# Rollett Group


## Prof. Anthony D. Rollett, rollett@andrew.cmu.edu

Carnegie Mellon University


## Research Directions

- Additive manufacturing, 3D printing of metals
- Micromechanical modeling
- Process modeling of additive manufacturing
- 3D characterization of micromechanical and microstructural evolution
- *in situ* characterization of defect formation in AM processes

## Computational Techniques

**Jones, Tang, Wilkin, Wong, Yarasi**

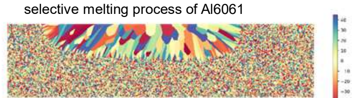
### Generation of Synthetic AM Microstructure

- Use of probabilistic models to simulate microstructure and texture development during fabrication of metal parts using laser powder bed fusion additive manufacturing

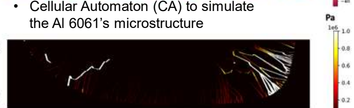
### Microstructural and Micromechanical Modeling

- **Thermal Lattice Boltzmann Cellular Automaton (TLB-CA)** model simulates the thermal history of the melt pool and the microstructural evolution
- **MASSIF**: Micromechanical Analysis of Stress-Strain Inhomogeneities with Fourier transforms is an image based technique that provides full-field stress & strain responses.
- Thermoelastic, eigenstrain, viscoplastic and elasto-viscoplastic formulations developed.
- Computationally more efficient than crystal plasticity finite element methods

- Thermal history simulation for selective melting process of Al6061



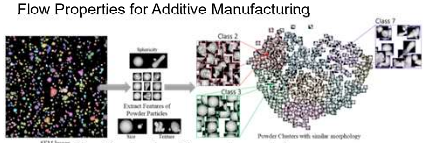
- Cellular Automaton (CA) to simulate the Al 6061's microstructure



- Hot cracking propensity prediction based on pressure depression value calculated at the grain boundary network.

### Powder Characterization for AM Using Computer Vision

- Computer Vision and Machine Learning to Associate Powder Characteristics with Flow Properties for Additive Manufacturing



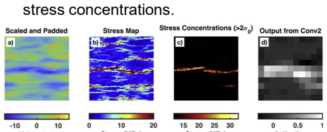
SuperPowder: describing powder morphology

GranuDrum to measure flowability

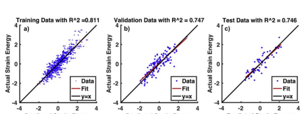
- Several powder flowability measurement instruments are available, including the GranuDrum, Hall Flowmeter, FT4 Rheometer.

### Stress Concentration Predictions in Rough Surfaces Using CNNs

- Development of a Convolutional Neural Network (CNN) to relate surface roughness to stress concentrations.




CNN is able to accurately detect stress concentrations in synthetically generated microstructures

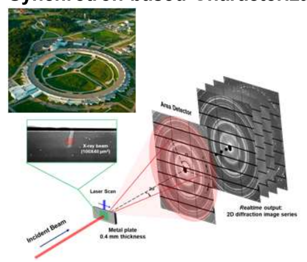


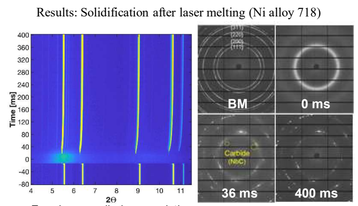
The CNN is capable of predicting, to a reasonable degree, the strain concentration metric in training, validation, and test data

## Advanced Characterization Techniques

**Aroh, Jiang, Oh, Wilkin, Zhang**

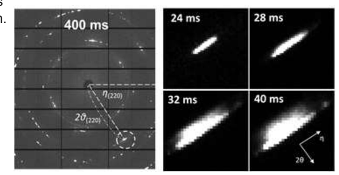
### Synchrotron-based Characterization Techniques for AM Applications






- Examine overall phase evolution
- Individual diffraction spots indicate how individual grains develop
- Investigation of solidification physics, precipitations, segregations, and temperature estimations

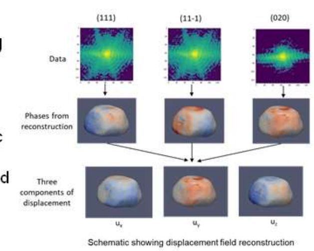
- The Advanced Photon Source at Argonne National Lab allows for a variety of experiments to be performed to investigate AM phenomenon.
- High speed diffraction experiments allow for development of an understanding of microstructure development during rapid solidification (top).
- Dynamic X-ray radiography gives insights into melt pool morphology and during AM processes (right).
- Computed tomography allows for detailed characterization of internal features, e.g., entrapped gas in powder, in-part porosity.




