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Deformation Mechanisms of SLM 316L Stainless Steels

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Disclaimer

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SEM2018

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LLNL-CONF

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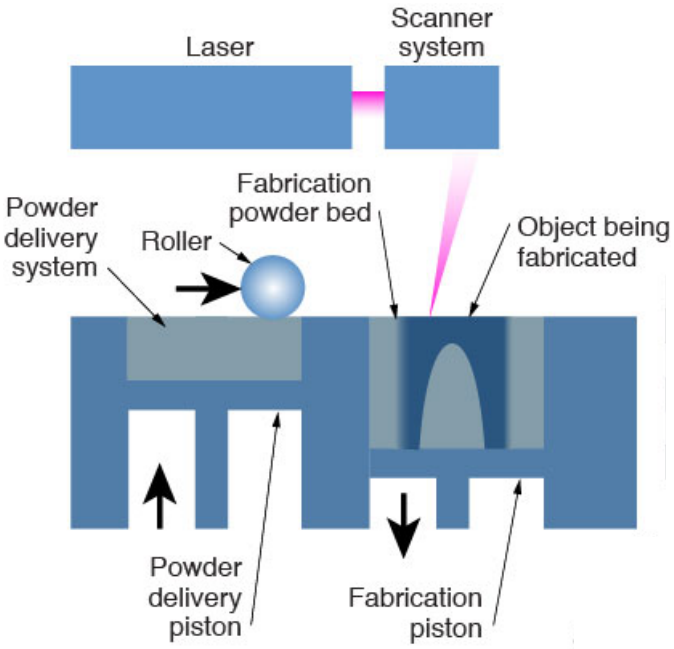
Selective Laser Melting – SS 316L

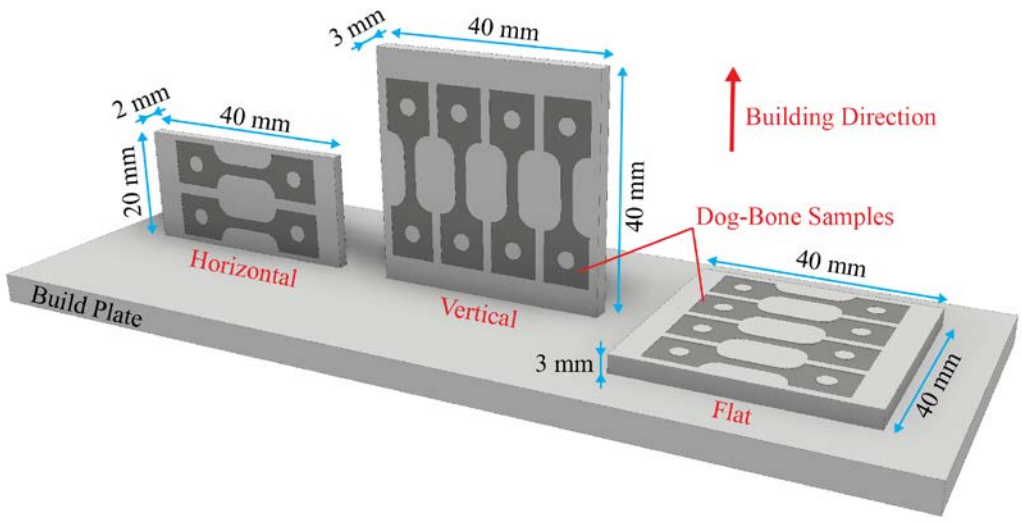
Concept Laser M2 Cusing

Open architecture Fraunhofer 3D printer

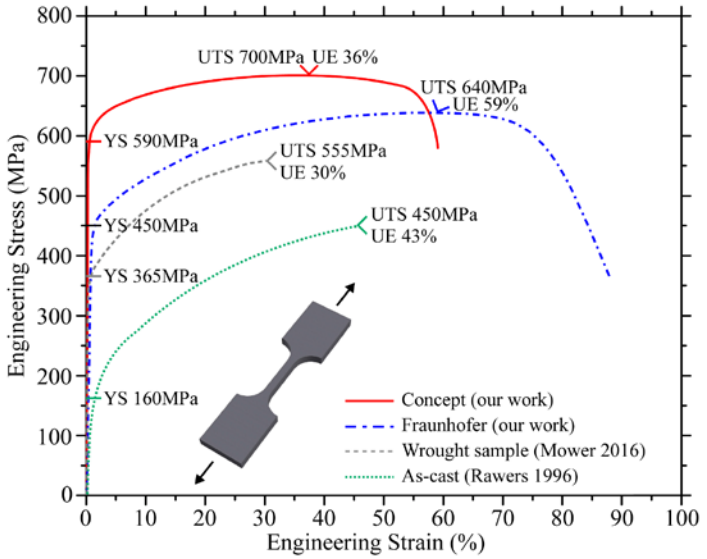
Powder Bed Fusion (PBF)
Selective Layer Melting (SLM)

