

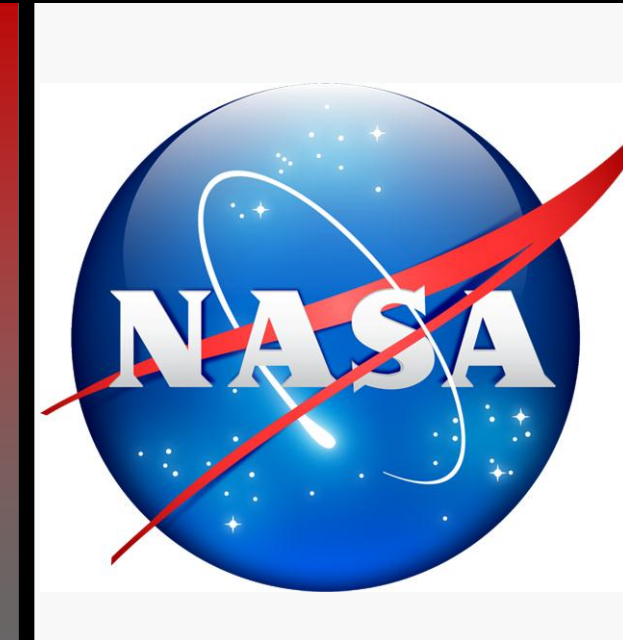


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# Computational Process Modeling for Additive Manufacturing

Stacey Bagg, NASA Marshall Space Flight Center

Wei Zhang, The Ohio State University



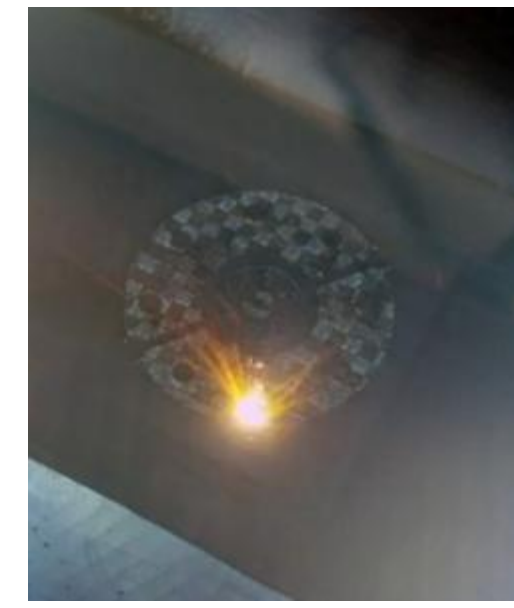
## Background

Powder-Bed Additive Manufacturing (AM) through Direct Metal Laser Sintering (DMLS) or Selective Laser Melting (SLM) is being used by NASA and the Aerospace industry to "print" parts that traditionally are very complex, high cost, or long schedule lead items. The process spreads a thin layer of metal powder over a build platform, then melts the powder in a series of welds in a desired shape. The next layer of powder is applied, and the process is repeated until layer-by-layer, a very complex part can be built. This reduces cost and schedule by eliminating very complex tooling and processes traditionally used in aerospace component manufacturing.



