Computational Process Modeling for Additive Manufacturing (OSU)

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CIMJSEA

NSF-I/UCRC: Center for Integrative Materials Joining Science for Energy Applications

Introduction / Review

- Industrial Relevance
  - Optimize material build parameters with reduced time and cost through modeling
- Goals of the project
  - Model microstructure evolution in a powder-bed additive manufacturing process, using thermal modeling from Applied Optimization and Simultaneous Transformation Kinetics modeling at OSU.
  - Validate model using metallography from coupons manufactured at MSFC using Cusing M2 powder-bed system and in-situ data acquisition from QM Meltpool.
- Previously Presented
  - Build samples on Cusing M2 machine
    - Single-track (no powder) on SS and IN625, Stair-steps, and 15 mm blocks
  - QM Meltpool data and trends.
    - Correlate to geometry measurements
  - Share data and parameters for calibration of powder-bed AM process model.
- In this presentation
  - Review AO Process Modeling results
  - Review metallography on samples produced
  - Review geometry analysis of welds

Project Milestones and Timing

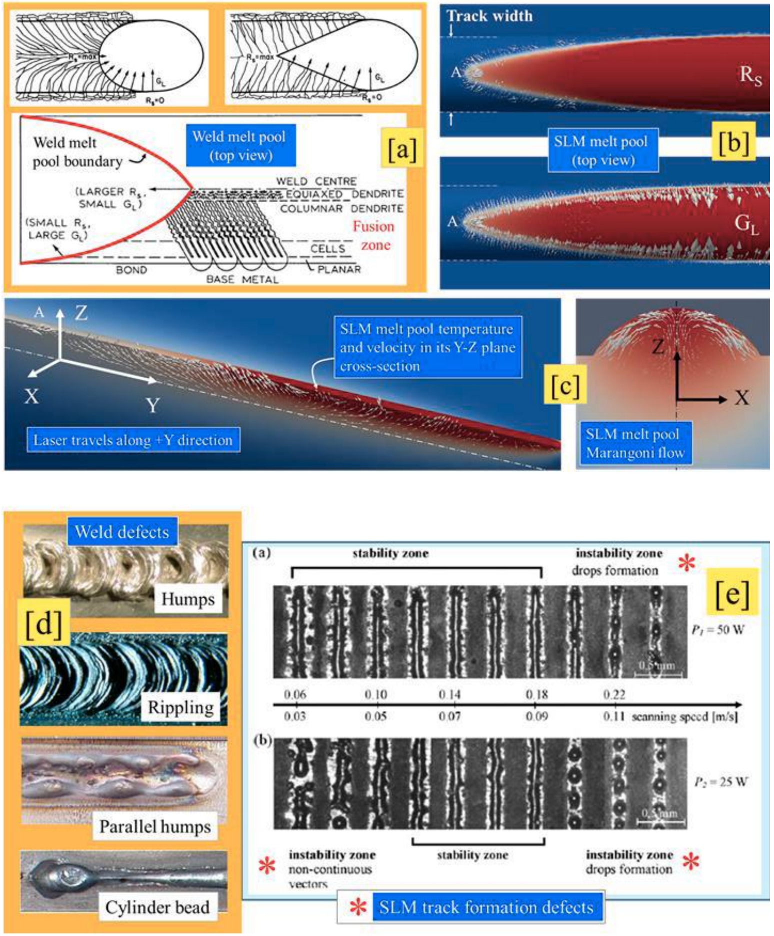
Date plan	Date Completed	Milestone/Deliverable	Status
7/30/2013	12/17/2013	Signed Space Act Agreement (NASA MSFC) and CIMJSEA Membership Agreement	100%
11/2013	1/3/2014	NASA will conduct single-track builds using powder-bed additive manufacturing and provide QM Meltpool Data to CIMJSEA	100%
12/2013	10/24/2013	NASA, AO and OSU will define coupon sample build parameters	100%
3/2014	10/25/2013	NASA will conduct coupon sample builds using powder-bed additive manufacturing and provide QM Meltpool data to CIMJSEA	100%
9/2014	10/31/2014	AO will provide Additive Manufacturing process modeling results for coupon builds[1]	100%
10/2014	12/23/2014	NASA will conduct metallography on coupon samples.	80%
4/2015		OSU will report results from Simultaneous Transformation Kinetics models	0%
12/16/2015		Final Reporting of Results	0%

This slide modified to show Space Act Agreement milestones & deliverables.

[1]AO continued project after leaving CIMJSEA under a NASA STTR.