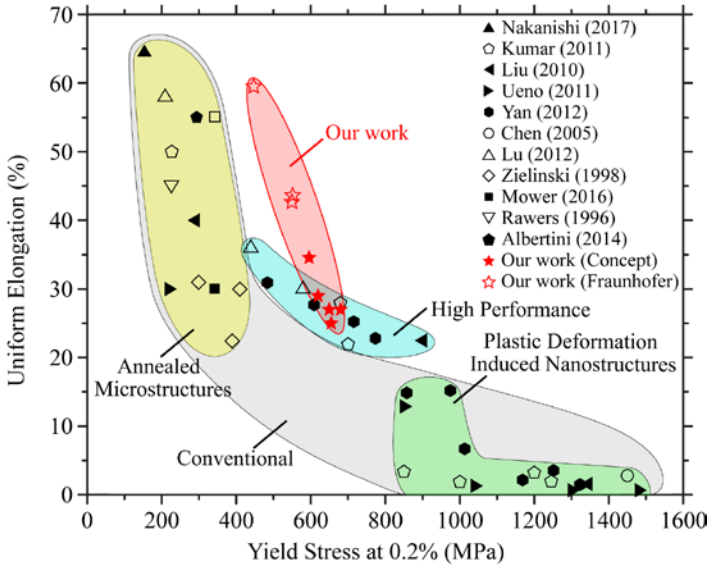


SLM SS 316L / Mechanical Properties

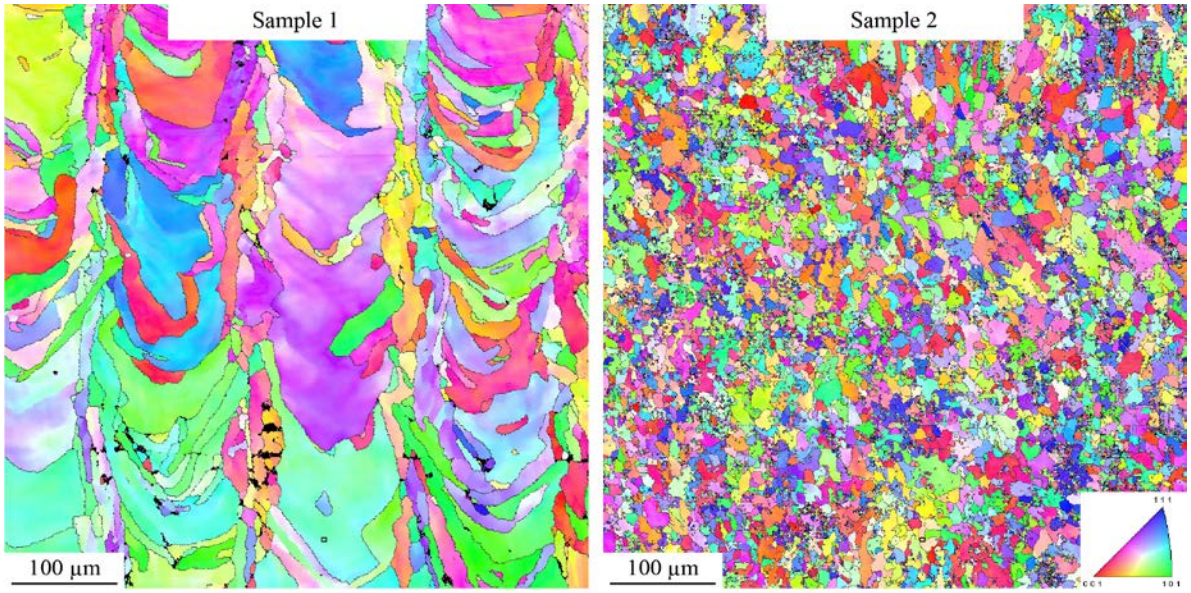


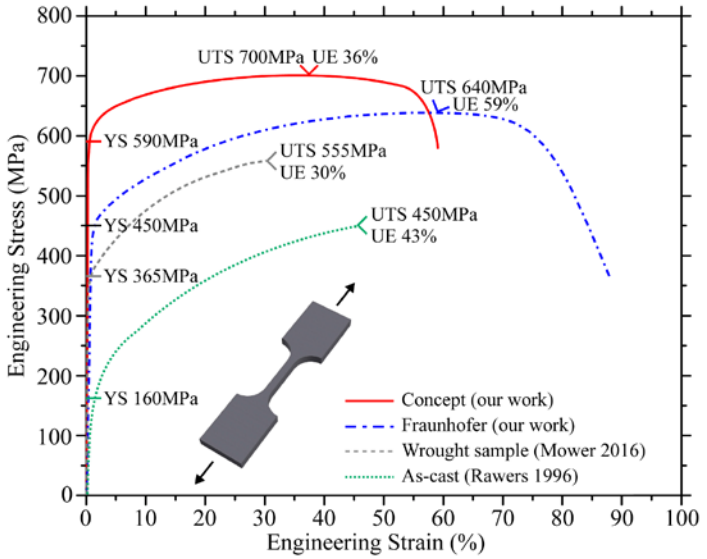
Laser power and speed optimization

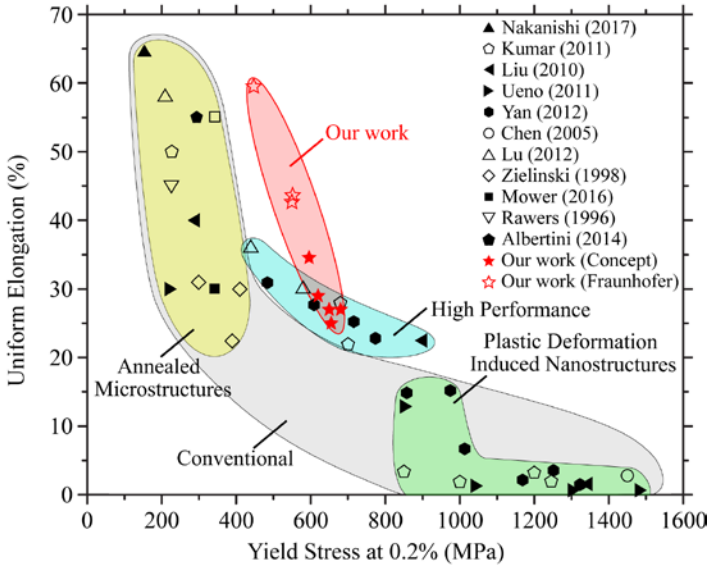




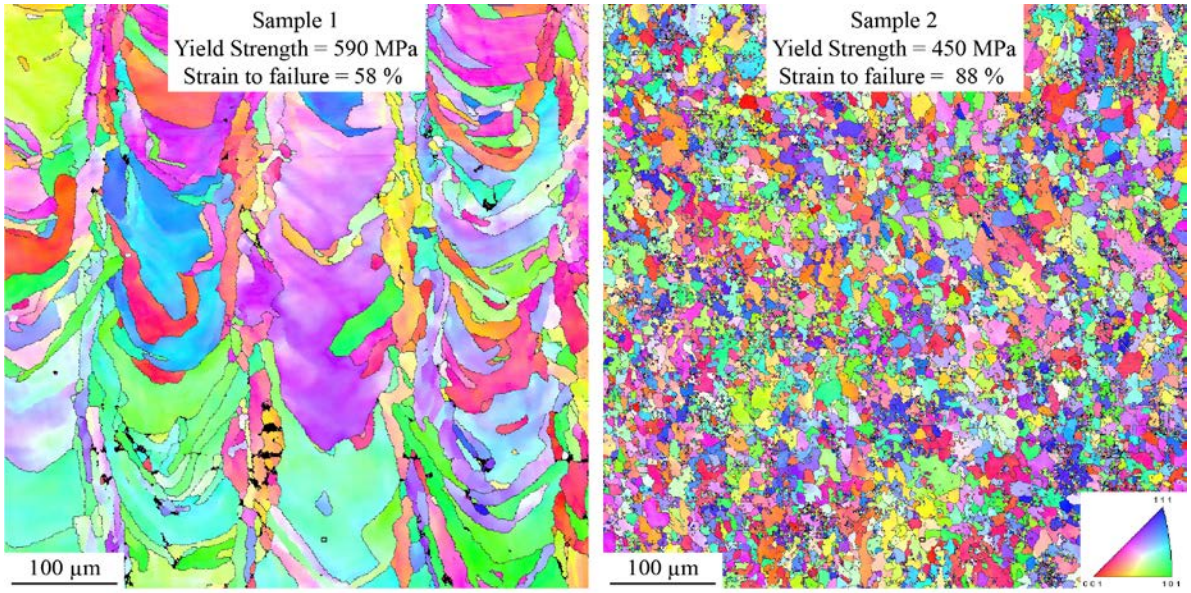
SLM SS 316L / Microstructure

