Predictive simulation for microstructure and porosity evaluation in SLM process

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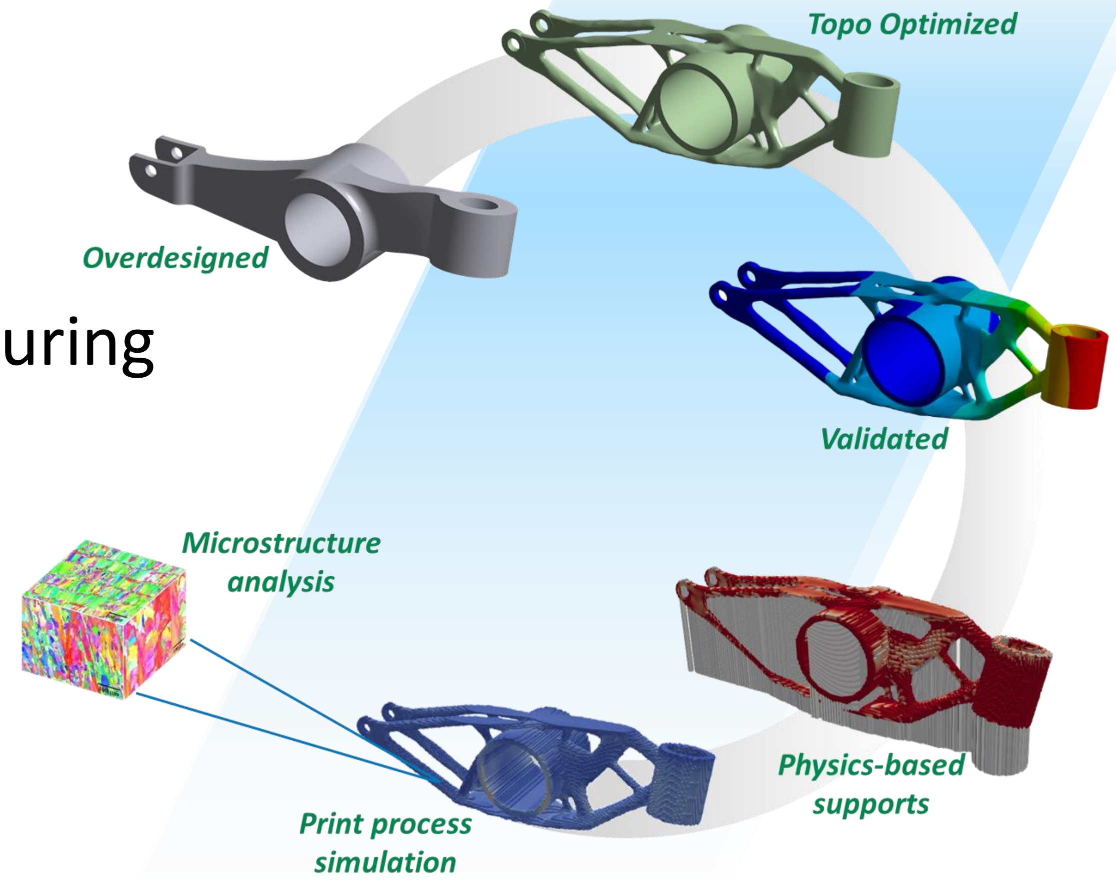
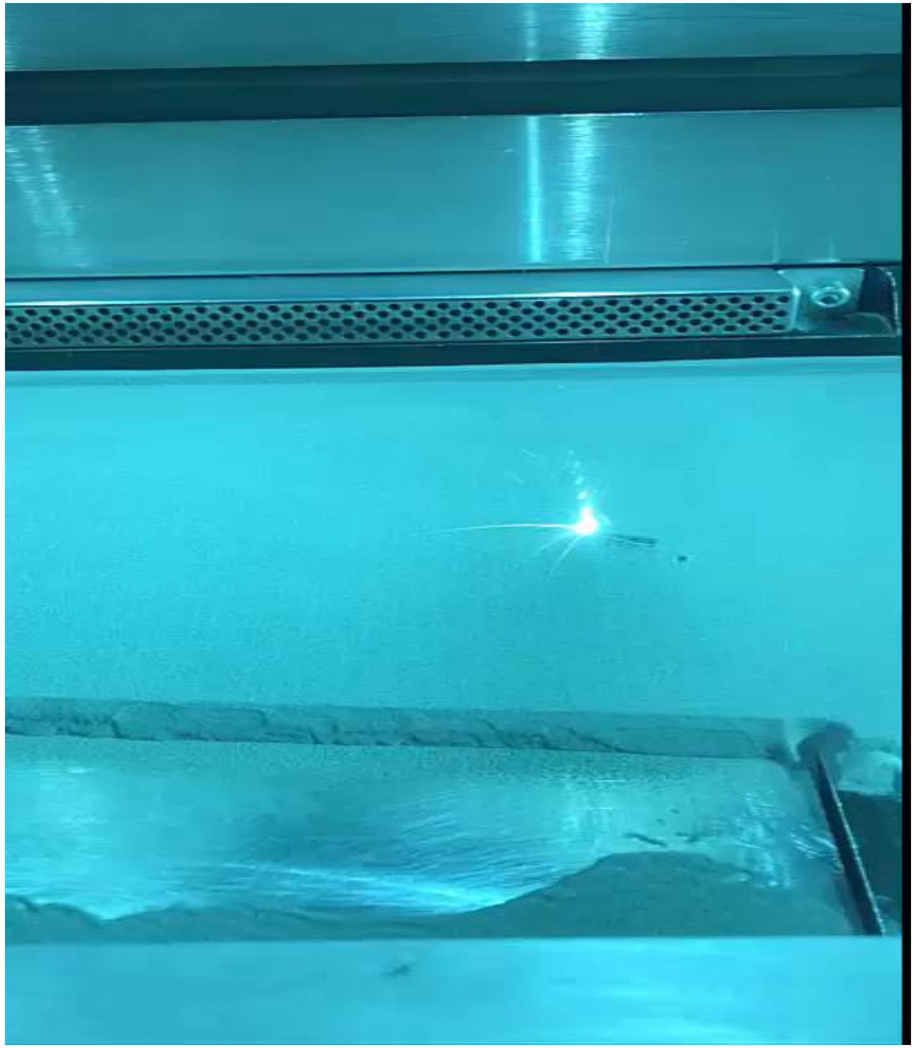
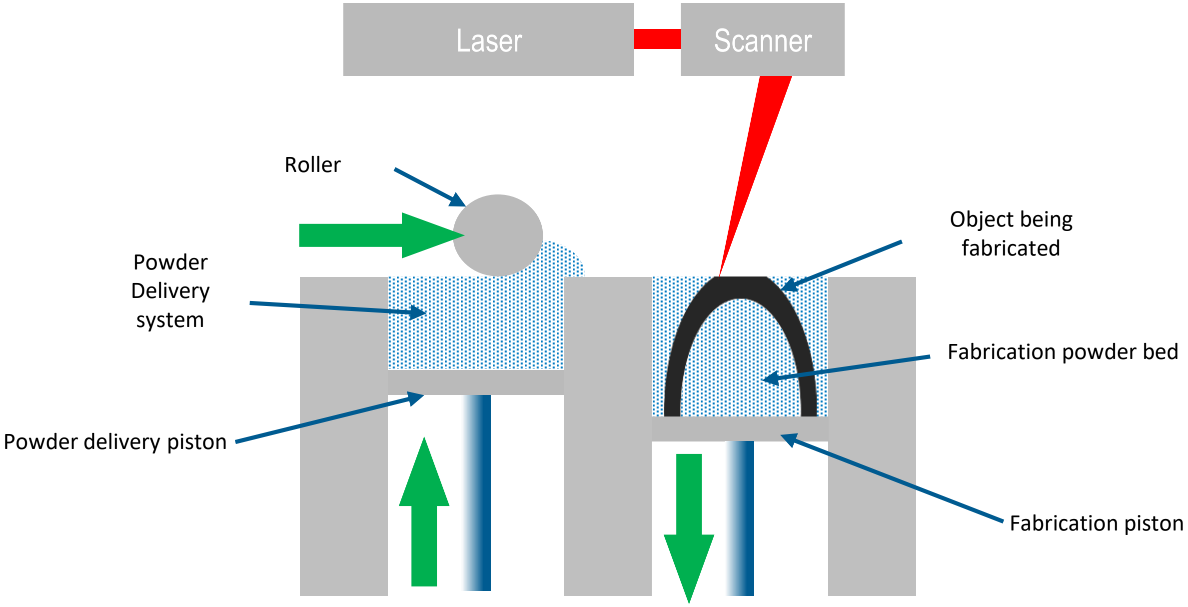
Agenda

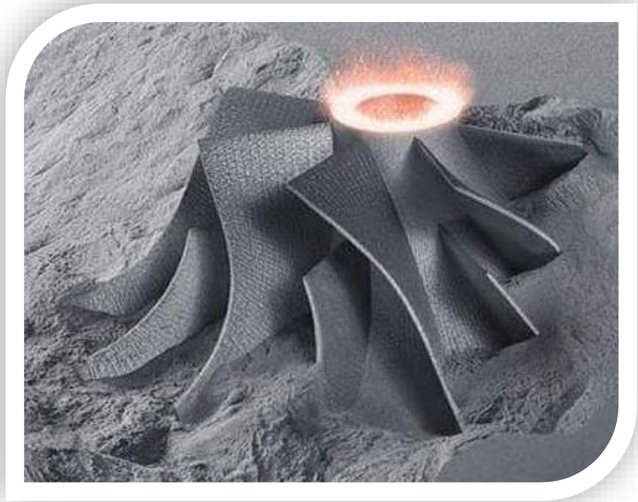
- Introduction
- Process simulation in Additive Manufacturing
- Melt-pool size and shape prediction
- Porosity and microstructure
- Conclusion

