ADAPT Monthly Members Meeting
14 February 2018

Attendees:

Invited Speaker
Todd Palmer, Penn State University

Member companies
Craig Brice, Lockheed Martin
Jeff Engel, Reaction Systems
Slade Gardner, Big Metal Additive
Ed Garboczi, NIST
Ray Bagley, Spatial Corp
Daniel Higgs, ALD Nanosolutions
Andrew Wessman, GE Additive
Jason Jones, Moog

CSM
Aaron Stebner
Nathan Johnson
Tom Gallmeyer
Henry Geerlings
Dana Drake
Branden Kappes
Sen Liu
Jeff King
Andrew Cornelius
Dinesh Mehta
Amy Brice

Guests
Flavio Garbanzo, Nucor
Tad Calkins, Boeing

Welcome/Introductions

Announcements

1. Meeting format: special topics every other month—we welcome ideas from members on special topics of interest (email Aaron, Branden, or Amy (abrice@mines.edu)).
2. Our new website is up (adapt.mines.edu) and the Member Content area is operational. Register to view the Member Content area, which currently contains meeting minutes and presentations. We are working with a team to develop video content for the website, including videos about adapt.citrination.

3. Henry Geerlings, ADAPT Masters student, is graduating soon and is looking for a job! His focus is in Computational Materials Science, specifically, developing a data processing pipeline for automating analysis of pores using computed tomography.
4. Aruvi Moorthy, ADAPT Masters student, recently graduated and is looking for a job! Aruvi's focus is on modeling the mechanical properties and anisotropy of 3D-printed Inconel. He specializes in mechanical testing, digital image correlation (DIC) and optical microscopy.
5. The Colorado School of Mines Board of Trustees approved the proposed Advanced Manufacturing degree program, which will launch Fall 2018.
    a. Degree options:
        i. Masters, Non-Thesis
        ii. Professional Graduate Certificate
        iii. Undergraduate Minor
        iv. Undergraduate Area of Special Interest
    b. The university has already granted budget to build a research lab for the new program
        i. A senior design team is building a laser metrology system, which will reside in the new lab
        ii. Two other senior design teams are building open-platform 3D printers
    c. Courses:
        i. New Data-Driven Materials Manufacturing course will launch in fall
        ii. The Intro to Additive Manufacturing course, which Craig Brice adjuncts, will be offered every semester
        iii. Two new courses will launch spring 2019: Solid Materials for Additive Manufacturing and Design for Additive
6. Dassault will conduct a 5-day Design for Additive workshop this summer using Dassault products via a grant through Mines (not ADAPT-specific). The targeted audience is industry folks—more details coming in next couple of months; point of contact is Prof. Tony Petrella at Mines.

Technical Talks
Invited guest speaker: Todd Palmer, Penn State University
Click name for bio

Todd's focus at PSU is on directed energy deposition (DED) processes
See presentation: **20180214_Influences of Feedstock Characteristics in Powder AM.pdf**

Powder feedstock
- origins
- characterization of feedstocks used in AM
- powder requirements for AM processes
- impact of atomization type
- impact of gas-atomization environment
- path forward

1. Origins
    a. How are powders fabricated—review of main categories
    b. Selection of a fabrication technique depends on understanding process characteristics, economics, resulting powder characteristics
    c. Different powder morphologies for different production methods: not all spherical
    d. Basics of the atomization process: input material and how prepared are important factors
    e. Categories of atomization: single fluid atomization (centrifugal, vacuum); two fluid atomization (gas atomized) (most common in AM)
    f. Particle breakup and formation in atomization processes
    g. Review of water atomization and the morphology of water atomized 316L powder for DED
    h. Review of gas atomization and the plasma rotating electrode process (PREP), which results in spherical, good-flowing powder
2. Characterization of Powder Feedstocks
    a. What particle attributes can be characterized: review of different attributes
    b. Powder feedstock characterization methods:
        i. Hall flow meter, apparent density, tap density, angle of repose (less popular method), particle size analysis, image analysis (broader sampling of particle morphology)
    c. Overview of powder characterization—governing standards and tools
    d. Comparison of 316L powder chemistry for powder bed fusion (PBF) systems
    e. Image analysis results for EOS powders
    f. Additional methods for measuring powder flowability—Revolution Powder Analyzer
    g. Future directions—powder rheology
3. Powder Requirements for AM Processes
    a. Common metallic material systems used in AM
    b. Metallic powders for AM
    c. Powder requirements for PBF systems
        i. Morphology for 316L stainless steel powder
        ii. Morphology of gas atomized 316L powder for PBF
        iii. Particle morphology of Ti-6Al-4V powder
    d. Powder requirements for DED processes
        i. Morphology of gas atomized 316L powder used in DED
        ii. Morphology of PREP Ti-6Al-4V powder used in DED
    e. DED allows for the use of blended elemental powders (e.g., NiTi compositions)
    f. Powder flow through nozzles for DED processes
4. Impact of Atomization Type
    a. Morphology of gas and water atomized 316L powder for DED
        i. Cracks in build with water-atomized powder
        ii. Chemistries of 316L powder—differences found in samples of gas vs. water atomized
    b. Suutala diagram shows increased cracking susceptibility for water atomized powders—Cr/Ni equivalence

