ADAPT Monthly Members Meeting
11 April 2018

Attendees:

Invited Guest Speaker
Owen Hildreth, Arizona State University

Member companies
Jason Jones, Moog (call-in)
Daniel Higgs, ALD Nanosolutions (call-in)
Benjamin Collins, ADA Technologies
David French, Ball Aerospace
Jacob Nuechterlein, Elementum 3D
Adam Polizzi, Elementum 3D
Nathan Dix, DMS
Abby Smeltzer, Ball Aerospace
Haley Fox, Ball Aerospace
Terry Curtland, Ball Aerospace
Craig Brice, Lockheed Martin
Ned Bryan, AFSB–Carson

Mines
Aaron Stebner
Branden Kappes
Jeff King
Tony Vandenberge
Lyujian Lu
Nathan Johnson
Connor McLean
Rui Liu
Amy Brice

Guests
Dustin Crouse, 3D Systems

Welcome/Introductions

Announcements

1. ADAPT meeting location for May–October: Starzer Welcome Center (on Mines campus), 1812 Illinois St., Golden CO 80401
2. Upcoming ADAPT meeting plans:
    a. May: Student design projects for the new Advanced Manufacturing educational lab

   b. June: Technical project updates from ADAPT faculty and grad students
   c. July: Special guest speaker Mohsen Seifi from ASTM; he will speak on ASTM standards work for metals AM
   d. August: Craig Brice (Lockheed Martin) and Slade Gardner (Big Metal Additive) will discuss different AM technologies and the criteria for choosing the best process for your application

3. Advanced Manufacturing Interdisciplinary Program at Mines: now live for registration: mines.edu/manufacturing [see flyer attached to email and to the ADAPT website meeting minutes page for an overview of the program; you are welcome to share the flyer with anyone inside or outside your organization]
   a. Professional certificate
   b. MS, Non-Thesis
   c. Courses being taught this fall include Intro to Additive Manufacturing (Craig Brice) and Data-Driven Materials Manufacturing (Branden Kappes)—these will be offered back to back on Mon/Wed evenings starting at 4:30
   d. The program is already approved by Ball's HR for reimbursement; talk to Aaron if your HR needs more information to establish a reimbursement policy
4. Mines Professor Tony Petrella will host DAM Workshop 2018: Design for Additive Manufacturing (more info at damworkshop2018.mines.edu)
   a. Program in coordination with Dassault
   b. Week-long, hands-on class, including lab portion
   c. Registration is open on the website; limited to 10 participants; plan to offer regularly after this initial event
   d. Not connected to ADAPT—see the website for registration and contact information
   e. Many elements from this workshop will be incorporated into the Design for Additive Manufacturing course launching Spring 2019 (taught by Tony Petrella) as part of the Advanced Manufacturing Interdisciplinary Program
5. Congratulations to ADAPT PhD student Rui Liu who successfully defended his thesis! Rui has taken a position with the Robotics Institute at Carnegie Mellon.

Technical Program

Special guest speaker Owen Hildreth, Assistant Professor at the School for Engineering of Matter, Transport, and Energy (SEMTE) at Arizona State University: **Dissolvable Metal Supports for 3D Printed Metals** [see presentation file on ADAPT website as well as audio recording (with slide visuals)]

1. With his background in localized etching and deposition technologies, Dr. Hildreth took on the challenge of dissolvable supports for metal.
   a. Example part passed around: quote for machine shop to take off supports was $4000; dissolvable support process cost about $2
2. Why dissolvable supports?
   a. Solution-based system improves throughput and consistency of parts

   b. Build settings don't change
   c. Can dissolve external and internal supports
   d. Surface roughness decreases
   e. Can be used to thin walls
   f. Can be used to remove trapped powder

3. High-level overview of Dr. Hildreth's process:
   a. Print part
   b. Heat treat part
   c. Etch part to selectively remove supports; component only loses ~50 microns of material from surface
      i. Not electropolishing, which depends on shape of part and location of counterelectrodes, conductivity of solution, and aspect ratios (none of these factors matter in the dissolvable process)

4. Corrosion Primer
   a. Corrosion is a chemical reaction that physically degrades material (e.g., rust, copper patina, silver tarnishing, pitting, crevice, galvanic)
   b. Galvanic corrosion: two dissimilar metals in electrical and electrolytic contact—results in preferential rusting
      i. Electromotive series (how easily a metal oxidizes—how noble or not noble)
   c. Passivation: alloys have additives that oxidize easily and form a passivation layer, e.g., stainless steel: Cr_2O_3 is the passivation layer that makes stainless steel stainless (it's dense, non-porous and chemically resistant)

5. Dissolvable supports: use another material for the supports (different from part alloy) that does not have passivating elements in it (e.g., carbon steel used as support material for stainless steel part in a part made with directed energy deposition (DED)). Carbon steel has good metallurgical compatibility with stainless steel, but carbon steel does not have chromium to protect from oxidation.

6. Dissolvable supports for DED (electrochemistry)
   a. Use same approach as for polymers: two different materials, one is soluble in acid, the other is insoluble
   b. Potentiodynamic polarization curve
   c. Anodically etch carbon steel support while stainless steel is cathodically protected
   d. Entire sample subject to anodic current – potential for entire part to be etched in electropolishing process

7. PBF: one material printed, can't selectively print two different materials—need a different approach to dissolvable supports (without changing printing parameters or equipment)
   a. Sensitization process: print part, dip in a solution, heat treat
   b. increases corrosion susceptibility by changing surface composition, creating a galvanic cell such that supports have to be removed
   c. Proof of concept (several different materials listed in presentation
   d. Process

i. Print part as normal
ii. Dip in sensitizing agent ("cherry red," commonly available, not hazardous)—coats surface to protect base component. The cherry red is a water-soluble carbon source.
iii. Heat treatment: carbon reacts with passivating elements (e.g., in stainless steels, it forms chromium carbide precipitates). Changes surface composition of supports from stainless steel to carbon steel.
iv. Selectively etch supports until supports fully removed; geometry of part doesn't change. Only top 50–100 microns of surface of part is affected (would likely be machined anyway).
v. Very slow and very consistent, independent of shape of part
vi. Big improvement over electropolishing techniques
vii. Process is inherently self-terminating

e. Targeting Etching Modes: double loop electrochemical potentiodynamic reactivations (DLEPR)
f. Surface finish—roughness removed during etching
g. Tensile bar testing w/ NASA: no negative effect on mechanical properties from this process

8. Advantages

- Remove internal and external supports with ease
- Remove trapped powder
- Consistent
- Self-terminating: user- and geometry-independent
- Broaden design space
- Improves surface finish
- Improves mechanical performance
- Fast compared to machining
- Keep existing printing parameters
- Works in single-material PBF printers
- Process entire build platforms at once
- Requires no specialized skill
- Robust, transportable equipment

Q&A (starts at 59:34 of the audio recording)

Next Meeting
Wednesday, May 9, 2018, 1:30–3:30
Starzer Welcome Center (Mines campus): 1812 Illinois St., Golden CO 80401
Agenda: Student design projects for the new Advanced Manufacturing educational lab