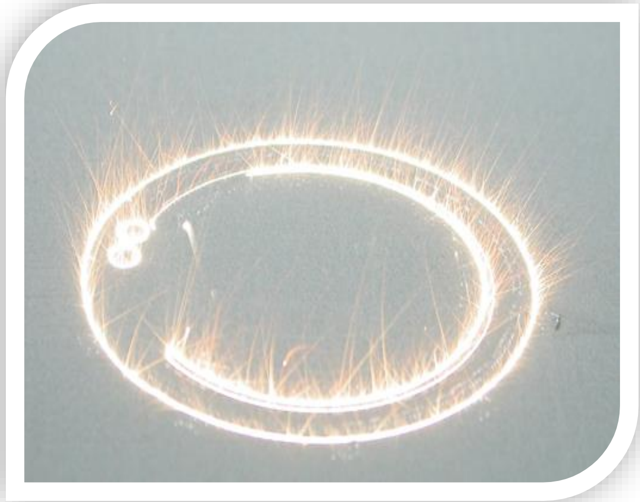


Metal Additive Manufacturing – Powder Bed Fusion

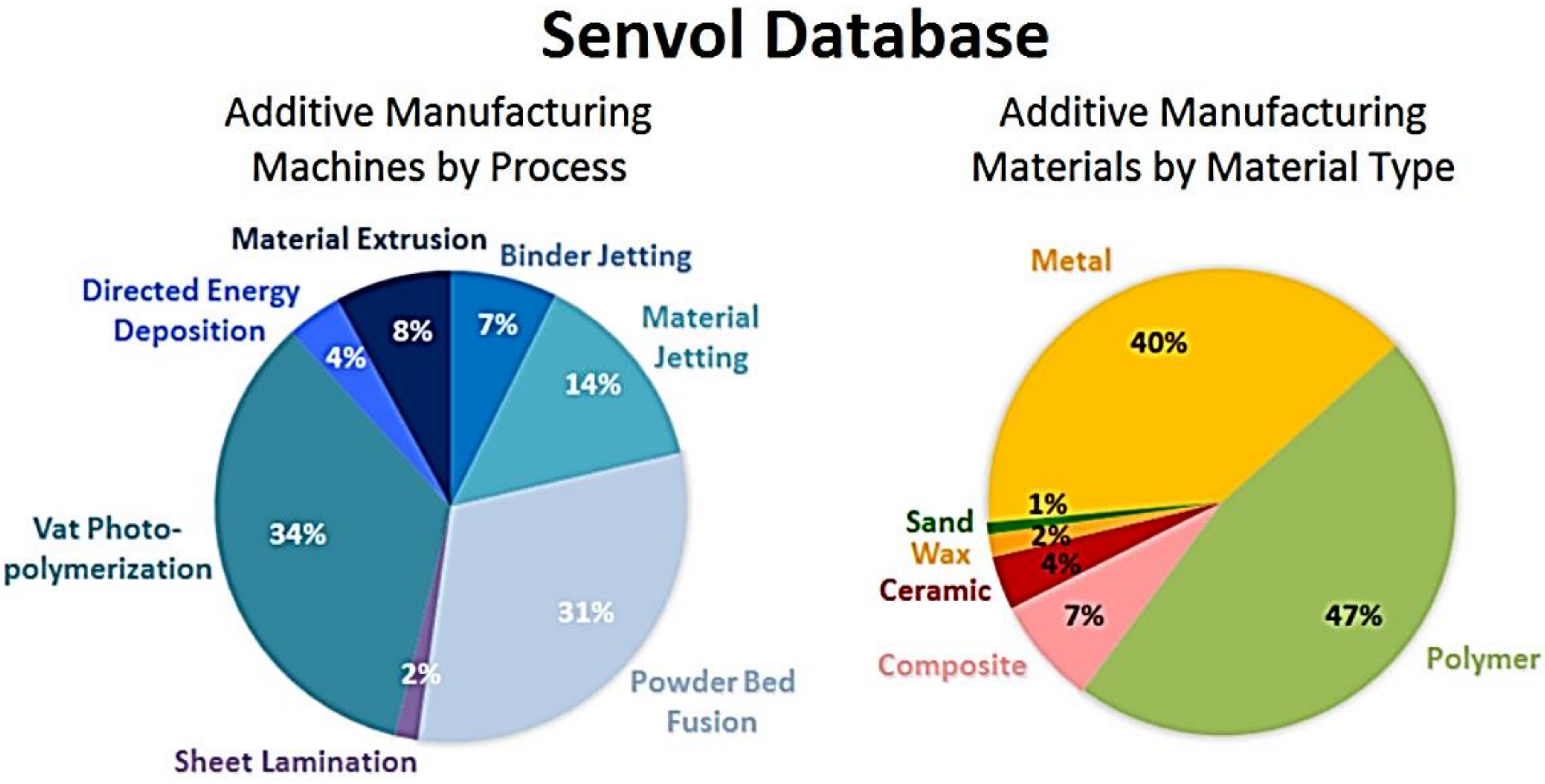






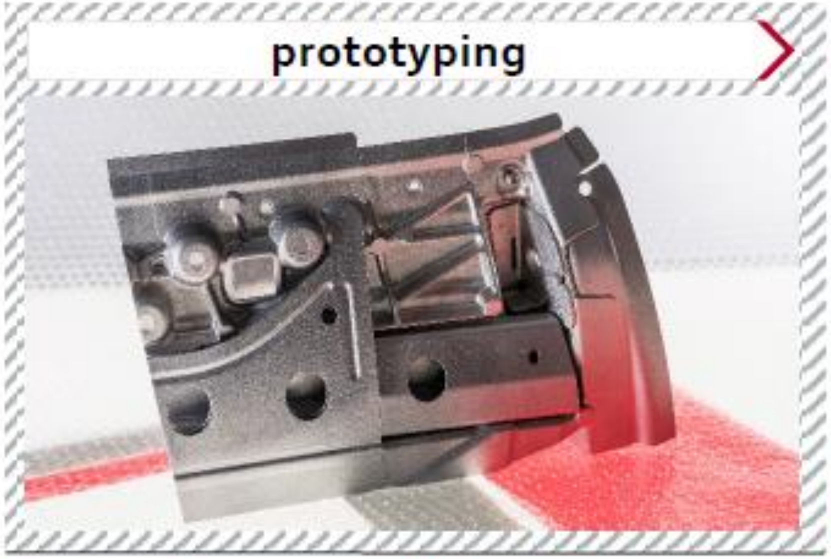


Today's market for Additive Manufacturing



[1] https://www.engineering.com

Practical Applications



Technology is established

- prototyping
- design studies
- show cars

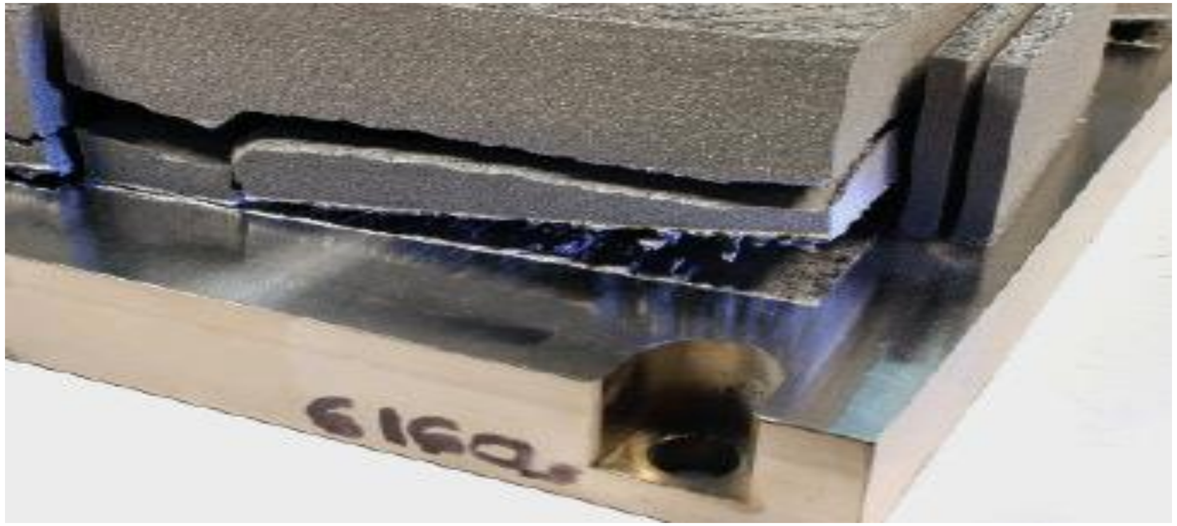
Technology is partly established and economically used

