THE ~~29~~TH ANNUAL INTERNATIONAL

SOLID FREEFORM FABRICATION SYMPOSIUM

– AN ADDITIVE MANUFACTURING CONFERENCE – 2018

August ~~13–15, 2018~~

Hilton ~~Hotel~~ Austin • Austin, Texas, USA

FINAL PROGRAM

Organized by the Mechanical Engineering Department/Lab for Freeform Fabrication under the aegis of the Advanced Manufacturing and Design Center at The University of Texas at Austin.

Sponsored by:

sffsymposium.engr.utexas.edu

SCHEDULE OF EVENTS

Function	Time	Location
Sunday, August 12		
Registration	2:00 p.m. to 5:00 p.m.	Hilton Austin, Salon H Foyer
Pre-Conference Social Event	6:00 p.m. to 8:30 p.m.	Buffalo Billiards **Must be 21 or older; Photo ID Required*
Monday, August 13		
Registration	7:00 a.m. to 5:00 p.m.	Hilton Austin, Salon H Foyer
Opening Remarks	8:00 a.m. to 8:15 a.m.	Hilton Austin, Salon HJK
Plenary Session and FAME Award Presentations	8:15 a.m. to 12:05 p.m.	Hilton Austin, Salon HJK
Break	9:55 a.m. to 10:25 a.m.	Hilton Austin, Salon HJK Foyer
Lunch	12:05 p.m. to 1:30 p.m.	On Your Own
Technical Sessions	1:30 p.m. to 5:00 p.m.	Hilton Austin, See Technical Program
Break	3:10 p.m. to 3:40 p.m.	Hilton Austin, Salon HJK Foyer
Welcome Reception	6:00 p.m. to 6:30 p.m.	Hilton Austin, Salon HJK Foyer
10th Annual Awards Program & Banquet	6:30 p.m. to 9:00 p.m.	Hilton Austin, Salon HJK
Tuesday, August 14		
Registration	7:00 a.m. to 5:00 p.m.	Hilton Austin, Salon H Foyer
Technical Sessions	8:15 a.m. to 12:05 p.m.	Hilton Austin, See Technical Program
Break	9:55 a.m. to 10:25 a.m.	Hilton Austin, Salon HJK Foyer
Lunch	12:05 p.m. to 1:40 p.m.	Hilton Austin, Salon H
Technical Sessions	1:40 p.m. to 4:00 p.m.	Hilton Austin, See Technical Program
Poster Session with Refreshments	4:00 p.m. to 5:30 p.m.	Hilton Austin, Salon JK
Wednesday, August 15		
Registration	7:00 a.m. to 5:00 p.m.	Hilton Austin, Salon H Foyer
Technical Sessions	8:00 a.m. to 11:50 a.m.	Hilton Austin, See Technical Program
Break	9:40 a.m. to 10:10 a.m.	Hilton Austin, Salon HJK Foyer
Lunch	11:50 a.m. to 1:10 p.m.	On Your Own
Technical Sessions	1:10 p.m. to 5:00 p.m.	Hilton Austin, See Technical Program
Break	2:50 p.m. to 3:20 p.m.	Hilton Austin, Salon HJK Foyer

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ABOUT THE SYMPOSIUM

REGISTRATION

The full-conference and student registration rates includes the following:

- Access to technical and poster sessions
- Sunday evening pre-conference event
- Monday evening awards banquet
- Tuesday lunch
- A flash drive copy of the post-conference proceedings

The daily registration rate includes the following:

- Access to technical and poster sessions that day
- One ticket to the social event on that day

Registration Hours

The registration desk will be located in the Salon H Foyer of the Hilton Austin during the following hours:
Sunday, August ~~12~~: 2:00 p.m. to 5:00 p.m.
Monday, August ~~13~~: 7:00 a.m. to 5:00 p.m.
Tuesday, August ~~14~~: 7:00 a.m. to 5:00 p.m.
Wednesday, August ~~15~~: 7:00 a.m. to 5:00 p.m.

Internet Access

Complimentary wireless internet is for attendees in the Hilton Austin meeting spaces. To access the wireless internet, open the wireless menu on your device and choose the network “**Hilton Meetings**” and enter the access code “**~~SFF2018~~**.”

Technical Sessions

All technical and poster presentations will be located at the Hilton Austin. See the Technical Program on pages ~~23-114~~ for locations.

Luggage Storage

Luggage storage will be available at no cost to attendees on Wednesday, August ~~15~~, from 7:00 a.m. to 6:00 p.m. in room 612 at the Hilton Austin. Please note that this room will not be secured and any items left for storage will be at the attendee’s own risk. TMS and/or the SFF conference are not responsible for lost, stolen, or damaged items left in the room.

ABOUT THE VENUE

Symposium programming and events will take place at the four-star Hilton ~~Hotel~~ Austin. The Hilton Austin is located at 500 East 4th Street in downtown Austin, adjacent to the Convention Center. Exclusive shopping, amazing restaurants, and fun live music venues in the 6th Street Entertainment District and surrounding areas are all just a few steps away from the Hilton Austin. The hotel also boasts fantastic views of the Capitol of Texas and Lady Bird Lake from 31 stories up.

Self-parking ($32) and valet parking ($41) are both available at the hotel. Visit the Hilton ~~Hotel~~ Austin website for more details.

PRE-CONFERENCE SOCIAL EVENT

6:00 p.m. to 8:30 p.m. • Sunday, August 12

Buffalo Billiards
Come and meet old friends and make new ones before the "business" starts Monday! Enjoy a "Tex-Mex" style fajita buffet at Buffalo Billiards, 201 East 6th Street in downtown Austin. The restaurant is only 0.3 mi (0.5 km) from the Hilton Hotel Austin. There is no additional charge to attend for conference registrants. No transportation will be provided. Guests must be 21 years or older to attend; photo ID will be required to enter Buffalo Billiards.

About Buffalo Billiards
From the Buffalo Billiards website: "This turn-of-the-century building was built in 1861 by the Ziller Family and named the Missouri House. Touted as Austin's first boarding house and rumored to be a brothel, many a cowboy had a good time here."

The entire venue consists of three full bars, 19 pool tables, seven shuffleboard tables, five foosball tables, 15 pinball machines, a collection of classic and modern arcade machines, and two air hockey tables. The SFF Symposium group will have the run of the place from 6:00 p.m. to 8:30 p.m.

CONFERENCE LUNCH EVENT

12:05 p.m. to 1:40 p.m. • Tuesday, August 14

An informal networking lunch will be provided near the meeting rooms in Salon H at the Hilton Hotel Austin at the lunch break on Tuesday. The cost is included in the conference registration fee. There is no organized Tuesday evening social event this year.

AWARDS PRESENTATION

Monday, August 13 • Hilton Austin

6:00 p.m.	Reception & Welcome
6:40 p.m.	Special Presentation
7:00 p.m.	Dinner
8:00 p.m.	Awards Presentation
9:00 p.m.	Event Concludes

Special Presentation: Dr. Tony Rollett

Anthony Rollett is the co-director of the NextManufacturing Center at Carnegie Mellon University (CMU). Prior to joining CMU in 1995, Tony was with the Los Alamos National Laboratory. He has over 200 peer-reviewed journal publications that cover a wide range of topics. The main focus of his research is on the measurement and computational prediction of microstructural evolution especially in three dimensions. His interests include strength of materials, constitutive relations, microstructure, texture, anisotropy, grain growth, recrystallization, formability and stereology.
His most recent honors include: Member of Honor of the French Society of Materials (SF2M) in 2015; the Edgar C. Bain Award from the Pittsburgh Chapter of ASM International in 2016; and appointment as U.S. Steel Professor of Metallurgical Engineering & Materials Science at Carnegie Mellon University in 2017. Tony has used the third generation (synchrotron x-rays) Advanced Photon Source at the Argonne National Laboratory to produce remarkable videography of melt pool and vapor keyhole phenomena in metal powder bed fusion.

Tony will introduce, present, and discuss these measurements. However, Tony has accepted the challenge to pitch the entire talk at a level that a 10–12 year old might understand (!). In addition, Tony will close the program with some novel entertainment that everyone will enjoy.

DINING OPTIONS
NEAR THE HILTON AUSTIN

Barbecue	Mexican	American	Italian	Seafood
Coopers (3rd/Congress) **Lamberts** (W.2nd/Guadalupe) **Iron Works** (Red River/Cesar Chavez) **Stubbs** (Red River/E.8th) **Terry Blacks** (Barton Springs Rd) **Franklin** (E.11th/Branch) **La Barbecue** (E.Cesar Chavez) **Freedman's** (W. 24th) **Micklethwait** (E.11th/Rosewood) **The Salt Lick** (Round Rock/Driftwood)	**La Condesa** (W.2nd/Guadalupe) **El Naranjo** (Rainey St.) **Manuels** (Congress/W.3rd) **Iron Cactus** (E.6th St) **Pelons** (8th/Red River) **Benjis Cantina** (W.6th/West Ave) **Uncle Julios** (Brazos/E.3rd) **Michelada's** (2nd/San Jacinto) **Matts El Rancho** (S. Lamar)	**Cannon + Belle** (Hilton Austin) **Moonshine** (4TH/Red River) **Parkside** (E.6th /San Jacinto) **Searsucker** (Colorado/W.5th) **Fixe** (W.5th/Nueces) **Max's Wine Dive** (San Jacinto/E.3rd) **Second Bar + Kitchen** (Congress/W.2nd) **Emmer & Rye** (Rainey St.) **No Va** (Rainey St.) **Swifts Attic** (3rd/Congress) **24 Diner** (S.Lamar/W. 6th)	**Italic** (W.6th/Colorado) **Botticellis** (S.Congress/Gibson) **La Traviata** (Congress/W. 4th) **Taverna** (W.2nd/Lavaca) **WinfloOsteria** (W.6th/Pressler) **Cipollina** (W.Lynn/W. 13th) **Vespaio** (S. Congress) **Numero 28** (W. 2nd/San Antonio) **Red Ash** (3rd./Colorado)	**Café Blue** (2nd/Trinity) **Eddie V's** (E. 5th/Trinity) **Capital Grille** (W. 4th/Colorado) **Trulucks** (Colorado/E.4th) **Perla's** (S. Congress/Gibson) **Surf and Turf Po Boy** (Lavaca/E. 4th) **Trio (inside Four Seasons)** (San Jacinto) **Clarks** (W. 6th/Blanco) **Dock and Roll** (S.1st)

Steakhouse	Asian	Sushi	French	Pizza
Eddie V's (E. 5th/San Jacinto) **Vince Young's** (2nd/San Jacinto) **Capital Grille** (W. 4th/Colorado) **Perry's** (W.7th/Colorado) **III Forks** (C. Chavez/Lavaca) **Austin Land & Cattle** (N.Lamar) **Lonesome Dove** (5th/Colorodo)	**Wu Chow** (W. 5th/San Antonio) **Kyoten** (E. 6th) **Mai Thai** (San Jacinto/E.3rd) **Sway** (S.1ST) **Elizabeth St. Café** (S.1st/W.Mary) **Koriente** (E.7th/Sabine) **Daruma Ramen** (E.6th)	**Bar-Chi** (Colorado/W.2nd) **Uchi** (S.Lamar) **Uchiko** (N. Congress) **Sushi Zushi** (W.5th) **Piranha Sushi** (San Jacinto/E.3rd) **Maiko** (W. 6th/Guadalupe) **RA** (4th/Colorado) **Lucky Robot** (S. Congress)	**Justine's Brasserie** (E. 5th) **Chez Nous** (5th/Neches) **Peche** (W.4th) **Blue Dahlia Bistro** (E.11th) **L'estelle House** (Rainey) **Elizabeth Street Café** (S. Congress/Elizabeth St) **Le Café Crepe** (2nd/San Jacinto)	**Backspace** (San Jacinto/E 6th) **Hoboken Pie** (Red River/E.8th) **Roppolo's** (6th/ Trinity) **Home Slice** (S. Congress) **Via 313** (Rainey St) **Numero 28** (W. 2nd/San Antonio)

Burgers/Sandwiches	Vegetarian/ Vegan	Fusion/Misc.	Breakfast	Brunch
Easy Tiger (E.6th/Sabine) **Casino El Camino** (E.6th/Red River) **Eureka** (6th/ Brazos) **Hopdoddy** (S.Congress) **Waller Creek Pub** (6th/ Sabine) **P Terry's** (6th/Congress) **Frank** (Colorado/W.4th)	**Koriente** (E.7th/Sabine) **Arlos (V)** (Red River) **Counter Culture Café (V)** (E. C. Chavez/Clara) **Bouldin Creek Café** (S.1st/W.Mary) **Mr. Natural** (E. C. Chavez/Chicon) **The Vegan Yacht (V)** (Spiderhouse) **(V) = Vegan**	**Austin Taco Project** (Hilton Austin) **G'RajMahal Indian** (Rainey St) **Malaga Tapas** (2nd/ San Antonio) **Clay Pit** (15th/Guadalupe) **Russian House** (E. 5th) **Buenos Aires Argentine** (E. 6th/Waller) **Bangers** (Rainey St)	**Cannon + Belle** (Hilton Austin) **Forthright** (Cesar Chavez/Brazos) **24 Diner** (S.Lamar/W.6th) **Annies Cafe** (Congress/E.4th) **1886 Café** (The Driskill) **Counter Café** (E.6th) **Le Café Crepe** (2nd/San Jacinto) **South Congress Café** (South Congress)	**Moonshine** (Red River/E.4th) **El Naranjo** (Rainey St) **Stubbs Gospel Brunch** (Red River) **No Va** (Rainey) **Swifts Attic** (Congress Avenue) **Taverna** (2nd/Lavaca) **Searsucker** (5th/Colorado) **Little Barrel & Brown** (S. Congress) **Forthright** (Cesar Chavez/Brazos)

Cafes	Beer/Wine/Liquor	Grocery/Pharmacy	Tour Info/Pickup	Address
Starbucks (Hilton Austin) **Hounds Tooth** (E.4th/Congress) **Jo's Coffee** (2nd/Colorado)	**All American Liquors** (E 5th/Brazos) **Twin Liquors** (Red River/E.7th) **Austin Wine Merchant** (W.6th)	**CVS Pharmacy** (5th/Congress) **Royal Blue Grocery** (3rd/Brazos) **Whole Foods Market** (W.6th/Lamar)	**Austin Visitor Center** (512)-478-0098 (Red River/E.4th)	**The Hilton Austin** **500 E. 4th St** **Austin, Texas** **(512)-482-8000**

DOWNTOWN MAP

Badges

All attendees are encouraged to wear SFF Symposium registration badges at all times during the conference to ensure admission to events included in the paid fee such as technical sessions, exhibition, and receptions.

Americans with Disabilities Act

The federal Americans with Disabilities Act (ADA) prohibits discrimination against, and promotes public accessibility for, those with disabilities. In support of, and in compliance with ADA, we ask those requiring specific equipment or services to contact TMS Meeting Services at mtgserv@tms.org in advance.

Cell Phone Use

In consideration of attendees and presenters, we kindly request that you minimize disturbances by setting all cell phones and other devices on "silent" while in meeting rooms.

Anti-Harassment

In all activities, the SFF Symposium is committed to providing a professional environment free of harassment, disrespectful behavior, or other unprofessional conduct.

Conference policy prohibits conduct that is disrespectful, unprofessional, or harassing as related to any number of factors including, but not limited to, religion, ethnicity, gender, national origin or ancestry, physical or mental disability, physical appearance, medical condition, partner status, age, sexual orientation, military and veteran status, or any other characteristic protected by relevant federal, state, or local law or ordinance or regulation.

Failure to comply with this policy could lead to censure from the conference organizers, potential legal action, or other actions.

Anyone who witnesses prohibited conduct or who is the target of prohibited verbal or physical conduct should notify a conference staff member as soon as possible following the incident. It is the duty of the individual reporting the prohibited conduct to make a timely and accurate complaint so that the issue can be resolved swiftly.

Photography and Recording

The SFF Symposium reserves the right to all audio and video reproduction of presentations at this meeting. By registering for this meeting, all attendees acknowledge that they may be photographed by conference personnel while at events and that those photos may be used for promotional purposes, in and on conference publications and websites, and on social media sites.

Any recording of sessions (audio, video, still photography, etc.) intended for personal use, distribution, publication, or copyright without the express written consent of the individual authors is strictly prohibited. Attendees violating this policy may be asked to leave the session.

Antitrust Compliance

The SFF Symposium complies with the antitrust laws of the United States. Attendees are encouraged to consult with their own corporate counsel for further guidance in complying with U.S. and foreign antitrust laws and regulations.

Emergency Procedures

The chances of an emergency situation occurring at the SFF Symposium are quite small. However, being prepared to react effectively in case of an incident is the most critical step in ensuring the health and safety of yourself and those around you. Please take a few moments to review the map of the Hilton Hotel Austin printed in this program (back cover). When you enter the building, familiarize yourself with the exits and the stairs leading to those exits. When you arrive at your session or event location, look for the emergency exits that are in closest proximity to you.

The Hilton Austin has an emergency response team in place 24 hours a day. The hotel's internal emergency number is 44 (can be dialed from any house phone). In the event of an emergency, calling the 44 emergency number will initiate the appropriate response. The hotel security department and a number of other hotel employees are also trained in CPR and First Aid.

Emergency evacuation routes and procedures are located on the inside of all guest room doors. The local fire department, police department, and paramedics are all approximately five minutes away from the conference location.

A BIG THANK YOU TO:

The **National Science Foundation** for providing meeting support (Grant Number CMMI-1826959)

The **Office of Naval Research** for providing meeting support (Grant Number N00014-18-1-2558)

Stratasys Digital Manufacturing (Jeff Rodocker, Pat Garner) for donating the FAME trophies.

TyRex Group Ltd. for hosting the refreshments during the Tuesday afternoon poster session.

Taylor & Francis Publishing for allotting a special issue of the *Virtual and Physical Prototyping Journal* for best papers for the meeting.

The Minerals, Metals & Materials Society for allotting a special issue of the journal *JOM* for best papers with a materials theme.

International SFF Symposium Organizing Committee

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Rich Crawford, UT-Austin
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THE 29TH ANNUAL INTERNATIONAL

SOLID FREEFORM FABRICATION SYMPOSIUM 2018

– AN ADDITIVE MANUFACTURING CONFERENCE –

TECHNICAL PROGRAM

PROGRAM HIGHLIGHTS: SPECIAL SESSIONS

Plenary Session and FAME Award Presentations (Monday AM)
Organized by the SFF 2018 committee

Special Session: Hybrid AM Processes
Session Organizer: Michael Sealy, University of Nebraska at Lincoln

1. Hybrid Additive-Subtractive Processes (Monday PM)
2. Surface treatments and Assistive Technology (Tuesday AM)
3. Hybrid Materials, Structures, Functions (Tuesday PM)
4. Direct/Indirect Build Strategies (Wednesday AM)

Special Session: Data Analytics in AM
Session Organizer: Prahalada Rao, University of Nebraska at Lincoln

1. Quality in Modeling 1 (Monday PM)
2. Quality in Modeling 2 (Tuesday AM)
3. Process Monitoring and Defect Mitigation (Tuesday PM)
4. Quality and Modeling 3 (Wednesday AM)

Special Session: Binder Jet Additive Manufacturing: Materials, Modeling, and Experiments
Session Organizer: C. Fred Higgs III, Rice University; Zachary C. Cordero, Rice University

1. Binder Jet AM 1 (Tuesday AM)
2. Binder Jet AM 2—Processing (Tuesday PM)

Day/Time	Monday AM	Monday PM	Tuesday AM	Tuesday PM	Tuesday PM	Wednesday AM	Wednesday PM	Day/Time
Room	8:00 AM to 12:00 PM	1:30 to 5:00 PM	8:15 AM to 12:05 PM	1:40 to 4:00 PM	4:00 to 5:30 PM	8:00 to 11:50 AM	1:10 to 5:00 PM	Room
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Session Name	Plenary Session and FAME Award Presentations
Room	Salon HJK
Chair	Chair: Richard Hague, University of Nottingham
8:00 AM	Introductory Comments
8:15 AM	Overview of Sandia's Born Qualified Project: Robert Roach, Sandia National Labs
8:35 AM	Technology Integration into Existing Companies: Christian-Friedrich Wilhelm Lindemann, Direct Manufacturing Research Center
8:55 AM	Data Mining Approaches for Price Determination of 3D Printing Services in Decentralized Manufacturing-as-a-Service Marketplace: Binil Starly, North Carolina State Univ
9:15 AM	Examining the Effect of DFAM Design Rule Presentation on Part Redesign Quality: Katherine Fu, Georgia Institute of Technology
9:35 AM	What Insights into Additively Manufactured Materials will Exascale Computing Enable?: James Belak, Lawrence Livermore National Laboratory
9:55 AM	Break
10:25 AM	A Physical Hash for Preventing and Detecting Cyber-physical Attacks in Additive Manufacturing Systems: Logan Sturm, Virginia Polytechnic Institute
10:45 AM	FAME Outstanding Young Researcher: Hybrid- Additive Manufacturing (AM): Role of Mechanical Design and Traditional Manufacturing Processes in the Adoption of Metal AM: Guha Manogharan, Pennsylvania State University
11:15 AM	Freeform and Additive Manufacturing (FAME) Award: The Advances in 4D Printing: Chee Kai Chua, Nanyang Technological University

TECHNICAL SESSION GRID - MONDAY PM

Session Name	Applications 1	Lattices and Cellular 1	Materials: Metals 1 - Broad Issues in Metal AM	Materials: Metals 2 - Stainless Steel 316L	Materials: Polymers 1 - Novel Materials and Processes	Physical Modeling 1 - Thermal Modeling in Powder Beds
Room	Salon G	Salon F	615AB	616AB	417AB	Salon A
Chair	Amrita Basak, Georgia Institute of Technology	Dhruv Bhate, Arizona State University	Elena Lopez, Fraunhofer IWS	Thomas Starr, University Of Louisville	Judith Lavin, Sandia National Laboratories	Wentao Yan, Northwestern University, U.S.
1:30 PM	Material Characterization for Lightweight Thin Wall Structures Using Laser Powder Bed Fusion Additive Manufacturing: Sean Dobson, University of Louisville Mechanical Engineering Department	Mechanical Properties of Ti6Al4V ELI Lattice Structure Fabricated by Selective Laser Melting: Effect of Pore Size and Porosity: Xingchen Yan, Universite de Technologie de Belfort-Montbeliard	Experience with Additive Manufacturing for Navy Sustainment: Edward Reutzel, ARL Penn State / CIMP-3D	Comparison of Stainless Steel 316L Parts Made by FDM-based and SLM-based Additive Manufacturing Processes: Haijun Gong, Georgia Southern University	Fast Scanning Differential Calorimetry for Semicrystalline Polymers in Fused Deposition Modeling: Emily Fitzharris,	An Efficient Meso-scale Thermal Simulation for Powder Bed Fusion: Yaqi Zhang, University of Wisconsin-Madison
1:50 PM	Effect of Inter-layer Cooling Time on Distortion and Mechanical Properties in Metal Additive Manufacturing (AM): William Chad Henry, GNK Aerospace	Microstructural and Mechanical Characterization of Ti6Al4V Cellular Struts Fabricated by Electron Beam Powder Bed Fusion Additive Manufacturing: Li Yang, University Of Louisville	Development of an Engineering Diagram for Additively Manufactured Austenitic Stainless Steel Alloys : Zachary Hilton, Missouri Univ of Science and Technology	Metallurgical and Mechanical Characterization of a 316L Steel Elaborated by Selective Laser Melting: Christophe Voltz, Cea	PEEK High Performance Fused Deposition Modeling Manufacturing with Laser In-situ Heat Treatment: Meng Luo,	Convection Heat Transfer Coefficients for Laser Powder Bed Fusion: Mohammad Masoomi, Auburn University
2:10 PM	Characterization and Analysis of Geometric Features for the Wire-arc Additive Process: Christopher J. Masuo, Oak Ridge National Laboratory	Effect of Wall Thickness and Build Quality on the Compressive Properties of 304L Thin-walled Structures Fabricated by SLM: Myranda Spratt, Missouri Univ of Science & Tech	The Role of Cellular Structure on Mechanical Properties in Additively Manufactured Metals: Ajit Achuthan,	Metal Powder Feedstock Reuse in Additive Manufacturing: Characterization of 316L Stainless Steel: Michael Heiden, Sandia National Labs	A Comparative Investigation of Sintering Methods for Polymer 3D Printing Using Selective Separation Shaping (SSS): Hadis Nouri, Univ of Southern California	Advanced Model Predictions of Mechanical Properties and Process Parameter Effects in High Throughput L-PBF Tension Specimens: Kyle Johnson, Sandia National Laboratories
2:30 PM	Surface Finish and Identification of Defects through Complementary use of Optical Metrology and X-ray Computed Tomography in Laser Powder Bed Fusion Additive Manufacturing: Jason Fox, National Institute of Standards and Technology	Mechanical Property Variation in Metal Lattice Struts: Amber Dressler, Univ of Texas At Austin	Multi-laser Processing Strategies for High Integrity Component Manufacture: Marc Saunders, Renishaw plc	Origin of Melt Flow and Its Effect in Laser Powder-bed Fusion: Wang Yafei, Tsinghua University	Not Just Nylon... Improving the Range of Materials for High Speed Sintering: Ryan Brown, University of Sheffield	Local Thermal Conductivity Mapping of Selective Laser Melted 316L Stainless Steel: Scott Schiffres, SUNY Binghamton
2:50 PM	Effect of Initial Surface Features on Laser Polishing of a Co-Cr-Mo Alloy Made by Powder-bed Fusion: Brodan Richter, University of Wisconsin Madison	Mechanical Performance of Ti-6Al-4V Octet Truss Lattice Structures Produced via Powder Bed Fusion (PBF): Michael Brand, Los Alamos National Laboratory	Real Time Monitoring of Additive Manufacturing Processes Using High-speed Synchrotron X-ray Imaging: Niranjan Parab, Argonne National Laboratory	Three-dimensional Characterization of Porosity Defects and their Correlation to Mechanical Properties in AM 316L Stainless Steel: Thomas Ivanoff, Sandia National Laboratories	An Experimental Study of the Influence of Energy Input on Porosity and Mechanical Properties of Nylon 12 Parts Produced via High Speed Sintering: Zicheng Zhu, University of Sheffield	Finite Element Modeling of the Selective Laser Melting Process for Ti-6Al-4V: Alaa Olleak, Rutgers University
3:10 PM	Break	Break	Break	Break	Break	Break
3:40 PM	Effect of Process Parameters on the Surface Roughness and Fatigue Behavior of Additively Manufactured Alloy 718: Joy Gockel, Wright State University	Mechanical Properties of Additively Manufactured Stainless Steel 17-4PH Schoen Gyroid Lattices: Amanda Sterling, Auburn University	Characterization of Spatter Particles Formed during Laser Powder Bed Fusion: Christopher Rock, North Carolina State University	The Influence of Defects on the Performance of 316L Stainless Steel from Metal Laser Powder Bed Fusion: Bradley Jared, Sandia National Laboratories	Tensile Strength of Interfaces in Multi-material 3D-printed Parts: Thomas Lumpe, ETH Zurich	Modelling the Melt Pool of the Laser Sintered Ti6Al4V Layers with Goldak's Double-ellipsoidal Heat Source: Emrecan Soylemez, Marmara University
4:00 PM	Effect of Subsurface Defects on Surface Topography in Additive Manufactured Parts: Zachary Reese,	An Investigation of the Fatigue Strength of Multiple Cellular Structures Fabricated by Electron Beam Powder Bed Fusion Additive Manufacturing Process: Li Yang, University Of Louisville	Investigating Failure Mechanism of Additively Manufactured Metal Sample with Simulated Defects Using Simultaneous Mechanical Testing and X-ray Computed Tomography: Felix Kim, National Institute of Standards and Technology	The Effects of Post-AM Annealing Treatments on AM316L Stainless Steel: Donald Susan, Sandia National Lab	Photopolymer Formulation to Maximize the Resolution and Quality of Microarchitectures Fabricated Using Digital Light Processing-based 3D Printing: Kavin Kowsari, Singapore University of Technology and Design (SUTD)	Multi-scale Modeling of Selective Laser Melting of Inconel 718: Kubra Karayagiz, Texas A&M University
4:20 PM	Effect of Shield Gas on Surface Finish of Laser Powder-bed Produced Parts: Colt Montgomery, Los Alamos National Laboratory	Assessment of Octet Truss Lattice Structures Having Hollow Struts: Andrew Greeley, Rochester Institute of Technology	Fatigue Life Prediction of Additively Manufactured Metallic Materials Using a Fracture Mechanics Approach: Brian Torries, Auburn University	Evolution of Microstructure and Mechanical Properties with Heat Treatment of PBF Austenitic 316L Stainless Steel: Tobias Ronneberg, Imperial College London	Material Property Changes in Custom-Designed Digital Composite Structures Due to Voxel Size: Dorcas Kaweesa, Penn State	Melt Pool Analysis and Meso-scale Simulation of Laser Powder Bed Fusion Process (L-PBF) with Ti-6Al-4V Powder Particles: Santosh Rauniyar, University of Louisville
4:40 PM	Surface Topology in Directed Energy Deposition Additive Manufacturing: Jakob Croghan, Iowa State University	Mechanical Response of Honeycomb Structures under Impact: Maggie Yuan,	Material Properties of Hybrid Metal Additive Parts at AM/Substrate Interfaces: Jason Weaver, Brigham Young University	Texture Development and Texture Dependant Mechanical Properties of Stainless Steel 316L Produced by Laser Powder Bed Fusion Process: Xianglong Wang, McGill University	Quantifying the Effect of Embedded Component Orientation on Flexural Properties in Additively Manufactured Structures: Swapnil Sinha, Penn State	
5:00 PM			The Mechanical Behavior of AISI H13 Hot-work Tool Steel Processed by Selective Laser Melting under Tensile Stress: Mei Wang, Huazhong University of Science and Technology	Joining of Elements Fabricated by a Robotized Laser/Wire Direct Metal Deposition Process by Using an Autogenous Laser Welding: Meysam Akbari, SMU	Incorporation of Nanomaterials for 3D Printing and Additive Manufacturing Applications : Cole Brubaker, Vanderbilt University	

Physical Modeling 2 - Multi- and Micro-scale Modeling	Process Development 1 - Deposition	Process Development 2 - Extrusion	Process Development 3 - Metal Powder Bed Fusion 1	Special Session: Data Analytics in AM 1 - Quality in Modeling 1	Special Session: Hybrid AM Processes 1 - Hybrid Additive-Subtractive Processes	Session Name
412	602	415AB	416AB	Salon B	404	Room
Saad Khairallah, Lawrence Livermore National Lab.	Christopher Williams, Virginia Tech	Wenchao Zhou, University Of Arkansas	April Cooke, TRUMPF Inc.	Brandon Lane, NIST	K. P. Karunakaran, Indian Institute of Technology Bombay	Chair
Powder Bed Modeling Big and Small: Simulating Microstructural Evolution from a Single Bead to (Closer to) the Part Scale: Daniel Moser, Sandia National Laboratories	Effect of Standoff Distance on Built Geometry in Directed Energy Deposition : Samantha Webster, Northwestern University	High Throughput Fine Feature Fused Filament Fabrication Using A Multi-valve Extrusion Head: Anthony Tantillo, Rochester Institute of Technology	Investigation of Pore Formation and Melt Pool Dynamics during Laser-metal Interaction Using High-speed Full-Field X-ray Imaging: Aiden Martin, Lawrence Livermore National Laboratory	Effects of Thermal Camera Spatial and Temporal Resolution on Feature Extraction in Selective Laser Melting: Xin Wang, Missouri University of Science and Technology	The Role of Hybrid Manufacturing in 3D-Printing - Attributes and Future Avenues: Phillip C. Chesser, Oak Ridge National Laboratory	1:30 PM
Multi-scale FEA Modeling and Experimental Validation of Laser Powder Bed Fusion: Chao Li, Autodesk Inc.	Insights into Powder Flow Characterization Methods for Directed Energy Distribution Additive Manufacturing Systems: Stephen Brown, ARL Penn State	Using a Cylindrical Coordinate System to Facilitate Simultaneous Operations in 3D Printing: Dennis Scheglov,	In-situ Micro-CT Observation of Void Evolution under Interrupted Tensile Loading in Additively Manufactured 316L Stainless Steel : Nathan Heckman, Sandia National Laboratories	Defect Signatures for Metal Laser Powder Bed Fusion: Bradley Jared, Sandia National Laboratories	Characterization of High-deposition Polymer Extrusion in Hybrid Manufacturing and Comparison to Alternative Additive Processes: TJ Barton, Brigham Young University	1:50 PM
Multi-scale Modeling of Microstructure Evolution and Cracking during Direct Laser Deposition of Alumina Ceramics: Xiangyang Dong, Missouri University of Science and Technology	Evaluating Parameters and Performance of a Metallized Material Spray-deposition Process: Daniella McCade, Sandia National Laboratories	Microextrusion Based 3D Printing – A Review: Edidiong Udofia, University of Arkansas	Characterizing the Dynamics of Laser Powder Bed Fusion Additive Manufacturing Processes by High-speed X-ray Imaging/Diffraction: Lianyi Chen, Missouri University of Science and Technology	Detection of Porosity in Laser Powder Bed Fusion Using Spectral Graph Theoretic Machine Learning of In-process Optical Emission Spectroscopy Signals.: Mohammad Montazeri, University of Nebraska-Lincoln	Mechanical Properties Evaluation of Ti-6Al-4V Thin-wall Structure Produced by a Hybrid Manufacturing Process: Lei Yan, Missouri Univ of Science and Technology	2:10 PM
Particle Scale Melt Modeling of Selective Laser Melting with Uncertainty Quantification: Daniel Moser, Sandia National Laboratories	Experimental Investigation of Printing Parameters on Material Distribution in 3D Spray Cementitious Material Printing Process: Bing Lu, Nanyang Technological University, Singapore	Effects of Discontinuous Build Strategies on the Mechanical Properties of Material Extrusion AM Parts: Joseph Bartolai, Penn State University	Characterizing Powder Spreading Dynamics in Powder Bed Fusion AM Process by High-speed X-ray Imaging : Luis Escano, Missouri Univ of Science & Tech	Artificial Intelligence-enhanced Multi-material Form Measurement for Additive Materials: Petros Stavroulakis, University of Nottingham	Accelerating the Development of Biomedical Polymer Composites for Fused Deposition Systems Through Direct Printing of Cryomilled Powders: Eric Weflen, Iowa State University	2:30 PM
Transport Phenomena and Grain Structure Evolution during Laser Assisted Additive Manufacturing: Huiliang Wei, Nanjing University of Science and Technology	Aligning Material Extrusion Direction with Mechanical Stress via 5-axis Tool Paths: James Gardner, Loughborough University	Design of a Low Cost, Desktop-scale, High Temperature System for Fused Filament Fabrication of High Performance Polymers: Callie Zawaski, Virginia Tech	Complementary IR Heating Systems for Selective Laser Melting/Sintering: Oliver Weiss, Heraeus Noblelight GmbH	Energy Consumption Optimization with Geometric Accuracy Consideration for Additive Manufacturing Processes: Wenmeng Tian, Mississippi State University	Development of Pre-machining Strategies for Laser-aided Metallic Component Remanufacturing: Xinchang Zhang, Missouri Univ of Science & Tech	2:50 PM
Break	Break	Break	Break	Break	Break	3:10 PM
Cellular Automata (CA) Modeling of Stainless Steel Nucleation and Growth Applied to Selective Laser Melting: Matthew Rolchigo, Iowa State University	Fieldable Platform for Large-Scale Deposition of Concrete Structures: Phillip C. Chesser, Oak Ridge National Laboratory	Theory and Methodology for High-performance Material-extrusion Additive Manufacturing under the Guidance of Force-flow: Ziqian Chen, Tongji University	DMP Monitoring as a Process Optimization Tool for Direct Metal Printing (DMP) of Ti-6Al-4V: Nachiketa Ray, 3D Systems	Geometric Deep Learning for On-demand Production of Customized Products by Additive Manufacturing: Jida Huang, University at Buffalo	Development of A Novel and Low Cost Multi Axis Fused Deposition Modeling Additive Manufacturing System: Abolfazl Zolfaghari, Tennessee Technological University	3:40 PM
A Novel Microstructure Simulation Model for Direct Energy Deposition Process: Jinghao Li, McGill University	Real-time Quality Monitoring of Construction-scale 3D Printing (Contour Crafting): Ali Kazemian, University of Southern California (USC)	Effects of Surface Treatments on Interlayer Bonding Strength of FDM-printed Parts: Chin-Cheng (Jim) Shih, Texas A&M University	Effect of Process Variables on Porosity Formation in Laser and E-beam Power-bed Additive Manufacturing: Jack Beuth, Carnegie Mellon Univ	Evaluating Transient Extrusion Process Effects on Heat Transfer Modeling: Alex Renner, Iowa State University	Development of a Very Large Scale Robotic Hybrid AM System through the LASIMM Project: Stewart Williams, Cranfield Univ	4:00 PM
Influence of Grain Size and Shape on Mechanical Properties of Metal AM Materials: Robert Saunders, U.S. Naval Research Laboratory	Maturation of Wire + Arc Additive Manufacture Systems for Production of Large Scale Titanium Structures: Jialuo Ding, Cranfield University	Fused Deposition Modeling Process Parameter Optimization under Uncertainty: Paromita Nath, Vanderbilt Univ	Effects of Identical Parts on a Common Build Plate on the Modal Analysis of SLM Created Metal: Tristan Cullom, Missouri University of Science and Technology	A Data-driven Framework for HP's MJF 3D Printer for Correlation and Prediction of Part Mechanical Properties: Sunil Kothari, HP	Effects of Direct Metal Deposition Combined with Intermediate and Final Milling on Part Distortion: Daniel Eisenbarth, inspire AG, ETH Zurich	4:20 PM
Epitaxial Columnar Grain Growth Modeling During Laser Power Bed Additive Manufacturing Based on a Dendrite Tip Tracking Approach : Albert To, Univ of Pittsburgh	On-line In-process Cryogenic Cooling of Ti64 during Wire + Arc Additive Manufacturing to Increase Productivity: Jialuo Ding, Cranfield University	Improving Fracture Strength of FFF Parts via Thermal Annealing in a Printed Support Shell: Ryan Dunn, US Army Research Laboratory	Energy and Charge Transport during Pulsed Electron Beam Melting of Solid and Powder Ti Using Custom Electron Beam Welder: Paul Carriere, RadiaBeam Technologies	Machine Learning for Modeling of Printing Speed in Continuous Projection Stereolithography: Haiyang He, Univ of Illinois At Chicago	Effects of Milling Thickness on Deposition Accuracy in Hybrid Additive/Subtractive Manufacturing: Shuai Zhang, Huazhong University of Science and Technology	4:40 PM
Experimental Calibration of Nanoparticle Sintering Simulation: Obehi Dibua, Univ of Texas Austin		Knowledge-based Material Production in the Additive Manufacturing Lifecycle of Fused Deposition Modeling: Detlev Borstell, Koblenz University of Applied Sciences	High-resolution, Layer-based Surface Profilometry of Selective Laser Melting for Defect Detection and Quality Control: Greg Loughnane, Universal Technology Corporation			5:00 PM

TECHNICAL SESSION GRID - TUESDAY AM

Session Name	Applications 2	Materials: Ceramics	Materials: Metals 3 - Nickel-based Alloys	Materials: Metals 4 - Stainless Steels 17-4PH and 304	Physical Modeling 3 - Advanced Thermal Modeling Techniques	Physical Modeling 4 - Modeling Part Performance
Room	415AB	602	615AB	616AB	Salon A	412
Chair	Ian Gibson, Deakin University	Desiderio Kovar, University of Texas at Austin	Ola Harrysson, North Carolina State Univ	Aref Yadollahi, Mississippi State Univ	Kyle Johnson, Sandia National Laboratories	Chong Teng, ANSYS
8:15 AM	Finite Element Analysis of Additively Manufactured Conformal Negative Stiffness Honeycombs: David Debeau, The University of Texas at Austin	Direct Write and 3D Printing of Ceramic Polymers: Materials, Approaches and Applications : Judith Lavin, Sandia National Laboratories	Effects of Process Parameters and Heat Treatment on the Microstructure and Mechanical Properties of Selective Laser Melted Inconel 718: Wenpu Huang, Huazhong University of Science and Technology	Effect of Powder Formation and Laser Scan Length on Powder Bed Fusion 17-4 Stainless Steel: Andelle Kudzal, Army Research Lab	Fast Solution Strategy for Transient Heat Conduction for Arbitrary Scan Paths in Additive Manufacturing : Jean-Pierre Delplanque, University of California, Davis	Low Cost Numerical Modeling of Material Jetting-based Additive Manufacturing: Chad Hume, Georgia Institute of Technology
8:35 AM	Qualification of Large Scale Directed Energy Deposition Components - Challenges and Outlook: Stewart Williams, Cranfield Univ	Effects of Electric Field on Selective Laser Sintering of Yttria-stabilized Zirconia Ceramic Powder: Deborah Hagen, Univ of Texas At Austin	Primary Processing Parameters and Porosity Development: Luke Sheridan, Air Force Research Laboratory	Effects of Design Parameters on Thermal History and Mechanical Behavior of Additively Manufactured 17-4 PH Stainless Steel: Rakish Shrestha, Auburn University	Nonisothermal Welding in Fused Filament Fabrication: Keith Coasey, University of Delaware	Numerical Prediction of Fracture in FDM Printed Parts: Sanchita Sheth, Univ of Texas At Arlington
8:55 AM	Measurement of Geometric Variation in Negative Stiffness Structures Produced by Microstereolithography: Clinton Morris, UT Austin	Fabrication of Ceramic Parts Using a Digital Light Projection System: Xuan Wang, California Polytechnic State University San Luis Obispo	Microstructure and Mechanical Properties of Laser Repaired Inconel718 Superalloy Assisted with Electromagnetic Stirring: Fencheng Liu, Nanchang Hangkong University	Effects of Powder Recycling on the Mechanical Properties of Additively Manufactured Stainless Steel 17-4PH: Amanda Sterling, Auburn University	Rheological and Heat Transfer Effects in Fused Filament Fabrication Additive Manufacturing: David Phan, University of Delaware	Screw Swirling Effects on Fiber Orientation and Predicted Elastic Properties in Large-scale Polymer Additive Manufacturing: Zhaogui Wang, Baylor University
9:15 AM	Design Guidelines for a Software-supported Adaptation of Additively Manufactured Components with Regard to a Robust Production: Stefan Lammers, Paderborn University	Slurry-based Laser Sintering of Alumina Ceramics: Sebastian Meyers, Ku Leuven	Creep Performance of Laser Powder Bed Fused Inconel 718 and Effect of Post Processing: Chris Hyde, The University of Nottingham	Fatigue and Fracture Behavior of 17-4 PH Stainless Steel Fabricated via Laser Powder Bed Fusion (LPBF): Aref Yadollahi, Mississippi State Univ	Solidification Simulation of Direct Energy Deposition Process by Multi-phase Field Method Coupled with Thermal Analysis: Yusuke Shimono, ITOCHU Techno-Solutions Corp.	Numerical Prediction of the Porosity of Parts Fabricated with Fused Deposition Modeling: Marcin Serdeczny, Technical University of Denmark
9:35 AM	A Methodology for Function-based Part Consolidation during Conceptual Design for Additive Manufacturing: Alexander Reik, Technical University of Munich	Leveraging Temperature-dependent Rheological Behaviors of Ceramic Slurry for Support-free Fabrication: Li He, University of Iowa	Influence of Cobalt on the Microstructure of in-situ mixed Inconel 718 and Co Manufactured in Selective Laser Melting: William Reynolds, Nottingham University	Crack Growth-based Fatigue Life Prediction of LPBF 17-4 PH SS Using Defect Characteristics: Aref Yadollahi, Mississippi State Univ	A Study of the Effect of Bond Length on Bond Strength in Fused Deposition Modeling Using Transient Heat Transfer Analysis: Junaid Baig, University of Texas at Arlington	Numerical Modeling of the Material Deposition and Contouring Precision in Fused Deposition Modeling: Raphael Comminal, Technical University of Denmark
9:55 AM	Break	Break	Break	Break	Break	Break
10:25 AM	Designing Support Structures for Removability: A New Approach to Optimize Build Orientation for Laser Powder Bed Fusion: Neichen Chen, Iowa State University	Material Properties of Ceramic Slurries for Applications in Additive Manufacturing Using Stereolithography: Erin Maines, Sandia National Labs	Mechanical Properties of Inconel 625 and 718 Processed Using a Renishaw's Multi Laser Powder Bed Fusion System: Ravi Aswathanarayanaswamy, Renishaw Plc	Mechanical Properties of 17-4 PH Stainless Steel Additively Manufactured under Ar and N2 Shielding Gas: Pooriya Dastranjy Nezhadfar, Auburn University	Thermal Diffusivity Response in MatEx: From FFF to BAAM: Anthony D'Amico, Worcester Polytechnic Institute	Effect of Environmental Variables on Ti-64 AM Simulation Results: Aaron Flood,
10:45 AM	Increasing Interlaminar Strength in Large Scale Additive Manufacturing: Alex Roschli, Oak Ridge National Laboratory	Additive Manufacturing of Alumina Components by Extrusion of In-situ UV-cured Pastes: Lok-kun Tsui, University of New Mexico	Relationship between Defects Population and Tensile Properties of Inconel 625 Alloy: Mihaela Vlasea, University of Waterloo	Recyclability of 304L Stainless Steel in the Selective Laser Melting Process: Austin Sutton, Missouri Univ of Science & Tech	A New Physics-based Model for Laser Powder-bed Additive Manufacturing: Yuze Huang, University of Waterloo	Continued Evolution of a Part-scale Finite Element Model for Selective Laser Melting at LLNL: Neil Hodge, LLNL
11:05 AM	Conceptual and Goal-oriented Strategies for AM-Enabled Part Consolidation within Technical Systems: Alexander Reik, Technical University of Munich	Mitigating Coffee-ring Defect Formation in Ceramic On-demand Extrusion Parts: Austin Martin, Missouri Univ of Science & Technology	Fabrication of Crack-free Regular-C HX Superalloy Using Laser Powder Bed Fusion: Mathieu Brochu, Mcgill University	The Influence of Build Parameters on the Compressive Properties of Selective Laser Melted 304L Stainless Steel: Okanmisope Fashanu, Missouri University of Science & Tech	Establishing Property-Performance Relationships through Efficient Thermal Simulation of the Laser-Powder Bed Fusion Process: Mohammad Masoomi, Auburn University	Managing Metal AM Process Variability for Machine Drift Using FEA-based Analysis: Charles Fisher, Naval Surface Warfare Center - Carderock
11:25 AM	Opportunities for Additive Manufacturing within Quantum Technologies: Sarah Everton, Added Scientific	Tuning Nanoparticle Suspension Viscoelasticity for Multimaterial 3D Printing of Silica-Titania Glass: Nikola Dudukovic, Lawrence Livermore National Laboratory	Multi-material Additive Manufacturing (MMAM) of Austenitic Stainless Steel 316L with Nickel-based Hastelloy X Using Selective Laser Melting (SLM): Parameter Optimization: Haiyang Fan, KU Leuven	Characterization of Impact Toughness of 304L Stainless Steel Fabricated through Laser Powder Bed Fusion Process: Aaron Flood, Missouri University of Science and Technology	An Investigation into Metallic Powder Thermal Conductivity in Laser Powder-bed Fusion Additive Manufacturing: Shanshan Zhang, University of Louisville	Flowability and Paving Processing DEM Simulation of Nylon Powder under Pre-heated Condition in SLS: Yuanqiang Tan, Huaqiao University
11:45 AM	Metal Big Area Additive Manufacturing (MBAAM) for Tooling Applications: Andrzej Nycz, ORNL			Weldability, Microstructure and Properties of 304 Stainless Steel Joint: Laser Welding and Laser-arc Hybrid Welding: Jingjing Yang, Huazhong University of Science and Technology		Processing Parameter and Transient Effects in Additive Manufacturing of Invar 36: Eric-Paul Tatman, Wright State Univ
12:05 PM						

