The Future of 3D Metal Printing

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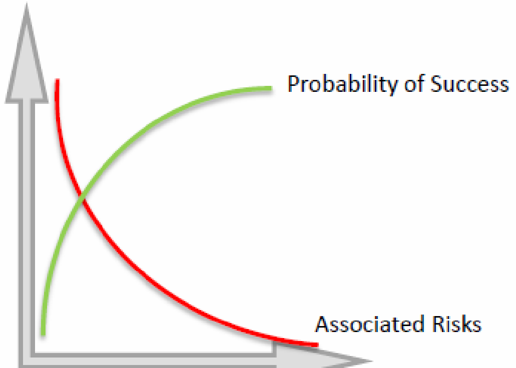
Deepankar Pal

Research Team,

3DSIM LLC

Motto, *Modus Operandi* & Contributions (+Big Picture)

- Motto
  - *Think Yesterday, Execute Today and Innovate* 'the' *Tomorrow.*
- *Modus Operandi*
  - Respect and Innov8.
- Contributions



Team: Abdul, Brent, Chong, Deepankar, Kai, Kevin, Nachiket, Pradeep

Business Aspects

- Need for fabricating lightweight, organic looking, smaller length scale parts has increased tremendously.
- Patents are expiring. Evolution of new desktop, research and production machines
- Simulation techniques and computer architectures are better than ever-will be elaborated as we go along.
- Business models have improved accordingly as the times changed from 'Mass Production' to 'Mass Customization' in the last 20 years.

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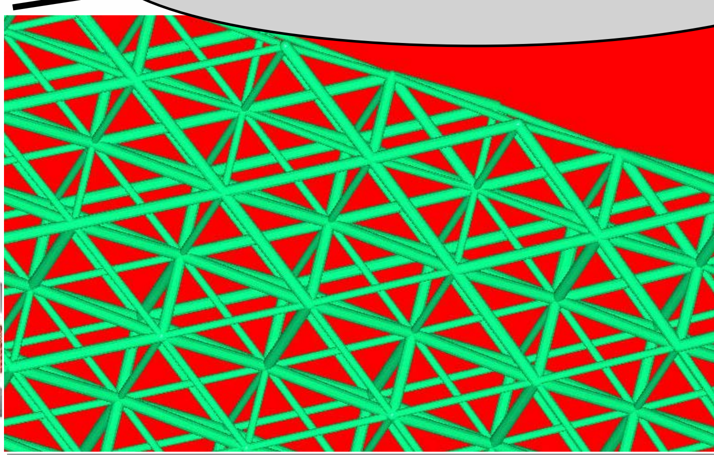
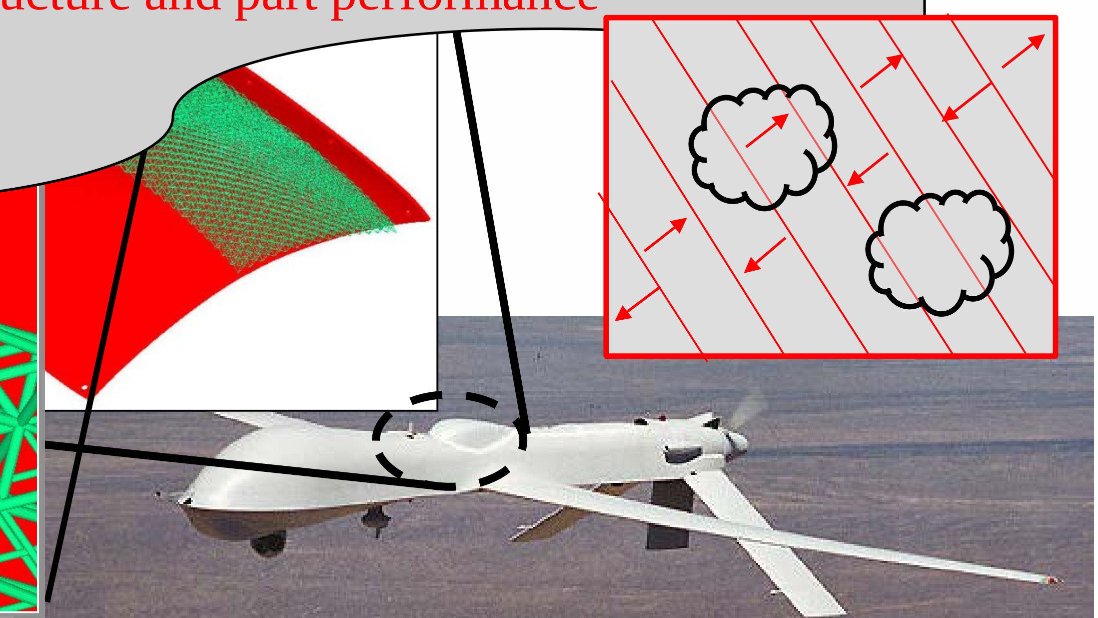
But we can't efficiently:

- Design structures this complex in CAD
- Predict what our machines will do when we print a new geometry we haven't printed before
- Predict the differences between printing the same part in two different locations/orientations
- Predict how different process parameters affect dimensional accuracy, microstructure and part performance





Problem Identification (Decoupling various aspects)

Processing

- Directed Energy Deposition
- Powder Bed Processing
- Roll Bonding/Friction Surfacing/ UAM

Materials

- Form-Powder, Wire or Pellet
- Metals/alloys

Energy Source

- Laser beam
- Electron beam
- Deformation boundary conditions

Geometry

- Prismatic
- Organic

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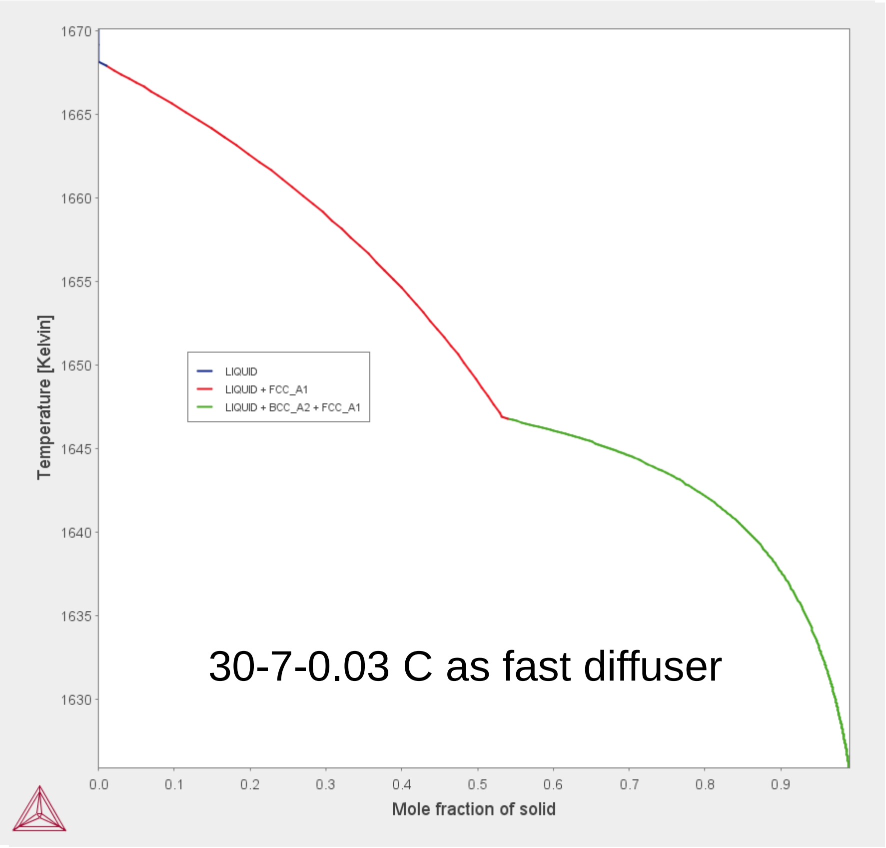
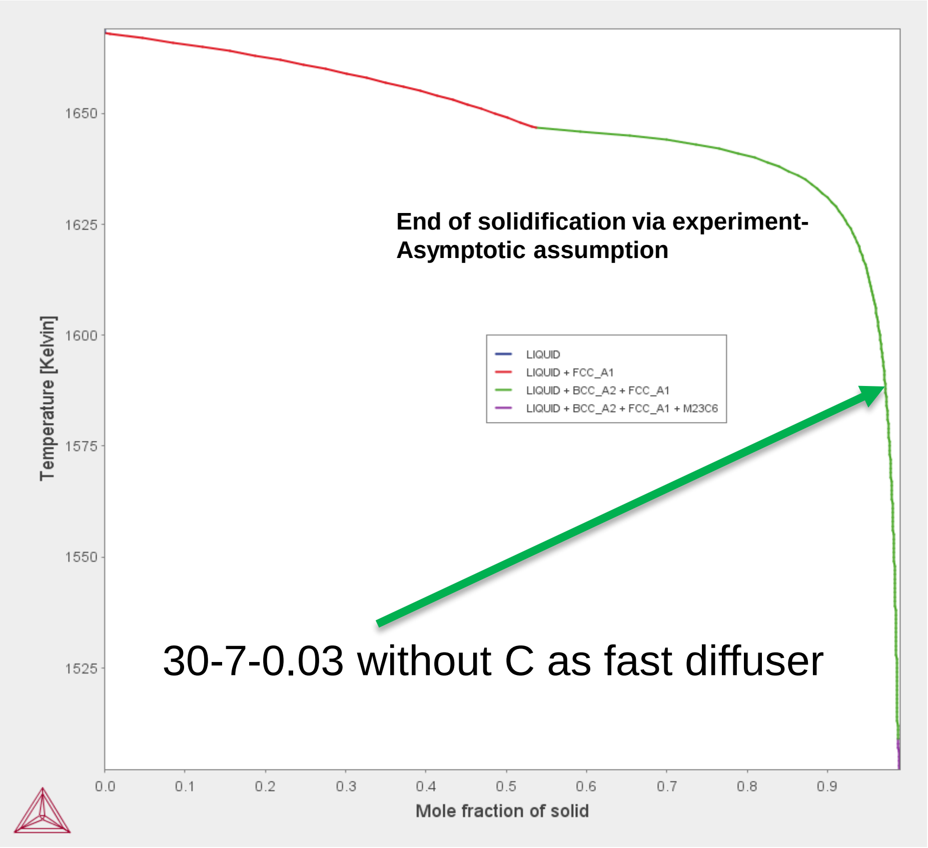
Why Numerical Techniques?

