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An Industry/University Cooperative Research Center

Coupling of Microscopy and Thermomechanical Models to Explain the Extent and Location of TRIP Product in Simulated PBF-LB of Ti-1023

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[b] Advanced Photon Source, Argonne National Laboratory, Lemont, IL, 60439, USA
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Background

22

Ti

Titanium

47.867

High specific strength

Elevated temperatures

Difficult to machine

$$$

Additive manufacturing of aerospace/defense parts

Ti-6Al-4V (α+β alloy) dominates AM

Extensively researched with robust microstructure-processing relationships and legacy data

Thermal cycling presents some processing difficulties (ie. residual stress cracking)

S. Liu and Y. C. Shin, "Additive manufacturing of Ti6Al4V alloy: A review," *Materials & Design*, vol. 164, p. 107552, Feb. 2019, doi: 10.1016/j.matdes.2018.107552.

Background

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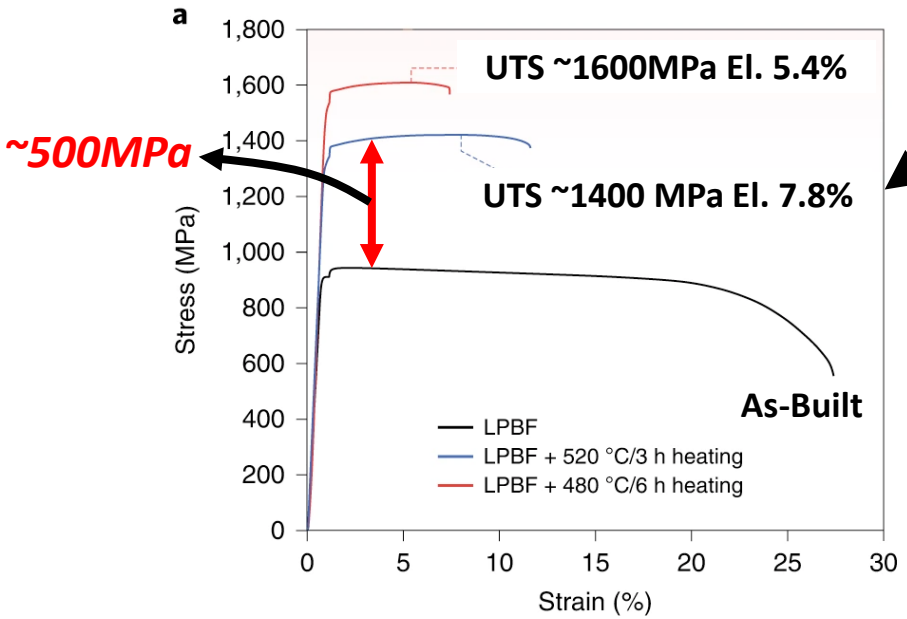
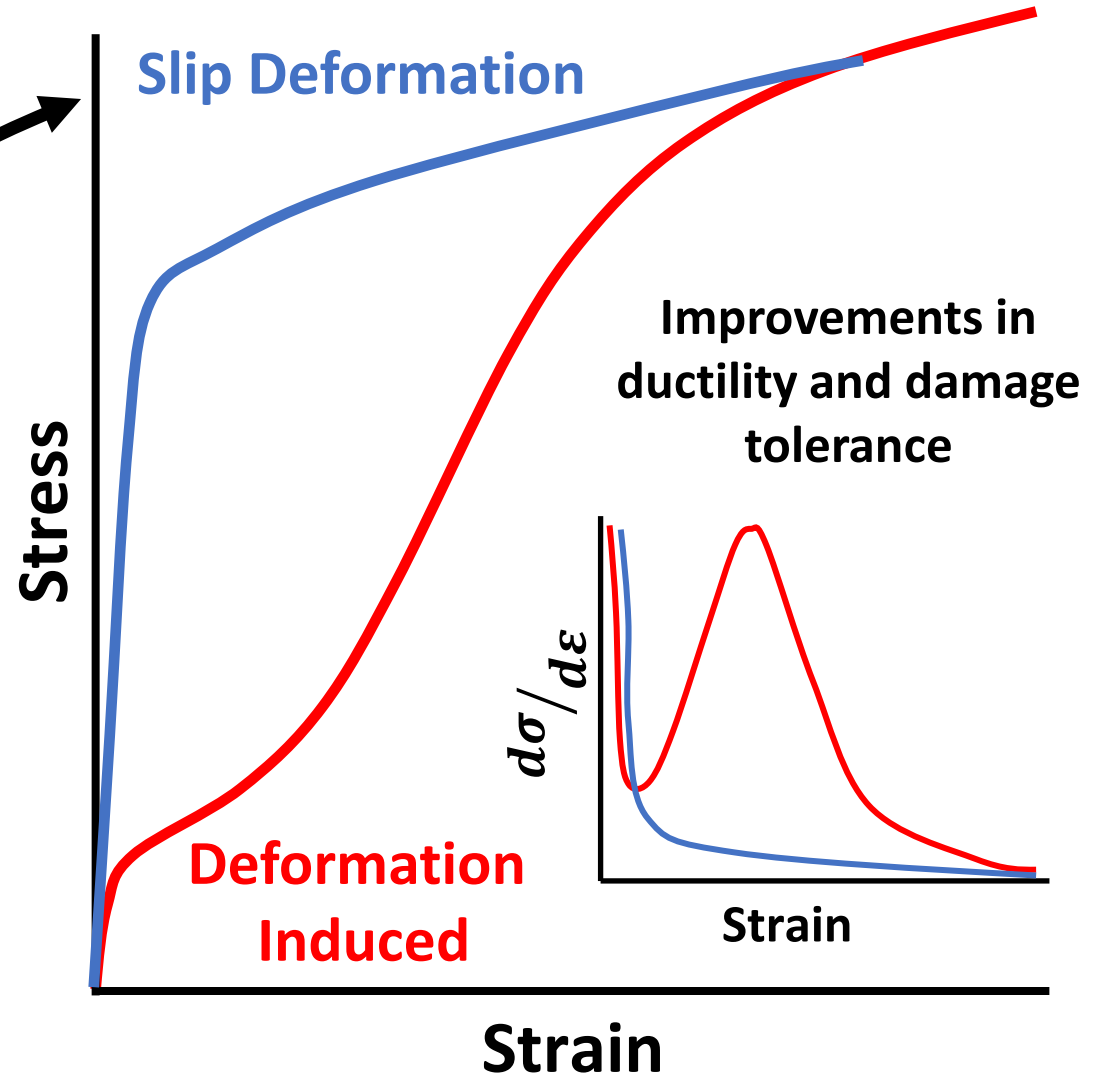
Background

Metastable β-Ti

Class of titanium which retains high temperature β-phase after rapid cooling

- Starting 'metastable' β microstructure facilitates enhanced properties
  - *Deformation induced transformations*
  - *High volume of precipitates*





Y. Zhu *et al.*, "Ultrastrong nanotwinned titanium alloys through additive manufacturing", *Nat. Mater.*, vol. 21, no. 11, Art. no. 11, Nov. 2022, doi: 10.1038/s41563-022-01359-2.

Experiments and Sample Fabrication

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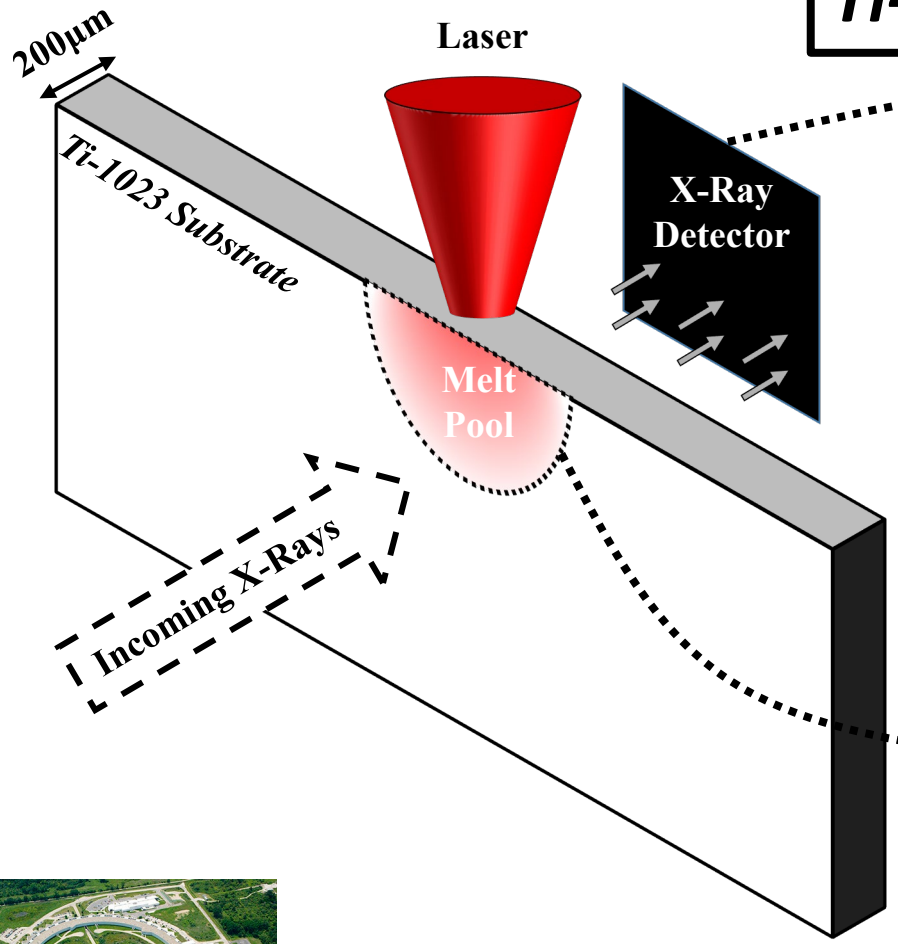
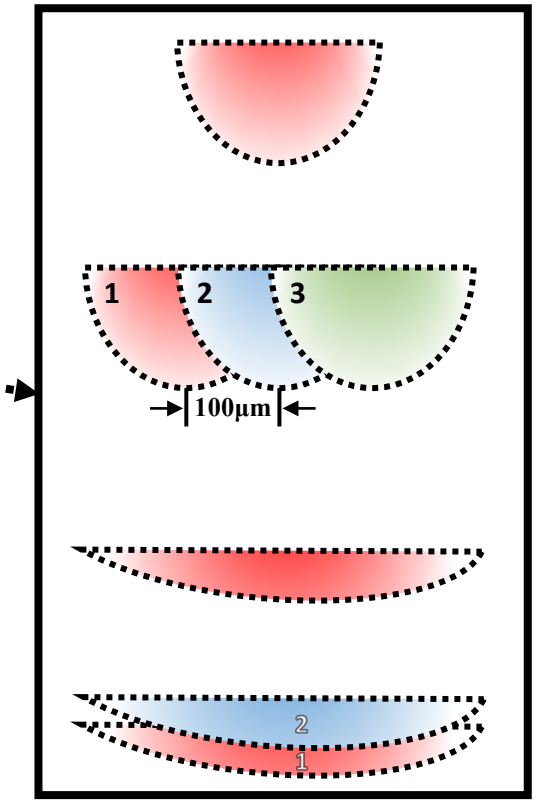
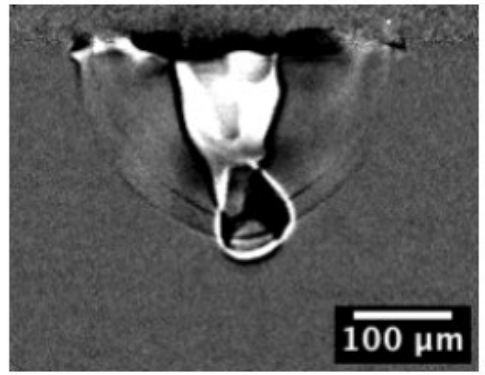
Investigated Alloy
Ti-10V-2Fe-3Al (wt.%)



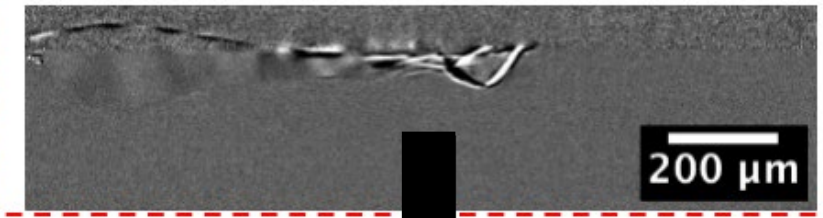


Used to calibrate models

Spot-Melt



Raster

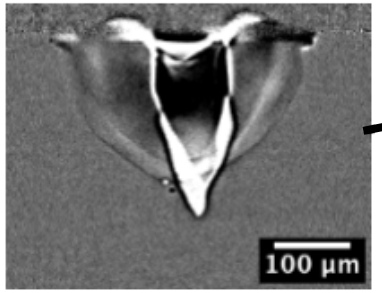


Able to understand alloy response at melt-pool scale

Advanced Photon Source
Argonne National Lab

https://www.aps.anl.gov/About/Welcome

Single Spot-Melts



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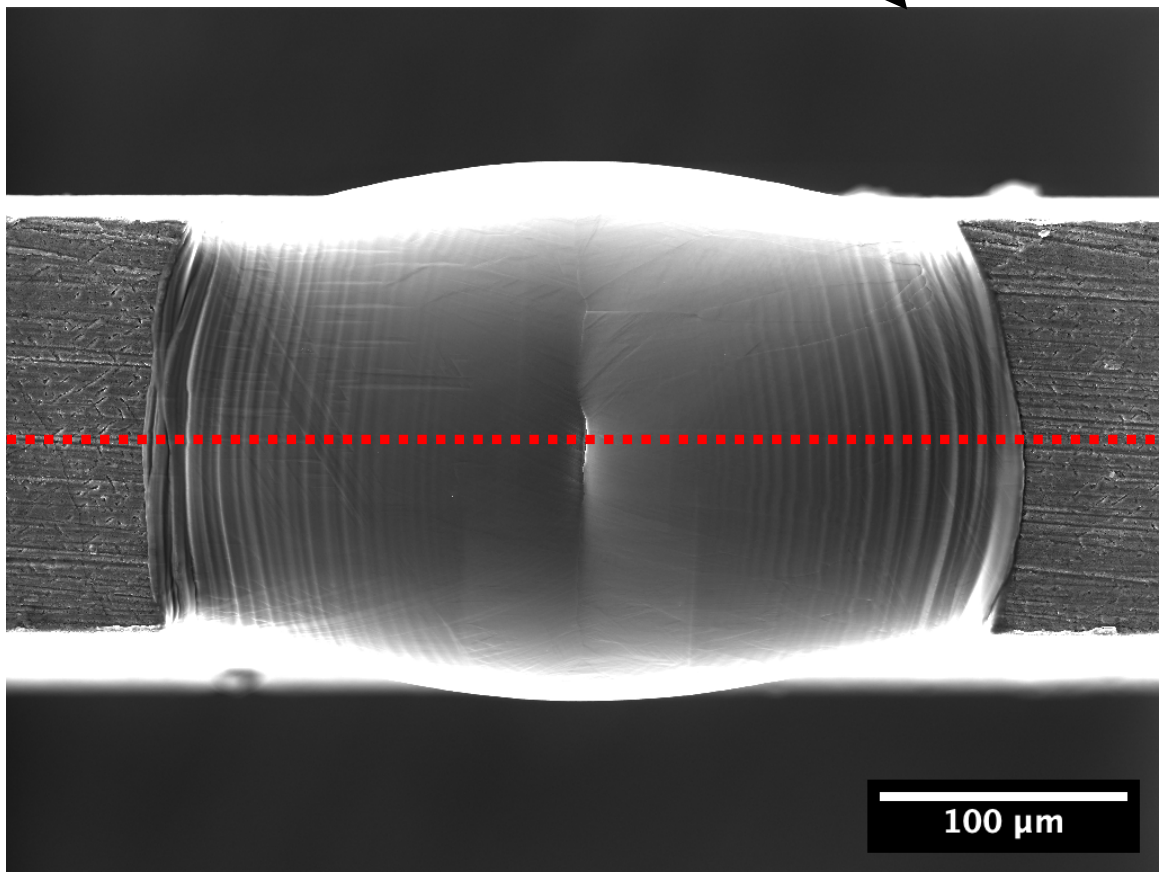
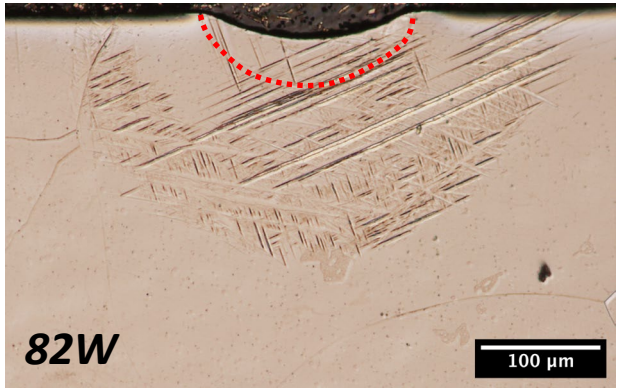
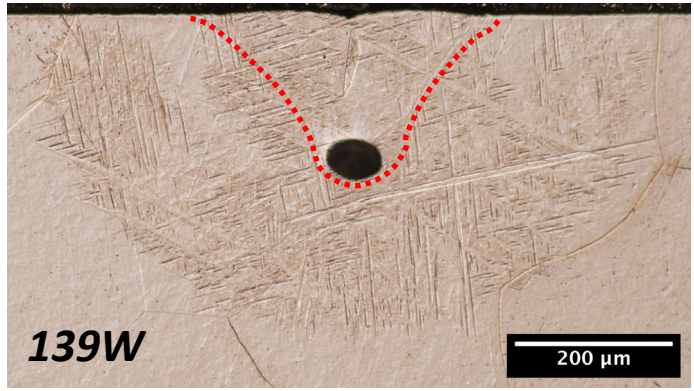
T.W. Duerig, et al., Formation and reversion of stress induced martensite in Ti-10V-2Fe-3Al, Acta Metallurgica 30 (1982) 2161–2172. https://doi.org/10.1016/0001-6160(82)90137-7.