TECHNICAL SESSION GRID - TUESDAY AM

Process Development 4 - Metal Powder Bed Fusion 2	Process Development 5 - Imaging	Special Session: Binder Jet AM 1	Special Session: Data Analytics in AM 2 - Quality and Modelling 2	Special Session: Hybrid AM Processes 2 - Surface Treatments and Assistive Technology	Topology Optimization 1	Session Name
416AB	Salon F	Salon E	Salon B	404	417AB	Room
Subhrajit Roychowdhury, GE Global Research	Toshiki Niino, Univ of Tokyo	Zachary Cordero, Rice University	Bradley Jared, Sandia National Laboratories	Frank Liou, Missouri University of Science and Technology	Albert To, Univ of Pittsburgh	Chair
On the Influence of Thermal Lensing during Selective Laser Melting of Metals: Louca Goossens, KULeuven	In-situ Optical Emission Spectroscopy during SLM of 304L Stainless Steel: Cody S. Lough, Missouri University of Science and Technology	On AM Spreading Process Maps Obtained Using Polydispersed Particle Modeling and Machine Learning: Prathamesh Desai, Rice University	Error: Low Disk Space - Development of a High-speed Temperature Imaging System for Powder Bed Fusion: Paul Hooper, Imperial College London	Tensile and Shear Strength of ABS from Hybrid Additive Manufacturing by Fused Filament Fabrication (FFF) and Shot Peening (SP): Xingtao Wang, University of Nebraska-Lincoln	GPU-accelerated Design Optimization for Ffrequency Response Problems with Parameter Uncertainty: Miguel Aguilo, Sandia National Laboratories	8:15 AM
Development of Novel High Temperature Laser Powder Bed Fusion System for the Processing of Crack-susceptible Alloys: Leonardo Caprio, Politecnico di Milano	Acoustic emission technique for online detection of fusion defects for single tracks during metal laser powder bed fusion.: Dean-paul Kouprianoff, Central University of Technology	Characterizing Binder-powder Interaction in Binder Jetting Additive Manufacturing via Sessile Drop Goniometry: Yun Bai, Virginia Polytechnic Institute	In-process Detection of Material Cross-contamination in Laser Powder Bed Fusion: Mohammad Montazeri, University of Nebraska-Lincoln	Fatigue Properties of Ultrasonic Treated Direct-metal-laser-sintering Manufactured Metallic Materials: Ajit Achuthan, Clarkson University	Multiscale Topology Optimization and Fabrication Framework for Laminated Composites: Narasimha Boddeti, SUTD	8:35 AM
Investigation of external illumination strategies for melt pool geometry monitoring in SLM: Luca Mazzoleni, Politecnico di Milano	Development of an Acoustic Process Monitoring System for the Selective Laser Melting (SLM): Niclas Eschner, wbk-Institut of Production Science	Elucidating the Role of Fluid-particle Interaction in Binder Jet Additive Manufacturing: Joshua Wagner, Rice Univ	In-process Monitoring of a High-speed Sintering Powder Bed with Structured Light Scanning: Petros Stavroulakis, University of Nottingham	Modeling Residual Stresses Evolution in Steel from Hybrid Processing by Directed Energy Deposition and Laser Shock Peening: Gurucharan Madireddy, University of Nebraska-Lincoln	Topology Optimization for Sandwich Structures with Continuous-CF/PA6I-PA6T Laminates as Skin Layers and PA6 or Short-CF/PA6 as a Core Layer: Kohji Suzuki, Chiba Institute of Technology	8:55 AM
Transient Dynamics of Powder Spattering in Laser Powder Bed Fusion Additive Manufacturing Process Revealed by In-situ High-speed High-energy X-ray Imaging: Qilin Guo, Missouri University Of Science & Tech	Development of an In-situ Layerwise Imaging System for Metallic Powder Bed Fusion Additive Manufactured Parts: Christian Gobert, Oak Ridge Institute for Science and Education	Feasibility of Non-contact Powder Bed Characterization through Thermal Measurements: Nathan B. Crane, University of South Florida	Machine Learning based Monitoring of Selective Laser Melting: BODI Yuan, UC Berkeley	Dynamic Mechanical Analysis of ABS from Hybrid Additive Manufacturing by Fused Filament Fabrication (FFF) and Shot Peening (SP): Haitham Hadidi, University of Nebraska-Lincoln	Topology Optimisation of Additively Manufactured Lattice Unit Cell by Bi-directional Evolutionary Structural Optimisation: Riyan Rashid, Swinburne University of Technology	9:15 AM
Towards High Build Rates - Combining Different Layer Thicknesses within One Part in Selective Laser Melting of 316L Steel: Michael Kniepkamp, PTW TU-Darmstadt	Defect Identification and Mitigation via Visual Inspection in Large-scale Additive Manufacturing: Michael Borish, Oak Ridge National Laboratory	Evaluating the Surface Finish of A356-T6 Cast Parts from Additively Manufactured Sand Molds: Brett Conner, Youngstown State University	Nondestructive MicroCT Inspection of Additive Parts: How to Beat the Bottlenecks: Anton du Plessis, CT Scanner facility	Residual Stress and Distortion Management in Hybrid Layered Manufacturing: Seema Negi, Indian Institute of Technology	Morphable Components Topology Optimization for Additive Manufacturing: Yeming Xian, Georgia Institute of Technology	9:35 AM
Break	Break	Break	Break	Break	Break	9:55 AM
Partial Contact Based Support Architecture Design for Additive Manufacturing: MD AHASAN Habib, North Dakota State University	Use of SWIR Imaging to Monitor Layer-to-layer Part Quality during SLM of 304L Stainless Steel: Cody S. Lough, Missouri University of Science and Technology	Economies of Complexity of 3D Printed Sand Molds for Casting: Eric MacDonald, Youngstown State University	Non-destructive Characterization of Additively Manufactured Components Using X-ray Micro-computed Tomography: Stefan Dietrich, KIT	Dual Purpose of Rolling in Additively Manufactured Mild Steel (ER70S-6): Filomeno Martina, Cranfield University	Optimizing Topology and Toolpath via Multi-axis Material Extrusion: Joseph Kubalak, Virginia Tech	10:25 AM
Local Microstructure Control across AM Processes and Alloy Systems: Jack Beuth, Carnegie Mellon Univ	Mitigating Defects Based on High Speed, In Situ X-ray Imaging of Laser Powder Bed Fusion: Nicholas Calta, Lawrence Livermore National Laboratory	Observations of Distortion during Sintering of Binder-jet Printed Ceramics: Lynnora Grant, Rice University	X-ray and Computed Tomography as a Tool for Quality Assurance, Process Optimization and Metrology Inspections in the Field of Additive Manufacturing: Philip Sperling, Yxlon International GmbH	Challenges of Measuring Adhesion of Printed Inks and the Potential for Surface Treatments to Alter the Adhesive Failure Mode : Clayton Neff, University of South Florida	Physics-based Support Structure Design Optimization via Fast Process Simulation and Lattice Structure Optimization : Albert To, Univ of Pittsburgh	10:45 AM
Laser Heated Electron Beam Gun Optimization to Improve Electron Beam Additive Manufacturing and Presentation of Open Source Controls for AM : Ralf Edinger, CANMORA TECH INC,	Experimental Evaluation of Coaxial Imaging of Directed Energy Deposition : Abdalla R. Nassar, Applied Research Lab at Penn State University	Surface Roughness Optimization of Parts Produced Using Binder Jet 3D Printing: Andrew Klein, ExOne	Predicting Product Quality Characteristics in a Laser-powder Bed Fusion Process: Gaurav Ameta, NIST	Viscosity Control of Pseudo-plastic Polymer Mixtures for Applications in Additive Manufacturing : Apoorv Vaish, Singapore University of Technology and Design	Laser Scan Pattern and Build Orientation Optimization for Laser Powder Bed Fusion Process : Albert To, Univ of Pittsburgh	11:05 AM
High Speed In Situ Measurement of the Cooling Rate in a Complex Part Manufactured Using Powder Bed Fusion: Jarred Heigel, National Institute of Standards and Technology	Low Cost, High Speed Stereovision for Spatter Tracking in Laser Powder Bed Fusion: Brett Conner, Youngstown State University	In Situ Investigations of Fracture in Sintering Materials: Joseph Carazzone, Rice Univ	Integrating Transient Thermal Simulations and In-situ High Speed Video for Laser Parameter Strategies in Metal Additive Manufacturing: Clara Druzgalski, LLNL	Junction Growth during Ultrasonic Additive Manufacturing: Austin Ward, Rice Univ	Build Direction and Infill Optimization for Fused Deposition Modeling: Aaditya Chandrasekhar, Univ of Wisconsin Madison	11:25 AM
Keyhole Mitigation at Turn around Using a Predictive Mesoscopic Model: Saad Khairallah, Lawrence Livermore National Lab.	Characterization of In Situ Diagnostics Using High Speed Imaging: Manyalibo Matthews, Lawrence Livermore National Laboratory		Scaling Models for Laser Powder Bed Fusion Process Mapping: A Comparison Using Iron, Invar 36 and SS316L: Allan Rogalsky, University of Waterloo	Curing Behavior of Thermosets for the Use in a Combined Selective Laser Sintering Process of Polymers: Katrin Wudy, Institute of Polymer Technology	Next-generation Fibre-reinforced Lightweight Structures for Additive Manufacturing: Ajit Panesar, Imperial College London	11:45 AM
						12:05 PM

TECHNICAL SESSION GRID - TUESDAY PM

Session Name	AM Infrastructure and Education	Applications 3	Applications 4	Applications: Biomedical 1	Broader Impacts	Materials: Composites 1
Room	Salon F	415AB	416AB	Salon A	616AB	615AB
Chair	David Rosen, Georgia Institute of Technology	Nathan Crane, University of South Florida	Xiayun Zhao, University of Pittsburgh	Jingyuan Yan, Clemson University	Joy Gockel, Wright State University	Chad Duty, University of Tennessee
1:40 PM	Printing Orientation and How Implicit It Is: Juan Granizo, Embry-Riddle Aeronautical University	Additive Manufacturing Assisting Thermoacoustic Refrigeration System Development : Alec Chamberlain, Texas State University	4D Printing of Composites with Embedded Continuous Fibers: Lan Huang, Xi'an Jiao Tong University	Development of Customized Cellular Structures to Match the Mechanical Properties of Human Trabecular Bone: Xuewei Ma, University of Missouri	MAPP - Manufacture Using Advanced Powder Processes: Candice Majewski, The University of Sheffield	A Review of Additive Manufacturing of Polymer Matrix Composites : Kivilcim Ersoy, FNSS Defense systems
2:00 PM	Making 3D Printing Affordable for "The Last, the Lost, the Least and the Lowest' @ DEI: Rahul Sharma, Dayalbagh Educational Institute	Metal Additive Manufacturing for Oil and Gas Applications: Lakshmi Vendra, Baker Hughes	An Investigation on Sound Characteristics of 3D-printed String Music Instruments: Joshua Riefer, Texas A&M University	Near-Field Electrospinning of a Polymer Bioactive Glass Composite: Krishna Kolan, Missouri University of Science and Technology	Understanding the Process of Adopting Selective Laser Melting of Metallic Materials: EVREN YASA, Eskisehir Osmangazi University	Additive Manufacturing of Sustainable Composites: Cecily Ryan, Montana State University
2:20 PM	Method for a Software-based Design Check of Additive Manufactured Components: Johannes Tominski, Paderborn University	Development and Validation of a CFD Optimized Integrated Pitot Sensor, Produced by Selective Laser Melting and Abrasive Flow Machining: Ferchow Julian, Inspire AG / ETH Zürich	3D Printable Lithium Ion Batteries as Energy Storage Devices: Hui Ying Yang, SUTD	Bone Tissue Engineering Scaffolds of Ti-6Al-4V with Variable Porosity: Design, Fabrication and Structural Evaluation: Xiang-yu Zhang, Tsinghua University	Real-time Pyrometer Feedback and Control in Metal Powder Bed Fusion: Ben Fulcher, Vulcan-Labs	Influence of Mesostructure on the Thermal and Mechanical Properties of Additively Manufactured Interpenetrating Phase Composites: Abdel Moustafa, Rice University
2:40 PM	A Methodology for Modular Design Rule Representation and Ontology Development for Additive Manufacturing: Hyunwoong Ko, NIST: National Institute of Standards and Technology	Understanding Distortion in Material Jetting Process: Ali Khoshkhoo, Binghamton University	Multimaterial Aerosol Jet Printing of Passive Circuit Elements: Seth Johannes, Sandia National Labs	Design Rules for Additively Manufactured Wrist Splints Created Using Design of Experiment Methods: Sarah Kelly, Loughborough Design School	The recycling of E-Waste ABS plastics by melt extrusion and 3D printing using solar powered devices as a transformative tool for humanitarian aid: Mazher Mohammed, Deakin University	Design and Robotic Fabrication of 3D Printed Moulds for Composites: Felix Raspall, Singapore University of Technology and Design
3:00 PM	Education of Additive Manufacturing - An Attempt to Inspire Research: Li Yang, University Of Louisville	Correlating Local Part Bed Temperature Variations with Mechanical Properties in Selective Laser Sintering of Carbon Fiber Reinforced Polyetheretherketone (PEEK): Scott Snarr, Univ of Texas At Austin	Additive Manufacturing of Liners for Shaped Charges: Cody Lough, Missouri University of Science and Technology	Evaluation of Fully Functional Specialised Software for the Production of Additive Manufactured Wrist Splints: Abby Paterson, Loughborough University	Additive Manufacturing with Modular Support Structures: Ismail Yigit, Koc Universitesi	Selective Laser Melting of Nickel Based Metal Matrix Nanocomposite Powder Produced by Electroless Plating: Ming Li, Texas A&M University
3:20 PM	Lattice Design Optimization: Crowdsourcing Ideas in the Classroom: Dhruv Bhate, Arizona State University	Additive Manufacturing Tools for Refrigeration Foaming Operations: Brian K. Post, Oak Ridge National Laboratory	Controlling Dispersion Characteristics of Ag-PDMS Conductive Composites: Mei Chee Tan, Singapore University of Technology and Design	Design and 3D printing of patient specific polymer hand splint concept: Mazher Mohammed, Deakin University	3D Printer Assisted Hands-on Education in Design and Manufacturing: Ankit Sahai, Dayalbagh Educational Institute	Thermal Management of Li-ion Batteries Using Phase Change Composite Fabricated by Selective Laser Sintering : Malek Nofal, Univ of Illinois Chicago
3:40 PM		Mesoscopic Experimental Investigation on Surface Roughness of Powder Bed in Powder-bed-based Additive Manufacturing: Hui Chen, Huazhong University of Science and Technology	Size and Topology Effects on Fracture Behavior of Cellular Structures: Yan Wu, University of Louisville	Mandibular Repositioning Appliance Following Resection Crossing the Midline- A 3D Printed Guide: Ian Gibson, Deakin University		Solid Free-form Fabrication of Mesh-reinforced Polymeric Composites: Hengky Eng, Singapore Institute of Manufacturing Technology

Materials: Non-traditional in AM	Residual Stress	Special Session: Binder Jet AM 2 - Processing	Special Session: Data Analytics in AM 3 - Process Monitoring and Defect Mitigation	Special Session: Hybrid AM Processes 3 - Hybrid Materials, Structures, Functions	Topology Optimization 2: Applications Modeling 1 - Process Planning	Session Name
602	412	Salon E	Salon B	404	417AB	Room
Saniya LeBlanc, George Washington Univ	Joseph Newkirk, Missouri University of Science and Technology	Andrew Klein, ExOne	Alaa Elwany, Texas A&M	Guha Manogharan, Pennsylvania State University	Carl Hauser, TWI Ltd; Richard Crawford, Univ of Texas	Chair
Fiber-fed Printing of Free-form Free-standing Glass Structures: John M Hostetler, Missouri University of Science and Technology	Designing for Residual Stress with Glass: Nicholas Leathe, Sandia National Laboratories	Binder Jet Printing and Post-processing of Ni-Mn-based Functional Magnetic Materials: Markus Chmielus, University of Pittsburgh	Crucial Measurements and Their Implications in Metal Powder Additive: Marshall Ling, SLM Solutions NA	Effect of Porosity on Electrical Insulation and Heat Dissipation of FDM Parts Containing Embedded Wires: Kazi Md Masum Billah, University of Texas El Paso	Topology Optimized Heat Transfer Using the Example of an Electronic Housing: Dennis Menge, Direct Manufacturing Research Center; Paderborn University	1:40 PM
Additive Manufacturing of Energetic Materials: Maxime Chiroli, French-German Research Institute of Saint-Louis	Understanding the Impact of Thermal Constraints on Residual Stress in 3D Metal Printed Parts: Shaun Whetten, Sandia National Labs	Densification of H13 Components Fabricated by Binder Jet Additive Manufacturing – Scaling up and Associated Challenges: Peeyush Nandwana, Oak Ridge National Lab	Machine Vision and Traditional Approaches for AM Process Monitoring and Control: Jack Beuth, Carnegie Mellon Univ	A New Digitally Driven Process for the Fabrication of Integrated Flex-rigid Electronics: Matthew Shuttleworth, Future Manufacturing Processes	Design Optimization, Fabrication, and Testing of 3D Printed Aircraft Structure Using Fused Deposition Modeling: Nicholas Lira, N/A	2:00 PM
Evaluating the Relationship between Deposition and Layer Quality in Large-scale Additive Manufacturing of Concrete: Nicholas Meisel, Penn State	Residual Stress Simulations and Comparison against Experimental Measurements for Additively Manufactured Ti-6Al-4V : Rishi Ganeriwala, Lawrence Livermore National Laboratory	Binder Jetting Additive Manufacturing of Water-Atomized Iron: Issa Rishmawi, University of Waterloo	Real-time Detection of Build Failures in Thin-wall Structures in Laser Powder Bed Fusion: Farhad Imani, Pennsylvania State University	Hybrid Manufacturing with FDM Technology for Enabling Power Electronics Component Fabrication: Jose Coronel, Univ of Texas El Paso	A Path Planning Algorithm for the Design of Additively Manufactured Functionally Graded Materials: Tanner Kirk, Texas A&M University	2:20 PM
Methods of Depositing Anti-reflective Coatings for Additively Manufactured Optics: Zachary Beller, Sandia National Laboratories	Correlations of Interlayer Time with Distortion of Large Ti-6Al-4V Component in Laser Metal Deposition with Wire: Yousub S. Lee, Oak Ridge National Laboratory	Microstructural Evolution, Densification Kinetics and Sintering Mechanisms of Binder Jet 3D Printed of Different Size Alloy 625 Powders: Markus Chmielus, University of Pittsburgh	Spatially Resolved Acoustic Spectroscopy for Additive Manufacturing: Towards Online Inspection: Paul Dryburgh, University of Nottingham	Digitally-driven Micro Surface Patterning by Hybrid Manufacturing: Matthew Smith, University of Leeds	5-Axis Path Planning for Direct Energy Deposition Using Deformed Centerline Transformation: Michael Dvorak, Missouri University of Science and Technology	2:40 PM
Transport Properties of Laser Processed Thermoelectric Materials: Saniya LeBlanc, George Washington Univ	Model Development for Residual Stress Consideration in Design for Laser Metal 3D Printing of Maraging Steel 300: Vedant Chahal, The University of Texas at Arlington	The Effect of Inkjetted Nanoparticles on Metal Part Properties in Binder Jetting Additive Manufacturing: Yun Bai, Virginia Polytechnic Institute	Toward Data- rich Additive Manufacturing: Paul Dryburgh, University of Nottingham	Hybrid Directed Energy Deposition for Smart Structural Elements: Eric MacDonald, Youngstown State University	Reinforcement Learning for Generating Toolpaths in Additive Manufacturing: Steven Patrick , University of Tennessee, Knoxville	3:00 PM
Characterization of 3D Printing Properties of Vitamin-D Enriched Orange Concentrate Using Different Starches: S M Azam, Jiangnan University	A Modified Inherent Strain Model for Fast Prediction of Residual Stress and Deformation for Laser Metal Additive Manufacturing: Albert To, Univ of Pittsburgh	Particle Encapsulation to Increase Powder Sinterability and Part Strength in Ceramic Binder Jetting Additive Manufacturing: Wenchao Du, Texas A&M University		Hybrid Printing and Nanoimprint Fabrication of Functional Surfaces: Hong Yee Low, Singapore University of Technology and Design	Control System Framework for Using G-Code-based 3D Printing Paths on a Multiple Degree-of-Freedom Robotic Arm: Andrzej Nycz, Oak Ridge National Laboratory	3:20 PM
Additively Manufactured Polyphenylene Sulfide: Structure and Properties of Composites and Blends: Nekoda van de Werken, University of New Mexico	Residual Stress Reduction of Laser Powder Bed Fusion Processes Using In Situ Laser Diode Annealing: William Smith, Lawrence Livermore National Lab	Volumetric Sintering of a Selectively Doped Polymer Using RF Radiation: Jared Allison, Univ of Texas Austin		Harsh Environmental Testing of Conductive Links for Resilient Hybrid Electronics: Clayton Neff, University of South Florida	3D Printed Electronics Design Software with Autorouting Capabilities: Jose Coronel, UTEP	3:40 PM

TECHNICAL SESSION GRID - WEDNESDAY AM

Session Name	Applications: Biomedical 2	Lattices and Cellular 2	Materials: Composites 2 - Extrusion-based Processes	Materials: Metals 5 - Aluminum and Copper	Materials: Metals 6 - Titanium Alloys 1	Materials: Polymers 2 - Extrusion-based Polymers
Room	Salon A	412	615AB	415AB	416AB	Salon J
Chair	Candice Majewski, The University of Sheffield	Li Yang, University of Louisville	Chao Ma, Texas A&M University	Anton du Plessis, CT Scanner facility	Evren Yasa, Eskisehir Osmangazi University	Abby Paterson, Loughborough University
8:00 AM	Interactions between Microbes and Laser Sintered Polymers: Robert Turner, University of Sheffield	X-ray Tomographic Imaging of 3D Printed Cellular Materials during In Situ Mechanical Deformation: Brian Patterson, Los Alamos National Laboratory	Characterizing Compositional Transitions in Pellet-based 3D Printing of Functionally Graded Materials: James Brackett, Univ of Tennessee Knoxville	Microstructure Influence on the Strain-rate and Stress-state Behavior of Solid-state AM AFS-Depostion Aluminum Alloy 6061: Brandon Phillips, The University of Alabama	Development of Titanium and Steel Alloys Optimized for AM: Bryan Webler, Carnegie Mellon Univ	Full Field Strain Measurement of Material Extrusion AM Parts with Both Solid and Sparse Infill Geometry: Joseph Bartolai, Penn State University
8:20 AM	In Situ Monitoring and Printability Analysis of Hybrid Hydrogels for Tissue Engineering: Srikanthan Ramesh, Iowa State Univ	Fabrication of Support-less Engineered Lattice Structures via Jetting of Molten Aluminum Droplets: Khushbu Zope, Rochester Institute of Technology	Continuously Reinforced and Wholly Thermoplastic Composite Filaments for Application in Fused Filament Fabrication: Mubashir Ansari, Virginia Tech	The Effect of Processing Parameter on Zirconium Modified Al-Cu-Mg Alloys Fabricated by Selective Laser Melting: Xiaojia Nie, Huazhong University of Science & Technology	Effect of Powder Degradation on the Fatigue Behavior of Additively Manufactured As-Built Ti-6Al-4V: Patricio E Carrion, Auburn University	A Novel Thermoplastic Polymer Weld Strength Theory for Material Extrusion AM: Joseph Bartolai, Penn State University
8:40 AM	Effects of DOD 3D Bioprinting on the Formability of Microspheres: Ryan Meza, California State University Northridge	Additive Manufacturing of Lightweight Mirrors: Nikola Dudukovic, Lawrence Livermore National Laboratory	Fabricating Functionally Graded Materials by Ceramic On-demand Extrusion with Dynamic Mixing: Wenbin Li, Missouri Univ of Science and Technology	Selective Laser Melting of Al6061 Alloy: Processing, Microstructure, and Mechanical Properties: Jinliang Zhang, Huazhong University of Science and Technology	Volume Effects on the Fatigue Behavior of Additively Manufactured Ti-6Al-4V Parts : Jonathan Pegues, Auburn University	Inter-bead Bond Strength Improvement of FDM Parts by Isothermal Heating: Rhugdhrivya Rane, University of Texas at Arlington
9:00 AM	Digital Micromirror Device (DMD)-based Stereolithography of 3D Vascular-like Structures with Living Cells Encapsulated: Soham Wadnap, Texas Tech University	Ballistic Evaluation of Additively Manufactured Metallic Lattice Structures: Brandon Mcwilliams, Us Army Research Lab	The Effect of Pre-shear Processing Conditions on 3D Printing of Reinforced Polymers: Dylan Hoskins, University of Tennessee	Effect of Process Parameters on Mechanical Properties of Wire and Arc Additive Manufactured AlCu6Mn : Yazhou Zhang, Wuhan National Laboratory for Optoelectronics	LPBF Powder Feedstock Effects: A Study in Ti6Al4V: Ajay Krishnan, Incodema3D	Conductive Polymer Options for Multi-material FFF Additive Designs: Louisa Orton, Brigham Young University
9:20 AM	Introduction of Antimicrobial Properties into Laser Sintered Polymers: James Wingham, The University of Sheffield	Cellular Structures for Blast and Impact Protection with Selective Laser Melting: Jonathan Harris, University of Cambridge	Multi-material Printing of Structural Components: Process Conditions and Bond Strength: Christine Ajinjeru, Univ of Tennesse Knoxville	Small-scale Characterization of Additively Manufactured Aluminum Alloys through Depth-sensing Indentation: Farwan Alghamdi, University of North Dakota	Effect of Heat Treatment on the Phase Transformation and Mechanical Properties of Ti6Al4V Fabricated by Selective Laser Melting: Xingchen Yan, Universite de Technologie de Belfort-Montbeliard	Using Fillers to Improve Printability of a Water Soluble Semi-crystalline Polymer for Material Extrusion Additive Manufacturing: Callie Zawaski, Virginia Tech
9:40 AM	Break	Break	Break	Break	Break	Break
10:10 AM	On Demand Direct-write 3D Printing of Visible Light Crosslinkable GelMA Soft Tissue Scaffolds Using an Iterative Learning Control Method: Ali Asghari Adib, The Ohio State University	Design and Optimization of Spatially-varying, Multi-material 3D Printed Soft Lattice Structures : Oliver Weeger, Singapore University of Technology and Design	Processing Short Fiber Reinforced Polymers in the Fused Deposition Modeling Process: Christian Schumacher, Paderborn University / DMRC	Visualization and Measurement with Dynamic X-ray Radiography of Laser Melting in 3D Printing: Anthony Rollett, Carnegie Mellon Univ	Characterization of Electron Beam Melted Parts Produced by Coarse Ti6Al4V Powders with Large Layer Thicknesses: Hengfeng Gu, North Carolina State University	The Effect of Crystallinity on Mechanical Properties of High Temperature Semi-crystalline Printed Thermoplastics: Vidya Kishore, Univ of Tennessee Knoxville
10:30 AM	Mechanical Property Characterization of Cell-laden Gelatin Methacrylate-based Hydrogels: Srikumar Krishnamoorthy, Texas Tech University	Dissipative Non-linear Topology: Nicholas Leathe, Sandia National Laboratories	Dynamic Mechanical Characterization of Additively Manufactured Fiber Reinforced Thermoplastic Composites with Respect to Toolpath Orientation: John Lindahl, Oak Ridge National Laboratory	Process Optimization, Microstructures and Mechanical Properties of the Cu-13.5Al-4Ni-0.5Ti Copper-based Shape Memory Alloy Produced by Selective Laser Melting: Wenzhi Zhu, State Key Laboratory of Materials processing and Die&Mould Technology, Huazhong	Toward Location-specific Control of Mechanical Properties in Ti-6Al-4V via Electron Beam Melting Process: Rahi Patel, Carnegie Mellon Univ	Influences of Printing Parameters on Semi-crystalline Microstructure of Fused Filament Fabrication Polyvinylidene Fluoride (PVDF) Components: Niknam Momenzadeh, University of Louisville
10:50 AM	Bioresorbable Vascular Scaffolds 3D Printed via microCLIP: Henry Oliver Ware, Northwestern University	Demonstration of Two-photon Polymerization Printing for Inertial Confined Fusion Capsules: Matthew Herman, Los Alamos National Laboratory	Impact Testing of 3D Printed Kevlar-reinforced Onyx Material: Brett Conner, Youngstown State University	Microstructure and Physical Properties of Pure Copper Fabricated via Electron Beam Melting: Christopher Ledford, NC State University	Microstructure, Mechanical Properties, and Fatigue Behavior of Electron Beam Additive Manufactured Ti-6Al-4V : Andrew Chern, Univ Of Tennessee Knoxville	Low-temperature Powder Bed Fusion Processing of Poly(Phenylene Sulfide): Camden Chatham, Virginia Tech
11:10 AM	A Sustainable Additive Approach for the Achievement of Tunable Porosity: Sharon Lau, Iowa State University	Flexure and Twist of Fused Deposited Lattice Materials: Enrique Cuan-Urquizo, Tecnológico de Monterrey	Deposition Controlled Magnetic Alignment in Iron-PLA Composites: Nathan Watson, Penn State	Composite Cu-C and Cu-W Thermal Concentrator Design Using LENS: Tim Price, Sandia National Laboratory	Understanding the Correlation between Mechanical Properties and Porosity Formation of 3D-printed TNM-B1 by Means of High-performance Computer Tomography: Elena Lopez, Fraunhofer IWS	Characterization of Stiffness Properties of Fused Deposition Modeling Thermoplastic Components: Ahmed Sherif El-Gizawy, University of Missouri
11:30 AM	Binder Jetting of Piezoelectric Ceramic: Luis Chavez,				The Behavior of Phase Transformation for Ti-Ta Alloy in Laser Powder-bed Fusion: Leilei Xing, Tsinghua University	Effects of Defects on the Mechanical and Electrical Properties of AM Parts: Sai Sri Nidhi Munaganuru,

TECHNICAL SESSION GRID - WEDNESDAY AM

Modeling 2: Design and Process Planning	Process Development 6 - Novel Methods 1	Process Development 7 - Powder Bed Fusion 1	Special Session: Data Analytics in AM 4 - Quality and Modeling 3	Special Session: Hybrid AM Processes 4 - Direct/Indirect Build Strategies	Session Name
417AB	616AB	Salon K	Salon B	404	Room
Nicholas Meisel, Penn State	Abdalla Nassar, Applied Research Lab at Penn State	Robert Landers, Missouri S&T Univ	Linkan Bian, Mississippi State Univ	Michael Sealy, University of Nebraska-Lincoln	Chair
Analysis of Additive Manufacturing Build Direction on Overhang Structures: Mohammed Isa, KOC University	A New Method of Improving Inkjet Printing Speed for Additive Manufacturing: Chao Sui, University Arkansas	Investigating Laser Beam Operations in Laser-powder Bed Fusion: Josh Koepke, Sandia National Labratories	Machine Learning based Monitoring of Advanced Manufacturing Technologies: Brian Giera, LLNL	Potentials and Challenges of Multi-material Processing by Laser-based Powder Bed Fusion: Maximilian Binder, Fraunhofer IGCV	8:00 AM
Topology-aware Routing of Electric Wires in FDM-printed Objects: Florens Wasserfall, University of Hamburg	Multiple Collaborative Printing Heads in FDM: The Issues in Process Planning : Marco Leite, Instituto Superior Técnico	Two-dimensional Characterization of Window Contamination in Selective Laser Sintering: Doug Sassaman, Univ of Texas At Austin	Precision Enhancement of 3D Printing via In Situ Metrology: Ling Li, University of California, Los Angeles	Omni-directional Cladding for Hybrid Layered Manufacturing: Karunakara Karuppasamy Poolan, Indian Institute of Technology Bombay	8:20 AM
Predicting Part Mass, Required Support Material, and Build Time via Autoencoded Voxel Patterns: Nicholas Meisel, Penn State	On the Nature of Stochastic Process Anomalies: Abdalla R. Nassar, ARL Penn State	Effects of Inter-layer Dwell Time in Laser Powder Bed Fusion: Richard Williams, City and guilds building room 570	Layer-wise Profile Monitoring of Laser-based Additive Manufacturing: Linkan Bian, Mississippi State Univ	Part Decompositions for 3+2 5-Axis Hybrid Manufacturing : Xinyi Xiao, Penn State	8:40 AM
Modeling a Scanning-mask Projection Vat Photopolymerization System For Large-area, High-resolution Additive Manufacturing: Viswanath Meenakshisundaram, DREAMS Lab, Virginia Tech	Conduction-based Laser Power Control for Overhang Structures: Ho Yeung, National Institute of Standards and Technology	Laser Metal Additive Manufacturing on Graphite: Arad Azizi, SUNY Binghamton	Interferometry Sensing Data Mining for Real-time Geometric Profile Measurement in Photopolymer Based Additive Manufacturing: Xiayun Zhao, University of Pittsburgh	A Digitally Driven Hybrid Manufacturing Process for the Flexible Production of Engineering Ceramic Components: Jack Hinton, Future Manufacturing Processes	9:00 AM
Continuous Property Gradation for Multi-material 3D-printed Objects: Christian Altenhofen, Fraunhofer IGD	Pick and Place Robotic Actuator for Big Area Additive Manufacturing: Alex M. Boulger, Oak Ridge National Laboratory	Laser Reflectometry and Its Potential for LPBF In-situ Process Monitoring and Optimization: Brandon Lane, NIST	In Situ Physics-based Monitoring of the Reliability of Printed, Flexible Electronics during Tensile Testing Using Digital Image Correlation: Roozbeh (Ross) Salary, State University of New York at Binghamton	A Novel Study on EDM Processing of Support Structures in Metal AM : Gregory Bicknell, Penn State University	9:20 AM
Break	Break	Break	Break	Break	9:40 AM
Novel Scanning Strategies to Replicate Processing Conditions across Laser Powder Bed and Directed Energy Deposition Processes: Nicholas Jones, Carnegie Mellon Univ	3D Printed Electronics: Mwamba Bowa, The University of Tennessee	Predictive Iterative Learning Control with Surrogate Model for Optimal Laser Power in Selective Laser Sintering: Alexander Nettekoven, Univ of Texas	Correlative Beam Path and Pore Defect Space Analysis for Modulated Powder Bed Fusion Process: Deniz Ertay, University of Waterloo	Effect of Substrate Surface Finish and Process Parameters on Dimensional and Geometrical Deviations of Additively Manufactured Stainless Steel Components: Mohamed Eldakroury, Iowa State Univ	10:10 AM
Towards Development of Simulation Based Scan Pattern Optimization Scheme: Gaurav Ameta, NIST	Additive Manufacturing of Soft Electronics & 3D Microfluidics Using Liquid Metal Patterning Processes: Dishit Parekh, North Carolina State University	Realtime Control-oriented Modeling and Distributed Sensing for Smart and Reliable Powder Bed Fusion: Xu Chen, University of Connecticut	Uncertainty Quantification and the Additive Manufacturing Digital Twin: Alaa Elwany, Texas A&M	Hybrid Manufacturing Process for Controlling Grain Structure in Directionally Solidified Castings: Zachary Cordero, Rice University	10:30 AM
	Fiber Pulling Printing--A Novel Additive Manufacturing Process of Continuous Fiber Reinforced Metal Matrix Composite: Xin Wang, Xi'an Jiaotong University	Microwave Assisted Selective Laser Melting of Technical Ceramics: Sam Buls, KU Leuven	A Study of L-PBF Process Parameters on Martensitic Phase Transformation Temperature of NiTi Shape Memory Alloys via Taguchi's Robust Design Methodology: Bing Zhang, Texas A&M University	Parametric Optimization of a Hybrid Process Combining Wire Arc Additive Manufacturing with Milling: Fang Li, Beijing University of Technology	10:50 AM
		Experimental Study of the Sub-systems in a Microscale Additive Manufacturing Process : Dipankar Behera, University of Texas at Austin		Examination of the Connection between Selective Laser-melted Components Made of 316L Steel Powder on Conventionally Fabricated Base Bodies: Martin Link, TU-Darmstadt (PTW)	11:10 AM
		Research on Relationship between Depth of Fusion and Process Parameters in Low-temperature Laser Sintering Process: Takashi Kigure, Tokyo Metro Industrial Tech Research Inst			11:30 AM