- Additive manufacturing energy source size scales are much smaller compared to the entire geometry leading to a myriad of microstructures unlike traditional manufacturing processes.
- Additive manufacturing also eases freeform structure fabrication and 'Testing on simplified geometries with more or less uniform microstructures is not enough'. Sub-size testing in SEM etc. is required.
- *In-situ* experiments such as measuring spatio-temporal thermal evolutions are hard to perform due to the dynamics involved in the process.

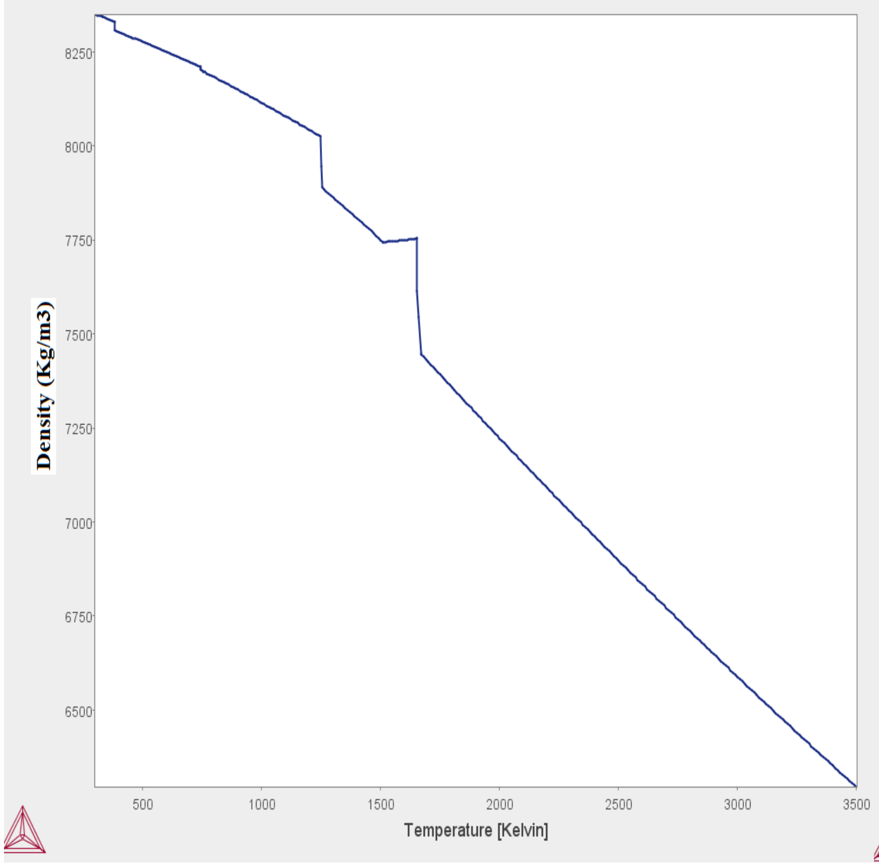
Materials Science Aspects

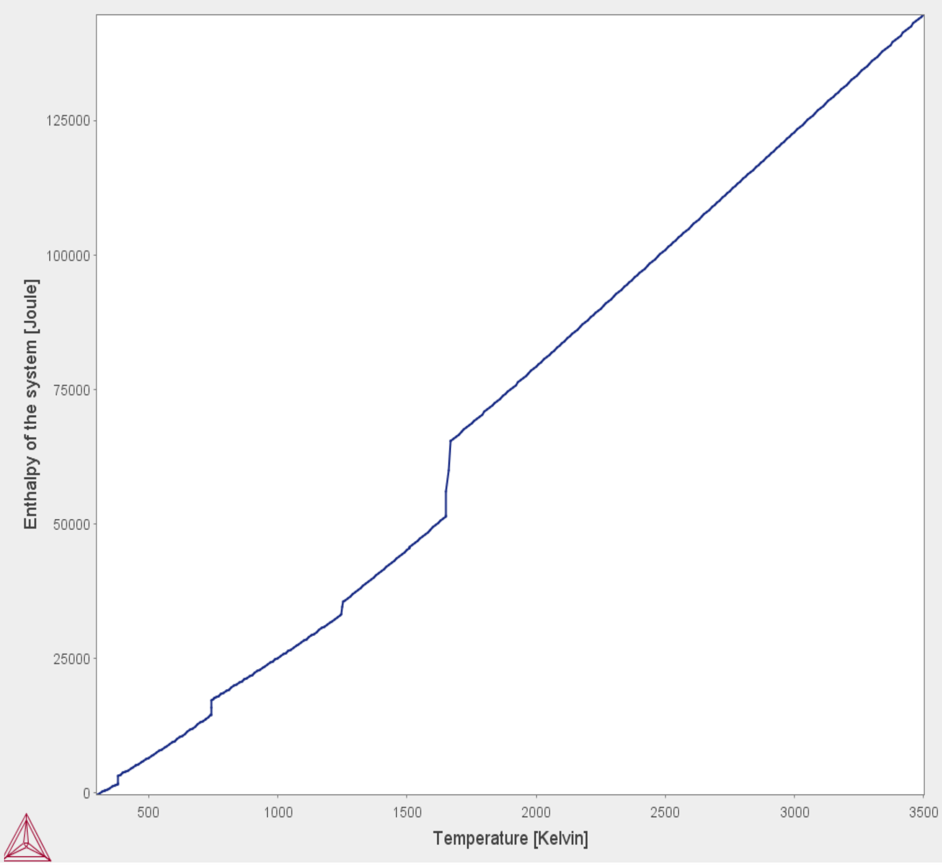
Phases & Microstructures





Thermo-physical property capture





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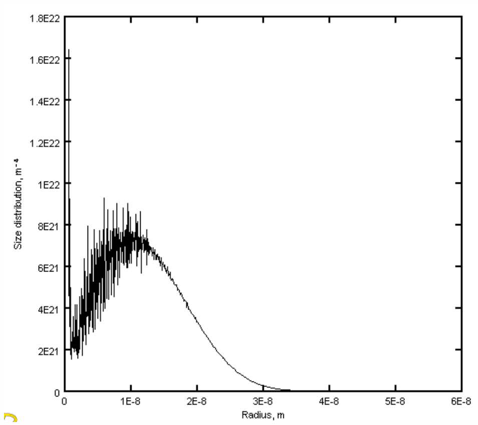
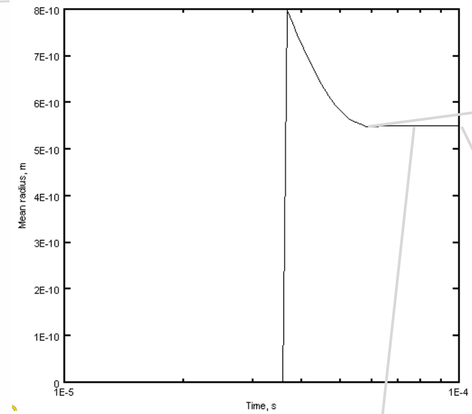
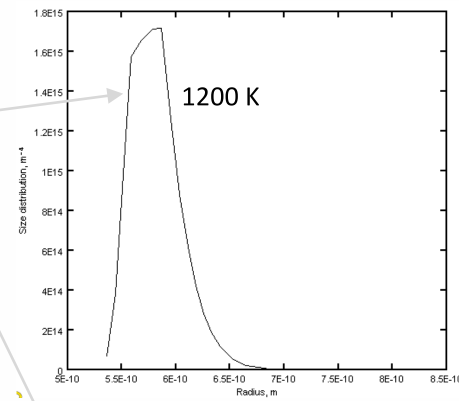
Deleterious Phase Precipitations

Deleterious phase precipitation at close to our cooling rates M23C6 size distributions in BCC phase.

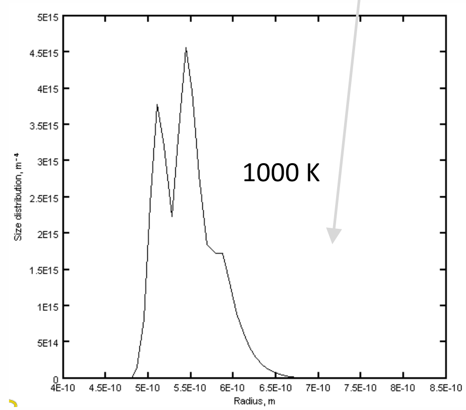


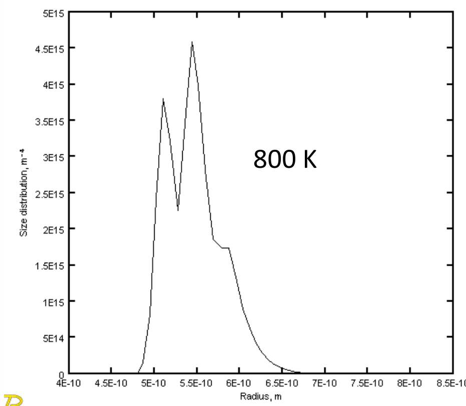
M23C6 precipitation at 10^{-3} s and at 1000K. Cooling rate ~ 6.5×10^{5} ^{0}C/s
Almost LENS cooling rate. Lower bound of SLM cooling rate





1: Figure 2





M23C6 precipitation at 10^{-3} s and at 1000K. Cooling rate ~ 8×10^{6} ^{0}C/s
Almost LENS cooling rate. Upper bound of SLM cooling rate

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Multi-scale Geometrical aspects