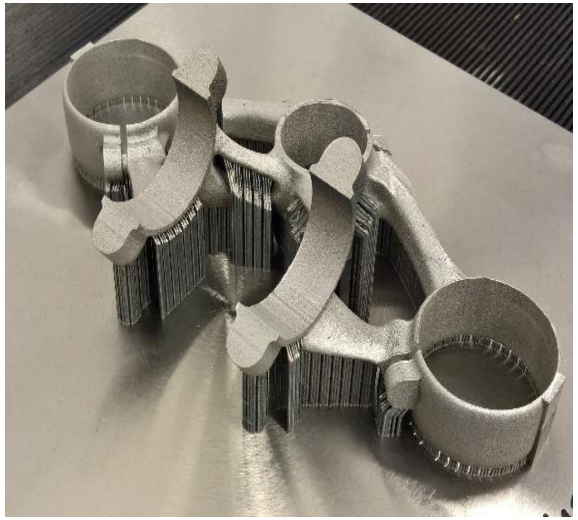
- hot forming tools
- high pressure die casting molds
- functional integration
- robot grapper

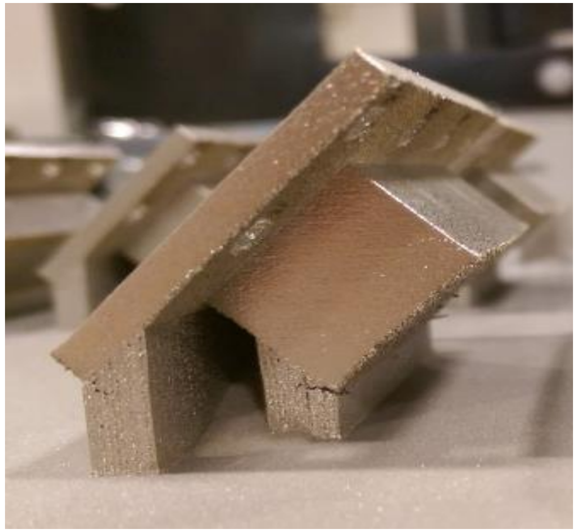
First parts in exclusive serial applications

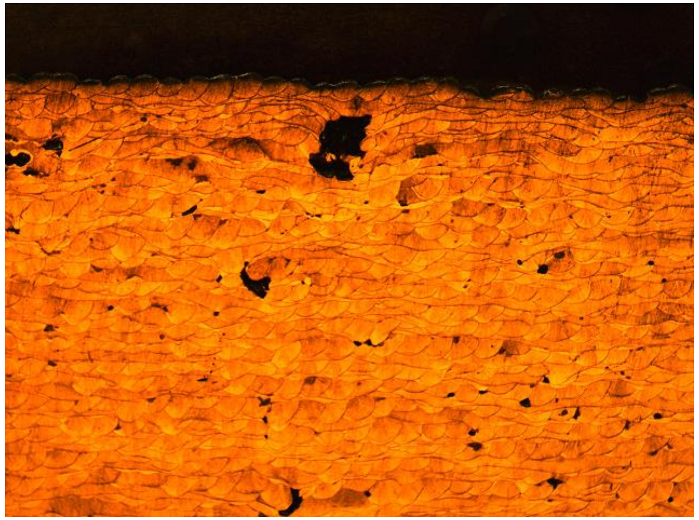
- light weight
- bionic structures
- mass customization
- after sales

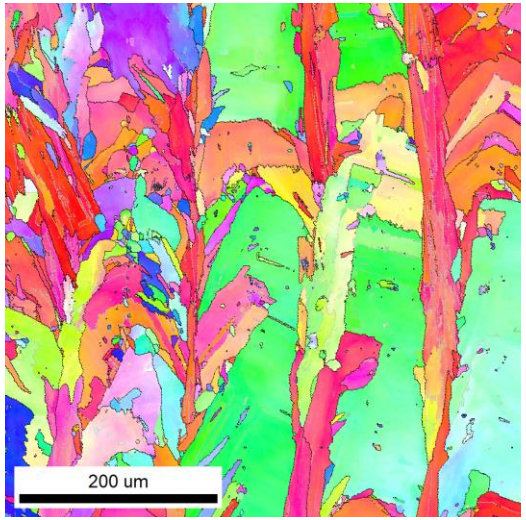
Main Challenges in Metal Additive Manufacturing

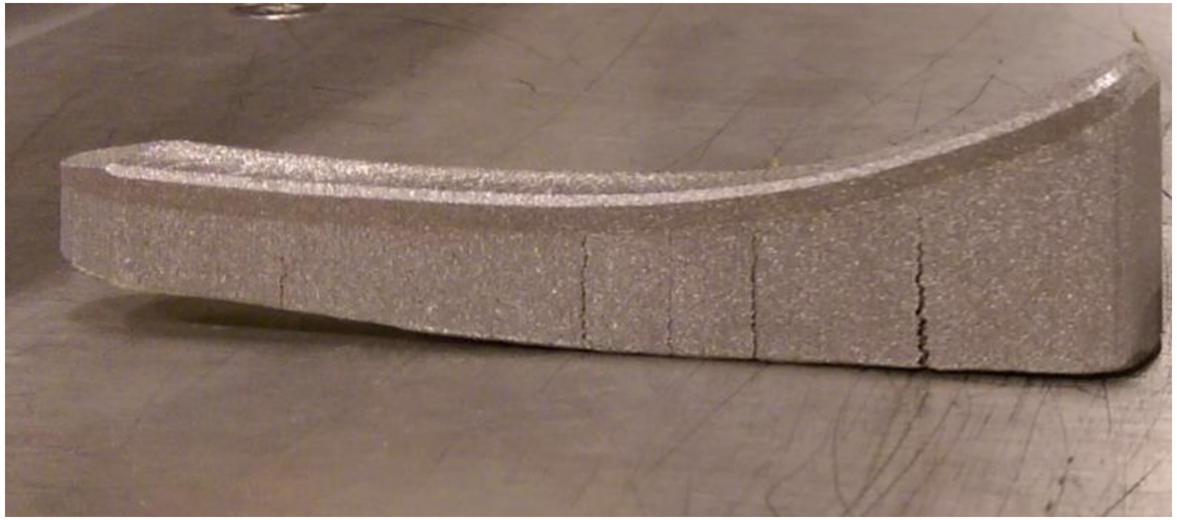








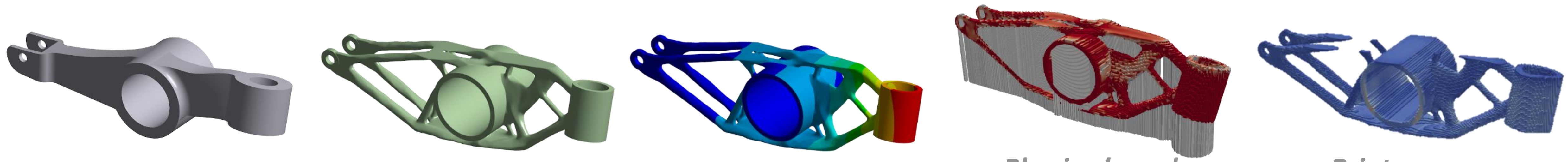




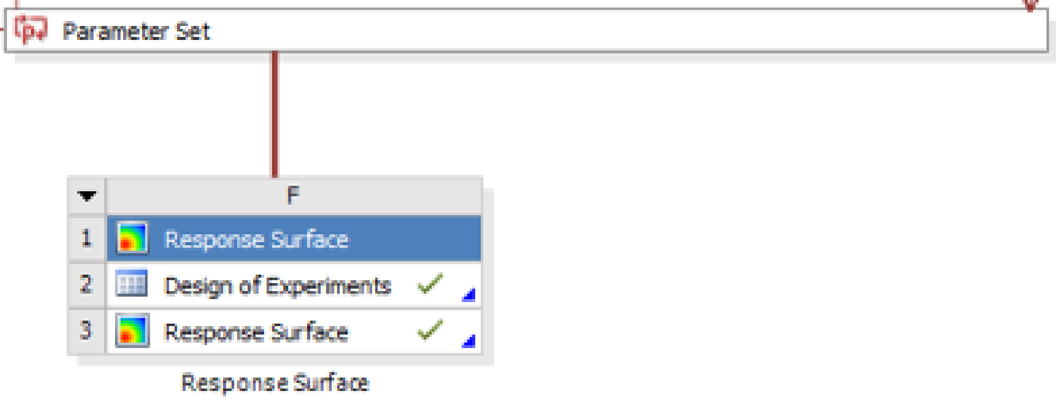
Design workflow for Additive Manufacturing

Design

Process Simulation



Overdesigned → *Topo Optimized* → *Validated* → *Physics-based supports* → *Print process simulation*

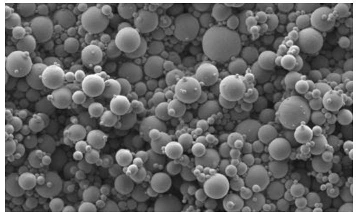


End-to-End Workflow
Parametric

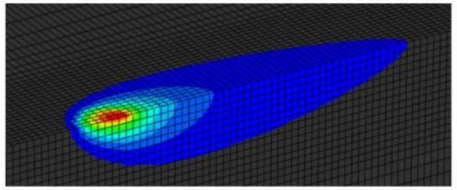
In AM we Create the Material Properties as we Create the Part

Forum Teratec

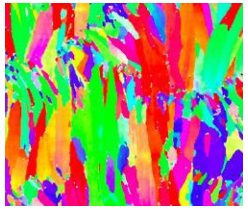
Constituent Materials



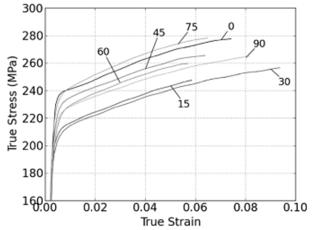
Process (Temperature Excursions)



