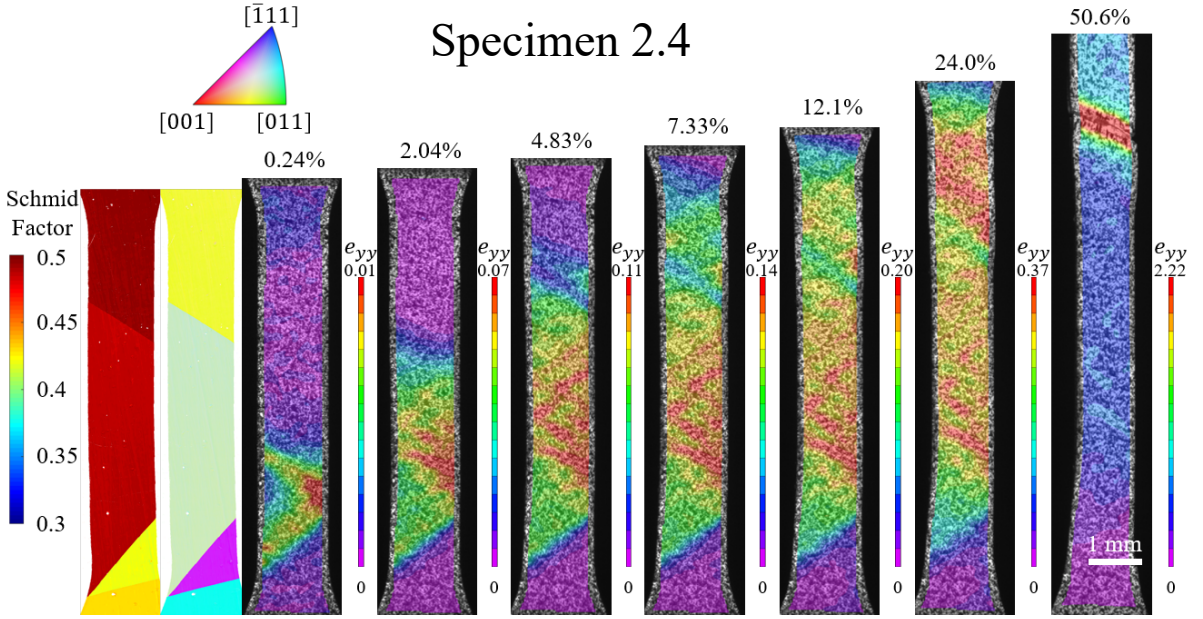


2.x – Loaded to Failure

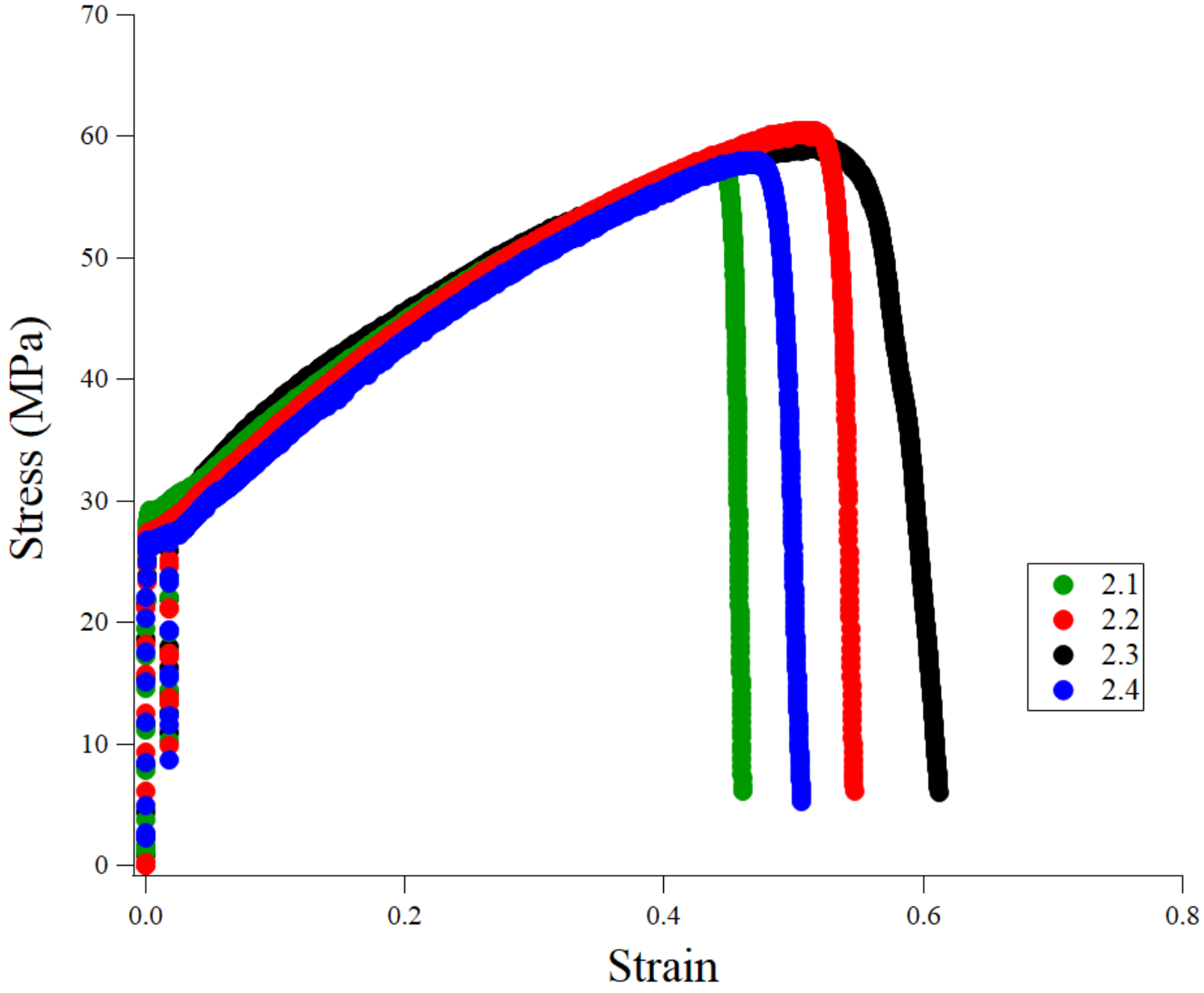




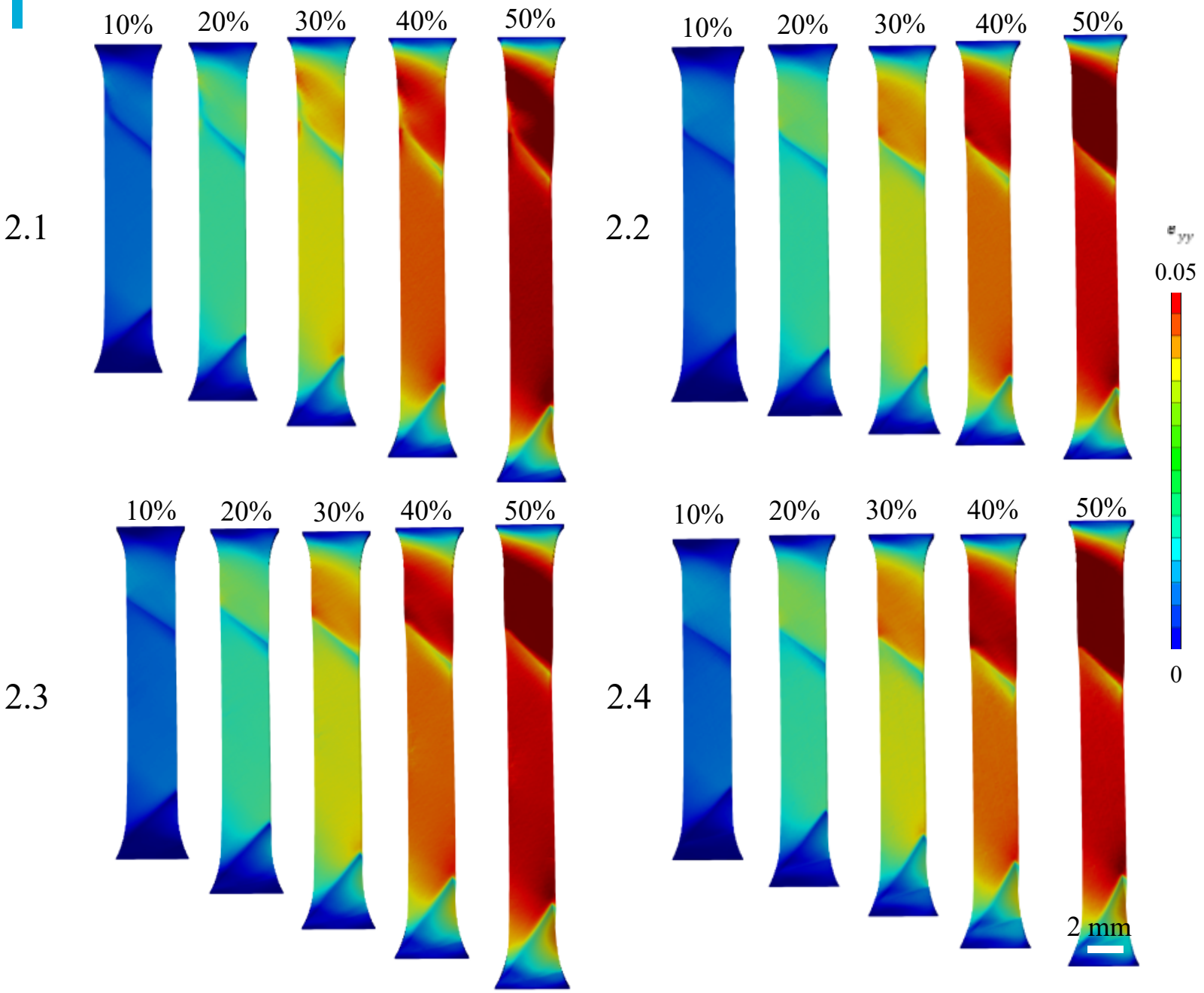




2.x – Loaded to Failure

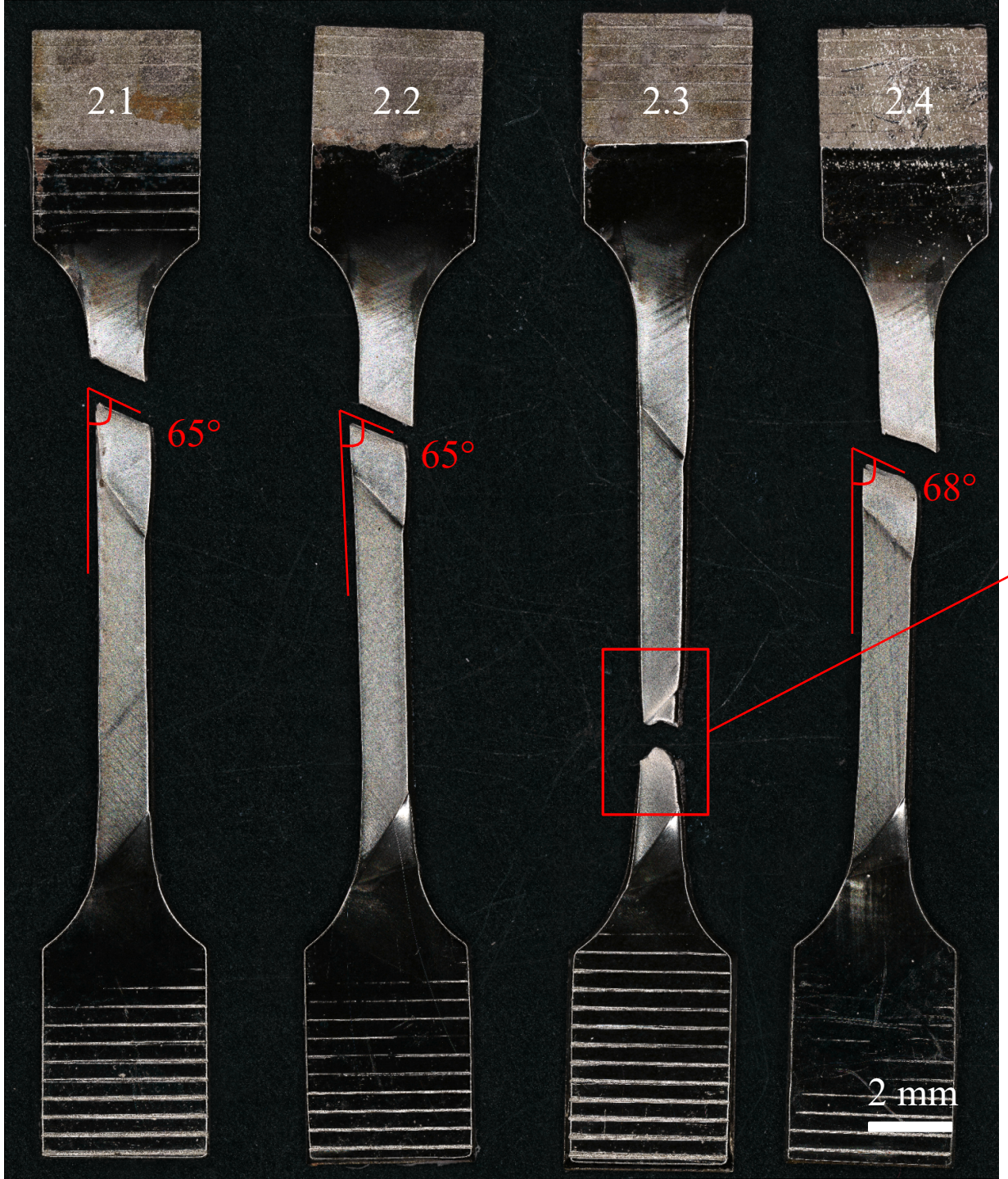


