ADAPT Monthly Members Meeting
14 March 2018

Attendees:

Member companies
Jeff Engel, Reaction Systems
Ed Garboczi, NIST
Jason Jones, MOOG (call-in)
David French, Ball Aerospace
Abby Smeltzer, Ball Aerospace
Jason Collier, Ball Aerospace
Jacob Nuechterlein, Elementum 3D
Adam Polizzi, Elementum 3D
Chris Borg, Citrine
Kyle Peterson, Citrine
Ned Bryan, AFSB-Carson
Daniel Higgs, ALD Nanosolutions
James Schwab, Lockheed Martin Space

Mines
Reid Winchester
Nathan Johnson
Tom Gallmeyer
Henry Geerlings
Dana Drake
Branden Kappes
Sen Liu
Rui Liu
Tony Vandenberge
Lyujian Lu
Xiaoli Zhang
Behnam Amin-Ahmadi
Dinesh Mehta
Senthamilaruvi Moorthy
Amy Brice

Welcome/Introductions

Announcements

Jacob Nuechterlein, ADAPT Board Member: the Board is always looking for feedback from members on ADAPT meetings and activities. Contact Jacob with your ideas: jacob@elementum3d.com

Technical Talks

1. Nathan Johnson, PhD Candidate–Materials Science, Colorado School of Mines
See presentation **Tailoring Mechanical Properties in Ti-6Al-4V**

- Mechanical properties vary in as-printed parts depending on the loading direction; currently post-processing is required; HIP removes anisotropy
- Goals: obtain desired mechanical properties as-printed; use mechanical anisotropy for tailoring mechanical responses
- As successive layers are deposited, underlying layers are thermally cycled; thermal cycling causes anisotropic response
- Due to thermal cycling, there is an increase in α' phase, which degrades mechanical properties
- Design experiment to control thermal cycling in builds – understand how cycles evolve and how microstructure grows as a result
- Build off of past research – get desired equiaxed structure by manipulating build process parameters; control thermal cycling to get equiaxed structure; next focus on controlling properties based on location in build by controlling process
- Progress to date has included a) understanding how thermal cycling impacts mechanical properties for simple geometries; b) characterizing microstructure of as-printed parts; c) formatting data for use with Citrination
- Next steps: a) measure thermal gradients, heat flow and radiation; b) build parts with different geometries; c) use Citrination to predict manufacturing conditions

2. Tom Gallmeyer, PhD Candidate–Materials Science, Colorado School of Mines
See presentation **Effects of Heat Treatment on L-PBF Inconel 718**

- Quality control/assurance in AM is the underlying motivation of Tom's research work
- Use preexisting alloy that has already been thoroughly characterized (Inconel 718) – understand how process parameters relate to properties to custom build
- Inconel 718 is strengthened through precipitation hardening (but what is it?). Secondary phase precipitates in heat treatment – if structure of precipitate isn't similar enough to matrix, incoherent boundaries result. Coherent precipitates improve strength of material.
- Major secondary phases in Inconel 718: $\gamma'$and γ'' (greatly increases strength); but other secondary phases, like laves and delta, are detrimental – they consume Nb, which is critical for γ'' formation (and therefore strengthening).
- Defects also influence material properties: point defects (solute strengthening), line defects (strain hardening), planar defects (boundary strengthening).
- Standard heat treatments for Inconel 718: Solution treating, aging – heat treatment schedule is critical to desired mechanical properties (review of TTT diagram). Step-wise heat treatment creates a more complex microstructure.
- Using novel process (AM) on existing material – demonstrated ability to produce superior mechanical responses
- Hierarchical microstructures observed in L-PDF Inconel 718

- Heat treatment does not lead to widespread recrystallization
- As-printed, nanoprecipitates form mainly near substructure boundaries
- Microsegregation corresponds to nanoprecipitate locations. Nb and Ti segregate to boundaries.
- Commercial heat treatment effectively homogenizes chemical partitioning
- Composite precipitates – interfacing b/t gamma prime and double prime
    - Reduces overall elastic strain field
    - Thermal stability (advantageous for high-temp applications)
    - Stacking fault localization
- Future work: a) investigate mechanisms by which co-precipitates form in AM Inconel 718 to control their location, size, and density; b) investigate heat treatments to precipitation strengthen without annealing dislocation networks

3. Rui Liu, PhD Candidate, Intelligent Quality Control
See presentation **AI-Powered Experiment Acceleration in Metal Additive Manufacturing**

- Challenge: 605-cylinder multi-parameter build – characterization is time-consuming and costly
- Solution: Experiment acceleration – simplify experiment plan before doing it
- Method framework (based on Facebook friend recommendation algorithm)
    - Experiment acceleration: part similarity → part repeatability
    - Step 1: unsupervised learning for grouping similar parts together
    - Step 2: research-goal-guided experiment acceleration
- Results: case study for porosity research
    - Research goal: process-porosity correlation
    - Simplification requirement: reduce trials by 40%
    - Known: machine settings; expect: less trials with similar pore size distribution
- Review of simplification plans and clusters
- Conclusion: the method effectively simplifies the experiment according to research goal and simplification requirements while keeping maximum data information

4. Dr. Xiaoli Zhang, Assistant Professor of Mechanical Engineering, Colorado School of Mines
See presentation **Statistical Learning from Prior Publications for Accelerating Metal AM Process Optimization**

- Presenting work done with student Sen Liu, PhD Candidate
- Motivation: experimental studies for process modeling and optimization are slow – need to accelerate
- Solution – vision: extract existing info from publications, use to build model to guide physical experiment design
- Automatically learn computational models from literature to guide design of experiments – framework is an iterative loop
- Case Study: part density
    - automated data retrieval

- data pre-processing – automatic data discretization
- data pre-processing - automatic feature selection
- Process-density modeling
- Model evaluation: inference structures for density prediction
- Evaluate effectiveness of framework

- Future work: build a comprehensive model considering density, hardness, yield strength, etc.

Next Meeting
Wednesday, April 11, 2018, 1:30–3:30
Golden Hotel, Golden Vista Room
Agenda: Guest Speaker Owen Hildreth: Electrochemistry in AM