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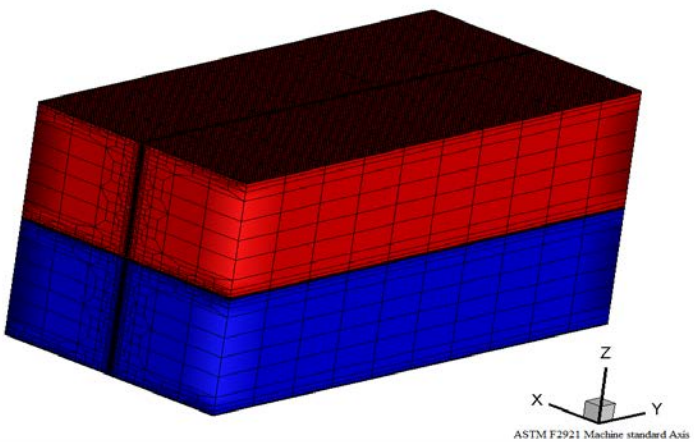
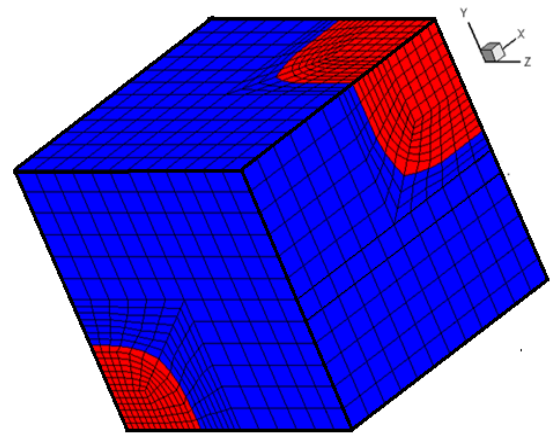
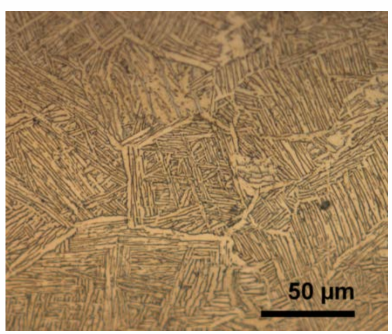
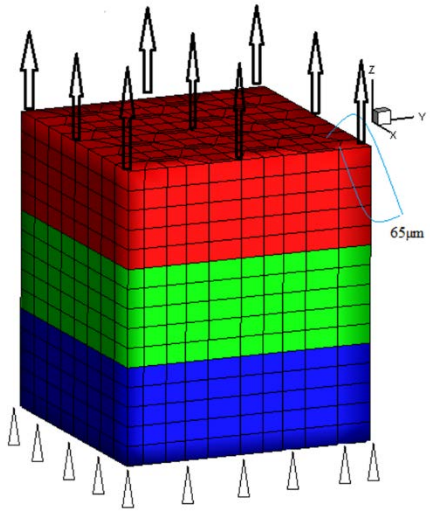
Some mesh examples









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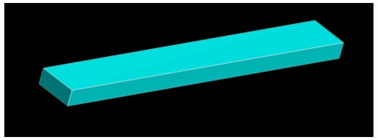
Process-Materials Coupling

Metal Laser Sintering

Metal laser sintering is a technique that uses a laser as the power source to sinter powdered metal material, aiming the laser automatically at points in space defined by a 3D model, binding the material together to create a solid structure.

Problem Complexity

THE CORRECT ANSWER REQUIRES VECTOR-BY-VECTOR COMPUTATION



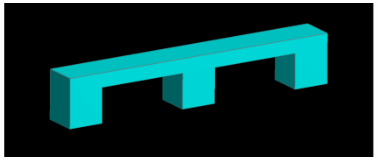
40mm x 5mm x 2mm part

Without Supports

Layers: 66

Hatches Considered: 17,490

Laser Positions: 13,216,038

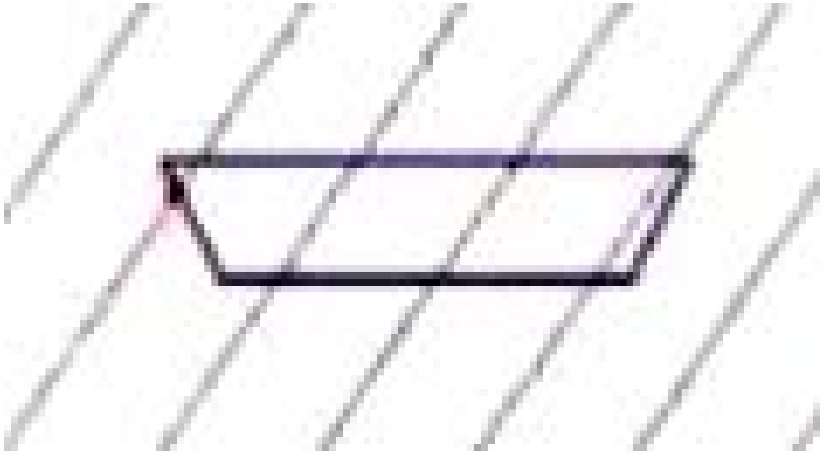


With pillar supports

Layers: 233

Hatches Considered: 61,745

Laser Positions: 25,766,422



ANSYS Computational Time

~150 years

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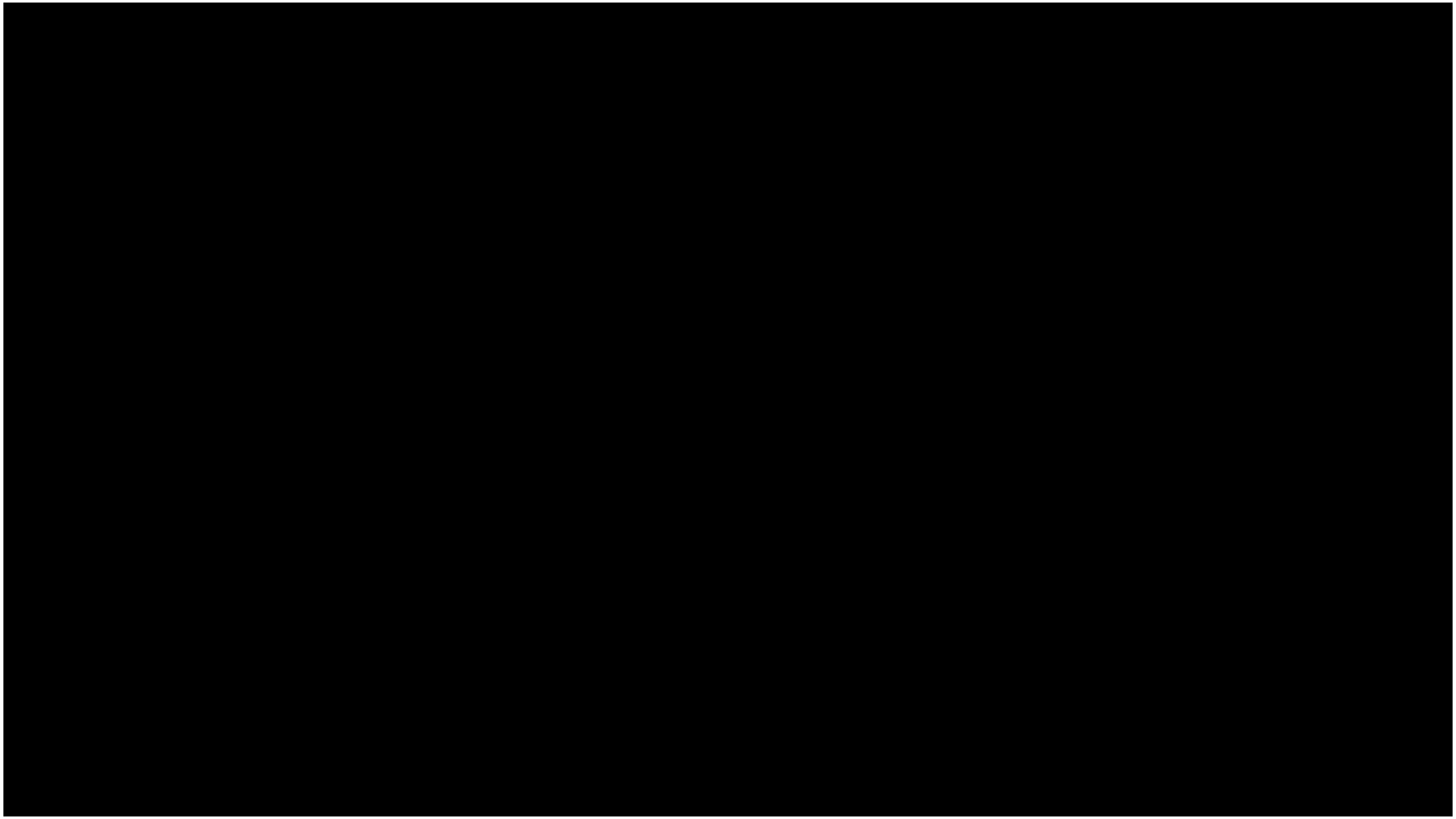
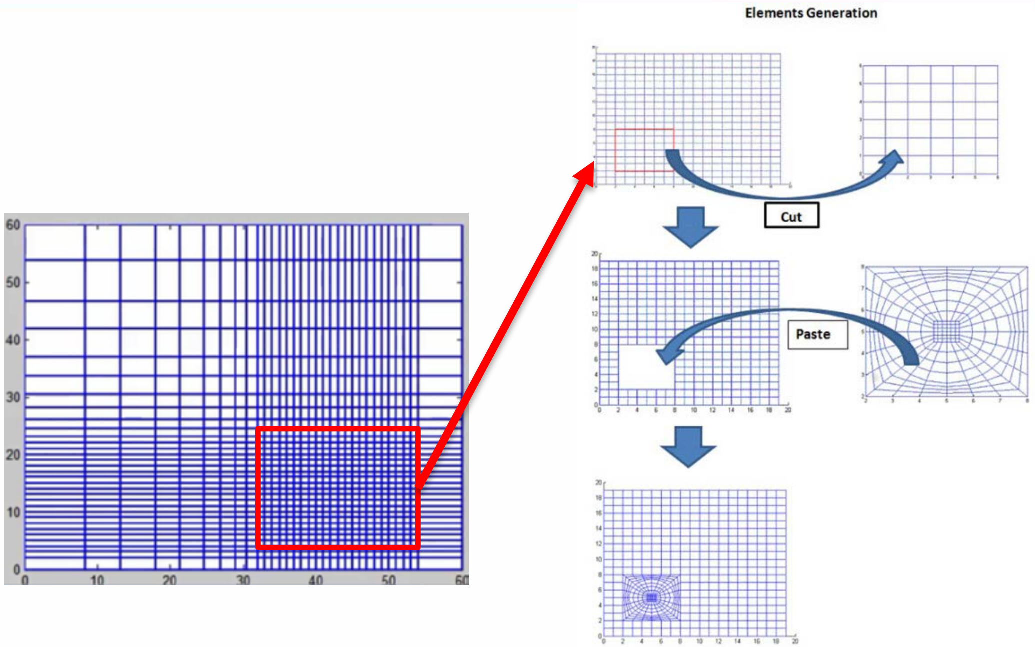
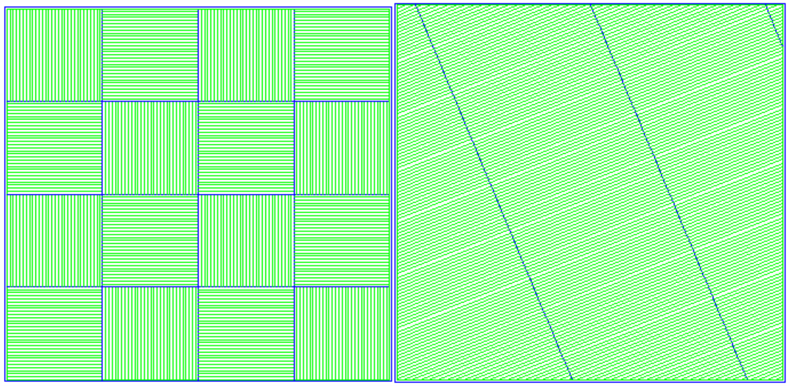
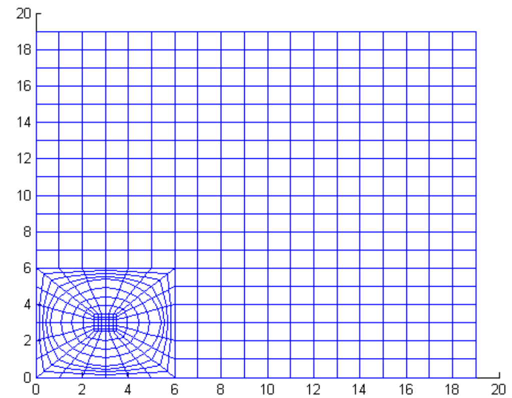
Global-local