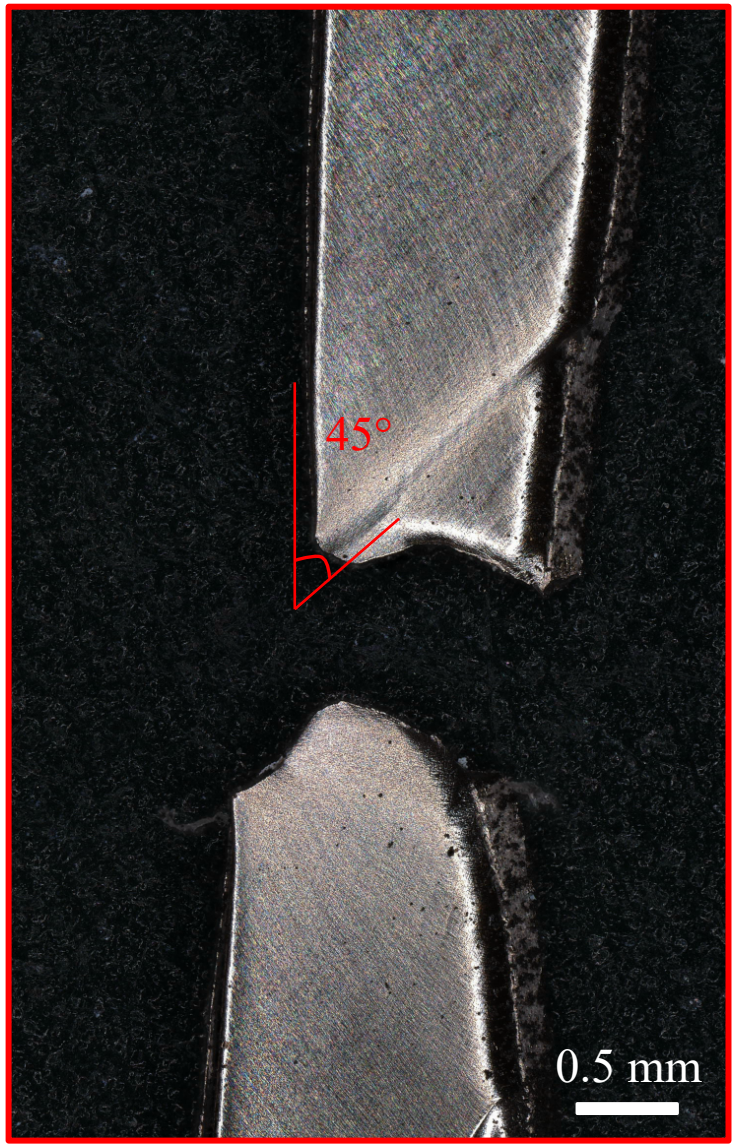
2.X Crystal Plasticity



- Nearly identical CP analysis between clones
- Does not show middle grain strain concentration at initiation
- Does not explain why 2.3 fails in middle grain