TECHNICAL SESSION GRID - WEDNESDAY PM

Session Name	Applications 5	Lattices and Cellular 3	Materials: Composites 3 - Direct Write, UV Curing, Nanomaterials	Materials: Metals 7 - Non-traditional Materials	Materials: Metals 8 - Titanium Alloys 2	Materials: Polymers 3 - Powder Bed Fusion
Room	415AB	412	615AB	404	416AB	Salon J
Chair	John Turner, UT-Battelle / Oak Ridge National Lab	Maggie Yuan, Beijing Institute of Technology	Denis Cormier, Rochester Institute of Technology	Wayne King, Lawrence Livermore National Laboratory	Hari Kishore Adluru, University of Texas Research Institute	David Leigh, Vulcan Labs
1:10 PM	A Brief History of the 3D Printed Car: Failures, Successes, and Future Opportunities: Brian K. Post, Oak Ridge National Laboratory	Efficient Topology Optimization of Variable-density Lattice Structure for Convective Heat Transfer: Albert To, Univ of Pittsburgh	Effects of in-situ Compaction and UV-curing on the Performance of Glass Fiber-reinforced Polymer Composite Cured Layer by Layer: Shiferaw Beyene, CU-ICAR	Mechanical Properties of Zr-based Bulk Metallic Glass Parts Fabricated by Laser-foil-printing Additive Manufacturing: Yingqi Li, Missouri Univ of Science & Tech	Effects of Layer Orientation on the Multiaxial Fatigue Behavior of Additively Manufactured Ti-6Al-4V: Patricio E. Carrion, Auburn University	Optimization of Optical Permeability of Powder Bed in Low-temperature Laser Sintering Process: Toshiki Niino, Univ of Tokyo
1:30 PM	Using Post-tensioning in Large Scale Additive Parts for Load Bearing Structures : Phillip C. Chesser, Oak Ridge National Laboratory	Topology Optimization Using Tailorable Free form Lattice Structures for Additive Manufacturing: Archak Goel, University of Cincinnati, Department of Mechanical and Materials Engineering	UV-assisted Direct Write of Polymer-bonded Permanent Magnets: Callum Bailey, United Technologies Research Center	Effect of Cooling Rate on the Microstructure Mechanical Properties of Zr-based Bulk Metallic Glasses by Selective Laser Melting: Yujing Liu, University of Western Australia	Depth-sensing Rate-dependent Deformation of an Additively Manufactured Ti-6Al-4V Alloy: Muztahid Muhammad, University of North Dakota	Surface Modification of Polymer Particles for Laser Sintering Applications: Sam Irving, University of Nottingham
1:50 PM	Using Big Area Additive Manufacturing to Directly Manufacture a Boat Hull Mold : Brian K. Post, Oak Ridge National Laboratory	On the Mechanical Behavior of Additively Manufactured Asymmetric Honeycombs: Dhruv Bhate, Arizona State University	3D Printing of Hybrid Core-shell Architectures via Direct Write: Robert Pack, Univ of Tennessee Knoxville	Influence of Light Elements on the Properties of Bulk Metallic Glass Parts Produced by Laser Beam Melting: Moritz Stolpe, Heraeus Additive Manufacturing GmbH	Individual and Coupled Contributions of Laser Power and Scanning Speed towards Process-induced Porosity in Selective Laser Melting: Subin Shrestha, University of Louisville	Laser Sintering of PA12/PA4,6 Polymer Composites: Dieter Strobbe, KU Leuven
2:10 PM	Precast Concrete Molds Fabricated with Big Area Additive Manufacturing: Alex Roschli, Oak Ridge National Laboratory	Finite Element Modeling of Metal Lattice Using Commercial FEA Platforms: Edel Arrieta, Univ of Texas El Paso	Effects of Filler Morphology and Nozzle Size on Anisotropy in 3D Printed Epoxy Composites: Nadim Hmeidat, University of Tennessee Knoxville	Laser Engineered Net Shaping of the CoCrFeMnNi High Entropy Alloy: Andrew Kustas, Sandia National Laboratories	Stress Corrosion Cracking Behavior of Additively Manufactured Ti-6Al-4V Parts Fabricated Using New and Heavily Recycled Powder: Jonathan Pegues, Auburn University	Understanding hatch-dependent part properties in SLS : Andreas Wörz, Institute of Polymer Technology
2:30 PM	3D Printed Fastener-free Connections for Non-structural and Structural Applications – An Exploratory Investigation: Patricia Clayton, The University of Texas at Austin	A CAD-based Workflow and Mechanical Characterization for Additive Manufacturing of Tailored Lattice Structures: Peter Koch, Technische Universität Dresden	Additive Manufactured Stainless Steel Nanocomposites with Uniform Dispersion of Nanoparticles: Minglei Qu, Missouri University of Science and Technology	A Novel Self Dispersion Reinforcement High Entropy Alloy Prepared by Selective Laser Melting: Jizhan Li,	Influence of Atmospheric Control in Laser Powder Bed Additive Manufacturing, on Part Quality and Long Term Powder Life: Youssef Gaber, Renishaw PLC	Effect of Thermal Exposure to Mechanical Properties of Laser Sintered Polyamide 11: David Leigh, Vulcan Labs
2:50 PM	Break	Break	3D Printing of Nanocomposites for Multifunctional Materials: Hoejin Kim,	Break	Effect of Energy Density on the Consolidation Mechanism and Microstructural Evolution of Laser Cladded Functionally-graded Composite Ti-Al System: Eyitayo Olatunde Olakanmi, Botswana International University of Science & Technology	Break
3:20 PM	Lattice Structure Support Fabrication Using Binder Jetting For Thin-Walled Features: Sebastian Vargas,	A Comparison of Modeling Approaches for Predicting the Elastic-plastic Response of Additively Manufactured Honeycomb Structures: Raghav Sharma, Arizona State University		Microstructure Evolution during Solid-state Ambient Condition Metal Additive Manufacturing: Anagh Deshpande, University of Louisville		Impact of Extended Sintering Times on Mechanical Properties in PA-12 Parts Produced by Powderbed Fusion Processes: Justin Nussbaum, Univ of South Florida
3:30 PM	Binder Jetting of High Temperature and Thermally Conductive (Aluminum Nitride) Ceramic: Carlos A. Diaz-Moreno,	Adaptive Shape Conforming Honeycomb Lattice Infill for 3D Printing of Thin Wall Objects: AMM Nazmul Ahsan, North Dakota State University		Fabrication and Microstructural Characterisation of Additively Manufactured Nickel Aluminum Bronze Parts: Mohsen Mohammadi, University Of New Brunswick		Investigation into the Crystalline Structure and sub-Tpm Exotherm of Selective Laser Sintered Polyamide 6: Peng Chen,
4:00 PM		Design for Additive Manufacturing (DfAM): Mixed Integer Non-linear Problem (MINLP) for Design of Aperiodic Metamaterial Objects: Rahul Rai, University at Buffalo-SUNY		Direct Writing of Films from High Speed Aerosol Deposition of Ag: Jeremiah McCallister, The University of Texas at Austin		Laser Sintering of Polyamide 6 for Advanced Industrial Applications: Stefan Josupeit, BASF 3D Printing Solutions GmbH
4:20 PM		Numerical and Experimental Study of the Effect of Artificial Porosity in a Lattice Structure: Anton du Plessis, CT Scanner facility		Additive Manufacturing of Soft Ferromagnetic Alloys Using Laser Engineered Net Shaping: Andrew Kustas, Sandia National Laboratories		The Influence of Contour Scanning Parameters and Strategy on Selective Laser Sintering PA613 Build Part Properties: Christina Kummert,
4:40 PM				High-speed, In-situ Monitoring of Microcracking of W for Different SLM Scan Strategies: Bey Vrancken, Lawrence Livermore National Laboratory		Processing of High Performance Fluoropolymers by Laser Sintering: Carlo Campanelli, University of Nottingham

TECHNICAL SESSION GRID - WEDNESDAY PM

Physical Modeling 5 - AM Modeling Innovations	Physical Modeling 6 - Improvements in AM Modeling	Process Development 8 - Novel Methods 2	Process Development 9 - Powder Bed Fusion 2	Process Development 10 - Spinning, Pinning, and Stereolithography	Session Name
Salon B	Salon A	616AB	Salon K	417AB	Room
Travis Mayberry, Raytheon Integrated Defense Systems	Aref Yadollahi, Mississippi State Univ	Jason Weaver, Brigham Young University	Phill Dickens, University of Nottingham	Bahram Asiabanpour, Texas State Univ	Chair
Where Next for AM Simulation?: Chong Teng, 3DSIM, LLC	Quantifying Uncertainty in Laser Powder Bed Fusion Additive Manufacturing Models and Simulations: Tesfaye Moges, National Institute of Standards and Technology	Mechanical Properties of Polymer Additive Manufactured Samples Using ARBURG Freeformer and Ultimaker 2+ Compared with a Conventional Injection Molding Process: Pascal Pinter, KIT	Dynamic Defect Detection in AM Parts: Kevin Johnson, Michigan Technological University	Study of Charge Effect during Melt Electrospinning Writing Process: Houzhu Ding, Stevens Institute of Technology	1:10 PM
Characterizing Additive Manufacturing Models: From High-fidelity to Low-fidelity: Wentao Yan, Northwestern University, U.S.	Mechanistic Examination of Post Processing to Improve the Fatigue Performance of Powder Bed Fused Ti-6Al-4V: Peipei Li, Cornell Univ	Immiscible-interface Assisted Direct Metal Drawing : Li He, University of Iowa	In-situ Defect Detection through Monitoring and Modeling of Plume Characteristics: Joe Walker, WSU	Fabrication of Aligned Nanofibers along Z-axis – A Novel 3D Electrospinning Technique: George Tan, Texas Tech University	1:30 PM
Assessing the Utility of a Superposition-based Finite Element Approach for Part-scale Thermal Simulations: Terrence Moran, Cornell University	Optimization of Inert Gas Flow inside Laser Powder-bed Fusion Chamber with Computational Fluid Dynamics: Chen Yu, Institute of High Performance Computing	High-efficiency, High-resolution Multimaterial Fabrication for Digital Light Processing-based Three-dimensional Printing: Kavin Kowsari, Singapore University of Technology and Design (SUTD)	Fault Detection in Selective Laser Sintering with Optical Coherence Tomography: Adam Lewis, The University of Texas at Austin	Z-Pinning Approach for Reducing Mechanical Anisotropy of 3D Printed Parts: Chad Duty, University of Tennessee	1:50 PM
Visualisation and MHD Modelling of Shielding Gas Flow and Coverage in WAAM: Ioannis Bitharas, Heriot Watt University	An Improved Vat Photopolymerization Cure Model Demonstrates Photobleaching Effects: Mohammad Mahdi Emami, Singapore University of Technology and Design (SUTD)	Exploring Additive Manufacturing via Semi-solid Metal Formation Process: Qing Dong, Advanced Technology and Innovation Institute	Investigating Melt Pool Dynamics in Laser-powder Bed Fusion Using a Two-color Pyrometer: Josh Koepke, Sandia National Labratories	Improved Mechanical Bond of Printed Dissimilar Materials Using Z-Pinning Approach: Jordan Failla, Manufacturing Demonstration Facility	2:10 PM
Smoothed Particle Hydrodynamics Simulation of Additive Friction Stir Manufacturing of Aluminum Alloy 6061 : George Stubblefield, University of Alabama	Effects of Elemental Segregation during SLM from Atomistic Simulations : Mark Wilson, Sandia National Laboratories	Tool-path Generation for Hybrid Additive Manufacturing: Marco Leite, Instituto Superior Técnico	Accurate Determination of Laser Spot Position during LPBF Process Thermography: Ivan Zhirnov, NIST	Structurally Intelligent 3D Layer Generation for Active-Z Printing: Jivtesh Khurana, Pennsylvania State University	2:30 PM
Break	Break	Break	Break	Break	2:50 PM
Non-equilibrium Phase Field Model Using Thermodynamics Data Estimated by Machine Learning for Additive Manufacturing Solidification: Sukeharu Nomoto, ITOCHU Techno-Solutions Corp.	Conceptual Modelling of Bi-directional Bead Geometry Prediction in Laser Metal Wire Deposition (LMD-w): Adeola Adediran, Oak Ridge National Laboratory	Coaxial Imaging of Directed Energy Deposition Processes—What Are We Actually Measuring?: Christopher Stutzman,	Nanoparticle Bed Deposition by Slot Die Coating for Microscale Selective Laser Sintering Applications: Dipankar Behera, University of Texas at Austin	Parallel Two-photon Lithography with Sub-diffraction Voxel Shaping: Sourabh Saha, Lawrence Livermore National Laboratory	3:20 PM
Multi-physics Modeling of Single Track Scanning in Selective Laser Melting: Bo Cheng, Robert Bosch LLC	Nonlinear and Linearized Gray Box Models of Direct-write Printing Dynamics: Andrej Simeunovic, Ohio State University	Structural Health Monitoring (SHM) of 3D Printed Structures: Tyler Smith, ORAU	Off-nominal Laser Power Testing in Selective Laser Sintering: Samantha Taylor, Univ of Texas At Austin	High-Temperature Vat-Photopolymerization: Viswanath Meenakshisundaram, DREAMS Lab, Virginia Tech	3:30 PM
Towards an Open-source, Preprocessing Framework for Simulating Material Deposition for a Directed Energy Deposition Process: Matthew Dantin, Mississippi State University	Predictive Model Based Curing Process Control in Selective Separation Shaping (SSS) Process for Fabrication of High Quality Cementitious Part: Xiang Gao, University of Southern California	Development of an Indigenous and Innovative Sand 3D Printer: K P Karunakaran, Indian Institute of Technology, Bombay	A Guideline for Additively Manufacturing New Materials Using Laser Powder Bed Fusion: Ibrahim Karaman, Texas A&M University	microCLIP Ceramic High-resolution Fabrication and Dimensional Accuracy Requirements: Henry Oliver Ware, Northwestern University	4:00 PM
High Speed Visualisation and Multiphysics Modelling of Laser PBF: Ioannis Bitharas, Heriot Watt University			Beam Shaping in Powder Bed Based Additive Manufacturing: A Numerical Approach to Determine Adjusted Beam Shapes: Jan Frederik Hagen, Institute of Photonic Technologies, University Erlangen-Nürnberg	Investigation on Constrained Surface for Continuous Projection Stereolithography: Haiyang He, Univ of Illinois At Chicago	4:20 PM
			Characterizing Laser Coupling Efficiency during Additive Manufacturing: Dan Tung, Sandia National Laboratories	Investigation of Acoustic Field for Localized Particle Manipulation in Vat Photopolymerization Additive Manufacturing of Anisotropic Nanocomposites: Lu Lu, University of Illinois at Chicago	4:40 PM

TECHNICAL POSTER SESSION GRID

Session	Poster Session	
Room	Salon JK	
4:00 PM	3D Bioprinting with Alginate Hydrogel and Polymer Bioactive Glass Composite: Krishna Kolan, Missouri University of Science and Technology	Fiber-Fed Glass Additive Manufacturing: Jason Johnson, Missouri University of Science and Technology
	3D Printed Aircraft Competition at the University of Texas at Arlington: Gavin Sabine, University of Texas Arlington	General Rules for the Powder Bed Build Setup - A Review: Tan Pan, Missouri University of Science & Technology
	Active Learning for Engineering Students at the Wind Lab 3D Printing Initiative: Alejandra Flores Sifuentes, Texas State University	Improving EBM Processability of Metallic Glass Using an Electrically Conductive Powder Coating: Zaynab Mahbooba, North Carolina State Univ
	Additive Manufacturing of Electrical Conductors: Juvani Downer, Missouri University of Science and Technology	Incorporation of Automated Ball Indentation Methodology for Studying Powder Bed Fabricated 304L Stainless Steel: Aaron Flood, Missouri University of Science and Technology
	Additive Manufacturing of Metal Bandpass Filters for Future Radar Applications: Bradley Grothaus, Missouri University of Science and Technology	Investigating Emissivity Dependence on Surface Roughness: Samantha Taylor, Univ of Texas At Austin
	Additive Manufacturing of Metal Functionally Graded Materials: A Review: Yitao Chen, Missouri University of Science and Technology	Investigation into Mechanical Property Variation in Overhang Geometries Manufactured by Selective Laser Melting: Christopher Smith, Missouri University of Science and Technology
	Additive Manufacturing of Stainless Steel Nanocomposites: Javel Wilson, Missouri University of Science and Technology	Laser-Aided Additive Manufacturing of Glass: Caroline Ketterer, Missouri University of Science and Technology
	An aerospace integrated component application based on Selective Laser Melting: design, fabrication and FE simulation: Fei Liu, Chongqing University	Layer Height Measurement for In-situ Monitoring of Selective Laser Melting: Aleksandr Shkoruta, Rensselaer Polytechnic Institute
	Application of SWIR Camera in the Monitoring and Control of Overhang Quality in Selective Laser Melting: Olaseni Adeniji, University of the District of Columbia	Low-cost Bio-printer Gantry Design and Prototyping Process Control for Future Medical Application: Xiao Zhang, Iowa State University
	CNTs/CF Reinforced Composites for Programmable Deformation by Fused Deposition Modelling 3D Printing: Lan Huang, Xi'an Jiao Tong University	Mechanical Challenges of 3d Printing Ceramics Using Digital Light Processing: Matthew Roach, Sandia National Labs
	Comparison of Ex Situ X-ray Tomography and In Situ Monitoring to Gain Control Over Defects during Laser Powder Bed Fusion: Jean-Baptiste Forien,	Mitigation of Hypervelocity Impact Damage in Additively Manufactured Composites : Lauren Poole, Rice University
	Corrosion Behavior of Selective Laser Melted 304L Stainless Steel: Michael Anderson, Missouri University of Science and Technology	Modeling Strategies and Optimization of Additive-manufactured Structural Elements: Flynn Murray,
	Design and Additive Manufacture of Quadcopter Drone Components: Ifeanyi Echeta, University of Nottingham	Multi-color Thermal Imaging in Laser Powder Bed Fusion Additive Manufacturing: Dong-Xia Qu, LLNL
	Development of a customized CPAP mask using reverse engineering and additive manufacturing: Zhichao Ma, Newcastle University	NASA EPDC Additive Manufacturing Badge Development: Riley Horner, Texas State University
	Development of a Thermoplastic Biocomposite for 3D Printing: John Obielodan, University of Wisconsin-Platteville	NASA Sounding Rocket Additive Manufacturing Payload: Jarett Tigges, Sandia National Laboratories
	Development of an Automated Laser Control System for Improving Temperature Uniformity in Selective Laser Sintering: Timothy Phillips, Univ of Texas at Austin	Path Planning for Glass Laser Additive Manufacturing : Andrew Moore, Missouri University of Science and Technology
	EBSM Online Monitoring System Based on Machine Vision: Xulong Ma, Tianjin SciTsinghua QuickBeam Tech. Co., Ltd.	Quantifying the Effects of Varied Laser Scan Velocity on Part Quality in Selective Laser Melting Process: Matthew White, Center for Additive Manufacturing and Logistics at NC State University
	Effects of Thermal Camera Spatial and Temporal Resolution on Feature Extraction in Selective Laser Melting: Xin Wang, Missouri University of Science and Technology	Research on 3D Scanning for Remanufacturing Automation Using Additive Manufacturing: Brenna Scott, Lincoln University of Missouri
	Elucidating the Role of Fluid-particle Interaction in Binder Jet Additive Manufacturing: Joshua Wagner, Rice University	Simulation of the Thermal Behavior and Analysis of Solidification Process during Selective Laser Melting of Alumina: Kai Zhang, Nanjing University of Science and Technology
	Evaluation of Thermal Metrics for the Comparison of Finite Element Models with In-situ Thermal Images for Laser-based Additive Manufacturing: William Furr, Center for Advanced Vehicular Systems	Tactile Sensor for Shear and Pressure Sensing Manufactured through Additive Manufacturing of Silicone Elastomer: Ketut Putra, Univ of Michigan
	Experimental Characterization of Direct Metal Deposited Cobalt-based Alloy on Tool Steel for Component Repair: Xinchang Zhang, Missouri Univ of Science & Tech	The Sidewall Inclination Angle’s Influence on Repairing V-shape Defect in Ti6Al4V Metallic Components with Direct Energy Deposition Process: Wei Li, Missouri Univ of Science & Technology
	Experimental Investigation of Build Direction Thermal Conductivity of PLA with Process Structure Relationship: Darshan Ravoori,	Using Additive Manufacturing in the Development and Manufacture of a Fixed Wing Drone : William Reynolds, University of Nottingham
	Fast Prediction of Thermal History in Large-scale Part Fabricated via a Laser Metal Deposition Process: Lei Yan, Missouri Univ of Science and Technology	Utilising Additive Manufacturing Techniques for the Design and Manufacture of an Airship: Richard Finch, University of Nottingham
	Fatigue Behavior of EBM Ti-6Al-4V after Surface Processing: A Preliminary Study: Carter Keough, North Carolina State Univ	Weakly Coupled Thermomechanical Topology Optimization and Large-scale Polymer Deposition: Jackson Ramsey, Baylor University

Plenary Session and FAME Award Presentations

Monday AM
August 13, 2018

Room: Salon HJK
Location: Hilton Austin

Session Chair: Richard Hague, University of Nottingham

8:00 AM Introductory Comments

8:15 AM
Overview of Sandia's Born Qualified Project: ***Robert Roach***[1]; [1]Sandia National Laboratories
This seminar will serve as an overview and progress update of Sandia's Born Qualified project. Goal of project is to combine the promise of additive manufacturing techniques with deep materials & process understanding to revolutionize component design, manufacturing, and qualification paradigms where materials, designs, and ultimately components are Born Qualified. The vision for product realization is a paradigm shift where margins to requirements, limits of physics, and process uncertainties are known at birth, and product changes can be swiftly propagated through the design-manufacture-sustainment chain to assess impacts. Deliverables include development and deployment of a broad science-base applicable to multiple materials that consists of materials models, process models, novel process diagnostics, data analytics, and optimization techniques. Prototypes will be delivered of exemplar parts where performance was predicted from manufacturing diagnostics and models, radically changing the purpose of product testing to validation rather than performance evaluation.

8:35 AM
Technology Integration into Existing Companies: Johannes Büsching[1]; ***Christian-Friedrich Wilhelm Lindemann***[1]; Ulrich Jahnke[1]; Anne Kruse[1]; Rainer Koch[2]; [1]Paderborn University / DMRC; [2]Paderborn University
The implementation of additive manufacturing as an industrial manufacturing process poses extraordinary challenges to companies due to their far-reaching differences from conventional processes. In addition to the major differences in the production process, the pre and post process steps in particular also require a rethinking for companies and their employees. To solve these challenges and specifically to assist SMEs in the integration of technologies five industrial companies are researching together within the BMBF research project "OptiAMix", coordinated by the Paderborn University. This paper focuses on the development of an optimal and standardized process chain and its implementation in a general integration methodology. This methodology enables the standardized integration of additive manufacturing and the full exploitation of its great potentials. Therefore, it also includes other technology-specific components such as strategic component selection, decision support for "make or buy" and the implementation of automated component marking.

8:55 AM
Data Mining Approaches for Price Determination of 3D Printing Services in Decentralized Manufacturing-as-a-Service Marketplace: ***Binil Starly***[1]; Deepak Pahwa[1]; [1]North Carolina State University
Cloud manufacturing service models has evolved two-sided marketplaces which connect clients with 3D printing services. The main innovation of such platforms is the instant pricing algorithms which has virtually eliminated the need for quote generation and evaluation. In this paper, we sought to understand what factors contribute to the pricing of parts uploaded to these platforms. Data was obtained from publicly available sources of information such as material cost, location, shape of part, size of supplier, current capacity, future capacity, service offerings, future demand, customer reviews etc. We propose a data mining based approach where we use Deep Learning methods to estimate how much a particular service bureau should be charging for their services to be competitive in the market. A simulated decentralized marketplace with a multi-agent based approach is developed to study if our approach can lead to a fair and efficient marketplace for both clients and service bureaus.

9:15 AM
Examining the Effect of DFAM Design Rule Presentation on Part Redesign Quality: Kenton Fillingim[1]; Richard Nwaeri[1]; ***Katherine Fu***[1]; Christiaan Paredis[2]; David Rosen[3]; [1]Georgia Institute of Technology; [2]Clemson University; [3]Singapore University of Technology and Design
The purpose of this study is to understand how modality of design rule presentation affects design quality within the context of design for additive manufacturing (DFAM). Four DFAM design rules for fused deposition modeling were chosen, relating to overhangs, planar surfaces, accessible support structures, and part size. Each rule was presented in four different modalities: text only, text with illustration, text with industry example, and text with 3D printed example. Each rule presentation included a justification, and all but the text-only presentation included a "desirable" and "undesirable" design example for the rule. Four part redesign problems were given, and pairing with presentation type and order was randomized. The study was conducted with 26 professional engineers in a within subjects experiment design. Preliminary results indicate that text-only presentations result in the lowest quality of part redesign for DFAM, while 3D printed presentations result in the highest quality of redesign.

9:35 AM
What Insights into Additively Manufactured Materials will Exascale Computing Enable?: ***James Belak***[1]; John Turner[2]; Curt Bronkhorst[3]; Lyle Levine[4]; ExaAM Team[5]; [1]Lawrence Livermore National Laboratory; [2]Oak Ridge National Laboratory; [3]Los Alamos National Laboratory; [4]National Institutes of Standards and Technology; [5]ORNL, LLNL, LANL, NIST
The Exascale Additive Manufacturing Project (ExaAM) is an integrated collaboration between U.S. DOE Labs (ORNL, LLNL and LANL) and NIST as part of the Exascale Computing Project (ECP). An ICME approach is used for up-front assessment of manufacturability and performance. The project integrates all the computational components of the AM process into an exascale modeling environment. The continuum-scale build simulation is coupled to mesoscale simulations of microstructure and defect development and evolution from which location-specific properties are determined for performance simulations. The project is driven by a series of demonstration problems that are amenable to experimental observation and validation. Here, we present our coupled exascale simulation environment for additive manufacturing and its initial application to AM builds. Work performed under the auspices of the U.S. DOE by LLNL, LANL and ORNL, and supported by the ECP (17-SC-20-SC), a collaborative effort of the U.S. DOE Office of Science and the NNSA.

9:55 AM Break

10:25 AM
A Physical Hash for Preventing and Detecting Cyber-physical Attacks in Additive Manufacturing Systems: Josh Brandman[1]; ***Logan Sturm***[1]; Jules White[2]; Christopher Williams[1]; [1]Virginia Polytechnic Institute; [2]Vanderbilt University
To prevent defects, AM systems need to be monitored for quality control. Onboard sensors are not sufficient because a cyber-attack that compromises the system will also compromise the sensors. This work proposes a cyber-physical hash, a cryptographic hash containing the nominal process parameters and toolpath that is physically printed as a QR code, to securely transfer data from the printer to a side channel measurement system. The physical hash protects the intellectual property of the print (e.g., geometry toolpath, process parameters), while still communicating the designer specifications to the monitoring system. This creates an air-gap between the monitoring system and the machine. In this paper, the overall concept and underlying algorithm of the physical hash is presented. The authors present a proof-of-concept validation that demonstrates the ability of a physical hash and in-situ monitoring to detect the existence (and absence) of several malicious attacks on a material extrusion AM process.

10:45 AM
FAME Outstanding Young Researcher: Hybrid- Additive Manufacturing (AM): Role of Mechanical Design and Traditional Manufacturing Processes in the Adoption of Metal AM: ***Guha Manogharan***[1]; [1]Pennsylvania State University
Today, Additive Manufacturing (AM) offers a unique ability to fabricate complex geometries using a variety of materials without any special tooling or costly process engineering time for limitless low volume production applications, ranging from custom bio-medical implants to integrated lattice structures for fluidic and high-strength applications. Unfortunately for most metal-based mechanical components, surface finish and tolerances are not sufficient for use within assemblies. In an effort to harness AM capabilities to their fullest extent, traditional manufacturing processes i.e., hybrid manufacturing through secondary proceses, such as machining, grinding, micro-finishing and abrasive chemical treatment are required to address these requirements. The focus of this talk is on presenting two unique hybrid AM approaches: (1) How can a universal direct metal AM hybrid approach accelerate the adoption of AM? and (2) How should mechanical design methodologies and casting-hydrodynamics evolve to integrate casting processes through indirect metal AM? The former challenge can be answered by combining AM with traditional manufacturing processes without significant modification to existing CNC machine configuration and by integrating advanced DDM tools such as non-contact metrology and in-process tool-path generation. The latter challenge can be solved by re-thinking fundamentals of casting-hydrodynamics with freeform design approaches using 3D Sand-Printing.

11:15 AM
Freeform and Additive Manufacturing (FAME) Award: The Advances in 4D Printing: ***Chee Kai Chua***[1]; [1]Nanyang Technological University
4D printing is envisioned to be the future of additive manufacturing (AM). However, there is a huge gap between current state of the art of 4D printing and real life applications. The main challenges are material compatibility and process reversibility. In this presentation, a brief introduction to Singapore Centre for 3D Printing (SC3DP) is presented first, followed by a review on recent advances in 4D printing with a particular focus on progress made at SC3DP including metal 4D printing and reversible 4D printing.

Applications 1

Monday PM	Room: Salon G
August 13, 2018	Location: Hilton Austin

Session Chair: Amrita Basak, Georgia Institute of Technology

1:30 PM
Material Characterization for Lightweight Thin Wall Structures Using Laser Powder Bed Fusion Additive Manufacturing: ***Sean Dobson***[1]; Li Yang[2]; Yan Wu[2]; [1]University of Louisville Mechanical Engineering Department; [2]University of Louisville Department of Industrial Engineering
In this study the geometry-process-material characteristics of the Ti6Al4V thin wall features fabricated by the EOS M270 laser melting powder bed fusion (LM-PBF) additive manufacturing (AM) was investigated. Samples with varying wall thickness, orientation, scanning speeds and laser power were fabricated and analyzed. The dimensional accuracies, microstructural characteristics and mechanical properties of the samples were evaluated experimentally. The results clearly indicated the significant coupling effects between the geometry design of these thin wall features and their material properties, which is critical to the design and manufacturing of many AM lightweight structures. By identifying significant design and process parameters for the thin wall structures, this study will enable further investigations of the integrated design theories for the AM lightweight structures.

1:50 PM
Effect of Inter-layer Cooling Time on Distortion and Mechanical Properties in Metal Additive Manufacturing (AM): Yashwanth Bandari[1]; Yousub Lee[1]; Peeyush Nandwana[1]; Bradley Richardson[1]; Adeola Adediran[1]; ***William Henry***[2]; Lonnie Love[1]; Katherine Gaul[1]; [1]Oak Ridge National Laboratory; [2]GNK Aerospace
Laser Metal Deposition with wire (LMD-w) is one of the novel Direct Energy Deposition (DED) processes that is gaining attention in aerospace industry due to the potential cost and lead time reductions for large-scale components. However, improving process parameters (for example, laser power, wire feed rate, robotic travel speed, inter-layer cooling time, etc.) is still under development. These parameters affect thermal gradients that cause residual stresses that in-turn influence distortion. These parameters also affect mechanical properties. Inter-layer cooling time, specifically, is one of the main factors for total production time, and it is used to help mitigate distortion. Therefore, this paper investigated the effects of different inter-layer cooling times on both distortion and mechanical properties. Distortion of deposited Ti-6Al-4V walls was measured automatically using a laser scanner. Finally, suitable recommendations are discussed to optimize the inter-layer cooling time to fabricate components with desired mechanical properties.

2:10 PM
Characterization and Analysis of Geometric Features for the Wire-arc Additive Process: ***Christopher Masuo***[1]; Andrzej Nycz[1]; Mark Noakes[1]; Lonnie Love[1]; Katherine Gaul[1]; [1]Oak Ridge National Laboratory
The wire-arc additive process expands the possibilities of effectively producing large-scale, complex metal objects through high deposition rates at low costs. However, this process is prone to irregularities in geometric features that occur from improper thermal conditions and build parameters that cause uneven build heights. This paper discusses a method to obtain consistent build characteristics and near net shape geometric features for the wire-arc additive process. Process parameters are established for each material printed to ensure characterization of layer build height and even flow in the interior of parts. Various sections of the build—perimeter, infill, and various thicknesses of walls require different strategies to correctly build the part. Open-loop build geometry is still not sufficient to build a part to near net shape of the original model. Average layer height is determined and used with adaptive height control to print the correct, modeled height.

2:30 PM
Surface Finish and Identification of Defects through Complementary use of Optical Metrology and X-ray Computed Tomography in Laser Powder Bed Fusion Additive Manufacturing: ***Jason Fox***[1]; Felix Kim[1]; Zach Reese[2]; Christopher Evans[2]; John Taylor[2]; [1]National Institute of Standards and Technology; [2]University of North Carolina at Charlotte
The development of additive manufacturing (AM) has allowed for increased complexity of designs over traditional manufacturing; however, this leads to greater difficulties in post process finishing of the part surfaces. Additionally, uncertainty surrounding the quality of the complex as-built surfaces hinders wide scale adoption of AM. As such, a strong understanding of the as-built surface finish is required to help determine the quality of the resultant part. In this work, samples made from nickel alloy 625 and 17-4 stainless steel were built using a commercially available laser powder bed fusion (LPBF) system. X-ray computed tomography (XCT) and optical measurements are aligned to determine the capability of XCT measurements as a tool for surface finish metrology and provide insight into locations of overhangs, undercuts, and near surface porosity, which are difficult to identify and assess through conventional surface finish metrology and may have a drastic effect on part performance.

2:50 PM
Effect of Initial Surface Features on Laser Polishing of a Co-Cr-Mo Alloy Made by Powder-bed Fusion: ***Brodan Richter***[1]; Nena Blanke[2]; Christian Werner[2]; Frank Vollertsen[2]; Frank Pfefferkorn[1]; [1]University of Wisconsin - Madison; [2]Bremer Institut für Angewandte Strahltechnik GmbH
One of the challenges facing widespread use of parts created by the powder-bed fusion process is the high surface roughness that necessitates some type of post-build finishing process. Laser polishing (i.e., remelting), which uses surface-tension-driven flow to reduce roughness on irradiated metallic surfaces, is one potential finishing process. This work examines the effect that surface features on the as-built part have on the performance of continuous-wave laser remelting of Co-Cr-Mo alloy (Celsit 21-P, Stellite 21 equivalent) samples produced by powder-bed fusion manufacturing. This is accomplished by the comparison of three-dimensional surface measurements before and after laser remelting using focus-variation microscopy. Engineering models used to simulate the surface profile as a result of laser remelting are presented. The results from this work provide insight on the fundamental physics occurring during laser remelting on parts made by powder-bed fusion and will aid parameter selection for surface consolidation and smoothing.

3:10 PM Break

3:40 PM
Effect of Process Parameters on the Surface Roughness and Fatigue Behavior of Additively Manufactured Alloy 718: Bo Whip[1]; Luke Sheridan[1]; ***Joy Gockel***[1]; [1]Wright State University
Metal additive manufacturing (AM) is a method to create complex components in a layer-by-layer process. There are several types of defects inherent to the AM process. This work investigates the relationship of process parameters, as-built surface roughness, and mechanical performance for AM components made of nickel-based superalloy 718. The surface roughness of components built using varied processing parameters was characterized using both nondestructive and destructive measurement techniques. Statistical correlations are presented between contour processing parameters and surface roughness metrics. Results show that destructive measurements are required to expose obstructed features and highly concentrated stress is present on crack-like surface features. However, nondestructive methods more easily provide a statistically significant sample size. Mechanical testing is used to determine the impact of the varied rough surfaces on the fatigue life. Understanding the surface roughness behavior can be used for further process optimization and to inform the qualification strategy for AM components.

4:00 PM
Effect of Subsurface Defects on Surface Topography in Additive Manufactured Parts: ***Zachary Reese***[1]; Jason Fox[2]; John Taylor[1]; Chris Evans[1]; Felix Kim[2]; [1]University of North Carolina at Charlotte; [2]National Institute of Standards and Technology
Additive manufactured (AM) components exhibit an abundance of surface textures and patterns. Past work investigating components created through laser powder bed fusion (LPBF) has shown that these patterns, specifically the chevron resulting from solidification of the melt pool on upward facing surfaces, can be correlated to quality of the final part. Additionally, these patterns have been observed to vary around the region of potential subsurface defects. In this work, parts with seeded subsurface defects at various depths from the top surface are printed in nickel alloy 625 on a commercially available LPBF machine. Surface height maps are obtained using a scanning white light interferometer (SWLI) to determine the defect's impact on the surface texture of subsequent layers. Data obtained from the SWLI are aligned with data from X-ray computed tomography (XCT) to confirm the locations of defects and applicability of this approach as an in situ detection method is discussed.

4:20 PM
Effect of Shield Gas on Surface Finish of Laser Powder-bed Produced Parts: ***Colt Montgomery***[1]; Michael Brand[1]; Robin Pacheco[1]; John Carpenter[1]; [1]Los Alamos National Laboratory
Additive manufacturing of metals is a novel manufacturing technique that allows for net-shape or near net-shape parts to be produced quickly. Within additive manufacturing a large concern is the produced surface finish, especially for upward and downward facing surfaces on complex geometries. Surface finish is of utmost importance for many engineering applications. In melting of powders the gas used dominates the thermal conductivity of the metal powder. Manipulation of the type of shield gas may provide a means to modify the surface finish without adjustment of established lasing parameters and thereby produce a higher quality part with minimal post processing. These results have potential applications in aerospace, automotive, and biomedical sectors where surface finish and complex geometries are extremely common.

4:40 PM
Surface Topology in Directed Energy Deposition Additive Manufacturing: Ali Khorasani[1]; ***Jakob Croghan***[1]; [1]Iowa State University
Additive manufacturing by direct energy deposition (DED), also referred to as laser metal deposition (LMD), often results in a poor surface topology on the component. This requires machining or another form of post-processing to obtain the proper geometric and mechanical requirements. Poor surface quality often comes from undesired powder particles sticking to the surface, the uneven deposition of beads, and layering (e.g. the staircase effect). Some parameters have a greater effect on these phenomena than others. This study focuses on the effects of scanning speed and laser finishing on the surface topology. A substantial improvement in surface quality has been obtained by laser finishing. However, scanning speed has dual effect on surface quality. With increasing scanning speed, the surface roughness increases and then decreases. These findings could be used as a guideline for selecting process parameters to obtain desirable surface quality in specific, LMD-built, industrial parts.

Lattices and Cellular 1

Monday PM Room: Salon F
August 13, 2018 Location: Hilton Austin

Session Chair: Dhruv Bhate, Arizona State University

1:30 PM
Mechanical Properties of Ti6Al4V ELI Lattice Structure Fabricated by Selective Laser Melting: Effect of Pore Size and Porosity: ***Xingchen Yan***[1]; Chaoyue Chen[1]; Ruixin Zhao[2]; Jiang Wang[2]; Yun Ye[3]; Rodolphe Bolot[4]; Wenyou Ma[3]; Zhongming Ren[2]; Hanlin Liao[1]; Min Liu[3]; [1]Universite de Technologie de Belfort-Montbeliard; [2]Shanghai University & State Key Laboratory of Advanced Special Steel; [3]Guangdong Institute of New Materials; [4]Université de Bourgogne Franche-Comté
Titanium lightweight structure is highly demanded for biomedical applications especially used as the bone substitution. This study evaluates the effect of pore size and porosity on the mechanical properties of Ti6Al4V ELI periodic lattice structures fabricated via selective laser melting (SLM) technology. A series of lattice structures, pore size ranged from 500-700µm and the porosity 60-70%, are designed by repeating an octahedral unit cell. A good consistency of morphology is detected between the original design models and the SLM-produced structures by SEM and micro-CT observation. Typically acicular martensite microstructure of the strut is confirmed by TEM, which contributes to the brittle deformation behavior. The uniaxial compression tests are conducted, meanwhile the deformation behavior was recorded by a digital camera. These lattice structures have comparable compressive strength and elastic modulus to those of cortical bone. Finite element analysis is also launched to estimate the deformation mechanism of the lattice structure.

1:50 PM
Microstructural and Mechanical Characterization of Ti6Al4V Cellular Struts Fabricated by Electron Beam Powder Bed Fusion Additive Manufacturing: Cody Ewing[1]; Yan Wu[1]; ***Li Yang***[1]; [1]University of Louisville
Despite the widespread use of the electron beam powder bed fusion (EB-PBF) additive manufacturing (AM) process in the fabrication of cellular structures, relatively little is known about the microstructural and mechanical properties of the individual cellular struts of different geometries fabricated by the EB-PBF. In this study, experimental investigation was carried out in the attempt to establish preliminary understanding of the material characteristics of the Ti6Al4V cellular struts using EB-PBF under various geometry design conditions (dimension and orientation angle). It was found that there exist significant geometry effects for the material characteristics of the Ti6Al4V cellular struts, which indicates that a non-uniform material model should be considered in the future design of these cellular structures.

2:10 PM
Effect of Wall Thickness and Build Quality on the Compressive Properties of 304L Thin-walled Structures Fabricated by SLM: ***Myranda Spratt***[1]; Joseph Newkirk[2]; K Chandrashekhara[2]; Sudharshan Anandan[2]; Rafid Hussein[2]; [1]Missouri University of Science & Techology; [2]Missouri University of Science and Technology
Lightweight metallic lattice structures are of interest due to their high specific strength, but they can be difficult to make with traditional manufacturing. Additive manufacturing has the design flexibility to make these complex structures. However, the resulting properties can be difficult to model due to difference between the designed and as-built structure. In this study, thin walled specimens were manufactured and tested under compression. Wall thicknesses of these specimens ranged from 0.1 to 0.5 mm. The effect of wall thickness on strength to density ratio was investigated. The build quality was also evaluated to determine how the results were influenced by the specimen quality. Differences between the nominal and as-built geometry were identified. Optical microscopy and microhardness measurements were done before and after compression testing. The results of this data were used to validate a finite element analysis of the chosen geometry

2:30 PM
Mechanical Property Variation in Metal Lattice Struts: ***Amber Dressler***[1]; Carolyn Seepersad[1]; [1]University of Texas at Austin
Direct metal laser sintered lattice structures offer favorable tradeoffs between mechanical stiffness and weight, which are of interest to designers. However, manufacturing defects present throughout the lattices create significant variability in mechanical properties and part performance. The goal of this research is to improve the understanding of how defects impact mechanical properties to enhance designers' ability to design metal lattice structures reliably. Before analyzing full lattices, it is important to understand how design parameters impact individual lattice struts during manufacturing. To test individual lattice struts, tensile specimen with five struts interrupting the gauge section were manufactured in three strut diameters and two build orientations. Before tensile testing the samples, several non-destructive analysis methods were conducted on each sample to document any differences in part characteristics. Following all testing, the fracture surfaces and experimental data were analyzed to investigate failure trends in search of robust designs.

2:50 PM
Mechanical Performance of Ti-6Al-4V Octet Truss Lattice Structures Produced via Powder Bed Fusion (PBF): ***Michael Brand***[1]; Colt Montgomery[1]; Robin Pacheco[1]; John Carpenter[1]; [1]Los Alamos National Laboratory
Titanium (Ti-6Al-4V) lattices with varying strut thicknesses yielding different relative densities will be fabricated via Powder Bed Fusion (PBF). Previous work was explored using the rhombic dodecahedron lattice cell structure. For this research the octet truss structure will be tested and evaluated which should yield higher strength than the rhombic dodecahedron cell structure. Samples will be tested in order to determine the tensile and compressive properties and will be compared to ASTM specifications for Ti-6Al-4V. Samples were tested in the as deposited state as well as after a specific heat treatment typically used for Titanium. Optical microscopy and scanning electron microscopy (SEM) was used to quantify the distribution of the grains in the as deposited and heat treated states.

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3:40 PM
Mechanical Properties of Additively Manufactured Stainless Steel 17-4PH Schoen Gyroid Lattices: ***Amanda Sterling***[1]; Brendan Lessel[2]; Nam Phan[2]; Nima Shamsaei[1]; [1]Auburn University; [2]US Naval Air Systems Command
With the advent of additive manufacturing (AM), innovative complex geometries can be utilized for light-weighting components without sacrificing structural integrity or required performance. Complex cellular lattice structures are particularly promising when paired with the Laser-Powder Bed Fusion (L-PBF) AM process due to the fine structure resolution that can be achieved. Different cellular densities and layer orientations of these ordered lattices can yield different strength-to-weight ratios and mechanical responses. Understanding these relationships will enable lattice optimization specific to end-user applications. Before such designs can be trusted to perform safely and reliably, the mechanical properties must be well understood. In this study, AM stainless steel 17-4 PH specimens comprised of the Schoen Gyroid lattice structure with varying cellular densities and layer orientations are produced and subjected to external loading. Results are compared and conclusions drawn to provide insight for improved lattice structure optimization.

4:00 PM
An Investigation of the Fatigue Strength of Multiple Cellular Structures Fabricated by Electron Beam Powder Bed Fusion Additive Manufacturing Process: Abigail Orange[1]; Yan Wu[1]; ***Li Yang***[1]; [1]University of Louisville
In this study multiple cellular structures, including the re-entrant auxetic, the octet-truss, and the BCC lattice, were evaluated for their relative performance of fatigue strength under compression-compression cyclic loading. Various design variations with different dimensions were fabricated via electron beam powder bed fusion (EB-PBF) additive manufacturing (AM) process and experimentally tested. Initial S-N based fatigue strength characterization with the BCC lattice shows significantly decreased fatigue strength of the cellular parts compared to the solid samples. Cross-design comparison were consequently carried out using constant maximum stress ratio level. The results indicate that the fatigue characteristics of the EB-PBF cellular structures are not only dependent on their topology types but also their geometry dimensions.

4:20 PM
Assessment of Octet Truss Lattice Structures Having Hollow Struts: John Ackerman[1]; ***Andrew Greeley***[1]; Denis Cormier[1]; [1]Rochester Institute of Technology
Engineered lattice structures are traditionally fabricated using solid (typically round or square) struts due to ease of fabrication. However, it is well known that hollow beams have considerably greater stiffness than solid beams of equivalent cross sectional area. In this paper, octet truss lattice structures fabricated with both solid and hollow struts of equivalent area are studied. Finite element analysis has been used to compare predicated performance between the two alternatives using both square and round struts. Simulated results are complemented by experimental results using lattice structures fabricated on a FormLabs Form 2 stereolithography machine using Tough resin. Recommendations on design of lattice structures for ease of uncured resin removal are made.

4:40 PM
Mechanical Response of Honeycomb Structures under Impact: ***Maggie Yuan***[1]; [1]Beijing Institute of Technology
A honeycomb structure with negative Poisson's ratio (NPR) was designed, fabricated, and analyzed for use in personal protective clothing (PPC). The mechanical properties were explored using quasi-static mechanical testing and the Hopkinson pressure bar experimental system, and results were compared to similar samples containing regular hexagonal and regular quadrilateral honeycomb structures. The experimental results showed that under quasi-static loading, the concave honeycomb structure had the highest compressive modulus and yield strength, which produced the highest strain absorption energy, anti-deformation performance and energy absorption. When exposed to a dynamic load at high strain rate, the concave honeycomb also exhibited the highest dynamic compression modulus, the best impact resistance and best energy absorption of the three structures. In summary, the concave honeycomb structure was more resistant to deformation and had higher impact resistance than the regular hexagonal and regular quadrilateral honeycombs, and exhibited better energy absorption, which makes it a good candidate for application as a personal safety protection material.