AdGIF UNREGISTERED - www.gif-animator.com

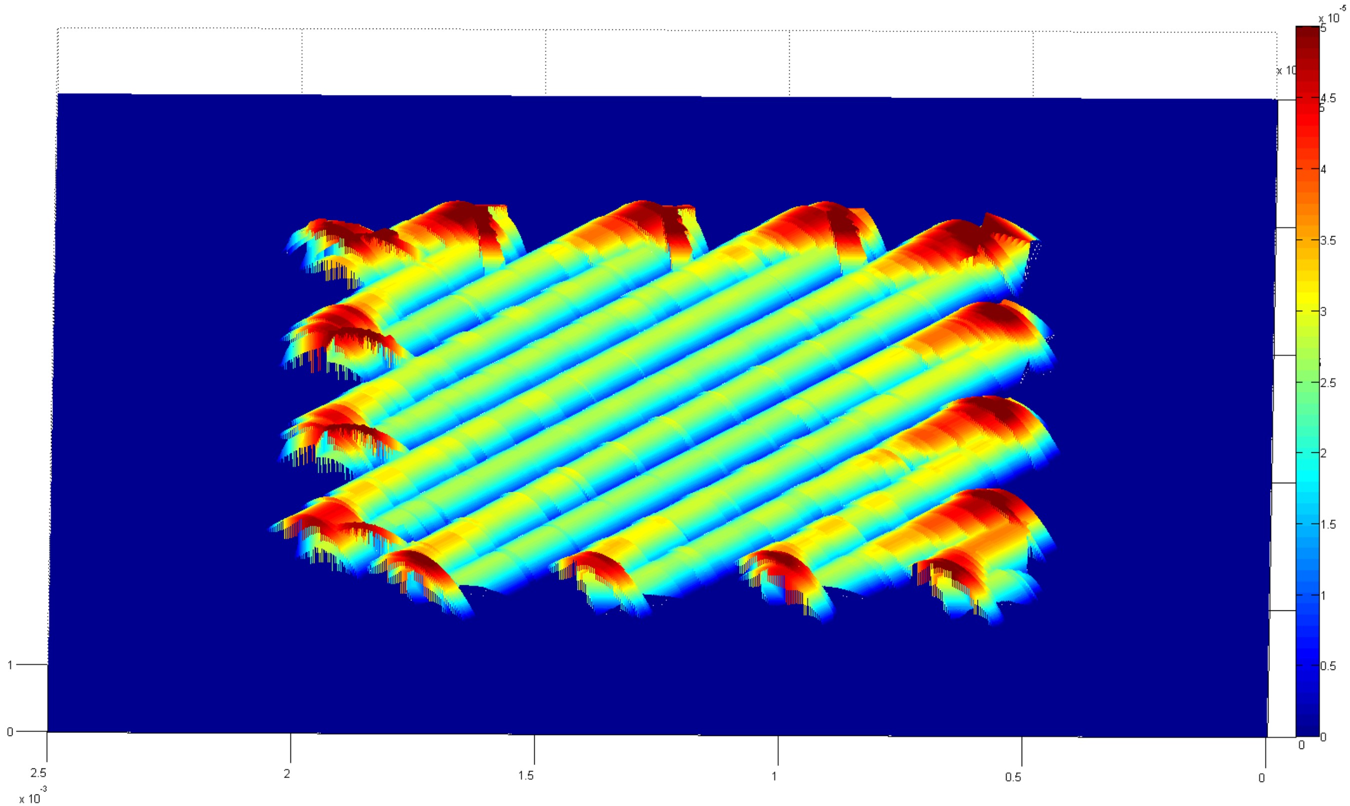


Suite of Efficiency solvers

- Automatic stiffness generation for part, heat affected and laser input length scales.
- On-the-fly runtime Periodic and Higher Order Homogenization
- Eigensolver methodology incorporation-isoparametric formulation for elements no longer used.
- Woodburry update using eigen methodology (under implementation)

Surface roughness

Case: 195 W, 200 mm/s
Mean: 15.6 μm
STD: 14.7 μm



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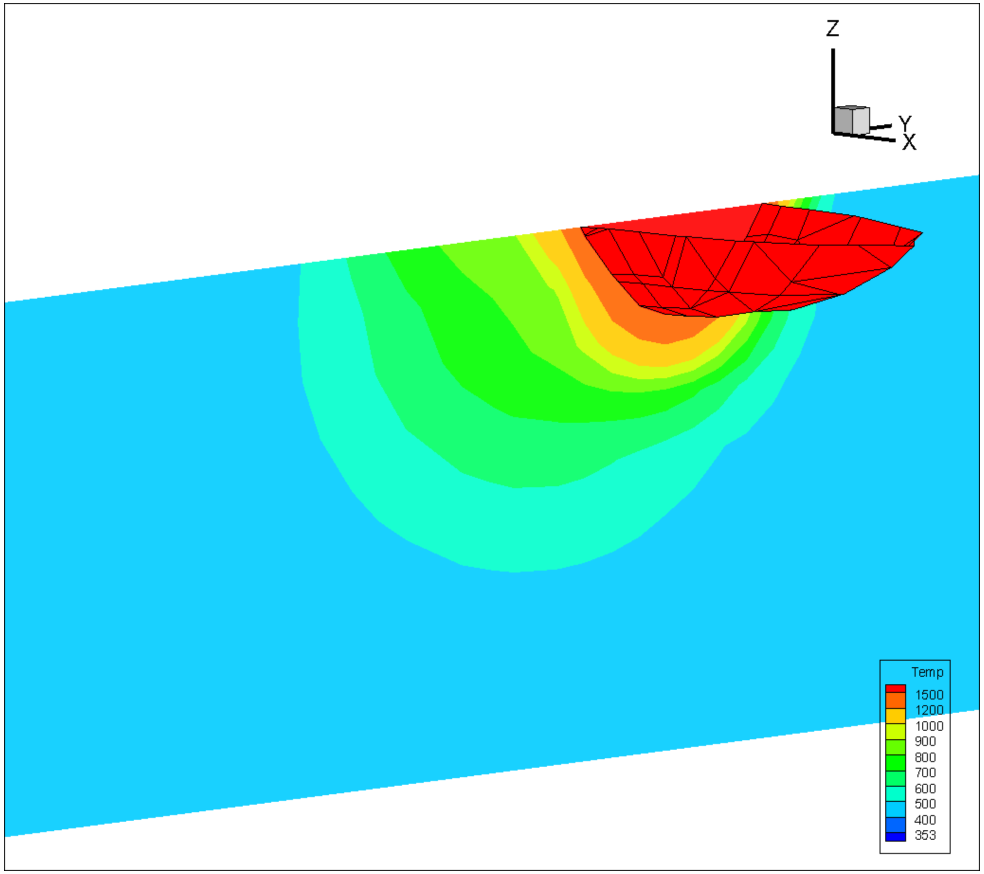
Some Results (Assymetric melt pool in17-4 PH)



In-situ Solutionizing in 17-4PH

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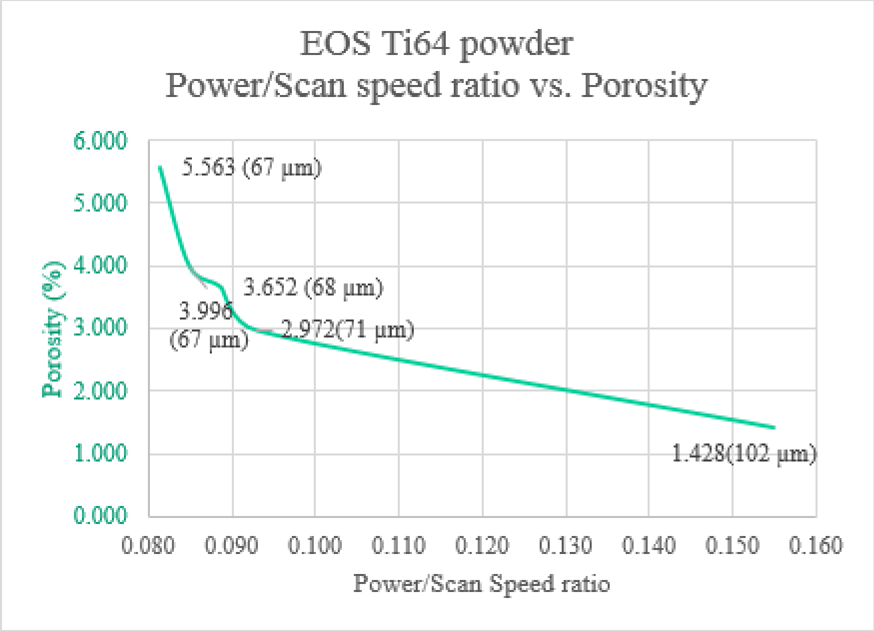
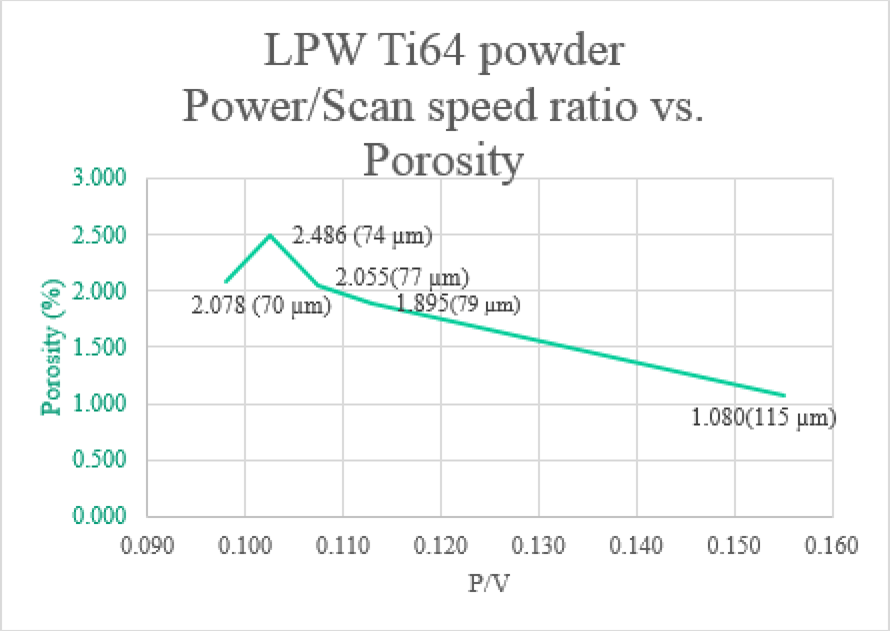
Some results
(Porosity of arbitrary powders)