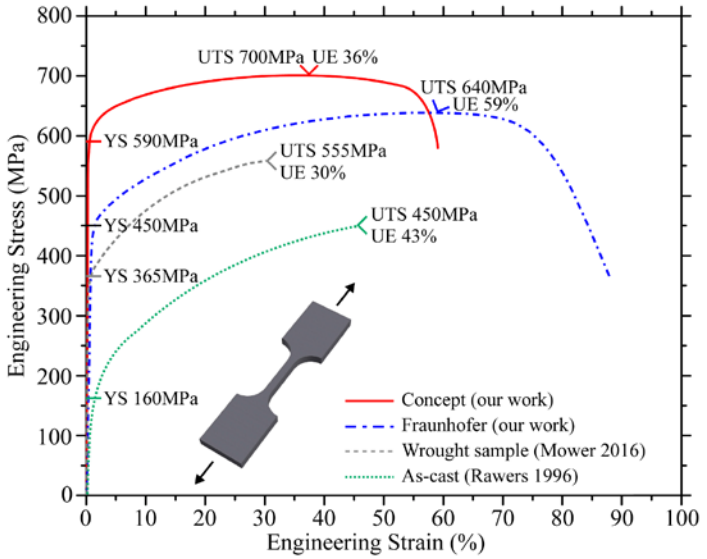


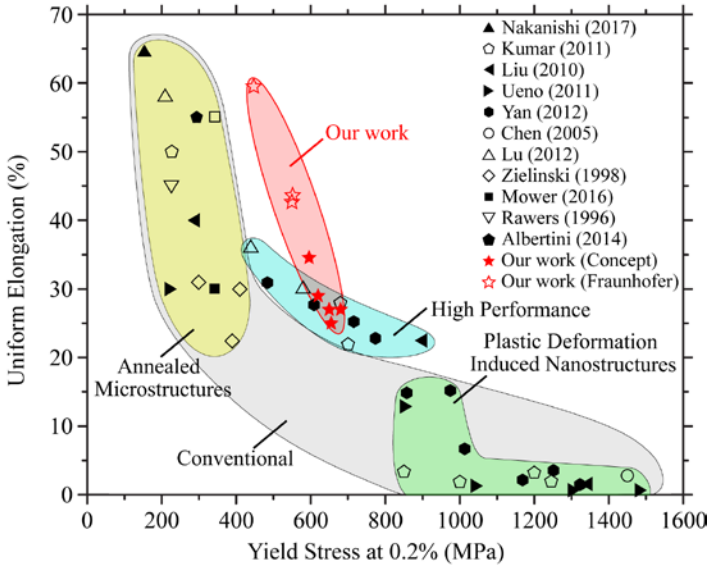




SLM SS 316L / Microstructure







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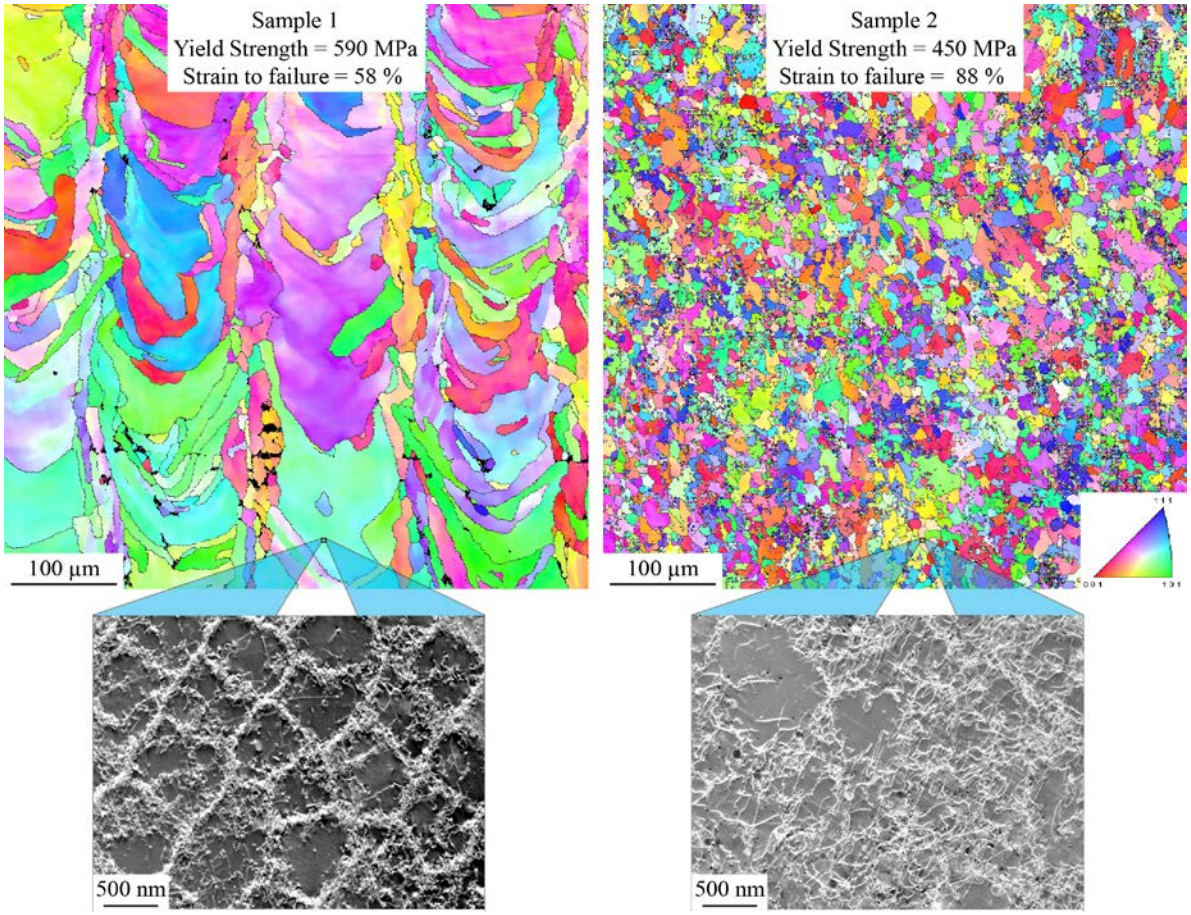
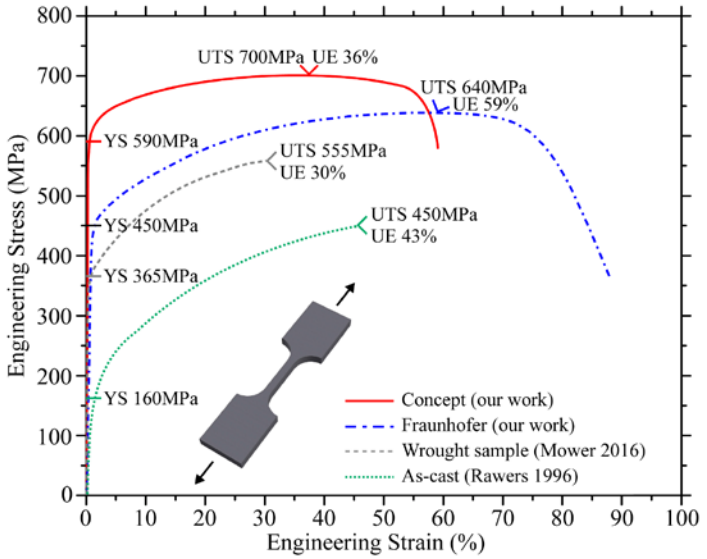
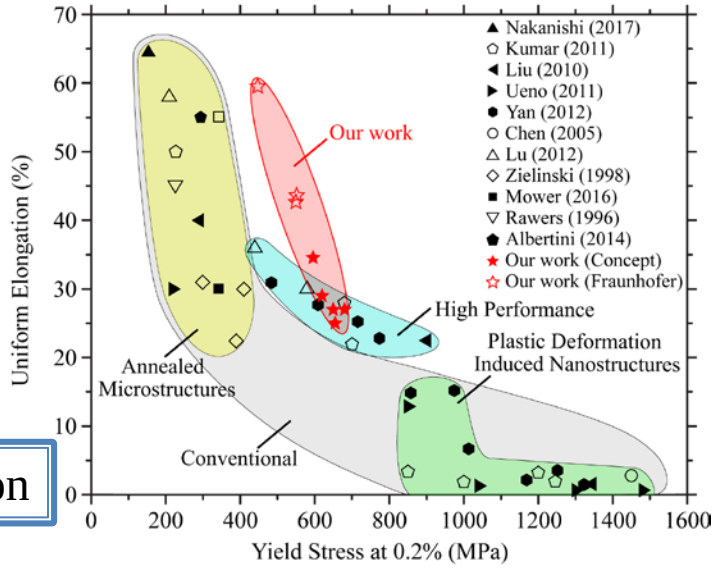
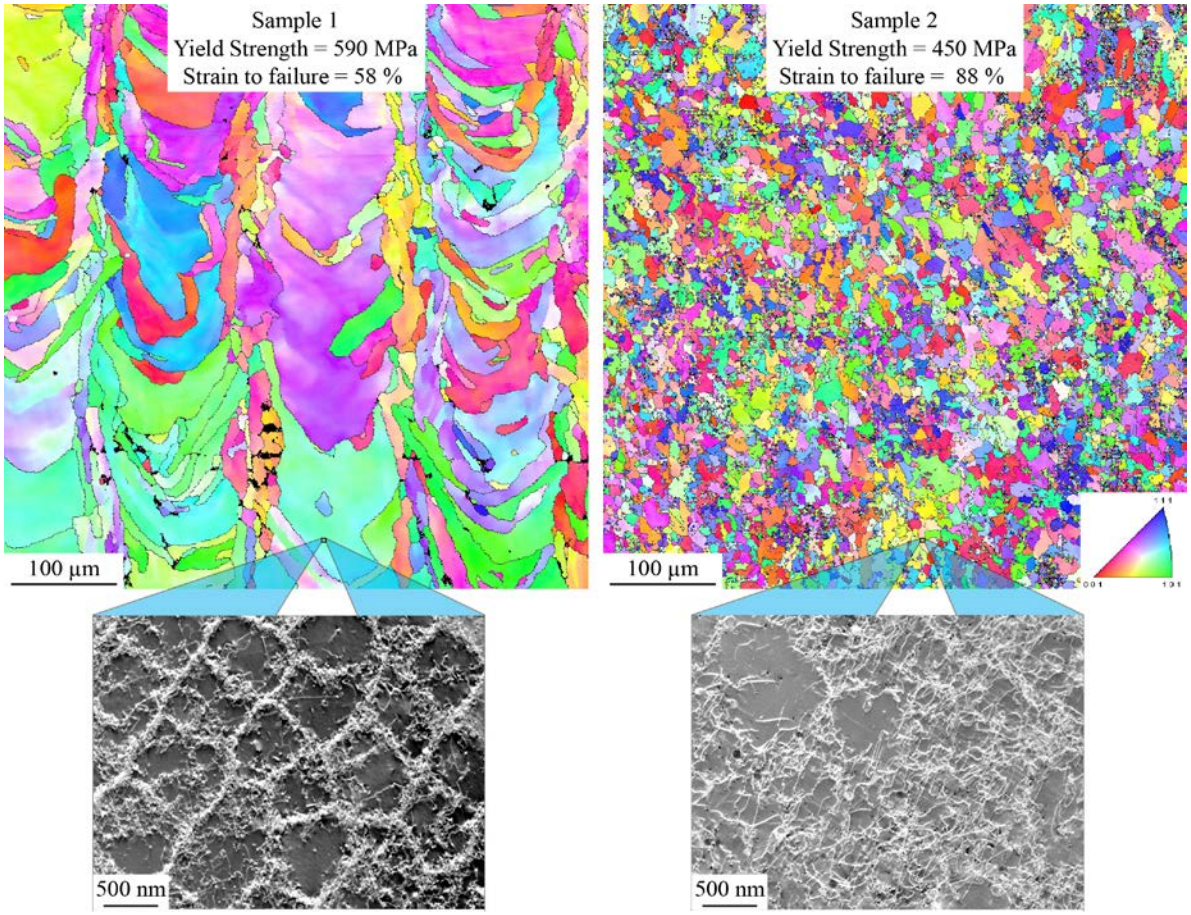