Materials: Metals 1 - Broad Issues in Metal AM

Monday PM — Room: 615AB
August 13, 2018 — Location: Hilton Austin

Session Chair: Elena Lopez, Fraunhofer IWS

1:30 PM
Experience with Additive Manufacturing for Navy Sustainment: ***Edward Reutzel***[1]; Stephen Brown[1]; Richard Martukanitz[1]; Gregory Welsh[2]; Mark Sapp[3]; Eric Petran[4]; [1]ARL Penn State / CIMP-3D; [2]NAVAIR - PAX River; [3]NAVAIR - FRC-East; [4]NAVSEA - PHNSY
Due to numerous benefits AM technology offers, it has garnered much recent attention across a range of industries. It's easy to forget that the U.S. Navy has been developing the foundations of laser-based metal repair technology for almost 25 years. Historically significant Navy laser-based repairs will be reviewed, then focus will shift to more recent activities. The qualification strategy that led to the 2010 implementation of laser-wire DEDAM in-situ repair of an Alloy 625 asset will be discussed. The test strategy and key characterization results that enabled the first flight demonstration (2016) of safety critical PBFAM Ti6Al4V components (MV-22B Osprey) will be provided. Finally, the qualification strategy and key test results for a laser-powder DEDAM repair of a component in an AV-8B Harrier engine will be reviewed. With ever-improving technology and growing familiarity amongst approval authorities, AM will be an important tool for the future of Navy sustainment.

1:50 PM
Development of an Engineering Diagram for Additively Manufactured Austenitic Stainless Steel Alloys: ***Zachary Hilton***[1]; Joseph Newkirk[1]; [1]Missouri University of Science and Technology
Austenitic stainless steels are the most widely applied type of stainless steels due to their good weldability and high corrosion resistance. A number of engineering diagrams exist for the purpose of providing insight into behavior of these steels. Examples of these diagrams are constitution diagrams (aka Schaeffler Diagrams) which are used to approximate the solidification path of the alloy and the amount of retained ferrite in the solidified matrix. Other diagrams are the Suutala diagram which approximates cracking susceptibility and phase maps which predict solidification path by varying a processing parameter such as cooling rate. By combining these diagrams a much more concrete conclusion can be made as to the behavior of a particular steel. This approach could be used to determine differences in behavior between two different compositions. The developed diagram is intended for use with rapid solidification phenomena as observed in the selective laser melting process.

2:10 PM
The Role of Cellular Structure on Mechanical Properties in Additively Manufactured Metals: Janith Wanniarachchi[1]; Philip Yuya[1]; ***Ajit Achuthan***[1]; [1]Clarkson University
The microstructure of additively manufactured (AM) metal parts is very rich with various unique features that are not found in traditionally manufactured metals. The cellular structure is a prominent such feature that is expected to influence the elastic-plastic behavior of metals significantly. Most of the AM metals show more substantial strength and lower ductility, possibly due to the resistance to dislocation motion by the cellular structure. In this study, the effect of the cellular structure on the local mechanical properties of powder jet manufactured parts are investigated. Initial results from the nanoindentation characterization on parts show a significant difference in the mechanical properties, between the cell walls and the cell interior. A substantial anisotropy in the mechanical properties is also seen. However, in samples were cellular structure removed by heat treatment, the properties were relatively more isotropic and uniform. Detailed studies to obtain a quantitative characterization is ongoing.

2:30 PM
Multi-laser Processing Strategies for High Integrity Component Manufacture: ***Marc Saunders***[1]; Ravi Aswathanarayanaswamy[1]; [1]Renishaw plc
Recent developments in mid-sized laser powder-bed fusion machines feature up to four lasers, each of which can address the entire build plate. This provides great flexibility in laser assignment, enabling rapid production of AM components. With multiple melt pools each emitting condensate and spatter, the relative position of the laser spots with respect to the inert gas flow is critical. This study investigates the extent to which a downstream laser is affected when processing through the emissions of upstream lasers in terms of melting behaviour and component mechanical properties. Recommendations are made for the relative positioning of lasers to maintain optimum component quality and process productivity.

2:50 PM
Real Time Monitoring of Additive Manufacturing Processes Using High-speed Synchrotron X-ray Imaging: ***Niranjan Parab***[1]; Cang Zhao[1]; Kamel Fezzaa[1]; Tao Sun[1]; [1]Argonne National Laboratory
High speed synchrotron hard X-ray imaging technique was used to monitor the underlying physical processes in three different additive manufacturing (AM) techniques: laser powder bed fusion (LPBF), direct energy deposition (DED), and binder jetting. For LPBF and DED experiments, a custom setup was built in conjunction with a 520 W ytterbium fiber laser. For binder jetting experiments, a commercially available printer was used. All three AM setups were synchronized with the high speed synchrotron hard X-ray imaging setup at beam line 32-ID, Advanced Photon Source, to record various physical phenomena in-situ and in real time. For laser based systems (LPBF and DED), many scientifically and technologically significant phenomena, including melt pool dynamics, powder flow and ejection, rapid solidification, and keyhole porosity formation, were investigated with high spatial and temporal resolutions. For binder jetting system, binder deposition and penetration and powder ejection in the wake of the binder were studied.

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3:40 PM
Characterization of Spatter Particles Formed during Laser Powder Bed Fusion: Rashmi Vadlakonda[1]; ***Christopher Rock***[1]; Tim Horn[1]; [1]North Carolina State University
Spatter generated during melting in additive manufacturing laser powder bed fusion was characterized and compared with atomized powder. Spatter particles were isolated from the powder bed and collected for analysis, in addition to spatter near the build. The spatter particles had features different than atomized powder, including mixed morphologies, particle sizes, surface films and spots. Typical bulk properties such as O2 content, morphology and particle size distribution were compared with atomized powder. Uncommon surface features were characterized using techniques such as SEM & EDS to determine any differences in properties compared with atomized powder.

4:00 PM
Investigating Failure Mechanism of Additively Manufactured Metal Sample with Simulated Defects Using Simultaneous Mechanical Testing and X-ray Computed Tomography: ***Felix Kim***[1]; Edward Garboczi[1]; Shawn Moylan[1]; [1]National Institute of Standards and Technology
Metal additive manufacturing (AM) is a revolutionary manufacturing technique, but the understandings of AM defects and the effects of the defects are limited. Without optimized AM processing parameters, AM-produced parts can contain defects such as porosity, cracks, and trapped powders, which directly affect the mechanical performances. The underlying fracture mechanism, critical defect type, size, and distribution are difficult to interpret from typical mechanical tests, and are critical aspects of fracture analysis. X-ray computed tomography (XCT) is a non-destructive three-dimensional (3D) imaging technique directly visualizing the material structure with defects with a resolution of a few micrometer or less. In this presentation, we will provide the details and results of mechanical testing performed with XCT on a sample with a simulated defect. The results show the actual material behavior and fracture mechanism where the evolution of defects such as crack growth and pore coalescence can be visualized.

4:20 PM
Fatigue Life Prediction of Additively Manufactured Metallic Materials Using a Fracture Mechanics Approach: ***Brian Torries***[1]; Rakish Shrestha[1]; Aidin Imandoust[1]; Nima Shamsaei[1]; [1]Auburn University
The present study aims to model the fatigue strength of additively manufactured metallic materials employing a fracture mechanics approach. Specimens with different build orientations were subjected to strain controlled fatigue testing. Upon failure, the defect(s) responsible for crack initiation were identified by fractographic analysis. From these defects an equivalent internal defect size is calculated using the method based on Murakami model. Using this parameter, the elastic-plastic energy release rate () was determined, and the relationship between and fatigue life was investigated. The results showed that this method improves the predictability of the fatigue strength of additively manufactured materials when the defects size and location is known. The relationship appeared to better fit the fatigue data of the experimental materials as compared to the relationship and contributed to a reduction in data scatter.

4:40 PM
Material Properties of Hybrid Metal Additive Parts at AM/Substrate Interfaces: John Linn[1]; ***Jason Weaver***[1]; Mike Miles[1]; Yuri Hovanski[1]; Robert Smith[2]; Jason Jones[3]; [1]Brigham Young University; [2]Qualified Rapid Products; [3]Hybrid Manufacturing Technologies
The capabilities of various metal Additive Manufacturing (AM) processes, such as Direct Metal Laser Sintering (DMLS) and Direct Energy Deposition (DED) are increasing such that it is becoming ever more common to use them in industrial applications. The ability to print atop a substrate broadens that scope of applications. There is ongoing research regarding the mechanical properties of additively processed materials, but not much regarding the interaction between additive material and its substrate. An understanding of the mechanical and performance properties of the AM/substrate interface is imperative. This paper describes a study of the strength properties of AM/substrate interfaces, with respect to torsion and tension, and compares them to their fully wrought and fully additive counterparts. DMLS and DED are used to produce test specimens of two different materials, SS316L and M300 steels.

5:00 PM
The Mechanical Behavior of AISI H13 Hot-work Tool Steel Processed by Selective Laser Melting under Tensile Stress: ***Mei Wang***[1]; Yan Zhou[1]; Jie Liu[1]; QingSong Wei[1]; Zhunfeng Fan[2]; [1]Huazhong University of Science and Technology; [2]State Nuclear Demonstration Power Plant Co., Ltd.
AISI H13 hot-work tool steel is commonly used for tools subjected to high temperatures and cyclic mechanical loads. Recently, SLM process has gained large attention at the hot-work tool field. The present study concerns the SLM process of the H13 tool steel with and without preheating. X-ray diffraction (XRD), field emission scanning electron microscope (SEM), and high-temperature tensile tests were applied to investigate the phases, microstructures and resultant mechanical properties of SLM processed H13. Results show that application of substrate preheating results in a more homogeneous microstructure and better mechanical properties compared to those without preheating. High-temperature tensile strength increased from 1066 MPa to 1183 MPa, and the total elongation increased from 5.7% to 8.1%. The high-temperature tensile strength of those parts with preheating was higher than those of the treated ASSAB 8407 Supreme H13 tool steel, while the total elongation was much lower than those.

Materials: Metals 2 - Stainless Steel 316L

Monday PM — Room: 616AB
August 13, 2018 — Location: Hilton Austin

Session Chair: Thomas Starr, University Of Louisville

1:30 PM
Comparison of Stainless Steel 316L Parts Made by FDM-based and SLM-based Additive Manufacturing Processes: ***Haijun Gong***[1]; Dean Snelling[1]; Kamran Kardel[1]; Andres Carrano[1]; [1]Georgia Southern University
The SLM-based additive manufacturing (AM) process has been of great interests for metal part fabrication. A number of studies have been conducted for an in-depth understanding of how the stainless steel 316L parts are fabricated using a powder bed fusion AM process. In comparison with SLM stainless steel 316L, this paper introduces an FDM-based AM process for making austenitic stainless steel 316L part using a metal-polymer composite filament (Ultrafuse 316LX). The stainless steel 316L metal specimens are printed by a standard FDM 3D printer loaded with Ultrafuse filament, followed by an industry standard debinding and sintering process. Tests are performed to understand the material properties, such as hardness and tensile strength, and microstructural characteristics. Cost and accuracy are also analyzed based on the features of FDM and SLM methods. A preliminary guideline is discussed on how to select these two alternative AM processes for stainless steel 316L parts fabrication.

1:50 PM
Metallurgical and Mechanical Characterization of a 316L Steel Elaborated by Selective Laser Melting: ***Christophe Voltz***[1]; Romain Lefèbvre[1]; Michel Démésy[1]; [1]CEA
Stainless steel elaborated by AM exhibit particular behavior. This material has high yield strength and ultimate tensile strength with less uniform elongation and elongation at break than forged steel. This presentation will investigate the mechanism of 316L strengthening and factors leading to a loss of ductility. Samples have been processed with EOS StainlessSteel 316L powder on EOSINT M290 machine with eosjob. Both metallurgical features and mechanical behavior, are investigated regarding different metallurgical states: as-received, stress relieved and thermal treated. The as-received material shows particular microstructure. We notice small precipitates located both at grain boundaries and in the matrix with ferrite islands. The possible contributions of various factors such as grain size, crystallographic orientation relative to build direction, residual stress, matrix precipitates are considered to explain the mechanical behavior regarding to the reference baseline 316L. The thermal treatments lead to microstructure evolution with material homogenization, precipitates and stress removing.

2:10 PM
Metal Powder Feedstock Reuse in Additive Manufacturing: Characterization of 316L Stainless Steel: ***Michael Heiden***[1]; Lisa Deibler[1]; Jeff Rodelas[1]; Josh Koepke[1]; David Saiz[1]; Bradley Jared[1]; [1]Sandia National Laboratories
The effects of laser interactions in the powder bed fusion process (PBF) on unused powder properties are still relatively unknown. Complex interactions include alloy element vaporization, particle fusion, denudation, particle collision, oxidation, and condensed vapor satellites, along with recoil ejecta (spatter). In this work, we study how these interactions affect the particles themselves, to investigate the reusability of feedstock and the reliability of built components. An extensive array of characterization techniques was applied to 316L stainless steel virgin and recycled (30 times) PBF feedstock to correlate powder characteristics with mechanical properties of as-fabricated AM parts. Additionally, vapor-condensate and spatter properties were characterized to better understand their formation mechanisms. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

2:30 PM
Origin of Melt Flow and Its Effect in Laser Powder-bed Fusion: ***Wang Yafei***[1]; Dianzhen Wang[1]; Leilei Xing[1]; Kailun Li[1]; [1]Tsinghua University
The additive manufacturing of 316L single tracks is conducted via pulsed laser powder-bed fusion with a varying point distance. Tracks in the conduction, transition, and keyhole modes are obtained in relation to the normalized enthalpy. Some simple, but effective, methodologies and models are adopted based on the solidified morphology and microstructure of single tracks to distinguish the driving force of the melt flow and its effects. The fine ripples in all the tracks result from an oscillatory Marangoni flow, whereas the coarse ripples in the tracks with a small point distance are induced by the recoil pressure. In the conduction mode, the flow driven by surface tension rapidly redistributes the melt along the scanning direction, and epitaxial columnar grains develop along the building direction. In the transition mode, the recoil pressure vertically spreads the melt with respect to the scanning direction, and the intense flow refines the microstructure.

2:50 PM
Three-dimensional Characterization of Porosity Defects and their Correlation to Mechanical Properties in AM 316L Stainless Steel: ***Thomas Ivanoff***[1]; Jonathan Madison[1]; Joshua Koepke[1]; Bradley Jared[1]; John Mitchell[1]; Laura Swiler[1]; [1]Sandia National Laboratories
Porosity defects (e.g. lack-of-fusion and gas-entrapment pores) can adversely impact mechanical properties in additively manufactured metals. Thus, developing structure-property relationships is necessary for qualification of additively manufactured metals. Identifying characteristic defects and defect distributions in three dimensions (3D) that correlate with reduced mechanical performance is essential for developing these relationships. Here, 316L stainless steel tensile bars fabricated by laser powder bed fusion are nondestructively characterized via micro-computed tomography, then evaluated using high-throughput mechanical testing. First- and second-order porosity-defect metrics (e.g. defect volumes and nearest-neighbor distances among others) are then correlated with mechanical performance. Both the details of the 3D characterization techniques used and the structure-property correlations determined are presented with a view toward recommendations for viable processing windows in this broadly studied structural steel.

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The Influence of Defects on the Performance of 316L Stainless Steel from Metal Laser Powder Bed Fusion: ***Bradley Jared***[1]; Jonathon Madison[1]; Laura Swiler[1]; Thomas Ivanoff[1]; Joshua Koepke[1]; David Saiz[1]; Harlan Brown-Shaklee[1]; Brad Boyce[1]; Nathan Heckman[1]; Todd Huber[1]; Jeff Rodelas[1]; Daniel Tung[1]; [1]Sandia National Laboratories
To facilitate adoption in high consequence applications, fundamental questions regarding the intrinsic reliability of additive metals must be answered. Research into the performance of 316L stainless steel produced by laser powder bed fusion has revealed the complexity of material behavior and the subsequent coupling of defect interactions. Important factors include feature size, process inputs, powder feedstock, surface finish, material microstructure and porosity. Work has been performed to isolate these factors and to quantify correlations with structural mechanical properties. High throughput tensile testing was performed to quantify stochastic material properties and introduce statistically relevant data sets. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. This document has been reviewed and approved for unclassified, unlimited release under SAND2018-3939 A.

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The Effects of Post-AM Annealing Treatments on AM316L Stainless Steel: ***Donald Susan***[1]; Dan Kammler[1]; Mark Rodriguez[1]; Joseph Michael[1]; Zahra Ghanbari[1]; Christina Profazi[1]; [1]Sandia National Laboratories

Additively manufactured stainless steel often exhibits high strength attributed to microstructure with fine-scale solidification substructure and small dispersed oxide particles. Post-AM annealing can be applied to optimize strength and ductility, i.e. maximize toughness. In this work, cubes were fabricated from 316L powder using a ProX-300 laser powder bed system. The samples were annealed from 600 to 1200°C to investigate residual stress relief, microstructure, and mechanical properties. Characterization techniques included hardness and tensile testing, optical and scanning electron microscopy, EBSD, and X-Ray diffraction. Moderately decreasing hardness was observed for anneals up to 1100°C, while significant reductions in hardness/strength, with concomitant recrystallization and grain growth, were observed only after 1200°C annealing. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

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Evolution of Microstructure and Mechanical Properties with Heat Treatment of PBF Austenitic 316L Stainless Steel: ***Tobias Ronneberg***[1]; Paul Hooper[1]; Catrin Davies[1]; [1]Imperial College London

Austenitic 316L stainless steel produced by powder bed fusion (PBF) is strong and ductile, but contains large residual stresses. It is often advised to heat treat PBF parts after production for stress relief and improved mechanical properties. However, the as-built material contains many poorly understood microstructural features that may be desirable and should not be removed by heat treatment. This study characterises the microstructure and mechanical properties of 316L samples at various levels of heat treatment from as-built to a fully annealed condition. Small features were found to be less resilient to heat treatment than the larger grain structure. The yield strength decreased significantly with heat treatment, while ultimate tensile strength and ductility remained stable until the grain structure was recrystallized. Heat treatment at the low temperature may provide stress relief without affecting the larger microstructural features in a significant way.

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Texture Development and Texture Dependant Mechanical Properties of Stainless Steel 316L Produced by Laser Powder Bed Fusion Process: ***Xianglong Wang***[1]; Jose Alberto Muñiz-Lerma[1]; Mohammad Attarian Shandiz[1]; Oscar Sánchez-Mata[1]; Mathieu Brochu[1]; [1]McGill University

Laser powder bed fusion (LPBF) has attracted great attention among the additive manufacturing (AM) processes due to its ability to fabricate near-net-shape and high-performance parts directly from a CAD model. This technique by nature is a highly localized rapid solidification process and it is not uncommon to develop textured microstructure during LPBF. Crystallographic texture is a critical factor that influences most of the mechanical, physical, and chemical properties of metallic materials. In that context, the possibility to produce components with different textures during LPBF will create an avenue of tailoring their properties. Present research will study the influence of processing parameters and sample orientations on the texture of stainless steel 316L (SS316L) fabricated by LPBF. The mechanism of the texture development will be rationalized. Finally, the effect of texture on the mechanical properties of SS316L fabricated by LPBF will also be demonstrated.

5:00 PM

Joining of Elements Fabricated by a Robotized Laser/Wire Direct Metal Deposition Process by Using an Autogenous Laser Welding: ***Meysam Akbari***[1]; Radovan Kovacevic[1]; [1]Southern Methodist University

A robotized laser/wire direct metal deposition (RLW-DMD) process has been employed, specifically in applications where higher deposition rates or larger build envelopes are needed. However, this process might have limitation in printing certain complex shape parts. Also, fabricating large parts, depending on the geometry, might cause a large distortion on the final buildup. In this study, welding of additively manufactured parts by RLW-DMD has been proposed to overcome those issues. Autogenous laser welding, performed at the same setup used for RLW-DMD, was utilized to join the thin-walled 316LSi DMD parts and mechanical and microstructural testing were then performed on the welded samples. The results showed that the mechanical properties of welded DMD parts are comparable with those of DMD parts. Furthermore, a component of complex shape was fabricated to show the capability of the developed process. Therefore, welding of RLW-DMD parts is able to broaden the applications of 3D-printed parts.

Materials: Polymers 1 - Novel Materials and Processes

Monday PM	Room: 417AB
August 13, 2018	Location: Hilton Austin

Session Chair: Judith Lavin, Sandia National Laboratories

1:30 PM

Fast Scanning Differential Calorimetry for Semicrystalline Polymers in Fused Deposition Modeling: ***Emily Fitzharris***[1]; David Rosen[1]; Meisha Shofner[1]; [1]Georgia Institute of Technology

Fused deposition modeling (FDM) faces challenges due to the limited number of materials developed to work with the process. Semicrystalline polymers are potential precursor materials, but the extension of FDM to work with semicrystalline polymers is challenging due to the crystallization that occurs during cooling. Conventional thermal characterization methods such as differential scanning calorimetry (DSC) have been used to characterize the crystallization behavior of these materials. However, the heating and cooling rates available are much slower than rates experienced during the FDM process. The recently developed fast scanning differential calorimetry can reach heating and cooling rates of 1000s of K/s. The objective of this research is to utilize the high heating and cooling rates available using fast scanning differential calorimetry to examine the crystallization of semicrystalline polymers at heating and cooling rates associated with FDM. Polyphenylene sulfide, a semicrystalline high temperature thermoplastic, was used as a case study.

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PEEK High Performance Fused Deposition Modeling Manufacturing with Laser In-situ Heat Treatment: ***Meng Luo***[1]; Xiaoyong Tian[1]; Junfan Shang[1]; Weijun Zhu[1]; Dichen Li[1]; [1]School of Mechanical Engineering, Xi'an Jiaotong University

Because of the thermal resistance, high mechanical properties, biocompatibility, PEEK have increasingly extended their application in medicals, aircraft, industrial fields and so on. However, the conflict between the interlaminar bonding effect and the crystallinity influences the performance a lot. In this study, a CO2 laser device was adopted to improve both the interlaminar shear strength and the crystallinity of PEEK part synchronously in FDM. A series of test was then successively implemented. And after the observation and the analysis of the results, an obvious improvement was got that its interlaminar shear strength could improve over 45%, while its crystallinity could improve over double times for PEEK. Additionally, the process suggests a much potential in developing the gradient distribution of the crystallinity or stiffness in multi-function integration manufacturing for PEEK-like semi-crystalline materials.

2:10 PM

A Comparative Investigation of Sintering Methods for Polymer 3D Printing Using Selective Separation Shaping (SSS): ***Hadis Nouri***[1]; Behrokh Khoshnevis[1]; [1]University of Southern California

Selective Separating Shaping (SSS) is a novel additive manufacturing process which is capable of processing polymeric, metallic, ceramic and cementitious materials. The focus of this research has been on exploration of capabilities of SSS for fabrication of polymeric parts. The SSS machine has been used to build specimens made of polyamide (PA6) material. The sintering behavior of three PA grades are studied to better characterize the impact of process parameters on mechanical properties of the samples. Bonds between layers under two different thermal sintering methods are investigated to achieve better control over shrinkage and maintain effective bonding between layers. ImageJ platform and binary surface plots have been used for image processing and evaluating final porosity under each heating mechanism. Further investigations are carried out on properties of the base materials and the choice of sintering mechanism to further improve resolution of final parts.

2:30 PM

Not Just Nylon... Improving the Range of Materials for High Speed Sintering: ***Ryan Brown***[1]; Tace Morgan[1]; Candice Majewski[1]; [1]University of Sheffield

High Speed Sintering is an emerging Additive Manufacturing process which uses an infrared absorbing ink and infrared lamp to selectively sinter layers of polymer powder. Currently, Nylon-12 and its composites are used as the default feedstock for the process due to their large processing windows. However, to meet the increasing variety of end use applications afforded by the benefits of Additive Manufacturing, a wider range of materials must be developed. This work presents the characterisation and testing of a new elastomeric material for use in High Speed Sintering. Parts were produced over a range of processing conditions, varying key parameters such as build bed temperature, ink density and sinter speed. Performance indicators including powder recovery, surface roughness and tensile data were evaluated over the range of conditions tested and all indicated the material's suitability for use as a High Speed Sintering material.

2:50 PM

An Experimental Study of the Influence of Energy Input on Porosity and Mechanical Properties of Nylon 12 Parts Produced via High Speed Sintering: ***Zicheng Zhu***[1]; Sam Tammas-Williams[1]; Candice Majewski[1]; [1]University of Sheffield

High Speed Sintering is a promising layer manufacturing technique, offering a good compromise between dimensional accuracy and mechanical performance whilst having the potential to achieve at least an order of magnitude higher production speed than Laser Sintering. Efficient consolidation of powder strongly depends on the molten polymer viscosity, which is a temperature dependent factor directly influenced by energy input. Part quality at a micro-level can be assessed through observations of porosity, which has a subsequent effect at the macro-level (e.g. mechanical properties). This study seeks to understand the effect of energy input on the porosity of High Speed Sintered parts in relation to major energy-related parameters, namely sinter speed, lamp power, ink grey level and layer thickness. It is found that an appropriate energy input that enables to heat Nylon powder close to its melting temperature seems to promote powder coalescence, resulting in fewer pores, leading to improved mechanical properties.

3:10 PM Break

3:40 PM

Tensile Strength of Interfaces in Multi-material 3D-printed Parts: ***Thomas Lumpe***[1]; Jochen Mueller[1]; Kristina Shea[1]; [1]ETH Zurich

Multi-material additive manufacturing increases significantly the design space beyond conventional, single-material 3D printers. To take full advantage of this and design reliable, multi-material parts, a solid understanding of the interface properties is crucial, as it affects the overall mechanical behavior and functionality, e.g. in multi-material compliant mechanisms and bi-stable joints. Currently, studies focusing on how multi-material 3D printed interfaces behave are little represented in scientific literature. This paper investigates the tensile strength of such multi-material interfaces based on the PolyJet material jetting process and presents a test methodology. Similar to single materials, strong dependencies on the print orientation and material combination are found. Interfaces between hard and soft materials are found to be as strong as the soft material itself, whereas interfaces between harder materials show strengths that are reduced by up to 50%. Based on these findings, design guidelines are derived for multi-material, 3D printed structures.

4:00 PM

Photopolymer Formulation to Maximize the Resolution and Quality of Microarchitectures Fabricated Using Digital Light Processing-based 3D Printing: ***Kavin Kowsari***[1]; Qi (Kevin) Ge[1]; [1]Singapore University of Technology and Design

Achievement of maximum resolution is a key precursor to obtain three-dimensional (3D) structural details suited for microstereolithographic applications. Here, we present a family of 'open-source' stereolithography printing materials optimized for maximum resolution and surface quality. To illustrate the potential of our recently-developed multimaterial digital light processing (DLP)-based 3D printing system to produce high-resolution, high-quality microarchitectures, we exploit a wide variety of resin formulations to determine optimal formulation to yield maximum printing resolution and surface quality for a tailorable range of thermomechanical properties. The observed changes are explained in fundamental terms of the relationship between the optical photofield and reaction kinetics.

4:20 PM

Material Property Changes in Custom-Designed Digital Composite Structures Due to Voxel Size: ***Dorcas Kaweesa***[1]; Nicholas Meisel[1]; [1]Penn State

Advances in additive manufacturing enable fabrication of complex structures using functionally graded materials (FGMs) at a voxel level. Prior to developing voxel-based FGM designs using compatible dithering approaches, it is essential to first understand the basic principles of voxel-based digital composite designs. While several research studies exist regarding different representations of voxel-based solid models, there is no extensive research on voxel-based digital composite structures. This paper bridges this gap by investigating custom voxel-based designs of digital composite structures. The objective is to determine how the material properties of such structures are impacted by different voxel sizes and build directions using the material jetting process. By quantifying different computational times of the voxel sizes, the relationship between the as-manufactured and the as-designed digital composites based on a color-based dithering approach, and the resulting material properties, we gain a better understanding of how voxel based digital composites should be designed.

4:40 PM

Quantifying the Effect of Embedded Component Orientation on Flexural Properties in Additively Manufactured Structures: ***Swapnil Sinha***[1]; Nicholas Meisel[1]; [1]Penn State

In-situ embedding with Additive Manufacturing (AM) enables a user to insert functional components in a part by pausing the print, inserting the component into a specially designed cavity, and then resuming the print. This introduces the capability to merge the reliable functionality of external parts into AM structures, allowing multifunctional products to be manufactured in a single build. Previous research has shown that process interruption introduces weaknesses at the paused layer, and the presence of an embedding cavity further reduces the maximum tensile strength of the part. The research presented in this paper expands this understanding by investigating the impact of a component's orientation on the strength of the material extrusion parts. Several primitive geometries are embedded with different orientations with a flush surface at the paused layer, and tested for maximum tensile and bending strength. The findings help to further design guidelines for embedding with material extrusion AM.

5:00 PM
Incorporation of Nanomaterials for 3D Printing and Additive Manufacturing Applications: ***Cole Brubaker***[1]; Kane Jennings[1]; Douglas Adams[1]; [1]Vanderbilt University
The development of new materials compatible with 3D printing processes has been a recent area of focus in the advancement of additive manufacturing technologies. In particular, the incorporation of nanomaterials is gaining interest due to the flexibility that this approach offers for the design of 'functionalized' materials. Through the re-design of the host matrix, new systems with customized material properties and responses that are of far more utility to users compared to the unmodified host matrix can be achieved. Through materials processing and design considerations ranging from solubility, miscibility, material strength, processability and optical characteristics, we herein demonstrate the ability to manufacture 3D-printed components with embedded gold nanoparticles and quantum dots. In each case, the optical response of embedded nanomaterials are harnessed for applications ranging from defect detection to the development of 3D-printed light guides, in an attempt to demonstrate the versatility of 'nanofunctionalized' materials for additive manufacturing applications.

Physical Modeling 1 - Thermal Modeling in Powder Beds

Monday PM — Room: Salon A
August 13, 2018 — Location: Hilton Austin

Session Chair: Wentao Yan, Northwestern University, U.S.

1:30 PM
An Efficient Meso-scale Thermal Simulation for Powder Bed Fusion: ***Yaqi Zhang***[1]; Vadim Shapiro[1]; [1]University of Wisconsin-Madison
As a widely used additive manufacturing technology to produce metallic parts, powder bed fusion (PBF) is driven by a moving heat source. Thermal simulation is a critical tool to understand the mapping between manufacturing parameters and the geometry of the melt pool and optimize manufacturing parameters. The challenging nature of thermal simulation stems from the physical and geometric complexity of the manufacturing process and inherent computational complexity which requires numerical solution at every time increment of the process. We proposed a new meso-scale thermal simulation (built on path level) which is applied directly on the as-manufactured model described by a typical process plan. The proposed thermal simulation captures the essential physics during the manufacturing process and is much more computationally efficient than both powder based simulation (e.g. DEM) and continuum-based techniques (e.g. FEM). The simulation is validated against experimental results in the literature and experimental results from NIST.

1:50 PM
Convection Heat Transfer Coefficients for Laser Powder Bed Fusion: ***Mohammad Masoomi***[1]; Arash Soltani-Tehrani[1]; Nima Shamsaei[1]; Scott Thompson[1]; [1]Auburn University
During laser-powder bed fusion (L-PBF), parts are fabricated under a purged, inert environment, typically using argon or nitrogen to minimize powder/part oxidation. Using computational fluid dynamics (CFD), simulations are performed for the L-PBF of multiple layers of Ti-6Al-4V. Local temperature, temperature gradients, temperature time-rates-of-change (including cooling rates), as well as dimensionless numbers descriptive of important thermophysics, are provided in order to quantify local convective heat transfer for various laser/gas motion directions. Results are used to define/predict local heat transfer coefficients during the additive manufacturing process. To validate numerical results, L-PBF experiments are performed while measuring inlet and outlet temperatures of the gas in the chamber. Effects of flow direction on the thermal response of the fabricated parts are studied, as well.

2:10 PM
Advanced Model Predictions of Mechanical Properties and Process Parameter Effects in High Throughput L-PBF Tension Specimens: ***Kyle Johnson***[1]; Laura Swiler[1]; Theron Rodgers[1]; Bradley Jared[1]; Sam Subia[1]; Kurtis Ford[1]; Mike Stender[1]; Joseph Bishop[1]; [1]Sandia National Laboratories
In this research, process-structure-property-performance relationships are numerically predicted for high-throughput stainless steel tension specimens produced by laser powder bed fusion. The thermal history is simulated and used in solid mechanics simulations using a viscoplastic internal state variable material model to predict residual stresses and resultant mechanical properties. The higher yield stress often observed in additively manufactured parts is predicted by incorporating effects of higher dislocation densities into the material model. Porosity is accounted for by the application of a continuum damage model, and the tensile response is simulated and compared to experiments. Finally, the effects of laser speed and power on the structural properties are investigated through a UQ study. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

2:30 PM
Local Thermal Conductivity Mapping of Selective Laser Melted 316L Stainless Steel: Jacob Simmons[1]; Arad Azizi[1]; Matthias Daeumer[1]; ***Scott Schiffres***[1]; [1]SUNY Binghamton
A major problem currently encountered with printing metal objects is the potential for defects to form within these objects during manufacturing. When a void or crack forms in a part, it produces a stress concentration at that point. This can, in turn, cause premature failure of the part. For companies that are putting additively manufactured components into critical systems, premature failure can be expensive and hazardous. We use frequency-domain thermoreflectance to measure additively manufactured aluminum and stainless steel films produced on an EOS M290 machine as a function of processing parameters (power and scan rate).

2:50 PM
Finite Element Modeling of the Selective Laser Melting Process for Ti-6Al-4V: ***Alaa Olleak***[1]; Zhimin Xi[1]; [1]Rutgers University
Physics-based modeling of the selective laser melting (SLM) process is critical for better understanding the influence of the parts quality with respect to the process parameters and different scanning strategies. The challenge is the balance between the model validity, the domain size of the model, and the computational time. In this paper, a transient thermal finite element model is developed using ANSYS to predict the melt pool size and the temperature history, along with a user subroutine that continuously updates the material state. The thermal process is further followed by mechanics-based modeling to predict the residual stress and the part distortion. The model is capable of handling practical domain size with reasonable computational efficiency by developing the re-meshing technique that adapts with the scanning vector. The effects of the model parameters on the parts quality are investigated and validated by experiment results.

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3:40 PM
Modelling the Melt Pool of the Laser Sintered Ti6Al4V Layers with Goldak's Double-ellipsoidal Heat Source: ***Emrecan Soylemez***[1]; [1]Marmara University
Laser sintering process has been widely studied to elucidate the effects of process parameters (Laser speed, laser power, scan strategy, hatch distance, layer thickness, etc.) on the manufactured parts. Experimental and numerical modelling studies have been investigating the melt pool shapes of the laser sintered layers to correlate the melt pool geometry with the part quality. Although modelling results agree with the experiments, the melt pool cross-section may form key holing rather than

semi-circular shape due to Marangoni effect, recoil pressure, and sudden evaporation for some process parameters combinations. To accurately model the melt pool depth, this study proposes a finite element analysis (FEA) model that simulates the laser source as the Goldak's double-ellipsoidal heat power density model. Single bead experiments of Ti6Al4V were conducted within the processing range of laser sintering system with the 400 W laser, and these experimental results allowed to verify simulated FEA results.

4:00 PM

Multi-scale Modeling of Selective Laser Melting of Inconel 718: ***Kubra Karayagiz***[1]; Luke Johnson[1]; Mohamad Mahmoudi[1]; Hannah Boon[1]; Ji Ma[1]; Alaa Elwany[1]; Ibrahim Karaman[1]; Raymundo Arroyave[1]; [1]Texas A&M University

Predicting the microstructure of SLM-fabricated parts is very challenging due to the complex thermal histories that result from rapid heating-cooling cycles upon successive passes of the laser beam. In the present work, we develop a multi-scale modeling framework for simulating the rapid solidification process during SLM of Ni-Nb alloy approximating Inconel 718. First, the thermal history is simulated using a finite element (FE) model, serving as input to the multi-phase-field (PF) model coupled with CALPHAD technique. As opposed to the requirement of the near equilibrium condition in the traditional phase field models, the employed phase field model accounts for highly non-equilibrium conditions, which makes it convenient to use for the SLM process. The developed framework is used to investigate the effect of process parameters on the final microstructure, particularly, the dendritic structure and Nb segregation. The predictions are validated through comparison with experiments.

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Melt Pool Analysis and Meso-scale Simulation of Laser Powder Bed Fusion Process (L-PBF) with Ti-6Al-4V Powder Particles: ***Santosh Rauniyar***[1]; Kevin Chou[1]; [1]University of Louisville

Laser powder bed fusion (L-PBF) process is accompanied by rapid melting and solidification that results in intense thermo-capillary convection within the melt pool. A 3D thermo-fluid model is developed in this study that incorporates a layer of randomly distributed powder particles of non-uniform sizes generated by a sequential powder adding algorithm. A moving volumetric heat source is applied to melt a single track in the powder layer through the user defined function in FLUENT software. Temperature dependent material properties including variable surface tension is used for the computation. The numerical model is used to quantitatively study the effect of the scanning speed on the melt pool geometry. Furthermore, the simulation results is compared with the experiment of the L-PBF process using Ti-Al6-V4 powder. Melt pool width at scanning speed 200 and 1000 mm/s with power 195 W is 318 and 143 µm respectively, which are in good agreement with experiment.

Physical Modeling 2 - Multi- and Micro-scale Modeling

Monday PM — Room: 412
August 13, 2018 — Location: Hilton Austin

Session Chair: Saad Khairallah, Lawrence Livermore National Lab.

1:30 PM

Powder Bed Modeling Big and Small: Simulating Microstructural Evolution from a Single Bead to (Closer to) the Part Scale: Theron Rodgers[1]; ***Daniel Moser***[1]; John Mitchell[1]; Fadi Abdelajwad[1]; Mario Martinez[1]; Kyle Johnson[1]; Jonathan Madison[1]; [1]Sandia National Laboratories

Microstructural evolution during laser powder bed fusion can be simulated at many length-scales with a wide range of techniques. Here, we will discuss the use of a Potts Monte Carlo simulation method at various length scales. Single track simulations will be performed using temperature and phase fields defined by high-fidelity thermofluid simulations, and will be compared against experimental single-bead results. Insights gained from these fine-scale simulations will then be applied to large-scale simulations of microstructural evolution over many passes and layers where the temperature and phase fields are determined by a coupled finite-difference based simulation of thermal conduction. Finally, simulations using a novel method of data storage will be presented. These simulations allow for the simulation of very large domains using a modest amount of memory.

1:50 PM

Multi-scale FEA Modeling and Experimental Validation of Laser Powder Bed Fusion: ***Chao Li***[1]; Erik Denlinger[1]; Michael Gouge[1]; Jeff Irwin[1]; Pan Michaleris[1]; [1]Autodesk Inc.

Stress and distortion buildup during production has been a major challenge for Laser Powder Bed Fusion (LPBF) to become a reliable and economically feasible manufacturing method. This distortion adds expense of the process, can take weeks or months of experimentation to minimize, and may prematurely end the businesses case for implementing AM into production. Thermo-mechanical Finite Element Analysis can efficiently and accurately predict and mitigate build failure prior to manufacture. This study demonstrates simulation-experimental comparisons that the Autodesk Netfabb Local Simulation tool can be used to make timely and useful predictions of distortion for common AM metals. It will also document the successful modeling of support structure failure and recoater blade interference. The concept of multi-scale modeling approach will be extended to the prediction of hot-spots and lack of fusion related defects on Part-Level AM builds. Simulations of largebuild are used to verify the scalability of the multi-scale model.

2:10 PM

Multi-scale Modeling of Microstructure Evolution and Cracking during Direct Laser Deposition of Alumina Ceramics: ***Xiangyang Dong***[1]; [1]Missouri University of Science and Technology

Direct laser deposition of ceramics is a promising additive manufacturing (AM) technique capable of directly fabricating complex geometry components of high-purity or functionally graded ceramics. However, crack control poses one major challenge and limits the applicability of this process in ceramics. In this paper, a novel multi-scale modeling approach is implemented to study microstructure evolution and crack formation during laser engineered net shaping (LENS) of alumina ceramics. Molecular dynamics simulations are used to investigate grain boundary during microstructure evolution and fracture formation. The obtained grain boundary mobility is combined with a kinetic Monte Carlo model to predict microstructure within deposited ceramics. A coupled thermo-mechanical analysis is performed to simulate crack formation during LENS. It is shown that composition and grain boundary play a major role in cracking, which could alter fracture mechanism. Simulation results show a good agreement with experiments and help select proper ceramic AM conditions depending on compositions.

2:30 PM
Particle Scale Melt Modeling of Selective Laser Melting with Uncertainty Quantification: ***Daniel Moser***[1]; Mario Martinez[1]; [1]Sandia National Laboratories
Selective Laser Melting (SLM) is an additive manufacturing technique used to rapidly create parts by selectively fusing successive layers of powder with a laser. Defects can arise in SLM parts due to poor selection of processing parameters. Detailed, particle-resolved, models of the SLM process can provide insight into the physical phenomena that give rise to defects. In this work, we present a coupled thermal-fluid multiphase flow model of the SLM process with an interface conforming mesh. The model is used to predict temperatures and resulting melt track shapes of line scans on bare plates and powder beds. Parametric uncertainty quantification is performed, sensitive process parameters identified, and output probability distributions predicted. Model results are compared quantitatively against experimental temperature data from pyrometers and melt track shape data from profilometry and cross section microscopy.

2:50 PM
Transport Phenomena and Grain Structure Evolution during Laser Assisted Additive Manufacturing: ***Huiliang Wei***[1]; [1]Nanjing University of Science and Technology
The capability of obtaining targeted grain structure largely determines whether a metallic material can be feasibly applied in the field of additive manufacturing (AM). Effective control of the grain structure relies on the quantitative understanding the AM process conditions. In this work, the transport of heat, mass and momentum and the evolution of grain structure during directed energy deposition of a nickel-based alloy are explored. The critical metallurgical variables including the temperature gradient, solidification growth rate, and cooling rate at the solidification front of the moving molten pool are obtained through a high-fidelity AM numerical model. The temporal evolution of the grain structure in the three-dimensional space is revealed. Additionally, the morphology, dimension, and spatial distribution of grains in series of sectional planes are examined. In particular, the grain structure on the curved and non-planar surface of the deposit is distinctly visualized.

3:10 PM Break

3:40 PM
Cellular Automata (CA) Modeling of Stainless Steel Nucleation and Growth Applied to Selective Laser Melting: ***Matthew Rolchigo***[1]; Jim Belak[1]; Saad Khairallah[1]; [1]Lawrence Livermore National Laboratory
Alloy microstructure development occurring under the complex thermal conditions of Additive Manufacturing processes is multifaceted, depending on local thermal conditions, kinetics and thermodynamics of solidification, and previous layer microstructure. We apply a 3D Cellular Automata (CA) model for microstructure prediction of as-solidified stainless steel, with grain growth based on ternary alloy solidification theory. Several methods for modeling nucleation are introduced, and the model's applicability towards texture development and the columnar to equiaxed transition are explored. Using input conditions from a high-fidelity fluid and heat transport model of the Selective Laser Melting process, predicted thermal conditions as a function of process variables such as beam shape are linked to microstructure development and compared to experimental grain orientation, size, and aspect ratios. The scalability of the model to large-scale problems and its potential use as a component of a high performance computing library for additive manufacturing modeling are discussed as well. Supported by the Exascale Computing Project (17-SC-20-SC), a collaborative effort of the U.S. DOE Office of Science and the NNSA.

4:00 PM
A Novel Microstructure Simulation Model for Direct Energy Deposition Process: ***Jinghao Li***[1]; Zhibo Luo[1]; Xiaoyi Guan[1]; Xianglin Zhou[2]; Mathieu Brochu[1]; Yaoyao Zhao[1]; [1]McGill University; [2]University of Science and Technology
A novel micro-structural simulation model will be proposed in grain level, called “Invasion Model” based on the cellular automata algorithm. Different from the previous micro-structure simulation methods, the novel model does not focus on the exact grain boundaries during grain growth behavior before the grains get in touch with each other which will usually lead into computational expensive. The key point of the grain boundary invasion model that reflect the competitive grain growth behavior is to imply an ‘invasion factor’ which means the opportunity that one single crystal can invade its neighbor crystal. This ‘Invasion factor’ only validate along the solidus surface and calculated by the relation of crystal orientation and thermal gradient for each single crystal. The temperature history will be provided by macro-scale simulations at a part or melt-pool level and will be matched with grids of Grain Boundary Invasion Model by differential algorithm.

