Linking Additive Manufacturing Process to Microstructure via Statistical-Based Analysis

Graduate Student Fellows:
Zilin Jiang, Dmitriy Kats, MJ Sarfi

Faculty Advisors:
Gregory J. Wagner, Wing K. Liu, Jian Cao

Academic Disciplines:
Mechanical Engineering

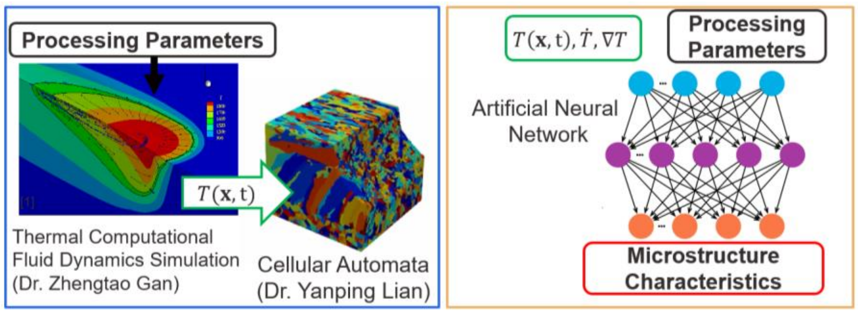
June 03, 2018

RESEARCH OBJECTIVE

Additive manufacturing is a potentially disruptive technology, but the influence of process parameters on the microstructure formed is unresolved. The microstructure is important to understand because it determines the performance of the additively manufactured part. If additively manufactured parts are to be used for load-bearing applications, there is a need to understand the process-structure relationship. Understanding that link will inform process conditions in order to optimize the microstructure for functionally graded materials because the material properties can be designed to the performance needs by tailoring the structure. Our objective was to establish a process to structure relationship for additive manufacturing builds through statistical-based analysis. This was executed by using a data-driven technique to formulate the process-structure relationship based off multi-physics simulation results that model the process and microstructure evolution.

Approach

In Dr. Liu and Dr. Wagner's research group, we have computational methods to predict the thermal flow as well as the microstructure developed. These methods require high performance clusters, so we have worked to represent the process-structure relationships with an artificial neural network since they are effective at capturing complex non-linear relationships such as those present in additive manufacturing.



[1] Gan, Zhengtao, *et al. International Communications in Heat and Mass Transfer 86 (2017): 206-214* [2] Lian, Yanping, et al. *Computational Mechanics* (2018): 1-16.[3] *https://cdn-images-1.medium.com/max/1600/1*J7RUyPQ-9UdHAiFMmWY9ww.jpeg.*

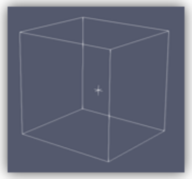
Results and Future Work

The favorable performance of the neural networks is shown to the right. Dmitriy will present the results at SES2018 in Spain in October. The approach will be extended to predict other microstructural characteristics during the summer for a future publication. Specifically, the neural network will be used to predict the local shapes and orientations of the grain. The possibility of using experimental data for neural network training of additive manufacturing builds will also be explored.

Neural Networks

Two neural networks were trained on the thermal data to effectively and accurately predict the local average grain size for single-track and multi-track builds. The inputs and outputs of the neural networks are below.

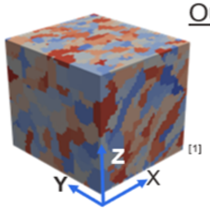
Inputs into neural network come from parameters and Thermal-Fluid simulation:



Probe in Cuboid

- Laser power and scan speed
- Probed 4 points in each cuboid.
- For each point recorded the following data:
  - -The thermal gradient at the critical undercooling
  - -The cooling rate at the critical undercooling

Outputs of Neural Network from Cellular Automaton



Example Cuboid

- Split microstructure domain into many cuboids and found the mean grain chord length
- Completed for all nine parametric cases as well as the multi-layer case

Neural Network 1 (Parametric) Performance

	Coefficient of Determination (R^2)	Mean Square Error	Mean Absolute Error	Percent Error (%)
Train	0.98	0.008	0.069	0.90
Test	0.95	0.020	0.111	1.45

Neural Network 2 (Multi-Layer) Performance

	Coefficient of Determination (R^2)	Mean Square Error	Mean Absolute Error	Percent Error (%)
Train	0.95	0.019	0.106	1.33
Test	0.94	0.029	0.127	1.64

NORTHWESTERN UNIVERSITY