- Specimens had very similar deformation until necking
- Three specimens failed in top grain
- Shear band at 65° without significant necking
- One specimen failed in bottom grain
- Necking followed by shear band formation



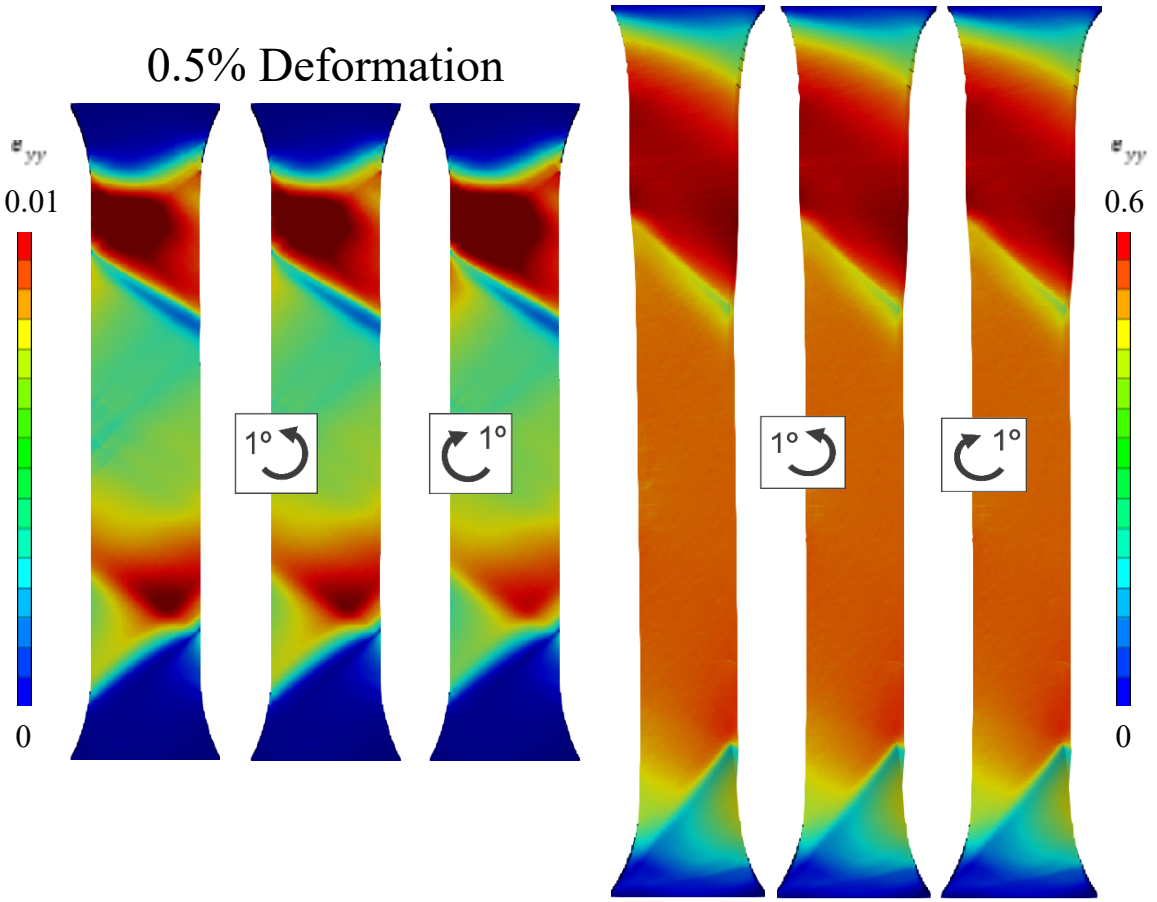


Why did they fail differently? Geometry and alignment evaluation

Specimen alignment

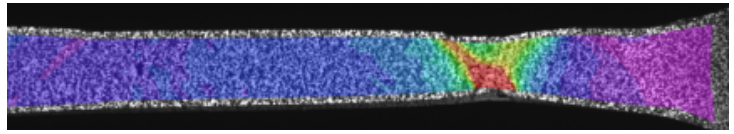
0.5% Deformation

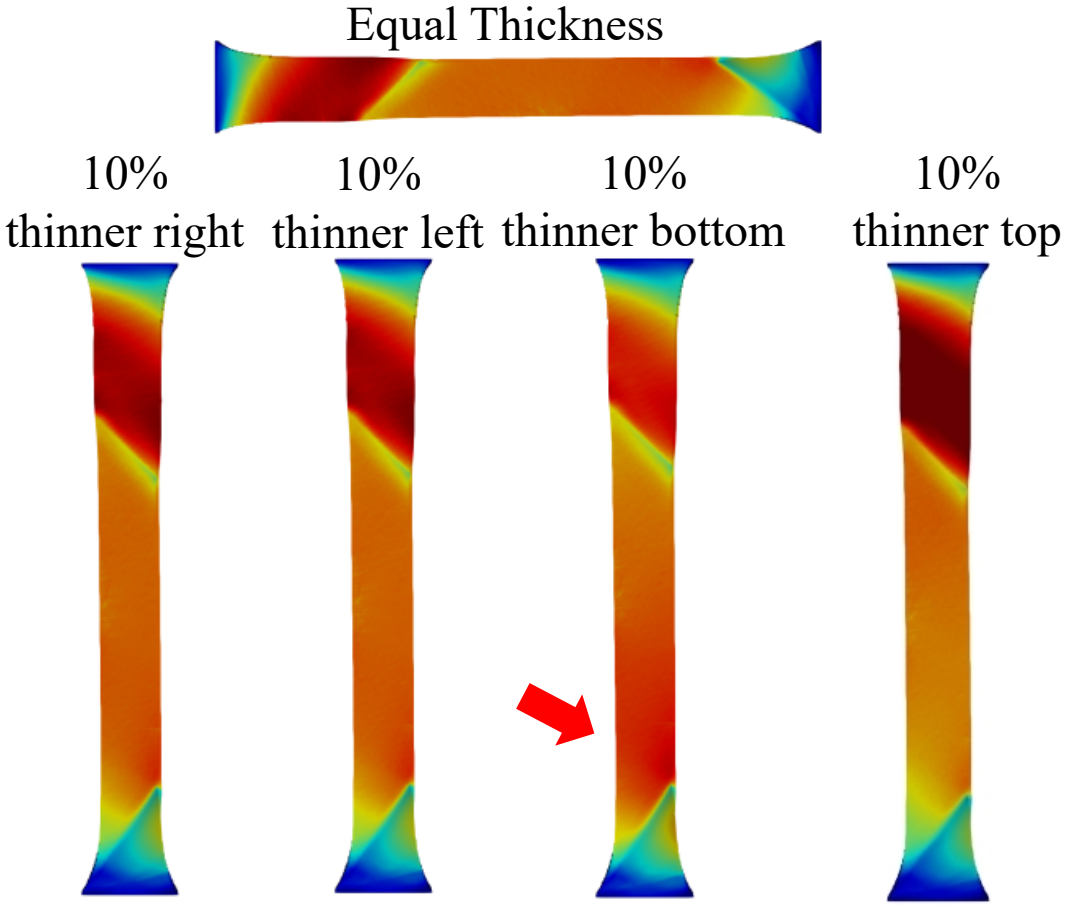
50% Deformation