AO Process Modeling STTR

- Adapt thermal-fluid analysis for the prediction of weld defects to the prediction and control of surface defects and melt pool instability during in SLM and control the as-deposited microstructure.
- Utilize physics-based analysis to predict variability caused in the individual SLM track cross-section geometry due to the statistical distribution of powder particles sizes and potential non-uniform placement of powders.
- Develop a probabilistic model to calculate levels of confidence and exceedance for the size and type of potential defects as a function of SLM process parameters.
- Determine thermal cycling during deposition and use it to predict solidification microstructure and solid state transformations during deposition.
- Demonstrate feasibility of the analytical procedures for In718

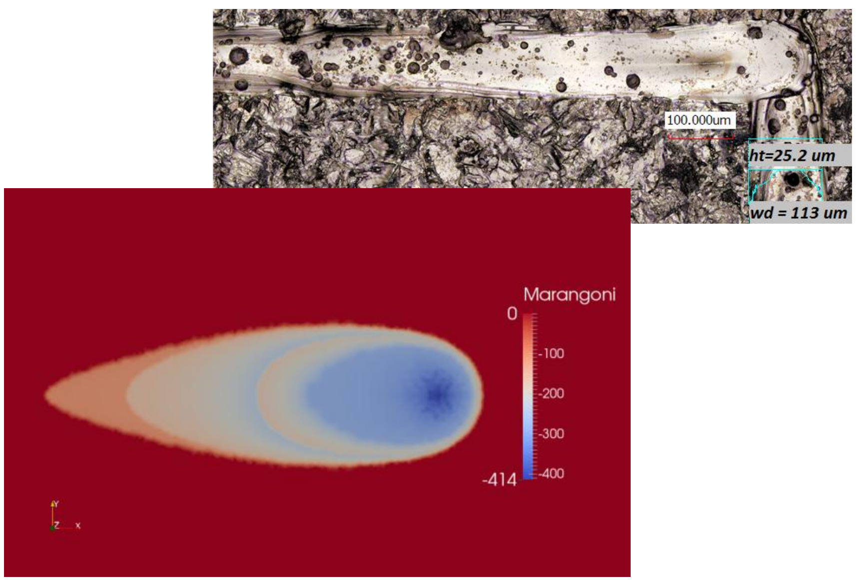


**This information publicly available from STTR abstract 14-1 T12.04-9903. Image from Applied Optimization Quad Chart.

AO Process Modeling Results

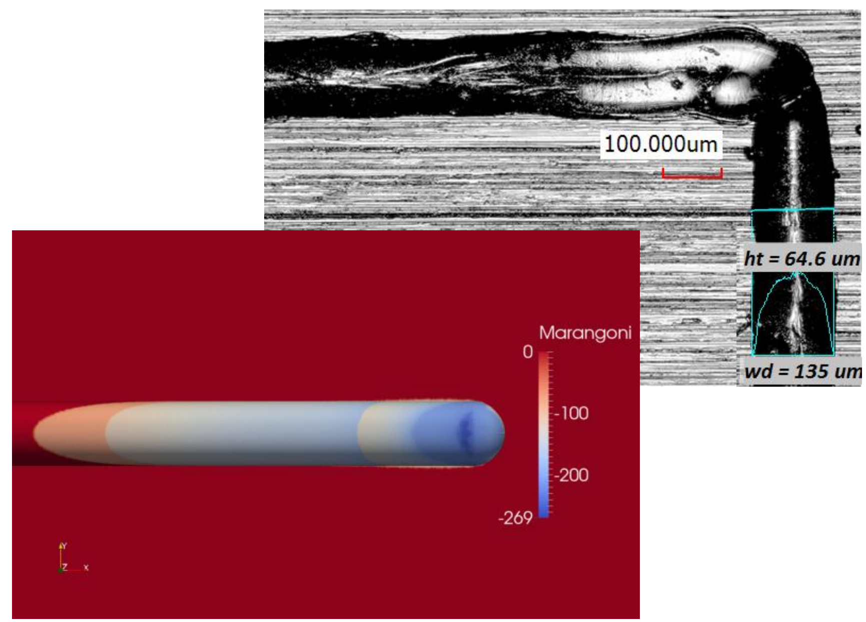
No Powder

- Bed Thickness = 0 um
- Power = 180 W
- Speed = 750 mmps



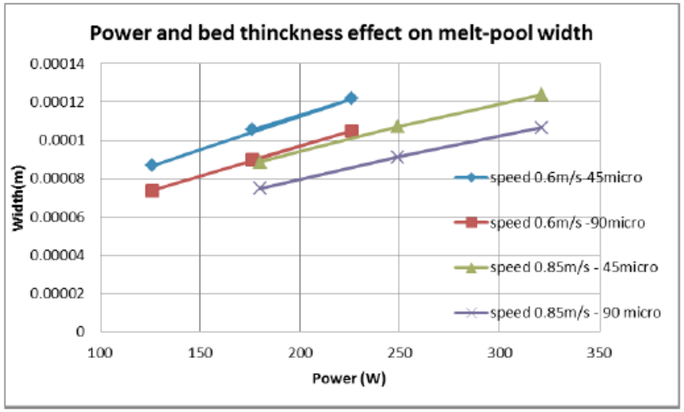
With Powder

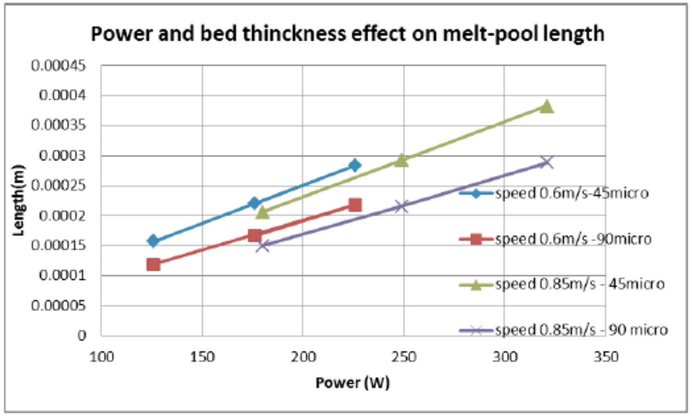
- Bed Thickness = 45 um
- Power = 176 W
- Speed = 600 mmps

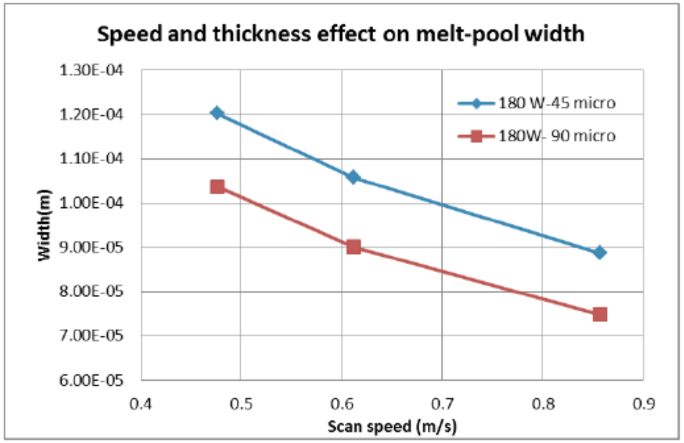


ISEP simulation results for IN718

-effect of power and scan speed-







Features:

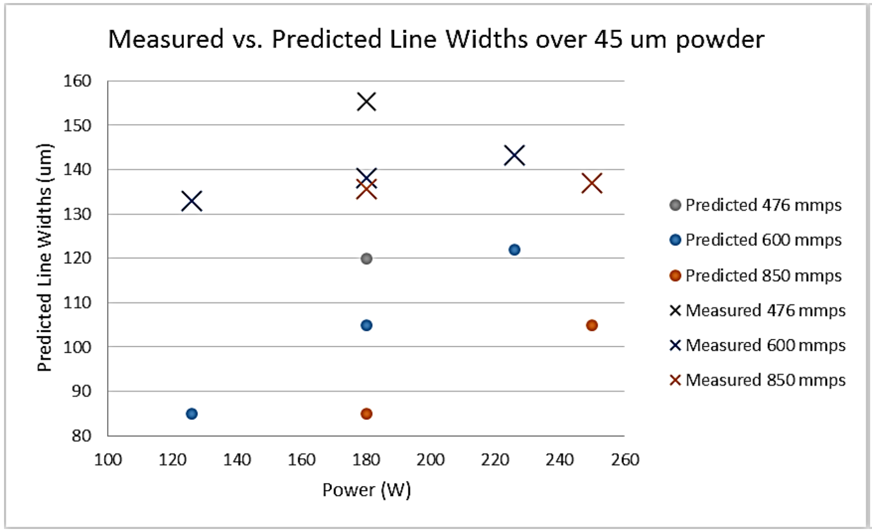
(1) The melt-pool width reduces with increasing the powder bed thickness.