NASA MSFC AM Lab, printed components and SLM Printer

CONCEPTLASER  
hofmann innovation group



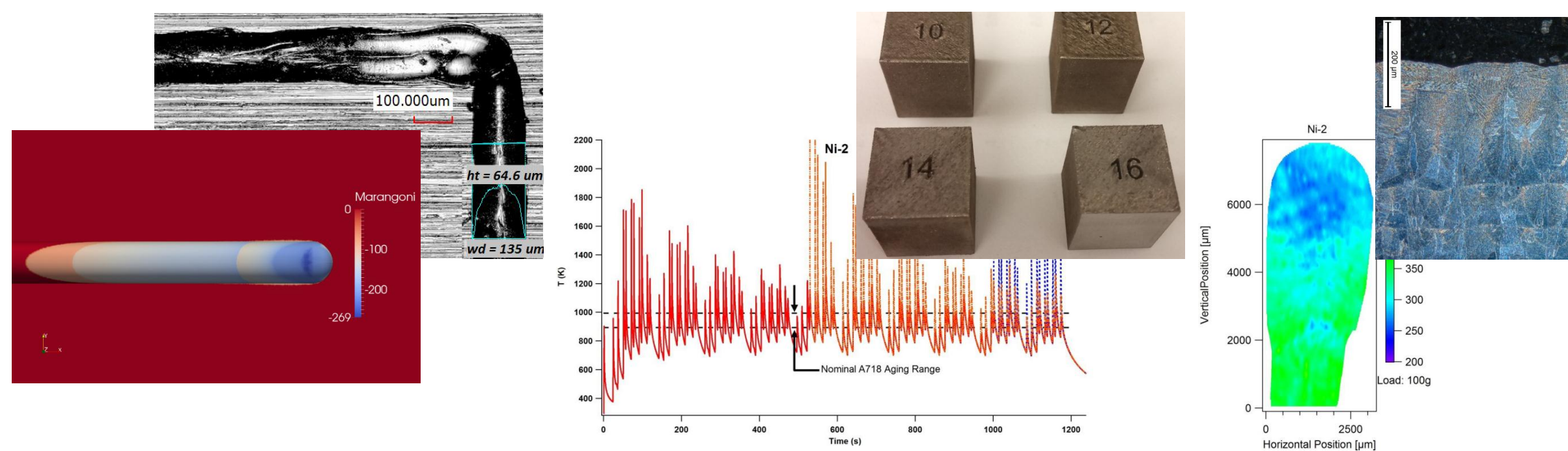
To use the process to print end-use items, NASA seeks to understand SLM material well enough to develop a method of qualifying parts for space flight operation. Traditionally, a new material process takes many years and high investment to generate statistical databases and experiential knowledge, but computational modeling can truncate the schedule and cost - many experiments can be run quickly in a model, which would take years and a high material cost to run empirically. This project seeks to optimize material build parameters with reduced time and cost through modeling.

## Motivation

- Model SLM Process and Microstructure Evolution of IN 718
  - Optimize material build parameters with reduced time and cost
- Increase understanding of build properties & reliability of builds
- Decrease time to adoption of process for critical hardware
- Potential to decrease post-build heat treatments

## Objectives & Approach

**Overarching Goal:** Model SLM Process and resulting material; calibrate and validate model using in-situ measurements and post-build metal evaluation.