Specimen Geometry

Clone 2.3

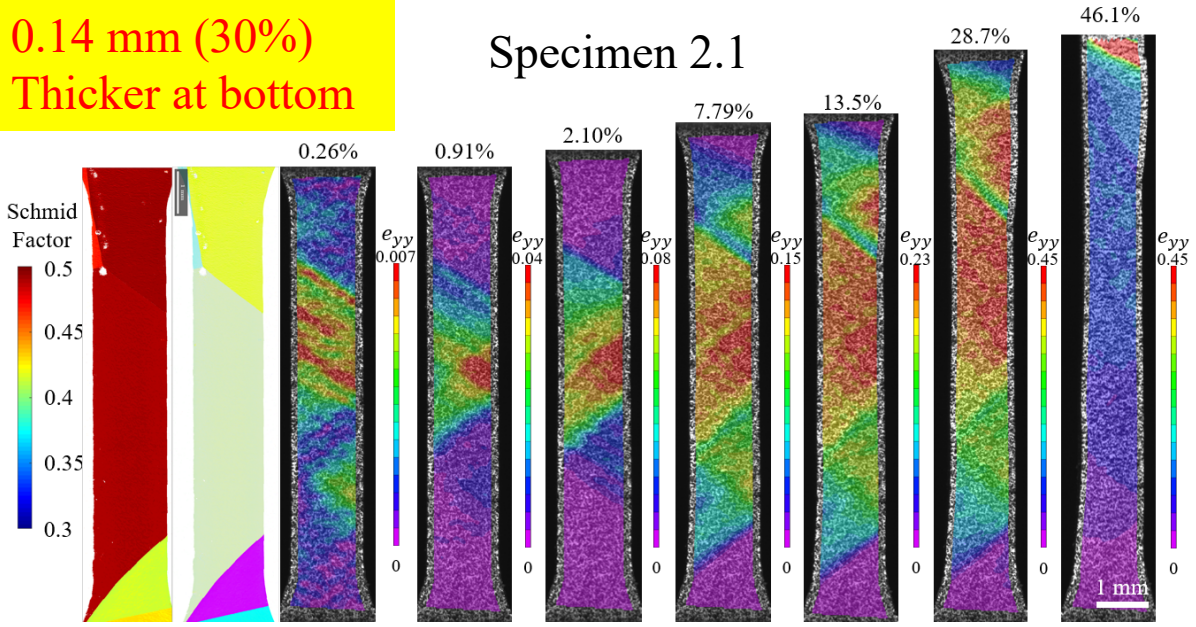




Measuring Grip Thickness

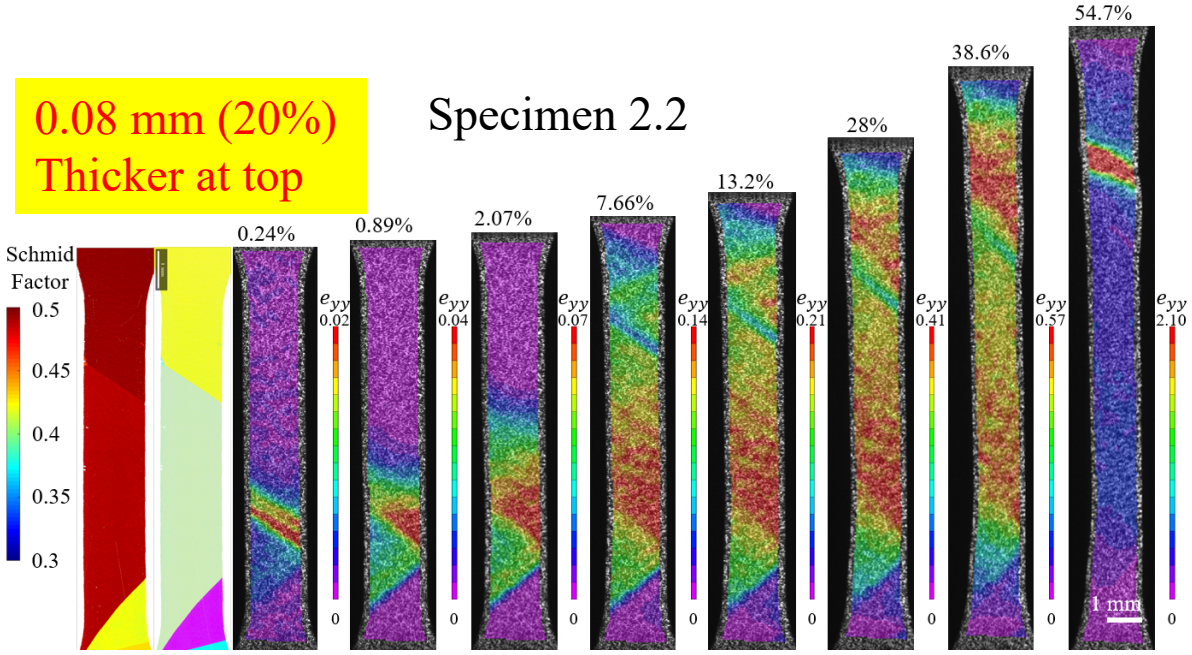
0.14 mm (30%)
Thicker at bottom

Specimen 2.1



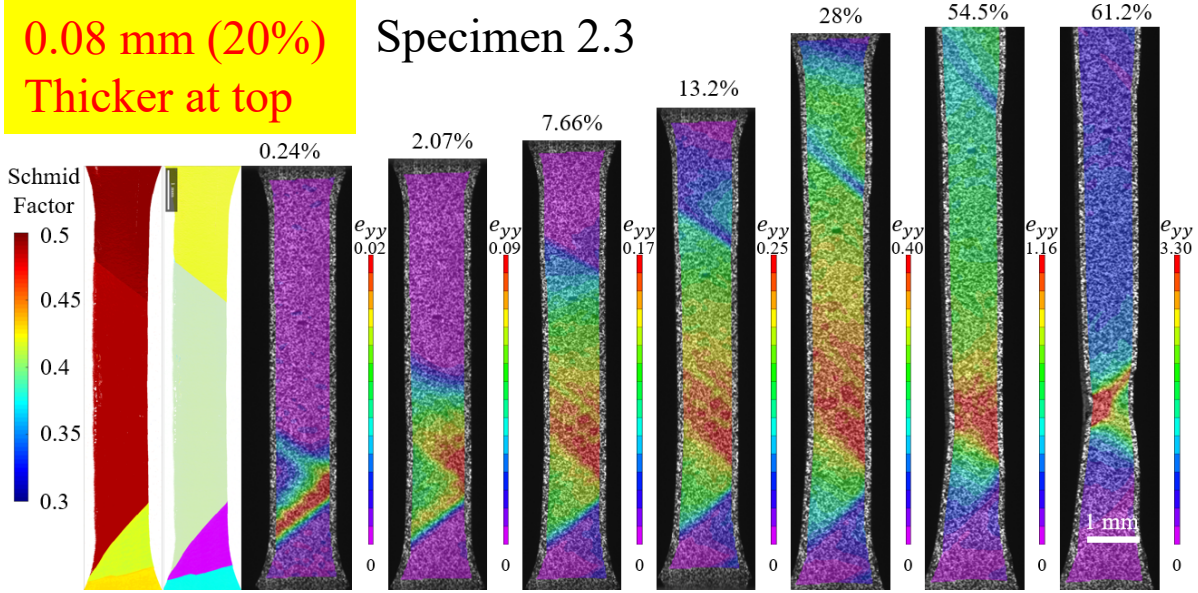
0.08 mm (20%)
Thicker at top

Specimen 2.2



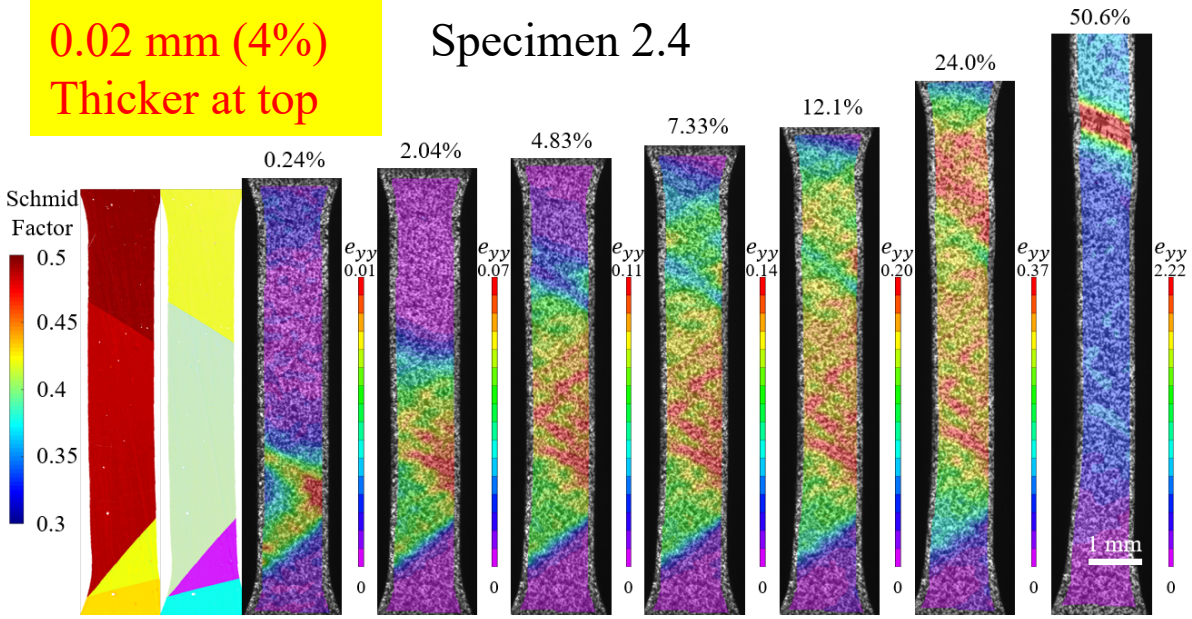
0.08 mm (20%)
Thicker at top

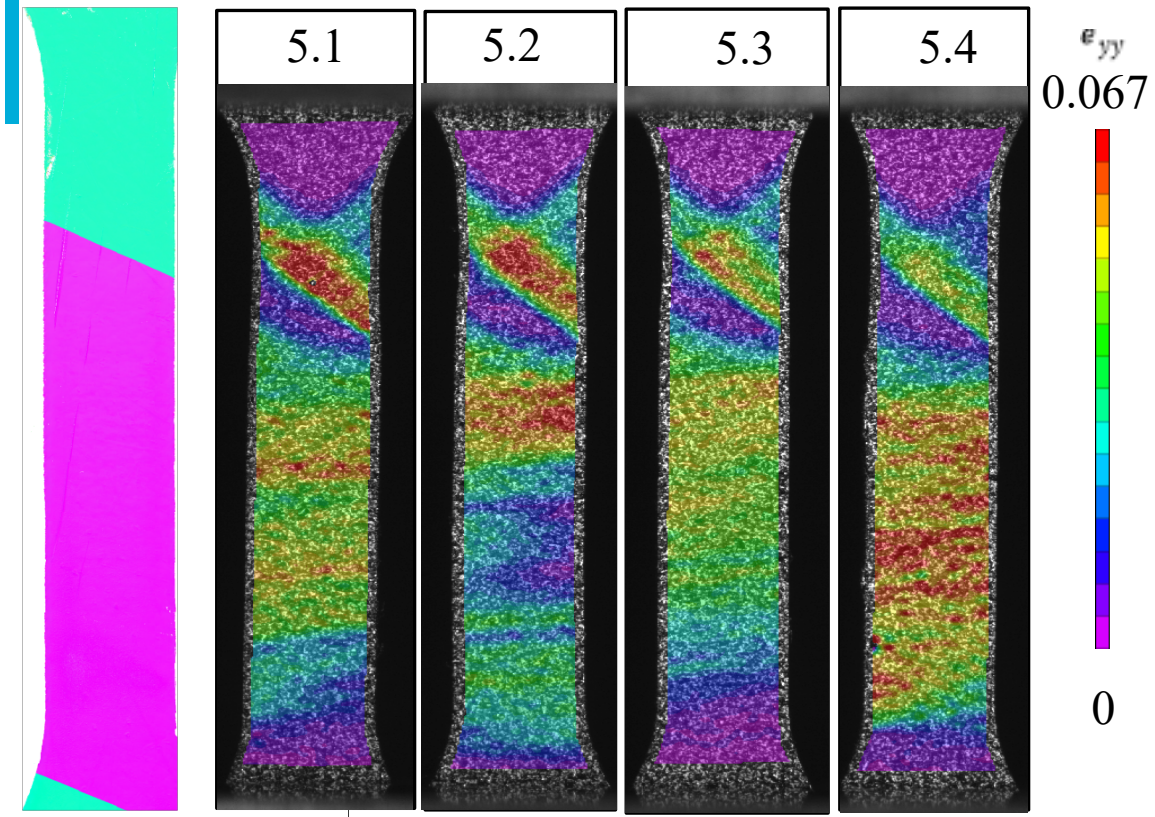
Specimen 2.3

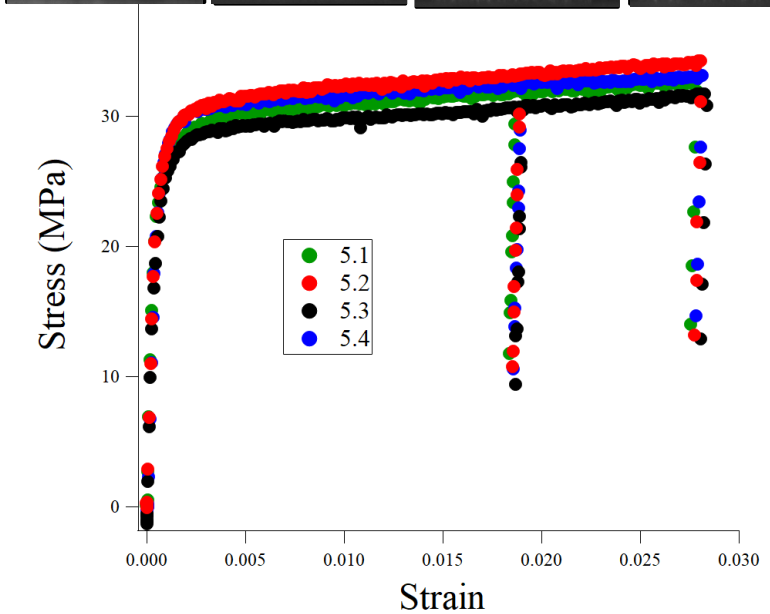


0.02 mm (4%)