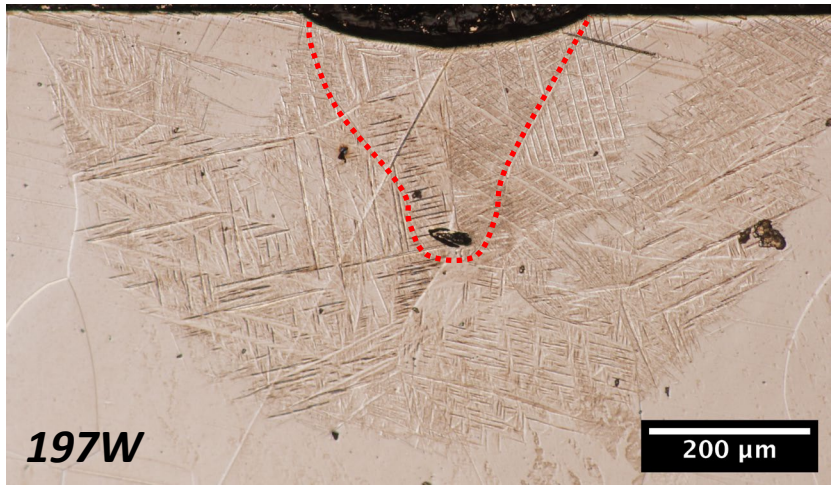
Top-Down



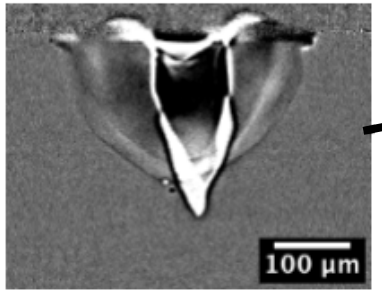
Cross-Section



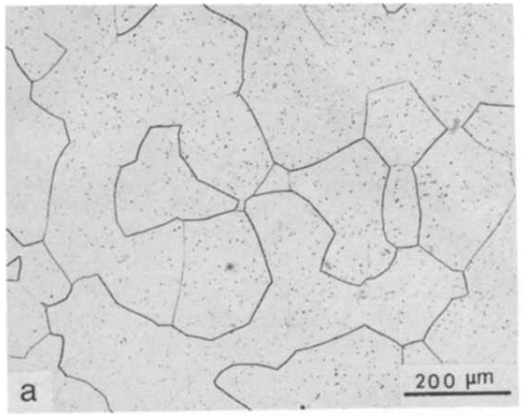




Single Spot-Melts



We know quenched Ti-1023 is single-phase…



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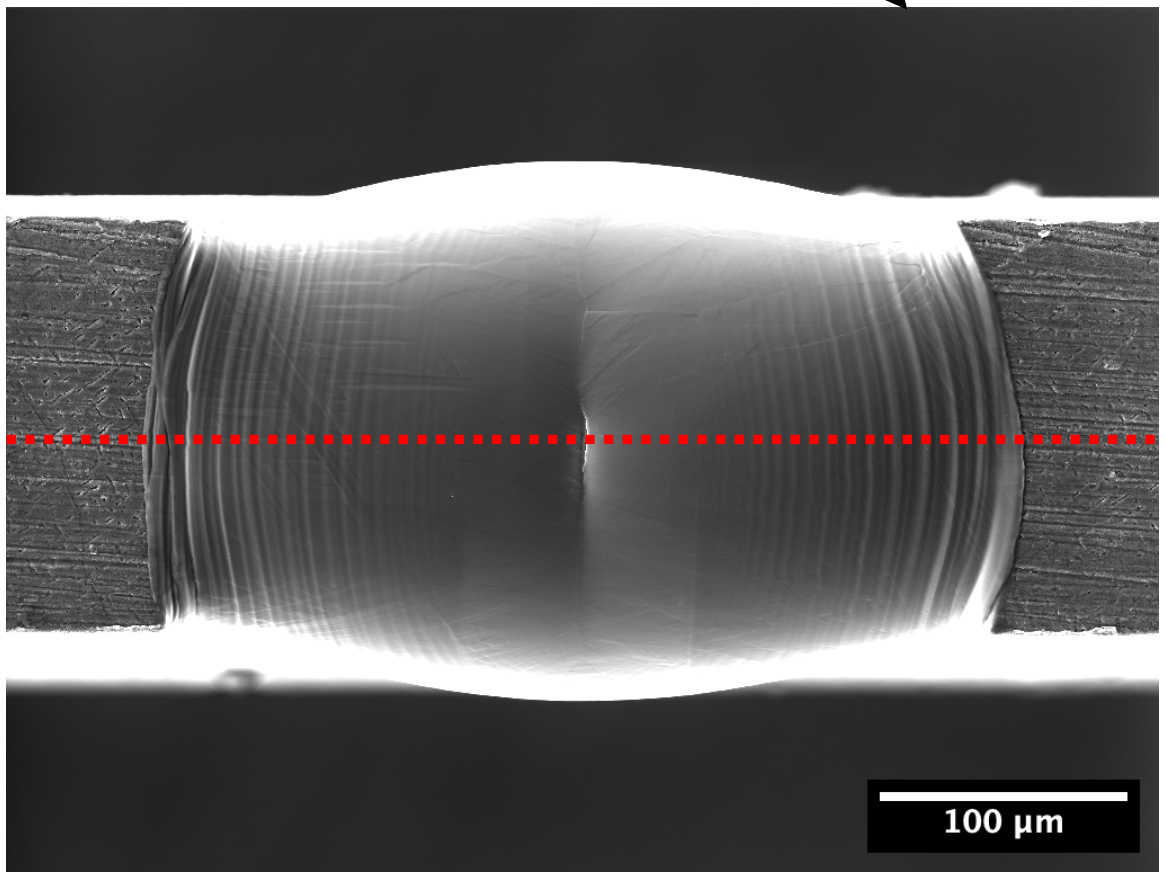
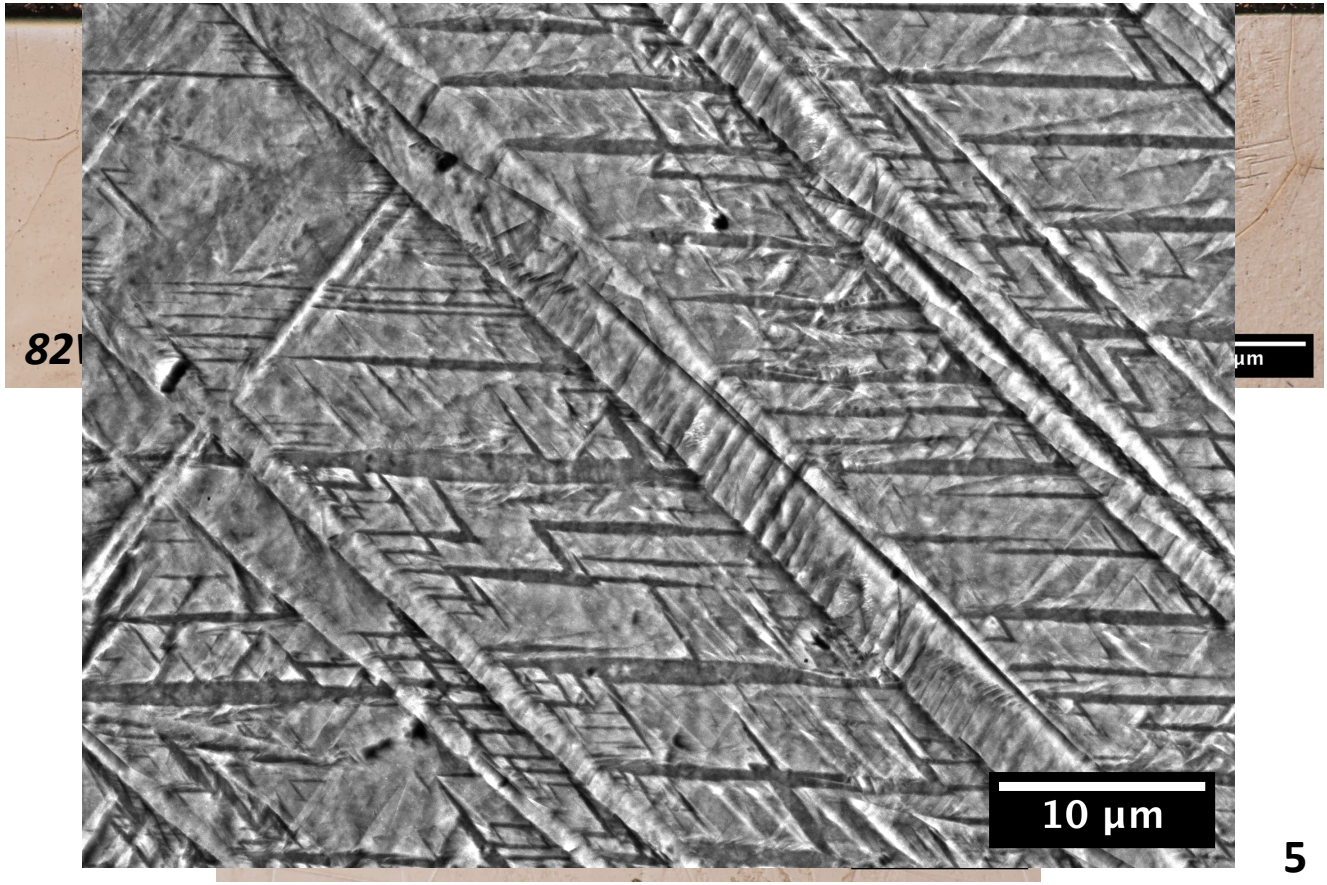


Cross-Section



Transformation Induced Plasticity

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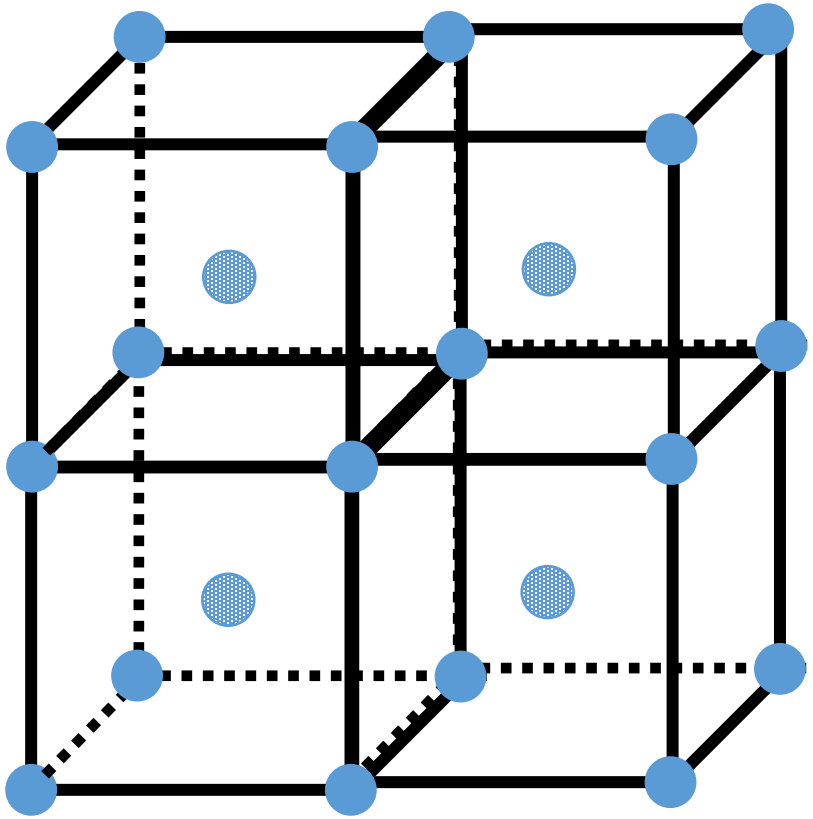
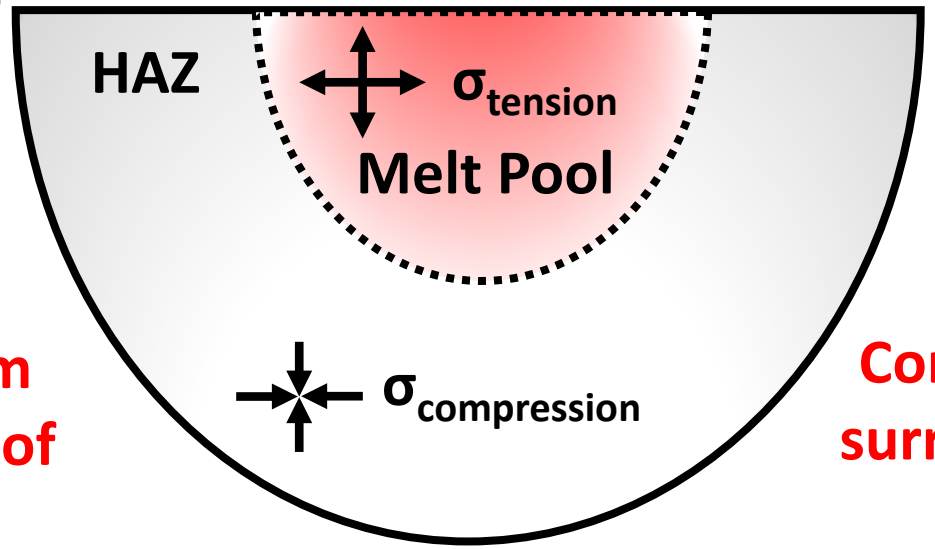
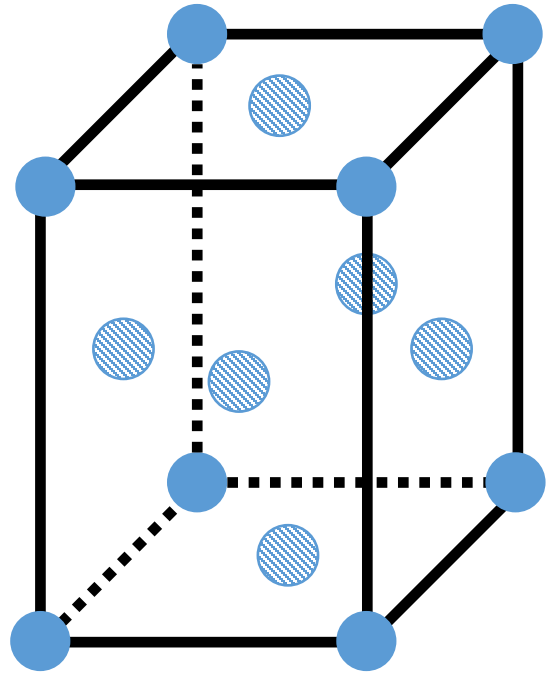