4:20 PM
Influence of Grain Size and Shape on Mechanical Properties of Metal AM Materials: ***Robert Saunders***[1]; Ajit Achuthan[2]; Athanasios Iliopoulos[1]; John Michopoulos[1]; Amit Bagchi[1]; [1]U.S. Naval Research Laboratory; [2]Clarkson University
Metal powder-based additive manufacturing (PAM) typically produce microstructures with a texture and columnar grain structure. The columnar grains can vary greatly in size and shape throughout the microstructure, which can significantly affect the mechanical properties of the resulting part. A previous study developed a microstructurally informed crystal plasticity constitutive model that took into account grain sizes and shapes. The results of the previous work demonstrated that including the grain size and shape effects can influence the prediction of mechanical behavior of the part based on a representative volume element (RVE) analysis. However, the extent of this influence is not known. This paper considers the extent of influence of the average grain shape and size on anisotropy and yield strength of a PAM part. The initial result indicate that there may be potential to tailor mechanical properties of a part by controlling the process parameters that determine its microstructure.

4:40 PM
Epitaxial Columnar Grain Growth Modeling During Laser Power Bed Additive Manufacturing Based on a Dendrite Tip Tracking Approach: ***Albert To***[1]; Jian Liu[1]; Yunhao Zhao[1]; Wei Xiong[1]; [1]University of Pittsburgh
An efficient model is proposed to simulate the competitive growth of epitaxial columnar dendritic grains by geometrically tracking the tip of the constituent stable primary dendrite arms. In the proposed model, the solidification front is discretized into a number of seed dendrites, where each dendrite is modeled as a growing line segment and its current growth direction is determined by the local thermal gradient and its crystallographic orientation. Since a dendritic grain is the sum of its constituent dendrites, by tracking the tip locations of each dendrite at each time step, the grain growth during solidification can be simulated. The proposed model also considers situations arisen from competition between converging dendrites and secondary dendrite growth from diverging dendrites. Besides its high efficiency, the proposed model is easy to implement and yields essential grain information which includes grain size, shape, and crystal orientation.

5:00 PM
Experimental Calibration of Nanoparticle Sintering Simulation: ***Obehi Dibua***[1]; Anil Yuksel[1]; Nilabh Roy[1]; Chee Foong[2]; Michael Cullinan[1]; [1]University of Texas at Austin; [2]NXP Semiconductors
Microscale Selective Laser Sintering models have been built as a basis to predict the properties of sintered nanoparticles under isothermal heating. These models use Phase Field Modelling (PFM) to track the diffusion of nanoparticles, resulting in properties such as the change in relative density and shrinkage of the sintered bed with time. To ensure the accuracy of these PFM models, experimental validation has to be done. This paper presents the experimental procedure and results for isothermally heating nanoparticles up to 450 – 600°C, at sintering times varying from 1 to 45 minutes. Uncertainty measurements are calculated from deviations in calculating the density. Experimental results gotten from this process are then used to calibrate the simulation to match simulation timesteps to time in minutes. The calibration constant derived is then used to map simulation constants to physical constants and are compared to bulk properties.

Process Development 1 - Deposition

Monday PM — Room: 602
August 13, 2018 — Location: Hilton Austin

Session Chair: Christopher Williams, Virginia Tech

1:30 PM
Effect of Standoff Distance on Built Geometry in Directed Energy Deposition: ***Samantha Webster***[1]; Jennifer Bennett[1]; Jian Cao[1]; [1]Northwestern University
Directed Energy Deposition (DED) is a powder-fed additive manufacturing process where a laser beam interacts with powder flow to build up parts. Many researchers have examined the effect of parameters such as laser power, powder flow rate, and scan speed on final part quality. However, the effect of the distance between the part surface and the laser/powder focal point, or the standoff distance, on part geometry has not been thoroughly examined. The experiments considered in this study deposited Inconel 718 on 1045 carbon steel at various standoff distances. The results showed that both standoff distance and substrate temperature significantly affected the clad height. The effect of substrate temperature in addition to standoff distance suggests the need for in-situ standoff distance control to maintain optimal standoff distances as the part temperature changes.

1:50 PM
Insights into Powder Flow Characterization Methods for Directed Energy Distribution Additive Manufacturing Systems: ***Stephen Brown***[1]; David Corbin[1]; Jacob Steinberg[2]; Edward Reutzel[1]; [1]ARL Penn State; [2]Raytheon
Powder-blown Directed Energy Distribution Additive Manufacturing systems often feed powdered metal into a melt pool generated by a laser. As the laser is moved, the melt pool solidifies, leaving behind a deposit. Such depositions may be built up into full components or used to add features on existing components. Distribution and uniformity of the powder flow is critical to achieve uniform and predictable depositions. For example, small deviations at the minute-level (cf. the resolution limit of the deposition) can propagate to gross deviations at the component-level. Meanwhile, large deviations in the powder flow can be yet unobservable to the naked eye, but produce catastrophic effects within small depositions. Such depositions are common to repair applications targeted at ARL Penn State, wherein relatively small deposits are created on larger, critical components. Novel and re-purposed OEM tools are compared to study these powder flow behaviors, providing new insights into process variability.

2:10 PM
Evaluating Parameters and Performance of a Metallized Material Spray-deposition Process: ***Daniella McCade***[1]; Kevin Hoyt[1]; Zachary Stephens[1]; [1]Sandia National Laboratories
It has been previously demonstrated that an additive manufacturing approach offers opportunities to coat surfaces in a controlled and reproducible manner. To fully realize these opportunities in a rigorous production environment, key process parameters need to be more fully understood and controlled. To that end, a process of using an ultrasonic spray nozzle to deposit uniform and consistent metal coatings on ceramics will be shown. Characterization of process parameters with respect to specific performance metrics will be presented.

2:30 PM
Experimental Investigation of Printing Parameters on Material Distribution in 3D Spray Cementitious Material Printing Process: ***Bing Lu***[1]; Mingyang Li[1]; Wenxin Lao[1]; Yiwei Weng[1]; Shunzhi Qian[1]; Ming Jen Tan[1]; Kah Fai Leong[1]; [1]Nanyang Technological University
In the past decade, 3D printing is getting into more and more industry areas including building and construction. However, most 3D cementitious material printing processes are limited in horizontal printing surface. Due to the nature of building and construction area, 3D spray cementitious material printing process was developed to apply material in vertical or even overhang surfaces. Unlike traditional manually operated spray method in building and construction, 3D spray cementitious material printing process requires higher accuracy on material distribution. In this paper, the effects of four printing parameters (cementitious material flow rate, air flow rate, nozzle travel speed, nozzle standoff distance) on material distribution in 3D spray cementitious material printing process were investigated experimentally. An experimental model, which can be further used in the control of 3D spray cementitious material printing process, was then developed upon on the results.

2:50 PM
Aligning Material Extrusion Direction with Mechanical Stress via 5-axis Tool Paths: ***James Gardner***[1]; Tom Nethercott-Garabet[1]; Nathaniel Kaill[1]; Ian Campbell[1]; Guy Bingham[1]; Daniel Engstrøm[1]; Nicolae Balc[2]; [1]Loughborough University; [2]Technical University of Cluj-Napoca
Mechanical properties of parts fabricated via the Material Extrusion (ME) process can be improved by optimising process settings, however, their properties are strongly influenced by build orientation due to the stair stepping effect initiating cracks whilst under load. 5-axis Material Extrusion (ME) enables the fabrication of parts without the layer-by-layer restrictions that conventional 3-axis strategies impose. By aligning extrusion direction with high stress tensors, 5-axis tool paths can be used to reduce the effects of weak inter-layer bonds. T o establish performance differences between parts manufactured by either strategy, wave spring-inspired geometry was selected for production, due to the multi-directional tensile loads acting throughout the material. 5-axis and 3-axis tool paths were generated via the Grasshopper 3D virtual environment within Rhinoceros 3D and MakerBot Desktop, and manufactured using a 5AXISMAKER and a MakerBot Replicator 2, respectively. To evaluate performance differences between the two strategies, compression tests were conducted on the parts.

3:10 PM Break

3:40 PM
Fieldable Platform for Large-Scale Deposition of Concrete Structures: ***Phillip Chesser***[1]; Brian Post[1]; Alex Roschli[1]; Randall Lind[1]; Alex Boulger[1]; Lonnie Love[1]; Katherine Gaul[1]; [1]Oak Ridge National Laboratory
Oak Ridge National Laboratory's Manufacturing Demonstration Facility is developing a novel, large-scale additive manufacturing, or 3D printing, system. The Sky Big Area Additive Manufacturing (SkyBAAM) system will ultimately be a fieldable concrete deposition machine with pick and place abilities that will allow for full-scale, automated construction of buildings. The system will be implemented with existing construction equipment meaning conventional cranes will be used to suspend the printhead. SkyBAAM will be cable-driven by four base stations and suspended from a single crane. The elimination of a gantry system, found commonly in large-scale additive manufacturing systems, will enable SkyBAAM to be quickly set up with minimal site preparation. The medium-scale version of SkyBAAM is currently in development. The system design, cable stiffness analysis, and tactics for freezing rotational degrees-of-freedom (DOF), detailed in this paper, will provide a basis for the final, large-scale version of the SkyBAAM system.

4:00 PM
Real-time Quality Monitoring of Construction-scale 3D Printing (Contour Crafting): ***Ali Kazemian***[1]; Behrokh Khoshnevis[1]; [1]University of Southern California
Automated construction through concrete 3D printing is deemed as a revolution in construction industry. The novel idea of scaling up additive manufacturing techniques for automated building construction has been topic of research for several years. The first viable construction-scale 3D printing system, Contour Crafting (CC), uses computer control to exploit the surface-forming capability of troweling to create smooth and accurate planar and free-form surfaces out of extruded materials. Some of important advantages of CC include unprecedented surface quality of printed elements, increased fabrication rate, and a vast choice of materials. In this study, perspectives on real-time quality monitoring of Contour Crafting process, as well as two proposed techniques and related details are discussed. Furthermore, the experimental data regarding real-time quality monitoring of CC extrusion process will be presented and investigated quality monitoring techniques will be compared in terms of repeatability and sensitivity to undesirable variations in the extrusion process.

4:20 PM
Maturation of Wire + Arc Additive Manufacture Systems for Production of Large Scale Titanium Structures: ***Jialuo Ding***[1]; Goncalo Pardal[1]; Pawel Kurzynski[1]; Malgorzata Tolisz[1]; Chao Lui[1]; Florent Michel[1]; Thomas Kissinger[1]; Filomeno Martina[1]; Stewart Williams[1]; [1]Cranfield University
Wire + Arc Additive Manufacture (WAAM) has many advantages for production of large scale engineering structures with significantly reduced manufacturing costs and lead times. However there are no mature intelligent WAAM systems available on the market. Based on ten years of intensive research into all aspects of WAAM, we have developed a mature WAAM system for production of large scale titanium components. We will present the key elements of this system including the specially designed WAAM hardware such as a local shielding device incorporating process monitoring, data logging and associated WAAM software for tool path planning and system/process control. Case studies of building large scale titanium parts will be provided to explain how the integrated hardware and software function as a system. Finally, different WAAM system configurations will be introduced for different applications.

4:40 PM
On-line In-process Cryogenic Cooling of Ti64 during Wire + Arc Additive Manufacturing to Increase Productivity: Romain Fayolle[1]; Goncalo Pardal[1]; Richard Wiktorowicz[2]; ***Jialuo Ding***[1]; Filomeno Martina[1]; Stewart Williams[1]; [1]Cranfield University; [2]Air Products
Wire + Arc Additive Manufacturing (WAAM) has much potential, however some challenges remain to be addressed. The hot material needs protection to avoid oxidation and the temperature of the underlying material must be controlled to retain the relationship between parameters and geometry. These factors limit productivity, because the part has to cool to a baseline temperature (typically 100C), before starting the following layer. We looked at on-line in-process cryogenic cooling of Ti64 using liquid Argon to reduce shielding requirements and times (by accelerating cooling to 400C), and to reduce inter-layer waiting times (by accelerating cooling to 100C). The first phase evaluated different setups to determine the best configuration. Once the best setup had been identified, cylinders were built in a continuous fashion, with and without cooling, to determine the increase in productivity which was found to be three-fold. No effects were seen on microstructure; tensile properties were moderately higher.

Process Development 2 - Extrusion

Monday PM — Room: 415AB
August 13, 2018 — Location: Hilton Austin

Session Chair: Wenchao Zhou, University Of Arkansas

1:30 PM
High Throughput Fine Feature Fused Filament Fabrication Using A Multi-valve Extrusion Head: ***Anthony Tantillo***[1]; Denis Cormier[1]; Peter Nystrom[2]; David Mantell[2]; [1]Rochester Institute of Technology; [2]Xerox Corporation
This talk will present a new approach to Fused Filament Fabrication which uses a single extrusion head having a high throughput melter and an array of nozzles each with its own valve. Independently addressable valves enable precise starting and stopping of filament flow in each nozzle. When material is printed with all valves open, high material deposition rates are achieved by printing wide ribbons of material with excellent layer-to-layer adhesion and near 100% part density. Fine details are produced by closing selected valves to print desired regions. The multi-valve head allows extremely high thermoplastic material deposition rates with thin layers that produce much finer feature detail than is achieved with high throughput single-nozzle systems using large nozzle diameters. This talk will describe the new multi-nozzle valved extruder and its operation. Performance of the multi-nozzle extruder will be discussed in terms of material deposition rate, material density, and mechanical strength.

1:50 PM
Using a Cylindrical Coordinate System to Facilitate Simultaneous Operations in 3D Printing: ***Dennis Scheglov***; Xu Chen[1]; Iddo Ben-Ari[1]; Jeffrey Meunier[1]; [1]University of Connecticut
This project aims to present a novel approach to the fused deposition modeling (FDM) method using a cylindrical coordinate system. The approach displays potential to reduce object fabrication time significantly, as well as make feasible the use of additive and subtractive methods in tandem (so-called hybrid manufacturing) and the creation of new three-dimensional composites and metamaterials.First, the method will be introduced in detail, followed by detailed descriptions of the algorithms written to plan build processes, with example outputs for various geometries. There will also be a brief discussion of the physical prototype device currently in development.

2:10 PM
Microextrusion Based 3D Printing – A Review: ***Edidiong Udofia***[1]; Wenchao Zhou[1]; [1]University of Arkansas
Whilst extrusion-based 3D printing processes have been successfully applied at the macroscale, this seeming simplicity belies the dynamic complexities needed for consistent, repeatable and cost-effective printing at the microscale. To fully tap into the promise of microextrusion (µEP) of fabricating fine resolution features, it is critical to establish an understanding of the fundamentals of ink flow, interface energy, drying, and process-property relationship of the printing process. Till date, a comprehensive and coherent organization of this knowledge is still lacking. In this paper, we present a framework of the underlying principles of the microextrusion process, offering an overall roadmap - stepwise guide for successful printing based on both numerical and experimental results in the literature. The impacts of various process parameters on resolution of printed features are identified. Experiments were carried out to validate the developed framework. Key challenges and future directions of microextrusion 3D printing are also highlighted.

2:30 PM
Effects of Discontinuous Build Strategies on the Mechanical Properties of Material Extrusion AM Parts: ***Joseph Bartolai***[1]; Jordan Kruse[1]; Timothy Simpson[1]; [1]Penn State University
Mechanical properties of parts produced via Material Extrusion Additive Manufacturing (MEAM) using discontinuous deposition strategies are measured. Typically, mechanical properties of MEAM parts are determined using ASTM standard test specimens. These test specimen represent a best case scenario for MEAM, namely, uniform length tool paths deposited in a continuous pattern across the specimen. However, the simple shape of the standard test specimen is not reflected in the complex geometric parts that MEAM is capable of producing. Thermal histories caused by build discontinuities create weld interfaces of less strength than thermal histories from continuous deposition. By isolating the material deposition discontinuity to a known location within the build, the effects of the discontinuous build strategy is studied directly, allowing us to propose novel discontinuous build strategies that result in stronger MEAM parts.

2:50 PM
Design of a Low Cost, Desktop-scale, High Temperature System for Fused Filament Fabrication of High Performance Polymers: ***Callie Zawaski***[1]; Christopher Williams[1]; [1]Virginia Tech
A heated build environment in Fused Filament Fabrication (FFF) additive manufacturing is used to prevent shrinkage and promote layer bonding in printed parts. High temperature, high performance materials often require ~200°C build environment to enable printing high quality parts. The difficulty of using environments over 100°C is that the electrical components must be separated from, or compatible with, the high temperature environment, which adds complexity and/or cost to the printer. In an effort to enable desktop-scale FFF printing of performance polymers at a low cost, the authors present a novel inverted FFF system design that can provide a build environment of up to 400°C. This system isolates the build environment from the electronics allowing for the use of inexpensive electronics. The design concept is evaluated by comparing the tensile properties of Ultem parts printed on a traditional open, desktop-scale printer against those made on the proposed system.

3:10 PM Break

3:40 PM
Theory and Methodology for High-performance Material-extrusion Additive Manufacturing under the Guidance of Force-flow: Yu Wang[1]; ***Ziqian Chen***[1]; Houqi Li[1]; Shuaishuai Li[1]; [1]Tongji University
Anisotropy on strength between different layers and filaments in material extrusion (MEX) process has a significant influence on mechanical properties of fabricated objects. A novel theory and methodology is proposed to improve mechanical properties of part by designing and controlling anisotropy and making anisotropy be in alignment with load paths under the guidance of force-flow. In this study, by (1) dividing part into several building areas and generating corresponding building direction considering the force-flow properties of the part; (2) generating novel toolpath which is based on principal stress lines (PSL) and is the mapping of direction and magnitude of PSL, the adverse influence of anisotropy on mechanical properties between different layers and filaments can be minimized respectively. A 6-aixs robot arm integrated with extrusion system is constructed to handle the multi-direction building of each building area. The study will advance the development of additive manufacturing from “prototype” to “end-use”.

4:00 PM
Effects of Surface Treatments on Interlayer Bonding Strength of FDM-printed Parts: ***Chin-Cheng (Jim) Shih***[1]; Li-Jung “Bruce” Tai[1]; [1]Texas A&M University
Fused Deposition Modeling (FDM), an extrusion-based 3D printing using a continuous filament to create scaffolds, is the most popular additive manufacturing method due to its convenience and lower cost. However, FDM printed parts are typically weak in layer deposition direction because of insufficient interlayer bonding between the laminated structures. To mitigate this issue, this research adopts both chemical and mechanical methods to treat the printed surface prior to the deposition of the next layer and investigates their effects on the interlayer bonding strength. Polylactic acid (PLA) is selected as the print material and the bonding strength is measured using a customized shear tester. The results show that the best treatment can increase the interlayer bonding by over 45%.

4:20 PM
Fused Deposition Modeling Process Parameter Optimization under Uncertainty: ***Paromita Nath***[1]; Zhen Hu[2]; Sankaran Mahadevan[1]; [1]Vanderbilt University; [2]University of Michigan-Dearborn
Process parameters greatly influence the properties of additively built parts. The process parameters affect the thermal history and thus the overall geometry of the part. This work presents a simulation-based methodology to optimize process parameters such as scan power, scan speed, layer width, and layer thickness to reduce the effects of process parameter variability on the variability of the geometry of the manufactured part. A sequentially coupled thermo-mechanical model is first developed to simulate the fused deposition modeling process. The temperature profile obtained from the thermal simulation model is then used as input for the structural analysis model to predict the dimensional inaccuracy of the additively manufactured part. Finally, a robust and efficient methodology is developed to optimize the process parameters, while accounting for both the process parameter variability and the additional uncertainty regarding the simulation model parameters. Experimental data is used to verify the proposed framework.

4:40 PM
Improving Fracture Strength of FFF Parts via Thermal Annealing in a Printed Support Shell: ***Ryan Dunn***[1]; Kevin Hart[1]; Eric Wetzel[1]; [1]US Army Research Laboratory
Polymeric structures fabricated using fused filament fabrication (FFF) have limited use in engineering applications due to their poor inter-laminar bonding. Recent work has shown that toughness of the inter-layer is dramatically improved by incorporating a post-process isothermal annealing of these parts at $T > T_g$. However, without confinement, annealing causes geometric distortion of the original printed shape. In our work, we utilize a dual-material print head to encase a low T_g polymer within a high T_g shell. The resulting structure is capable of withstanding isothermal annealing at temperatures between the T_g of each polymer, providing a tough interior while maintaining the original shape through the annealing process. Fracture toughness of annealed, encased parts was evaluated using single edge notch bend (SENB) fracture specimens and reached values of more than 1700% of the as-printed toughness. Sample scaling influences the applicability of this technique and part design and modelling is discussed.

5:00 PM

Knowledge-based Material Production in the Additive Manufacturing Lifecycle of Fused Deposition Modeling: Cordula Auth[1]; ***Detlev Borstell***[2]; Reiner Anderl[1]; [1]TU Darmstadt; [2]Koblenz University of Applied Sciences

The additive manufacturing (AM) lifecycle starts with the material production. This phase has an impact on the AM process and its quality. Nowadays, information concerning material production is not connected to the manufacturing process or the manufactured component. Increasing digitalization enables data acquisition, handling and management. Nevertheless, an integrated data concept for all AM lifecycle phases has not been realized yet. Using gained information of the material production to evaluate component quality and process stability is a huge research gap. Therefore, this paper deals with establishing a data connection between material production and manufacturing phase. After explaining the motivation and the AM lifecycle, the concept for a knowledge-based material production in the AM lifecycle of fused deposition modeling is developed. The following implementation and validation phases contain the sensor plan for the material extruder and the experimental examination of the effects of filament diameter changes.

Process Development 3 - Metal Powder Bed Fusion 1

Monday PM — Room: 416AB
August 13, 2018 — Location: Hilton Austin

Session Chair: April Cooke, TRUMPF Inc.

1:30 PM

Investigation of Pore Formation and Melt Pool Dynamics during Laser-metal Interaction Using High-speed Full-Field X-ray Imaging: ***Aiden Martin***[1]; Nicholas Calta[1]; Joshua Hammons[1]; Michael Nielsen[1]; Richard Shuttlesworth[1]; Manyalibo Matthews[1]; Jason Jefferies[1]; Trevor Willey[1]; Jonathan Lee[1]; [1]Lawrence Livermore National Laboratory

Laser powder bed fusion (LPBF) is a rapidly developing technique for additive manufacturing (AM) of metal parts. Conventional in situ diagnostic techniques for LPBF AM provide surface sensitive information but are unable to probe the sub-surface where pores which can result in part failure are formed. Here, high-speed full-field X-ray imaging is used to investigate the formation and movement of pores within the melt pool during laser-based heating of Al6061 and Ti-6Al-4V alloys. The results reveal that at the end of a LPBF AM track, the rapidly solidifying melt pool traps non-spherical pores at the base of the vapor depression, and pores within the melt pool are entrained by eddy currents. This information is critical for physical models describing the LPBF AM process and developing mitigation strategies for pore formation in printed parts. Prepared by LLNL under Contract DE-AC52-07NA27344, LDRD Project 17-ERD-042.

1:50 PM

In-situ Micro-CT Observation of Void Evolution under Interrupted Tensile Loading in Additively Manufactured 316L Stainless Steel: ***Nathan Heckman***[1]; Harlan Brown-Shaklee[1]; Bradley Jared[1]; Reese Jones[1]; Brad Boyce[1]; Thomas Ivanoff[1]; Jonathan Madison[1]; [1]Sandia National Laboratories

Additively manufactured stainless steels can show a wide range of material properties, even when printed using the same parameters. Part of the explanation for this phenomenon is that printing techniques tend to introduce voids into the material, whose networks can influence the mechanical properties. To quantitatively understand how these voids influence the material properties, it is critical to comprehend how the voids evolve throughout deformation. In this work, in-situ micro-CT is performed during interrupted tensile tests of additively manufactured 316L to identify both which void networks contribute to material deformation and how these voids progress throughout tensile loading. Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. This document has been reviewed and approved for unclassified, unlimited release under SAND2018-785028 A.

2:10 PM

Characterizing the Dynamics of Laser Powder Bed Fusion Additive Manufacturing Processes by High-speed X-ray Imaging/Diffraction: ***Lianyi Chen***[1]; Tao Sun[2]; [1]Missouri University of Science and Technology; [2]Argonne National Laboratory

Laser powder bed fusion (L-PBF) is a major additive manufacturing technique for producing complex-shaped metal parts by selectively melting successive layers of metal powders using a laser beam. Understanding the physics of L-PBF process is critical for establishing location-specific processing-microstructure-property relationships. The non-transparency of metals to visible light and the highly localized (tens of micrometers) and very short (tens of microseconds) interaction of a laser beam with metal powders during L-PBF pose a huge challenge to the characterization and understanding of this process. The detailed physics of the L-PBF process and the mechanisms of defect formation and microstructure evolution are still not clear. In this talk, I will present an overview of our research on characterizing the dynamics of L-PBF additive manufacturing process by high-energy high-speed x-ray imaging/diffraction. The dynamics of powder spreading, powder spattering, melt pool evolution, pore evolution and solidification will be discussed.

2:30 PM

Characterizing Powder Spreading Dynamics in Powder Bed Fusion AM Process by High-speed X-ray Imaging: *Luis Escano*[1]; Lianyi Chen[2]; Niranjan Parab[3]; Lianghua Xiong[2]; Qilin Guo[2]; Cang Zhao[3]; Kamel Fezzaa[3]; Wes Everhart[4]; Tao Sun[3]; [1]Missouri University of Science & Technology; [2]Missouri University of Science and Technology; [3]Argonne National Laboratory; [4]Honeywell FM&T

In powder bed fusion additive manufacturing processes, powder spreading behavior affects the powder bed quality, consequently the quality of the part produced. Even though extensive works have been done about powder flow behavior, the particle-scale dynamics of powder spreading process under additive manufacturing conditions is still not clear. In this talk I will present our results on particle-scale characterization of powder spreading behavior in powder bed fusion additive manufacturing process by in-situ high-speed high-energy x-ray imaging.

2:50 PM

Complementary IR Heating Systems for Selective Laser Melting/ Sintering: ***Oliver Weiss***[1]; Daniel Kleine[2]; Peter Koppa[2]; Holger Zissing[1]; Thomas Tröster[2]; [1]Heraeus Noblelight GmbH; [2]Paderborn University

AM methods like HSS and MJF are based on pre-heating and sintering by means of infrared emitters. Also in SLS top heating is common in many systems. Aim of our work was to systematically investigate the infrared heating behaviour of different plastic and metal powder materials to develop optimized top heating systems for SLM/SLS. For this, firstly the emissivity of powder materials was determined to enable pyrometric temperature measurements. Then heating tests with different IR emitter types were conducted. In a next step an example is given of how a top heating system can be designed with optimum IR spectrum and power density by using numerical ray tracing simulation to calculate and optimize the IR irradiance on the powder bed surface and other AM process chamber components. The top heating system will be one part of a complementary heating solution for SLS/SLM consisting also of (high temperature) powder bed heating.

3:10 PM Break

3:40 PM
DMP Monitoring as a Process Optimization Tool for Direct Metal Printing (DMP) of Ti-6Al-4V: ***Nachiketa Ray***[1]; Manisha Bisht[1]; Lore Thijs[1]; Jonas Van Vaerenbergh[1]; Sam Coeck[1]; [1]3D Systems
Metal Additive Manufacturing (AM) has evolved as a production technique for rapid prototyping as well as high volume precision manufacturing. In this work, DMP Monitoring, a new feature of 3D Systems' direct metal printer, ProX® DMP 320 has been used as a tool for process parameter optimization. The effect of the variations of process parameters like layer thickness, laser power, scan speed and hatch spacing on the physical and mechanical properties of the additively manufactured Ti-6Al-4V samples have been investigated. In addition to the conventional post-processing evaluation methods like Archimedes' density, X-ray CT and tensile testing, new in-situ process monitoring tools are assessed and compared with the traditional evaluation methods.

4:00 PM
Effect of Process Variables on Porosity Formation in Laser and E-beam Power-bed Additive Manufacturing: Sneha Narra[1]; Ross Cunningham[1]; Colt Montgomery[1]; Ming Tang[1]; Chris Pistorius[1]; Anthony Rollett[1]; ***Jack Beuth***[1]; [1]Carnegie Mellon University
The porosity observed in additively manufactured (AM) parts is a concern for components designed to undergo high-cycle fatigue. This talk summarizes research across four publications and includes new results, all with the goal of eliminating porosity as a practical concern in AM powder bed processing. E-beam and laser powder-bed AM Ti-6Al-4V samples are fabricated over a range of processing conditions to investigate the effects of processing parameters on porosity. Process mapping techniques are used to control melt pool size and the minimum depth of melt pool overlap. Synchrotron-based X-ray microtomography is performed on the specimens and also on the powder to measure porosity within the powder that may transfer to the samples. Clear connections between processing parameters and resulting porosity formation mechanisms are observed. Cases with essentially no porosity are identified and explained.

4:20 PM
Effects of Identical Parts on a Common Build Plate on the Modal Analysis of SLM Created Metal: ***Tristan Cullom***[1]; Robert Landers[1]; Douglas Bristow[1]; Edward Kinzel[1]; Kevin Johnson[2]; Jason Blough[2]; Andrew Barnard[2]; Troy Hartwig[3]; Ben Brown[3]; [1]Missouri University of Science and Technology; [2]Michigan Technological University; [3]Kansas City National Security Campus
Modal analysis is a potential NDE technique for metal parts created with selective laser melting. Conceptually the objective is to establish a fingerprint based on the Frequency Response Function (FRF) of validated parts which can be compared to the fingerprints from new parts. The FRF is dependent on the material/geometric state of the part and changes in either result in changes in the resonant modes of the part. A complication arises when identical parts are printed on the same build plate. The interaction between valid parts shifts the resonant modes and can frustrate modal fingerprinting. This paper studies the dynamic absorber phenomena for printed metal parts. The coupling is measured and the potential for shifting the resonant frequencies by loading the parts not under test explored. The implications for detecting localized or homogenous defects are determined. This work was funded by Honeywell Federal Manufacturing & Technologies, US DOE Contract: DE-NA0002839.

4:40 PM
Energy and Charge Transport during Pulsed Electron Beam Melting of Solid and Powder Ti Using Custom Electron Beam Welder: ***Paul Carriere***[1]; Pedro Frigola[1]; Ralf Edinger[2]; Stephen Yue[3]; [1]RadiaBeam Technologies; [2]CANMORA Tech; [3]McGill University
Energy and charge transfer during pulsed electron beam melting of commercially pure Ti in solid and powdered state is presented using a custom, open-access electron beam welding unit. These measurements are parametrically conducted at variable accelerating voltages, beam currents and focus settings. A novel, single layer powder fixture is presented, enabling experiments on both loose and contact-sintered powder. By instrumenting workpiece as a Faraday Cup, we demonstrate the formation of a current which opposes the incident beam, and is dependent on both the beam power and energy density. We attribute this current signal to electron-impact ionization of the Ti vapor, with powdered material evaporating strongly compared to solid. Pulsed melting of loose, room-temperature powder suggests this ionization current neutralizes some electrostatic powder charging. This measurement technique represent a low-cost method to characterize the processing window electron beam melting, following similar work on single layer laser powder melting.

5:00 PM
High-resolution, Layer-based Surface Profilometry of Selective Laser Melting for Defect Detection and Quality Control: ***Greg Loughnane***[1]; John Middendorf[1]; Nathan Levkulich[2]; Nathan Klingbeil[2]; [1]Universal Technology Corporation; [2]Wright State University
In-situ monitoring for metals Additive Manufacturing (AM) is rapidly growing in popularity, yet the tools and algorithms necessary to ensure that components have reliable and predictable microstructures and mechanical properties remain largely undeveloped. This work details how one mode of in-process data, high-resolution laser-line surface profilometry, can be used to detect a wealth of information about specific classes of defects and overall part quality, especially when used across commercial AM systems (e.g., Concept Laser, EOS, OPENSLM). We will characterize defect types that occur during both spreading and melting and demonstrate how statistical quality predictors can be used to avoid undesirable build conditions (e.g., keyhole-mode, lack-of-fusion). This data-driven investigation details the use of specific regression and classification models and provides a case study in using large volumes of data to train process-control algorithms. Demonstrating related corrective actions for learning-algorithm determinations on commercial AM systems will also be discussed.

Special Session: Data Analytics in AM 1 - Quality in Modeling 1

Monday PM Room: Salon B
August 13, 2018 Location: Hilton Austin

Session Chair: Brandon Lane, NIST

1:30 PM
Effects of Thermal Camera Spatial and Temporal Resolution on Feature Extraction in Selective Laser Melting: ***Xin Wang***[1]; Douglas Bristow[1]; Robert Landers; Edward Kinzel[1]; [1]Missouri University of Science and Technology
Selective Laser Melting (SLM) is a common additive manufacturing process which uses a laser energy source to fuse metal powder layer by layer. A common measurement tool for measuring the thermal history is a thermal camera that records the thermal emission of the part's surface. The temperature history in the melt region in an SLM process is characterized by high temporal and spatial gradients. This study investigates the effects of sampling frequency and spatial resolution of thermal cameras when monitoring the temperature in SLM processes. High fidelity simulation data for a single track in an SLM process is used to quantify the effects of the camera's spatial and temporal resolution. Next, the effect these resolutions have on feature extraction, namely peak temperature and melt pool morphology, is investigated by applying feature extraction methodologies to the down sampled simulation data. Finally, the feature extraction methodologies are applied to experimental data.

1:50 PM
Defect Signatures for Metal Laser Powder Bed Fusion: ***Bradley Jared***[1]; Jonathon Madison[1]; Thomas Ivanoff[1]; John Mitchell[1]; Erich Schwaller[1]; Joshua Koepke[1]; Laura Swiler[1]; David Saiz[1]; Daryl Dagel[1]; Harlan Brown-Shaklee[1]; [1]Sandia National Laboratories
Defect "signatures" are being investigated to provide a predictive framework for quantifying material performance distributions for 316L stainless steel produced by metal laser powder bed fusion. Data sets from in-situ two-color pyrometry and ex-situ computed tomography (CT) will be discussed relative to defect detection. Data analysis has proven particularly challenging as pyrometry data sets have encompassed hundreds of thousands of thermal images, and single micron CT voxel resolutions produce GB sized image stacks. Techniques and results for data orientation, registration, scaling, cross-correlation and defect detection will be discussed. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. This document has been reviewed and approved for unclassified, unlimited release under SAND2018-3940 A.

2:10 PM
Detection of Porosity in Laser Powder Bed Fusion Using Spectral Graph Theoretic Machine Learning of In-process Optical Emission Spectroscopy Signals.: Abdalla Nassar[1]; ***Mohammad Montazeri***[2]; Alexander Dunbar[1]; Prahalad Rao[2]; [1]Applied Research Laboratory, Penn State University; [2]University of Nebraska
The objective of this work is to identify porosity severity-levels based on in-process sensing of optical emissions from the laser-interaction zone in powder bed fusion (L-PBF). To realize this objective, Inconel 718 cylinders are built on a commercial L-PBF machine (3D systems ProX 200) with different process settings. Optical emissions are monitored using a multispectral photodetector array to estimate the line-to-continuum emissions around 520 nm. The line-to-continuum ratios are subsequently related, on a layer-by-layer basis, to the level of porosity in the part obtained from offline X-ray computed tomography (CT) scans. The link between the in-process multispectral sensor and CT data is made via the spectral graph Laplacian eigenvectors and eigenvalues extracted from the photodetector signals. Using the proposed approach, the porosity in terms of the pore percentage and distribution is quantified from in-process sensor data with accuracy close to 90% and computation time less than 1 millisecond.

2:30 PM
Artificial Intelligence-enhanced Multi-material Form Measurement for Additive Materials: ***Petros Stavroulakis***[1]; Danny Sims-Waterhouse[1]; Amrozia Shaheen[1]; Sofia Catalucci[1]; Georgios Tzimiropoulos[1]; Richard Leach[1]; [1]University of Nottingham
The range of materials used in additive manufacturing (AM) is ever growing nowadays. This puts pressure on post-process optical non-contact form measurement systems as different system architectures work most effectively with different types of materials and surface finishes. In this work, a data-driven artificial intelligence (AI) approach is used to recognise the material of a measured object and to fuse the measurements taken from three optical form measurement techniques to improve system performance compared to using each technique individually. More specifically, we present a form measurement system which uses AI and machine vision to enable the efficient combination of fringe projection, photogrammetry and deflectometry. The system has a target maximum permissible error of 50 µm and the prototype demonstrates the ability to measure complex geometries of AM objects, with a maximum size of (10 × 10 × 10) cm, with minimal user input.

2:50 PM
Energy Consumption Optimization with Geometric Accuracy Consideration for Additive Manufacturing Processes: ***Wenmeng Tian***[1]; Junfeng Ma[1]; Morteza Alizadeh[1]; [1]Mississippi State University
There are two major concerns which hinder the broader adoption of AM in more industrial applications: part quality and energy consumption. These two types of outcomes are highly interdependent, and thus it is difficult to optimize one without changing the other. However, prior pertinent studies usually considered and optimized quality and energy consumption individually. This proposed study aims develop a data-driven framework to optimize energy consumption in AM fabrication without compromising part quality. Linear regression models are used to capture the relationship between process design parameters and the two types of outcomes, respectively. Then a nonlinear optimization framework is proposed to minimize the energy consumption on the part level given specific quality requirements. A case study based on a fused filament fabrication (FFF) process is used to illustrate the effectiveness of the proposed methodology.

3:10 PM Break

3:40 PM
Geometric Deep Learning for On-demand Production of Customized Products by Additive Manufacturing: ***Jida Huang***[1]; Tsz-Ho Kwok[2]; Chi Zhou[1]; Wenyao Xu[1]; [1]University at Buffalo; [2]Concordia University
Additive manufacturing (AM) transforms the traditional mass production to mass customization paradigm which allows for on-demand production of highly personalized products. However, the complex geometry poses computational challenge for data processing of customized products. State-of-the-art deep learning has achieved remarkable performance in many fields. However, most deep learning methods are targeted on the Euclidean structured data and not capable of processing non-Euclidean manifold 3D objects. In this paper, a geometric deep learning method is introduced to study the intrinsic geometric characteristics of customized products. An application of support generation for customized teeth aligner is investigated. Considering supports removal effect and customer comfort as well as ease-of-printing and to study the intrinsic property of support regions, a generalized convolutional neural network (CNN) is proposed to learn from the personalized aligner models. With trained models, support regions on new models can be easily determined. Experimental results demonstrate the effectiveness the proposed approach.

4:00 PM
Evaluating Transient Extrusion Process Effects on Heat Transfer Modeling: ***Alex Renner***[1]; Holly Baiotto[1]; Eliot Winer[1]; [1]Iowa State University
Steady-state process parameters used in heat transfer analyses may not apply to Desktop 3D printers that vary feed rate to reduce print time. An infrared thermal camera evaluated transient process variable effects on heat transfer modeling of inter-road bond quality. ASTM D638 tensile bar parts were printed with manufacturer recommended print settings for comparison with parts printed at three constant print speeds and three extruder set temperatures. The position and quantity of printed roads that cooled below glass transition temperature in a layer showed that conduction and convection must vary with print head speed. Experiment results were compared to a software simulation application developed to test heat transfer models. The simulation accurately predicted printed road temperature for constant print speeds. Adding transient extrusion processes variables to the simulation has the potential to reduce the volume and variety of in-process Additive Manufacturing process analyses.

4:20 PM
A Data-driven Framework for HP's MJF 3D Printer for Correlation and Prediction of Part Mechanical Properties: ***Sunil Kothari***[1]; Viseth Sean[2]; Juan Catana[1]; Jun Zeng[1]; Gary Dispoto[1]; [1]HP; [2]Chapman University
Theoretical understanding of several additive manufacturing technologies must be supplemented with the ground truth gathered from the sensor data. Raw sensor data has to be fused and error-corrected before it can be used to correlate process variables to the final part quality and to customize theoretical models for a specific process. We highlight our challenges and outcomes for HP's Multi-Jet fusion technology in coming up with a data-driven methodology for relating final part quality to sensorial data and process variables. We also highlight a custom workflow for ingesting high resolution thermal camera images and routines for motion correction andpass assignments and visualizations for several custom analyses developed for correlating and predicting the part mechanical properties.

4:40 PM
Machine Learning for Modeling of Printing Speed in Continuous Projection Stereolithography: ***Haiyang He***[1]; Yang Yang[2]; [1]University of Illinois at Chicago; [2]PPDAI GROUP INC.
Continuous projection stereolithography can achieve build speeds 25~100 times faster than conventional layer-by-layer Stereolithography process. However, various process parameters and unknown factors that affect the continuous printing process make the process planning and optimization challenging. In this paper, we investigate machine learning techniques for planning and optimization of the Continuous Projection Stereolithography process. Especially, the optimal printing speed is modeled and optimized. Synthetic dataset is generated by physics based simulations. Experimental dataset is obtained for training Machine Learning models to find the appropriate speed range and the optimum speed. Conventional machine learning techniques such as Decision Tree, Naïve Bayes, Nearest Neighbors and Support Vector Machine (SVM), ensemble methods such as Random Forest, Gradient Boosting and Adaboosting and state-of-the-art deep learning approaches like Siamese Network are tested and compared. Experimental results validate the effectiveness of the machine learning models. Thus, future designed experiments could be first input to the learned model to predict the outcome, base on which the experiments could be selectively and efficiently performed.

Special Session: Hybrid AM Processes 1 - Hybrid Additive-Subtractive Processes

Monday PM　　　　Room: 404
August 13, 2018　　Location: Hilton Austin

Session Chair: K. P. Karunakaran, Indian Institute of Technology Bombay

1:30 PM
The Role of Hybrid Manufacturing in 3D-Printing - Attributes and Future Avenues: Yashwanth Bandari[1]; Alex Roschli[1]; ***Phillip Chesser***[1]; Peter Lloyd[1]; Jason Jones[2]; Lonnie Love[1]; Katherine Gaul[1]; [1]Oak Ridge National Laboratory; [2]Hybrid Manufacturing Technologies
Hybrid manufacturing is a technique that combines additive, subtractive, and metrology processes. The ability to add, subtract, and inspect material helps address geometrical challenges of additive manufacturing and the high buy-to-fly ratio challenges of subtractive manufacturing. Hybrid manufacturing allows the production of ready-to-use parts within one workstation. Existing hybrid systems are largely built upon existing commercial machine tools and adapted with additive process integration. Although hybrid manufacturing has been researched since the late 1990s, the transition from research to the commercial arena has been very gradual. Topics under development for large-scale adoption of this process include designing reconfigurable hardware and controllers, improving control systems and process planning software, process monitoring and inspection, and further integrating additive and subtractive processes. In addition to the above-mentioned topics, this paper also details the development of hybrid systems and identifies future avenues of research and development to commercialize these systems for high-value manufacturing.

1:50 PM
Characterization of High-deposition Polymer Extrusion in Hybrid Manufacturing and Comparison to Alternative Additive Processes: ***TJ Barton***[1]; Louisa Orton[1]; Mike Miles[1]; Yuri Hovanski[1]; Jason Jones[2]; Jason Weaver[1]; [1]Brigham Young University; [2]Hybrid Manufacturing Technologies
Hybrid manufacturing processes that include both additive and subtractive operations have unlocked many of the design limitations characteristic of solely additive or subtractive processes. Such hybrid processes allow for the high complexity and low material waste available from additive operations, while enabling the higher final tolerances, surface finishes, and overall speeds of conventional subtractive operations. However, certain undesirable effects of additive processes may remain in hybrid parts, such as possible porosity, surface incontinuities, internal stresses, and distortion. This paper considers the material properties, including these undesirable effects, of hybrid test artifacts created with a computer numerically controlled (CNC) milling machine in conjunction with a high-deposition-rate polymer extruder, referred to as the Poly-Ambit system. Furthermore, the study compares the deposited structure and mechanical performance of printed materials obtained from this Poly-Ambit system to that of traditional fused filament fabrication (FFF) desktop printers and big area additive manufacturing (BAAM) systems.