Thicker at top

Specimen 2.4







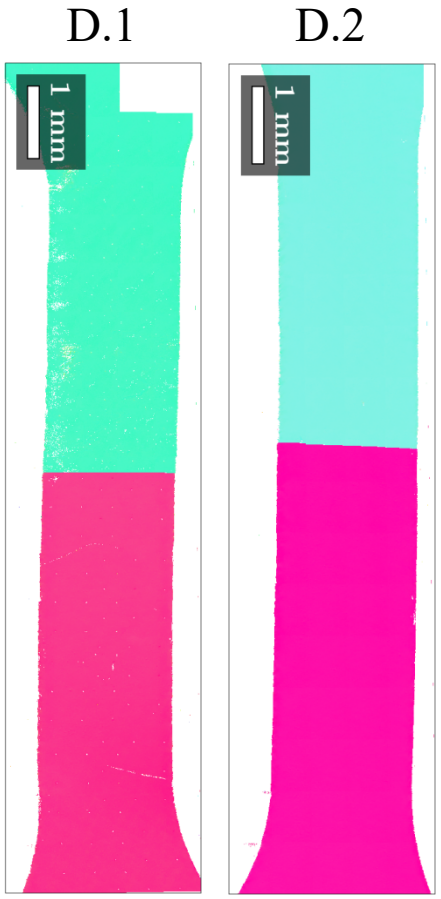
Microstructure Clones Summary

- Microstructural clones – nearly identical oligocrystal microstructures
- Repeatable deformation responses and local strain concentration
- Novel experimental tool to investigate the stochasticity and repeatability of microstructures
- Coordination of microstructural clones and computational crystal plasticity to improve models and mechanism understandings