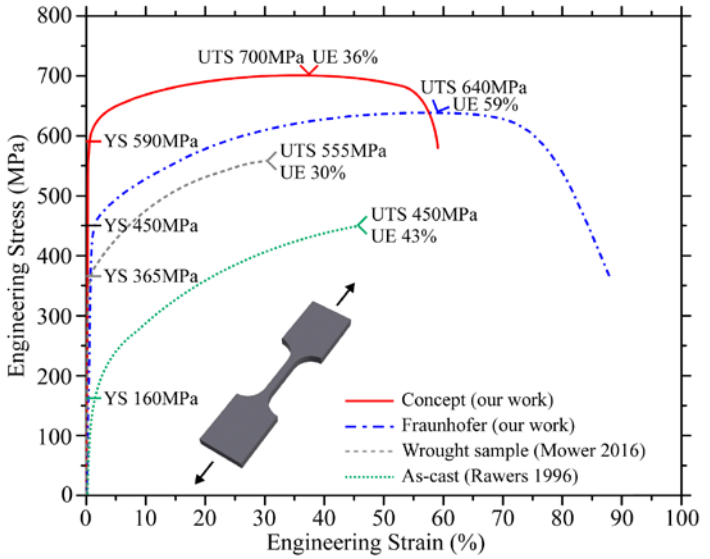


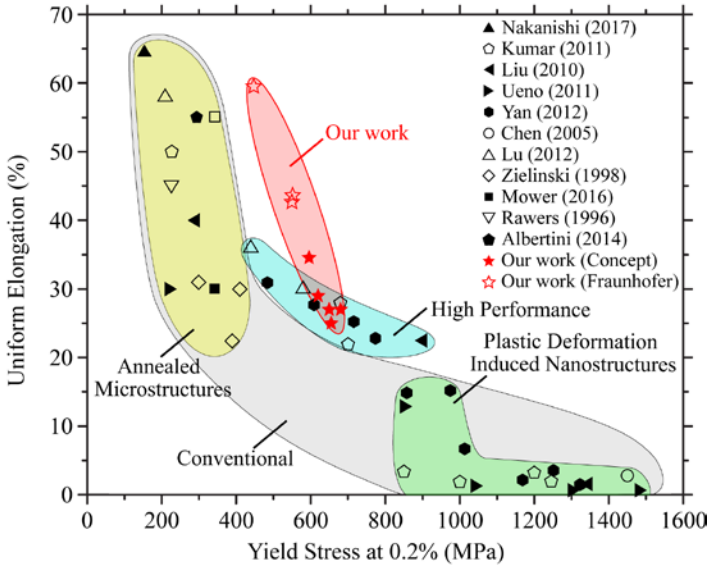


Features below the grain scale take control of the deformation

SLM SS 316L / Microstructure



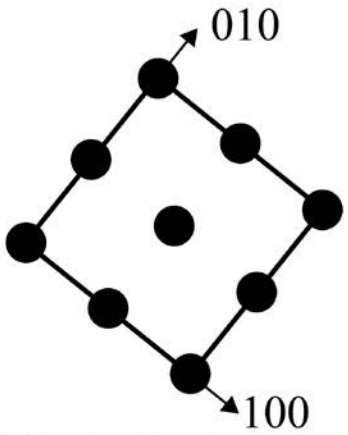




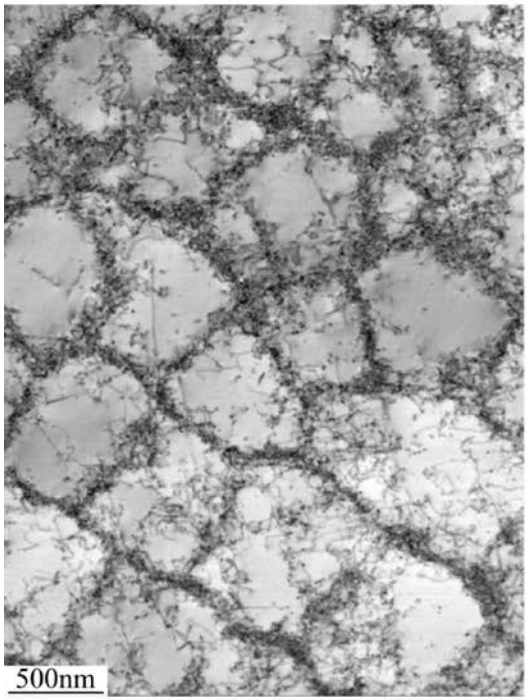
Different laser power and speed

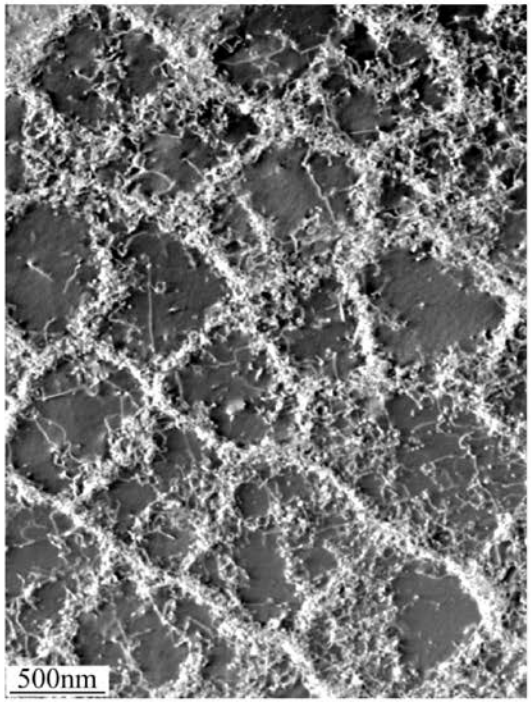
Different beam size

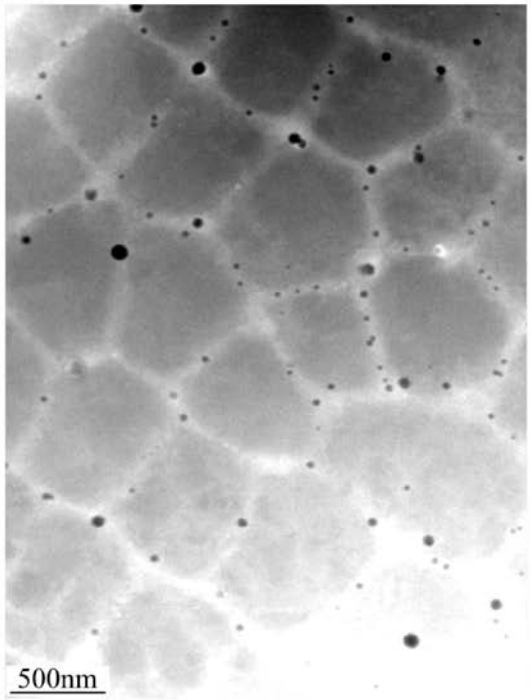
SLM SS 316L / Cellular Structure



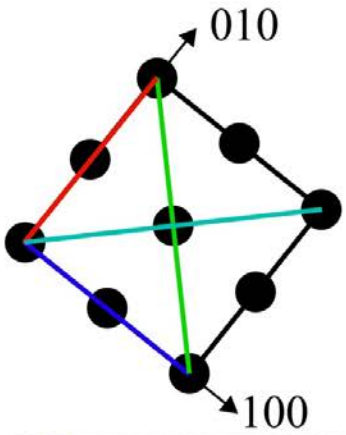
Solidification structure
Cell walls contain dislocations and segregated elements