2:10 PM

Mechanical Properties Evaluation of Ti-6Al-4V Thin-wall Structure Produced by a Hybrid Manufacturing Process: ***Lei Yan***[1]; Wenyuan Cui[1]; Joseph Newkirk[1]; Frank Liou[1]; Eric Thomas[2]; Andrew Baker[2]; James Castle[2]; [1]Missouri University of Science and Technology; [2]The Boeing Company

Hybrid manufacturing (HM) process combines the precision of computer numerical control and the freeform of additive manufacturing to expand the feasibility of advanced manufacturing. The intent of this paper is to explore the relations between HM processing parameters and mechanical properties of the final parts manufactured by one type of HM process that combines laser metal deposition and computer numerical control milling. Design of experiment (DoE) is implemented to explore the Ti-6Al-4V thin-wall structure fabrication process with different HM build strategies. Vickers hardness and tensile tests are conducted to evaluate the mechanical property variance within the final parts fabricated according to the DOE matrix. Finally, a prediction model of yield strength is obtained by ANOVA test based on the DoE results.

2:30 PM

Accelerating the Development of Biomedical Polymer Composites for Fused Deposition Systems Through Direct Printing of Cryomilled Powders: ***Eric Weflen***[1]; Sharon Lau[1]; Maria Brown[1]; Jared Gross[1]; Lauren Meyer[1]; Zoe Pearson[1]; Iris Rivero[1]; [1]Iowa State University

Additive manufacturing holds potential for the production of patient-specific scaffolds for bone tissue regeneration, but limited biomaterial options for Fused Deposition Modeling (FDM) restrict innovation. New biomaterial development for scaffolds often emphasizes syringe-based systems that allow for small material batches. However, these systems may have non-ideal nozzle geometry or reduced thermal control compared to filament-based extrusion systems. Solid state processing via cryomilling can be used to quickly generate new biomaterial composites, but accurate and repeatable printing remains a challenge. This study presents an approach for the fabrication of scaffolds from cryomilled biomaterials using the unique combination of a syringe pump and more traditional FDM temperature control and nozzle geometry. Polylactide (PLA), in pellet and cryomilled forms, is printed in this custom system with key process parameters being varied. Cell culture scaffolds are evaluated for dimensional accuracy and repeatability, and we demonstrate the ability to produce a larger anatomically shaped scaffold.

2:50 PM

Development of Pre-machining Strategies for Laser-aided Metallic Component Remanufacturing: ***Xinchang Zhang***[1]; Wenyuan Cui[2]; Leon Hill[2]; Wei Li[2]; Frank Liou[2]; [1]Missouri University of Science & Technology; [2]Missouri University of Science and Technology

Repair or rebuilding worn metal components earned increasing interest for parts that need replacement but are costly to manufacture. In general, damaged parts need pre-machining prior to material deposition to remove oil, residue, oxidized layers or inaccessible sharp and deep areas. Therefore, this paper introduced pre-machining strategies so that contaminated materials were machined off from the damaged parts and ensuring that the target surface is exposed to laser and powder feed nozzle. Machining strategies for surface impact and indentation, cracking, wear and corrosion were proposed. Each strategy takes 3D scanned damaged model as input and the geometry around the defects that need to be machined was defined. NC code for machining was obtained and damaged parts were CNC machined. The missing geometry was obtained and sliced to generate deposition tool path. Components were finally repaired using laser-aided direct metal deposition process and further analyzed to assess the repair quality.

3:10 PM Break

3:40 PM

Development of A Novel and Low Cost Multi Axis Fused Deposition Modeling Additive Manufacturing System: ***Abolfazl Zolfaghari***[1]; Yunbo Zhang[1]; Steve Canfield[1]; [1]Tennessee Technological University

In regular Fused Deposition Modeling (FDM) machine, the layers are deposit in plane, and direction of deposition does not change, and direction of layer deposition doesn't change during fabrication. Therefore, these systems have limitations and issues in fabrication of support free shapes with higher accuracy. In order to address the issues, multi axis additive manufacturing systems have been developed. One of the problems of the current multi axis system is higher price compared to regular additive manufacturing systems. Thus, companies or individuals working in this area, are not interested to use them. In order to address this issue, a new multi axis system with considerably lower cost in comparison with the previous systems have been proposed and developed in this research. Obtained results from the developed system prove its superior over traditional FDM 3D printing and its potential to be used as a low cost multi axis additive manufacturing system.

4:00 PM

Development of a Very Large Scale Robotic Hybrid AM System through the LASIMM Project: ***Stewart Williams***[1]; Filomeno Martina[1]; Mark Prince[2]; Javier Galarza[3]; André Cereja[4]; Eurico Assunção[4]; [1]Cranfield University; [2]Global Robots; [3]Loxin; [4]EWF

Hybrid AM systems combine deposition and subtraction into one system, potentially having many advantages. A common approach for hybrid systems is to add additive capability to an existent CNC milling system; often limiting the build envelopes as systems become significantly more expensive as the size is increased. In the LASIMM project a different approach is being taken with the whole hybrid system based on multi-axis robots. The system comprises 2 standard industrial robots for deposition, a parallel kinematic mounted robot for subtraction and a rotational part manipulator. All robots are mounted on rails so that components up to 6 meters long and 2 meters wide in size and 2 tonnes in mass can be produced. Deposition is provided through 2 x cold metal transfer welding systems. The system will be described and shown, along with the design and operational philosophy for it, with a special focus on its modularity.

4:20 PM

Effects of Direct Metal Deposition Combined with Intermediate and Final Milling on Part Distortion: ***Daniel Eisenbarth***[1]; Fabian Soffel[2]; Konrad Wegener[2]; [1]inspire AG, ETH Zurich; [2]Institute of Machine Tools and Manufacturing, ETH Zurich

Combining Direct Metal Deposition and milling in one machine promises the additive fabrication of complex parts with high surface quality and dimensional accuracy. However, residual stress induced by the additive process can impair the final part shape after finishing. Undercuts and inaccessible areas are particularly prone to distortion, since they require intermediate milling steps during buildup. Herein, both strategies to reduce residual stresses by process optimization and to compensate distortion by adapted toolpaths are discussed, applying empirical models. The effects of intermediate and final milling on dimensional accuracy are analyzed during the fabrication of a critical cantilever from stainless steel. 3D scans reveal that additive buildup on a semi-finished part leads to local warpage of milled surfaces. However, global distortion is not significantly affected by intermediate milling steps. An approach is finally proposed that improves the transition between additive and subtractive process steps.

4:40 PM
Effects of Milling Thickness on Deposition Accuracy in Hybrid Additive/Subtractive Manufacturing: ***Shuai Zhang***[1]; Ming Gao[1]; Xiao Zeng[1]; [1]Huazhong University of Science and Technology
In order to the manufacturing of aluminum alloy parts with complex inner cavity, hybrid technique integrating wire arc additive manufacturing (WAAM) and high-speed milling of Al5Si alloy was carried out by alternating the two processes. The effects of milling thickness (t) on sample profile accuracy was measured. According to surface roughness (Ra), it was obtained that when the t was less than 1.2 mm, the Ra was less than 70 µm. Moreover, the empirical formula was derived from the change rule of deposition height that the deposition height (h) varied with the number of layers (n) and the thickness (t). Based on the force analysis of metal droplets, the effect of milling on the spreading of metal droplets was explored. It was found that the increase of the milling thickness led to a decrease of the average contact angle and oscillation intensified of metal droplets.

Applications 2

Tuesday AM　　Room: 415AB
August 14, 2018　　Location: Hilton Austin

Session Chair: Ian Gibson, Deakin University

8:15 AM
Finite Element Analysis of Additively Manufactured Conformal Negative Stiffness Honeycombs: ***David Debeau***[1]; Carolyn Seepersad[1]; [1]The University of Texas at Austin
Conformal negative stiffness honeycombs provide repeatable impact mitigation for curved surfaces, in response to loads from multiple directions. These loads are thresholded at a constant level, which is ideal for impact mitigation. Due to the complexity of the design, additive manufacturing is used to fabricate the parts. The geometric defects that result from manufacturing make accurate finite element analysis difficult. A technique that combines measurements from CT imagery, with a multi-step finite element analysis will be demonstrated for improving the accuracy of mechanical property predictions and estimating prediction windows for important mechanical properties as a function of manufacturing-induced variation. The analysis will be compared to actual dynamic impulse tests.

8:35 AM
Qualification of Large Scale Directed Energy Deposition Components - Challenges and Outlook: ***Stewart Williams***[1]; Goncalo Pardal[1]; Alex Chenglie[1]; Pawel Kurzynski[1]; Jialuo Ding[1]; Filomeno Martina[1]; [1]Cranfield University
DED processes are suitable for producing complex, meter-sized components potentially significantly reducing cost and lead times. Qualification is essential but extremely challenging. Methods used for processes like welding are difficult to implement because the thermal cycle, which is the main determinant of the material properties, is highly variable. This is because it is affected by factors like the local deposition strategy and part geometry, leading to a huge number of process parameters which are needed to compensate for these variations in a large component. For this reason a physics based approach to qualification is being investigated, To enable this process monitoring is critical. For the thermal cycle a number of techniques are being explored, including melt pool size assessment, pyrometry and thermography. For structural integrity of large components an on-line NDT approach is required. The challenges of the process monitoring and on-line NDT will be discussed and the outlook presented.

8:55 AM
Measurement of Geometric Variation in Negative Stiffness Structures Produced by Microstereolithography: ***Clinton Morris***[1]; L Bekker[2]; Christopher Spadaccini[2]; M Haberman[3]; Carolyn Seepersad[1]; [1]Univerity of Texas at Austin; [2]Lawrence Livermore National Laboratory; [3]University of Texas at Austin
Recent research in design has focused on developing strategies to identify and produce negative stiffness (NS) metamaterials which exhibit exceptional vibrational attenuation while maintaining stiffness. To produce these metamaterials, low volume fractions of NS structures are embedded within an appropriate viscoelastic material. The NS structures are characterized by curved beams that exhibit a nonlinear stress-strain response when loaded transversely. To manufacture the NS inclusions microstereolithography was identified because the process is capable of producing millimeter-scale parts with micron-scale features. The curved beams indicative of the NS structures must have precise geometries to ensure the NS metamaterials perform reliably. Therefore the geometric variation of critical features of the beams produced via microstereolithography were measured with a scanning electron microscope (SEM). Following measurement, probabilistic distributions were generated to model the geometric variation that were incorporated into a set-based design approach to identify NS inclusion designs that lead to reliable metamaterial performance.

9:15 AM
Design Guidelines for a Software-supported Adaptation of Additively Manufactured Components with Regard to a Robust Production: ***Stefan Lammers***[1]; Johannes Tominski[1]; Sebastian Magerkohl[1]; Tobias Lieneke[1]; Thomas Künneke[1]; Detmar Zimmer[2]; [1]Direct Manufacturing Research Center (DMRC); [2]Paderborn University
The design of additively manufactured components requires a rethinking in the design process. This is inhibited by a lack of knowledge about additive manufacturing technologies. For this reason, a large number of design guidelines have been developed in recent years. In their present form the design guidelines are not suitable for processing in a software algorithm, since the guidelines have a certain redundancy and partly influence each other. This paper describes several steps to consolidate the existing guidelines and to prepare them in a way that they can be used in a software algorithm for a design check. Therefore existing guidelines are collected, prioritized and quantified with regard to their relevance for a robust production. To quantify the guidelines, test specimens are developed, produced and evaluated in order to obtain a limit value for the geometric properties which have to be checked with a software under different boundary conditions.

9:35 AM
A Methodology for Function-based Part Consolidation during Conceptual Design for Additive Manufacturing: ***Alexander Reik***[1]; [1]Technical University of Munich
The impressive potential of additive manufacturing (AM) has been exploited successfully in many cases yet. Nevertheless, the potential of part consolidation with the newly revealed possibilities offering advantages along the whole product lifecycle is being approached slowly. As AM is often narrowed down to the part-level by habit, this paper presents an assembly-level methodology that is applied within conceptual design. First, the methodology determines the assembly‘s scope that is maximally possible regarding project constraints. Second, it identifies the functions that must be performed within the considered scope and depicts the relations between the identified functions and parts existing by now. Third, the identified functions are clustered depending on the strength of the dependencies among themselves. Fourth, these clusters are analyzed concerning part, lifecycle and AM characteristics and, finally, an entity of integrated functions is defined. A sensor bracket case study is presented to prove effectivity of the proposed methodology.

9:55 AM Break

10:25 AM

Designing Support Structures for Removability: A New Approach to Optimize Build Orientation for Laser Powder Bed Fusion: ***Neichen Chen***[1]; Matt Frank[1]; Foxian Fan[2]; Xinyi Xiao[2]; Tim Simpson[2]; [1]Iowa State University; [2]Penn State University

Build orientation is an important decision in additive manufacturing process planning, especially when fabricating metallic parts with laser powder bed fusion. Build orientation drives many important factors including build height and projected area on the build plate. In many cases, build orientation is selected for minimizing build height to reduce time and the amount of powder feedstock used. Support structure design and placement need to be adjusted to minimize distortion and support overhangs accordingly. The removal of support structures is not commonly considered even though it can be both challenging and time consuming. A new algorithm has been developed to assess support structure removability, which enables more informed decisions during build planning. In this paper, the tradeoffs between build time, support material, and post-processing are explored with examples. Implications on the design process and workflow are discussed along with future work to optimize support structure design and build orientation.

10:45 AM

Increasing Interlaminar Strength in Large Scale Additive Manufacturing: ***Alex Roschli***[1]; Chad Duty[2]; John Lindahl[1]; Brian Post[1]; Vlastamil Kunc[1]; Phillip Chesser[1]; Lonnie Love[1]; Katherine Gaul[1]; [1]Oak Ridge National Laboratory; [2]University of Tennessee

Interlaminar strength of extrusion-based additively manufactured parts is known to be weaker than the strength seen in the printed directions (X and Y). With Big Area Additive Manufacturing (BAAM), large parts lead to long layer times that are prone to splitting, sometimes referred to as delamination, between the layers. Fiber filled materials, such as carbon fiber reinforced ABS, are used to counter-act the effects of thermal expansion, but the fibers stay in-plane meaning that no fibers span from layer to layer, which helps counteract the weak interlaminar strength that causes splitting. A solution to this is a patent pending approach known as “z-pinning”. The process involves strategically positioning voids across multiple layers that will be backfilled with hot extrudate. This paper will explore the benefits and results of using “z-pinning” in large scale additive manufacturing.

11:05 AM

Conceptual and Goal-oriented Strategies for AM-Enabled Part Consolidation within Technical Systems: ***Alexander Reik***[1]; Joachim Zettler[2]; Andreas Nick[2]; [1]APWORKS GmbH and Technical University of Munich ; [2]APWORKS GmbH

Since additive manufacturing gains more attention within the industrial field and the quality and reproducibility of additively manufactured parts increasingly reach the requirements, research begins to utilize the technology’s capabilities in a bigger scope. Therefore, the attention does not concentrate only on single parts but investigates the applicability on assemblies. Reviewing approaches from literature for part consolidation lead to the criticism that these approaches just name the reached benefits after a consolidation has been accomplished and do not determine an exact goal for such an endeavor. Therefore, this work investigates the different benefits an AM-enabled part consolidation can achieve along the product lifecycle. Further, it derives strategies to identify suitable candidates for part consolidation within a selected assembly of an exemplary technical system. The strategies follow different goals regarding the AM-enabled benefit along the product lifecycle and therefore have different results.

11:25 AM

Opportunities for Additive Manufacturing within Quantum Technologies: ***Sarah Everton***[1]; [1]Added Scientific Ltd

This presentation will give an introduction to the burgeoning quantum sector and highlight some of the market applications for quantum technologies. Currently, quantum sensing devices are large pieces of laboratory equipment with limited industrial applications. However, utilising the benefits afforded by additive manufacturing (AM), an order-of-magnitude reduction in size, weight and power requirement is plausible.The OPTAMOT project carried out by Added Scientific Ltd. in conjunction with the Physics departments at University of Nottingham and University of Sussex, has focussed on re-designing magneto-optical trap (MOT) assemblies for manufacture by laser-powder bed fusion. The resulting MOT performance characteristics and achieved reductions in size, weight and power will be presented.

11:45 AM

Metal Big Area Additive Manufacturing (MBAAM) for Tooling Applications: ***Andrzej Nycz***[1]; Mark Noakes[1]; Christopher Masuo[1]; Lonnie Love[1]; [1]Oak Ridge National Laboratory

Oak Ridge National Laboratory’s Manufacturing Demonstration Facility is researching wire-arc based metal deposition technology, which is one of the key methods accelerating the development of metal large-scale additive manufacturing applications. The first demonstration of large-scale wire-arc metal deposition’s capabilities was the 3D printed excavator arm revealed in March 2017. Currently, development has shifted to focus on creating large parts for the tooling industry. This includes cold and hot stamp dies, fixtures, molds, and other types of forming or pattern devices. Using large-scale wire-arc metal deposition for tooling presents new challenges in geometrical features, thermo-mechanical properties, deposition rates, process conditions, and material selection. However, if successful, the technology has a chance to revolutionize manufacturing on a local and global scale. This work focuses on the challenges, recent research experiences, new solutions, and future needs of the additive manufacturing tooling industry.

Materials: Ceramics

Tuesday AM — Room: 602
August 14, 2018 — Location: Hilton Austin

Session Chair: Desiderio Kovar, University of Texas at Austin

8:15 AM

Direct Write and 3D Printing of Ceramic Polymers: Materials, Approaches and Applications: ***Judith Lavin***[1]; David Keicher[1]; Seethambal Mani[1]; [1]Sandia National Laboratories

The evolution of additive manufacturing in ceramics has led to an increasingly diverse and flexible means of printed ceramics. Given the relatively recent advances in printers, materials and tooling the opportunities are vast for the exploration of printed ceramics. To that end, we at Sandia National Labs are invested in exploring innovative approaches and materials to gain a unique understanding in the printing of highly loaded ceramic polymer based pastes and resins. Here, we will present ongoing work investigating stereolithographic (SLA) and direct write extrusion printing of highly loaded alumina polymers, post processing and the incorporation of printed parts into components. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S.

8:35 AM

Effects of Electric Field on Selective Laser Sintering of Yttria-stabilized Zirconia Ceramic Powder: ***Deborah Hagen***[1]; Desiderio Kovar[1]; Joseph Beaman[1]; [1]University of Texas at Austin

Selective Laser Sintering (SLS) of ceramic material is particularly challenging. High sintering temperatures and slow sintering kinetics of ceramic material combined with poor thermal shock resistance have resulted in cracking when ceramics are sintered to full density one layer at a time. This work investigates the use of an electric field applied simultaneously with laser scanning to accelerate the kinetics of sintering to produce a multi-layer SLS ceramic part. Ceramic sintering rates have been shown to increase by orders of magnitude during furnace-based flash sintering, in which electric field applied simultaneously with furnace heating. The In this work we investigate the flash sintering effect during SLS processing using yttria-stabilized zirconia ceramic.

8:55 AM

Fabrication of Ceramic Parts Using a Digital Light Projection System: ***Xuan Wang***[1]; Dylan De Caussin[1]; [1]California Polytechnic State University

In this paper, fabrication of ceramic parts using projection-based stereolithography by curing the mixture of ceramic and photopolymers was investigated. A stereolithography device with a UV LED projection light source was built. A series of resin and ceramic powders were experimented to explore the viscosity of mixture and the resultant part quality. It was found that the viscosity was very high for all of the mixtures with high ceramic loading which will influence the quality of parts. The fabricated green body was sintered afterwards to achieve higher relative density. The binder was found to be burned out and the ceramics were densified.

9:15 AM

Slurry-based Laser Sintering of Alumina Ceramics: ***Sebastian Meyers***[1]; Quinten Feys[1]; Shoufeng Yang[1]; Jef Vleugels[1]; Jean-Pierre Kruth[1]; [1]Ku Leuven

Additive manufacturing of ceramics is gaining interest. Lithography based processes specifically are rapidly emerging as promising manufacturing techniques for alumina ceramics. However, they are not well suited for processing some ceramics like SiC. Additionally, lithography-based techniques are very time-consuming due to the slow debinding process. In this work, a slurry-based laser sintering process is investigated. Laser sintering allows for a broad palette of materials to be used. Since the binder content is only about 16 vol% with respect to ceramic, the debinding process is also faster and less risky with respect to crack formation and part warping in comparison to lithography-based manufacturing. The alumina slurry used here was optimized by changing the dispersant content until a minimum viscosity was reached. This slurry was then used as a starting material for laser sintering. After debinding and furnace sintering, multi-layer alumina parts with densities up to 97% were obtained.

9:35 AM

Leveraging Temperature-dependent Rheological Behaviors of Ceramic Slurry for Support-free Fabrication: ***Li He***[1]; Xuan Song[1]; [1]University of Iowa

Stereolithography has attracted a lot of interest in fabricating complex ceramic objects. However, when building structures with complex overhanging branches, this process requires creating support structures underneath, which consequently lead to many issues in the resulting components, such as poor surface quality, high risk of damage, etc. In this article, a new Suspension-Enclosing Projection-Stereolithography (SEPS) process is presented to enable the support-free fabrication of ceramic structures with complex overhangs. In this process, a high solid-loading ceramic slurry is used as the feedstock material. The support-free fabrication of an overhang is achieved by dynamically tuning the temperature-dependent yield stress of the feedstock material before and after the material is coated via a modified slot-die extruder. The rheological properties of the ceramic slurry under different temperatures are studied. This new process provides an efficient route for fabricating geometries with complex overhanging branches.

9:55 AM Break

10:25 AM

Material Properties of Ceramic Slurries for Applications in Additive Manufacturing Using Stereolithography: ***Erin Maines***[1]; Nelson Bell[1]; Lindsey Evans[1]; Matthew Roach[1]; Lok-Kun Tsui[1]; Judith Lavin[1]; David Keicher[1]; [1]Sandia National Laboratories

Stereolithography (SLA) is a process that uses photosensitive polymer solutions to create 3D parts in a layer by layer approach. In addition to printing traditional/commercially available resins, we at Sandia National Labs are interested in using SLA for the printing of ceramic loaded resins, namely alumina, that we are formulating here at the labs. One of the most important aspects for SLA printing of ceramics is the properties of the slurry itself. The work presented here will discuss the experimental approach in identifying, optimizing, and characterizing slurry formulations to achieve highly loaded alumina resins. We will use these materials to print parts ranging in complexity and measure the material characteristics/properties before and after sintering. This work will allow for a more comprehensive understanding of what basic slurry properties will yield the desired results of sintered parts. SAND2018-3007 A

10:45 AM

Additive Manufacturing of Alumina Components by Extrusion of In-situ UV-cured Pastes: ***Lok-kun Tsui***[1]; Erin Maines[2]; Lindsey Evans[2]; David Keicher[2]; Judith Lavin[2]; [1]University of New Mexico; [2]Sandia National Laboratories

Additive manufacturing of ceramic materials is an attractive technique for rapid prototyping of components at small scales and low cost. We have investigated the printing of alumina pastes loaded at 70-81.5 wt% solids in a UV curable resin. These can be deposited by extrusion from a syringe head on a Hyrel System 30M printer. The print head is equipped with an array of UV LEDs which solidify the paste without the need for any applied heating. Parameters optimized include print speed, layer height, applied force, and deposition rate. Using A15 alumina and submicron A16 powder precursors, we can achieve bulk densities of 91% and 96% of theoretical density respectively. The influence of dispersants and surfactants added to the powder on the rheology of the pastes, the print process parameters, and the quality of the final components are also investigated.

11:05 AM

Mitigating Coffee-ring Defect Formation in Ceramic On-demand Extrusion Parts: ***Austin Martin***[1]; Wenbin Li[1]; Jeremy Watts[1]; Ming Leu[1]; Gregory Hilmas[1]; Tieshu Huang[2]; [1]Missouri University of Science and Technology; [2]NNSA's Kansas City National Security Campus

Ceramic On-Demand Extrusion (CODE) is a direct-write (DW) process which allows for the creation of near theoretically dense parts with large cross-sections due to oil-assisted, uniform drying. The coffee-ring effect, a term coined when insoluble particles flow toward the outside portion of a droplet due to contact line pinning, has been observed during the final drying of CODE parts. This effect scales with part size, and for large dimensions this effect can cause macroscopic defects. This study explores the mitigation of the coffee-ring effect in a 3 mol % yttria-stablized zirconia (3YSZ) colloidal paste. Chemical modifications, such as pH and surfactant concentration, which affect the paste colloidal stability, and physical methods, such as induced Marangoni flow, which suppresses the coffee-ring effect, are investigated. The relative strengths of these parameters were examined and used to eliminate the defect. Finally, the effect these modifications have on the final microstructure will be discussed.

11:25 AM
Tuning Nanoparticle Suspension Viscoelasticity for Multimaterial 3D Printing of Silica-Titania Glass: ***Nikola Dudukovic***[1]; Lana Wong[1]; Du Nguyen[1]; Joel Destino[2]; Tim Yee[1]; Frederick Ryerson[1]; Tayyab Suratwala[1]; Eric Duoss[1]; Rebecca Dylla-Spears[1]; [1]Lawrence Livermore National Laboratory; [2]Creighton University
The lack of predictive methodology is frequently a bottleneck in AM materials development. Exploration of new printable materials hence often relies on trial and error. We present an approach for 3D printing of multimaterial silica-titania glass using direct ink writing (DIW). We formulate simple inks from suspensions of fumed silica nanoparticles in an organic solvent with a molecular TiO2 precursor. Using a small set of experimental data and DLVO theory, we develop a predictive tool for designing inks with matched desired rheological properties at matched solids loading. The model captures the effects of all formulation parameters on the measured viscoelasticity in a single curve. We further demonstrate that these inks can be printed and post-treated to fully transparent glass with spatial change in composition and refractive index. ***This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-743648.***

Materials: Metals 3 - Nickel-based Alloys

Tuesday AM — Room: 615AB
August 14, 2018 — Location: Hilton Austin

Session Chair: Ola Harrysson, North Carolina State Univ

8:15 AM
Effects of Process Parameters and Heat Treatment on the Microstructure and Mechanical Properties of Selective Laser Melted Inconel 718: ***Wenpu Huang***[1]; Zemin Wang[1]; Jingjing Yang[1]; Huihui Yang[1]; Xiaoyan Zeng[1]; [1]Huazhong University of Science and Technology
In this study, Inconel 718 superalloy was fabricated by selective laser melting (SLM) and solution treated at 980-1230 °C subsequently. The process window was firstly set up based on the density of the samples. Samples were fabricated using various parameters within the process window to investigate the effects of process parameters on microstructure and mechanical properties. The average dendrite arm spacing and the volume fraction of Laves phase raise along with the increasing energy input. However, no distinct difference of tensile properties was found under parameters in the process window. Interdendritic Laves phase decreases with the solution temperature, while the grain size has the opposite trend. Finally, the solution temperature was fixed at 1080 °C to dissolve Laves phases and obtain fine grains. After solution + aging heat treatment, the tensile strengths and ductility all exceed the wrought Inconel 718.

8:35 AM
Primary Processing Parameters and Porosity Development: ***Luke Sheridan***[1]; Joy Gockel[2]; Onome Scott-Emuakpor[1]; Tommy George[1]; [1]Air Force Research Laboratory; [2]Wright State University
The literature has shown that processing plays a significant role in defect development in AM components. It is well understood that defects cause debits in fatigue life, but reducing defect density in AM components, whether through post-processing or improved process control, can significantly prolong the lives of components. Therefore, an experiment has been conducted to determine the influence of several primary processing parameters on the porosity in AM components. Over 100 IN718 AM specimens were imaged using both destructive and non-destructive methods, and pore measurements were collected. Regression models were constructed for various pore attributes, and analysis of variance was conducted to determine the most significant process parameter interactions for the formation of porosity. This work paves the way for a larger study which will shed light on the effect of processing on fatigue performance and direct future efforts toward closing the processing-structure-property-performance loop for fatigue of AM components.

8:55 AM
Microstructure and Mechanical Properties of Laser Repaired Inconel718 Superalloy Assisted with Electromagnetic Stirring: ***Fencheng Liu***[1]; [1]Nanchang Hangkong University
Electromagnetic stirring was combined with laser additive remanufacturing to achieve the repaid and high quality repairing of Inconel718 superalloy samples. Microstructure analysis showed that with the increase of magnetic field intensity, the interdendritic eutectic Laves phase with continuous strip-like changed to discontinuous and worm-like, and its volume fraction decreased to 3.85 vol.% when the magnetic field intensity was 2T. This also resulted in much more uniformly distribution of alloy elements such as Nb and Mo in repaired area. After direct aging treatment, larger amount of γ' phase precipitated and its volume fraction significantly increased from 60% to 63%, 70% and 64% when the magnetic field intensity was 0, 1, 2 and 3T. Tensile tests showed a much higher tensile strength of 926 and much higher elongation of 20% was obtained when the magnetic field intensity is 2T. Direct aging treatment then raised tensile strength up to 1351 MPa.

9:15 AM
Creep Performance of Laser Powder Bed Fused Inconel 718 and Effect of Post Processing: Zhengkai Xu[1]; James Murray[1]; ***Chris Hyde***[1]; Adam Clare[1]; [1]The University of Nottingham
The creep performance of laser powder bed fusion manufactured Inconel 718 specimens, in the as-built, heat-treated and hot-isostatic pressed conditions are compared with conventional hot-rolled equivalents. The hot-rolled specimens displayed the best creep resistance, while the hot-isostatic pressed specimens yielded the worst performance, even inferior to the as-built condition. However, the heat-treated specimens displayed an improved creep resistance in comparison to the as-built benchmark. Fractography revealed that intergranular cracking was the primary failure mode for the as-built samples with preferential intergranular precipitation, caused during the hot-isostatic pressing, explaining a decrease in creep resistance. Only sparse intergranular precipitates found in the heat-treated equivalents explains an increase in creep resistance. The hot-rolled specimens are shown to have the smallest grain size and showed the least extensive cracking, particularly in locations of the finest grains. This explains the avoidance of intergranular fracture, and thereby the more ductile creep fracture surfaces in this case.

9:35 AM
Influence of Cobalt on the Microstructure of in-situ mixed Inconel 718 and Co Manufactured in Selective Laser Melting: ***William Reynolds***[1]; Adam Clare; Blanka Szost; Alper Evirgen; [1]Nottingham University
In-situ alloying has been used to further understand the formulation of flexible and cost-effective novel alloys in Selective Laser Melting (SLM). Alloys of Inconel 718, Inconel 718 + 5% Co and Inconel 718 + 9% Co additions were used in this study using simply mixed powder feedstock. The size of Inconel powder particles is 36µm and the size of the Co powder particles is 1-3µm. The effect of the Co additions to Inconel 718 on its microstructure was assessed by SEM imaging, EBSD and XRD. The effect of in-situ alloying with Inconel 718 has not been studied in literature thus far. The Co additions to the Inconel 718 have changed the solidification mechanics of the melt pool, transitioning it from predominantly dendritic growth to a cellular growth mechanism. The effect of Co additions has resulted in elemental phase segregation in the melt pool but requires further study of the amount.

9:55 AM Break

10:25 AM
Mechanical Properties of Inconel 625 and 718 Processed Using a Renishaw's Multi Laser Powder Bed Fusion System: ***Ravi Aswathanarayanaswamy***[1]; Rhys Jones[1]; Laura Howlett[1]; Marc Saunders[1]; [1]Renishaw Plc
In this study, the density and mechanical properties of Inconel 625 and 718 parts fabricated using a quad-laser Renishaw machine were analysed. Tensile bars were built using 1) all four lasers to address the build platform with one laser assigned per part, 2) using all four lasers to address each part on the build platform and 3) parts built using a single laser only. High part densities were observed for all three scenarios. In all cases room temperature ductility in both as-built and heat-treated conditions was higher than previously reported, which can be traced to improved gas flow.

10:45 AM
Relationship between Defects Population and Tensile Properties of Inconel 625 Alloy: Hamed Asgari[1]; Mehrnaz Salarian[2]; ***Mihaela Vlasea***[2]; [1]University of Waterloo, Waterloo; [2]University of Waterloo
X-ray computed tomography (XCT) is a non-destructive method for imaging internal and external 3D features of a solid object. In this study, Inconel 625 tensile samples were manufactured by Selective Laser Melting (SLM) at a constant scan speed but different laser power. Micro-scale CT examination was performed on the samples before and after tensile tests to evaluate the size, morphology, and distribution of the pores along the gauge length. In addition, fracture surfaces of the tensile tested samples were examined using Scanning Electron Microscopy (SEM) to clarify the origin of failure and pore formation. Detailed information obtained from XCT method contributed to establish a relationship between defects population and tensile properties of the samples

11:05 AM
Fabrication of Crack-free Regular-C HX Superalloy Using Laser Powder Bed Fusion: Oscar Sanchez Mata[1]; Jose Muniz Lerma[1]; Xianglong Wang[1]; Mohammad Attarian Shandiz[1]; ***Mathieu Brochu***[1]; [1]McGill University
Despite being considered weldable, HX has been reported to suffer from solidification issues when processed using laser powder bed fusion. To circumvent this issue, one explored strategy is to reduce the concentration of key alloying elements, and simultaneously altering the mechanical properties. The goal of this presentation is to highlight the recent advanced in the manufacturing of crack-free Hastelloy X with conventional composition. Results obtained for different geometries were analysed using high resolution SEM for as-built and heat treated conditions. Basic mechanical properties will also be reported.

11:25 AM
Multi-material Additive Manufacturing (MMAM) of Austenitic Stainless Steel 316L with Nickel-based Hastelloy X Using Selective Laser Melting (SLM): Parameter Optimization: ***Haiyang Fan***[1]; Shoufeng Yang[1]; [1]KU Leuven
Multi-material additive manufacturing (MMAM) enables site-specific properties on a single part, which unlocks a new field for design and fabrication of components with polyfunctionality. To create parts with both corrosion and high temperature resistance, samples comprising of stainless steel 316L (SS 316L) and Hastelloy X (HX) were fabricated via selective laser melting (SLM). The SS 316L was firstly built as baseplate and then the building of HX alloy on SS 316L was implemented with varying laser speed 100-800mm/s together with different hatch space 30-90 ìm. The optical microscope (OM) and SEM were employed to examine the interfacial defects; EDS measurements indicated a heterogeneous convection of materials, and the bonding width ranges from dozens of micron to a few hundred microns, depending on the energy density (ED). Results showed that 200 mm/s-90 ìm and 600 mm/s-45 ìm are the two best combinations to fabricate a multi-material SS 316L-HX.

Materials: Metals 4 - Stainless Steels 17-4PH and 304

Tuesday AM — Room: 616AB
August 14, 2018 — Location: Hilton Austin

Session Chair: Aref Yadollahi, Mississippi State Univ

8:15 AM
Effect of Powder Formation and Laser Scan Length on Powder Bed Fusion 17-4 Stainless Steel: ***Andelle Kudzal***[1]; Billy Hornbuckle[1]; Josh Taggart-Scarff[1]; Brandon McWilliams[1]; [1]Army Research Laboratory
Previous work has shown that the overall microstructure and mechanical properties for powder bed fusion (PBF) additively manufactured parts can be controlled through adjusting the laser processing parameters to locally control the thermal history. In this work cones with varying heights were manufactured using PBF in order to examine the effect of laser scan length as a means to control phase transformation kinetics and grain size in 17-4 stainless steel within a single part. It was found that decreasing the scan length allows for more uniform melt pools reducing the defect concentration dramatically. Microstructures were examined using optical microscopy, x-ray diffraction, and electron backscatter diffraction. Porosity was quantified using micro-computed-tomography and optical microscopy to measure the effect of scan length on defect size and concentration. The effect the powder forming gas as well as the chamber atmosphere on defect formation, material and mechanical properties will also be presented and discussed.

8:35 AM
Effects of Design Parameters on Thermal History and Mechanical Behavior of Additively Manufactured 17-4 PH Stainless Steel: ***Rakish Shrestha***[1]; Pooriya Dastranjy Nezhadfar[1]; Mohammad Masoomi[1]; Jutima Simsiriwong[2]; Nima Shamsaei[1]; [1]Auburn University; [2]University of North Florida
In this study, the effects of part size on thermal history and mechanical properties of additively manufactured 17-4 PH stainless steel were investigated under monotonic tensile and strain-controlled fatigue loadings. Two sets of specimens were machined from square rods and oversized specimens, which were fabricated using a laser bed powder fusion (L-PBF) process, to introduce variation in specimen geometry and consequently thermal history. Monotonic tensile tests were conducted at a strain rate of 0.001 s-1. Fully-reversed (Re = -1), strain-controlled fatigue tests were performed at 0.003 and 0.0035 mm/mm, and varying test frequency to maintain a constant average strain rate in all tests. Experimental results indicated minimal effect of specimen geometry on the tensile properties of L-PBF 17-4 PH SS, which were also found to be comparable to the wrought material. On the other hand, some influence of specimen geometry on fatigue behavior was observed. Specimens machined from square rods exhibited slightly higher fatigue resistance as compared to specimens machined from oversized specimens. Furthermore, thermal simulations demonstrated higher bulk heating in specimens machined from oversized specimens as compared to those from square rods, which indicated the effect of part geometry on thermal history experienced by the fabricated part.

8:55 AM
Effects of Powder Recycling on the Mechanical Properties of Additively Manufactured Stainless Steel 17-4PH: ***Amanda Sterling***[1]; Arash Soltani Tehrani[1]; Scott Thompson[1]; Nima Shamsaei[1]; [1]Auburn University
With the increasing interest in additive manufacturing (AM), more industry and research consumers are adopting this technology into their work scopes; the Laser-Based Powder Bed Fusion process, a common AM method for metals, is of particular interest. One obstacle in using AM for production is the high cost of powder feedstock. A tactic to offset this cost is to reuse the powder between AM builds/'prints', but there is no in-depth understanding of how the feedstock may change or affect mechanical properties of the produced parts. By incorporating unique powder/part characterization methods, this study quantifies the rheological properties of continually recycled stainless steel 17-4 PH powder through successive printing of mechanical test coupons, focusing on particle size/shape, flowability, and density. The AM coupons are subjected to mechanical testing, the results of which are correlated with the changing powder quality.

9:15 AM
Fatigue and Fracture Behavior of 17-4 PH Stainless Steel Fabricated via Laser Powder Bed Fusion (LPBF): ***Aref Yadollahi***[1]; Mohamad Mahmoudi[2]; Haley Doude[1]; Alaa Elwany[2]; Linkan Bian[1]; James Newman[1]; [1]Mississippi State University; [2]Texas A&M University
In this study, effects of build/crack orientation and heat treatment on fatigue and fracture behavior of 17-4 precipitation hardening stainless steel fabricated via a laser powder bed fusion (LPBF) process are investigated. The crack growth rate data versus stress intensity factor range were generated based on compression precracking procedures at different stress ratios, over a wide range of rates from threshold to fracture. Fully-reversed (R = -1) fatigue tests were performed at room temperature. Mechanism of failure, defects and microstructural features were characterized using scanning electron microscopy and X-ray computed tomography. Experimental results indicate that building orientation play a significant role on fatigue crack growth behavior as well as fatigue strength in both low cycle and high cycle. Moreover, in the presence of large lack-of-fusion defects, which serve as crack initiation sites, post-fabrication heat treatment is detrimental for fatigue performance of this particular alloy in longer life regimes.

9:35 AM
Crack Growth-based Fatigue Life Prediction of LPBF 17-4 PH SS Using Defect Characteristics: ***Aref Yadollahi***[1]; Mohamad Mahmoudi[2]; Haley Doude[1]; Alaa Elwany[2]; Linkan Bian[1]; James Newman[1]; [1]Mississippi State University; [2]Texas A&M University
In this study, fatigue life of 17-4 precipitation hardening (PH) stainless steel (SS) fabricated via a laser powder bed fusion (LPBF) process is predicted based on crack growth approach. To perform fatigue life calculations, effective stress intensity factor as a function of crack growth rate is obtained from testing LPBF 17-4 PH SS compact tension (CT) specimens, before and after heat treatment. Characteristics of process-induced defects—including size, shape, and location—that served as crack initiation site are considered herein to predict the fatigue life of heat treated and non-heat treated specimens using the plasticity-induced crack closure model, FASTRAN. Considering that the cracks (i.e. process–induced defects) already exist in the materials fabricated via additive manufacturing (AM) process, the results indicate that crack growth-based modelling of fatigue is a promising technique for predicting the life of AM materials.

9:55 AM Break

10:25 AM
Mechanical Properties of 17-4 PH Stainless Steel Additively Manufactured under Ar and N2 Shielding Gas: ***Pooriya Dastranjy Nezhadfar***[1]; Mohammad Masoomi[1]; Scott Thompson[1]; Nima Shamsaei[1]; [1]Auburn University
This study investigates the effect of using either argon or nitrogen as the shielding gas on the final mechanical properties of additively manufactured (AM) 17-4 PH stainless steel (SS). The difference in thermo-physical properties of shielding gases during the additive manufacturing process can affect part thermal response. Simulations are performed to elucidate the differences in temperature, temperature gradient and cooling rate for argon and nitrogen building environments. Mechanical properties of fabricated parts are studied through micro-hardness and tensile tests. Tensile tests are carried out under 0.001 s-1 strain rate at room temperature. Using both numerical and experimental results, the effects of shielding gas type on AM 17-4 PH SS will be presented and discussed.

10:45 AM
Recyclability of 304L Stainless Steel in the Selective Laser Melting Process: ***Austin Sutton***[1]; Caitlin Kriewall[2]; Ming Leu[2]; Joseph Newkirk[2]; [1]Missouri University of Science & Technology; [2]Missouri University of Science and Technology
During part fabrication by selective laser melting (SLM), a large amount of energy is input from the laser into the melt pool, causing generation of spatter and condensate, both of which have the potential to settle in the surrounding powder-bed compromising its reusability. In this study, 304L stainless steel powder is subjected to five reuses in the SLM process to assess its recyclability through characterization of both powder and mechanical property. All powder was characterized by particle size distribution and shape measurements, oxygen content with combustion analysis, and phase identification by X-ray diffraction. The evolution of powder properties with reuse was also correlated to tensile and Charpy impact behavior. The results show that reused powder coarsens and accrues more oxygen with each reuse. The effects of powder coarsening and oxygen increase on the tensile and toughness properties of fabricated parts are being investigated.

11:05 AM
The Influence of Build Parameters on the Compressive Properties of Selective Laser Melted 304L Stainless Steel: ***Okanmisope Fashanu***[1]; Mario Buchely[1]; Rafid Hussein[1]; Sudharshan Anandan[1]; Myranda Ferris[1]; Joseph Newkirk[1]; K Chandrashekhara[1]; [1]Missouri University of Science & Technology
Selective Laser Melting (SLM) is a metal additive manufacturing (AM) method which involves layer-by-layer manufacturing of a part with sequential melting of metal powder based on a CAD model. The build parameters used during processing have a significant effect on the

properties of a manufactured part. In this study, the influence of two build parameters, build direction and hatch angle, on the compressive properties of 304L stainless steel were evaluated. Elastic modulus and plastic deformation behavior were determined, and the effect of build parameters was quantified. The microstructure was analyzed to study the effect of build parameters on damage propagation pathways in the material. A design of experiment (DOE) study was conducted using different levels of the build parameters to study the effects on the aforementioned properties. As a result of this study, material models for numerical modeling were developed.

11:25 AM

Characterization of Impact Toughness of 304L Stainless Steel Fabricated through Laser Powder Bed Fusion Process: Sreekar Karnati[1]; Atoosa Khiabani[1]; ***Aaron Flood***[1]; Frank Liou[1]; Joseph Newkirk[1]; [1]Missouri University of Science and Technology

In this research the impact toughness of powder bed based additively manufactured 304L stainless was investigated. Charpy specimens were built in vertical, horizontal and inclined (45deg) orientations to investigate the variation in toughness with build direction. These specimens were tested in as-built and machined conditions. A significant difference in toughness was observed with varying build directions. The lowest toughness values were recorded when the notch was oriented in line with the interlayer boundary. The highest toughness was recorded when the notch was perpendicular to the interlayer boundary. A significant scatter in toughness values was also observed. The variation and distribution among the toughness values were modeled by performing 3-parameter Weibull fits. The performance and variation of the additively manufactured 304L were also compared with the toughness values of wrought 304 stainless. The additively manufactured material was observed to be significantly less tough and more variant in comparison to wrought material.