BCC β-phase

Deformation



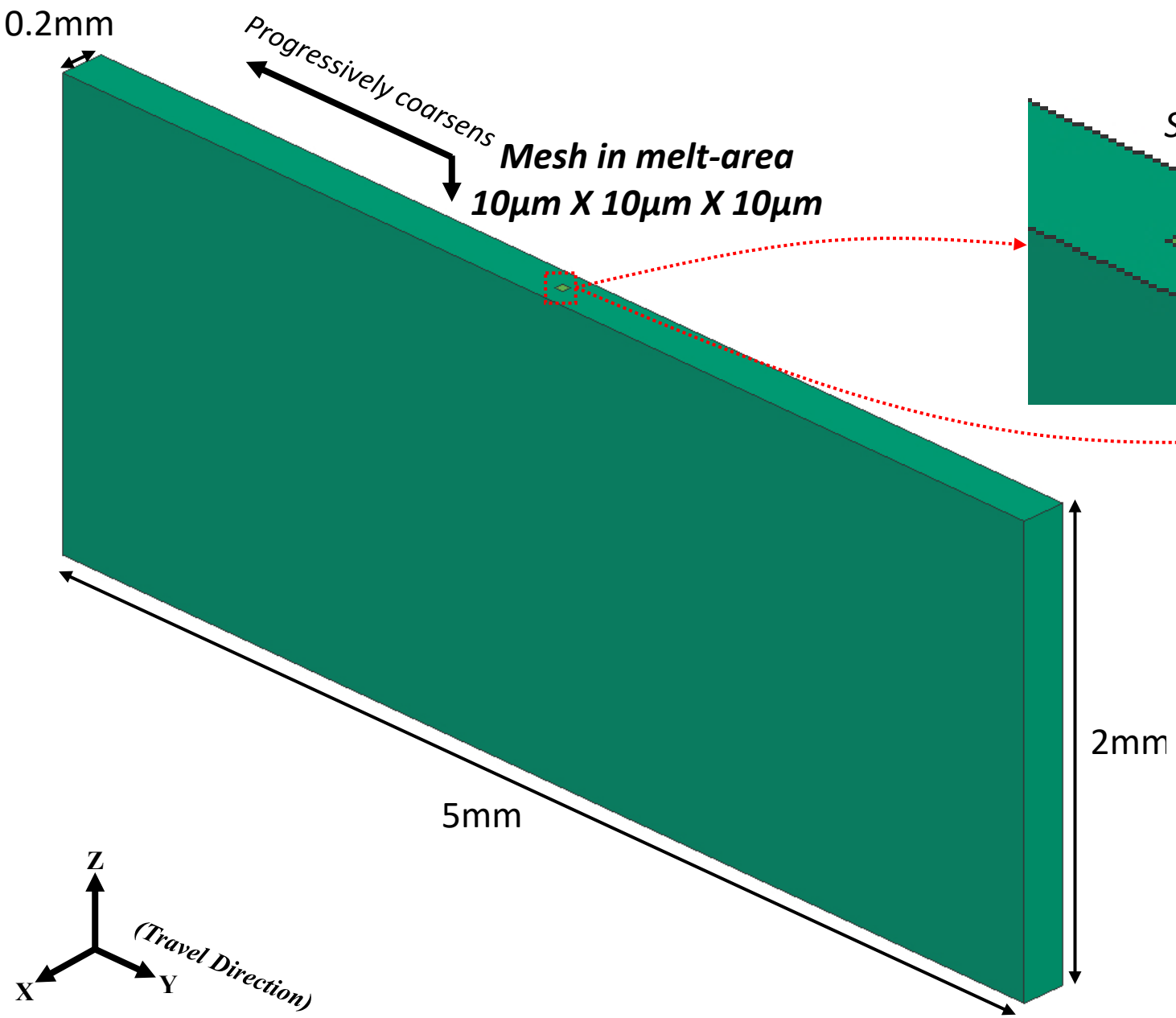


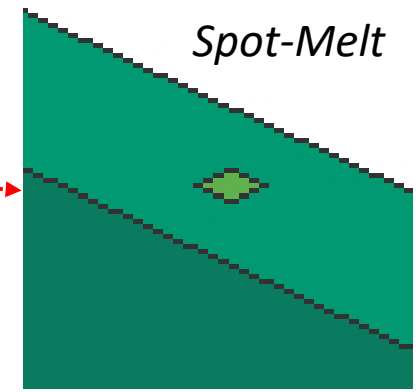
Orthorhombic α''-phase

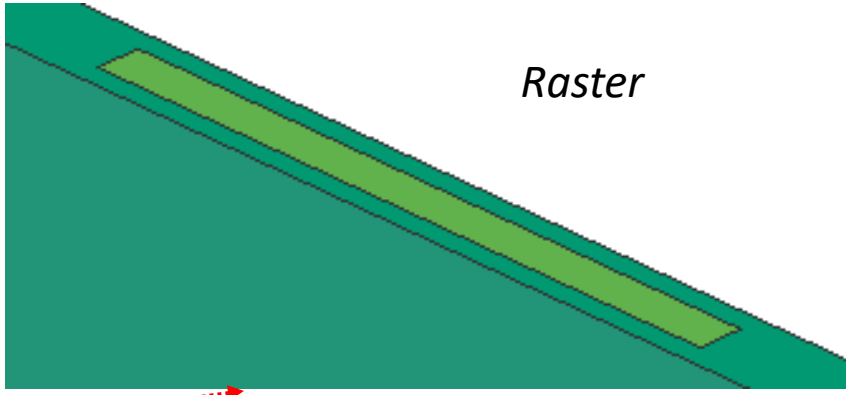
Tensile stresses from thermal contraction of melt-pool

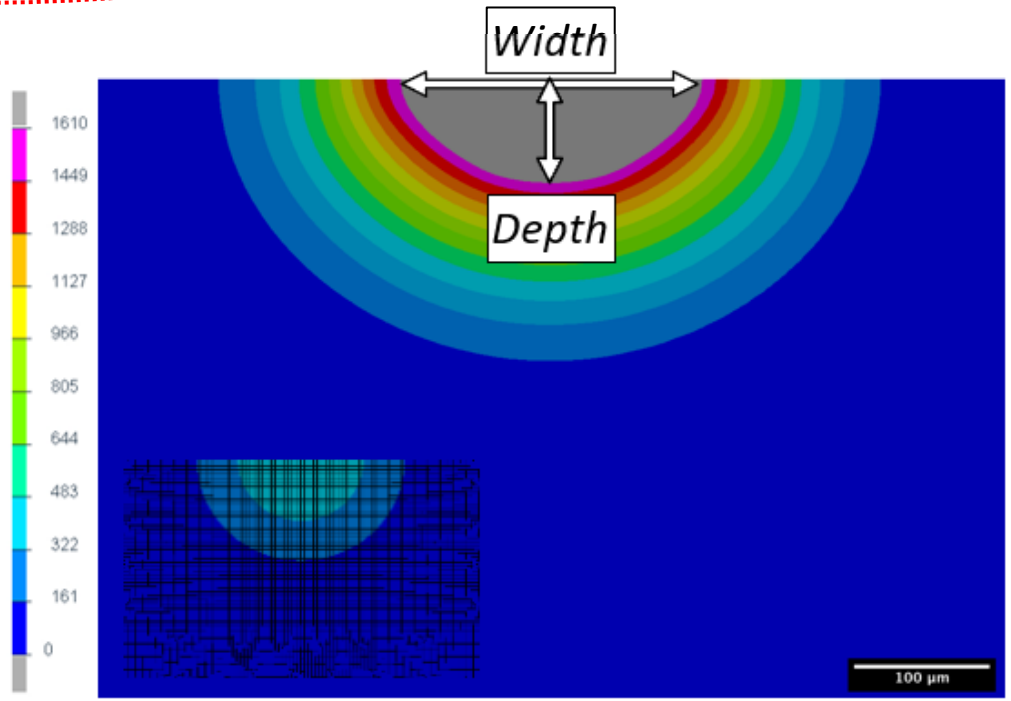
Compressive stresses from surrounding material inhibit this contraction

Thermomechanical Model - SYSWELD









Single Spot-Melts

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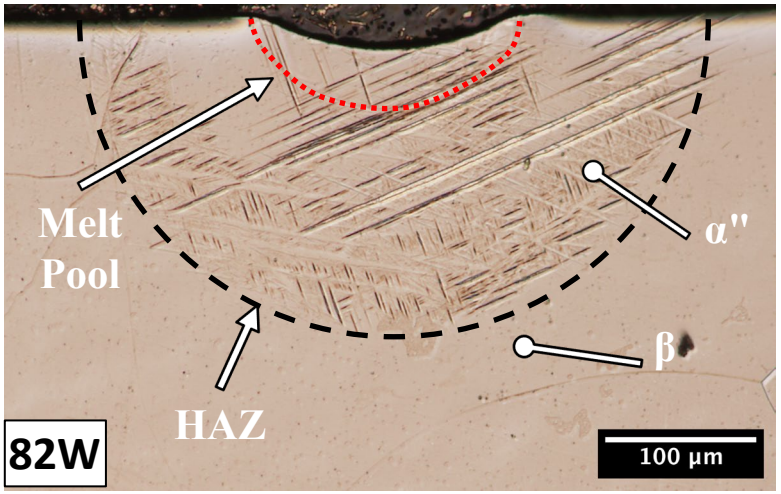
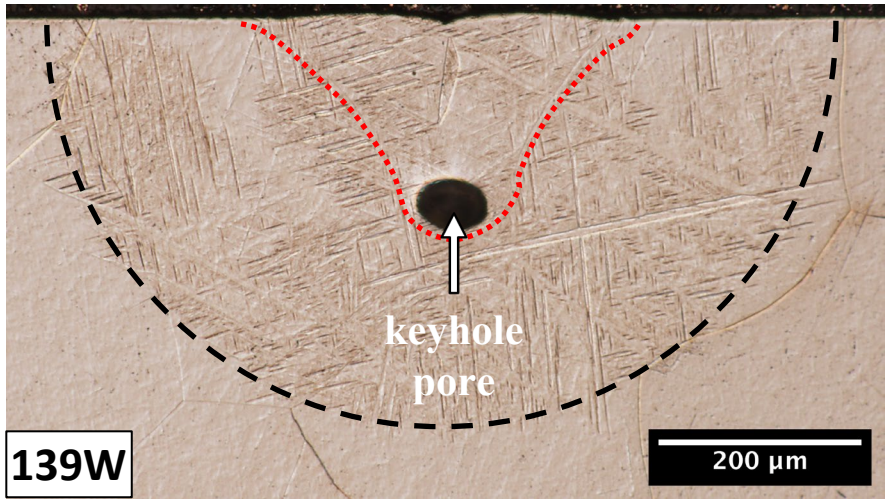
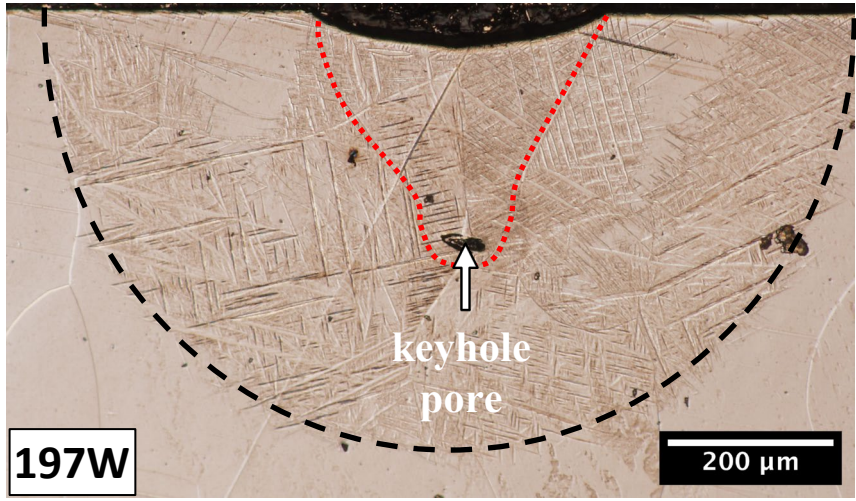
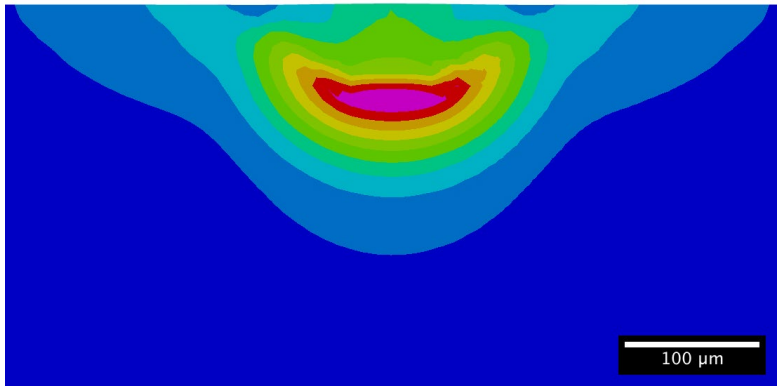
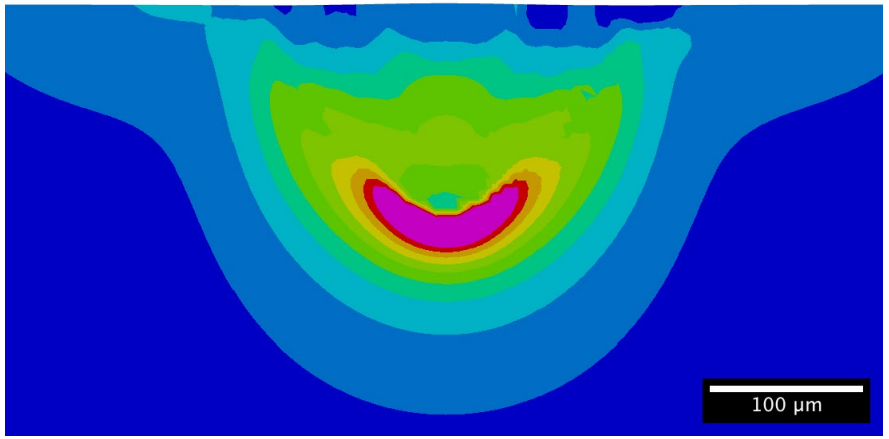


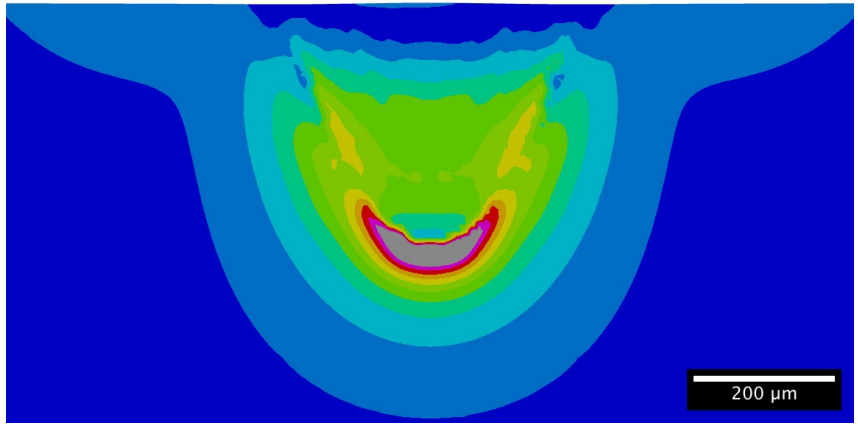


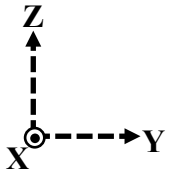


Thermomechanical Simulations (SYSWELD)