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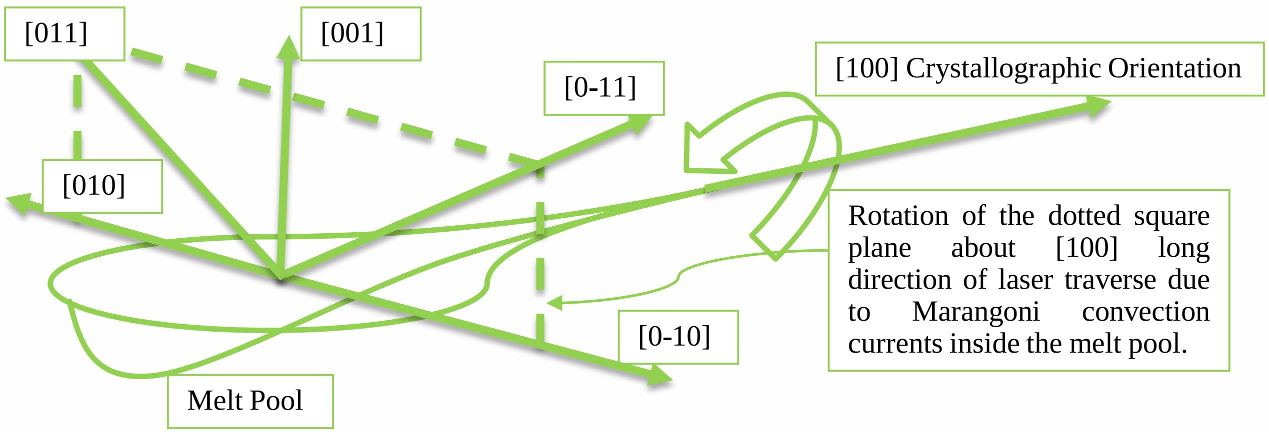
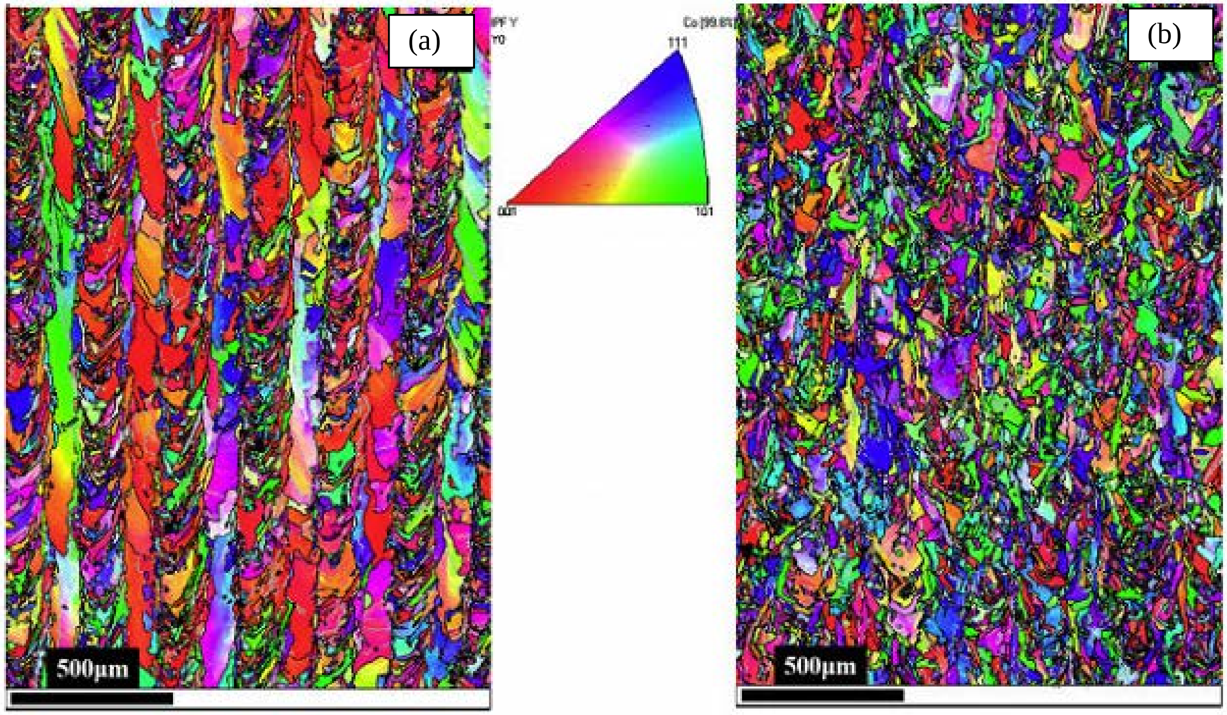
EBSD image reconstruction

(for no solid state transformations in **cubic polycrystalline** materials)



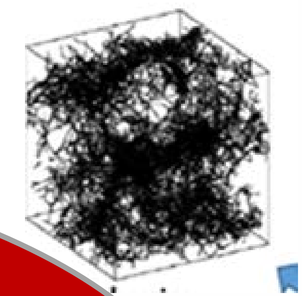
Experimental validations

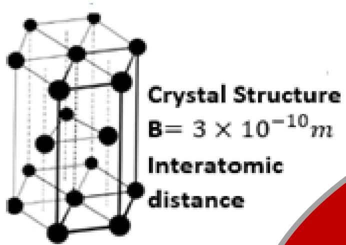


Structure ⇨ Properties Solver

Inputs

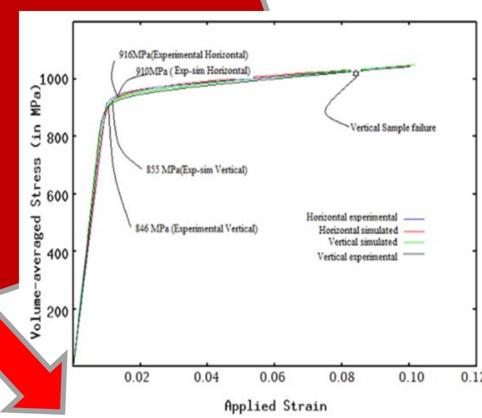
Crystal structure (Euler angles & dislocation density), thermal history and mechanical loading information (e.g. tensile/fatigue test).