11:45 AM

Weldability, Microstructure and Properties of 304 Stainless Steel Joint: Laser Welding and Laser-arc Hybrid Welding: ***Jingjing Yang***[1]; Wenpu Huang[1]; Guanyi Jing[1]; Zemin Wang[1]; Xiaoyan Zeng[1]; [1]Wuhan National Laboratory for Optoelectronics

Welding is a promising process for joining small components produced by selective laser melting (SLM) to fabricate the large-scale and complex-shaped parts. In the work, the morphologies, microstructures, microhardness, tensile properties and corrosion resistance of the SLMed 304 stainless steel joints under laser welding and laser-arc hybrid welding were investigated. Results show that the microstructures of both the two joints are similar, consisting of cellular dendrites in austenite matrix within columnar grains. The two joints exhibit smaller microhardness, lower tensile properties, and superior corrosion resistance than those of the SLMed plates. But, the tensile properties of the joints are higher than the traditional wrought counterpart. The microhardness and tensile properties (~750 MPa, ~680 MPa and ~22%) of laser-welded joints are superior to those of laser-arc hybrid welded joints. Therefore, the SLMed 304 stainless steel plates show a good weldability to verify its feasibility of joining their components by welding.

Physical Modeling 3 - Advanced Thermal Modeling Techniques

Tuesday AM — Room: Salon A
August 14, 2018 — Location: Hilton Austin

Session Chair: Kyle Johnson, Sandia National Laboratories

8:15 AM

Fast Solution Strategy for Transient Heat Conduction for Arbitrary Scan Paths in Additive Manufacturing: Alexander Wolfer[1]; ***Jean-Pierre Delplanque***[1]; Saad Khairallah[2]; Andrew Anderson[2]; Sasha Rubenchik[2]; [1]University of California, Davis; [2]Lawerence Livermore National Laboratory

Due to the multi-physics complexity of metal-based powder bed fusion processes, the most accurate numerical simulations require computational times that prevent full part-scale predictions. Often, simpler analytic solutions are used to predict trends over these scales, but have limiting assumptions. We present a novel solution strategy for rapidly predicting the transient heat conduction during powder bed metal additive manufacturing processes. This allows for quick predictions of melt pool geometry and thermal gradients as a function of process and material parameters. The semi-analytic Green's function approach splits up the solution to deal with the heat introduced by the source separately from the heat diffused into the material. This separation eases computational expenses by allowing calculations to be localized around the heat source. Validation of this solution method is carried out by comparison to numerical simulations at various computational domain sizes and for different heat source scanning patterns.

8:35 AM

Nonisothermal Welding in Fused Filament Fabrication: ***Keith Coasey***[1]; Michael Mackay[1]; David Edwards[1]; [1]University of Delaware

FFF offers an alternative option to traditional polymer manufacturing techniques by allowing for the fabrication of items without molds or templates. However, these parts are strength limited, resulting in a decrease in the interlaminar fracture toughness relative to the bulk material. Here we have proposed a nonisothermal healing model which provides a theoretical framework between the diffusion of molten polymers and the development of interfacial toughness in the FFF process. Using an analytic solution to the Fourier field equation and corresponding heat transfer correlations, the temporal-spatial temperature profile of the extrudate can be modeled. By examining the rheological properties of Acrylonitrile-Butadiene-Styrene and modeling the temperature dependent relaxation behavior, an expression for nonsiothermal welding can be utilized. The effect of various process parameters on the degree of interfacial healing are determined and compared to experimental data. The model compares well to the data when the degree of initial wetting is considered.

8:55 AM
Rheological and Heat Transfer Effects in Fused Filament Fabrication Additive Manufacturing: ***David Phan***[1]; Zachary Swain[1]; Michael Mackay[1]; [1]University of Delaware
The connection between rheological and heat transfer effects is investigated in the fused filament fabrication technique. The pressure drop in a Taz 4-printer hot-end was measured by monitoring the electrical power used to advance filament through the nozzle at different printing outputs. Pressures of order 5000 psi were measured. In order to understand why such large pressures occur, a printer nozzle mimic was made and placed on an extruder that supplied constant temperature polymer melt. A rheological model was constructed to correlate pressure as a function of mass flow rate and temperature. We determined the actual printer temperature by knowing the pressure in the hot-end as a function of print speed. A Nusselt-Graetz number analysis is developed, the results of which demonstrate heat transfer limitations hindering FFF. Our work highlights the importance of rheological and heat transfer effects, which when considered together, will allow for optimization of the FFF process.

9:15 AM
Solidification Simulation of Direct Energy Deposition Process by Multi-phase Field Method Coupled with Thermal Analysis: ***Yusuke Shimono***[1]; Mototeru Oba[1]; Sukeharu Nomoto[1]; [1]ITOCHU Techno-Solutions Corp.
Multi-phase field method (MPFM) coupled with thermodynamics database of calculation of phase diagrams (CALPHAD) has been successfully applied to simulations of solidification microstructure evolutions in engineering casting processes. As MPFM is based on local (quasi-)equilibrium assumption in solidification theory, applying MPFM to solidification of additive manufacturing (AM) processes is not studied enough because of extremely large cooling rate and temperature gradient. On the other hand, some researchers have reported experimental observations of the columnar-to-equiaxed transition (CET) in the solidification of the AM processes included Direct Energy Deposition (DED). They suggest that the local (quasi-)equilibrium assumption can be applied to solidification of AM processes.In this study, solidification microstructures of Ti-alloys in DED are calculated by MPFM. Temperature distributions obtained by thermal analyses in finite element method are used in MPFM. It is confirmed that the microstructures have CET. The results are summarized in a solidification map for DED process conditions.

9:35 AM
A Study of the Effect of Bond Length on Bond Strength in Fused Deposition Modeling Using Transient Heat Transfer Analysis: ***Junaid Baig***[1]; Robert Taylor[1]; Ankur Jain[1]; [1]University of Texas at Arlington
This work aims to quantify the degree of bonding in 3D printed parts in the Fused Deposition Modelling (FDM) process by calculating the bond potential between the extruded layers using finite element (FE) heat transfer analysis. Successive transient analyses were carried out using this model by constantly updating the boundary conditions and geometric model during the deposition of the extruded bead. Temperatures at critical points were calculated over a period of time to calculate the bond potential and analyze the degree of bonding between the layers printed in z-axis. Furthermore, geometry and heat transfer coefficient were altered to investigate their influence on the bond potential. Finally, experimental analysis was carried out with tensile specimens by printing them according to the FE model to establish a relationship between the calculated bond potential and the strength of the FDM parts.

9:55 AM Break

10:25 AM
Thermal Diffusivity Response in MatEx: From FFF to BAAM: ***Anthony D'Amico***[1]; Amy Peterson[1]; [1]Worcester Polytechnic Institute
Increased adoption of additive manufacturing for functional part creation is limited by poor part properties, which are in turn limited by poor interlayer bonding. In AM processes such as Material Extrusion (MatEx) bonding is thermally driven. The range of MatEx printers, from desktop scale systems (FFF) to room scale systems (BAAM), makes it an ideal focus. Existing experimental measurements and models of heat transfer in FDM are limited. Therefore, using finite element analysis, we have developed a 3D model to simulate heat transfer during MatEx. By varying both system scale and material properties, such as thermal diffusivity, we can help direct future rational material design and print parameter selection. In our work we have found distinct temperature regimes rapidly develop and cooling in BAAM is orders of magnitude slower than FFF cooling. Additionally we have observed BAAM and FDM respond dissimilarly to thermal diffusivity changes.

10:45 AM
A New Physics-based Model for Laser Powder-bed Additive Manufacturing: ***Yuze Huang***[1]; Ehsan Toyserkani[1]; Behrad Khamesee[1]; [1]University of Waterloo
This paper addresses a physics-based model for laser powder-bed additive manufacturing. The model can perform an efficient prediction of the melt pool dimension, process heating/cooling rate, 3D profiles of simple multi-track structure, and has the potential to be employed for the fast process optimization and controller design. The novelty of the model lies in these three parts. First, the mass and heat transfer were analytically coupled with considering the schematic particle distribution. Second, the melt pool geometry variation before the contact line being arrested is compensated by a novel approach that counts for the dynamic wetting angle. Third, the residual heat effect in the multi-track scanning is accounted by a dynamic initial temperature.Sensitivity analysis shows that the layer thickness has the largest effect on the track height, followed by the scanning speed. And the laser power has the greatest effect on the melt pool depth.

11:05 AM
Establishing Property-Performance Relationships through Efficient Thermal Simulation of the Laser-Powder Bed Fusion Process: ***Mohammad Masoomi***[1]; Basil Paudel[1]; Nima Shamsaei[1]; Scott Thompson[1]; [1]Auburn University
The concept and verification of a unique numerical method for efficiently predicting the thermal history of additively manufactured parts are presented in this study. This numerical method assumes a constant, uniform heat flux applied on 'bulk layers'. These bulk layers consist of several layers and permit the use of coarser meshes and longer time steps. Various-sized, stainless steel 17-4 (SS 17-4 PH) cubes with thermocouple holes were fabricated using a laser-powder bed fusion (L-PBF) system for validation. Thermocouples were inserted into the holes after they were constructed and de-powdered while still in the chamber, the process was then resumed as to measure successive layer melting. Using experimental measurements and simulation results from new numerical methodology, relationships between process parameters and part size are elucidated. Such relationships can be used to ensure that parts of various sizes have similar thermal histories, and thus performance metrics.

11:25 AM

An Investigation into Metallic Powder Thermal Conductivity in Laser Powder-bed Fusion Additive Manufacturing: ***Shanshan Zhang***[1]; Brandon Lane[2]; Justin Whiting[2]; Kevin Chou[1]; [1]University of Louisville; [2]National Institute of Standards and Technology

This study investigates the thermal conductivity of metallic powder in laser powder-bed fusion (LPBF) additive manufacturing. The intent is to utilize a methodology combining laser flash testing, finite element (FE) modeling and an inverse method to indirectly measure the thermal conductivity of In625 and Ti-6Al-4V powder in LPBF. The testing specimen geometry was designed with powder enclosed after LPBF fabrications to mimic the powder bed state. The specimens were then tested in a laser flash system to measure the thermal diffusivity. Next, the developed FE model and inverse method were applied to analyze the thermal conductivity of LPBF powder from the experiment. The results indicate that In625 powder thermal conductivity in LPBF increases with the increase of temperatures, ranging from 0.65 W/m·K to 1.02 W/m·K at 100 °C and 500 °C, respectively. Further, In625 powder has a higher thermal conductivity, about 35%, than Ti-6Al-4V powder at the same testing temperature.

Physical Modeling 4 - Modeling Part Performance

Tuesday AM — Room: 412

August 14, 2018 — Location: Hilton Austin

Session Chair: Chong Teng, ANSYS

8:15 AM

Low Cost Numerical Modeling of Material Jetting-based Additive Manufacturing: ***Chad Hume***[1]; David Rosen[1]; [1]Georgia Institute of Technology

Material jetting-based additive manufacturing is a promising manufacturing approach with increasing interest in mesoscale applications such as microfluidics, membranes, and microelectronics. At these size scales, significant edge deformation is observed limiting the resolvable feature size. Currently, predicting and controlling such deformations would require extensive experimentation or computationally prohibitive simulations. The objective of this work is to develop a computationally low cost material jetting model that enables the simulation and prediction of mesoscale feature fabrication. To this end, a quasi-static boundary-based method is proposed and demonstrated as a simplified and accurate means of predicting the line-by-line, layer-by-layer feature development. To validate this method, results are compared with high fidelity 3D fluid simulations, as well as a simple deposition height change model found in the literature. The benefits and limitations of each are discussed.

8:35 AM

Numerical Prediction of Fracture in FDM Printed Parts: ***Sanchita Sheth***[1]; Robert Taylor[1]; Hari Kishore Adluru[1]; [1]University of Texas at Arlington

This work discusses a method for numerically predicting fracture in Fused Deposition Modeling (FDM) printed polymer parts. Pre-processing of FDM geometry was done in Abaqus CAE (SIMULIA TM). FEA and post-processing were done in BSAM. BSAM uses a regularized extended finite element approach of Discrete Damage Modeling. Elastic Modulus of the material for different raster orientations was predicted by the software. DCB (Double Cantilever Beam) and ENF (End-Notched Flexure) specimens were modeled in a similar way and the Mode I and Mode II fracture toughness values were predicted. These values were then compared with experimental test data. The obtained values are used to predict fracture in FDM printed parts.

8:55 AM

Screw Swirling Effects on Fiber Orientation and Predicted Elastic Properties in Large-scale Polymer Additive Manufacturing: ***Zhaogui Wang***[1]; Douglas Smith[1]; [1]Baylor University

Large-scale polymer Additive Manufacturing employs a single screw extruder to melt and deliver the pelletized feedstock resulting in significantly higher flow rates as compared to conventional filament-extrusion AM processes. Swirling motion in the melt flow during processing generates a unique pattern of flow-induced fiber alignment when fiber-filled polymer feedstock is processed. This paper investigates the effect of the single screw swirling motion on the fiber orientation and predicted elastic properties of a printed extrudate. A finite element extruder nozzle flow is created, where the extruder screw tip, the extrusion nozzle, and a short section of free extrudate compose the melt flow domain. Of particular interest in this work is the distance between the screw tip and the nozzle convergence region. The results indicate that the swirling motion has an effect on predicted fiber orientation distribution and predicted elastic properties, and RSC-model predicted results are in good agreement with published measurements.

9:15 AM

Numerical Prediction of the Porosity of Parts Fabricated with Fused Deposition Modeling: ***Marcin Serdeczny***[1]; Raphaël Comminal[1]; David Pedersen[1]; Jon Spangenberg[1]; [1]Technical University of Denmark

In this paper, we study the effect of the printing parameters, namely the layer height and the strand-to-strand distance, on the porosity of components produced with Fused Deposition Modeling (FDM). The FDM process is based on the extrusion of melted polymer through a nozzle, which forms a 3D object layer by layer from the subsequent deposition of strands. Previous numerical modeling and experimental studies have showed that the cross-section of the strands depends on the printing parameters. Using Computational Fluid Dynamics, we predict the shape of the cross-sections of multiple strands printed next to each other, and we estimate the porosity of the part. The results of this study show how the porosity of the parts produced by FDM can be controlled by adjustment of the printing parameters, incorporating the knowledge about the strand's cross-sectional shape.

9:35 AM

Numerical Modeling of the Material Deposition and Contouring Precision in Fused Deposition Modeling: ***Raphael Comminal***[1]; Marcin Serdeczny[1]; David Pedersen[1]; Jon Spangenberg[1]; [1]Technical University of Denmark

We will present a numerical model of the material deposition in fused deposition modeling. The flow of the material extruded from the nozzle of the printing head is simulated with the computation fluid dynamics approach. The molten thermoplastic is modeled as an incompressible Newtonian fluid with a free surface. The numerical model provides a prediction of the cross-section of the printed strand. The influence of the printing parameters, such as the printed speed and the layer thickness, on the cross-section of the printed strand is investigated with the numerical model. Finally, the numerical model is used to simulate the contouring of the slice of a part containing a sharp corner. The purpose of the simulation is to quantify the geometrical deviation of the contour. Furthermore, the numerical model provides a tool toward numerical optimization of the processing parameters in extrusion-based additive manufacturing.

9:55 AM Break

10:25 AM
Effect of Environmental Variables on Ti-64 AM Simulation Results: ***Aaron Flood***; Frank Liou[1]; [1]Missouri University of Science and Technology
In metal AM the environment where the process is completed is critical and therefore care should be taken to ensure that the simulation matches reality. This paper will investigate the effect that various environmental factors have on the results of the simulation. This will help to determine their importance in the simulation setup. The material properties which relate to this are the convective coefficient and the emissivity. These material properties will be investigated to determine their effect on the outcome of the simulation. In addition to these properties, the size of the substrate with respect to the fixturing will be investigated to determine if any results are altered. Lastly, the ambient temperature will be investigated to determine the effect this has on the simulation results.

10:45 AM
Continued Evolution of a Part-scale Finite Element Model for Selective Laser Melting at LLNL: ***Neil Hodge***[1]; Rishi Ganeriwala[1]; Jonas Nitzler[1]; Robert Ferencz[1]; [1]Lawrence Livermore National Laboratory
Selective Laser Melting (SLM) is a manufacturing process which can realize significant benefits over traditional manufacturing processes, including significantly shortened time between design and manufacture of parts, and the ability to create parts with much more geometric complexity than has previously been possible. However, the extreme sensitivity of the results to input parameters results in a process that is difficult to predict, and thus control. Indeed, it is not uncommon for the resulting parts to vary significantly from the desired geometry and have undesirable residual stresses. The SLM process is difficult to model for several reasons, including the complex, dynamic physical phenomena, as well as its severely multiscale character. The current presentation will describe ongoing work within the parallel, implicit finite element code Diablo, toward several goals: (1) addition and improvement of physical models, and (2) improvement of simulation throughput, while simultaneously minimizing accuracy degradation.

11:05 AM
Managing Metal AM Process Variability for Machine Drift Using FEA-based Analysis: ***Charles Fisher***[1]; Sam Pratt[1]; Jeff Robertson[2]; Arjaan Buijk[2]; [1]Naval Surface Warfare Center - Carderock; [2]Simufact Engineering
Metal AM part qualification is subject to significant variability in fabrication driven by many non-quantified and non-understood factors. Users of metal AM systems understand there is natural “drift” in the process that leads to change in the resulting build. This drift can be related to the optics, gases, and many other factors, but is assumed to be a fairly linear, continuous change over time. This work describes the latest progress to quantify the process drift, monitor it over time, and establish limits to the drift that are tied to the required dimensional control of parts. The approach leverages a printed test artifact coupled with finite element analysis (FEA) process simulation to routinely quantify the residual stress and strain imparted by AM fabrication and evaluate the effects. This method can enable users to take preventative actions to correct the process drift before it results in quality spillage from non-conforming parts.

11:25 AM
Flowability and Paving Processing DEM Simulation of Nylon Powder under Pre-heated Condition in SLS: ***Yuanqiang Tan***[1]; Xiangwu Xiao[2]; Jiangtao Zhang[1]; Yuntian Feng[3]; [1]Huaqiao University; [2]Xiangtan University; [3]Swansea University
On the basis of Hertz-Mindlin contact model, electrostatic and Van der Waals contact force was introduced to describe the contact dynamics behavior of fine nylon powder particles. Under preheating temperature, the mechanical properties of the powder, including Hamaker constant, elastic modulus and the generation factor of charge, were obtained by the experiments. The DEM model of Nylon powder bed was set up and verified by AFM measurement results. Based on EDEM-API, the code used to calculate the dynamics of nylon powder paving processing in SLS was developed. Numerical simulation of flow process and the powder paving process under different working conditions was carried out. The properties of the compact density, the uniformity of the density and the smoothness of the powder bed were used to characterize the powder bed quality. The quality of paving powder bed affected by the structure and movement parameters of the roller were analyzed.

11:45 AM
Processing Parameter and Transient Effects in Additive Manufacturing of Invar 36: ***Eric-Paul Tatman***[1]; Chigozie Obidigbo[1]; Joy Gockel[1]; [1]Wright State University
Additive manufacturing (AM) provides benefits such as low cost and lead times that are attractive for composite tooling fabrication. Invar is common in tooling because of its low CTE but is heavy and difficult to machine. Using AM allows for fabrication of near net shape tools and the ability to combine dissimilar materials. This research focused on the use of finite element analysis and simple experiments to understand the material behavior for Invar 36. Steady-state results show that melt pool behavior is similar to other AM materials and transient results have exposed process variation concerns. For multiple material deposition, stress at the interface of the materials is a concern. Initial modeling results are presented for the stresses at the interface between the Invar and Steel subjected to thermal loads representative of the AM process. Results indicate Invar is suitable for use in AM, which can enable rapid tooling fabrication.

Process Development 4 - Metal Powder Bed Fusion 2

Tuesday AM — Room: 416AB
August 14, 2018 — Location: Hilton Austin

Session Chair: Subhrajit Roychowdhury, GE Global Research

8:15 AM
On the Influence of Thermal Lensing during Selective Laser Melting of Metals: ***Louca Goossens***[1]; Yannis Kinds[1]; Jean-Pierre Kruth[1]; Brecht Van Hooreweder[1]; [1]KULeuven
Multi kilowatt single mode lasers are increasingly being used in Selective Laser Melting (SLM), typically with the aim of improving productivity. However, the high power densities present in the optical path lead to a thermally induced focal shift i.e. thermal lensing. Whilst thermal lensing has been studied for many processes, it’s impact on parts produced by SLM is currently unknown. Therefore this work discusses the characteristics of a thermally induced focal shift supplemented by a method for the compensation of this effect. In addition, SLM parts with and without thermal lensing compensation are compared in order to show the effect on final part quality.

8:35 AM

Development of Novel High Temperature Laser Powder Bed Fusion System for the Processing of Crack-susceptible Alloys: ***Leonardo Caprio***[1]; Gianmarco Chiari[1]; Ali Gökhan Demir[1]; Barbara Previtali[1]; [1]Politecnico di Milano

In the present industrial panorama, Laser Powder Bed Fusion (LPBF) systems enable for the near net shaping of metal powders into complex geometries with unique design features. This makes the technology appealing for many industrial applications, which require high performance materials combined with lightweight design or conformal cooling channels. However, many of the alloys that would be ideal for the realisation of these functional components are classified as difficultly weldable due to their cracking sensitivity. Currently, industrial SLM systems employ baseplate preheating to minimise these effects although this solution is limitedly effective along the build direction and often does not achieve high enough temperatures for the realisation of crack-free specimen. In this work, the design and implementation of a novel inductive high temperature LPBF system is presented. Furthermore, preliminary results regarding depositions of Titanium Aluminide alloy with and without preheating are reported, showing the potential of the solution developed.

8:55 AM

Investigation of External Illumination Strategies for Melt Pool Geometry Monitoring in SLM: ***Luca Mazzoleni***[1]; Leonardo Caprio[1]; Matteo Pacher[1]; Ali Gökhan Demir[1]; Barbara Previtali[1]; [1]Politecnico di Milano

Coaxial monitoring in SLM can be applied using different configurations in terms of sensor choice and observed bandwidth. The use of external illumination to observe the melt pool geometry by suppressing the process emission is an option, where the melt pool geometry can be visualized independently from the changes in the emission behavior. However, the correct choice of the illuminator and the configuration in which it is implemented is an issue that requires further attention. This paper is aimed at obtaining a direct observation of the molten pool geometry using an external illumination source to suppress process emission. A coaxial imaging system was devised for this purpose and two different setups for light launching were designed and tested, namely a diode laser beam coaxial to the working laser and a lateral low-coherence laser illuminating the whole build platform. The advantages and criticalities of each experimental setup are extensively discussed. External illumination was found to be useful for interpreting directly the SLM melting conditions. Furthermore, the real scan position and velocity could be measured through an image processing algorithm on the captured frames.

9:15 AM

Transient Dynamics of Powder Spattering in Laser Powder Bed Fusion Additive Manufacturing Process Revealed by In-situ High-speed High-energy X-ray Imaging: ***Qilin Guo***[1]; Cang Zhao[2]; Luis Escano[1]; Zachary Young[1]; Lianghua Xiong[1]; Kamel Fezzaa[2]; Wes Everhart[3]; Ben Brown[3]; Tao Sun[2]; Lianyi Chen[1]; [1]Missouri University of Science and Technology; [2]Argonne National Laboratory; [3]Honeywell FM&T

Powder spattering is a major cause of defect formation and quality uncertainty in the laser powder bed fusion (LPBF) additive manufacturing (AM) process. It is very difficult to investigate this with either conventional characterization tools or modeling and simulation. The detailed dynamics of powder spattering in the LPBF are still not fully understood. Here, we report insights into the transient dynamics of powder spattering in the LPBF process that were observed with in-situ high-speed high-energy x-ray imaging. Powder motion dynamics, as a function of time, environment pressure, and location, are presented. The moving speed, acceleration, and driving force of powder motion that are induced by metal vapor jet/plume and argon gas flow are quantified. A schematic map showing the dynamics and mechanisms of powder motion during the LPBF process as functions of time and pressure is constructed. Potential ways to mitigate powder spattering during LPBF process are discussed and proposed.

9:35 AM

Towards High Build Rates - Combining Different Layer Thicknesses within One Part in Selective Laser Melting of 316L Steel: ***Michael Kniepkamp***[1]; Jana Harbig[1]; Christoph Seyfert[2]; Eberhard Abele[1]; [1]PTW TU-Darmstadt; [2]EOS GmbH Electro Optical Systems

Additive manufacturing of metallic parts using powder bed based fusion processes like selective laser melting are increasingly used in industrial applications. With typical layer thicknesses of 20-40 microns, good surface qualities and high geometrical accuracy can be achieved compared to other AM processes. However, low layer thicknesses are to the detriment of build rates as more layers are required. Increasing layer thickness can significantly increase build rates at the cost of surface quality and accuracy. In this paper, a new parameter set for a layer thickness of 60 microns is developed and combinations of different layer thicknesses within one part are investigated. This strategie set aims at achieving increased build rates while high geometrical accuracy can be maintained when locally required. Specimens with combinations of different layer thicknesses in various build orientations are produced and mechanically tested. Micrographs of the layer transitions are examined and design recommendations are given.

9:55 AM Break

10:25 AM

Partial Contact Based Support Architecture Design for Additive Manufacturing: ***MD Ahasan Habib***[1]; Bashir Khoda[1]; [1]North Dakota State University

Support structures are required in several additive manufacturing (AM) processes to hold the overhang section, restrain the model deformation or warp which need to be removed at the post processing stage of fabrication. The consequences of the support structure are wastage of resources and bad surface quality. In this research, a partial contact-based support architecture design technique is proposed to ensure ease of its removal and minimize support-model contact imprint on the surface. The creep deformation of the extruded material is used by controlling the raster width at the support-model interface layer to achieve the discrete contact. The gravitational sagging of the support material is modeled considering the material properties and the process parameters. The concave profile of the sagged support material consequently permits the controlling of the model-support partial contact and material fusion. Fabricating overhang object with the proposed technique allows ease-of-removal of support material and better surface quality.

10:45 AM

Local Microstructure Control across AM Processes and Alloy Systems: Sneha Narra[1]; Rahi Patel[1]; ***Jack Beuth***[1]; [1]Carnegie Mellon University

Microstructure control, including the localized control of microstructure within AM fabricated components has been advanced by the authors. This talk will summarize efforts to date on controlling microstructure in electron beam fabrication of Ti64, and laser beam fabrication of AlSi10Mg and IN 718. Microstructural outcomes to be controlled will include grain size and texture. Results will include the level of resolution achievable in defining interfaces between different regions of microstructural control, in different planes of a component. The effect of beta grain size control on mechanical properties in the electron beam AM will be described, as will the linkages between control of microstructures formed at solidification with those formed during solid state transformations for both e-beam and laser processes.

11:05 AM

Laser Heated Electron Beam Gun Optimization to Improve Electron Beam Additive Manufacturing and Presentation of Open Source Controls for AM : ***Ralf Edinger***[1]; [1]Canmora Tech Inc.

Electron Beam Additive Manufacturing (EBAM) is melting individual layers, which added together will result in a 3-dimensional part requiring many hours of continuous electron gun operation. As a result, the electron beam gun is exposed to thermodynamic loads, gas back spattering and process related variations which must be considered to improve part accuracy. Discussed will be solutions to improve systematic cooling and initial ideas to reduce cathode degradation during the melting process. Changes in the cathode emission impacts electron energies therefore changing beam deflection and focusing accuracy and repeatability. In addition to optimizing the machine hardware we will discuss dynamically adjusting control loops modifying process parameters based on an Open Source Additive Manufacturing platform/software.

11:25 AM

High Speed In Situ Measurement of the Cooling Rate in a Complex Part Manufactured Using Powder Bed Fusion: ***Jarred Heigel***[1]; Eric Whitenton[1]; [1]National Institute of Standards and Technology

Microstructure of metal parts manufactured using additive manufacturing depends on the thermal history during the process. High-speed infrared thermography enables the measurement of cooling rates that can correlate with microstructure. Often, these measurements are performed during single-track scans on bare substrates. However, the thermal history of complex multi-layer parts can be drastically different due to a variety of factors. This work presents preliminary thermographic measurements acquired during the production of a complex part using laser powder bed fusion. The part has multiple features which induce a range of thermal responses. The calculated cooling rates of select layers are compared. The comparison reveals the relationship between cooling rates, local part geometry, and laser scan strategy. Further comparisons with earlier work indicate that the cooling rates from single-track scans on bare substrates are an order of magnitude faster than those observed during the manufacture of the multi-layer part in the current study.

11:45 PM

Keyhole Mitigation at Turn around Using a Predictive Mesoscopic Model: ***Saad Khairallah***[1]; Jianchao Ye[1]; Gabe Guss[1]; Michael Crumb[1]; John Roehling[1]; Alexander Rubenchik[1]; Manyalibo Matthews[1]; Andy Anderson[1]; [1]Lawrence Livermore National Laboratory

A mesoscopic high fidelity simulation model is combined with laser ray tracing to understand the main physics in Laser Powder Bed Fusion. The model is applied to calculate absorptivity of SS316L and Ti64 as well as melt pool dimensions as a function of laser power and scan speed. The experimental validation of these results proves that the laser ray tracing enabled model is a predictive tool with little controlled approximations. The model is further employed to optimize laser power during turn around and prevent keyholing and generation of pore defects. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE- AC52-07NA27344. Lawrence Livermore National Security, LLC.

Process Development 5 - Imaging

Tuesday AM	Room: Salon F
August 14, 2018	Location: Hilton Austin

Session Chair: Toshiki Niino, Univ of Tokyo

8:15 AM

In-situ Optical Emission Spectroscopy during SLM of 304L Stainless Steel: ***Cody Lough***[1]; Bristow Douglas[1]; Landers Robert[1]; Edward Kinzel[1]; [1]Missouri University of Science and Technology

This paper explores performing in-situ Optical Emission Spectroscopy (OES) during Selective Laser Melting (SLM) of 304L stainless steel. OES has widely been used in laser welding and slightly used in Directed Energy Deposition (DED) Additive Manufacturing (AM). There are limited reports of OES in powder bed based AM. In this paper OES is implemented with the spectrometer in-line with the laser beam path on a Renishaw AM250 SLM platform. The collected optical emission signal is discussed and correlated with engineering properties (density, modulus, yield strength, and ductility) and microstructure (porosity, grain size, texture and phase field) of manufactured parts. OES is then examined as a potential for radiometric feedback in control of the SLM process.

8:35 AM

Acoustic Emission Technique for Online Detection of Fusion Defects for Single Tracks during Metal Laser Powder Bed Fusion.: ***Dean-paul Kouprianoff***[1]; Nicolaas Luwes[1]; Ina Yadtriotsava[1]; Igor Yadtroisev[1]; [1]Central University of Technology

One of the main drawbacks of laser based powder bed fusion is lack of fusion between tracks following non-optimal input process parameters, scanning and building strategies and/or inhomogeneity in the delivered powder layer. Unstable geometrical characteristics of single tracks and high roughness of the powder layer can cause porosity in 3 dimensional printed parts. In this study a non-destructive online monitoring technique using acoustic emission was utilized to determine lack of fusion and balling effect of single tracks. This phenomenon was simulated by an increased powder layer thickness. Short Time Fourier Transform was used as a tool for analysis of the acoustic behaviour of the system and comparison of acoustic emission (AE) during processing of single tracks.

8:55 AM

Development of an Acoustic Process Monitoring System for the Selective Laser Melting (SLM): ***Niclas Eschner***[1]; Lukas Weiser[1]; Gisela Lanza[1]; [1]wbk-Institut of Production Science

The current selective laser melting (SLM) process lacks on process quality and reproducibility. Recent research work focuses on the integration of optical measuring technology. Beneath, acoustic sensor seem to be promising as well. Initial results show it's suitability but lack on further analysis of its capabilities. An acoustic process monitoring system is qualified for SLM in this work, to identify different types of defects. For this purpose, various integration possibilities for acoustic measurement techniques are discussed. The most promising structure-borne sound concept is integrated and tested in a test bed. With this, specific parameter selection can be used to influence the component property and create relevant defects. The resulting defective components are inspected with appropriate reference measurement technology and the defect characteristics are correlated with the recorded process signals. Throughout, an evaluation of the current process quality is carried out and possible control strategies for reproducibility increase are derived.

9:15 AM
Development of an In-situ Layerwise Imaging System for Metallic Powder Bed Fusion Additive Manufactured Parts: ***Christian Gobert***[1]; Andelle Kudzal[1]; Ryan Rogers[2]; Brandon McWilliams[2]; [1]Oak Ridge Institute for Science and Education; [2]Weapons and Materials Research Directorate, US Army Research Laboratory
The layerwise construction of powder bed fusion additive manufacturing (PBFAM) presents the opportunity to image the build surface in-situ, potentially enabling the observation of defects or indications of defects for real-time part qualification. Combining conventional imaging sensors, image processing tools and machine learning algorithms to monitor the progress of PBFAM builds could be the realization to relatively inexpensive on-site part qualification. This work presents the initial development of a defect detection system, which uses supervised machine learning to detect part porosity in PBFAM builds using in-situ layerwise images. Specifically a high resolution commercial camera was setup to capture multiple images of the build surface and post-process computerized tomography (CT) scans where used to label discretized image regions for latter supervised machine learning classification. Implementation and performance of machine learning algorithms on generated data sets was examined with further work and potential opportunities for online monitoring systems discussed and planned.

9:35 AM
Defect Identification and Mitigation via Visual Inspection in Large-scale Additive Manufacturing: ***Michael Borish***[1]; Brian Post[1]; Alex Roschli[1]; Phillip Chesser[1]; Lonnie Love[1]; Katherine Gaul[1]; [1]Oak Ridge National Laboratory
Defect identification and mitigation is an important avenue of research to improve the overall quality of objects created using additive manufacturing (AM) technologies. Identifying and mitigating defects takes on additional importance in large-scale, industrial AM. In large-scale AM, defects that result in failed prints are extremely costly in terms of time and materials spent. To address these issues, researchers at Oak Ridge National Laboratory's Manufacturing Demonstration Facility investigated the use of a laser profilometer and thermal camera to collect data concerning an object as it was constructed. This data provided feedback for an in-situ control system to adjust object construction. Adjustments were made in the form of automated height control. This paper presents results for both a polymer- and metal-based system. Object construction for both systems was improved significantly, and the resulting objects were more geometrically identical to the "ideal" 3D representation.

9:55 AM Break

10:25 AM
Use of SWIR Imaging to Monitor Layer-to-layer Part Quality during SLM of 304L Stainless Steel: ***Cody Lough***[1]; Xing Wang[1]; Robert Landers[1]; Douglas Bristow[1]; Edward Kinzel[1]; [1]Missouri University of Science and Technology
This paper evaluates using in-situ SWIR imaging to monitor part quality and identify potential defect locations introduced during Selective Laser Melting (SLM) of 304L stainless steel. The microstructure (porosity, grain size, and phase field) and engineering properties (density, modulus, and yield strength) depend on the thermal history during SLM manufacturing. Tensile test specimens have been built with a Renishaw AM250 using varied processing conditions to generate different thermal histories. SWIR imaging data is processed layer-to-layer to extract features in the thermal history for each process condition. The features in the thermal history are correlated with resulting part engineering properties, microstructure, and defects. The use of SWIR imaging is then discussed as a potential for processes monitoring to ensure part quality and develop layer-to-layer control in SLM.

10:45 AM
Mitigating Defects Based on High Speed, In Situ X-ray Imaging of Laser Powder Bed Fusion: ***Nicholas Calta***[1]; Aiden Martin[1]; Jenny Wang[1]; Philip Depond[1]; Vivek Thampy[2]; Anthony Fong[2]; Saad Khairallah[1]; Gabe Guss[1]; Andrew Kiss[2]; Kevin Stone[2]; Christopher Tassone[2]; Johanna Nelson Weker[2]; Michael Toney[2]; Anthony Van Buuren[1]; Manyalibo Matthews[1]; [1]Lawrence Livermore National Laboratory; [2]SLAC National Accelerator Laboratory
Pores in laser powder bed fusion (LPBF) parts continue to present significant challenges because they are difficult to avoid and can lead to part failure. Effective strategies to reduce the likelihood of pores provide an opportunity to improve confidence in the quality of LPBF parts. The likelihood of keyhole pore formation increases in serpentine scan patterns at turning points due to a momentary increase in energy density as the effective scan speed decreases. Here, we use high speed, in situ X-ray imaging to directly probe pore formation during a laser scan turning point in Ti-64. Based on in situ observations and physics-based modelling, we apply mitigation strategies to eliminate pore formation at the turn around point by modulating laser power in real time. Multiple strategies were investigated, and the most effective ones eliminate porosity while maintaining the desired surface geometry. Prepared by LLNL under Contract DE-AC52-07NA27344.

11:05 AM
Experimental Evaluation of Coaxial Imaging of Directed Energy Deposition: Wesley Mitchell[1]; ***Abdalla Nassar***[1]; Christopher Stutzman[1]; Edward Reutzel[1]; [1]ARL Penn State
Coaxial imaging is a commonly used sensing technique to monitor directed energy deposition (DED) additive manufacturing processes. Optical emissions from the region around the meltpool are imaged onto a camera sensor during processing and captured images are used for quality assessment and closed-loop control. In this study, a commercially available coaxial imaging system's accuracy is evaluated by comparing meltpool sizes calculated from coaxial images to deposition sizes measured using optical profilometry. Data were captured and analyzed for single-track deposits of grade 5 Titanium (Ti-6Al-4V) at multiple laser powers, velocities, and powder mass flow rates. We show that, while representative of the deposition size in some limited processing regimes, the coaxial meltpool images do not directly correlate to the resultant deposition size under the range of processing conditions necessary for feedback control. Additionally, the meltpool images are completely insensitive to powder mass flowrate.

11:25 AM
Low Cost, High Speed Stereovision for Spatter Tracking in Laser Powder Bed Fusion: Christopher Barrett[1]; Evan Harris[1]; Carolyn Carradero-Santiago[1]; Jason Walker[1]; Eric MacDonald[1]; ***Brett Conner***[1]; [1]Youngstown State University
In situ monitoring of laser processing during powder bed fusion of metals has primarily focused on evaluation of melt pool dynamics at a microscopic level. In this study, optical monitoring of laser powder bed fusion is conducted of the entire build bed with two high speed cameras operating in stereovision. The primary goal of the monitoring system is to identify and track spatter particles that are ejected from the melt pool during laser processing. Ejected spatter particles solidify in mid-flight before typically landing within the bounds of the powder bed, potentially within the cross-section of the previously fabricated layer. Such particles are unwanted as they can disrupt the formation of the next layer or cause inclusions in the fabricated part. Here, the effects of processing parameters on the formation of spatter (size, quantity, and velocity) are studied.

11:45 AM
Characterization of In Situ Diagnostics Using High Speed Imaging: ***Manyalibo Matthews***[1]; Gabe Guss[1]; Thomas Achee[2]; Nicholas Calta[1]; Sergey Shevchik[3]; Saad Khairallah[1]; Alaa Elwany[2]; Christian Leinenbach[3]; Kilian Wasmer[3]; [1]Lawrence Livermore National Laboratory; [2]Texas A&M University; [3]Swiss Federal Laboratories for Materials Science and Technology
Defects created during metal additive manufacturing complicate the ability to qualify parts for production in industrial applications. In situ process monitoring can enable improved part qualification but a clear interpretation of the monitoring signals is needed. In this work we study acoustic and thermal emission process monitoring using high speed imaging to correlate defect creation mechanisms with process monitoring signals. Supported by modeling, the relationship of process monitoring signals with material properties is also presented, providing insight into the connection between defect creation and expected part performance. Prepared by LLNL under Contract DE-AC52-07NA27344.

Special Session: Binder Jet AM 1

Tuesday AM	Room: Salon E
August 14, 2018	Location: Hilton Austin

Session Chair: Zachary Cordero, Rice University

8:15 AM
On AM Spreading Process Maps Obtained Using Polydispersed Particle Modeling and Machine Learning: ***Prathamesh Desai***[1]; Akash Mehta[2]; Wentai Zhang[3]; C. Fred Higgs III[1]; [1]Rice University; [2]ANSYS Inc.; [3]Carnegie Mellon University
The spreading step in powder-bed AM consists of a rolling and sliding spreader which enforces a shear flow of an AM powder between itself and an additively manufactured substrate. A rheometry-calibrated model based on a polydispersed discrete element method (DEM) is applied to simulate the spreading process. A Particle Tessellated Surface Interaction Scheme is introduced to accurately capture the collisions of the virtual AM powder with the spreader and a 3D printed spreading substrate. The DEM results are compared to the experimental findings from single layer spreading of an industrial grade Ti-6Al-4V powder using a retrofit to a commercial 3D printer. Since the DEM simulations are computationally expensive, machine learning was employed to interpolate between the highly non-linear results obtained by running a few DEM simulations. This enabled a spreading process map to be generated to determine the spreading parameters to achieve the best surface roughness and porosity.

8:35 AM
Characterizing Binder-powder Interaction in Binder Jetting Additive Manufacturing via Sessile Drop Goniometry: ***Yun Bai***[1]; Christopher Williams[1]; [1]Virginia Polytechnic Institute
Understanding the binder-powder interaction and primitive formation is critical to advancing the binder jetting Additive Manufacturing process and improving the printing accuracy, precision, and mechanical properties of printed parts. In this work, the authors propose an experimental approach based on sessile drop goniometry on a powder substrate to characterize the powder granulation process. In this experiment, the dynamic contact angle in capillary pores is calculated based on the measured binder penetration time, and the binder penetration depth and width is measured directly from the powder granules retrieved from the powder substrate. Coupled with models of capillary flow, the technique can provide a fundamental understanding of the binder-powder interactions that determine material compatibility and can also be used to predict printing parameters. Enabled by this gained understanding, the effects of solid loadings in nanoparticle suspensions on their interactions with differently sized powder substrates (i.e., different powder bed porosity) was investigated.

8:55 AM
Elucidating the Role of Fluid-particle Interaction in Binder Jet Additive Manufacturing: ***Joshua Wagner***[1]; C. Fred Higgs III[1]; [1]Rice University
In binder jet additive manufacturing, coupled fluid-particle interaction is a primary factor governing the final quality of a 3D printed part; thus, better understanding of this complex physics will allow for improved printing performance and resolution. In this work, we seek to elucidate the fluid and particle dynamics occurring when a liquid droplet impinges a powder bed and forms a bonded particle agglomeration – effects of ballistic impact, capillarity, and surface tension are studied. The investigation is carried out through the use of high-speed, microscopic imaging to examine a liquid droplet impacting a particle bed. Ultimately, we show how this experimental work will be used to validate a multiphase (solid-liquid-gas) numerical framework that is currently being developed to model the phenomenon.

9:15 AM
Feasibility of Non-contact Powder Bed Characterization through Thermal Measurements: James Pierce[1]; ***Nathan Crane***[1]; [1]University of South Florida
Many additive manufacturing (AM) processes rely on powder for processing. The performance of the powder is very sensitive to a wide variety of factors. Binder jetting (BJ), is particularly sensitive to packing uniformity and packing density in the spread bed. Three of the main components that affect the green density and ultimately, mechanical strength of the final component include: saturation percentage, curing temperature and powder bed density. While most of these parameters can be measured offline, there is not a good way of monitoring the process to verify that these parameters are within desired bounds during printing. This work examines whether thermal diffusivity can be correlated to one or more of these key powder bed parameters. Utilizing long pulse thermography; the thermal diffusivity is measured and compared for different powder bed densities and binder curing conditions. Results show that the thermal diffusivity is highly sensitive to both parameters.