Microstructure



Mechanical Properties



we must understand this…

…but Designers really want this

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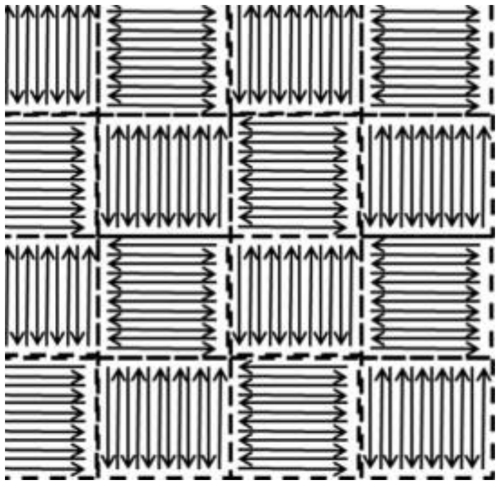
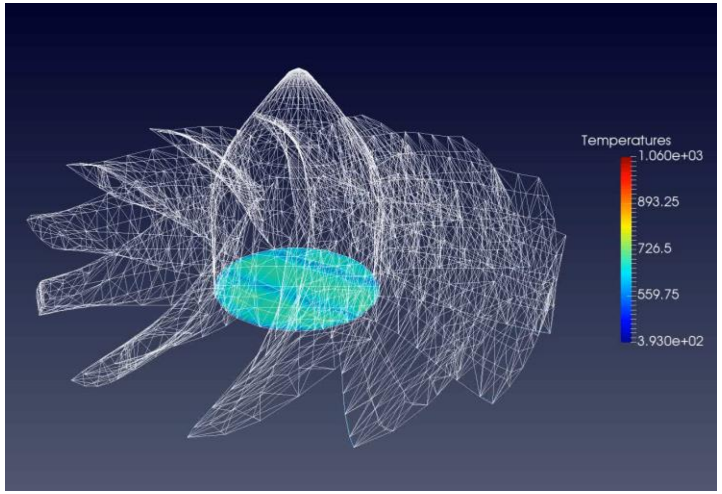
Key to Accurate Predictions is to get Exact Thermal History

Each Machine Manufacturer uses different **Scan Pattern** logic.



A unique **Scan Pattern…**

…results in a unique **Thermal History**



…which results in different:

- Strain Magnitudes
- Defect Distributions
- Microstructures
- Mechanical Properties

Which is why Predicting **Thermal History** at the **Meltpool level** for **Full-Scale** components is critically important!

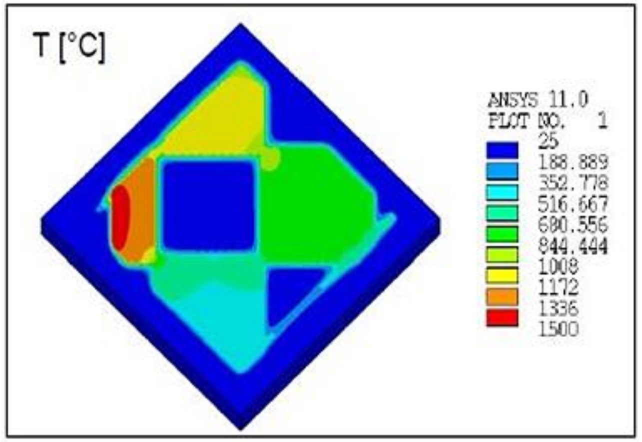
Which scale would you like to simulate?

Main challenge for the simulation

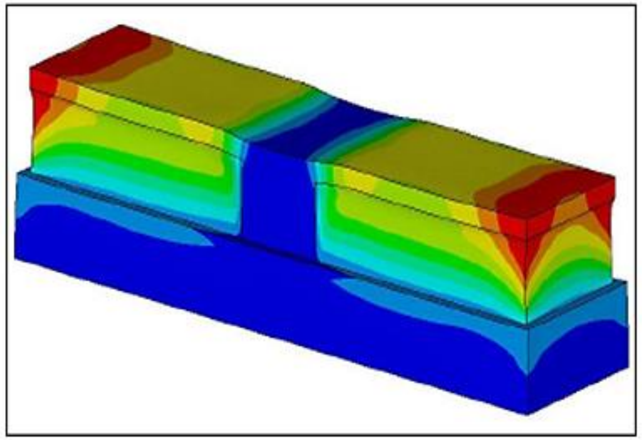
- Local discretisation: layerwise structure (dimensions of the laser spot are in µm, dimensions of the structure are in cm.
- Time discretisation: process times (exposure time of single layers is in ms, total process time can be hours)

Solution

- Simulation for single layers in a **detailed model**
- Simulation of the whole structure in a **global model**



Detailed Model



Global Model

Source:CADFEM

Prediction of the melt-pool dimensions : Single Bead

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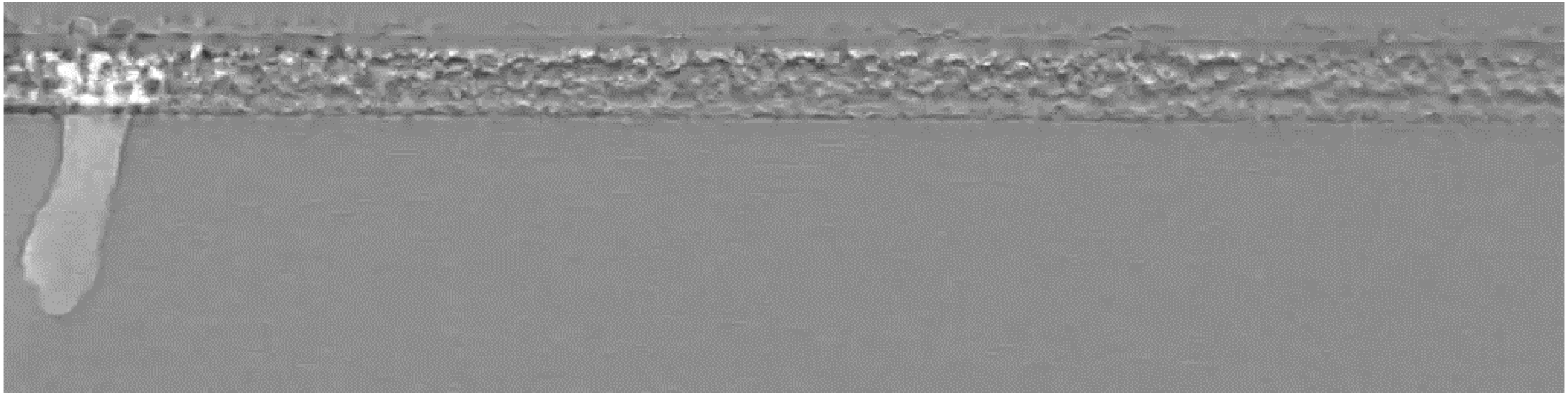
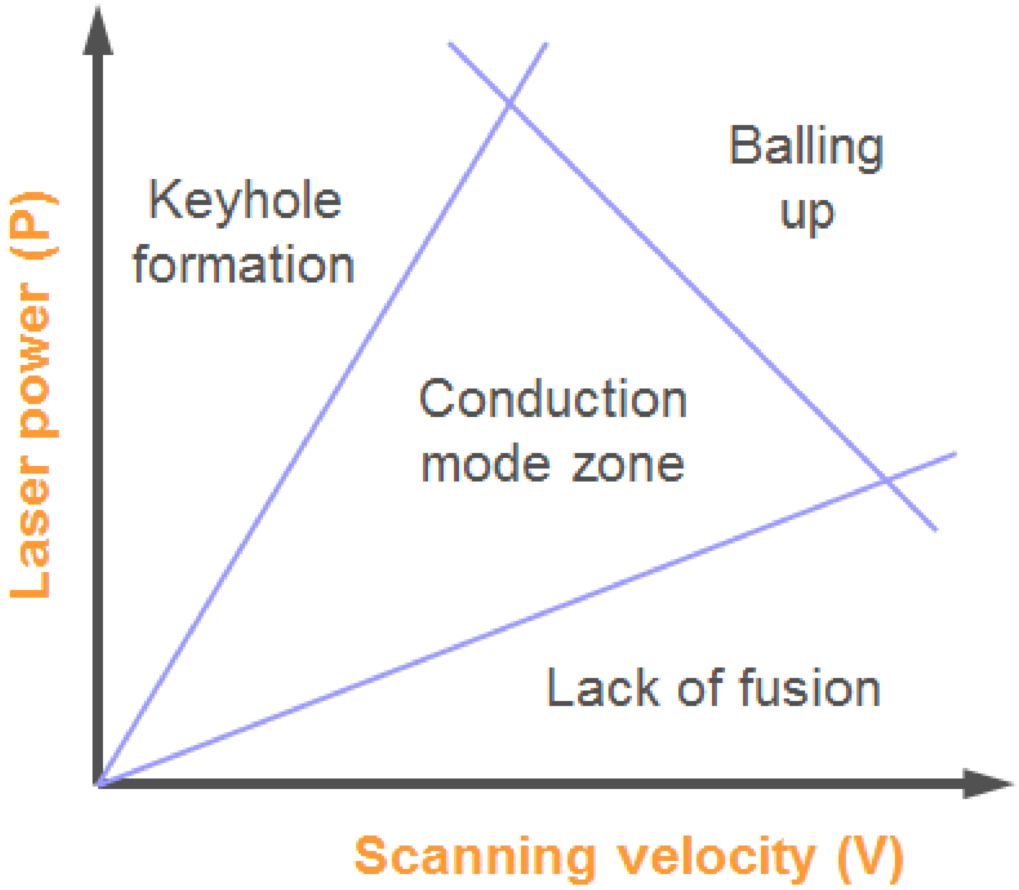
Ultrahigh-speed synchrotron x-ray imaging technique in Ti-6Al-4V