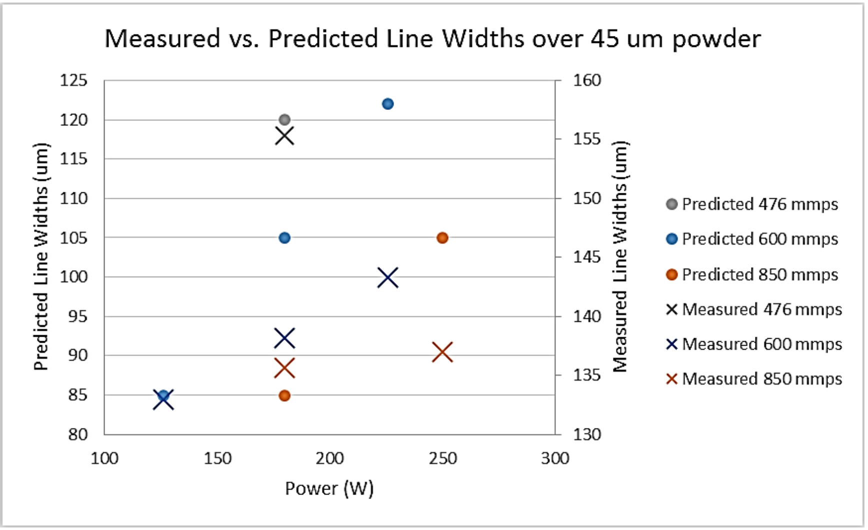
(2) The melt-pool width decreases with the increment of scan speed.

Credit: This slide and all graphs are from Applied Optimization NASA STTR Telecom September 2014

AO Predictions Compared with Single Line Builds (With Powder)

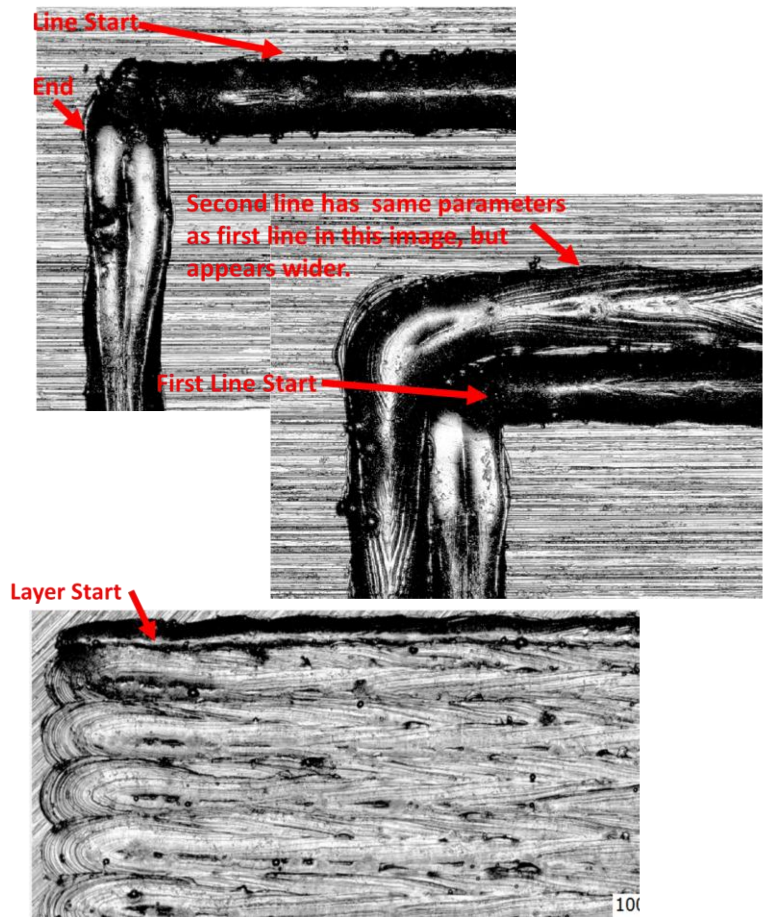
- 45 um powder (approximately) single line builds of In718 powder on In718 Build Plate
- Shows same general shape, but wider lines than predicted and less variation
  - This concept is exaggerated on RHS plot by putting measured widths on a second axis