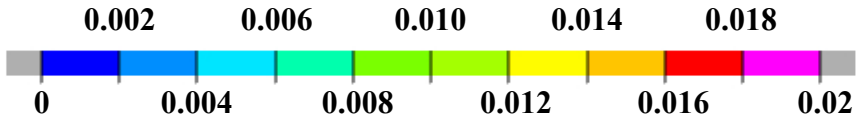




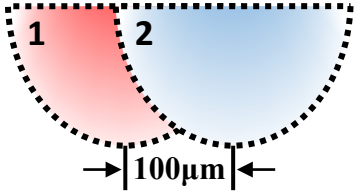




Von Mises Strain



Overlapping Spot-Melts



Cooled to RT before next spot-melt

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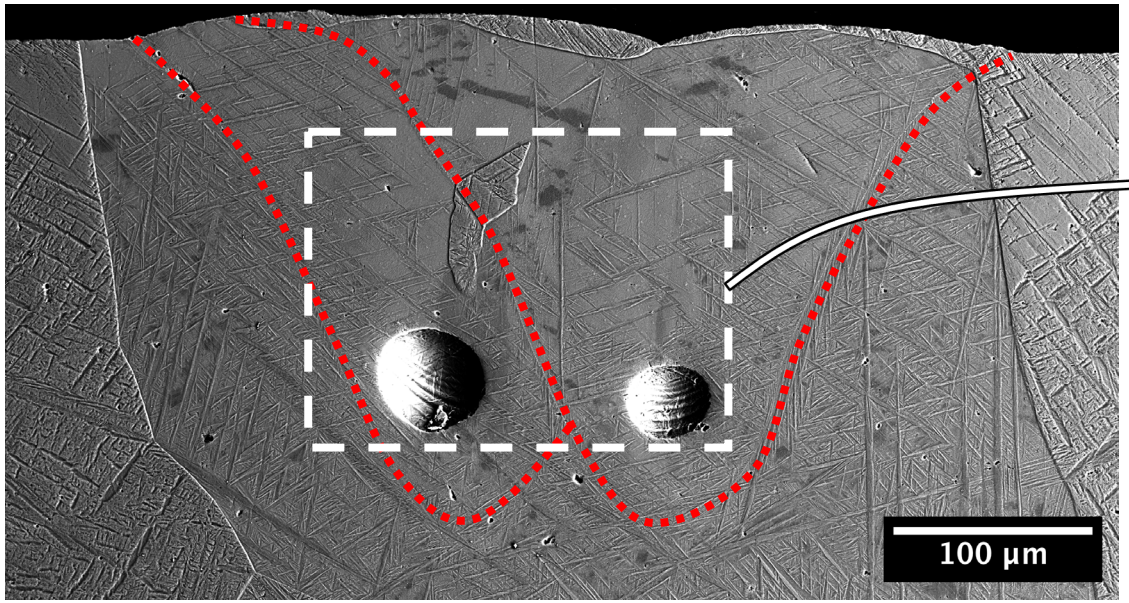
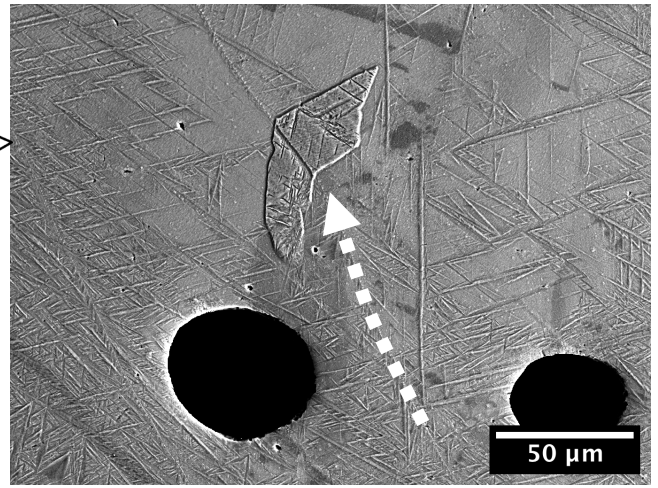
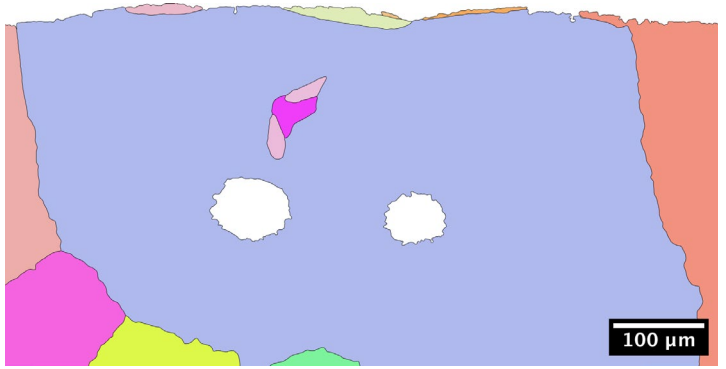
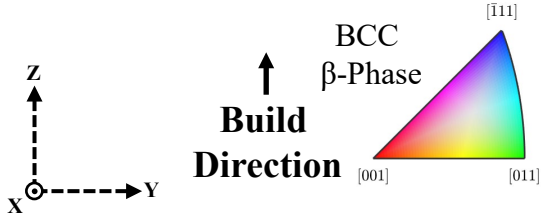
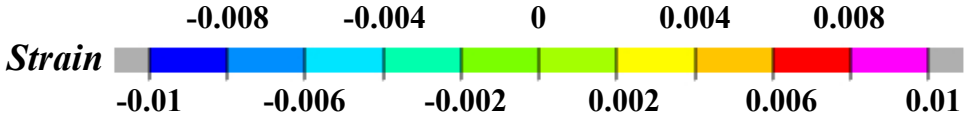
139W Double Hit

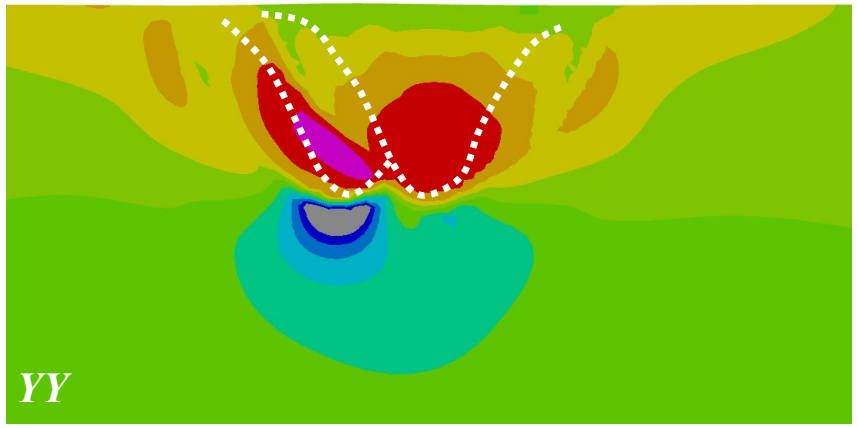




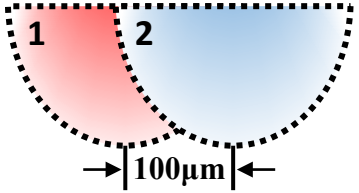








Overlapping Spot-Melts



Cooled to RT before next spot-melt

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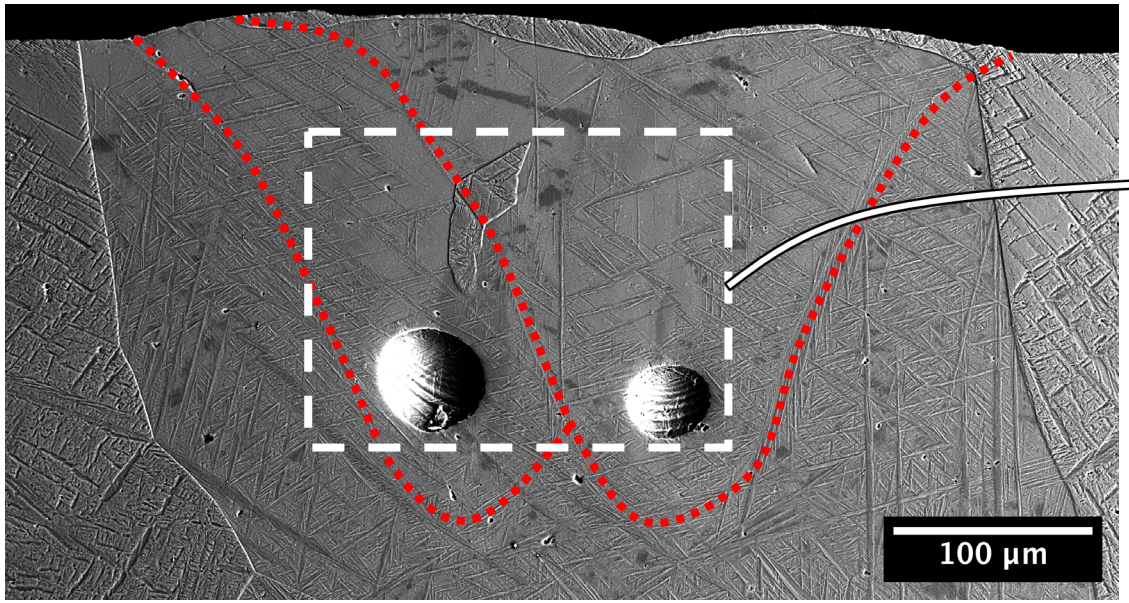
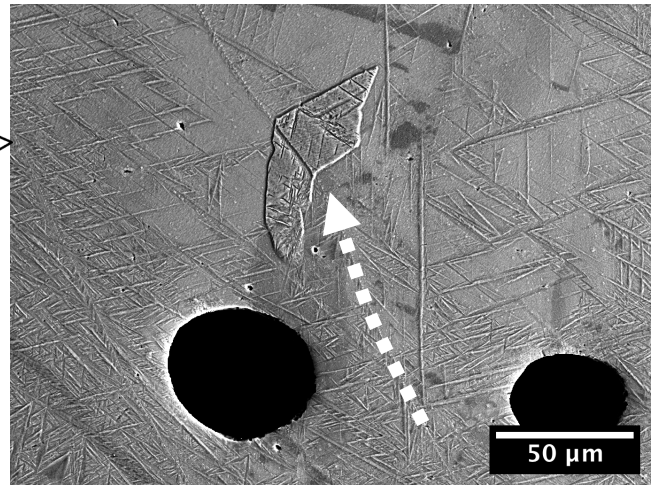
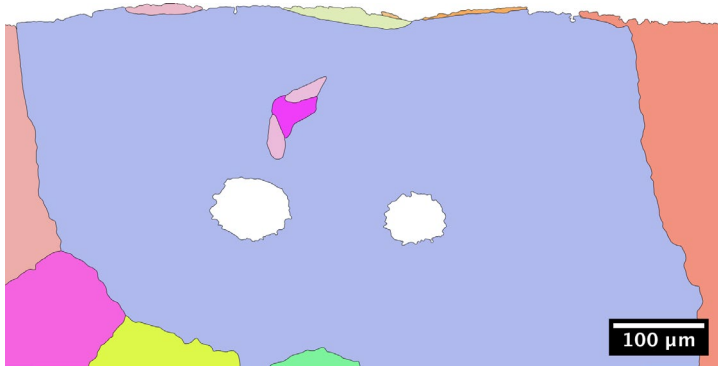
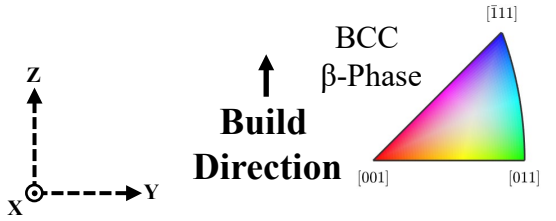
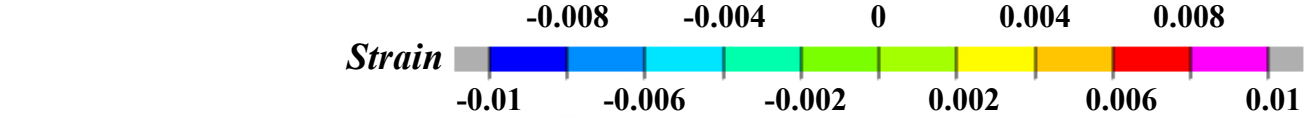
139W Double Hit