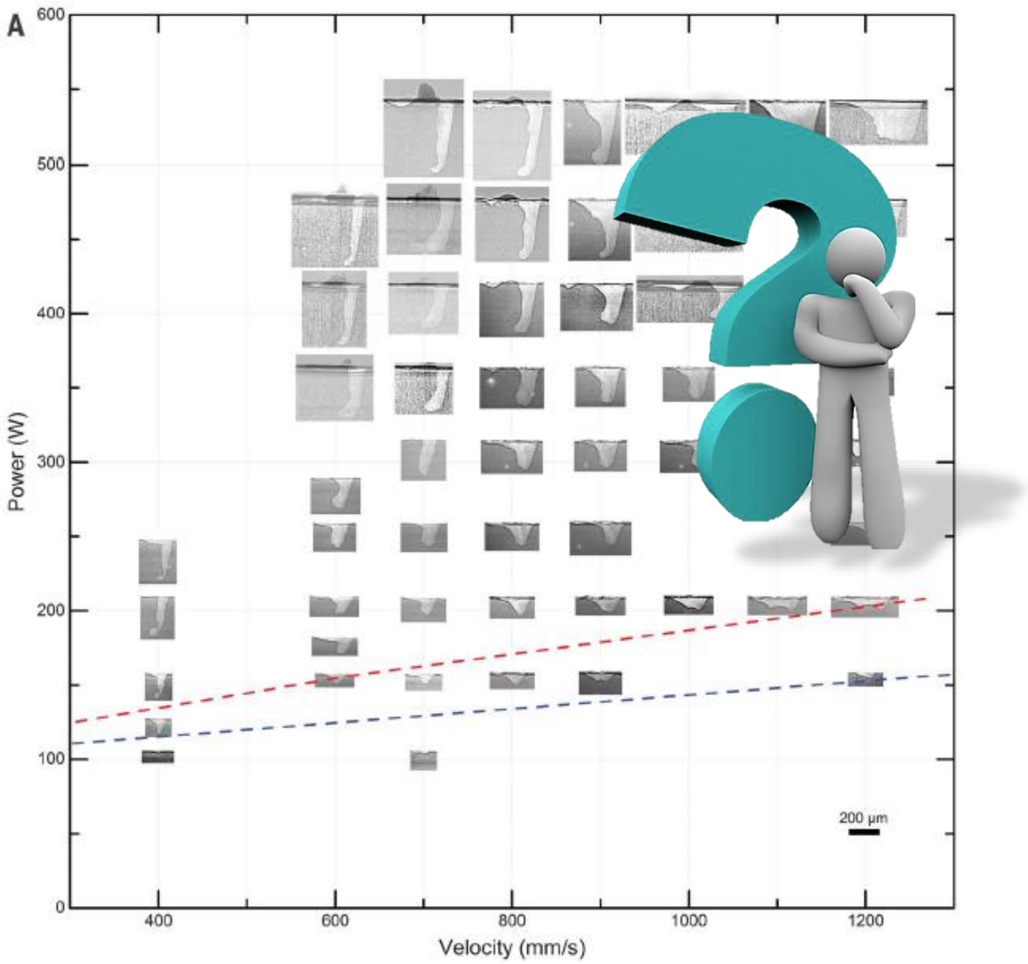
„Keyhole threshold and morphology in laser melting revealed by ultrahigh-speed x-ray imaging“, Cunningham et al. 2019

Single Bead Simulation

Sometimes described



It is really like:

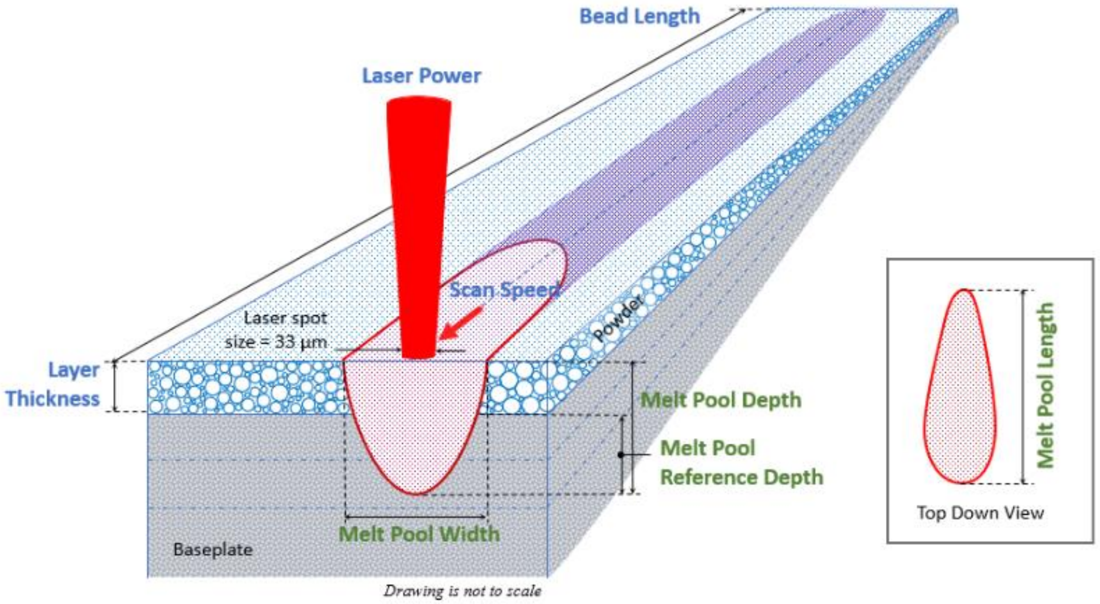


Finding optimal parameters is not easy!

https://www.linkedin.com/pulse/x-marks-spot-find-ideal-process-parameters-your-metal-marc-saunders/

Single Bead Simulation

A Single Bead Parametric Simulation is a tool used to obtain information about the melt pool characteristics of your selected material. It is set up to follow the industry practice of testing on-powder single beads on PBF machines in which the laser runs in one single scan line across powder. **The goal is to determine the geometry of the melt pool** (width, length, and depth) as shown in the following figure.



Single bead scan on powder showing melt pool dimensions
(Inputs in blue, outputs in green)

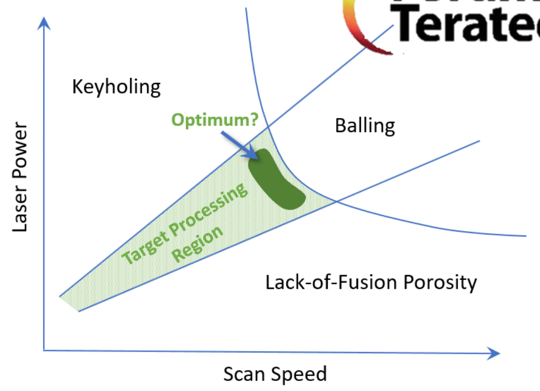
Usability:

- ✓ **Finding machine parameter**
- ✓ **Using least amount of power and material**

Single Bead Simulation : Results diagram

If more process parameters are considered the diagram could also include other criteria that are not satisfied:

Type of Porosities in Additive Manufacturing

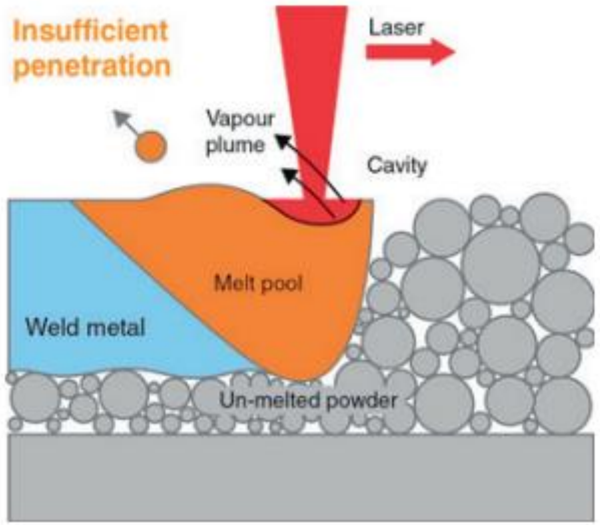


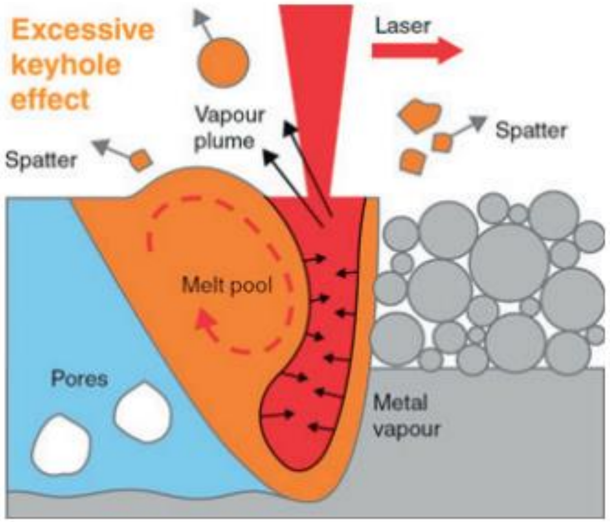
ANSYS Additive

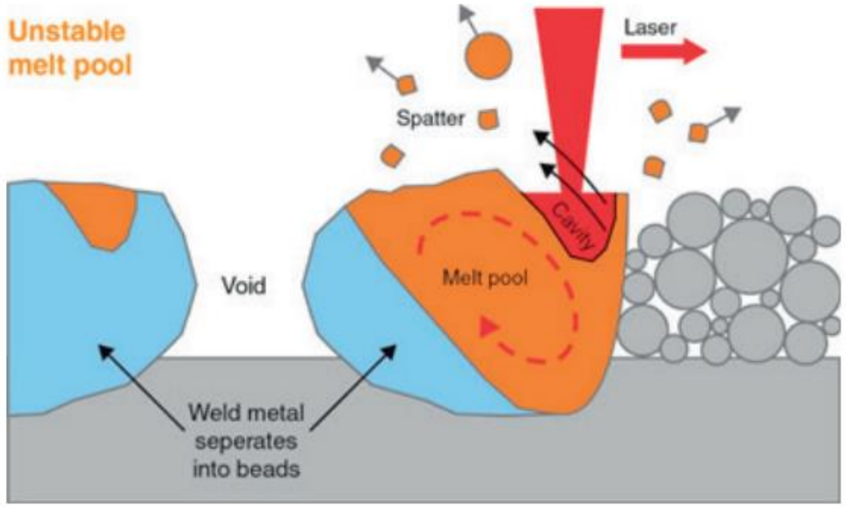
Lack of fusion

Keyhole formation

Balling up

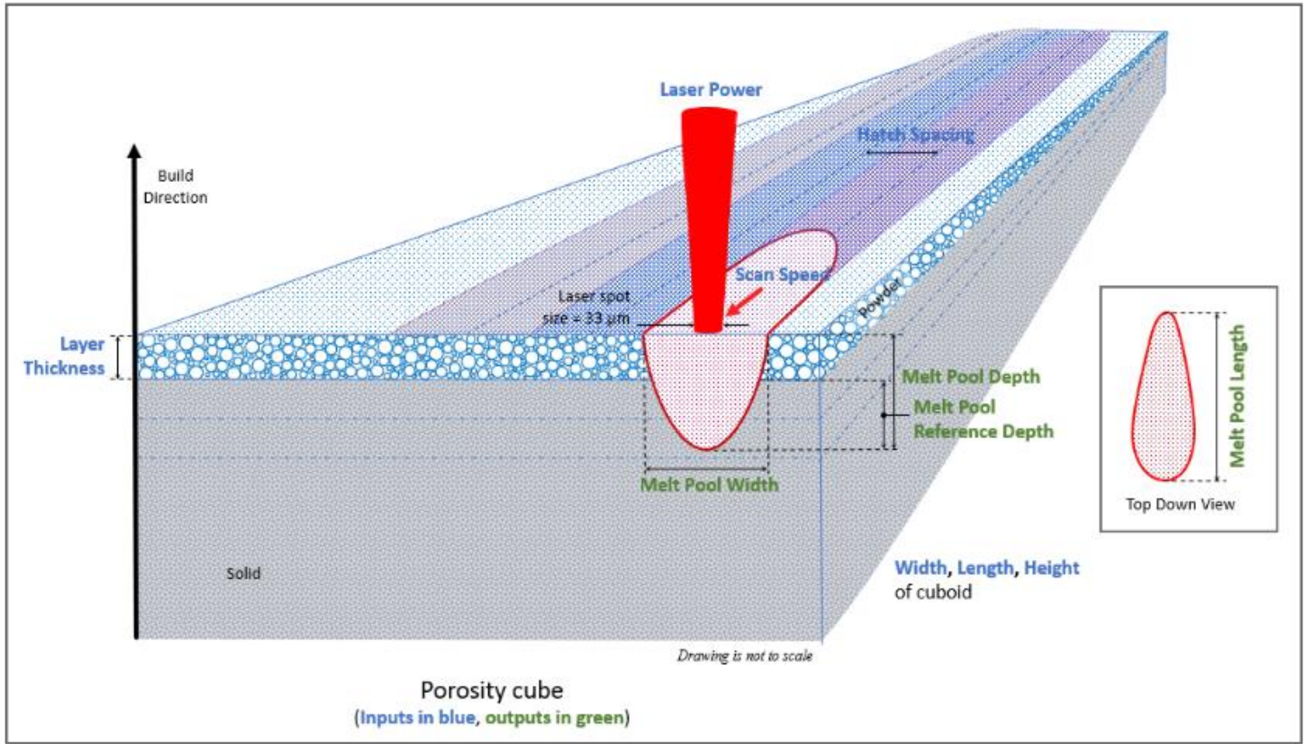




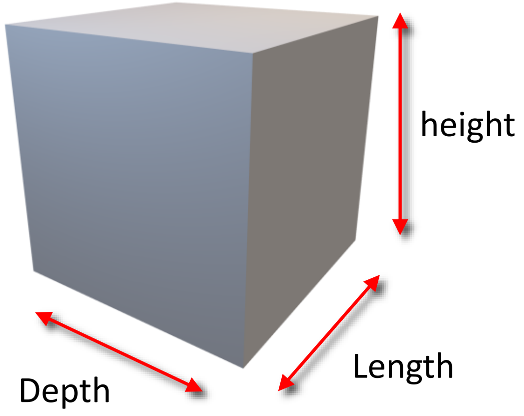


"X marks the spot - find the ideal process parameters for your metal AM parts" Renishaw

Predict Porosity on volume level



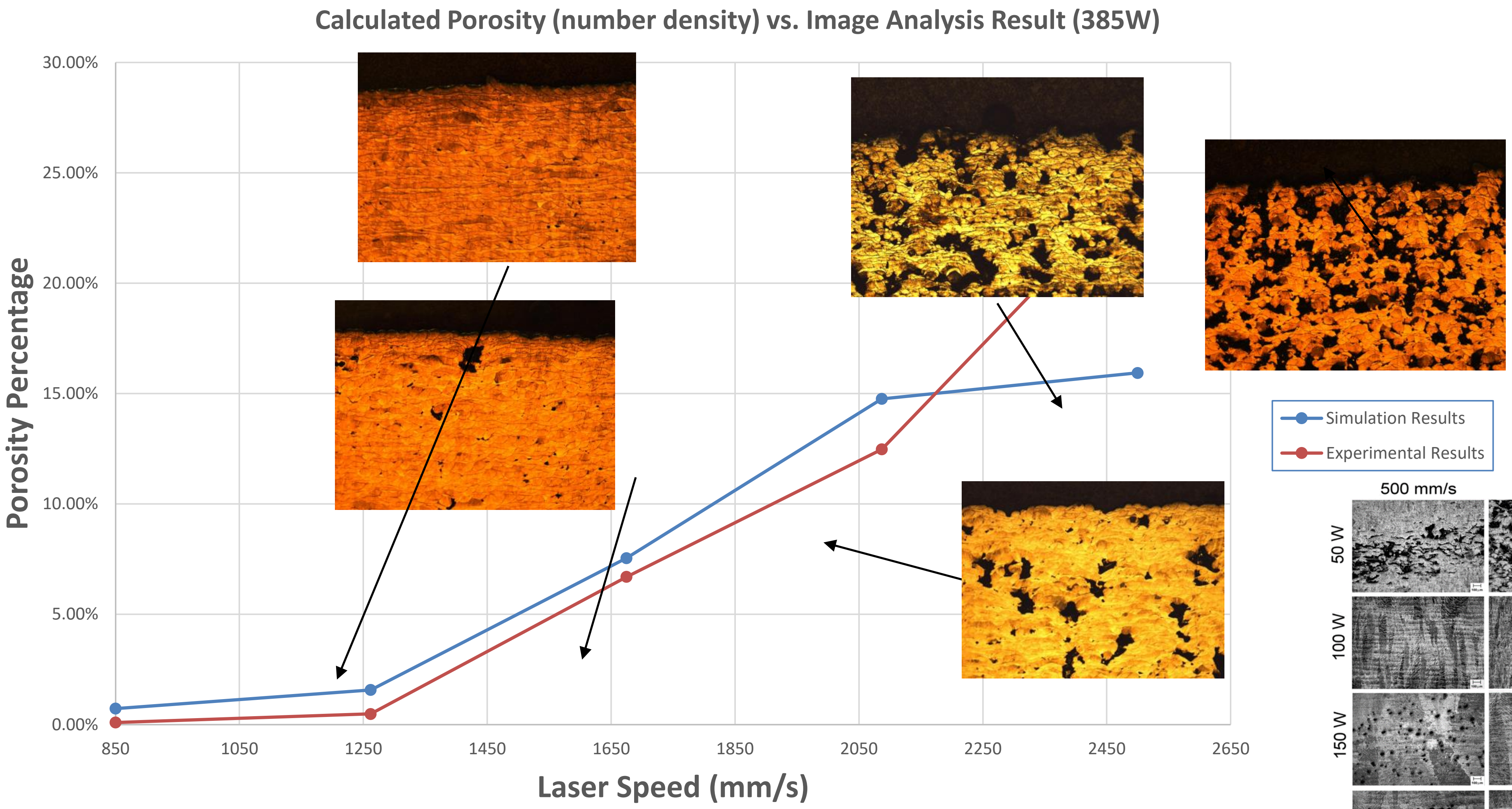
Porosity cube
(Inputs in blue, outputs in green)