Future Work

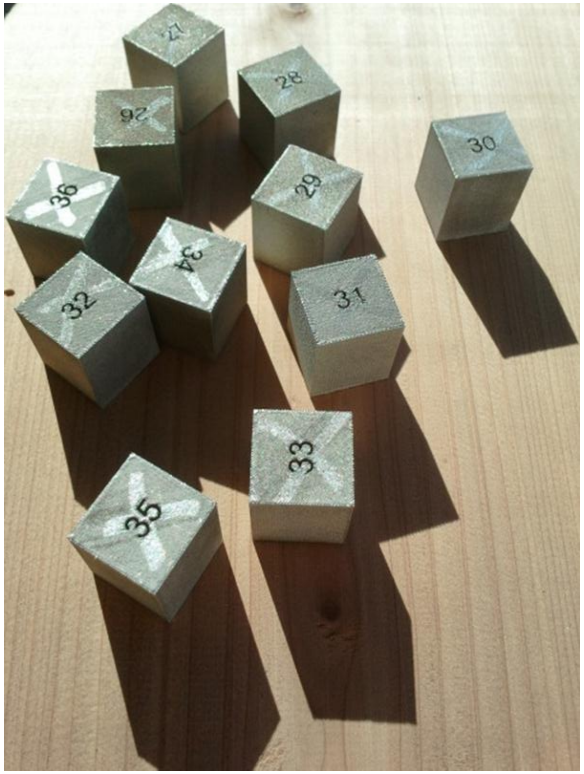
- AO has modeled double tracks – compare to measurements
  - Effect between 1st and 2nd line where the 2nd line is much wider and flatter – presumption is the 1st line takes in more powder starving subsequent tracks.
- AO is making predictions on defects – compare to visual defects
- AO has applied for a Phase II STTR (Reviews currently underway)



Coupon Builds

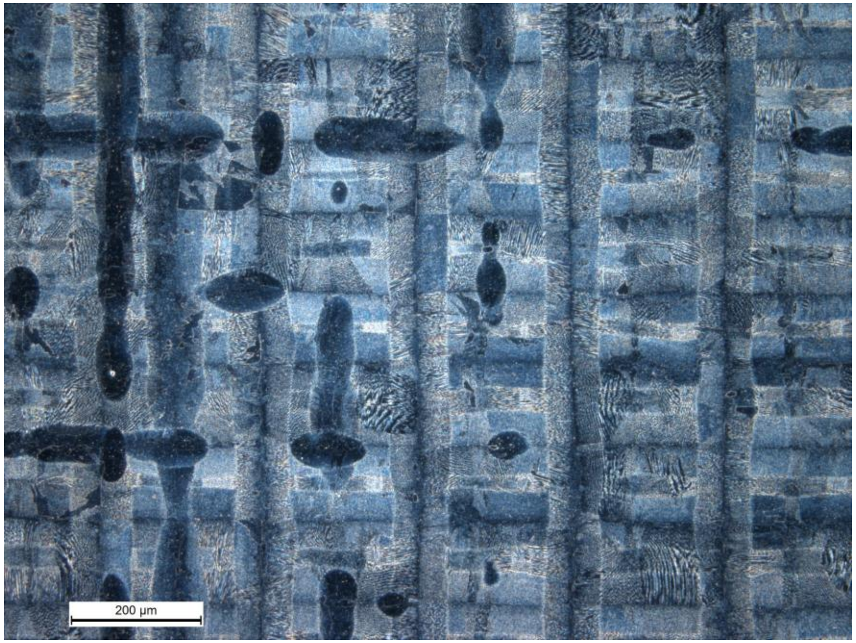
- Optical microscopy has been completed on the following matrix:

Sample	Power	Scan speed	Line width	Hatch Spacing
19	178.5	850	0.15	0.105
20	214.2	850	0.15	0.105
21	249.9	850	0.15	0.105
22	285.6	850	0.15	0.105
23	321.3	850	0.15	0.105
24	357	850	0.15	0.105
25	360	1714	0.15	0.105
26	360	1429	0.15	0.105
27	360	1224	0.15	0.105
28	360	1071	0.15	0.105
29	360	952	0.15	0.105
30	360	857	0.15	0.105
31	360	850	0.303	0.212
32	360	850	0.251	0.176
33	360	850	0.216	0.151
34	360	850	0.189	0.132
35	360	850	0.169	0.118
36	360	850	0.151	0.106