### Bragg Coherent Diffractive Imaging

Projection of displacement in Twinned Au nanocrystal

- X-ray diffraction tool used to image elastic strain on nanoscale (resolution ~20 nm)
- Coherent diffraction patterns reconstructed to project lattice displacement
- Reconstructing multiple Bragg peaks provides full displacement field, and thus, the elastic strain



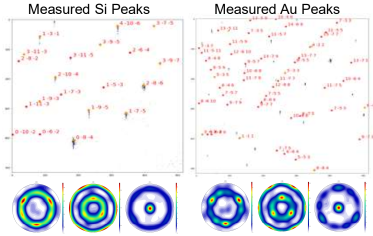

Schematic showing displacement field reconstruction

### Laue Diffraction Microscopy

- Laue Diffraction finds orientation of grains in a polycrystalline sample
- Connect Laue diffraction with BCDI and accelerate the measurements of Bragg peaks.
- Developed a workflow for indexing diffraction peaks and determining sample orientation at the APS
- EBSD and Laue diffraction simularity validates the workflow

Forward Modeled vs Measured Si Peaks

Forward Modeled vs Measured Au Peaks



Pole figures from EBSD results

## People & Collaborations

**Ph.D. students:** Seunghee Oh, Joseph Aroh, Srujana Rao Yarasi, Guanan Tang, Yueheng Zhang, Katelyn Jones, Ruby Jiang, Nick Lamprinakos, Evan Adcock, Junwon Seo, Rajib Halder, Gregory Wong

**Collaborators:** Advanced Photon Source, AFRL, Ametek, BlueQuartz, Boeing, CHESS, Deakin Univ., Georgia Tech, IISc, Imperial College, Iowa State Univ., LANL, Lehigh Univ., LLNL, NASA, NextManufacturing Center, Northrop-Grumman, NRL, ORNL, Seoul National Univ., UC Davis, Univ. of Lorraine, US Steel

## Additive Manufacturing

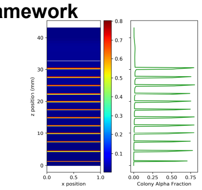
**Adcock, Aroh, Halder, Jiang, Lamprinakos, Oh, Tang, Seo, Yarasi**

### Fabrication of Stainless Steel Parts for Residual Stress Model Development

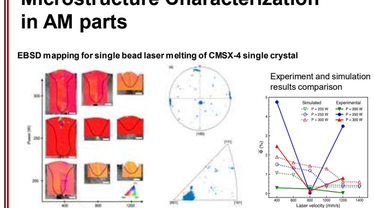
- SS316L parts fabricated to investigate superposition approach to residual stress modeling

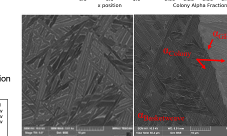
### Robotic Laser Wire Additive Manufacturing System with Comprehensive Quality Assurance Framework

- Mapping between process parameters, microstructure, and properties.
  - Thermal Model – to simulate the thermal history
  - Microstructure Model – to predict phase fractions and alpha lath from thermal history
  - Strength Model – to predict the macroscopic strength, while accounting for microstructure

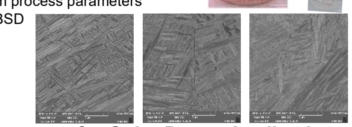


### Microstructure Characterization in AM parts

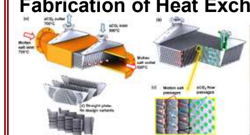


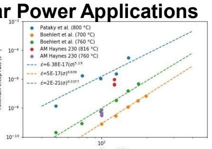



- Microscopy techniques used to evaluate differences in microstructure development from process parameters
- Above: single track melt pool EBSD
- Top-right: SEM of Wirefeed Ti64
- Right: Optical of Wirefeed Ti64
- Lower-right: SEM of LPBF Ti64



### Fabrication of Heat Exchangers for Solar Power Applications





- Design, fabricate and experimentally validate the performance of molten salt to supercritical $CO_2$ heat exchangers (HX) for concentrating solar power (CSP) applications using additive manufacturing (AM).
- The challenges are to calibrate the AM process to print fully dense parts using non-traditional AM materials, e.g., Haynes 230/282, with accurate dimensions.
- The compact AM HX design can deliver high energy generation efficiency and is capable to operate in a highly corrosive, high temperature (> 700°C), and high pressure environment, and withstand cyclic operation.

## Recent Papers


1. "An Updated Index Including Toughness for Hot-Cracking Susceptibility", Tang et al. *Metallurgical and Materials Transactions A* (2022).
2. "Grain reorientation and stress-state evolution during cyclic loading of an α-Ti alloy below the elastic limit", Lim et al. *International Journal of Fatigue* (2022).
3. "Study of printability and porosity formation in laser powder bed fusion built hydride-dehydride (HDH) Ti-6Al-4V", Wu et al. *Additive Manufacturing* (2021).
4. "Simulation Study of Hatch Spacing and Layer Thickness Effects on Microstructure in Laser Powder Bed Fusion Additive Manufacturing using a Texture-Aware Solidification Potts Model", Pauza et al. *Journal of Materials Engineering and Performance* (2021).
5. "Microscale Observation via High-Speed X-ray Diffraction of Alloy 718 During In Situ Laser Melting", Oh et al. *JOM* (2021).