

MANE 6962: Experimental Mechanics Final

On the Application of Atomic Force Microscopy in
Prediction of Dendritic Crystal Structure

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Table of Contents

1. Status of Current Research
2. Dendrite Growth Mechanics
3. Application of AFM to 3D Manufacturing

Status of Current Research

FEM Selective Laser Melting Process

- Powdered metal is deposited on a bare substrate
- Laser and mirror is used to direct the beam onto a location on the powder using GCode
- Powder melts and solidifies onto build plate/part.
- New layer of powder deposited.

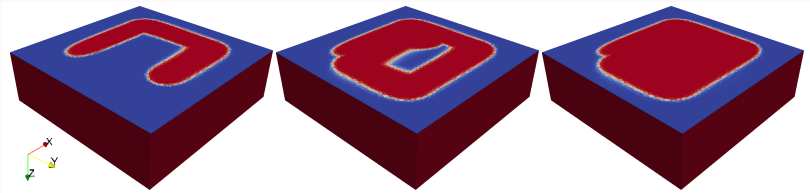


Figure 1: FEM of Laser Melt Path

Experimental, Finite Element, and Phase Field sub-projects

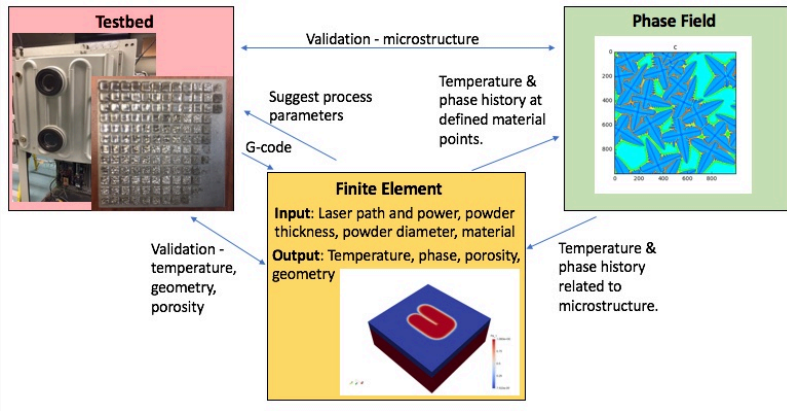


Figure 2: Testbed, Phase Field, and Finite Element Subprojects of the RPI 3D Metal Manufacturing Project

Energy Temperature Relation

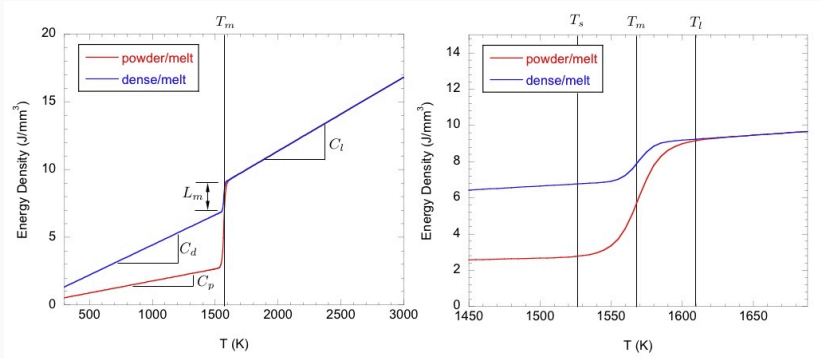


Figure 3: The energy capacity of the powder and substrate for Inconel 718. C_d , C_p , C_t , represent the heat capacity of the dense metal, powder, and liquid, respectively. L_m , is the latent heat capacity. Left hand figure shows the region around melting distinguishing the liquidus and solidus temperatures around melting.

Dendrite Growth Mechanics

System Solidification

- Free Growth initially, with singular spherical solid in liquid
- The region directly ahead of the fluid becomes supercooled, the degree of which determines the rate at which the interface grows.
- Interface propagates at constant velocity in a shape preserving manner

MANE 6962: Experimental Mechanics Final

└ Dendrite Growth Mechanics

└ Initial Conditions

System Solidification

- Free Growth initially, with singular spherical solid in liquid
- The region directly ahead of the fluid becomes supercooled, the degree of which determines the rate at which the interface grows.
- Interface propagates at constant velocity in a shape preserving manner

direction of solidification is determined by the crystal anisotropy forcing it to go in energy favorable directions. takes in thermal energy and from the hot liquid and gets hotter. This is opposed to along a wall or other point which will serve as nucleation point for solidification

Boundary of Dendritic Growth



Figure 4: Image of three primary arms with branching secondary arms courtesy of H.K.D.H. Bahadeshia