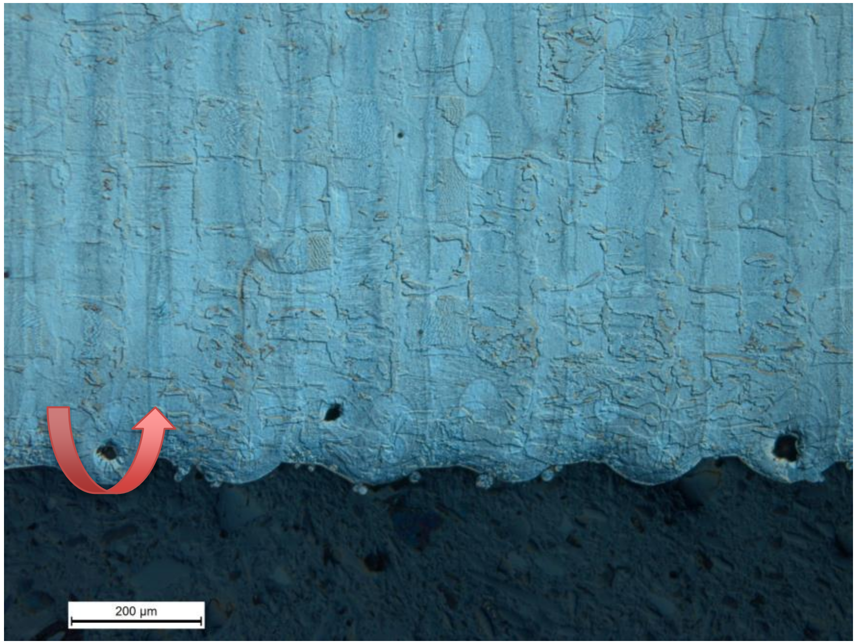


Optical Microscopy Layer Observations

X-Y Plane imaged to verify hatch spacing (Darkfield #35 100x)



Turn-around ("meander") can build in porosity at edges (X-Y Plane – DIC #23 100x)

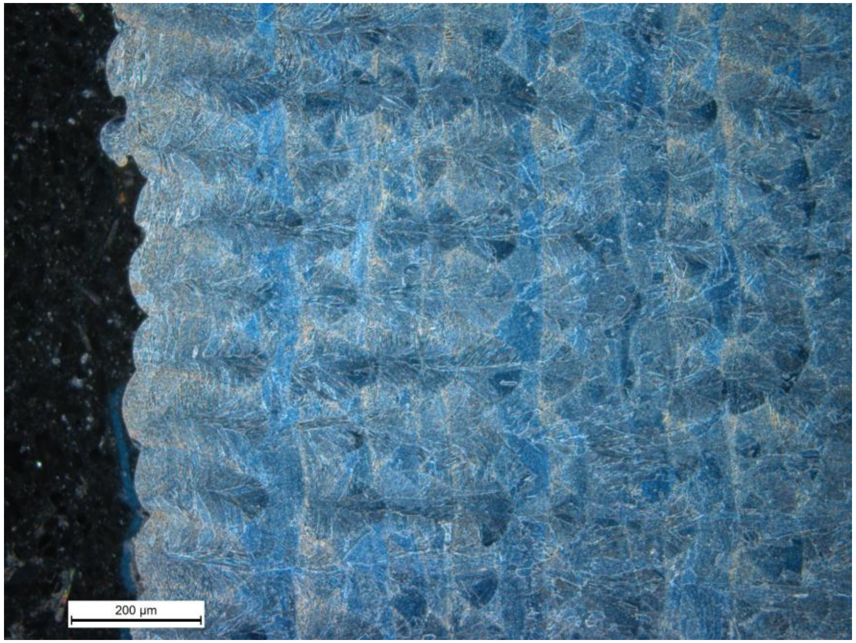


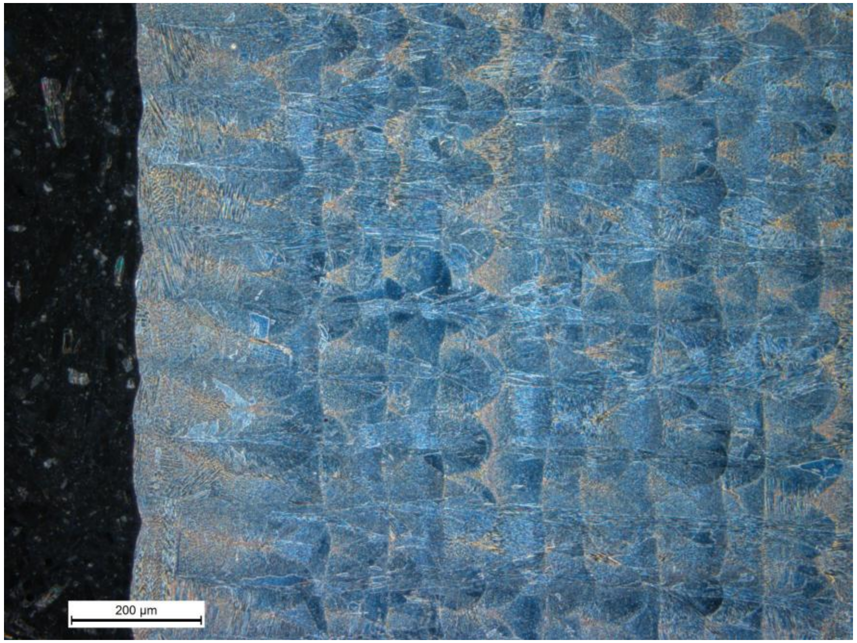
Build Direction (Z)