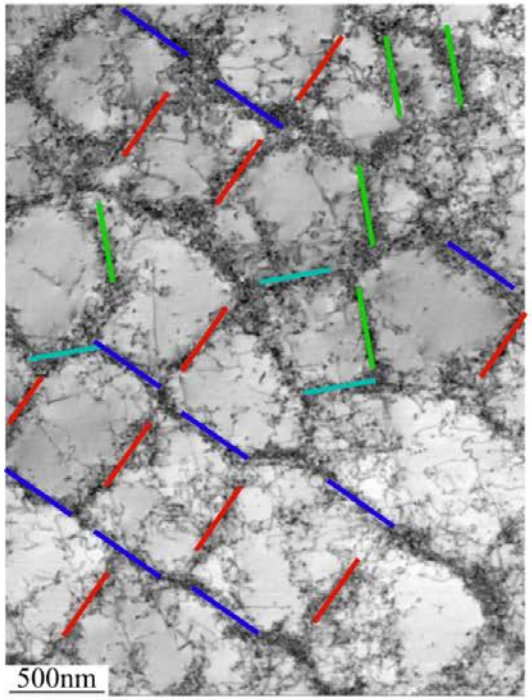


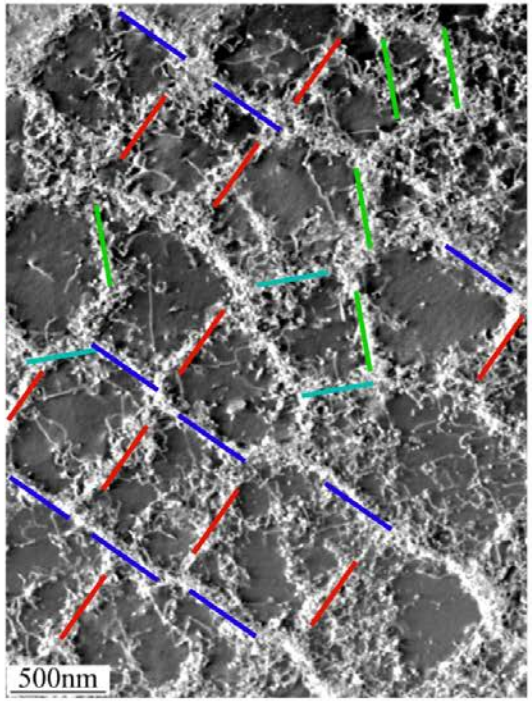


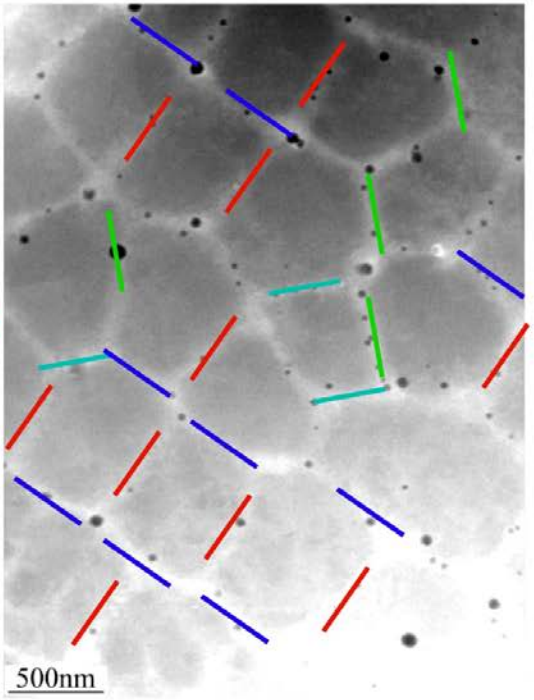
SLM SS 316L / Cellular Structure



Cell walls line up along specific crystallographic directions



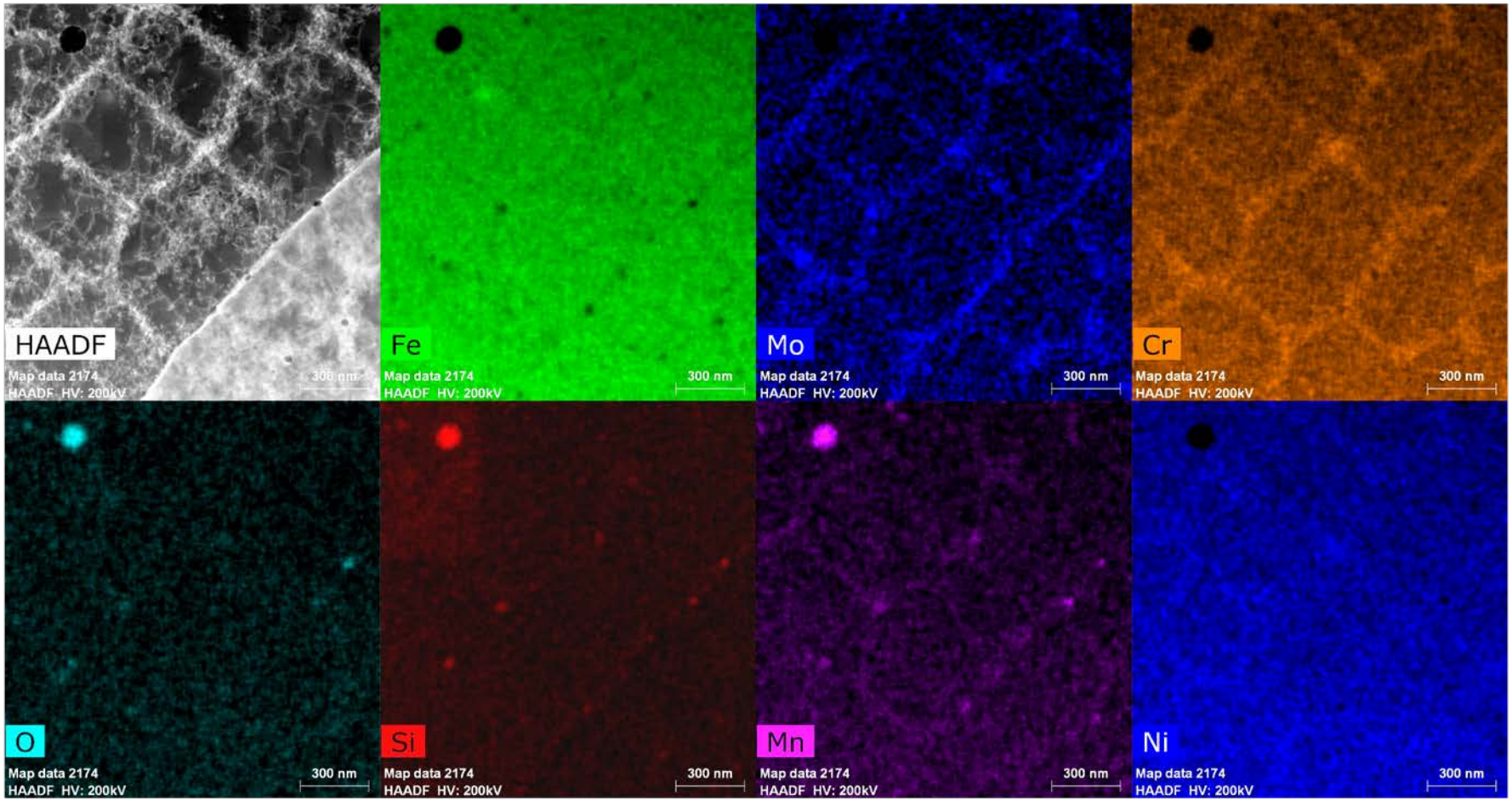




SLM SS 316L / Cellular Structure

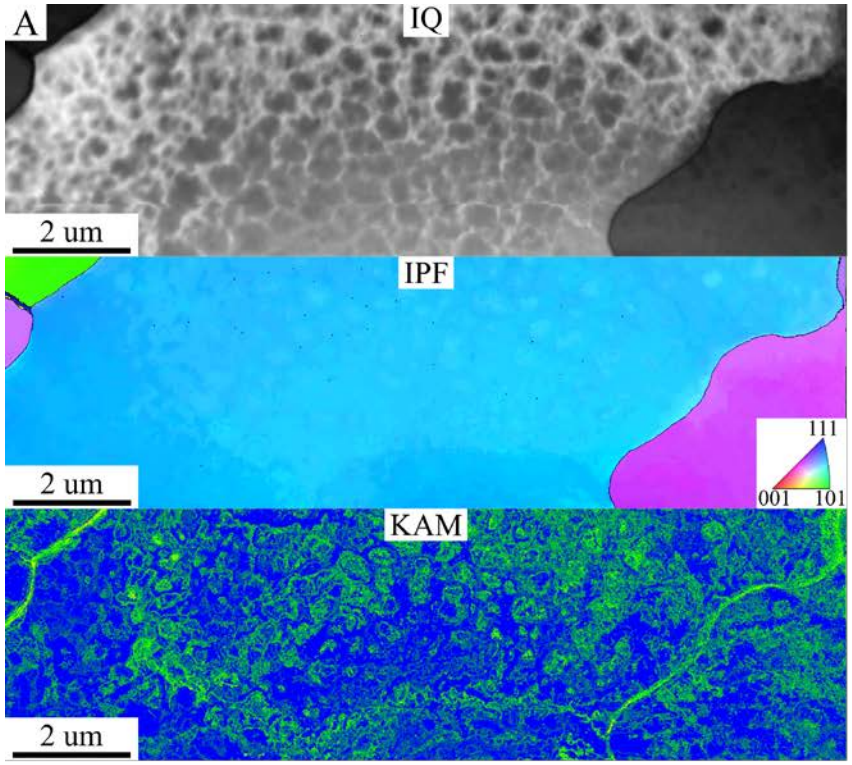
Mo and Cr segregation in cell walls

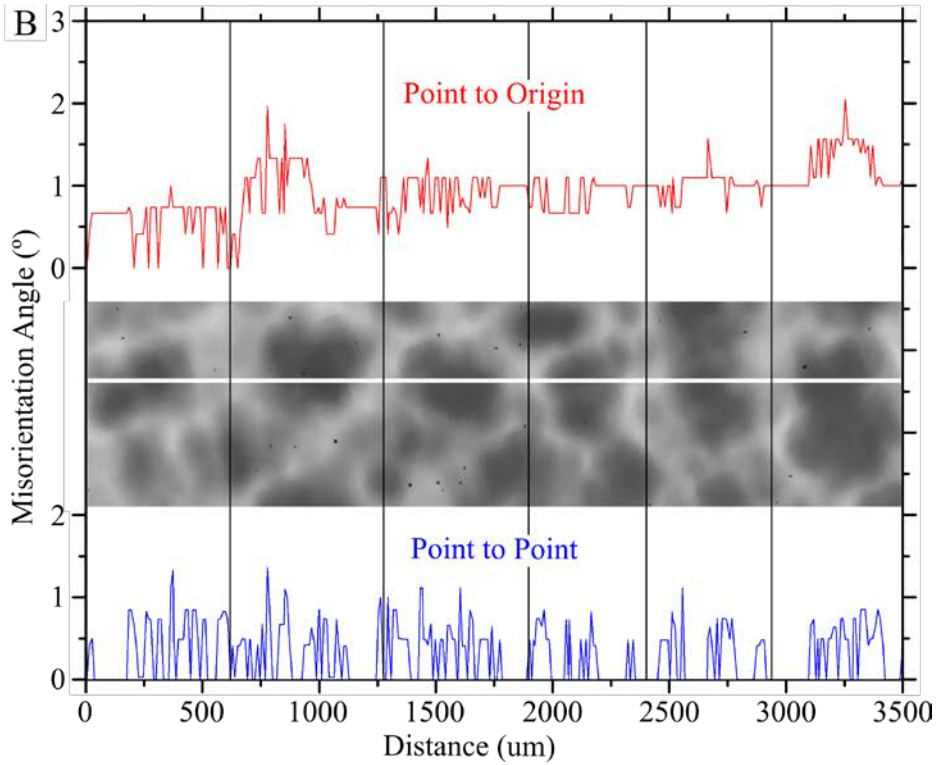
Presence of particles inside walls



SLM SS 316L / Cellular Structure

Orientation Mapping in a TEM (probe size 5nm)



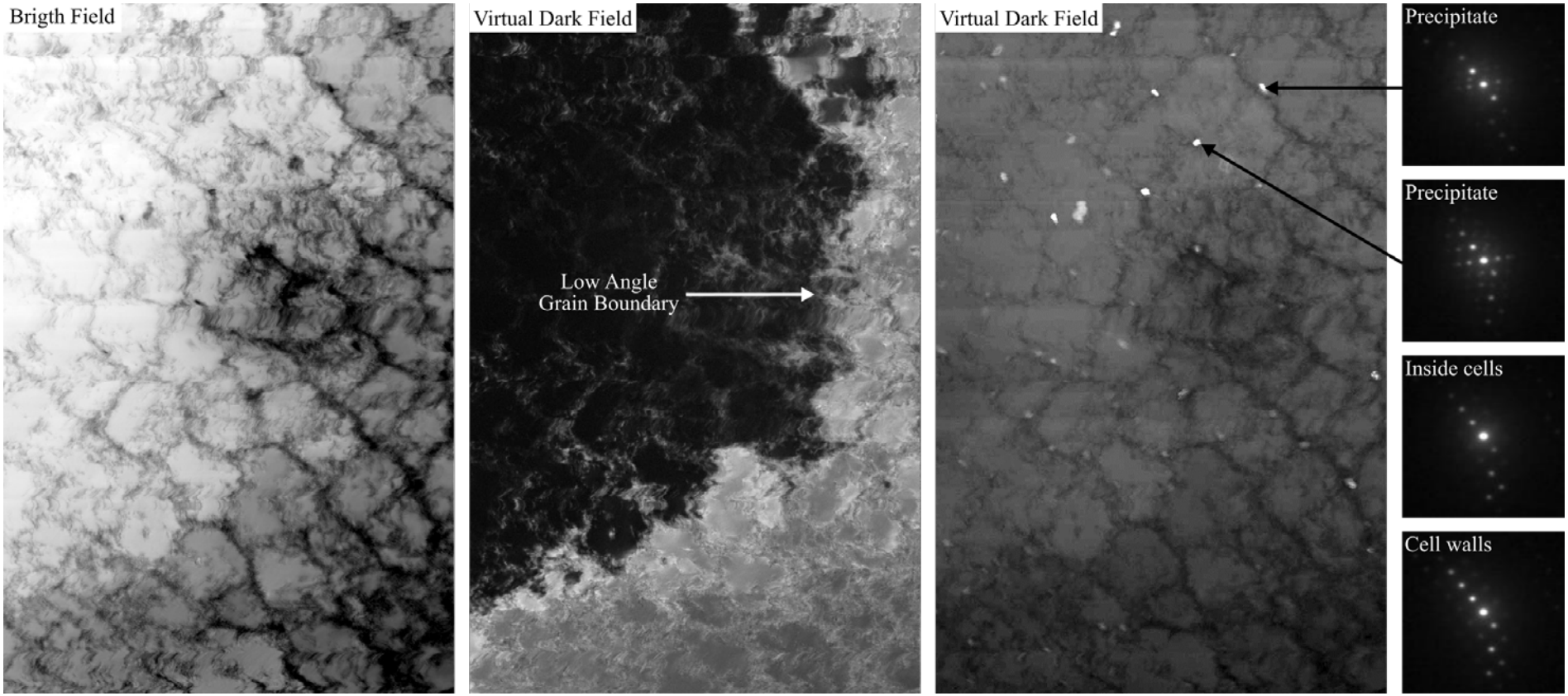


Very low misorientations related to the cell structure

- Different from conventional dislocation cells
- In agreement with solidification structure

SLM SS 316L / Second Phase

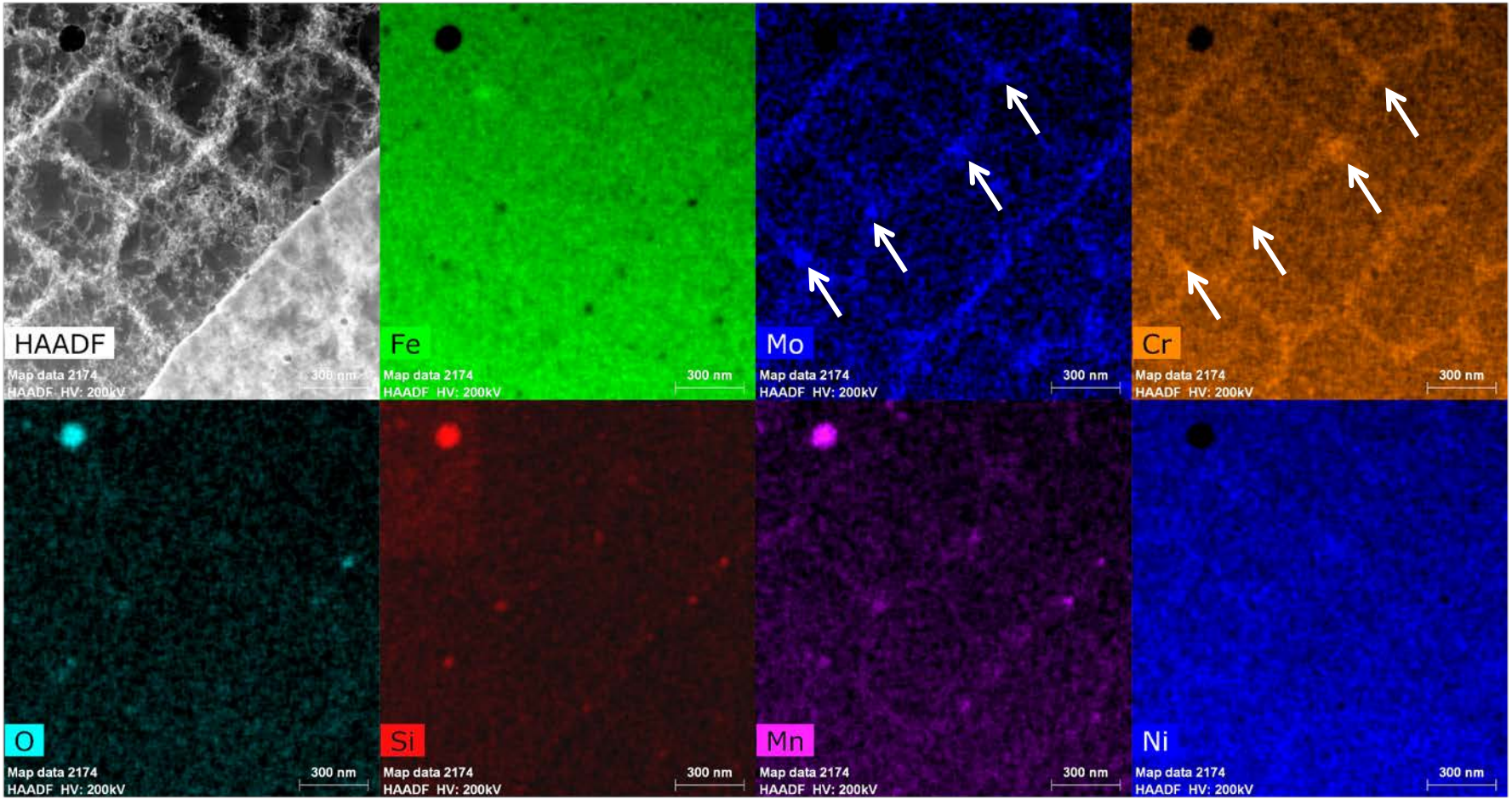
Orientation Mapping in a TEM (probe size 5nm)