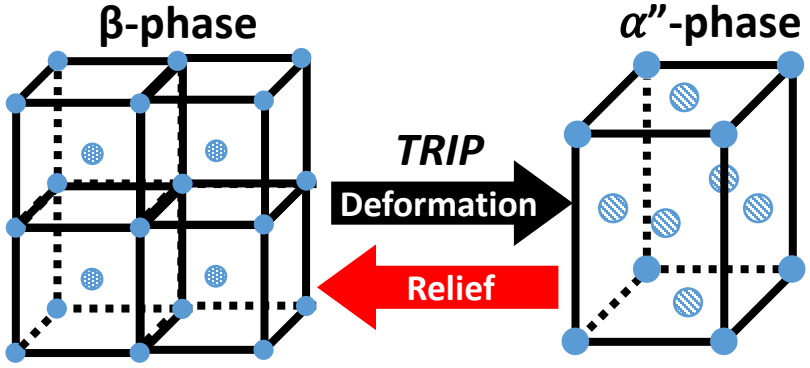


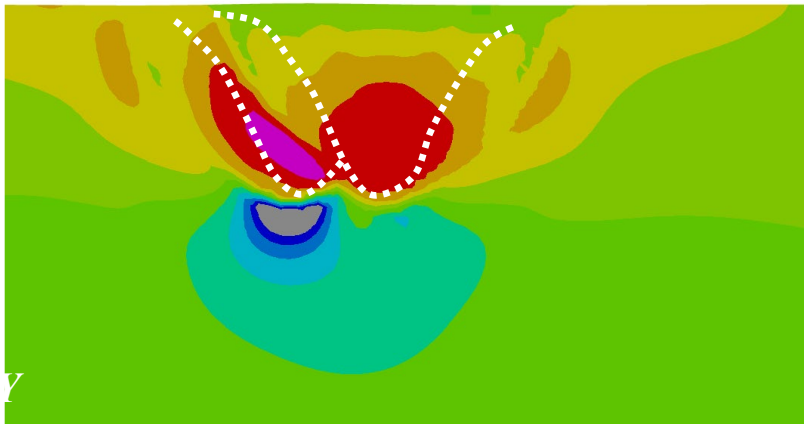




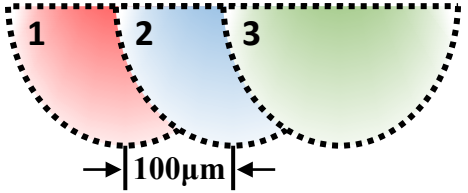








Overlapping Spot-Melts



Cooled to RT before next spot-melt

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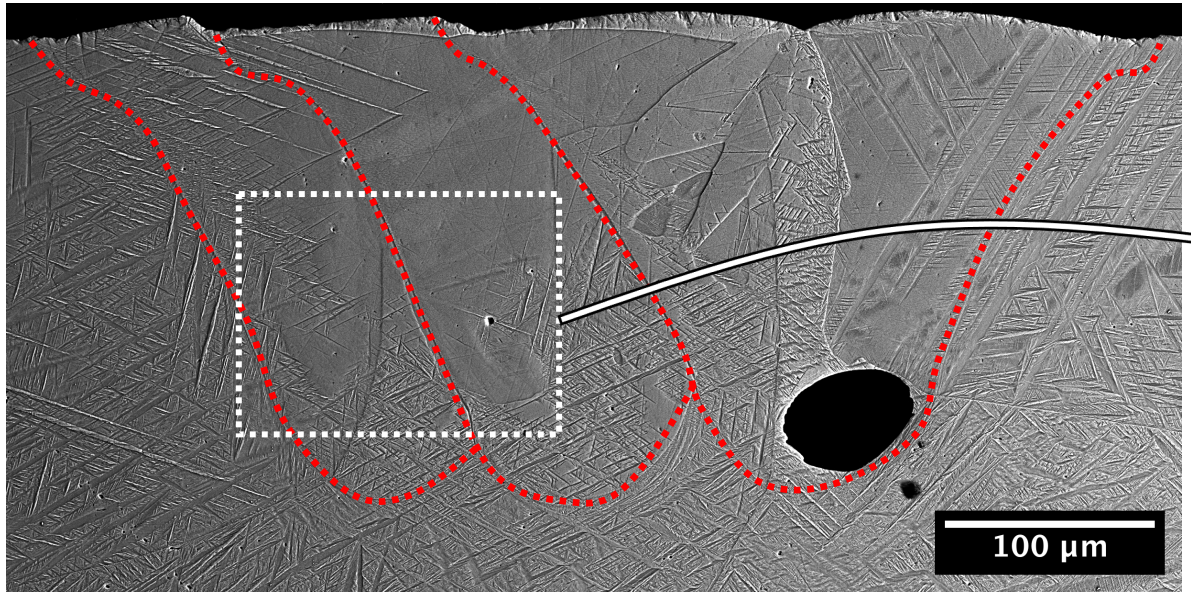
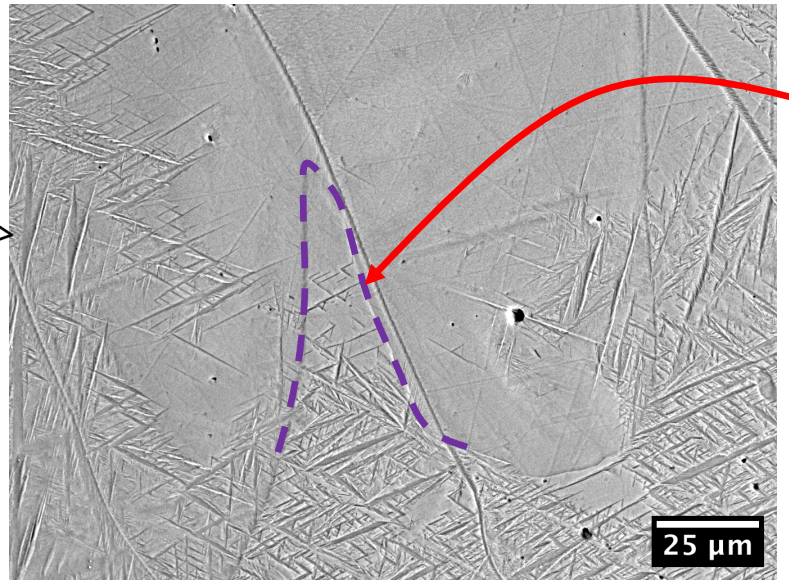
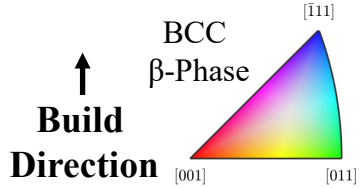
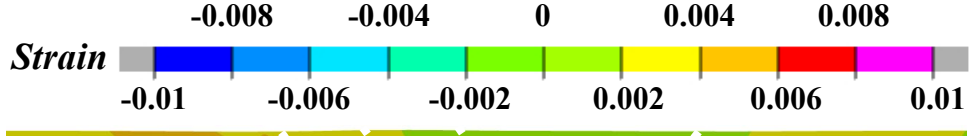
139W Triple Hit

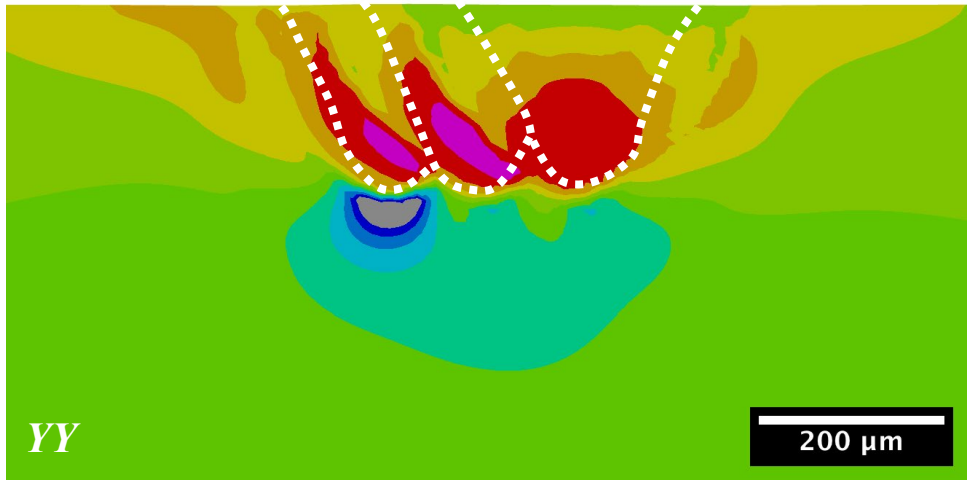


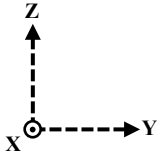


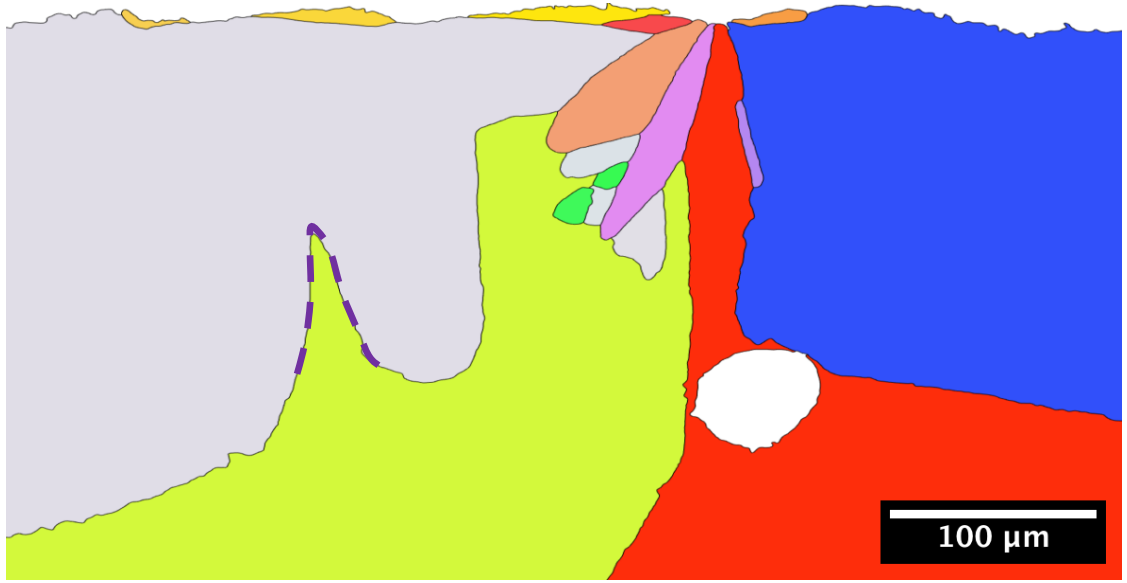
Abrupt α" suppression











An Aside– Schmid Factor

geometric factor controlling shear stress on a specific slip system due to loading

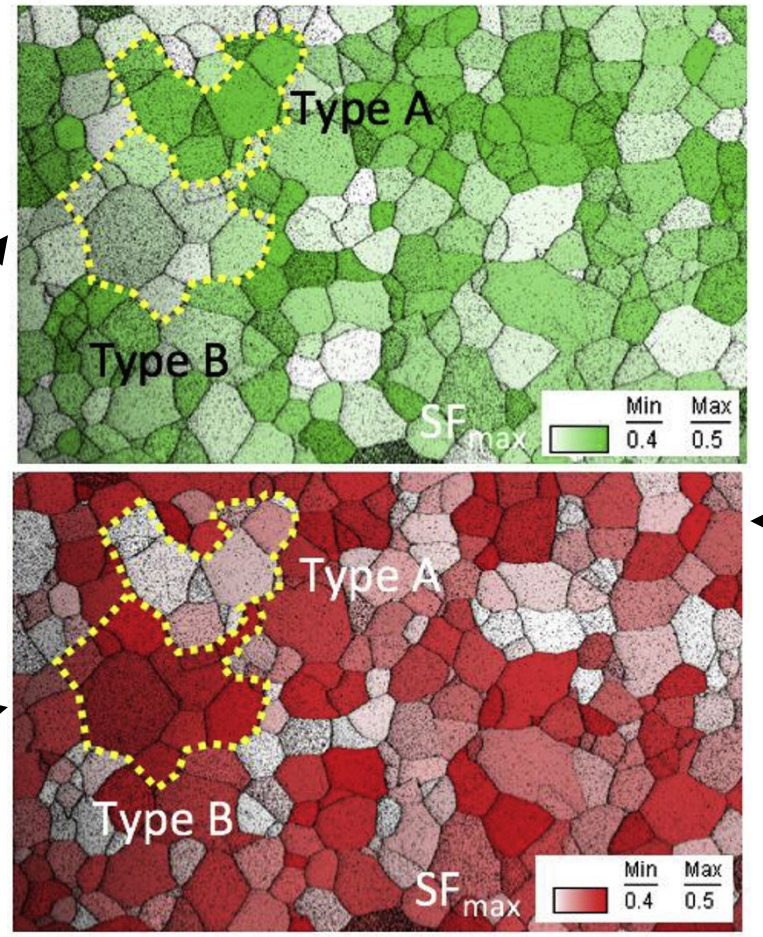
Schmid Factor used to predict deformation mechanism of each grain

BCC β-phase

$\{110\}\langle 1\bar{1}1\rangle$ **Dislocation slip**

$\{112\}\langle 11\bar{1}\rangle$ **Martensite shear**

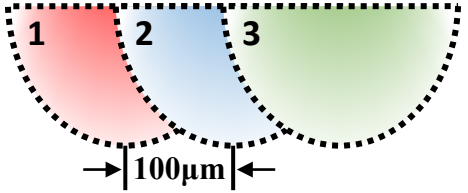
$\{332\}\langle 11\bar{3}\rangle$ **Twinning**



Loading Direction

L. Lilensten *et al.*, "On the heterogeneous nature of deformation in a strain-transformable beta metastable Ti-V-Cr-Al alloy," *Acta Materialia*, vol. 162, pp. 268–276, Jan. 2019, doi: 10.1016/j.actamat.2018.10.003.

Overlapping Spot-Melts



Cooled to RT before next spot-melt

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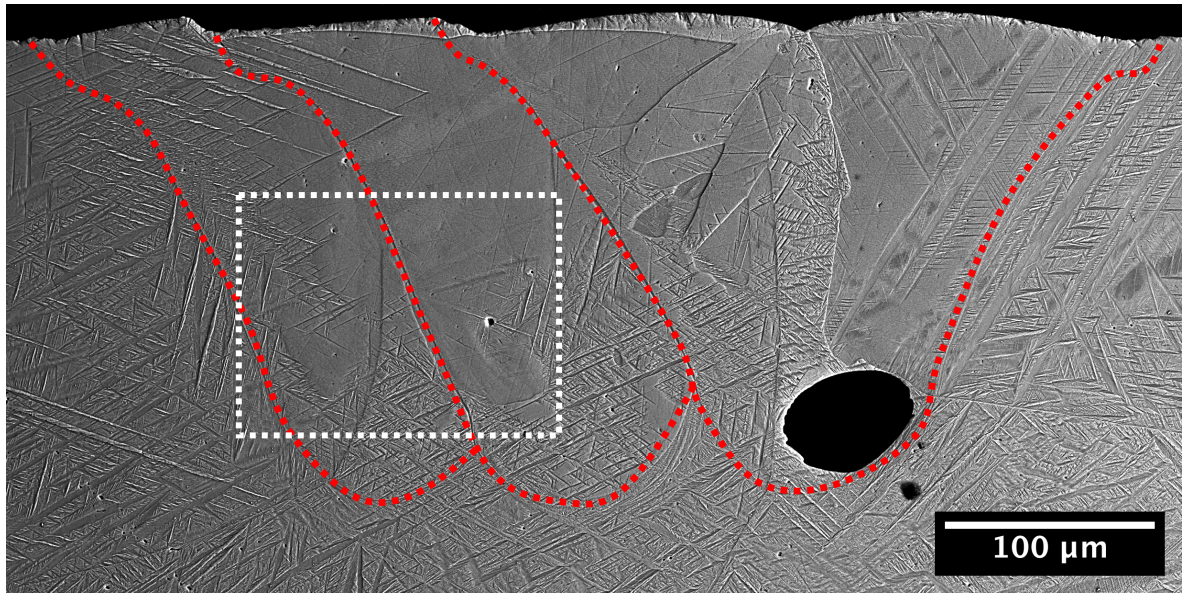
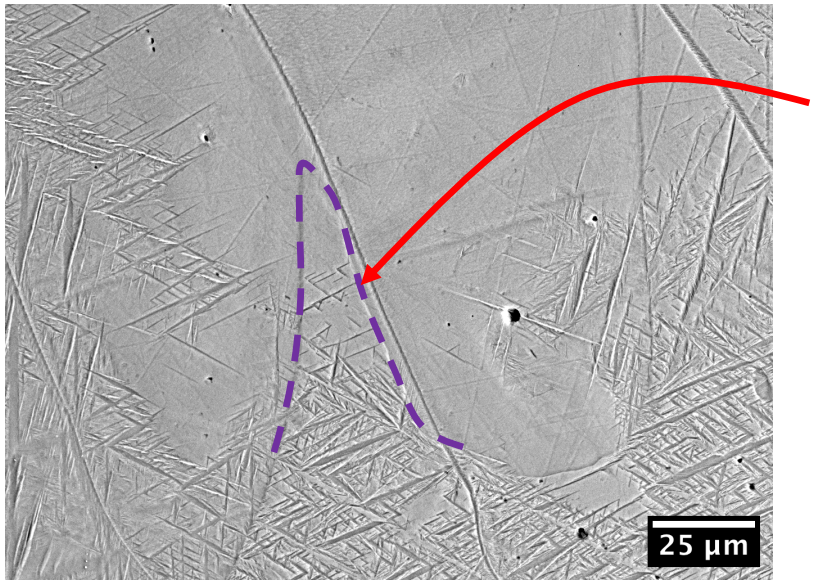
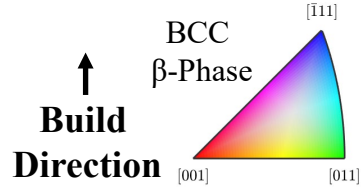
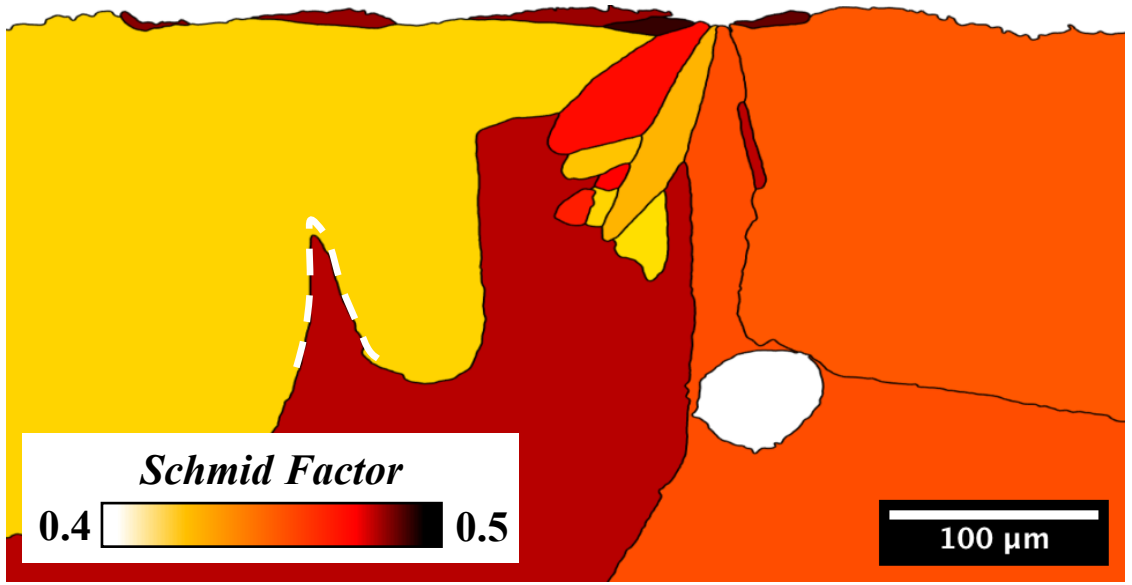
139W Triple Hit