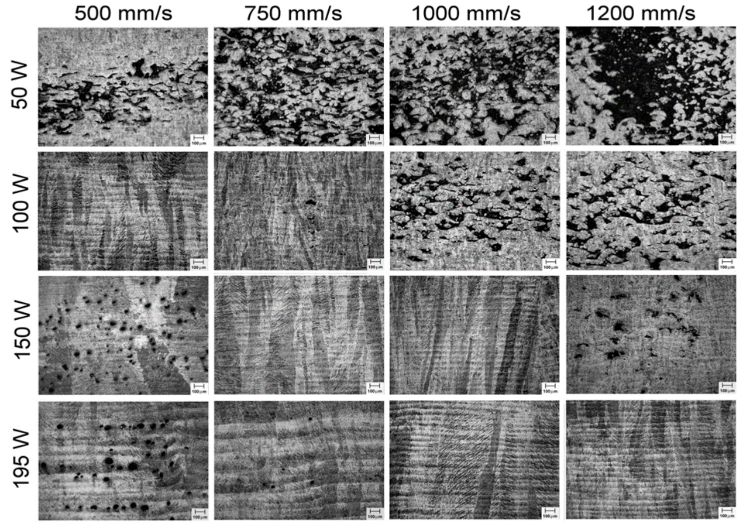


Geometry Height (mm)	Geometry Length (mm)	Geometry Width (mm)	Starting Layer Angle (deg)	Layer Rotation Angle (deg)	Laser Power (W)	Scan Speed (mm/s)	Layer Thickness (mm)	Hatch Spacing (mm)	Slicing Stripe Width (mm)	Void Ratio	Powder Ratio	Solid Ratio
3	3	3	57	67	150	800	0.04	0.05	10	0	0	1
3	3	3	57	67	150	800	0.04	0.07	10	0	0	1
3	3	3	57	67	150	800	0.04	0.09	10	0	0.0008	0.9992
3	3	3	57	67	150	800	0.04	0.11	10	0	0.0242	0.9758
3	3	3	57	67	150	800	0.04	0.13	10	0	0.0976	0.9024

Candidates with porosity lower than 0.5%

Porosity Prediction Output



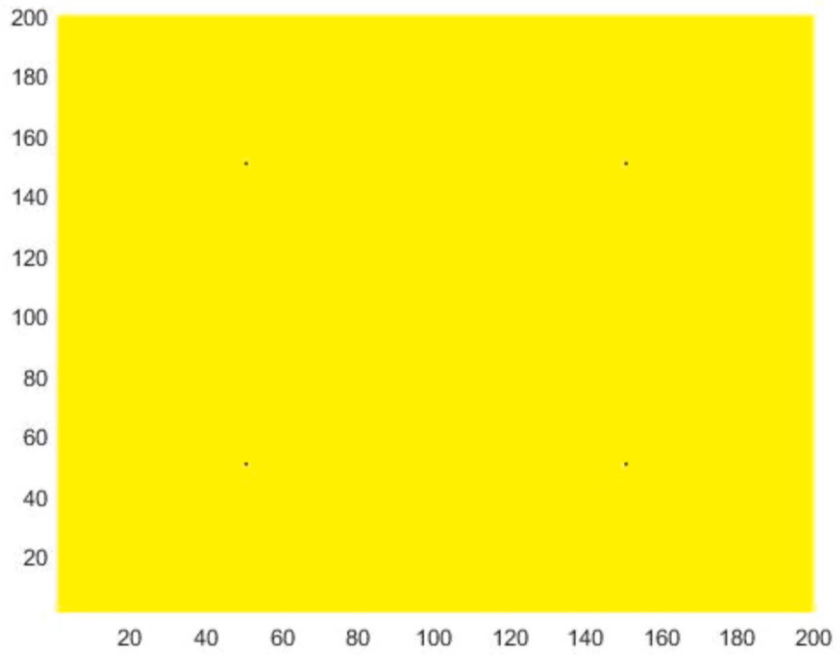


Cellular Automata method for Microstructure Prediction

The Cellular Automata method is an algorithm which describes the spatial and temporal evolution of a physical system by applying deterministic or probabilistic transformation rules.

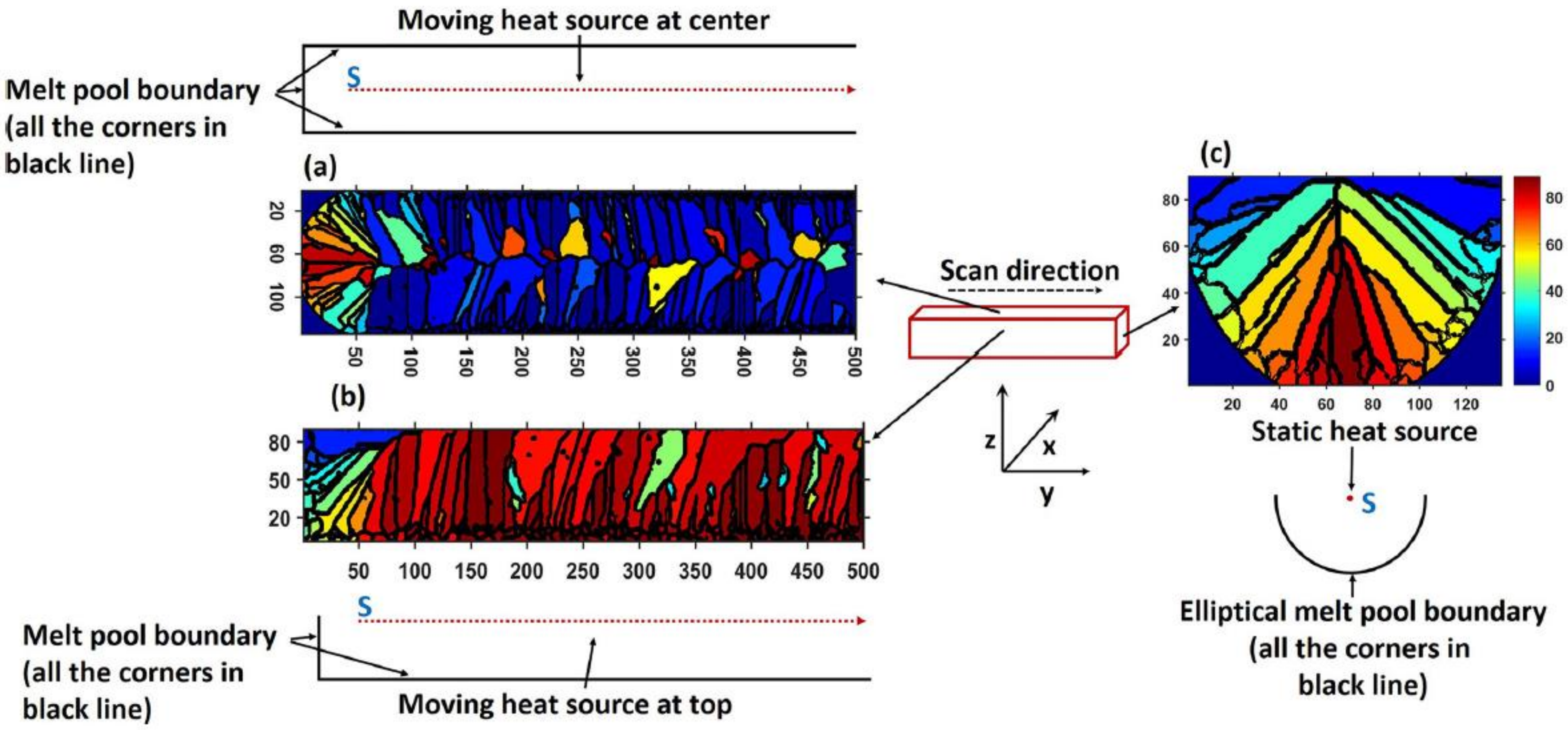
In this method, the spatial domain is divided into finite cells such that they can fit the simulation domain with integral multiples of the finite cell size, and the state of every cell is determined by the state of its neighbor cells according to a set transformation rule.

In the present model, four variables are assigned to each cell: (a) a state variable defines the state of a cell i.e., solid, liquid, and interface; (b) an orientation variable represents the preferred growth orientation of the grain; (c) a grain number variable is used to distinguish the grains from one another; and (d) a solid fraction variable is used to track the transition of the liquid cell to solid cell.