Dendritic Growth over Time

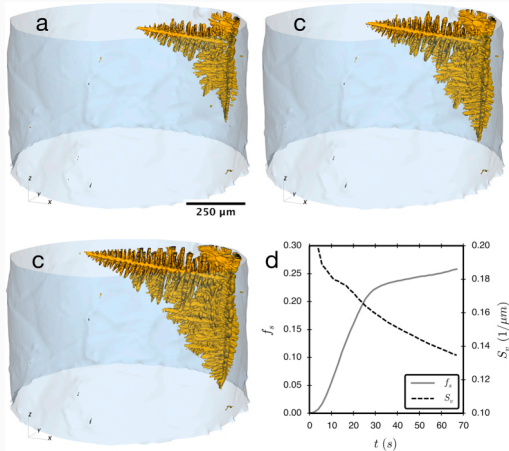


Figure 5: Courtesy of Gibbs, et. al., 2015

MANE 6962: Experimental Mechanics Final

└ Dendrite Growth Mechanics

└ Dendritic Growth over Time

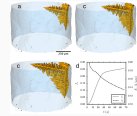


Figure 5: Courtesy of Gibbs, et. al., 2015

- Not a specifically metallic process even if our interests lie somewhere
- look to dendrite formation in other materials such as water or some other
- look to the poly on heated work surface fixing the problem of heat

Processes of Dendrite Formation

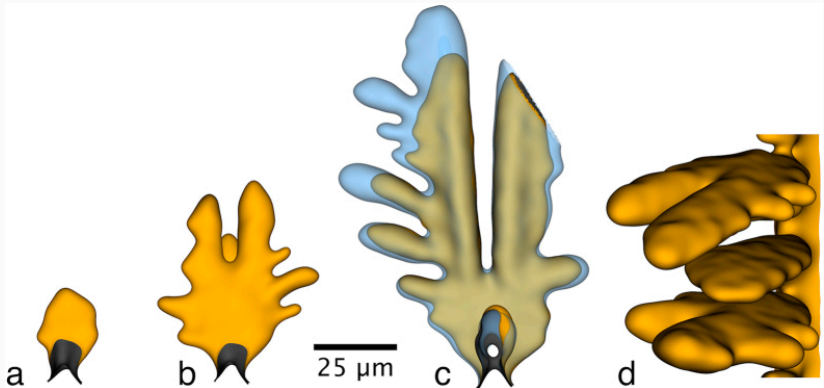


Figure 6: Time Dependent Growth of Secondary Dendrite Arms separated by 1.8 s., courtesy of Gibbs, et. al, 2015.

Application of AFM to 3D Manufacturing

Problems Applying AFM

- AFM mainly used for based on thin film as representation of cells to determine bulk mechanical properties, see Erim and Andrew's work on identification of burned tissue.
- The melting and vaporization temperature of metals are very high.

Negatives of (4D) micro-tomography

- Gibbs: "The spatial and temporal discretization sizes are $0.65\ \mu\text{m}$ voxels (edge length) and 1.8 seconds between each 3D reconstruction."
- Temporal resolution fine enough for secondary dendrite arms as the primary arms travel too quickly.




Current AFM Usage in the Investigation of Dendritic Growth

- Investigation of the direct relationship between crystal anisotropy by AFM. However, utility is maximized in thin films.
- AFM is used in the dendritic growth of thin films of Poly [(S)Lactide]

Conclusions

- There does not appear to be a direct application in measuring the mechanical properties of dendritic crystal formation for the AFM *in the research group*.
- Is still useful in investigating the physical phenomena of dendritic growth
- Problem appears to come from a difference in characteristic length scale.
- Perhaps using a full field strain visualizer such as Ncorr would prove more applicable than operation of the AFM.

Questions?

-  Roy, S. and Juha, M. and Shephard, M. S. and Maniatty, A. M..Heat transfer model and finite element formulation for simulation of selective laser melting. *Computational Mechanics*, vol. 62.3, pp. 273--284, 2018.
-  Y. Kikkawa, H. Abe, T. Iwata, Y. Inoue, and Y. Doi. In Situ Observation of Crystal Growth for Poly[(S)-lactide] by Temperature-Controlled Atomic Force Microscopy. *Scientific Reports*, vol. 2.3, pp. 940--945, 2001.
-  Gibbs, J. W. et. al. The Three-Dimensional Morphology of Growing Dendrites. *Scientific Reports*, vol. 5. art. 11824. 3 July 2015.



Bhadeshia, H.K.D.H. Dendritic Solidification. *University of Cambridge*

<http://www.phase-trans.msm.cam.ac.uk/dendrites.html>