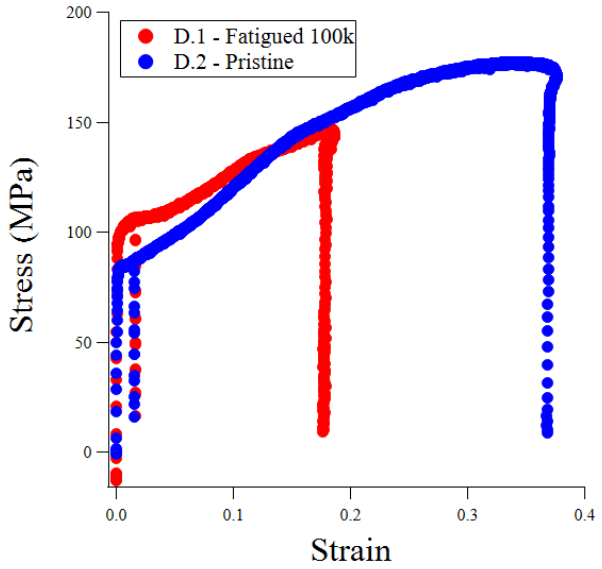
Extra Slides

FUTURE WORK – Effect of Microstructure Modification

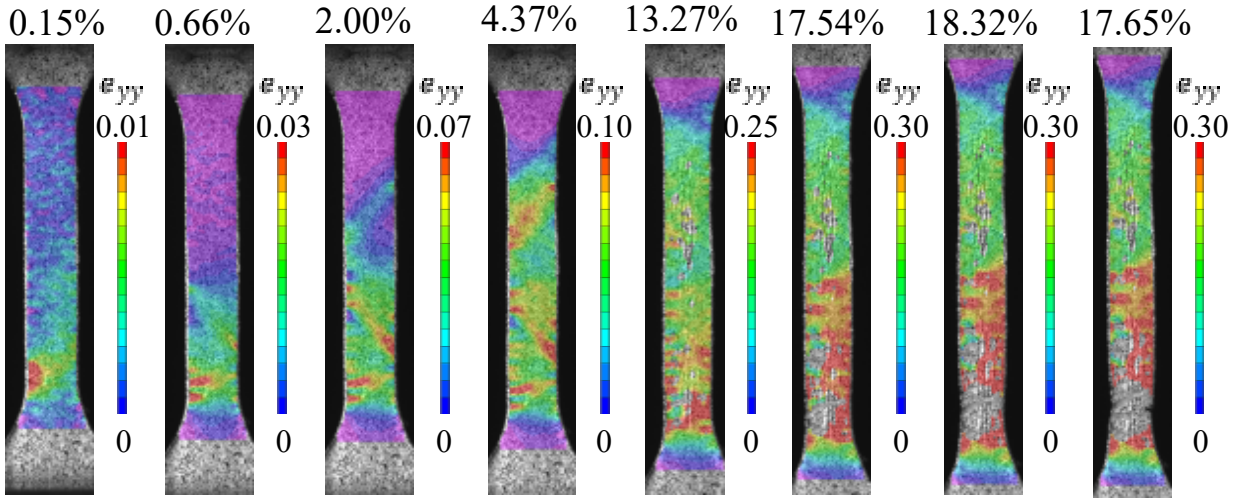
Now that we have developed microstructure clones, how can we use this tool to expand our knowledge on microstructure deformation?



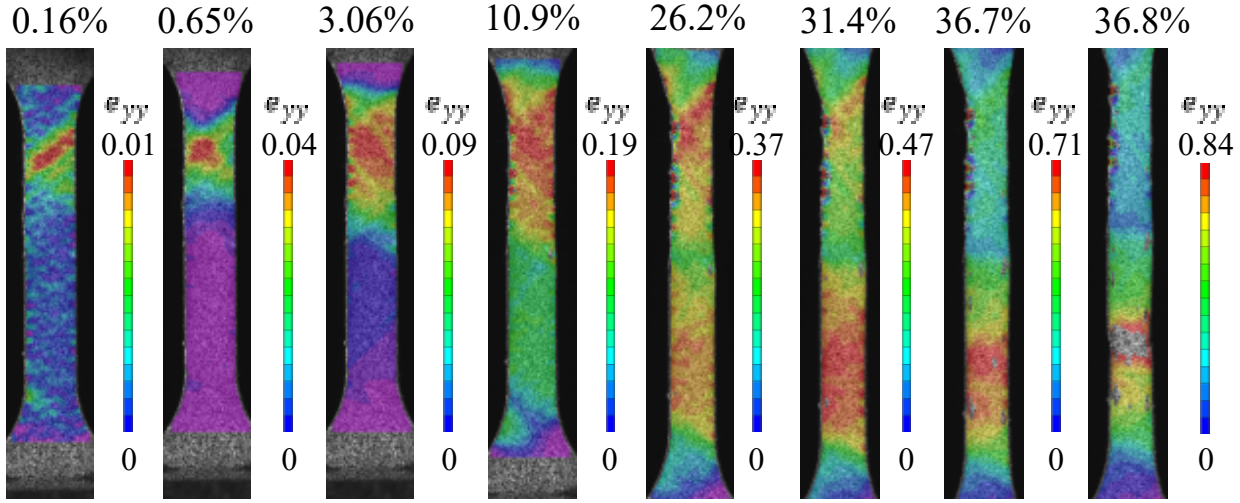
Fatigue one specimen to increase dislocation content



