Metals & Materials Summit, 24-25 September, 2022, IIT Bombay

Modelling Process-Structure-Property Correlations in Metal Additive Manufacturing

Gunratna Borkar[1], Nitesh K. Sachan[1], Veer Singh[1], Samyak Khetan[1], Haeshini Jegan[2], Pratibha Gouda[3], A. Durga[1]

[1]IIT Bombay, [2]NIT Tiruchirapalli, [3]NIT Durgapur

Introduction

- 3D model
- Layer-by-layer buildup
- Series of micro-joints holding the object together

3D CAD Modelling → Slicing → Layer by Layer build up → Assembly

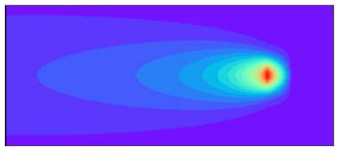
Why and why not use AM?

Metal Additive Manufacturing

Advantages
- Design Freedom
- Complex geometries
- Complete automation
- Less material wastage

Limitations
- Slow process
- Size limitations
- Less dimensional control
- Poor surface quality

Temperature Variation



Temperature variation can be modelled using Rosenthal model [1] or other advanced thermal models taking into account:

- Conduction
- Convection
- Radiation
- Fluid Flow

Temperature variation across space and time

↓

Solidification Rate and Temperature Gradients

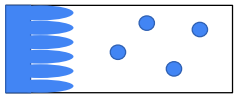
Grain Morphology | Segregation | Defects

↓

Mechanical Properties

Modelling of Columnar to Equiaxed Transition [3]

- Why model CET?
- What is the effect of CET on the properties of final product?
- How can we optimize this process?

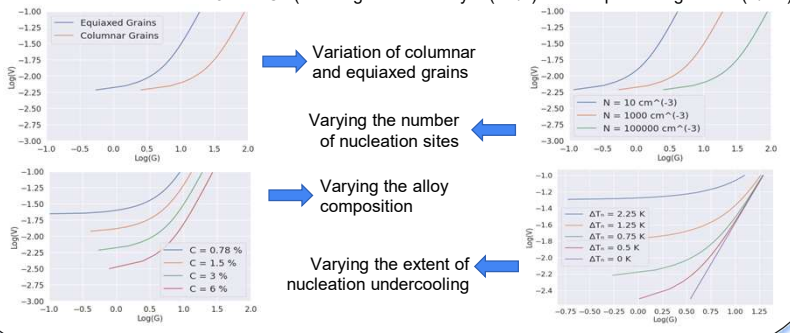


Equiaxed region modelled based on the volume fraction (Φ) of grains at columnar front

Φ > 0.49 – Fully equiaxed grains

Φ < 0.0049 – Fully columnar grains

Predicted results for AL-3wt.% Cu (Plot of growth velocity V (cm/s) and temperature gradient (K/cm))



Variation of columnar and equiaxed grains

Varying the number of nucleation sites

Varying the alloy composition

Varying the extent of nucleation undercooling

Effects of Defects and Variation in Mechanical Properties

Types of Defects

- Porosity
  - Insufficient powder spreading
  - Lack of fusion
  - Key holing and Shrinkage
  - Improper process parameters
- Incomplete Fusion
  - Lack of energy input
  - Low density scan path
- Cracking
  - Thermal Stress
  - Residual stress
  - Grain misorientation

Influencing Factors

Process parameter optimization
- Laser power
- Scan speed
- Scan strategy
- Hatch spacing
- Layer thickness

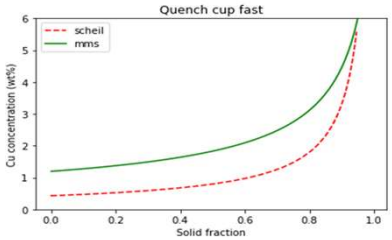
Process parameters can be linked directly to defects and mechanical properties using Machine Learning (ML) [4]

Why ML?

- AM is an expensive process
- Lot of time required for optimization through experiments
- Using ML algorithms, process parameters can be optimized by skipping high expenses

Segregation

Microsegregation during AM does not follow Scheil-Gulliver solidification model

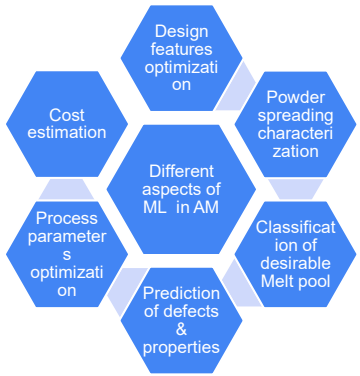


Comparison between Yao et al. [2]'s segregation micro-model prediction and Scheil profiles of Al–3Cu alloys under Quench cup fast casting condition (cooling rate 100 °C/s)

- Rapid solidification
- Extension to Multi-component alloys
- Coupling with Calphad databases

Future Work

- Optimizing the grain morphology for different process parameters and multi-component alloys
- Link thermal models to microstructure prediction
- Use of ML in AM:



References: **1.** Imani Shahabad, S., Karimi, G., & Toyserkani, E. (2021). An Extended Rosenthal's Model for Laser Powder-Bed Fusion Additive Manufacturing: Energy Auditing of Thermal Boundary Conditions. *Lasers in Manufacturing and Materials Processing*, *8*(3), 288-311. **2.** Yao, Z., Huo, Y., Li, M., & Allison, J. (2022). A Quantitative Study of Microsegregation in Aluminum–Copper Alloys. *Metallurgical and Materials Transactions A*, 1-19. **3.** Hunt, J. D. (1984). Steady state columnar and equiaxed growth of dendrites and eutectic. *Materials science and engineering*, *65*(1), 75-83. **4.** Fu, Y., Downey, A. R., Yuan, L., Zhang, T., Pratt, A., & Balogun, Y. (2022). Machine learning algorithms for defect detection in metal laser-based additive manufacturing: a review. *Journal of Manufacturing Processes*, *75*, 693-710.