Optical Microscopy Top Surface Observations

"Cold" parameters lead to highly distorted top surface (Y-Z Plane Darkfield #26 100 x)

"Good" parameters lead to very flat top surface – good spreading (Y-Z Plane Darkfield #28 100x)



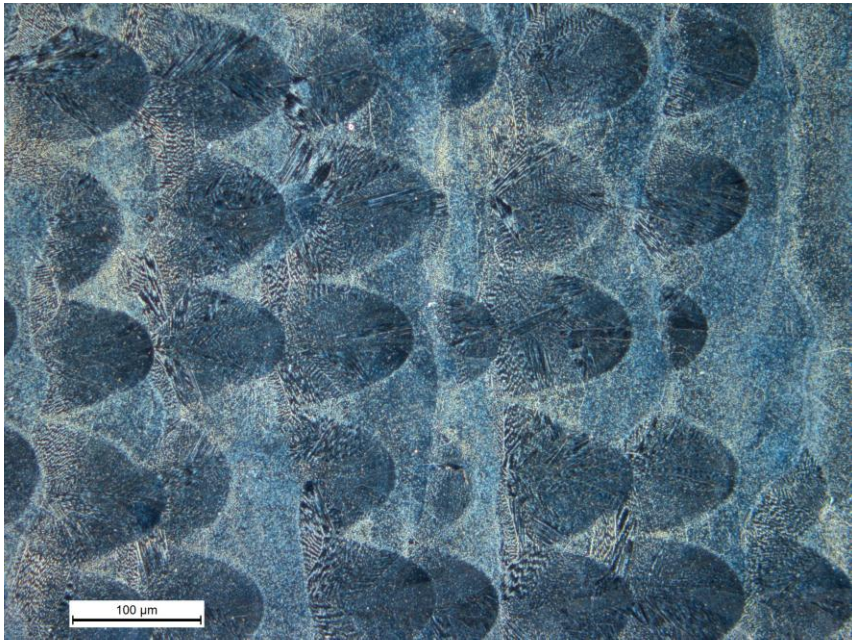


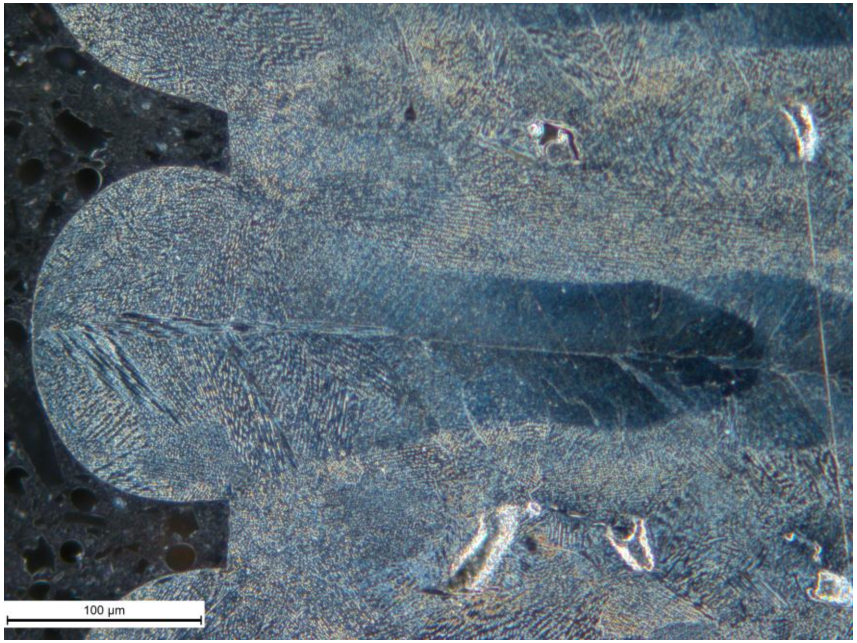
Build Direction (Z)