D.1 – After Fatigue Pulled to Failure

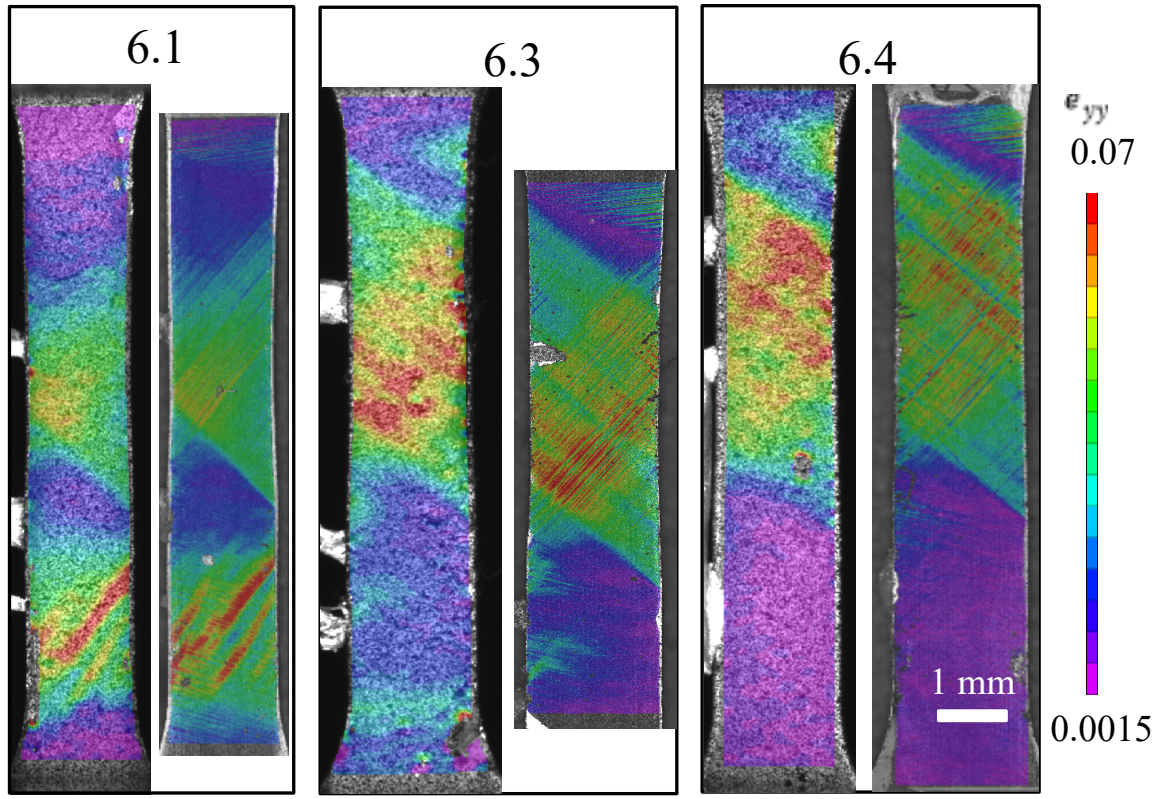


D.2 – Pristine Pulled to Failure

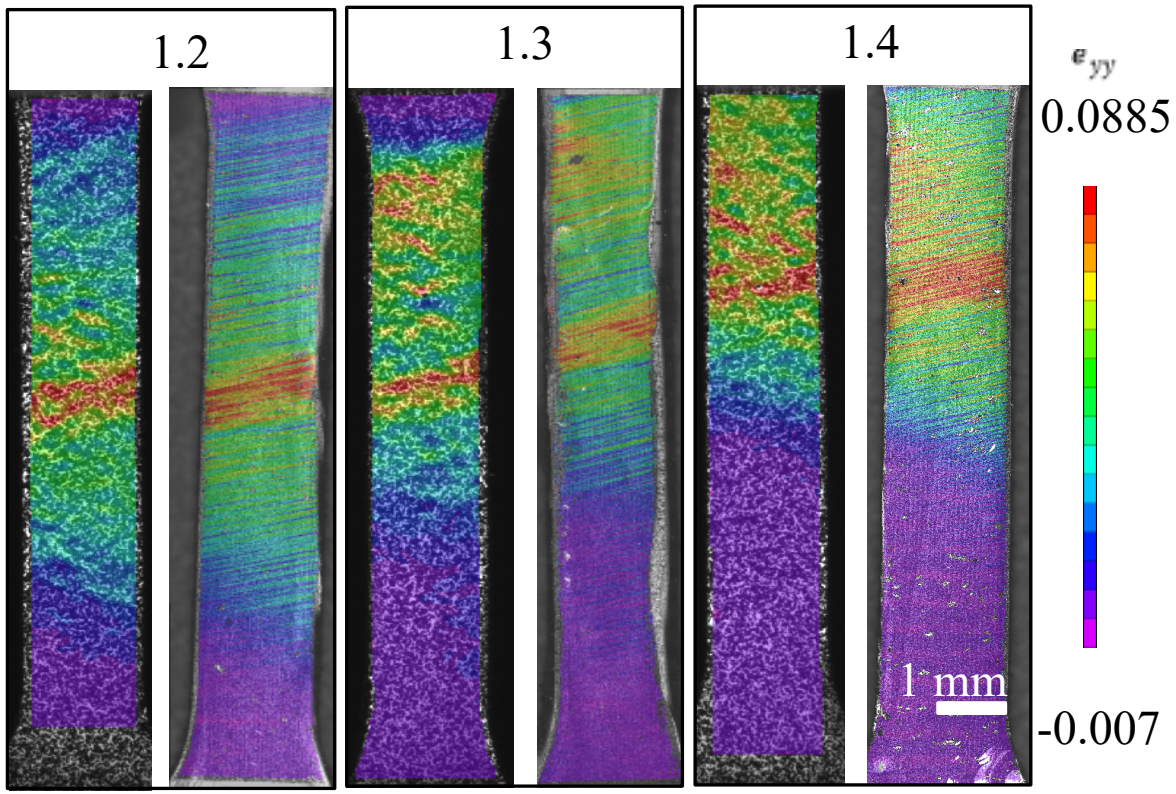


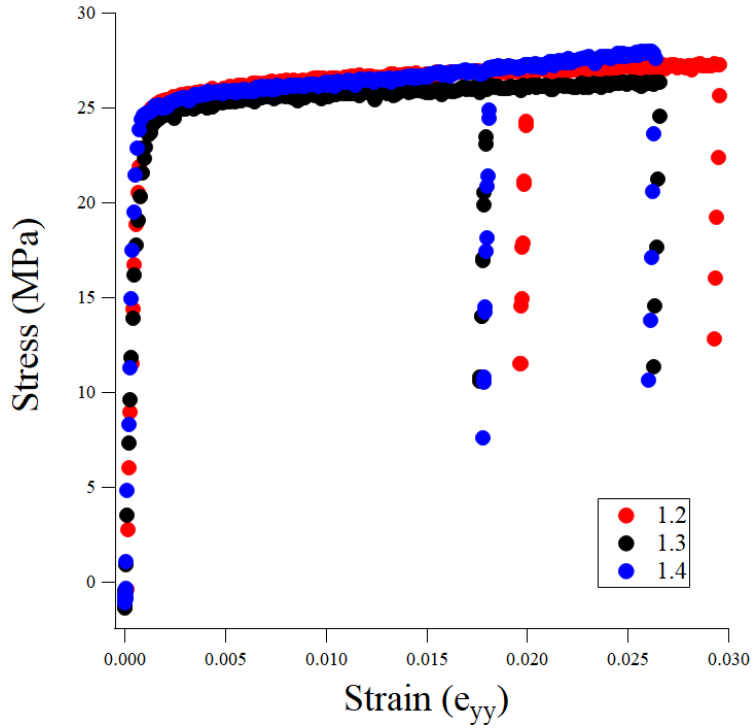
Microstructure Clones – Extra Slides

Dual Digital Image Correlation Technique



1.x – Loaded to 3% Strain

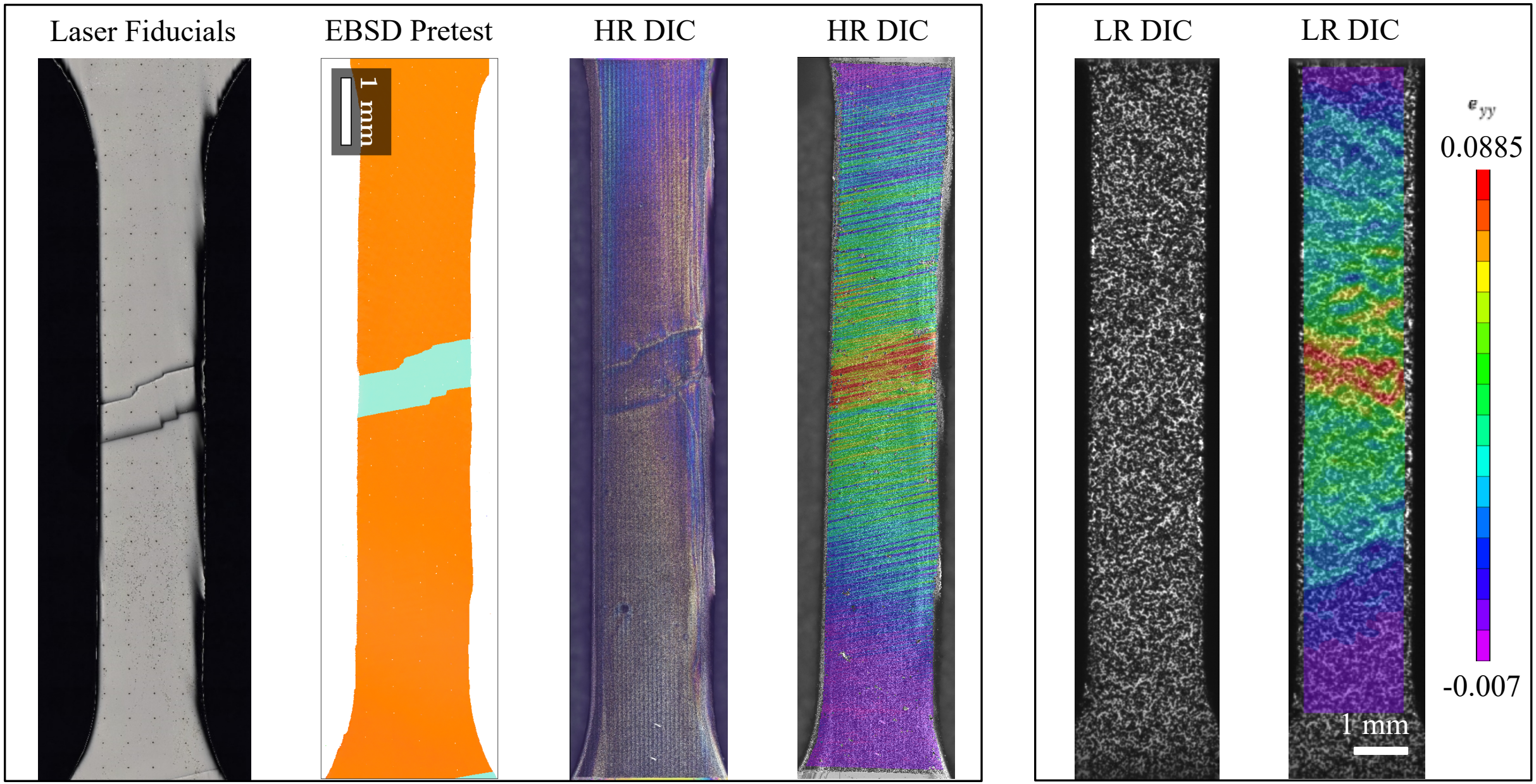




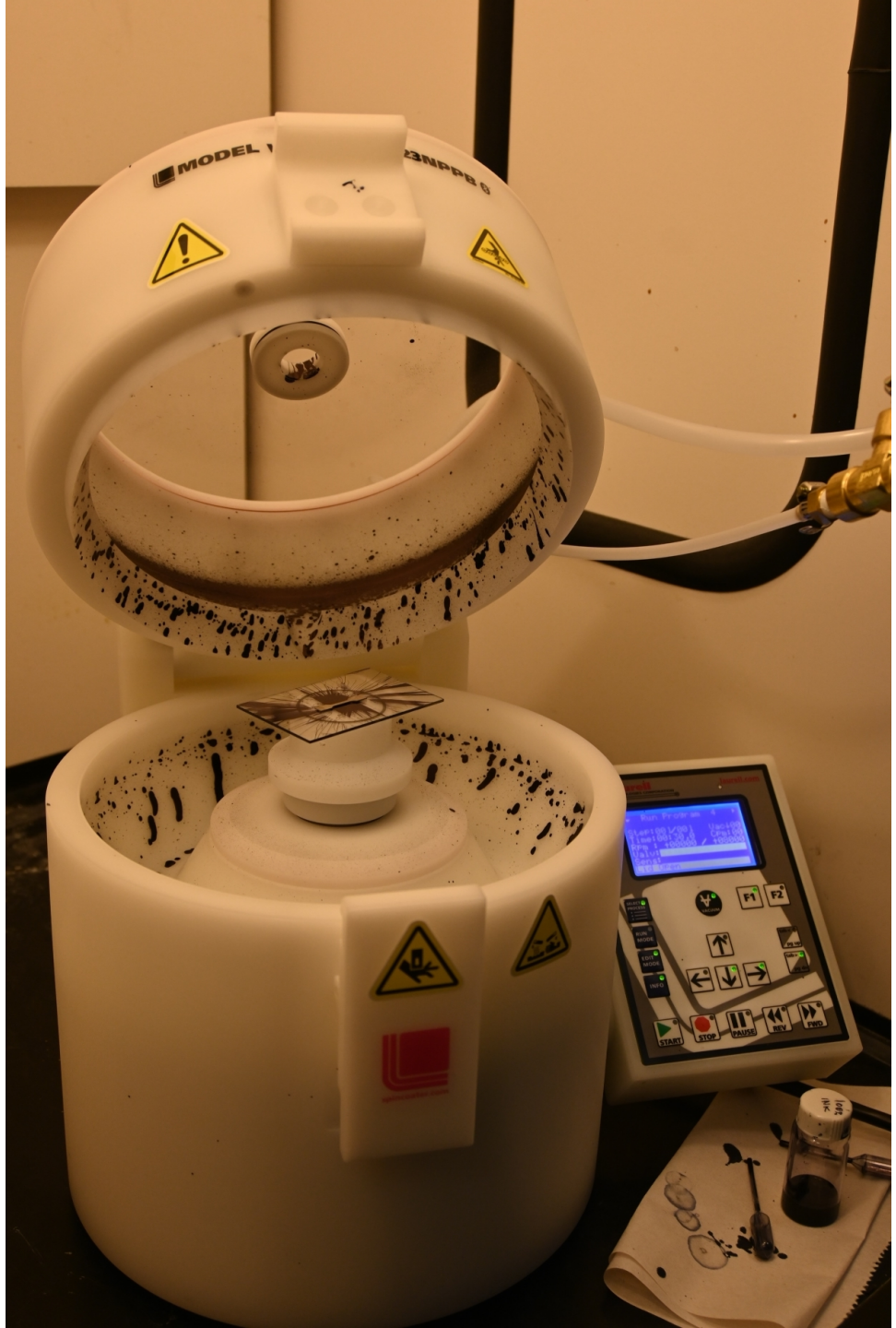
Specimen Imaging

Front of Specimen – Mirror Finish

Back of Specimen – EDM Finish