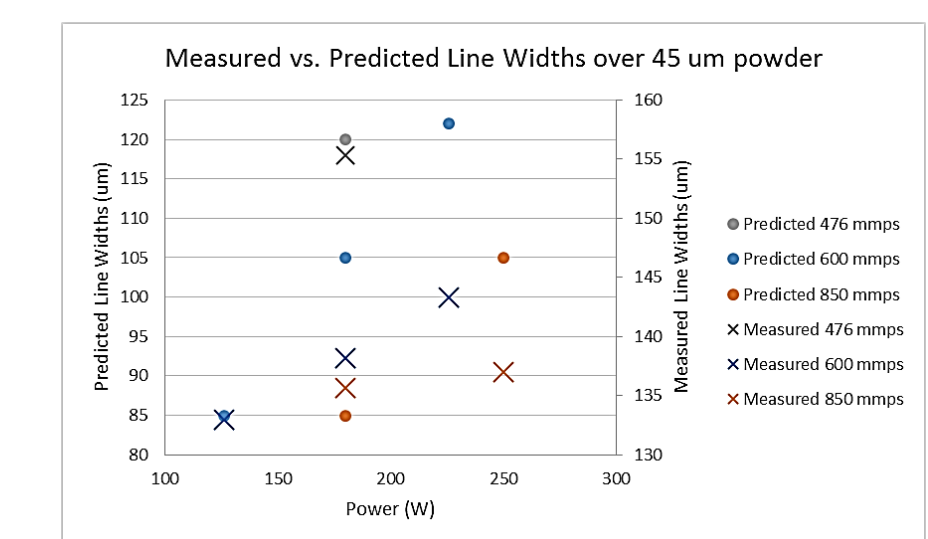
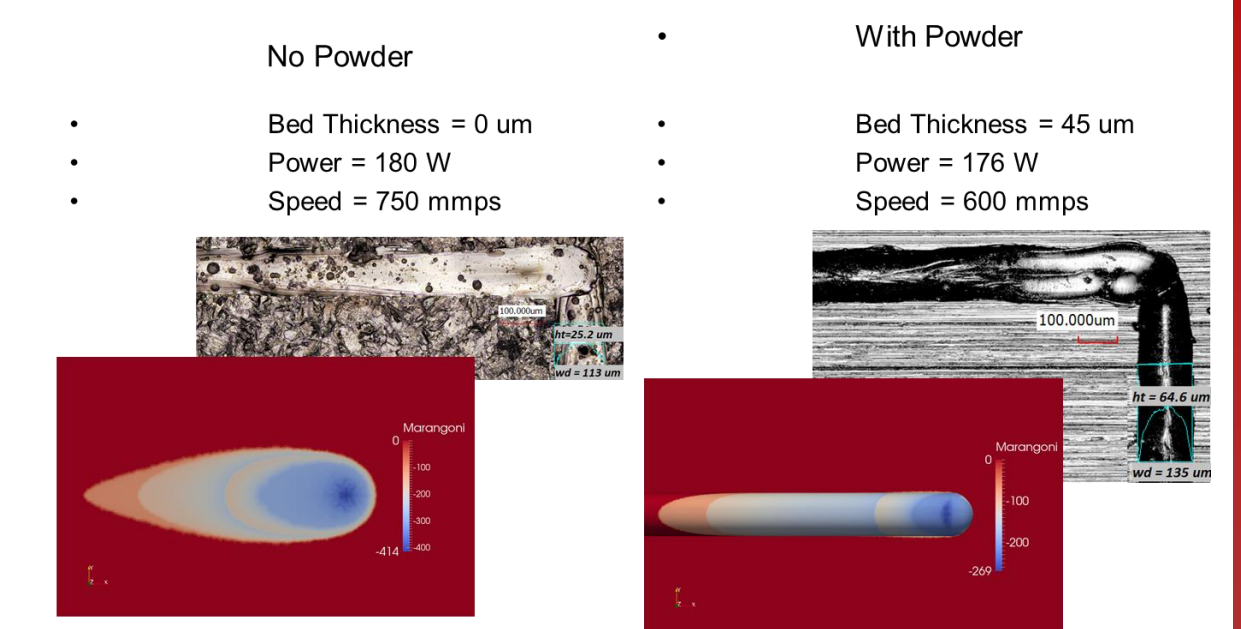


• From Left to Right: Single track AO Prediction and MSFC build, Multi-layer AO Prediction of LENS process [Makiewicz Thesis] and MSFC block build, STK Prediction [Makiewicz Thesis] and MSFC Microscopy of block