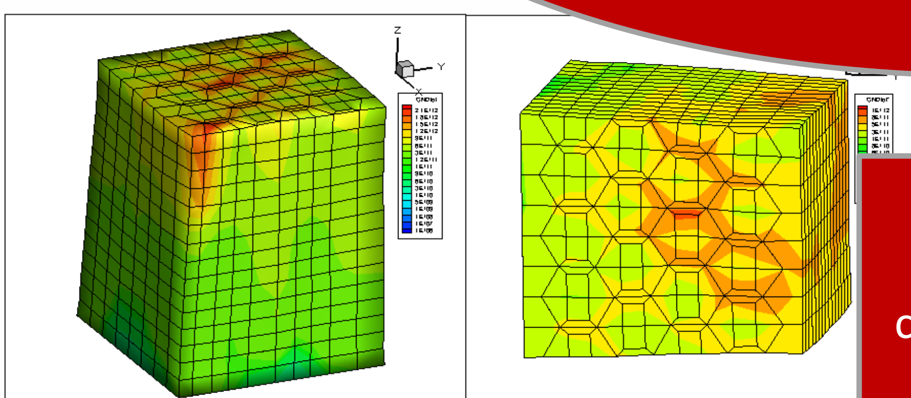




3DSIM Material Solver

Multi-scale Dislocation Density based Crystal Plasticity Finite Element Solver

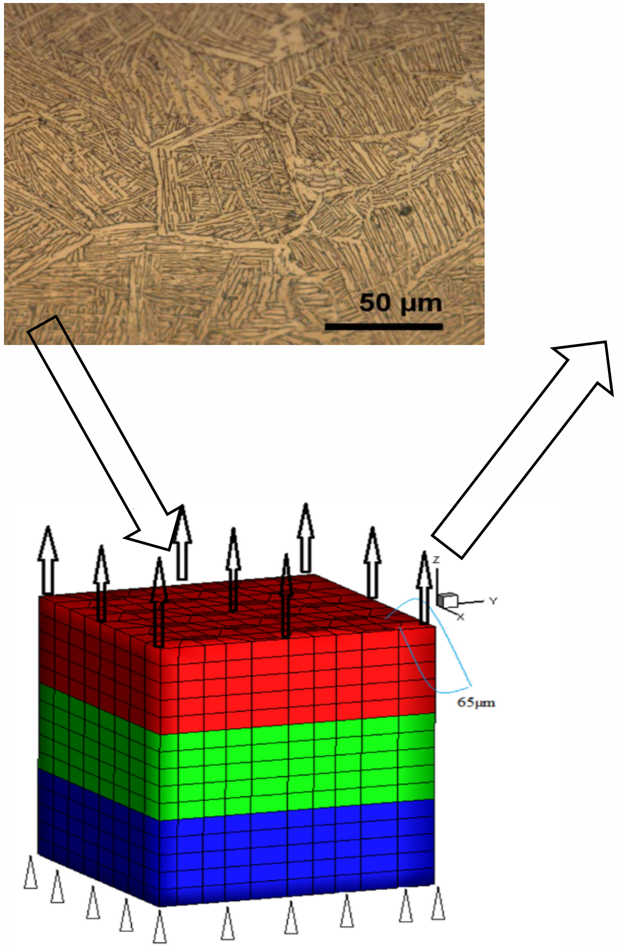




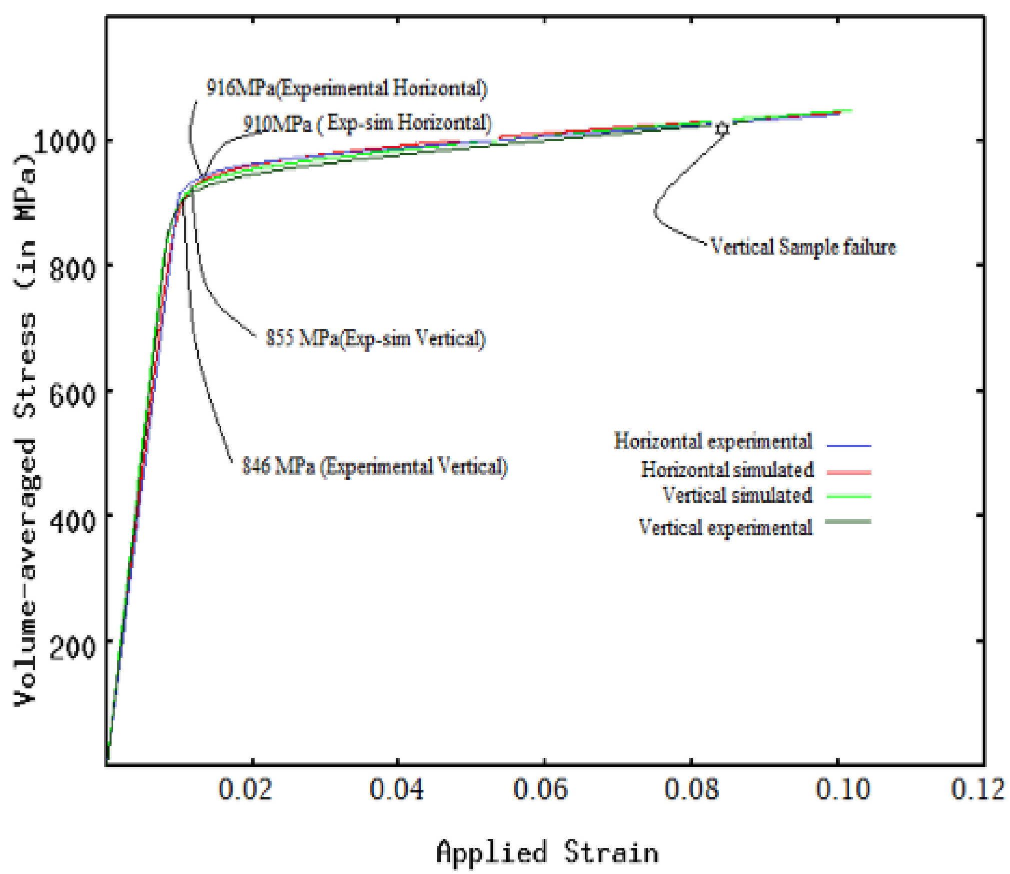
Outputs

Dislocation Density history, stress/strain curves, slip details, Modified Microstructure (grain size, orientation, etc)

Validation of Mechanical Property Predictions



Ti64 Tensile Behavior (EBM processing)



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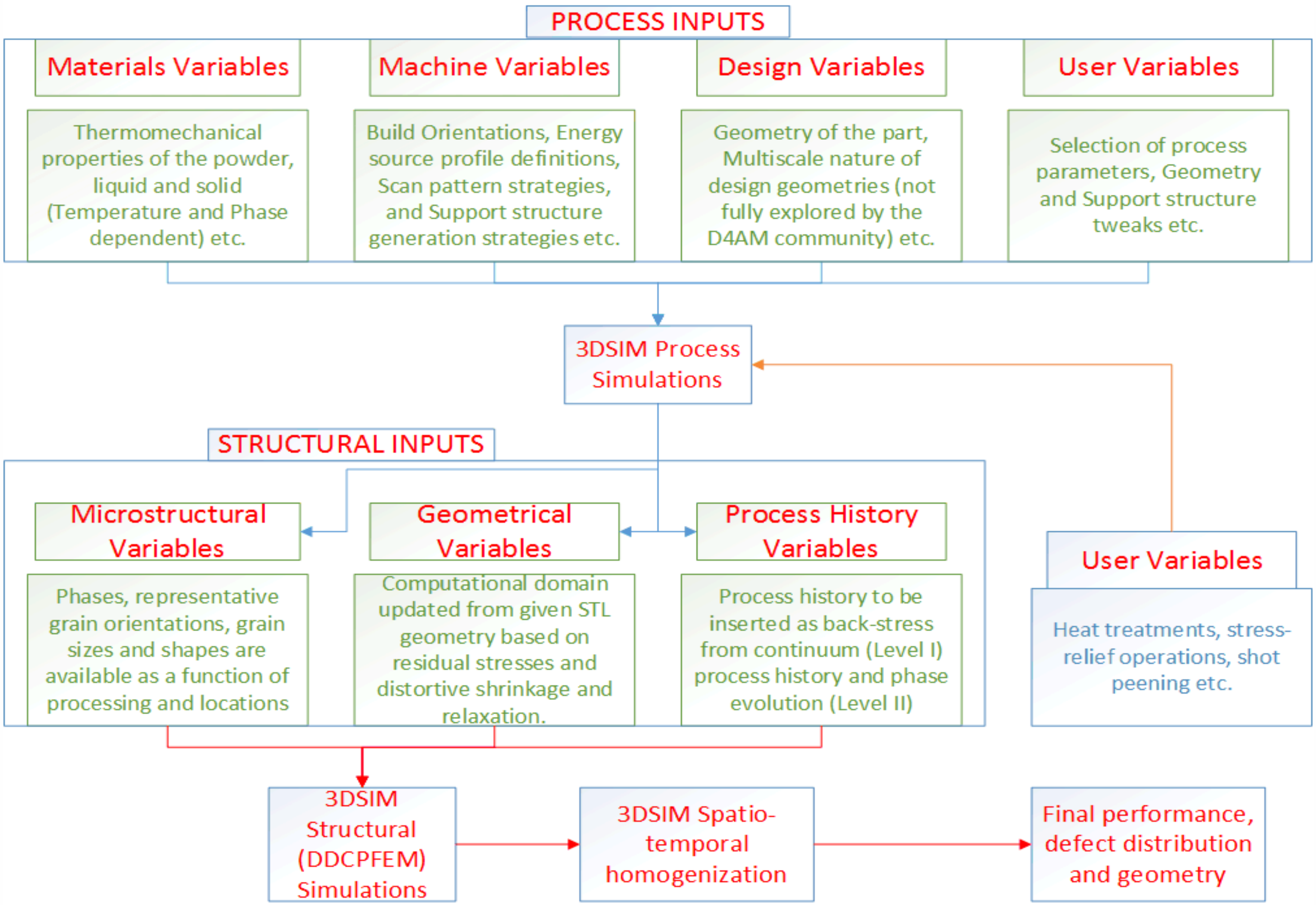
Process-Structure-Performance Linkage



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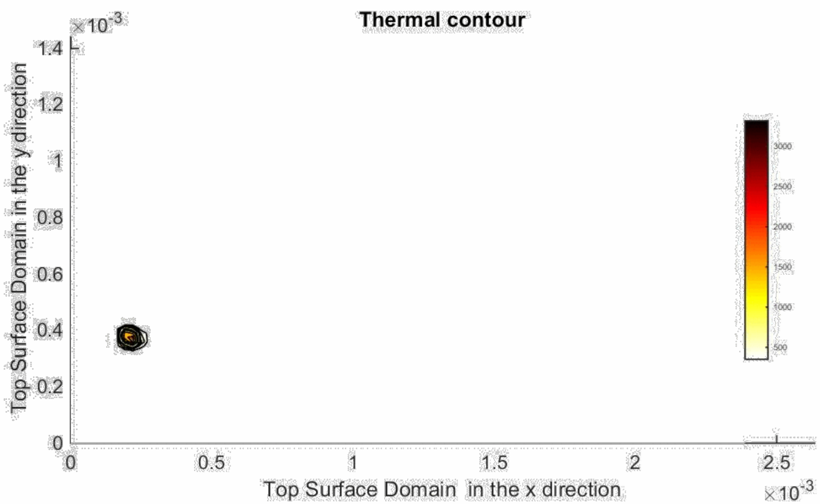
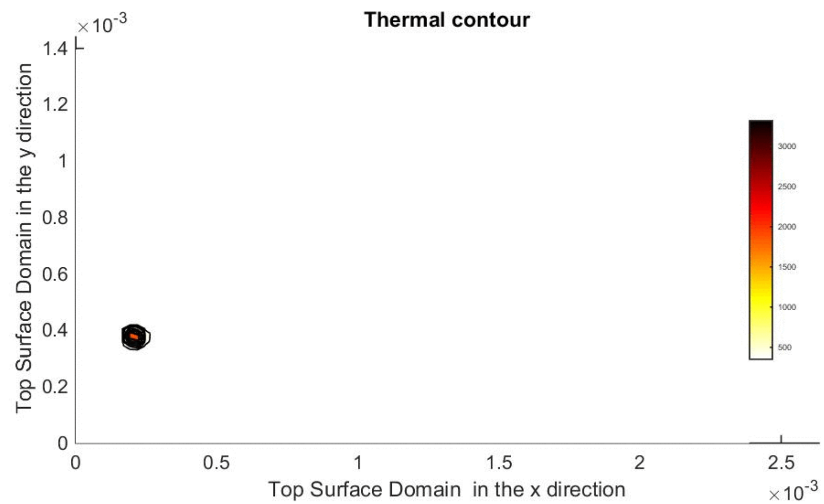
Demo of Thermal Solver

Demo information: top surface with different combination of laser power and speed