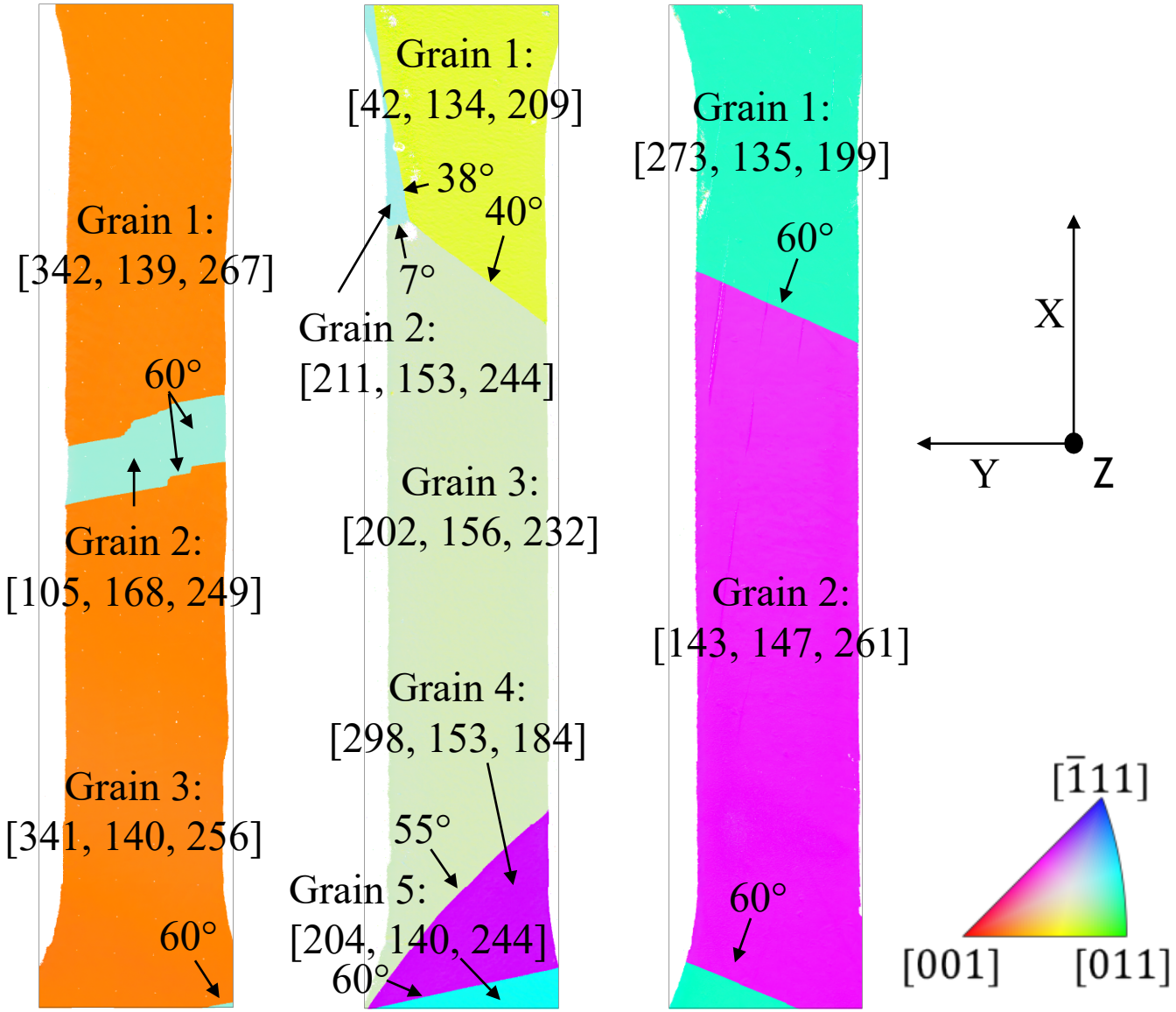
XXX


MODEL
START
STOP
PAUSE
REV
FWD


EBSD Explained
GEMINI
X-Max
SYMMETRY
CAUTION

Three Clone Sets Chosen for Study

(a) Clone Set 1.x (b) Clone Set 2.x (c) Clone Set 5.x



Clone Set 1.x

- Parent grain (orange) with jagged horizontal twin (blue)

Clone Set 2.x

- Five main grains
- High and low angle grain boundaries

Clone Set 5.x

- Parent grain (teal) with large angled twin (purple)

Clone Sets 1.x and 5.x loaded to 3% strain
Clone Set 2.x loaded to failure