Revealing second phase particles

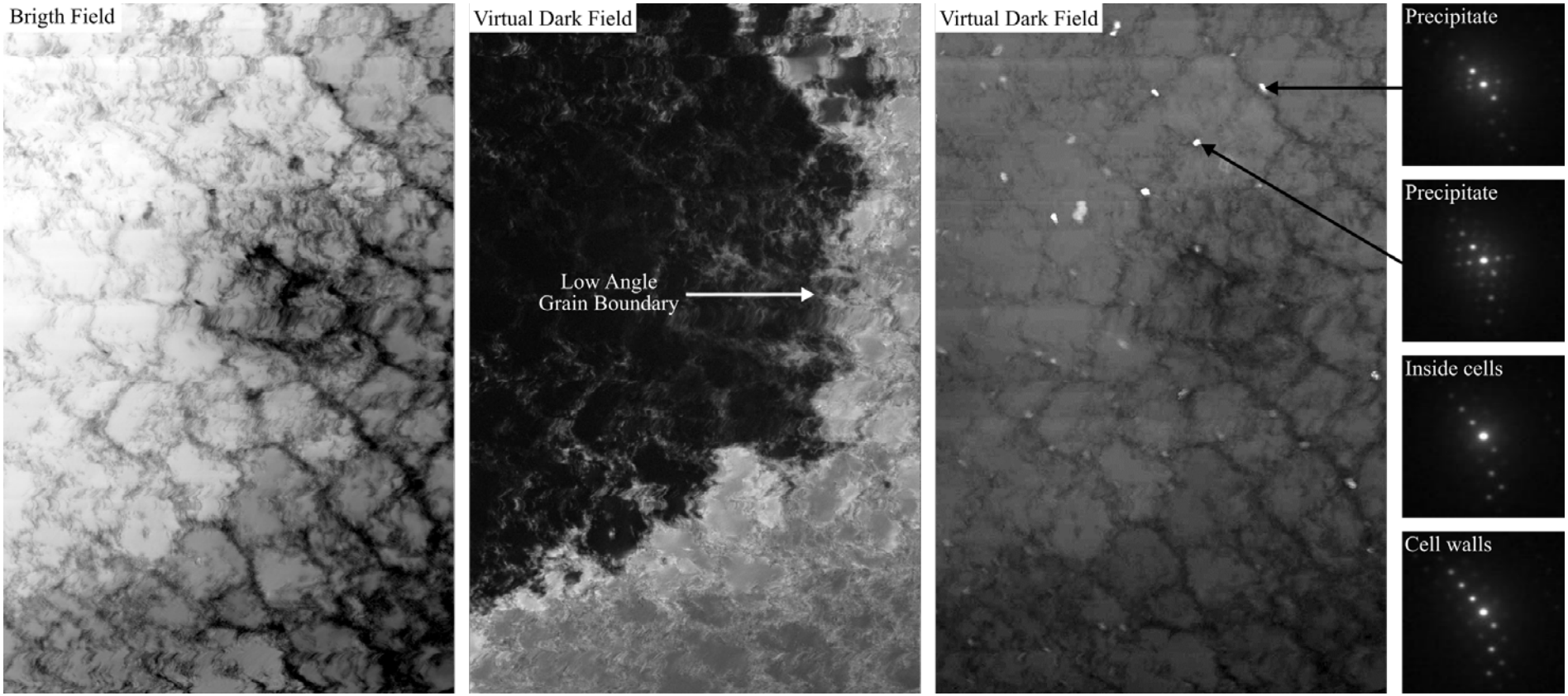
SLM SS 316L / Second Phase

Second phase particles may correspond to local Mo-Cr segregations



SLM SS 316L / Second Phase

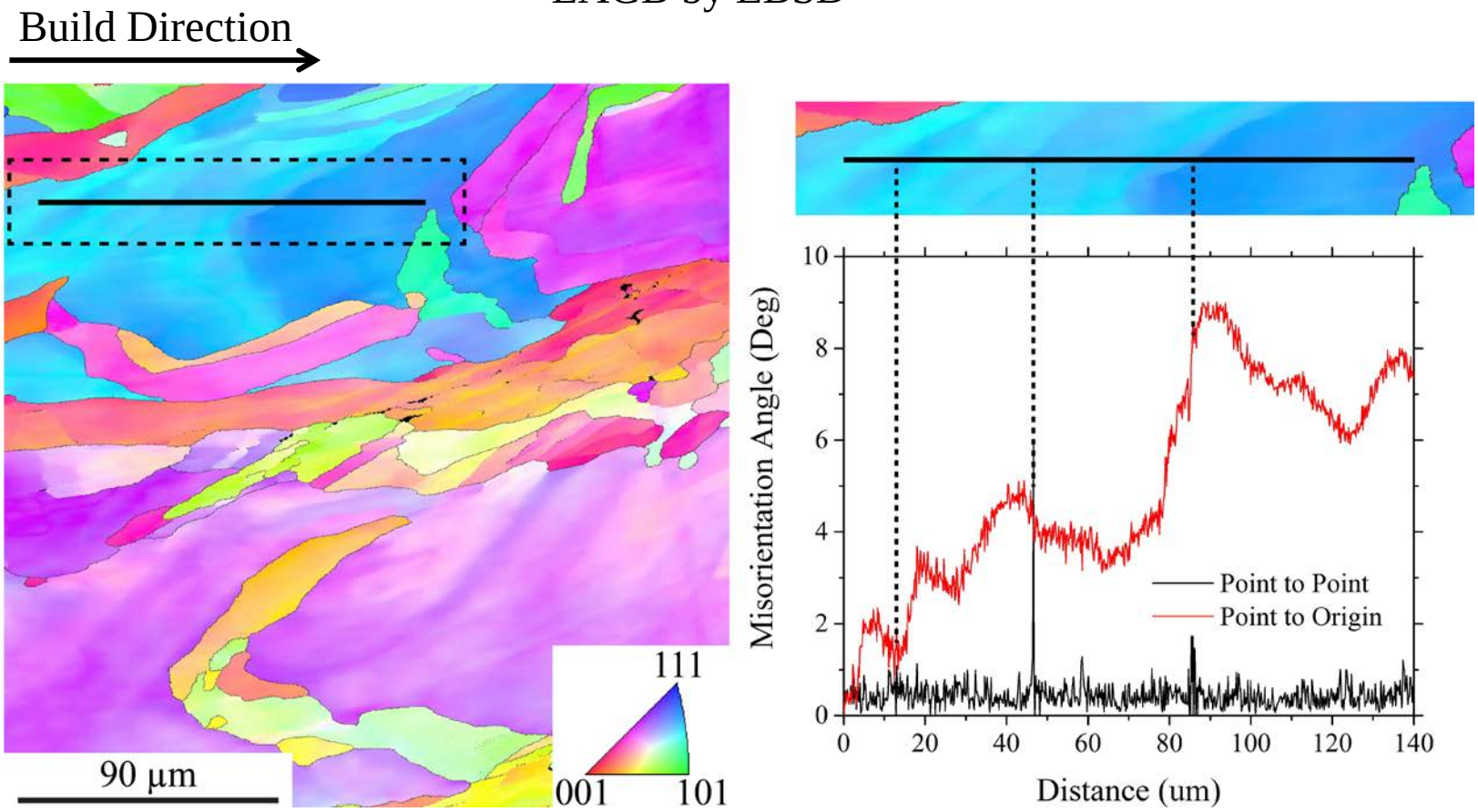
Orientation Mapping in a TEM (probe size 5nm)



Revealing second phase particles

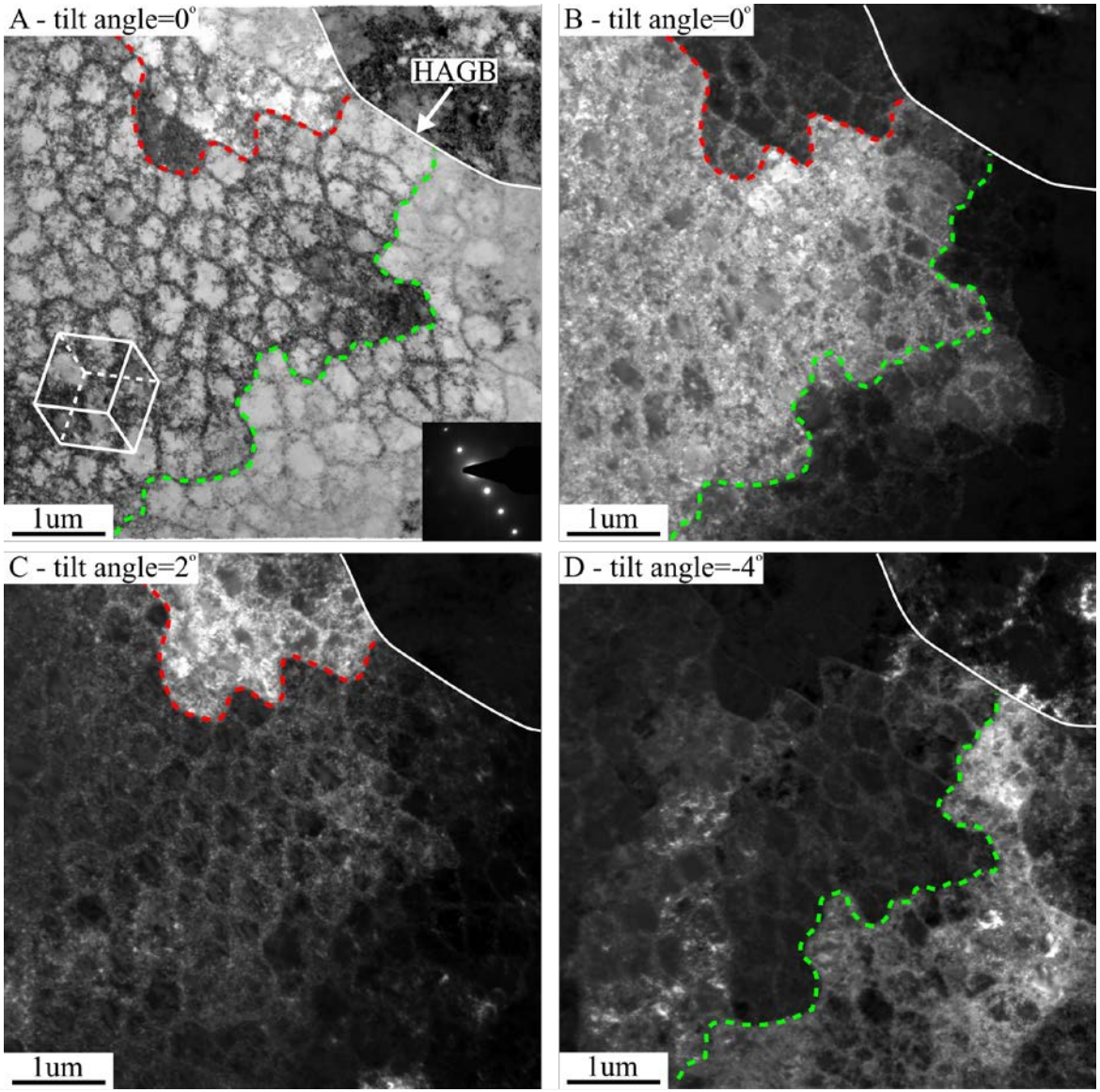
SLM SS 316L / Low Angle Grain Boundaries