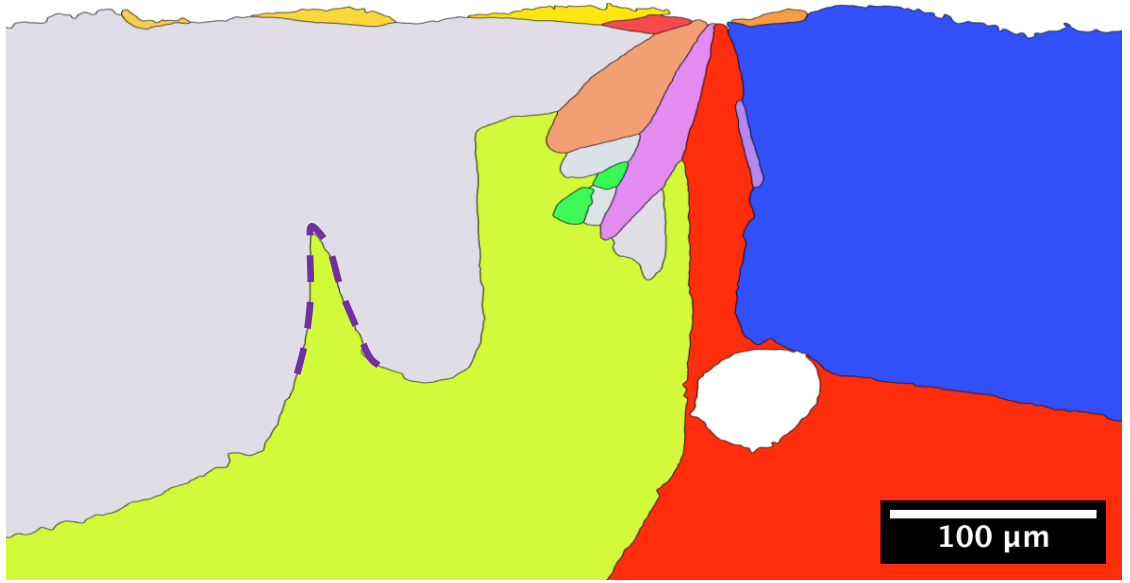




Abrupt α" suppression

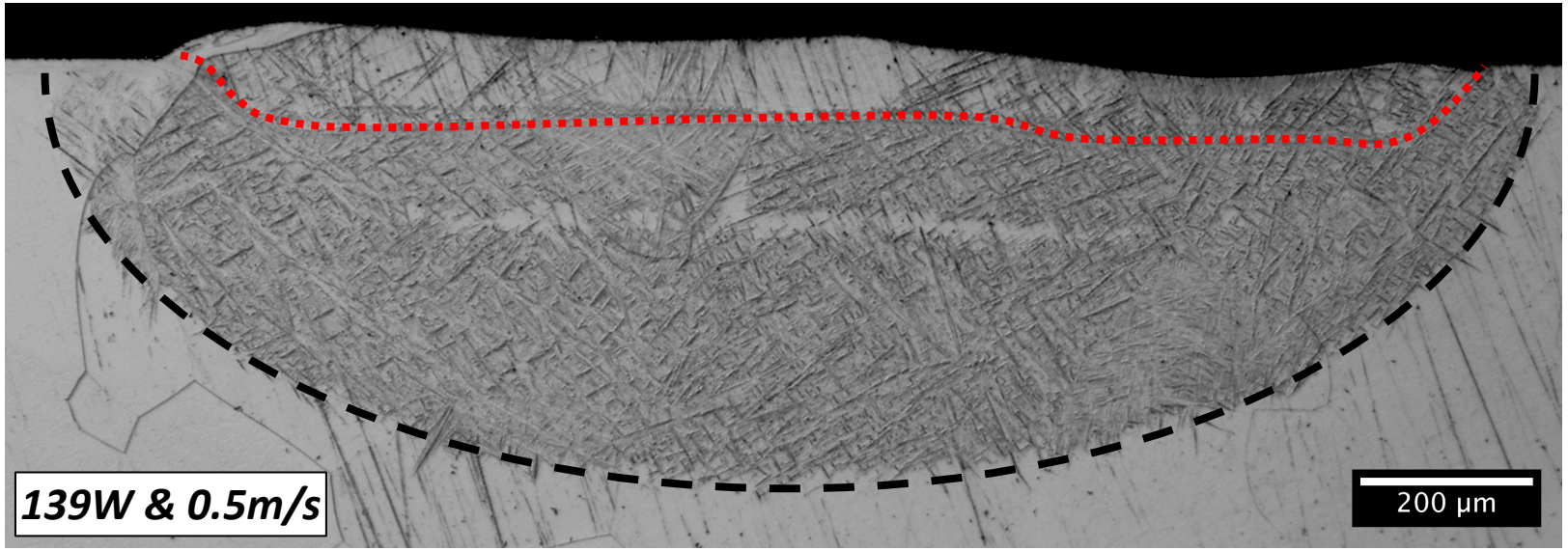






Rasters

Travel Direction →



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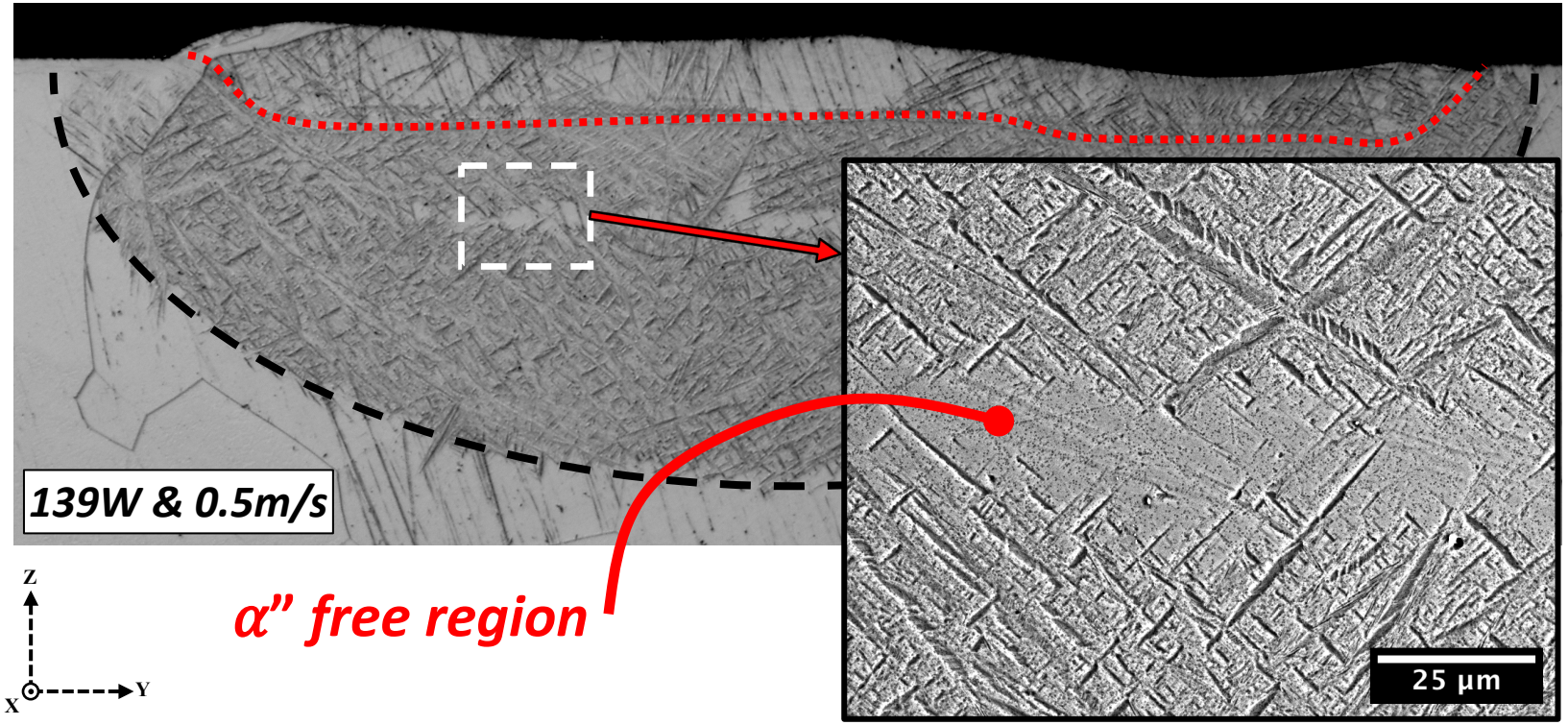
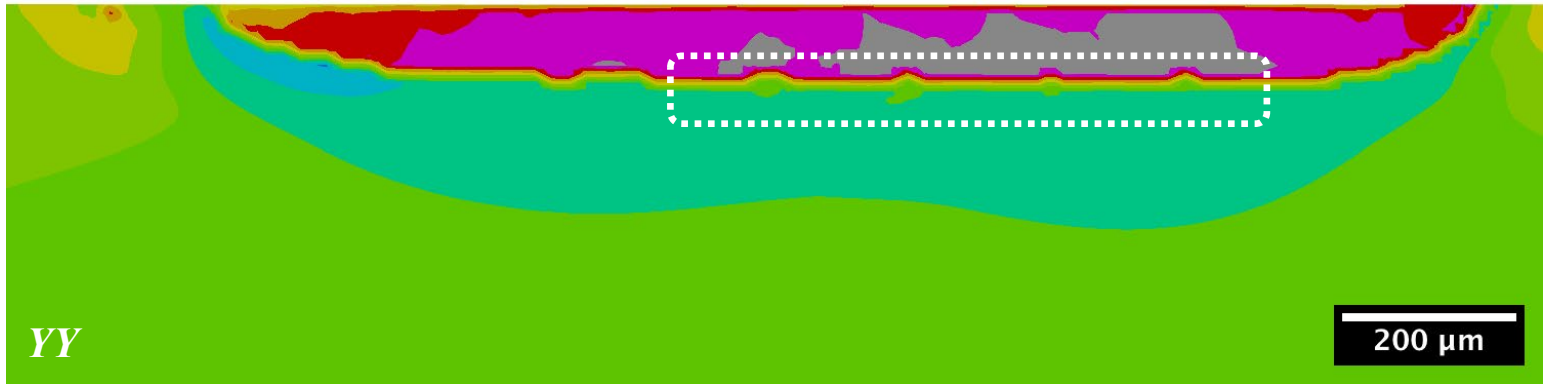
Rasters





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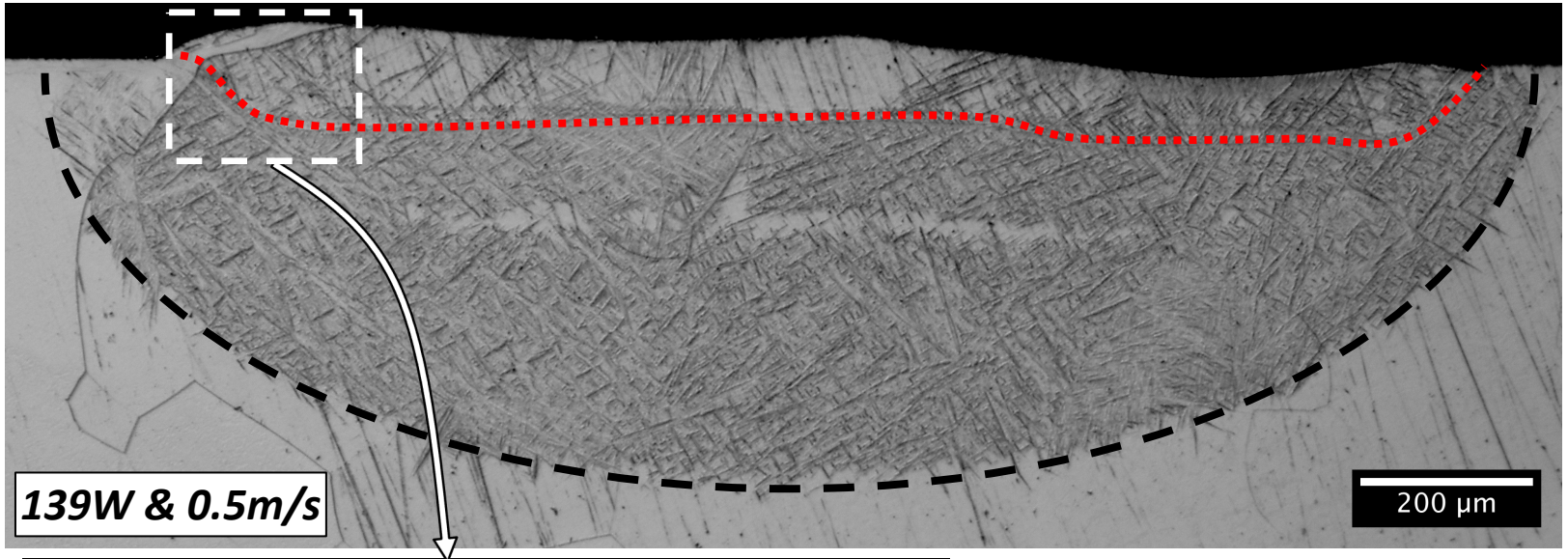
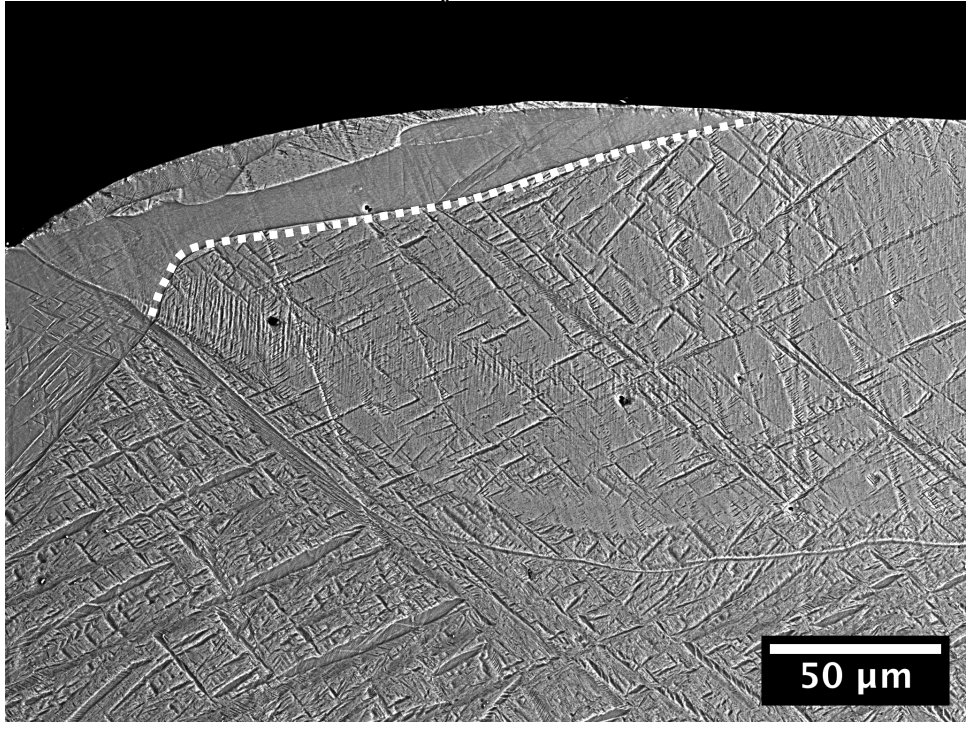
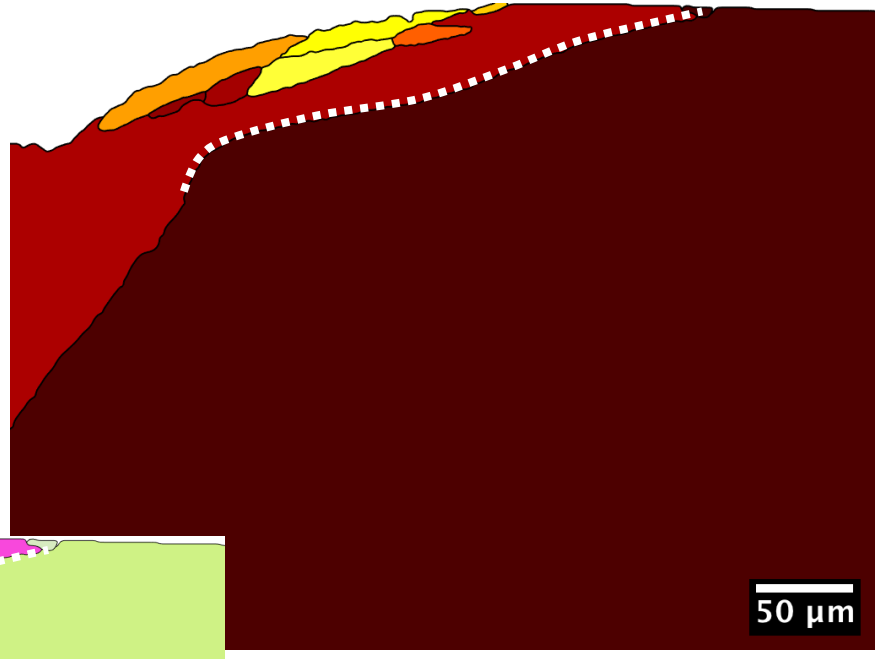
Rasters