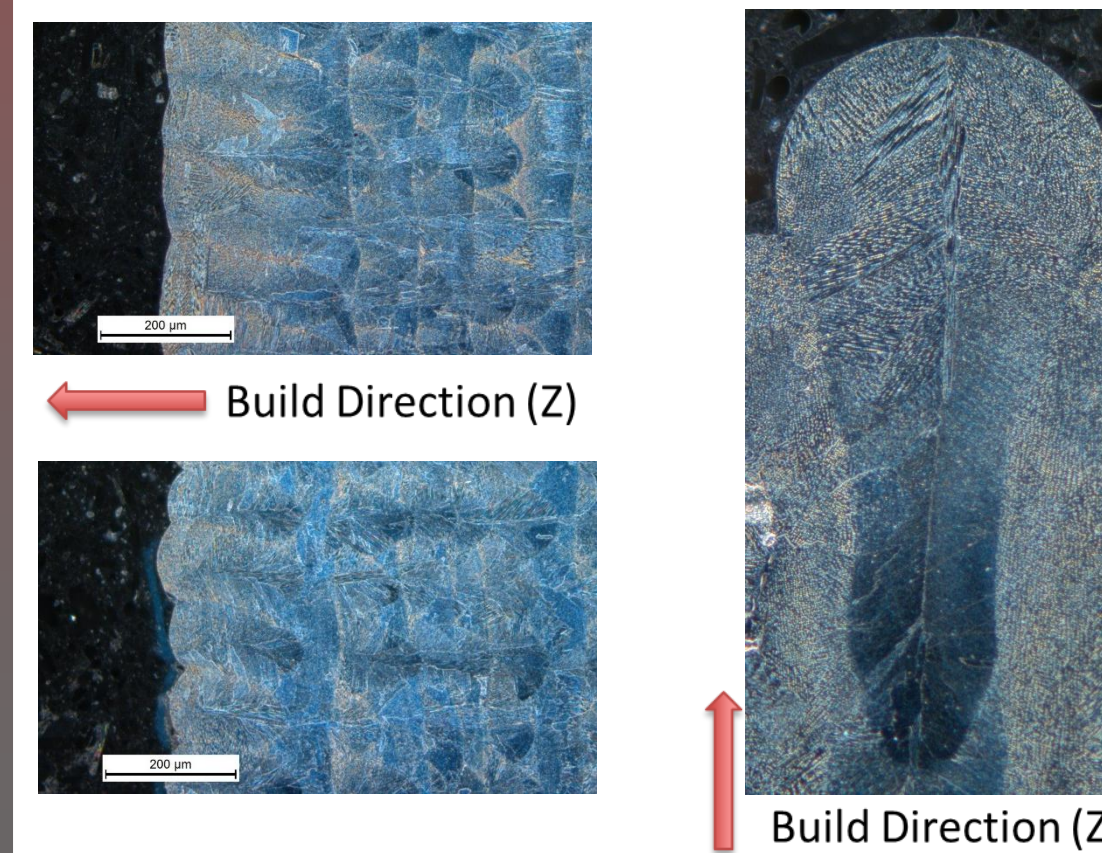
- Conduct single-track and coupon builds at various build parameters
- Record build parameter information and QM Melt pool data
- Refine Applied Optimization powder bed AM process model using data
- Report thermal modeling results
- Conduct metallography of build samples
- Calibrate STK models using metallography findings
- Run STK models using AO thermal profiles and report STK modeling results

## Results & Discussion

- Applied Optimization has remained active in modeling the SLM Process through a NASA STTR. Under this STTR they have made predictions of single-track dimensions and stability and have determined the effects of various thermo-fluid properties on the weld bead shapes and defects.
- AO Weld geometry predictions have been compared to NASA MSFC single-track builds. The track dimensions show the same trends as the predictions, although the actual values are shifted – higher precision measurement techniques are now being employed to reduce statistical uncertainty.



Above: AO Predictions compared with NASA samples



Optical microscopy of printed cubes was conducted. The microscopy reveals parameters where the weld flattens on top (good spreading), or where it is too cold (limited spreading) or too hot (keyhole mode and micro-cracking).

Top Left: Good parameters showing flat top surface and top layer of welds. Bottom Left: Cold parameters showing uneven top surface and top layer of welds. Right: Hot parameters showing keyhole shape weld.

## Conclusions

- AO has made good progress modeling single-track welds, and understanding the thermo-fluid mechanics involved in the SLM process.
- Single-track builds have been conducted and agree with the trends predicted in the AO model.
- Cube samples have been built and optical microscopy reveals identifiable weld bead geometry and verification of geometric parameters (such as hatch spacing)
- Cube sample metallography also reveals identifiable micro-cracking, porosity, surface deformations, non-uniform weld shapes, and other defects.

## Future Work

- AO has modeled double tracks which will be compared to double-track samples built at MSFC.
- AO is making predictions on weld defects in layers which will be compared to single-layer samples built at MSFC.
- Metallography of cube samples will be completed to calibrate Simultaneous Transformation Kinetics models and make predictions on microstructure evolution in SLM material.