    c. Schaeffler diagram shows change in solidification mode
5. Impact of Gas Atomization Environment
    a. How does feedstock and processing impact the heat treatment response
        i. Impact of nitrogen vs. argon atomization—morphology differences, differences in chemical compositions
    b. Determination of retained austenite in powder feedstock by X-ray diffraction and impact of atomization process on retained austenite fraction
    c. Effect of nitrogen content
        i. Higher N content corresponds to more retained austenite
    d. Argon and nitrogen atomized powders exhibit opposite aging responses
6. Path forward
    a. Major thrusts identified in Roadmapping Effort; one big result was establishing feedstock and AM part testing protocols
    b. Priority R&D activities in part/feedstock testing
    c. See document **20180214_CAMMRoadmpa.pdf**: Consortium for Additive Manufacturing Materials (CAMM) Strategic Roadmap for the Next Generation of Additive Manufacturing Materials

Break

Member Discussion

- Coatings
- Daniel Higgs, ALD Nanosolutions: 25 people based in Broomfield, CO; ALD = atomic layer deposition—a sequential gas-phased process in which they can do surface modification on powders to create nano-thin coatings; ~10 nm coating to create a hermetic seal on powder
    - Ex: coat lithium cathode materials for batteries to retain capacity
- Looking into learning more about flowability, small elemental changes, interfaces between ceramic materials and organic binders or between metal powder and binders
- Raising money; Series A to fund internal development to collaborate with others
- Coatings can be thicker, but with higher cost and longer time
- Main materials ALD deposits are metal oxides, some metals, and polymers are a new area

- Ed Garboczi from NIST
- 3D analysis of powder using X-ray CT and mathematical analysis
- Particle size: diameter used for spherical particles, size analysis for other shapes
- More PSD standards/methods needed for AM industry
- Pre- and post-Tekna analysis of powders

- Discussion on powder specifications (they're very broad and were not developed for AM processes) and the differences in powder feedstocks that fall within specs and how these differences affect part quality. Discussion on exclusivity of some powders to specific machines and desire for powders to be non-exclusive ("any powder for any machine").

- Ed Garboczi (NIST-Boulder) mentioned a new ASTM program entitled Additive Manufacturing Powder Metallurgy (AMPM) and provided the following information post-meeting:

The ASTM Proficiency Testing Program Office received a request to explore expanding the ASTM PTP to include a new proficiency testing program on Metal Powders in the area of additive manufacturing utilizing a number of ASTM standard test methods. A further survey indicated great interest in launching such a program. The proposal was considered by the Committee B09, Metal Powders and Metal Powder Products and F42, Additive Manufacturing Technologies. This request is being implemented and the program launched in early 2018, entitled Additive Manufacturing Powder Metallurgy (AMPM).

Ed Garboczi (NIST-Boulder) and Justin Whiting (NIST-Gaithersburg), along with Frank Venskytis, are acting as technical reviewers for this program.

Amy Meacock, Director – Proficiency Test Programs at ASTM, is organizing this effort. Her contact information follows: ameacock@astm.org, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, USA, tel +1.610.832.9688 cell +1.484.904.2803 fax +1.610.834.3619, www.astm.org

Justin Whiting and Ed Garboczi will also be presenting two ASTM webinars on AM powder characterization on Feb. 20 (Whiting, standard methods) and Feb. 27 (Garboczi, 3D X-ray CT methods). See www.astm.org for how to register and cost information.

Next Meeting
Wednesday, March 14, 2018, 1:30–3:30
Colorado School of Mines Ben Parker Student Center, Ballroom E
Agenda: Progress reports on research projects