Optical Microscopy Weld Bead Observations

"Good" parameters show regular, stacked, oblong scallops (X-Z Plane Darkfield #27 200x)

"Hot" Parameters show entering keyhole region (Y-Z Plane Darkfield #31 300x)

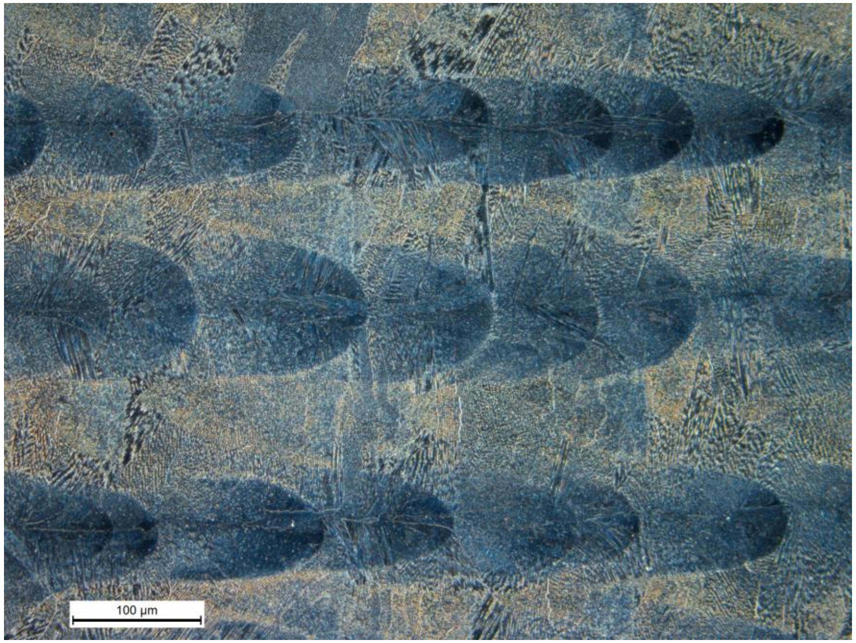




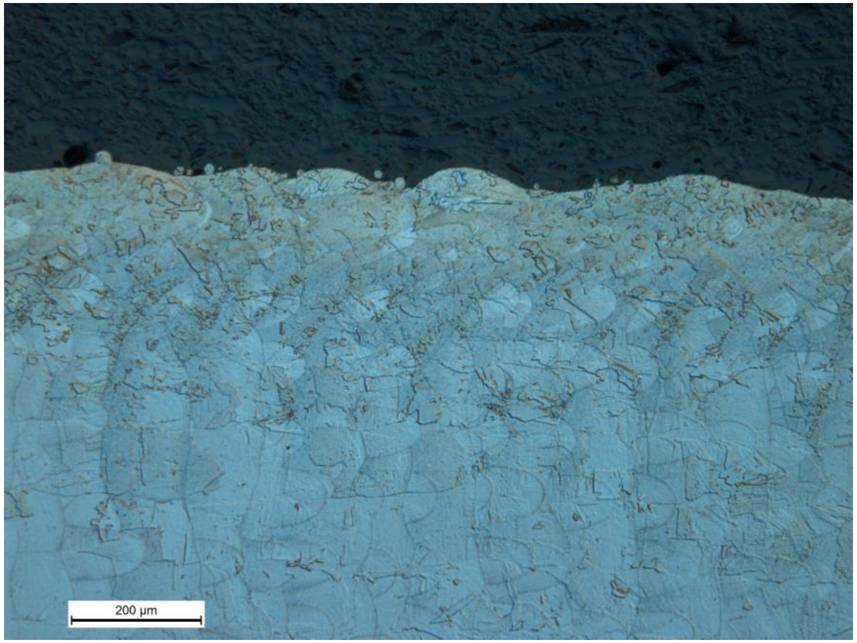
Build Direction (Z)

Optical Microscopy additional observations

Cracking along mid-line observed – can span many layers. Additionally, bead shape can be directionally dependent (X-Z Plane Darkfield #33 200x)



Edge effects observed pushing material down – mechanism unknown (Y-Z Plane DIC #30 100x)



Build Direction (Z)

Future Work

- Observe solidification indications (dendrite arm spacing, phases, etc.)
- Calibrate STK
- Conduct STK modeling & Validate model

Questions?