195W 1200mm/s



250W 800mm/s



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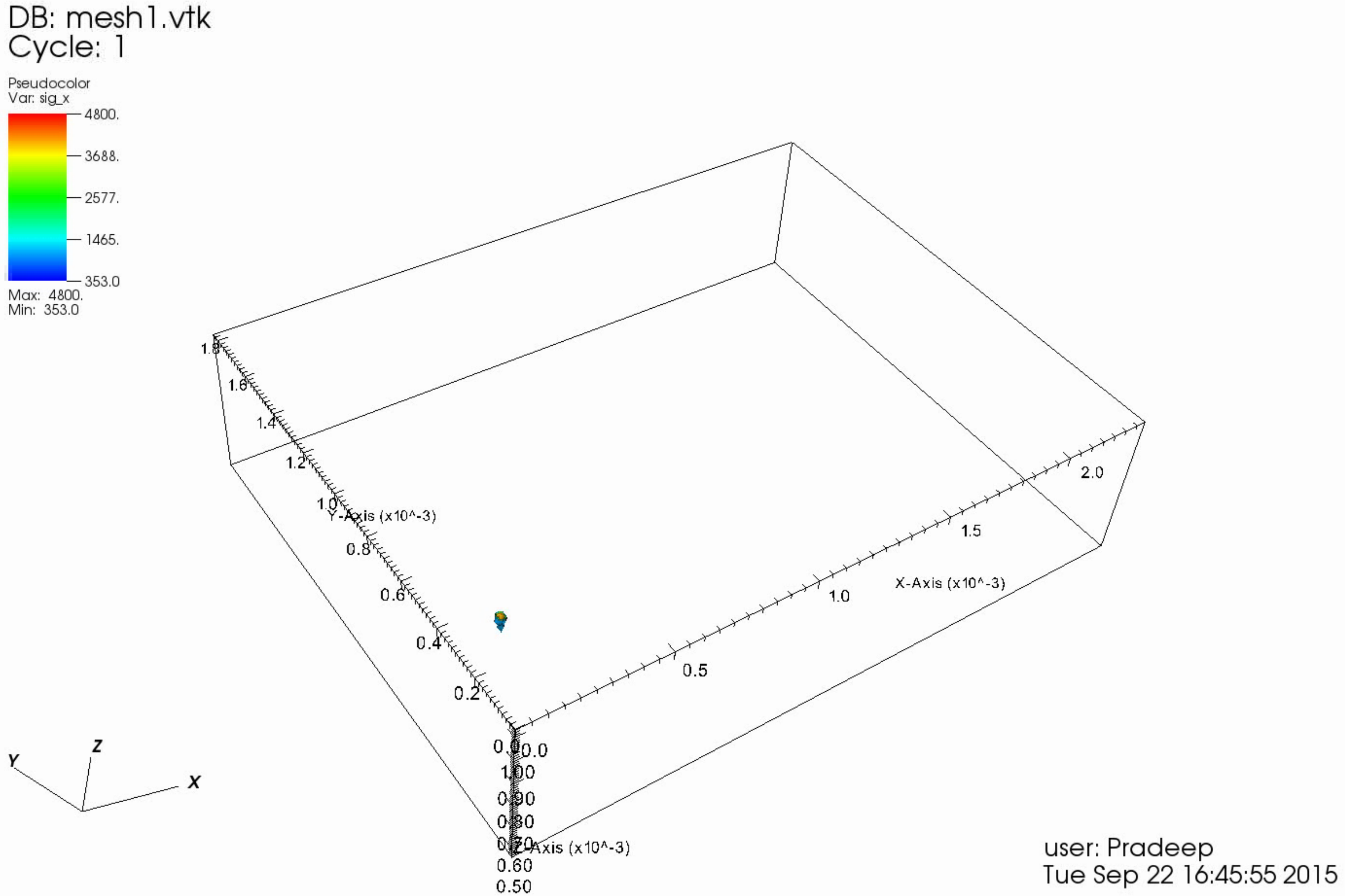
Isothermal Contour of Temperature Field



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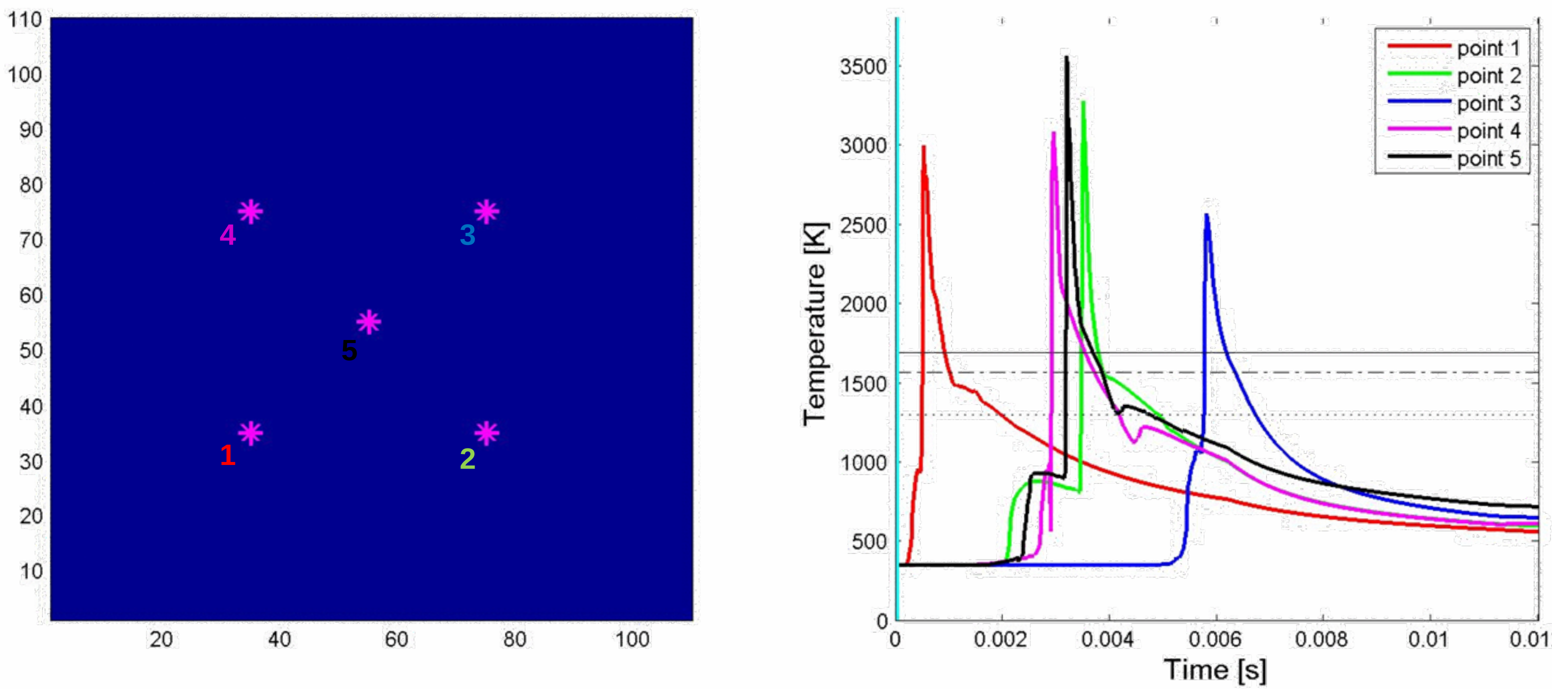
Material State Tracking

- Spatiotemporal thermal response of part is predicted using 3DSIM's Finite Element Method (FEM) rapid response thermal solver.

- Thermal history tracked at any point of interest
  phases determined by comparing T and dT/dt against CCT diagram



335W 1800mm/s

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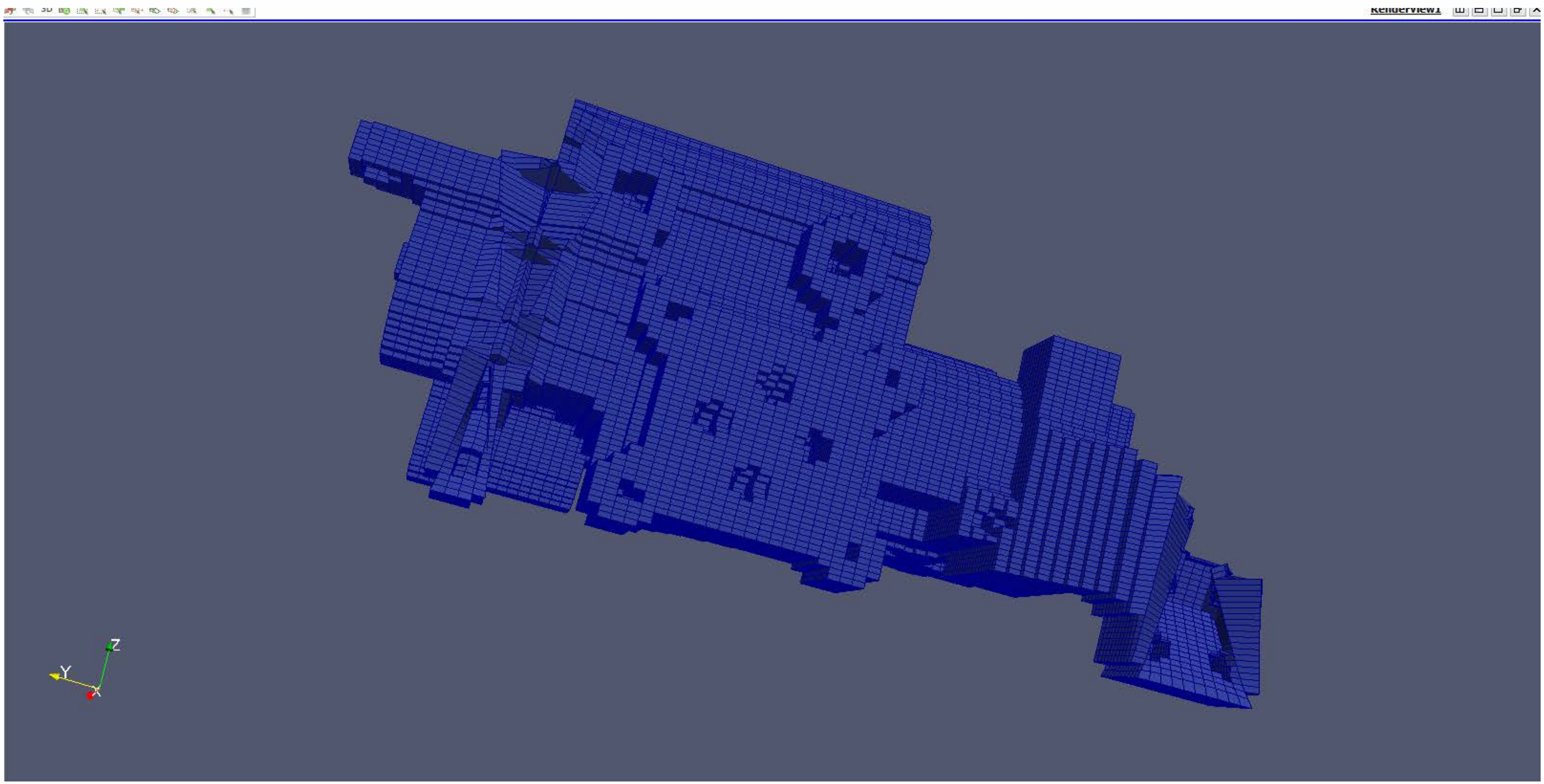
Residual Stress and Warping (Nachiket)