LAGB by EBSD



High Angle Grain Boundaries (>10°) = 48%
Low Angle Grain Boundaries (1-10°) = 52%

SLM SS 316L / Low Angle Grain Boundaries



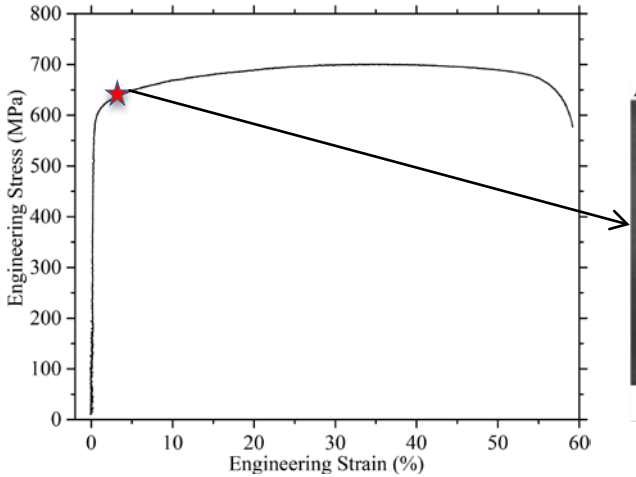
LAGB by TEM

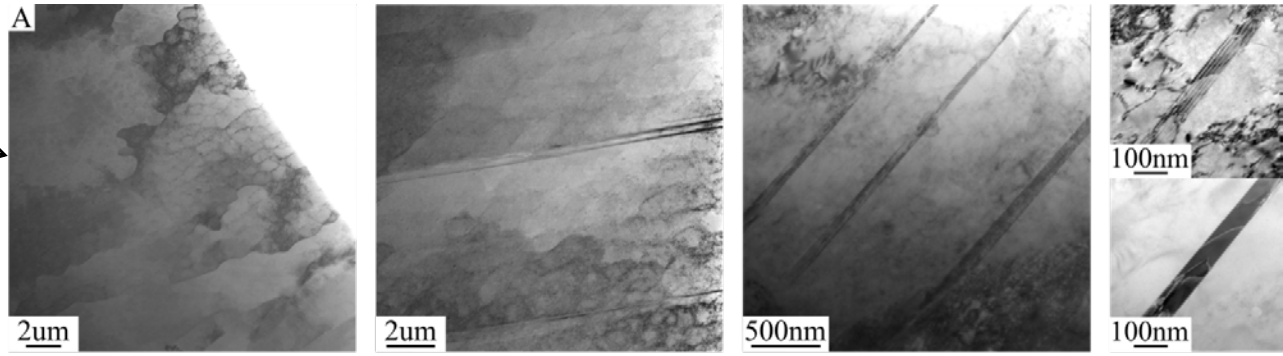
LAGB follow cell walls.

Important for the stability of the microstructure

SLM SS 316L / Deformation Mechanisms

TEM after a few % of strain

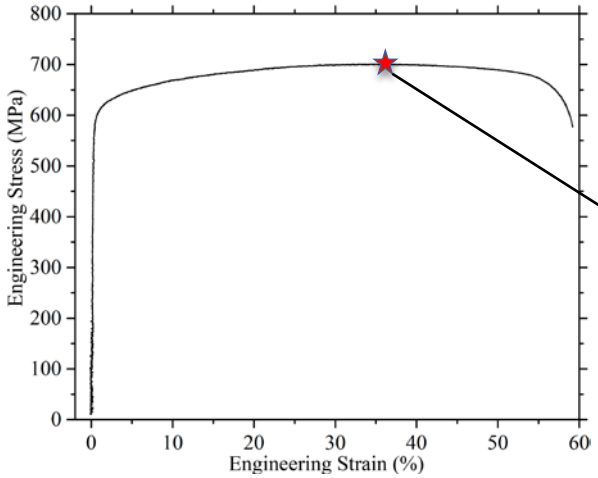


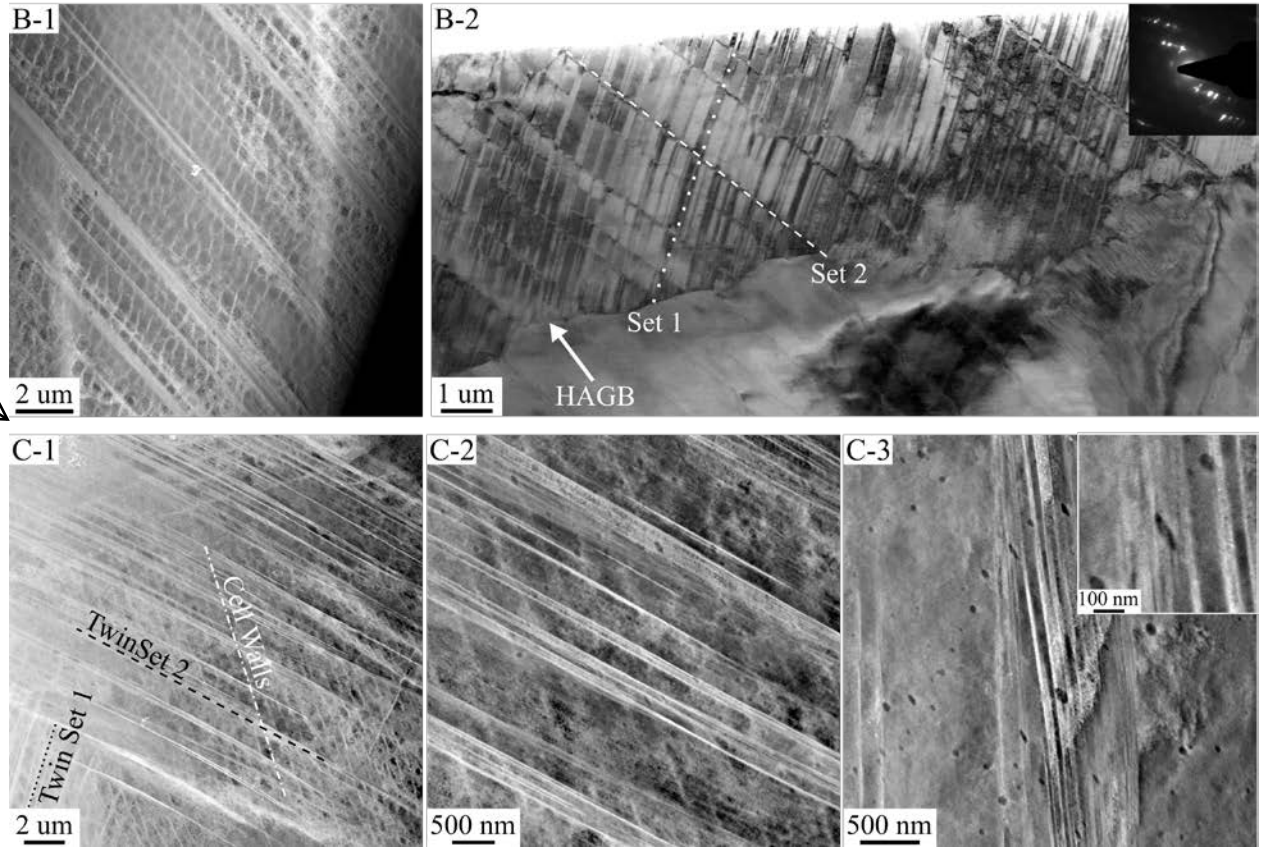


Onset of twinning around 3% of plastic strain

SLM SS 316L / Deformation Mechanisms

TEM in uniformly deformed region after fracture



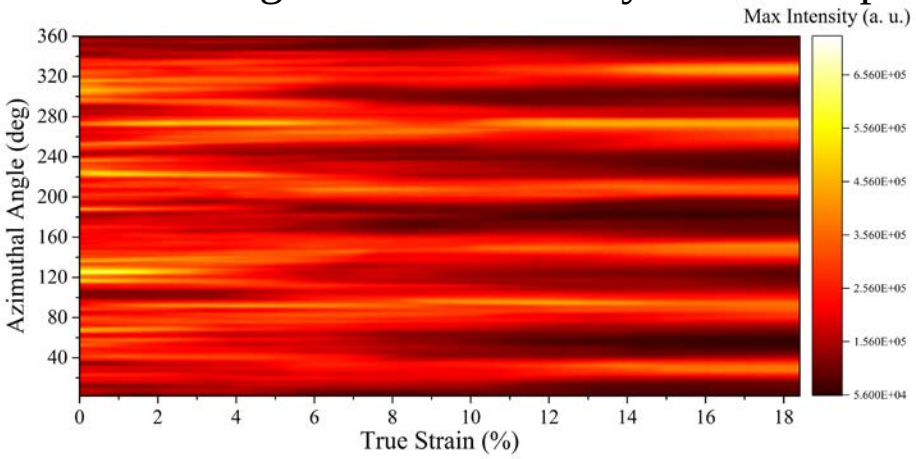


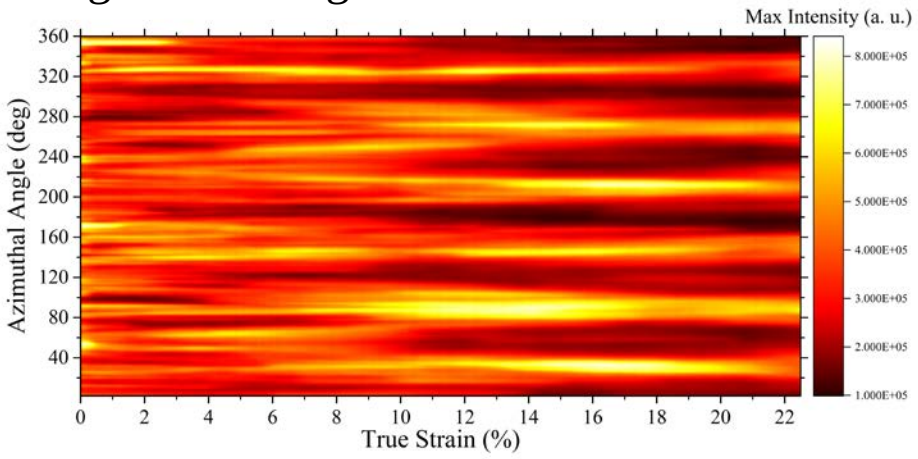
- Elongated dislocation cells still present
- Twinning everywhere with 2 twinning systems activated in many grains
- Silicate particles sheared by twins