Travel Direction →

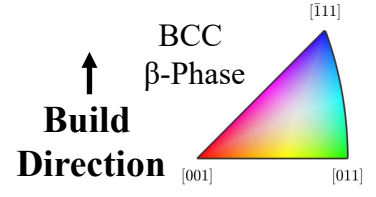




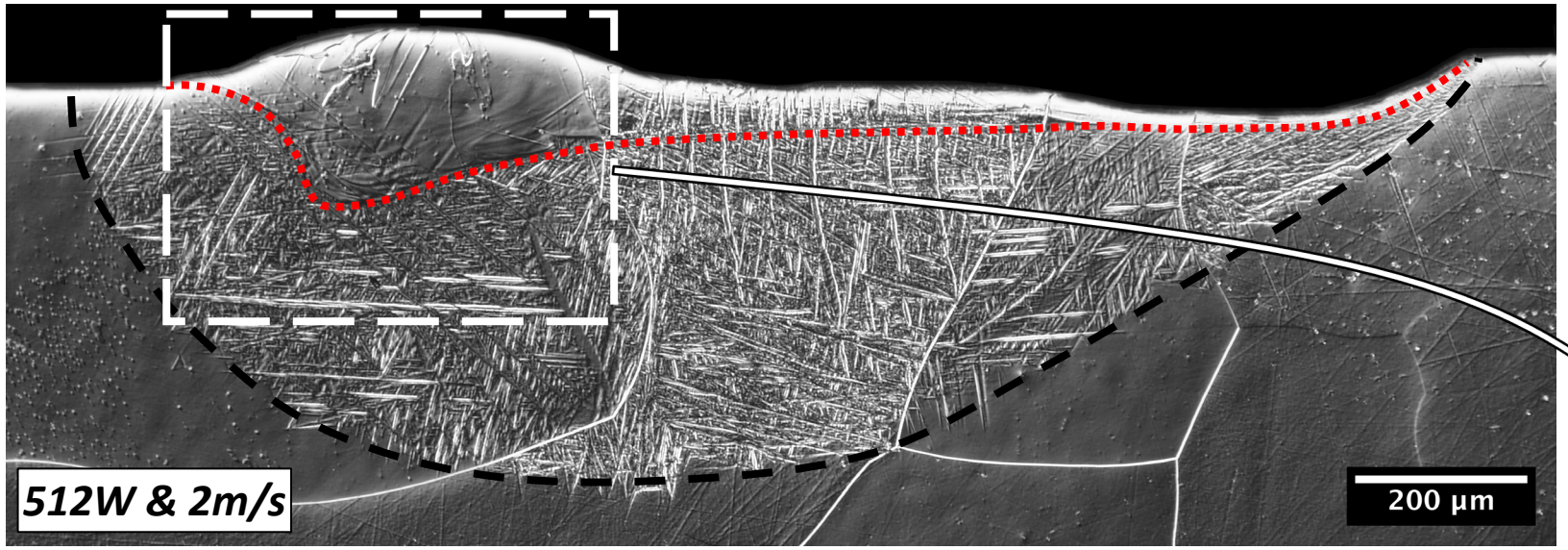


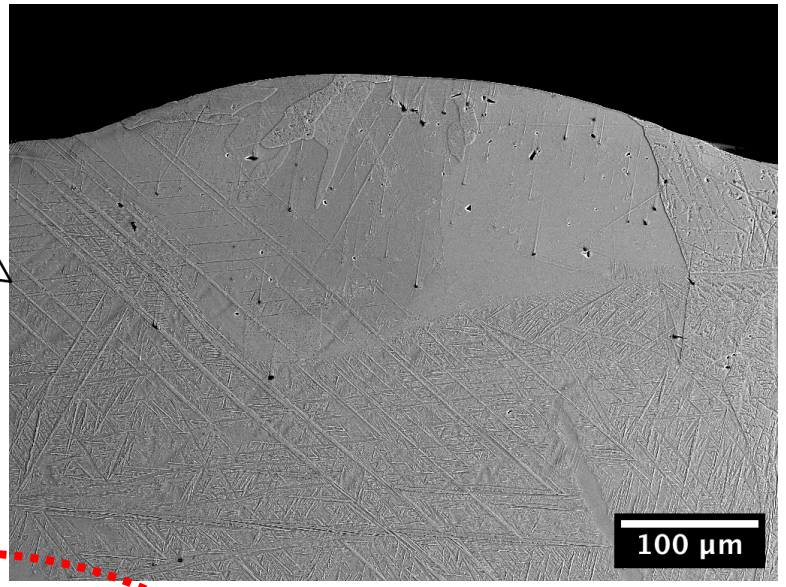
Schmid Factor

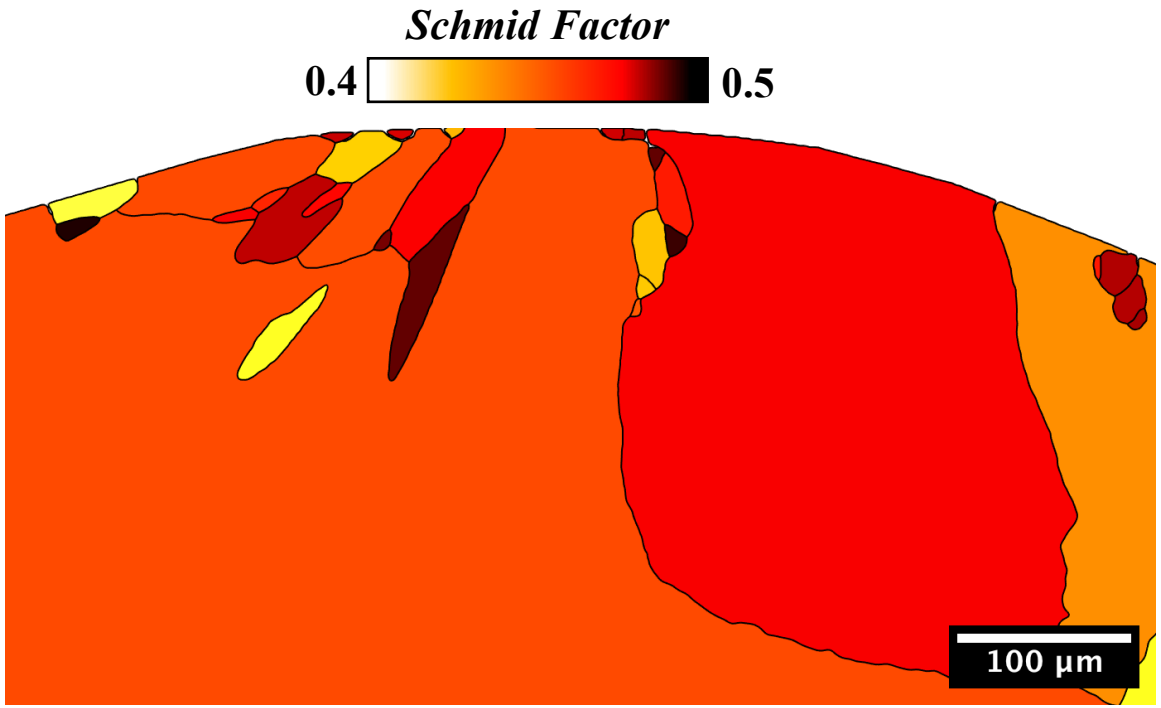
0.4 — 0.5

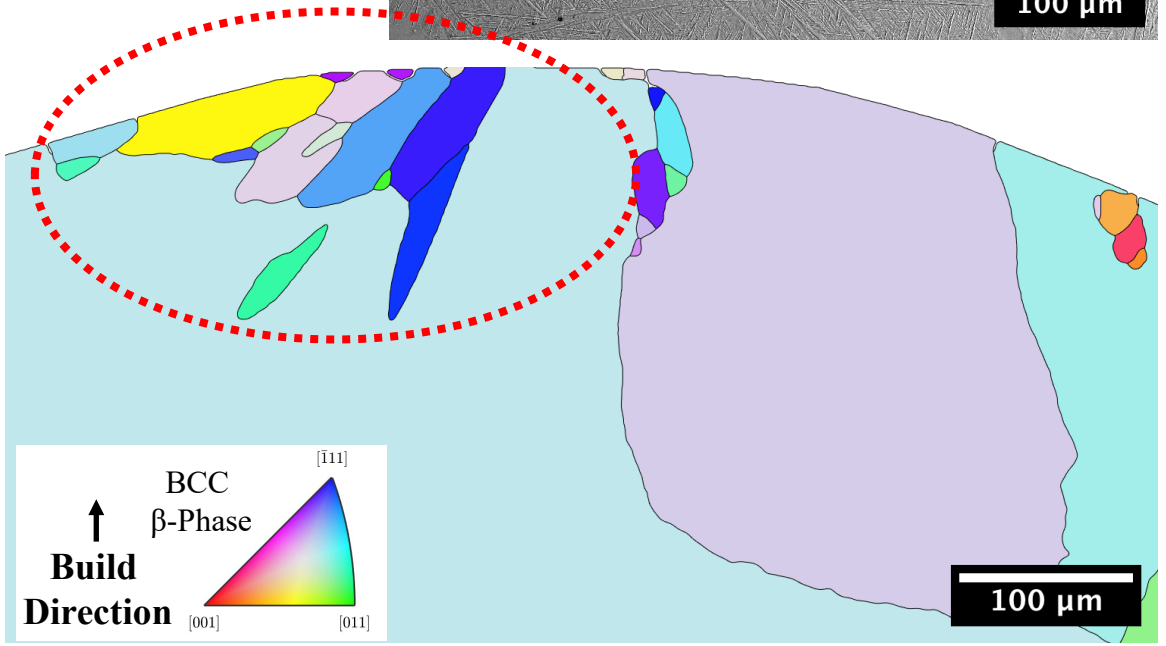


Rasters

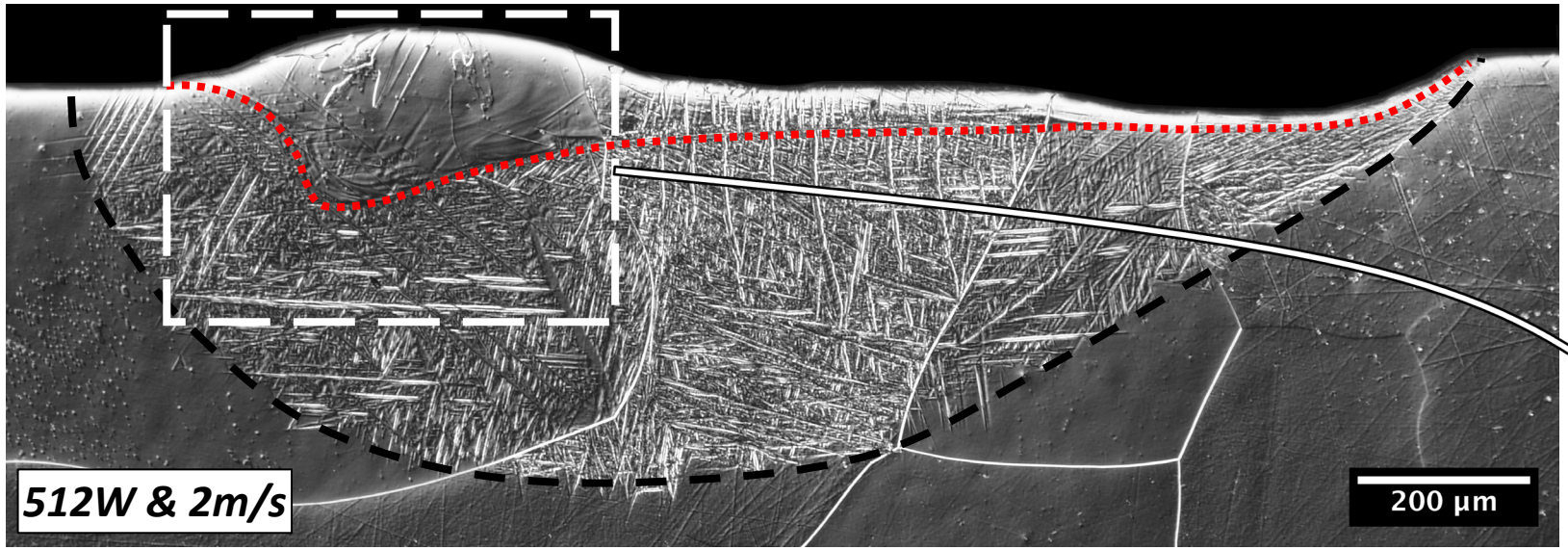

Travel Direction
512W & 2m/s
200 µm

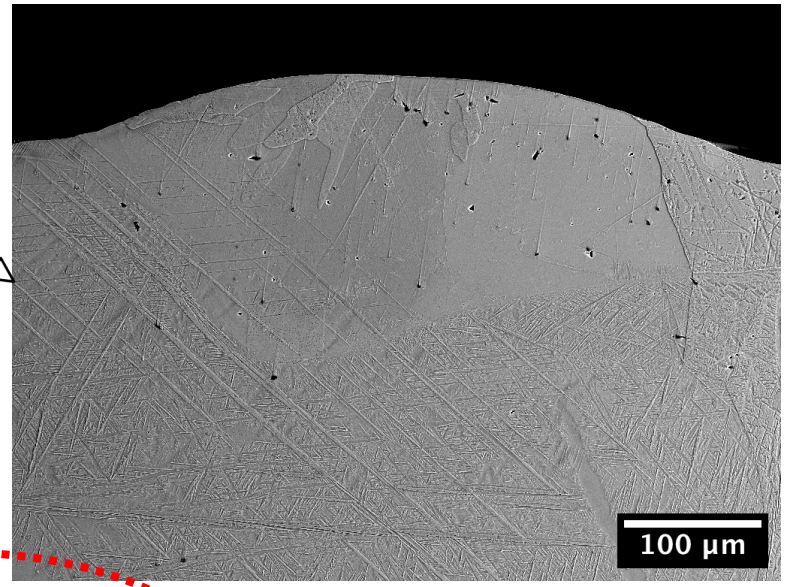

100 µm


Schmid Factor
0.4
0.5
100 µm

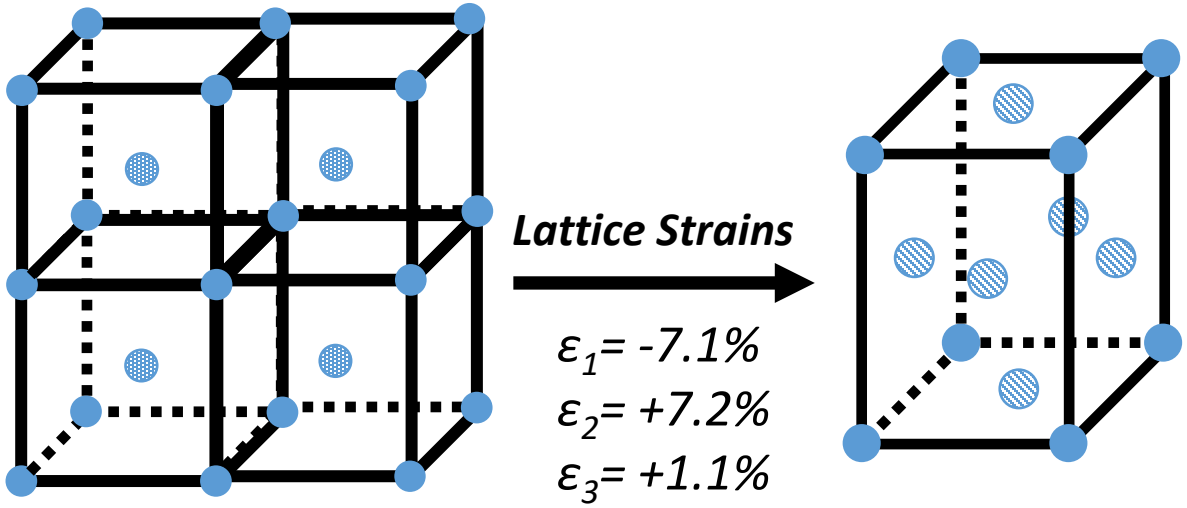

BCC
β-Phase
Build
Direction
[001]
[011]
100 µm

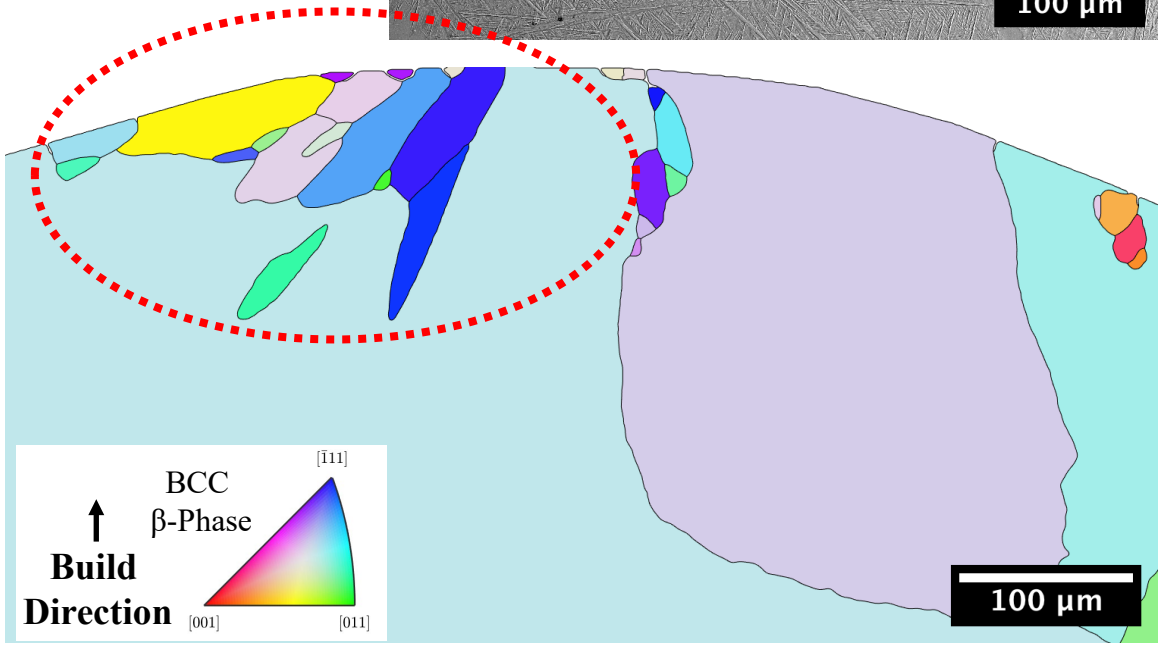
Rasters



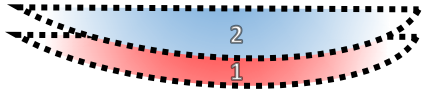


Decreased grain size increases stress necessary for TRIP





Remelted Rasters



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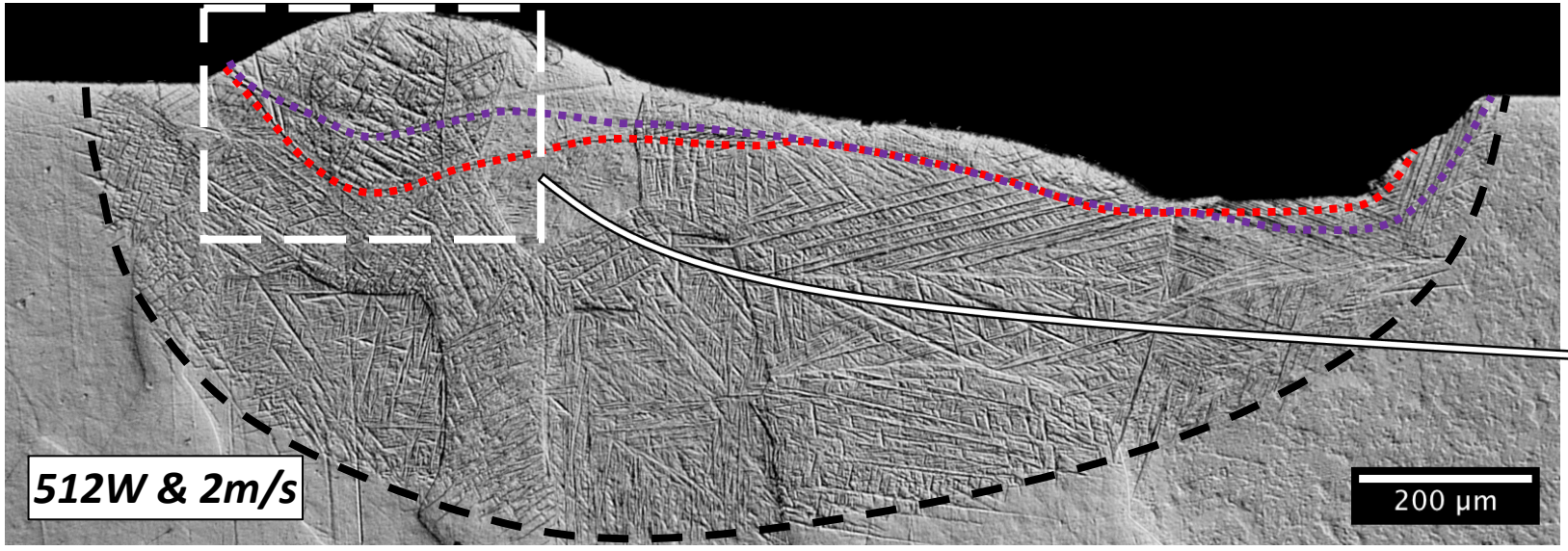