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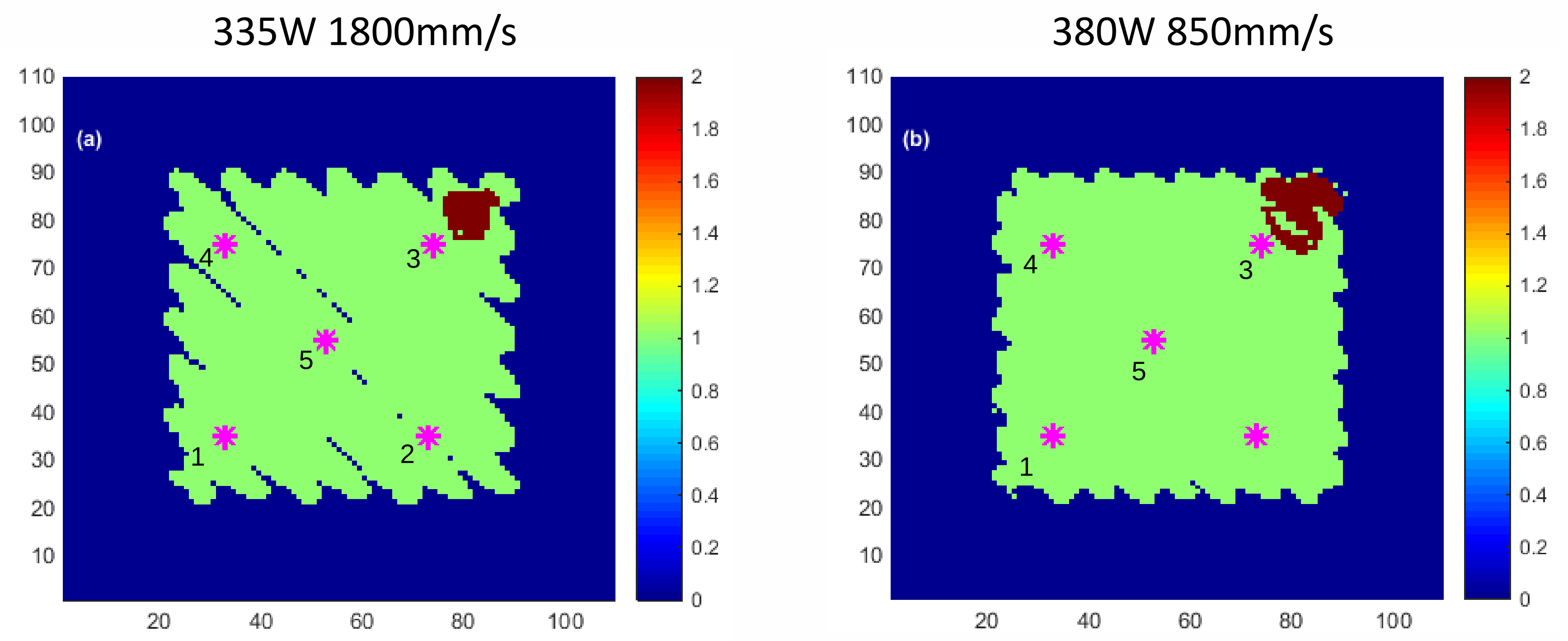
Other Capabilities

Voids Comparison:



- Case A- voids due to lack of fusion (less overlap between scan lines)
- Greater heat accumulation in corners with short scan lines (top right)

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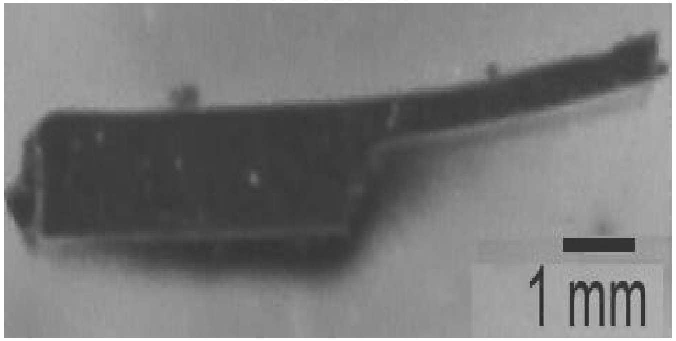
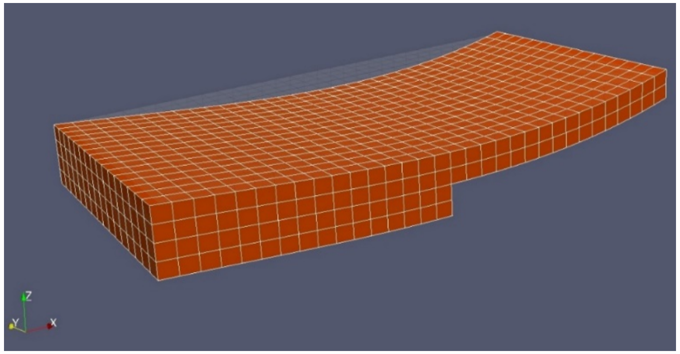
Support Optimization Tool

Support structure Example: Standard

Experiment Sample

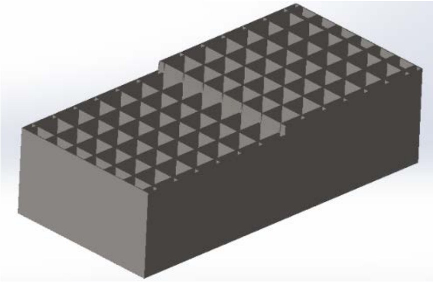


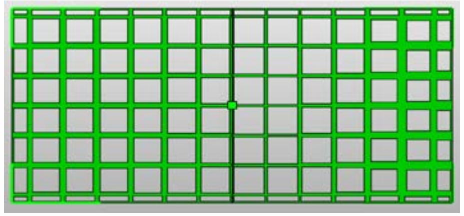
FEM Stress calculation



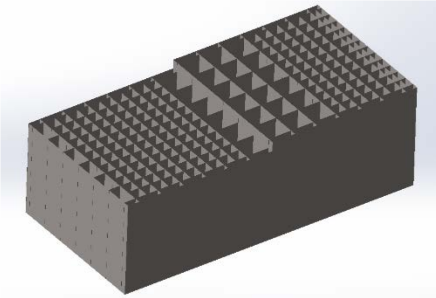
Stress based optimized support structure(Showing in 3D and 2D)

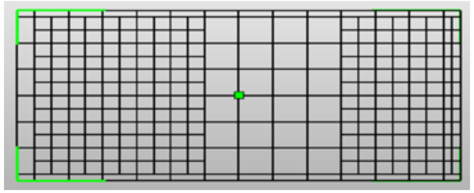
Supports structure with non-uniform thickness





Supports structure with non-uniform spacing (single bead wall)

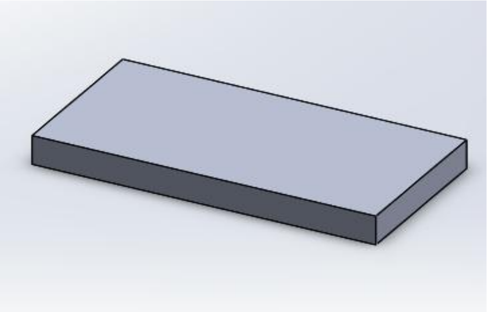




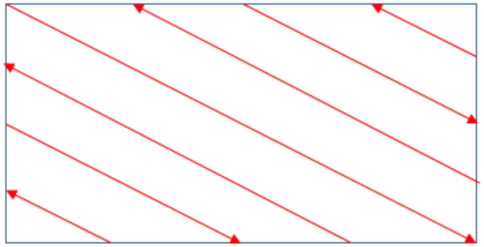
Support Optimization Tool (cont.)

Support structure Example: Sample with oriented scan pattern

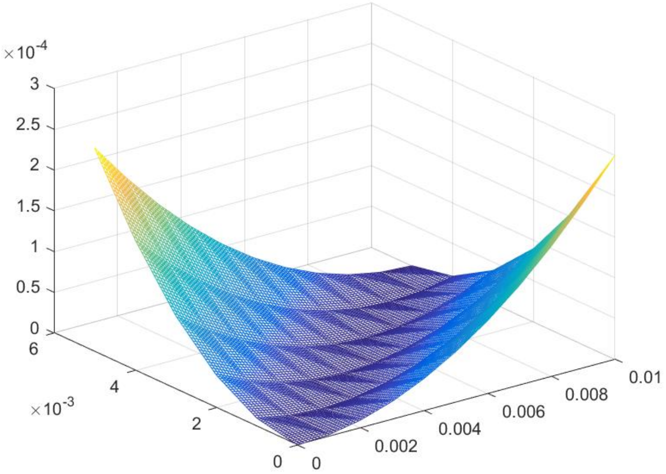
CAD model



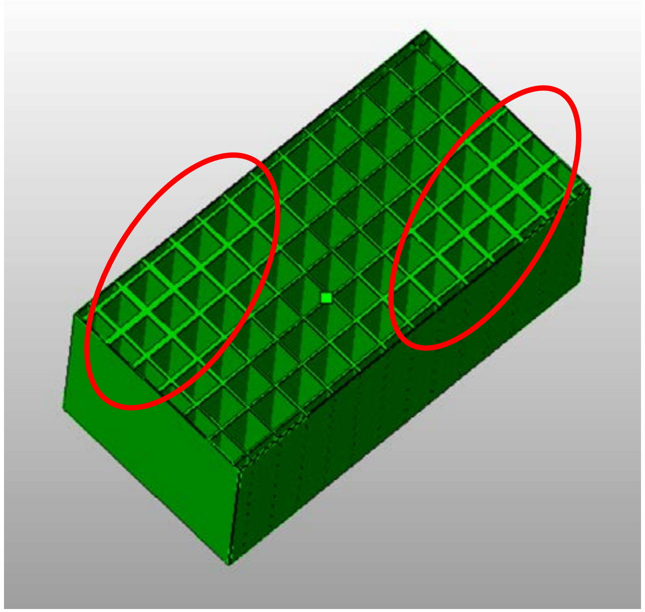
Scan pattern



Displacement distribution
Unit: m



Support structure



Questions

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