SLM SS 316L / Deformation Mechanisms

Insight from synchrotron XRD

Changes in max intensity of the 111 peak along the full ring as a function of strain



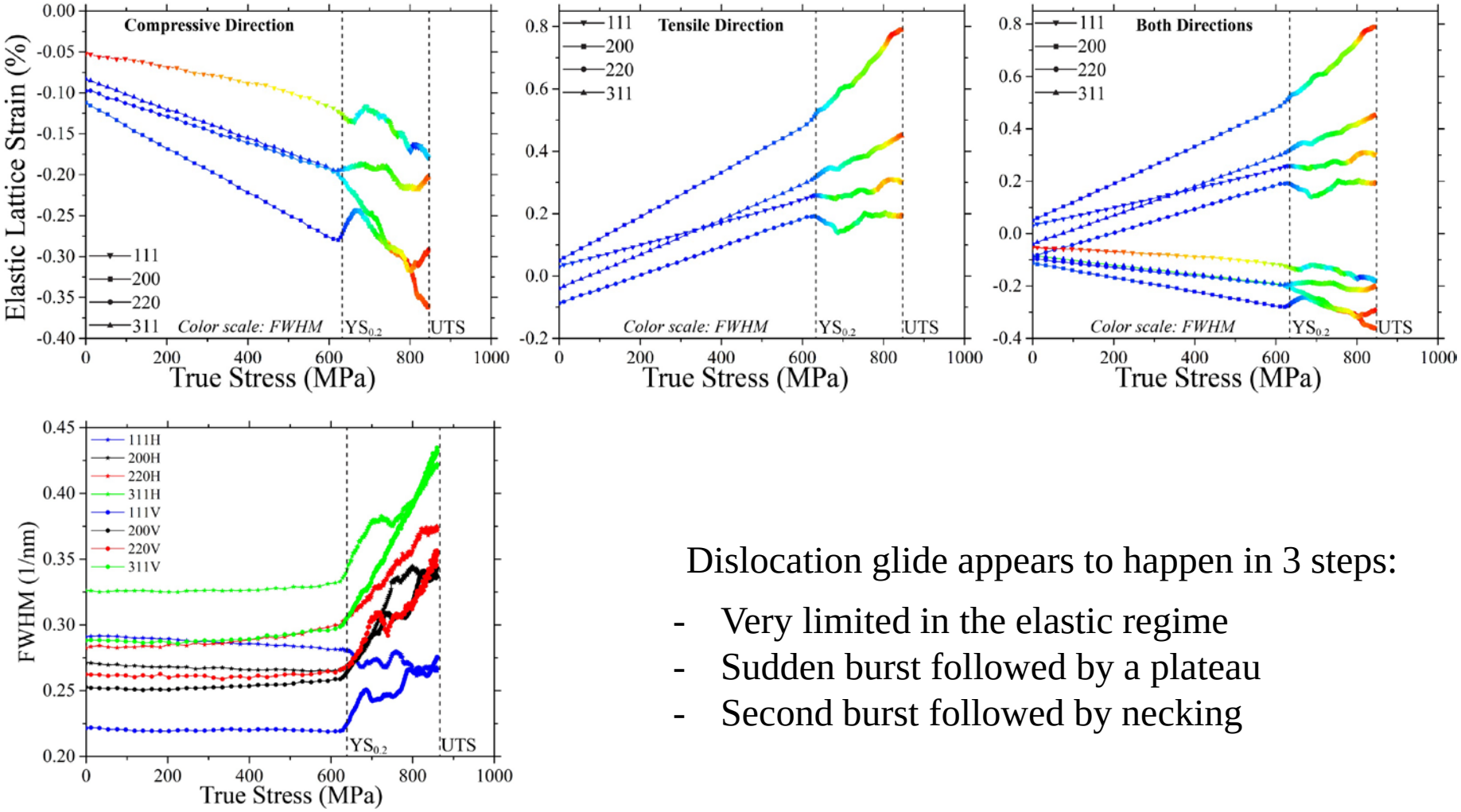


60° angle between peaks: signature of twinning

Twinning starts in the early stage of plastic deformation as observed by TEM

SLM SS 316L / Deformation Mechanisms

Insight from synchrotron XRD

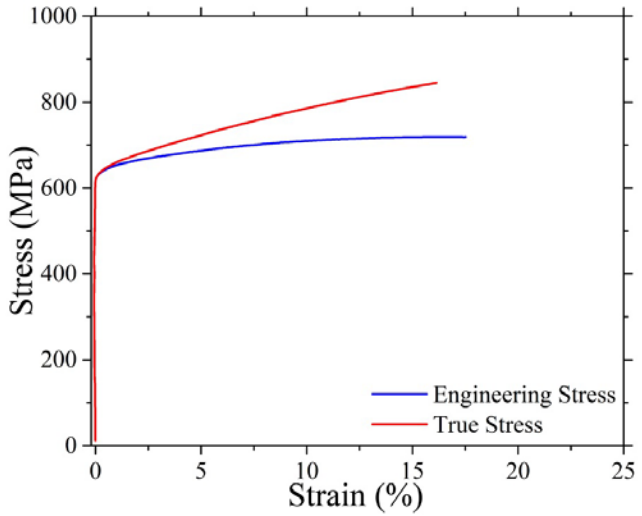


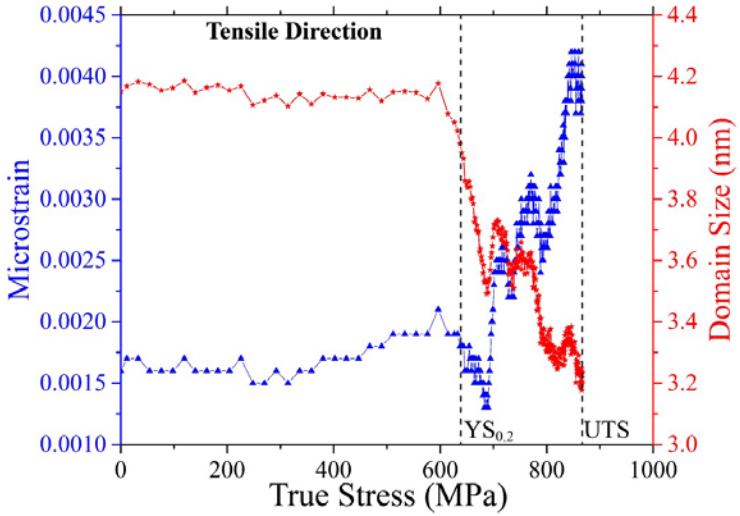
Dislocation glide appears to happen in 3 steps:

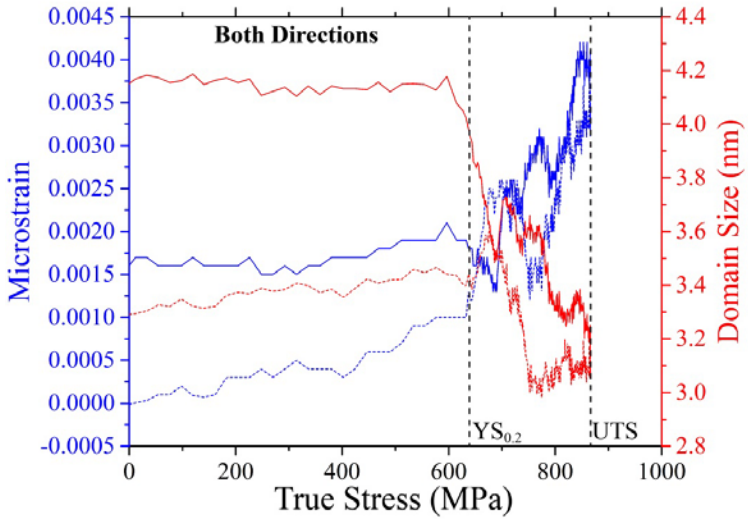
- Very limited in the elastic regime
- Sudden burst followed by a plateau
- Second burst followed by necking

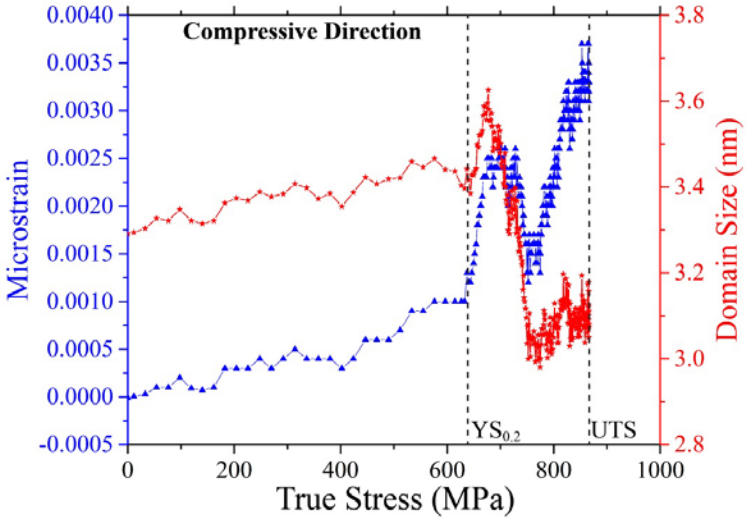
SLM SS 316L / Deformation Mechanisms

Insight from synchrotron XRD









SLM SS 316L / Conclusion

★ Out of equilibrium microstructure with multi-scale features influencing mechanical properties

- HAGB
- LAGB
- Cellular structure
- Particles
- Initial dislocations density

★ Cellular structure still present after fracture: thanks to chemical segregation?

★ Twinning: an important mechanism that may not be influenced by cellular structure or LAGB

In situ TEM tensile testing to determine the interaction between defects (dislocations and twins) and cellular structure

Thank you! Any questions?

Acknowledgments: S. Burke, P. Alexander, M. Pearson, P. Eschbach, C. Evans, S. Torres, E. Sedillo, W. King, and C. Kamash for their experimental assistance and discussion.

Lawrence Livermore National Laboratory

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