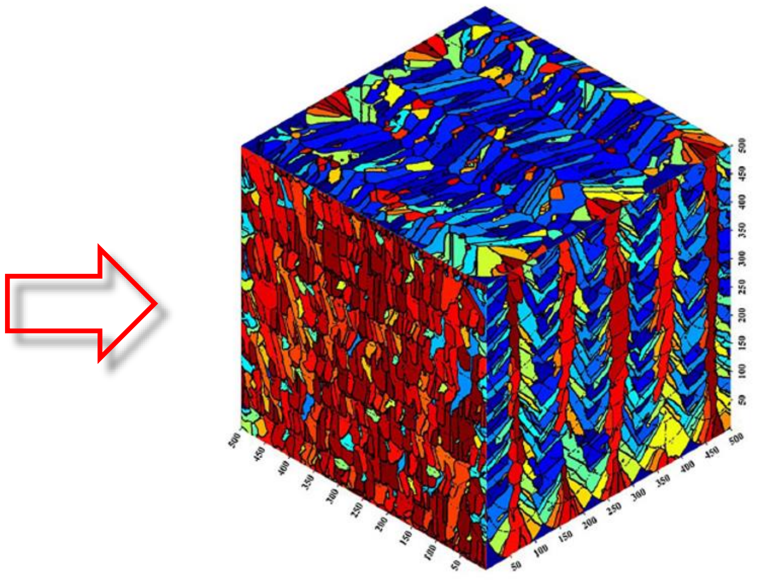


"Understanding grain evolution in additive manufacturing through modeling" Akram et. al.

Cellular Automata method for Microstructure Prediction

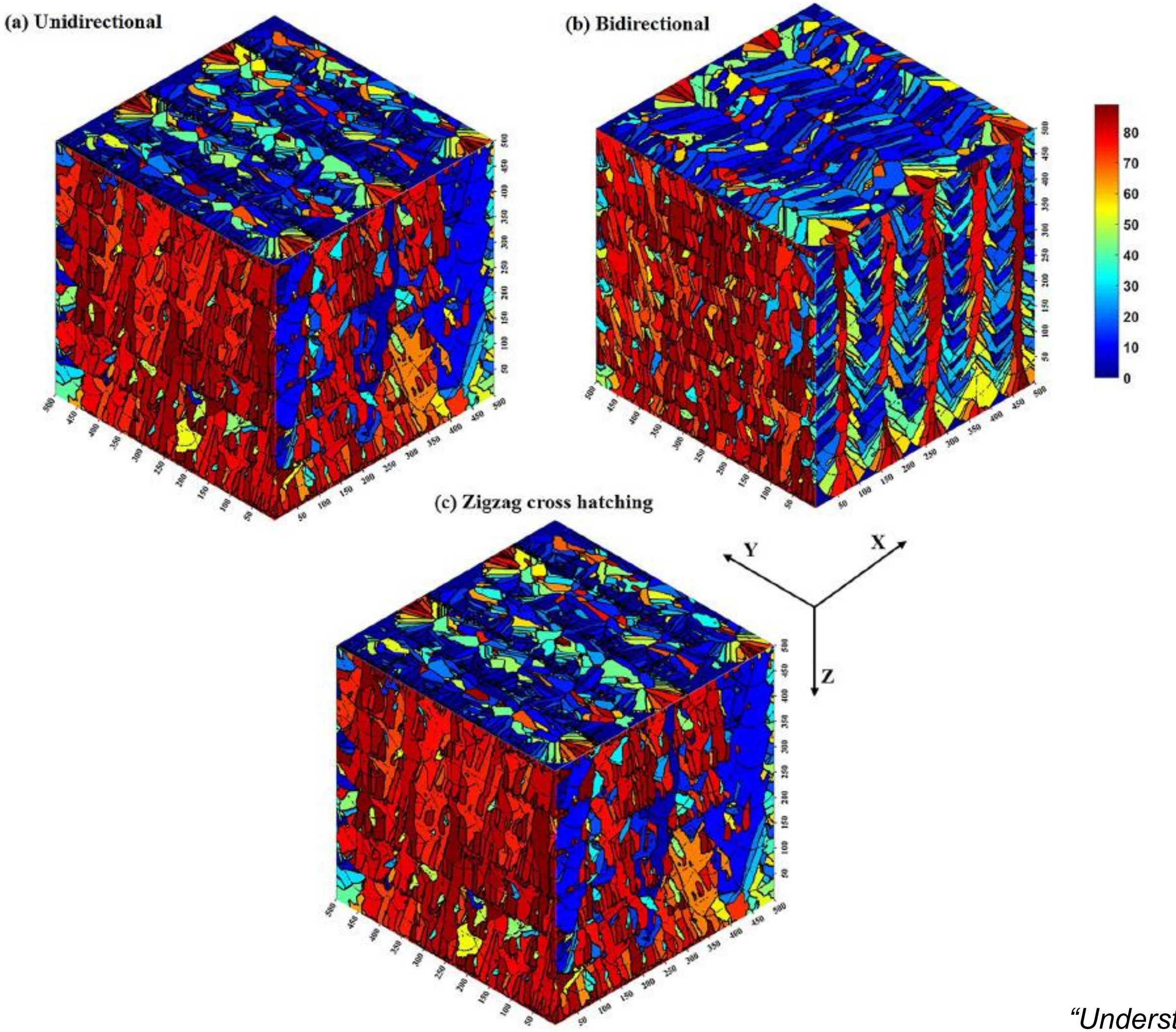


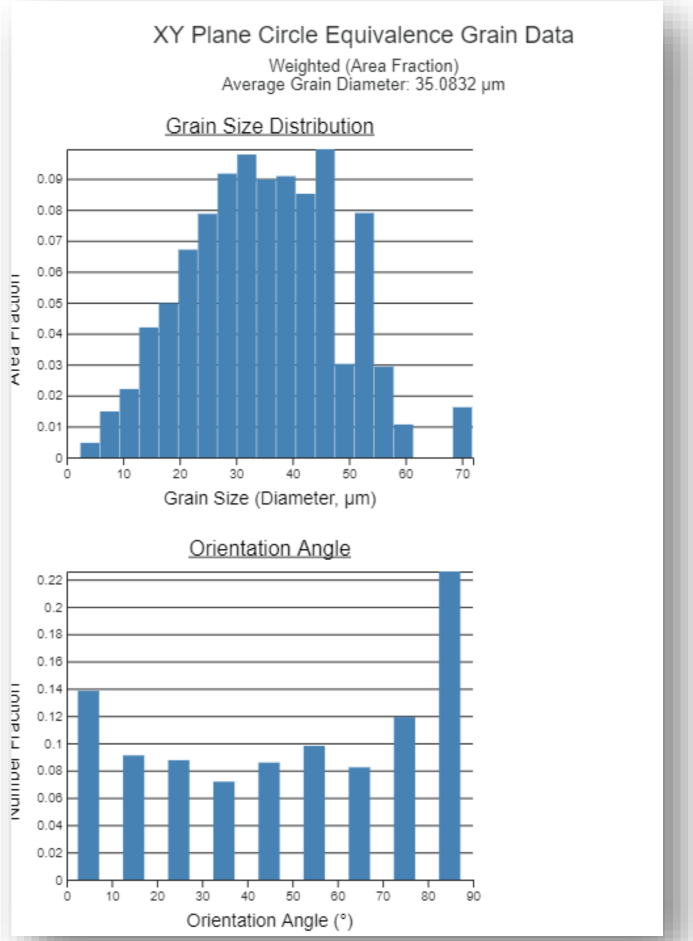
Bidirection orientation



"Understanding grain evolution in additive manufacturing through modeling" Akram et. al.

Microstructure Outputs



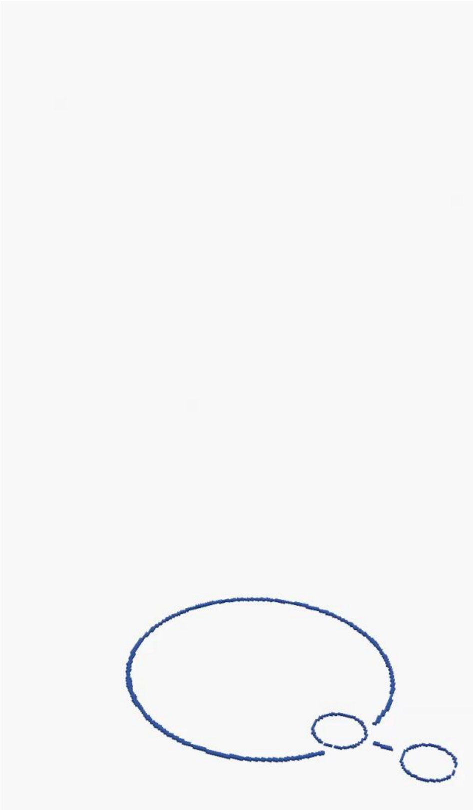


"Understanding grain evolution in additive manufacturing through modeling" Akram et. al.

Conclusion

Process Simulation Enable a New Means for Quality Assurance and More Accurate Predictions to help you increase your productivity while :

- **Insuring tolerances for parts dimensions**
- **Having optimal Build Setup**
  - **Process Parameters**
  - **Supports**
  - **Build Defect Prediction**
- **Tuning parts mechanical properties to your needs**
  - **Microstructure**
  - **Porosity**



Thank you!

Process Simulation

Post process
- Support removal
- Heat treatment
- HIP'ing
- Surface Finishing

Quality Control
- Metrology Comparison
- Sensor Prediction

Print Prep
- Physics-Based Support Generation
- Support Failure Prediction

Exploring Materials
- Phase Changes
- Microstructure
- Properties
- Heat Treatment Strategies

Print

Predicting
- Distortion
- Residual Stresses
- Blade Crashes
- Using 4 Strain Modes

Determining Optimal
- Geometry Compensation
- Process Parameters
- Scan Pattern

Print Design
- STL File Manipulation
- Part Orientation
- Support Generation

Validation
- Analysis
- Optimization

Design for AM (DfAM)
- CAD
- Topology Optimization
- Lattice Structures

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