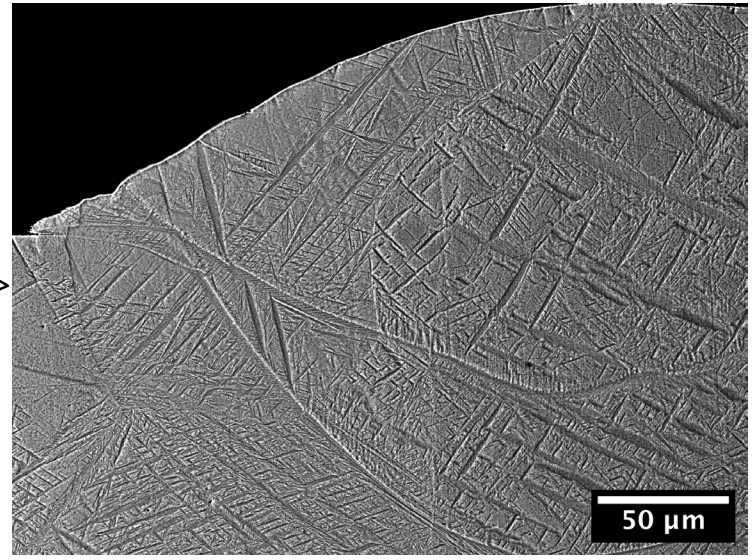
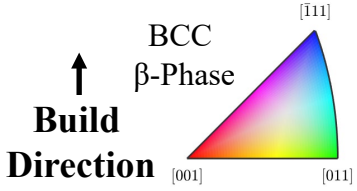
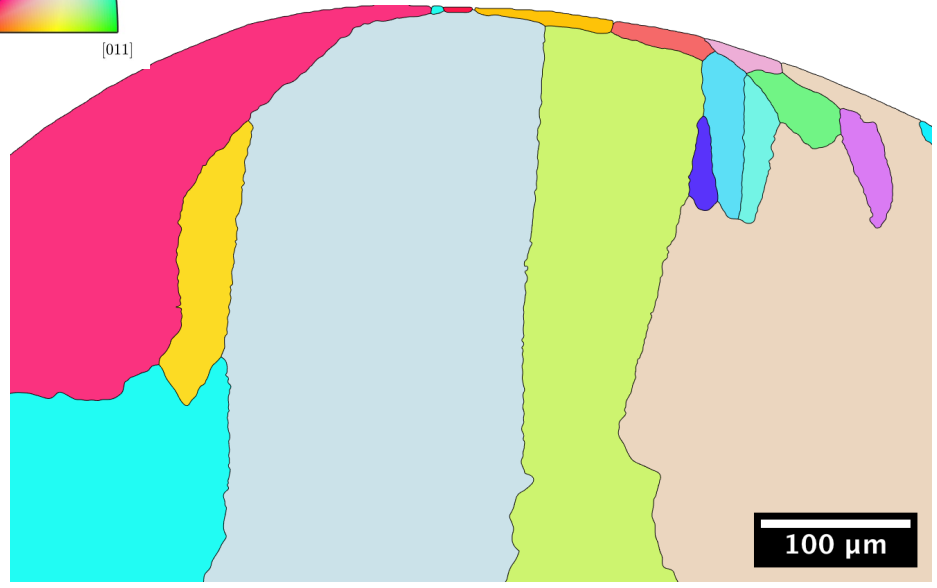




Removal of small grains reduces triggering strain for TRIP





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Summary & Conclusions

Questions?
jasien@mines.edu

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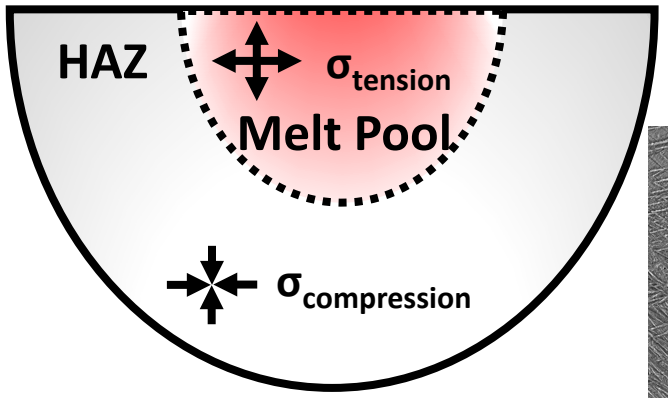
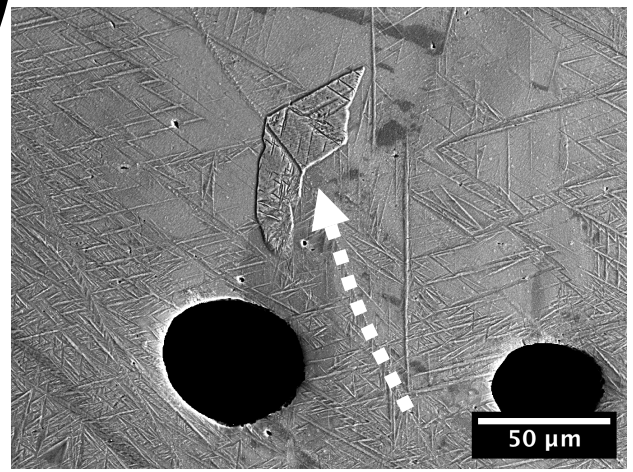
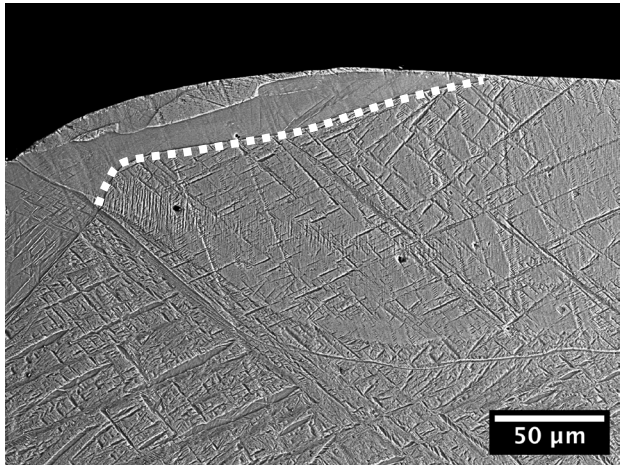
TRIP is influenced by processing and microstructural features

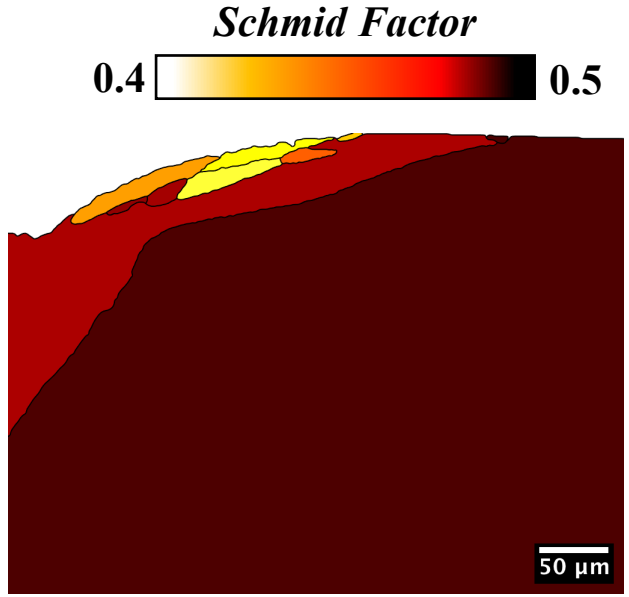
Melt-pool size
Thermal cycling





Schmid Factor
Grain Size





Accommodation of residual stresses/strains in Ti-1023 may produce crack-free parts with tuned microstructures and properties.