9:35 AM
Evaluating the Surface Finish of A356-T6 Cast Parts from Additively Manufactured Sand Molds: Caitlyn Rodomsky[1]; ***Brett Conner***[1]; [1]Youngstown State University
Binder jetting of sand allows for the design and rapid fabrication of complex molds and cores. The surface finish of the printed molds and cores can be transferred to the cast part. A benchmark casting was designed to compare the surface roughness and surface features of several angles on the cast part. The benchmark casting contained surfaces with angles from 5 degrees to 30 degrees at 5 degree intervals. Benchmark castings from coated and uncoated mold surfaces were evaluated. Angles from 5 degrees to 20 degrees produced a prominent stair step feature. A Keyence microscope was used to measure the arithmetic mean roughness (Ra) and root mean square surface roughness (Rq) of the part surfaces. These measurements are compared to a more conventional contact profilometer. The suitability of Ra and Rq for characterizing stair step features will be discussed.

9:55 AM Break

10:25 AM
Economies of Complexity of 3D Printed Sand Molds for Casting: Ashley Martof[1]; Ram Gullapalli[2]; Jon Kelly[3]; Brandon Lamoncha[4]; Jason M. Walker[3]; Brett Conner[3]; ***Eric MacDonald***[3]; [1]Youngstown Business Incubator; [2]Case Western Reserve University; [3]Youngstown State University; [4]Humtown Products
Additive Manufacturing (more commonly referred to as 3D printing) is resulting in a metamorphosis of the sand casting industry as 3D printed sand molds enable castings of unmatched geometric complexity. AM is often described as providing "complexity for free" and the identification of castings that are sufficiently complex to benefit from 3D printing is generally left to the intuition of the designer or foundryman. New software tools are necessary for foundries to identify opportunities in which the additional costs of AM are compensated by the benefits of increased structural complexity. This paper describes a complexity evaluation tool that scores CAD models to determine the most economical casting approach based on STL slicing and geometry evaluation. The three potential outcomes include (1) traditional sand casting, (2) AM-enabled sand casting and (3) a hybrid of the two with 3D printed cores in traditional casting flasks. Several case studies are described and evaluated.

10:45 AM
Observations of Distortion during Sintering of Binder-jet Printed Ceramics: ***Lynnora Grant***[1]; Mark Cantu[1]; Zachary Cordero[1]; C. Higgs[1]; [1]Rice University
Sintering enhances the mechanical properties of binder-jet printed parts by densifying the material at the cost of distortion due to material creep. In this work, we investigate the sintering process to understand the deformation of titanium (IV) oxide green bodies during thermal treatment. We gather data on the relative density and shrinkage of parts using in situ sintering videos. This data is used to develop constitutive equations that predict final part geometries, accounting for the effects of creep, in an effort to increase the dimensional accuracy of the binder-jet printing process.

11:05 AM
Surface Roughness Optimization of Parts Produced Using Binder Jet 3D Printing: ***Andrew Klein***[1]; [1]ExOne
Binder jet 3D printers produce green parts that are then sintered to high density. As has been previously presented, by using powders that are commonly used in the metal injection molding industry, significant improvements in mechanical properties, dimensional accuracy and surface finish were able to be achieved. By modifying powder size, layer thickness and binder droplet size, print jobs can be optimized for speed, density or surface roughness. This experiment studies how modifying layer thickness and droplet size for a given powder affects surface roughness of the sintered components. The presentation will highlight the results of the experiment and showcase parts that are printed with the optimized settings.

11:25 AM
In Situ Investigations of Fracture in Sintering Materials: ***Joseph Carazzone***[1]; Michael Bonar[1]; Henry Baring[1]; Mark Cantu[1]; Zachary Cordero[1]; [1]Rice University
Binder jetting is an additive manufacturing technique which joins layers of powder material using an organic binder. Processing at high temperatures then consolidates the powder into a monolithic article. Important for ceramics, this high temperature sintering procedure suffers problems with distortion and fracture due to the large strains involved. In the present work, we exploit 3D printing to systematically investigate a long-standing problem: cracking during sintering. A sintering material normally experiences restraint on its densification, which can lead to stress buildup and crack growth from stress concentrating regions. To quantify this, we use binder jetting to prepare notched tensile fracture specimens, for which fracture mechanics parameters can be calculated. Through in situ monitoring, we measure quantities relevant to sinter cracking such as crack length and relative density as functions of time. By combining these data, we can arrive at a fracture mechanics model for quantifying and predicting sinter cracking behavior.

Special Session: Data Analytics in AM 2 - Quality and Modelling 2

Tuesday AM	Room: Salon B
August 14, 2018	Location: Hilton Austin

Session Chair: Bradley Jared, Sandia National Laboratories

8:15 AM
Error: Low Disk Space - Development of a High-speed Temperature Imaging System for Powder Bed Fusion: ***Paul Hooper***[1]; [1]Imperial College London
Data rates from the latest generation of machine vision imaging systems exceed several gigabytes per second. For a typical 24 hour laser powder bed fusion build the total data that can be acquired is substantial and exceeds many hundreds of terabytes. In this talk the development of a two wavelength high-speed melt pool temperature imaging system that operates at 100,000 frames per second is detailed. Time resolved evolution of the melt-pool temperature field is presented and the systems usefulness in determining the influence of scan strategy, parameters and geometry on part quality is explored. The challenges encountered in analysing these large data volumes are described, along with implications for data reduction strategies and storage. The viability of using such systems for machine automation and online process control is also discussed.

8:35 AM
In-process Detection of Material Cross-contamination in Laser Powder Bed Fusion: ***Mohammad Montazeri***[1]; Reza Yavari[1]; Prahalad Rao[1]; Paul Boulware[2]; [1]University of Nebraska; [2]Edison Welding Institute
The objective of this work is to develop and apply a spectral graph theoretic approach to detect the occurrence of material cross-contamination in real-time in laser powder bed fusion (L-PBF) process using data acquired from in-process sensors. Inconel alloy 625 test parts were made at Edison Welding Institute on a custom-built L-PBF apparatus integrated with multiple sensors, including a silicon photodetector (with 300 nm to 1100 nm optical wavelength). During the process two types of foreign contaminant materials, namely, tungsten and aluminum particulates under varying degrees of severity were introduced. To detect cross-contamination in the part, the photodetector sensor signatures were monitored hatch-by-hatch in the form of spectral graph transform coefficients. These spectral graph coefficients were able to detect the onset of material cross-contamination within 5% error and in less than one millisecond.

8:55 AM
In-process Monitoring of a High-speed Sintering Powder Bed with Structured Light Scanning: Nicholas Southon[1]; ***Petros Stavroulakis***[1]; Ruth Goodridge[1]; Richard Leach[1]; [1]University of Nottingham
This paper presents in-process fringe projection measurements of a polymer powder bed in a high-throughput additive manufacturing polymer powder bed fusion process. The measurements were obtained from outside of the build chamber with a commercial projector and an industrial camera which were provided with access through an observation window. The detailed analysis of height maps revealed the ability to detect powder spreading irregularities, consolidation through sintering of the powder bed and part curling. The high-level information produced from the analysis of the measurements enables process control decisions, such as the optimisation of process parameters and in-line fault detection during an additive manufacturing build. In summary, we show that fringe projection can be used in combination with other in-line measurement solutions to reduce the number of build failures and improve part reliability in powder bed fusion.

9:15 AM

Machine Learning based Monitoring of Selective Laser Melting: ***Bodi Yuan***[1]; Gabriel Guss[2]; Aaron Wilson[3]; Stefan Hau-Riege[2]; Philip Depond[2]; Sara McMains[4]; Manyalibo Matthews[2]; Brian Giera[2]; [1]University of California, Berkeley; [2]Lawrence Livermore National Laboratory; [3]Google; [4]UC Berkeley

We demonstrate an approach of applying machine learning to Selective Laser Melting (SLM) to enable on-line monitoring. We collect video of track welds, created under variety of conditions. We use structured light to generate height maps of the tracks and analyze this with our automated image processing algorithm that measures the average and standard deviation of all tracks. These measurements serve as labels to the high-speed video. Using labeled video data, we train our Convolutional Neural Network (CNN) to predict both of these track measurements from 10 ms video clips alone. We test our CNN and find it gives accurate predictions, evaluated via coefficients of determination. In addition, we investigate key examples within out datasets to reveal strengths/limitations of our CNN and potential strategies to improve upon our approach. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

9:35 AM

Nondestructive MicroCT Inspection of Additive Parts: How to Beat the Bottlenecks: ***Anton du Plessis***[1]; Ina Yadroitsava[2]; Igor Yadroitsev[2]; [1]Stellenbosch University; [2]Central University of Technology

MicroCT is widely in use for the inspection of additively manufactured parts. The main use of the technique is to detect large unwanted voids inside the part. However, the ability to detect these kind of defects is strongly affected by image quality, which is often directly related to the scan time. Selecting fast scan settings (eg. 5 minutes per part) can work for many situations where major flaws need to be identified, but this may result in the missing of important defects such as layered stop-start flaws. Possible ways of overcoming this problem are discussed. After scanning, image analysis requires computing power, time and skilled human interface for proper analysis. Reduction of the image analysis workflow is possible using semi-automated analyses and the data size can be reduced using simple methods. In this paper all the above is discussed in relation to reducing the bottlenecks often associated with microCT.

9:55 AM Break

10:25 AM

Non-destructive Characterization of Additively Manufactured Components Using X-ray Micro-computed Tomography: ***Stefan Dietrich***[1]; [1]Karlsruhe Institute of Technology

Quality control and microstructure characterization are essential corner stones of the process optimization through the understanding of process-microstructure-relations in additive manufacturing. The scope of this work is to investigate the relationships between porosity and the process parameters as well as component geometry based on X-ray micro-computed tomography data and thus improving the ability for improved process control. Using test geometries manufactured via laser beam manufacturing and metal fused filament fabrication and through the application of specialized image analysis and data fusion algorithms an extensive analysis of pore morphology, position and orientation with respect to the printing path could be carried out. The results show a clear connection between printing strategies as well as part geometry and allow for a direct connection to mechanical performance characteristics determined by the pore architecture like for example fatigue and failure behaviour.

10:45 AM

X-ray and Computed Tomography as a Tool for Quality Assurance, Process Optimization and Metrology Inspections in the Field of Additive Manufacturing: ***Philip Sperling***[1]; [1]Yxlon International GmbH

Computed tomography has become one of the most important and powerful non-destructive testing (NDT) methods. Depending on the material, geometry and wall thickness of the additive manufactured part we chose the most suitable industrial CT system. Different application examples will be presented during the presentation to show qualitative and quantitative data, challenges, problems and typical defects for this production method. During the presentation different examples how to use an industrial CT scanner as a tool for process optimization. CT is a technology to do measurements for geometrical features. Today´s x-ray and CT devices can support the analysis and inspection tasks for quality assurance, metrology and process optimization for different industries.

11:05 AM

Predicting Product Quality Characteristics in a Laser-powder Bed Fusion Process: ***Gaurav Ameta***[1]; Roany Ak[1]; Thurston Sexton[1]; Jason Fox[1]; [1]National Institute of Standards and Technology

Additive Manufacturing presents an opportunity for manufacturing complex and customized parts that may not be practical through traditional manufacturing processes. But AM processes are still not very well understood due to the complexity of the process and related variability. Predictive analytics have great potential for identifying the correlations between input and output parameters (e.g., product quality) and capability of understanding and designing the outcomes given uncertain inputs. The aim of this paper is to demonstrate an application of data-driven methods in predicting (a) melt pool width and (b) product quality characteristics, including surface finish, tensile strength, and hardness, in a Laser-Powder Bed Fusion process. In doing so, a Bayesian network model is built based on expert knowledge considering the associated uncertainty. Finally, a process map is presented based on the prediction results obtained through the case study. This process map is used for validation with expert knowledge.

11:25 AM

Integrating Transient Thermal Simulations and In-situ High Speed Video for Laser Parameter Strategies in Metal Additive Manufacturing: ***Clara Druzgalski***[1]; Gabe Guss[1]; Manyalibo Matthews[1]; [1]Lawrence Livermore National Laboratory

To ensure part quality in metal additive manufacturing, in-process monitoring and fine control over machine parameters are necessary. A simulation was developed to study transient, multi-track scan patterns to predict how the thermal field evolution effects melt pool dimensions. Experiments of turn-around scan paths on stainless steel plates were conducted at a range of laser power and velocity conditions. A high speed camera monitored the transient melt pool surface area, and this data was used to calibrate and validate the simulation. The model simulates the transient melt pool surface area and depth throughout the scan path trajectory to develop a laser power and velocity strategy that maintains melt pool uniformity. Prepared by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS-749571.

11:45 AM

Scaling Models for Laser Powder Bed Fusion Process Mapping: A Comparison Using Iron, Invar 36 and SS316L: ***Allan Rogalsky***[1]; Mihaela Vlasea[1]; [1]University of Waterloo

A known challenge in the additive manufacturing industry is the narrow range of available alloys. In addition most recipe development efforts in the open literature take a phenomenological approach where outcomes are related to machine parameters and results are primarily applicable to the particular material and equipment studied. To comparatively study the performance of dissimilar alloys, this work focuses on generating a collection of non-dimensional scaling models for the limiting physics of the process. These are used to design experiments spanning the industrially relevant manufacturing process space. Results are compared for materials representative of the full range of iron alloy thermal diffusivity, melt fluidity and melting enthalpy. In this comparison, pure iron and SS316L provide the extremes and Invar 36 is an intermediate point. If these materials can be placed on a unified process map it would also be expected to work for a wide range of other materials.

Special Session: Hybrid AM Processes 2 - Surface Treatments and Assistive Technology

Tuesday AM Room: 404
August 14, 2018 Location: Hilton Austin

Session Chair: Frank Liou, Missouri University of Science and Technology

8:15 AM
Tensile and Shear Strength of ABS from Hybrid Additive Manufacturing by Fused Filament Fabrication (FFF) and Shot Peening (SP): Michael Sealy[1]; Haitham Hadidi[1]; Reece Eddins[1]; Carson Buel[1]; ***Xingtao Wang***[1]; Gurucharan Madireddy[1]; Wenlong Li[1]; Mehrdad Negahban[1]; [1]University of Nebraska-Lincoln
In order for surface treatments to modify properties beyond the near surface, a new hybrid additive manufacturing approach is proposed that combines three-dimensional printing with layer-by-layer surface treatments. In this study, shot peening (SP) was coupled with fused filament fabrication (FFF) to improve the quasi-static tensile and shear mechanical properties of a ABS 430 polymer. Shot peening jets a stream of beads at high velocity to plastically deform a workpiece. This hybrid approach is hypothesized to enhance polymer properties through the introduction of compressive stresses within preferential printed layers. The goal of this research was to understand the effect of layer peening sequence on the tensile and shear strength and the elongation of preferentially shot peened ABS polymer parts produced on a Dimension Elite Stratasys FFF printer. Results indicate that hybrid-AM processing increased the elongation and reduced variability in the data.

8:35 AM
Fatigue Properties of Ultrasonic Treated Direct-metal-laser-sintering Manufactured Metallic Materials: Rasool Mazruee Sebdani[1]; ***Ajit Achuthan***[1]; [1]Clarkson University
Producing super-alloys with enhanced material properties is desirable for several applications. Additive manufacturing offers new avenues to derive metals with enhanced properties, especially using hybrid technologies. In hybrid technologies two different technologies are applied to derive enhanced properties. In this study, we combined ultrasonic peening (UP) technology for local micro-structure modification of DMLS printed samples in a real-time fashion. Previously, we showed that the hybrid DMLS-UP approach can be used to control yield strength and ductility as desired. However, the yield-strength to ductility inverse-type relationship was still observed in these materials. The main goal of the current study is to investigate the effect of the DMLS-UP hybrid technology on enhancing fatigue properties of IN718 samples. According to initial LCF testing, although ductility reduced as a consequence of increased strength, interestingly, no compromise was observed on fatigue resistance. Microstructural analysis is ongoing to determine the deformation mechanisms behind this unusual behavior.

8:55 AM
Modeling Residual Stresses Evolution in Steel from Hybrid Processing by Directed Energy Deposition and Laser Shock Peening: Michael Sealy[1]; ***Gurucharan Madireddy***[1]; Chao Li[2]; [1]University of Nebraska-Lincoln; [2]Autodesk, Inc.
Additive manufacturing of metals often results in parts with unfavorable mechanical properties. Laser shock peening (LSP) is a high strain rate mechanical surface treatment that hammers a workpiece and induces favorable mechanical properties. The overarching objective of this work is to investigate the role LSP has on layer-by-layer processing of 3D printed metals. A finite element model of hybrid-AM by LSP on steel was developed to help understand thermal and mechanical cancellation of residual stress when cyclically coupling printing and peening. Results indicate layer peening frequency is a critical process parameter and highly interdependent on the heat generated by the printing laser source. Optimum hybrid process conditions were found to exists that favorably enhance mechanical properties. With this demonstration, hybrid-AM has ushered in the next evolutionary step in additive manufacturing and has the potential to profoundly change the way high value metal goods are manufactured.

9:15 AM
Dynamic Mechanical Analysis of ABS from Hybrid Additive Manufacturing by Fused Filament Fabrication (FFF) and Shot Peening (SP): Michael Sealy[1]; ***Haitham Hadidi***[1]; Tayler Sundermann[1]; Brady Mailand[1]; Ethan Johnson[1]; Cody Kanger[1]; Mehrdad Negahban[1]; [1]University of Nebraska-Lincoln
An alternative method to change the energy absorption and stiffness of a polymer is hybrid additive manufacturing (hybrid-AM). Hybrid-AM is the use of additive manufacturing with one or more secondary processes that are fully coupled and synergistically affect part quality, functionality, and/or process performance. In this study, fused filament fabrication (FFF) was coupled with layer-by-layer shot peening to study the dynamic mechanical properties of ABS 430 polymer using dynamic mechanical analysis (DMA). Shot peening is a mechanical surface treatment that impinges a target with a stochastically dispersed, high velocity stream of beads. Compressive residual stress was imparted to preferential layer intervals during printing to modify the elasticity (stiffness), viscosity, toughness, and glass transition temperature. Coupling printing and peening increased the storage and loss moduli as well as the tangent delta. DMA results suggest that preferential layer sequences exists that possess higher elasticity and better absorb energy upon sinusoidal dynamic loading.

9:35 AM
Residual Stress and Distortion Management in Hybrid Layered Manufacturing: ***Seema Negi***[1]; Sajan Kapil[1]; Arun Sharma[1]; Priyanka Choudhary[2]; K Rakeshkumar[3]; Parag Bhargava[1]; K.P. Karunakaran[1]; [1]Indian Institute of Technology; [2]National Institute of Technical Teachers Training and Research; [3]Father Conceicao Rodrigues Institute of Technology
Hybrid Layered Manufacturing (HLM) is the synergic integration of cladding (addition) and milling (subtraction). Residual stress and distortion are complementary issues in metal ***Additive Manufacturing (AM)***. These issues can be managed through prevention and curing. Prevention techniques mitigate the development of residual stress by pre-heating and choosing appropriate build strategies such as area-filling and alternate cladding (on both side of the substrate). Curing techniques treat the already developed residual stress and distortion using hammering and post-heating. In HLM, induction preheating and pneumatic hammering are respectively used before and after cladding each layer. Furthermore, different area-filling strategies such as ***direction-parallel***, ***contour-parallel*** and ***fractals*** have different levels of temperature distribution thus can influence residual stress and distortion. The investigations (numerical simulations and experimental validation) on these various residual stress and distortion management techniques adopted in HLM are presented in this paper.

9:55 AM Break

10:25 AM
Dual Purpose of Rolling in Additively Manufactured Mild Steel (ER70S-6): Philip Dirisu[1]; Supriyo Ganguly[1]; ***Filomeno Martina***[1]; Stewart Williams; [1]Cranfield University
Surface Waviness (SW) is one of the major problems confronting the economic use of as-deposited components made with wire plus arc additive manufactured (WAAM) process.In this study hybrid deposition process (WAAM + rolling) has been used to reduce surface waviness of additively manufactured mild steel (ER70S-6). A dog bone specimen was used to evaluate the mechanical and fatigue properties of the as-deposited and rolled condition with microstructural variations. The SW of both conditions was characterized with optical microscope and Axio vision software. Maximum SW of 0.18mm and 0.05mm was recorded for the as-deposited and rolled condition. The results for the as-deposited and rolled conditions have been compared with their mechanical properties, fatigue life, fracture behavior and correlated with their microstructural variation. This study shows that WAAM mild steel components could be used in the as-deposited condition for engineering application with cold working combined to reduce SW.

10:45 AM
Challenges of Measuring Adhesion of Printed Inks and the Potential for Surface Treatments to Alter the Adhesive Failure Mode: ***Clayton Neff***[1]; Edwin Elston[2]; Amanda Schrand[2]; Nathan Crane[1]; [1]University of South Florida; [2]Air Force Research Laboratory, Fuzes Branch, Munitions Directorate
Multi-material additive manufacturing (AM) has been demonstrated to fabricate functional printed electronics by depositing conductive inks on substrates or potentially free-form geometry. The adhesion of printed conductive inks to substrates is paramount in order for the electronic systems to function properly, especially when subjected to applied stresses. However, measuring adhesion of printed inks has been mostly qualitative to date by either scotch tape or scratch testing in the industry. These qualitative methods can be used to provide a coarse indication of adhesion, but lack the capability to provide a truly quantitative value that can be compared to standard values or application requirements. This work seeks to elucidate the challenges of measuring the adhesion of conductive inks quantitatively with single lap shear testing. Surface treatments consisting of plasma, flame, and sandblasting can increase the adhesion and alter the adhesive failure mode of printed inks.

11:05 AM
Viscosity Control of Pseudo-plastic Polymer Mixtures for Applications in Additive Manufacturing: ***Apoorv Vaish***[1]; Shien Lee[1]; Pablo Valdivia y Alvarado[2]; [1]Engineering Product Development Pillar, Singapore University of Technology & Design; [2]Engineering Product Development Pillar, Singapore University of Technology & Design ; Digital Manufacturing and Design Centre(DManD)
Various Additive Manufacturing (AM) processes exploit the rheological properties of non-Newtonian (e.g. pseudo-plastic) polymers for stability and feature realization. For Embedded 3D-Printing (e3DP) and Direct Ink-Writing (DIW), features are deposited on top or within a layer of matrix/base material and the rheological properties of the matrix are crucial for satisfactory prints. Due to their high apparent viscosities in static conditions, these base polymers do not flow easily when poured in bulk in the fabrication space. Traditionally, manual methods were employed to spread them into an even layer. In this study, an approach to use oscillatory shear stresses generated by a vibrating actuator is presented. The proposed approach lowers the kinematic viscosity of the polymers which facilitates gravity-driven flow resulting in a flat polymer-air interface. A fluid-rheology model detailing the parameters influencing the process is presented and experiments are performed using these parameters.

11:25 AM
Junction Growth during Ultrasonic Additive Manufacturing: ***Austin Ward***[1]; Zachary Cordero[1]; [1]Rice University
Ultrasonic additive manufacturing is a solid-phase hybrid manufacturing technique that joins foil feedstock layer-by-layer into net-shaped components. Because of the low-temperature nature of ultrasonic additive manufacturing, this technique is commonly applied to dissimilar metal systems that are difficult to use as feedstock in fusion-based additive manufacturing techniques. Currently, the interlayer bond formation process is not well understood, requiring trial and error to determine the relationship between the process parameters and the resulting interlayer strength. In this work, we propose that interlayer junction growth is driven by thermal softening of the contacting asperities due to frictional heating. Under this hypothesis, we develop an analytical model that predicts the real contact area between build layers. We then validate this model using published shear strength data from components made using ultrasonic additive manufacturing. The resulting framework can determine the process parameters required to maximize interlayer strength when printing new materials.

11:45 AM
Curing Behavior of Thermosets for the Use in a Combined Selective Laser Sintering Process of Polymers: ***Katrin Wudy***[1]; Dietmar Drummer[1]; [1]Institute of Polymer Technology
Selective laser sintering (SLS) of polymers is an additive manufacturing process, which enables the production of functional technical components. Unfortunately, the SLS process is restricted regarding the materials that can be processed and thus resulting component properties are limited. The investigations in this study illustrates a totally new additive manufacturing process which combines reactive liquids like thermoset resins and thermoplastics to generates multi material SLS parts. To introduce thermoset resins into the regular SLS process, the time-temperature-dependent curing behavior of the thermoset and the infiltration behavior has to be understood in order to assess the process behavior. The curing behavior was analyzed by rotational viscosimeter. Furthermore, the fundamental infiltration behavior was analyzed with micro dosing infiltration experiments. Finally, a thermoset resin in combination with a dosing system was choosen for integration in a laser sintering system.

Topology Optimization 1

Tuesday AM	Room: 417AB
August 14, 2018	Location: Hilton Austin

Session Chair: Albert To, Univ of Pittsburgh

8:15 AM
GPU-accelerated Design Optimization for Ffrequency Response Problems with Parameter Uncertainty: ***Miguel Aguilo***[1]; Joshua Robbins[1]; Thomas Voth[1]; [1]Sandia National Laboratories
This work presents a graphics processing unit (GPU) accelerated design optimization solver for frequency response problems under uncertainty. Uncertainty aware optimization problems are computationally complex due to the substantial number of model evaluations that are necessary to accurately quantify and propagate uncertainties due to design imperfections. This computational complexity is magnified if a high-fidelity, physics-based numerical model is used during synthesis optimization. This work combines a GPU-accelerated structural dynamic finite element solver and the stochastic reduced order model (SROM) method to design a structural component that matches a prescribed frequency response. Results will highlight how the GPU-accelerated structural dynamic finite element solver and SROM method effectively 1) alleviate the prohibitive computational cost associated with uncertainty aware design optimization for frequency response problems; and 2) quantify and propagate the inherent uncertainties due to design imperfections.

8:35 AM

Multiscale Topology Optimization and Fabrication Framework for Laminated Composites: ***Narasimha Boddeti***[1]; Kurt Maute[2]; Martin Dunn[3]; [1]Singapore University of Technology and Design; [2]University of Colorado, Boulder; [3]University of Colorado, Denver

We present a general workflow for design and fabrication of laminated short fiber-based composites through multiscale topology optimization (TO) and additive manufacturing (AM). This is an extension of our earlier work where we simultaneously design the macroscale topology and the microstructure for 2D and 3D structures. Here, we specialize this framework for plates and shells (specifically, cylindrical and spherical). The workflow consists of three components: 1) Design automation via TO synthesizes the topology and spatially varying microstructural parameters, 2) Material compilation converts the abstract results from design automation to physically realizable arrangement of matrix and fibers and 3) Digital Fabrication via AM. Our TO machinery enables us to incorporate various structural design objectives and constraints which we used to tailor the framework for different AM technologies such as material jetting, selective laser sintering and fused deposition modeling. We demonstrated the framework with voxel-based material jetting and validated it through experimentation.

8:55 AM

Topology Optimization for Sandwich Structures with Continuous-CF/PA6I-PA6T Laminates as Skin Layers and PA6 or Short-CF/PA6 as a Core Layer: ***Kohji Suzuki***[1]; [1]Chiba Institute of Technology

In this study, density-type topology optimization (SIMP method) was applied to find some light-weight sandwich structures with continuous-CF/PA6I-PA6T (continuous-CF/amorphous nylon) laminates as upper and lower skin layers and neat PA6 (nylon 6) or short-CF/PA6 composite as a core layer. Topology optimization runs for mean compliance minimization have been carried out to achieve plausible optimum solutions, which are validated via their comparisons to the cases of conventional foam and honeycomb cores. FDM 3D printing demonstrations will also be shown.

9:15 AM

Topology Optimisation of Additively Manufactured Lattice Unit Cell by Bi-directional Evolutionary Structural Optimisation: ***Riyan Rashid***[1]; Syed Masood[1]; Dong Ruan[1]; Suresh Palanisamy[1]; Xiaodong Huang[1]; Rizwan Abdul Rahman Rashid[1]; [1]Swinburne University of Technology

The ability of additive manufacturing to develop parts with complex shapes has increased the bandwidth of product design. This has facilitated the use of Topology Optimisation (TO) technique to optimise the distribution of material throughout the part, thereby obtaining minimum weight without compromising the mechanical performance of the component. In this study the Bi-directional Evolutionary Structural Optimisation (BESO) algorithm was used to generate topologically optimised lattice unit cells. A simple bending beam with 50% reduced volume was printed in two different unit cell arrangements using Selective Laser Melting (SLM) process. Prior to printing, the density of SLM-printed AlSi12 samples was enhanced by using appropriate scanning strategy. The flexural properties of these topology optimised beams were compared with the solid beam. The topologically optimised beams absorbed about seven times more energy per unit volume till the displacement of maximum bending load when compared with the solid beam at the same displacement.

9:35 AM

Morphable Components Topology Optimization for Additive Manufacturing: ***Yeming Xian***[1]; David Rosen[1]; [1]Georgia Institute of Technology

This paper addresses two issues: 1. Topology optimization (TO) yields designs that may require support structures if additively manufactured, which increase material and clean-up costs. 2. Material anisotropy is induced during additive manufacturing, which results in inaccurate TO results if such material properties are not included in the algorithm. This paper, based on a moving morphable components approach where structure is composed of several building blocks, introduces constraints for minimum build angle, as well as a penalty constraint for building blocks hanging from the top of the design space, so that the TO output is printable. Additionally, orthotropic material properties are integrated in the optimization. In a separate optimization algorithm, each building block is assumed to have its own fibre orientation.

9:55 AM Break

10:25 AM

Optimizing Topology and Toolpath via Multi-axis Material Extrusion: ***Joseph Kubalak***[1]; Alfred Wicks[1]; Christopher Williams[1]; [1]Department of Mechanical Engineering, Virginia Tech

Material extrusion produces anisotropic mechanical properties due to the use of 3 degree of freedom (DoF) tools that limit deposition to within the XY-plane. This produces poorly bonded layers stacked along a build axis, decreasing mechanical performance. By integrating additional DoF into the motion control system, novel deposition strategies can fabricate more efficient structures. In this paper, parts featuring both optimized topology and toolpath are fabricated. Specifically, the parts have topology optimized (TO) structure consisting of continuous extrusions (roads) fully aligned with 3D strain contours. To generate toolpaths, a TO algorithm produces an element-based representation of the geometry with deposition directions defined per-element. Roads are propagated through the structure using the optimized directions and ordered for collision-free printing. The toolpaths are fabricated using a 6-DoF robotic arm. Mechanical tests of the optimized structures are compared to geometrically similar structures with unaligned depositions to quantify the effect of optimized multi-axis toolpaths.

10:45 AM

Physics-based Support Structure Design Optimization via Fast Process Simulation and Lattice Structure Optimization: ***Albert To***[1]; Lin Cheng[1]; Qian Chen[1]; Xuan Liang[1]; [1]University of Pittsburgh

A new design optimization method based on fast process simulation is proposed for the design of support structure, in order to reduce residual stress and distortion. First, a modified inherent strain method is proposed for fast prediction of the stress and deformation. Second, a projection scheme is proposed to map the domain of support structure for a given solid component, in which the minimum support area is found for the next step. Third, lattice structure topology optimization is applied to minimize the mass consumption of support structure subjected to yield stress constraints. This not only prevent failure of the AM build by limiting the residual stress below the yield strength, but also reduce material required for support structure. Several examples are performed and manufactured to demonstrate the efficiency of the proposed algorithm. Both numerical simulation and experiments prove that the proposed method can ensure the success of metal AM builds.

11:05 AM

Laser Scan Pattern and Build Orientation Optimization for Laser Powder Bed Fusion Process: ***Albert To***[1]; Lin Cheng[1]; Qian Chen[1]; [1]University of Pittsburgh

Residual stress-induced cracking of metal components fabricated by laser powder bed fusion additive manufacturing (AM) depend on the laser sintering path and build orientation. Generally, the residual stresses induced are anisotropic, and hence laser sintering path optimization could significantly improve mechanical performance, e.g., by minimizing residual stress. In this paper, a laser scan pattern integrated structural topology optimization method is proposed to address two issues: 1) Scan pattern optimization for fixed geometry to minimize residual stress and 2) build orientation optimization to minimize support volume and residual stress. In order to accelerate the design process, the full-body inherent strain method is utilized in the topology optimization method to perform fast prediction of residual stress. The effectiveness of this method for improving mechanical performance and preventing build failure is demonstrated by several examples.

11:25 AM
Build Direction and Infill Optimization for Fused Deposition Modeling: ***Aaditya Chandrasekhar***[1]; Tej Kumar[1]; Behzad Rankouhi[1]; Krishnan Suresh[1]; [1]University of Wisconsin Madison
In fused deposition modeling (FDM), parts often exhibit anisotropy that strongly depends on the build direction and infill pattern. To minimize the compliance of an FDM printed part, we propose here a topology optimization framework that optimizes both the build direction and the infill pattern. Both homogeneous and fiber-reinforced polymers are considered. The framework is demonstrated via numerical examples, and validated through physical experiments.

11:45 AM
Next-generation Fibre-reinforced Lightweight Structures for Additive Manufacturing: Janos Plocher[1]; Sanjay Vanen[1]; ***Ajit Panesar***[1]; [1]Imperial College London
In an attempt to realise next-generation lightweight parts and to fully utilize the inherent design freedom of AM, we propose a topology optimisation based design procedure that includes the anisotropic considerations for continuous fibre printing of variable stiffness composites. In this paper, we aim to improve the normalized compliance of a beam in a three-point bending scenario, followed by a custom toolpath generation, in which the change in fibre orientation is derived from the medial axis information. FDM with a dual-nozzle system printing nylon and nylon-sized carbon fibre bundles was utilized for fabrication. Results from the corresponding Finite Element Analysis are compared with those of the experimental test and a general benchmarking with the solely reinforced pendants was conducted. Preliminary findings indicate promising results and we believe this novel methodology contributes greatly to industry and the AM-community in pursuit of lightweight end-use parts.

AM Infrastructure and Education

Tuesday PM — Room: Salon F
August 14, 2018 — Location: Hilton Austin

Session Chair: David Rosen, Georgia Institute of Technology

1:40 PM
Printing Orientation and How Implicit It Is: ***Juan Granizo***[1]; Cassandra Gribbins[1]; Heidi Steinhauer[1]; [1]Embry-Riddle Aeronautical University
A study on how implicit the printing orientation is for people with no previous experience in additive manufacturing was conducted. The study was developed with high-school students divided into two groups, where only one group was introduced a series of activities to show the importance of printing orientation and its relation with stress and strength of parts. Both of the groups were evaluated in the construction of a bridge using pre-printed parts and 3-D doodle pens. The study also took into consideration the amount of filament that was used in the assembly of the bridge, to keep track of the most optimized models. The bridges were then tested until failure to study its structural integrity. Finally, a detailed comparison between the two studied groups was perform to show how implicit the printing orientation is in the design process of parts.

2:00 PM
Making 3D Printing Affordable for "The Last, the Lost, the Least and the Lowest' @ DEI: ***Rahul Sharma***[1]; Ankit Sahai[1]; Ishant Singhal[1]; [1]Dayalbagh Educational Institute
Dayalbagh Educational Institute model advocates frugal (jugaad) approach to problem solving, tries to do 'more with less' by creating 3D Printers(3DP) economically innovated using locally available materials, manpower and resources. DEI model of entrepreneurship is tethered to student-community byproviding accessible 3DP resources for students by giving them opportunity to design and build 3DP using open access technology, thereby promoting a higher adoption rate among students. Student initiative "SCI-HIGH" is launched where UG students teach high-school students, in developing their own 3D printers. Versatility, speed, and cost are three factors in bringing 3D printers to everyone's homes, DEI is paving path for everyday users to get their hands-on 3DP thus promoting human force to innovate, develop, operate and service 3DP to target a major portion of society and not limiting to the people in the research area. This work is providing momentum in making the technology excellent job enabler.

2:20 PM
Method for a Software-based Design Check of Additive Manufactured Components: ***Johannes Tominski***[1]; Stefan Lammers[1]; Christian Wulf[2]; Detmar Zimmer[1]; [1]Paderborn University; [2]INTES Ingenieurgesellschaft für technische Software mbH
Additive manufacturing offers the potential to produce complex structures such as topology-optimized components or lattice structures. However, even these numerical generated structures are subjected to manufacturing restrictions. Therefore, the compliance with design rules should be checked to ensure a robust production. For complex structures this check requires a high effort. Hence, there is a need to develop a method for a software-based designcheck that automatically verifies the compliance with design rules of complex structures. Within the framework of the developed method, the frequently used STL format, which is usually applied during preparation of the manufacturing process, is used. This format approximates components using triangles. By systematically linking these triangles, geometrical attributes of components which are relevant for a controlled manufacturing can be identified. Comparing these attributes to a database, which contains attribute limits of divergent manufacturing conditions, allows a designcheck regarding robust manufacturing process.

2:40 PM
A Methodology for Modular Design Rule Representation and Ontology Development for Additive Manufacturing: ***Hyunwoong Ko***[1]; Paul Witherell[1]; David Rosen[2]; Samyeon Kim[2]; [1]National Institute of Standards and Technology; [2]Singapore University of Technology and Design
Additive manufacturing (AM)'s unique capability and constraints require a set of new design principles and methodologies to capture design rule knowledge for AM. To achieve this goal, first, this study proposes a formal methodology for representing design rules for AM by extending a structured modular hierarchy and associated formalisms in the Guide-to-Principle-to-Rule (GPR) methodology. Second, this study develops a design for AM (DfAM) ontology based on the extended GPR methodology. Then, a case study is performed with overhang, thin wall, and honeycomb features. The proposed methodology and ontology enable explicitly representing and documenting AM's reconfigurable design rules from a form feature level to geometry, process, and material parameter levels. Also, validated design rules are expected to contribute to the development of standards of design rules for AM. This study creates future work for performing modular design optimizations and discovering new design rules for AM by applying machine learning techniques.

3:00 PM
Education of Additive Manufacturing - An Attempt to Inspire Research: ***Li Yang***[1]; [1]University Of Louisville
Although additive manufacturing (AM) technologies have undergone significant development in recent years, challenges remain in the understanding of the physics of the processes as well as many other aspects. Therefore, in the education of the next generation AM workforce, it is considered beneficial that the students can also be exposed to some open subjects via research experiences. While such efforts are generally practiced through research projects, it might also be realized via graduate courses. In this paper some of the attempts along such direction was discussed. In various courses at University of Louisville, contemporary AM research subjects are introduced to students via self-guided literature review, research-oriented labs, and design competitions. Through systematic planning of the project structures, it is anticipated that the efforts will lead to enhanced learning experiences for the students with increased appreciation of the research and development activities currently taken place.

3:20 PM
Lattice Design Optimization: Crowdsourcing Ideas in the Classroom: ***Dhruv Bhate***[1]; [1]Arizona State University
Crowdsourcing is a powerful method of generating ideas, particularly when there are many possible solutions to a particular problem with no obvious process towards arriving at the optimum one. In this paper, results of a crowdsourcing exercise conducted in a 30-student classroom are reported. Students were tasked with using lattice design concepts to minimize the weight of a beam under bending, tension and torsion. Using the nTopology software, they approached the problem in three steps: (1) Selection/design of a unit cell, (2) Distribution of cell size, and (3) Optimization of the thickness of individual members. The first two steps were design decisions made by the students, the last step used nTopology's native solver. This work shares insights gained both in lattice design itself, as well as on the use of crowdsourcing in the classroom, particularly in the context of the rapidly evolving field of Design for Additive Manufacturing.

Applications 3

Tuesday PM — Room: 415AB
August 14, 2018 — Location: Hilton Austin

Session Chair: Nathan Crane, University of South Florida

1:40 PM
Additive Manufacturing Assisting Thermoacoustic Refrigeration System Development: ***Alec Chamberlain***[1]; Bahram Asiabanpour[1]; Zaid Almusaied[1]; Mohamed Saghri[1]; Danielle Cortez[1]; [1]Texas State University
Traditional refrigeration systems (Vapor Compression Refrigeration) have historically provided a cheap and effective method of cooling by using mechanically compressed refrigerants. While this is cheaper compared to alternative methods, these refrigerants are harmful to the environment and can make systems more complicated to maintain. One alternative, Thermoacoustic refrigeration (TAR), requires no harmful refrigerants and is much easier to maintain. However, complexities with design and manufacture of certain components have made TAR's traditionally expensive to implement. Additive Manufacturing (AM) provides a means around this problem. In this research, components of TAR system were designed and fabricated using AM. A variety of 3D printing methods and materials were used. The TAR was assembled and tested with multiple configurations using a wave generator, audio amplifier, resonator, stack, and an oscilloscope. The performance of individual components as well as compatibility with other components was evaluated based on dimensional accuracy.

2:00 PM
Metal Additive Manufacturing for Oil and Gas Applications: ***Lakshmi Vendra***[1]; Anjani Achanta[1]; [1]Baker Hughes
Additive Manufacturing (AM) has gained increasing prominence and had the most significant commercial impact in aerospace sector in the last few years. The adoption of AM in the oil and gas industry has been slow, though the potential economic benefits it offers are manifold. Improving product performance, reducing costs and lead time, creating a more flexible and distributed supply chain are some of the major focus areas for the oil and gas industry today which cannot be attained through traditional manufacturing methods. A broad overview of the state of Metal Additive Manufacturing pertaining to oil and gas applications is provided. Potential applications of AM in the oilfield are highlighted including demonstrated examples such as components for downhole logging and drilling tools, turbomachinery, pipeline components etc. A lack of qualification and certification methodologies along with technical and cultural challenges that hamper AM's adoption in the industry are discussed.

2:20 PM
Development and Validation of a CFD Optimized Integrated Pitot Sensor, Produced by Selective Laser Melting and Abrasive Flow Machining: ***Ferchow Julian***[1]; Dominik Kläusler[2]; Mirko Meboldt[2]; [1]Inspire AG; [2]ETH Zürich
In this paper, a lightweight volume flow sensor was developed which can be integrated into an Selective Laser Melting (SLM) valve design. In addition, the sensor is developed in a way that the surfaces of the internal structures can be post-processed. As a measuring principle, a pitot tube was determined, which was subsequently constructed in two printing directions. The Abrasive Flow Machining (AFM) process should be used as a post-processing method. Based on a CFD analysis, the measuring sensor design was therefore flow optimized in order to obtain a regular removal by the AFM. With the help of a test bench, the pressure loss and the volume flow were measured. The results of the developed sensor were compared with an established sensor and further validated. The results of the volume flow measurement show that the chosen measuring principle is suitable for AM in particular for SLM.

2:40 PM
Understanding Distortion in Material Jetting Process: Kamran Kardel[1]; ***Ali Khoshkhoo***[2]; Andres Carrano[1]; [1]Georgia Southern University; [2]Binghamton University
Dimensional distortion is a detrimental consequence of the curing process in photopolymerization and constitutes one of the most common defects encountered in additive manufacturing. Material jetting is one of the more recently developed processes that have achieved commercial maturity. However, the conditions that mitigate distortion are not well characterized, and design guidelines for this technology are not available in this regard. This work seeks to clarify the effect of specimen thickness and build orientation upon the type and magnitude of distortion. Flat specimens were printed in two different ratios, three orientations, and four thickness values and scanned with a wide-area 3D measurement system to quantify distortion. The goal of this research is to develop a comprehensive design guide to minimize distortion in material jetting process. The preliminary results indicated that thickness factor when measured with the indices height of the highest peak and profile radius, is statistically significant.

3:00 PM

Correlating Local Part Bed Temperature Variations with Mechanical Properties in Selective Laser Sintering of Carbon Fiber Reinforced Polyetheretherketone (PEEK): ***Scott Snarr***[1]; Joseph Beaman[1]; Scott Fish[1]; [1]University of Texas at Austin

Parts currently produced by Selective Laser Sintering (SLS) often exhibit inconsistent mechanical properties establishing a need for better process control. Previous research has confirmed a correlation between mechanical properties and the thermal history of the part throughout the sintering process. This research further explores this correlation by investigating the effect that local powder bed temperature variations and gradients have on a part's tensile strength. Multiple sets of XY tensile bars were fabricated while a stationary Mid-Wave Infrared (MWIR) camera was used to record pixelated temperature data for each layer. Temperature gradients across the interior of a part during the sintering process were then quantified. Variations between the part interior temperature and its adjacent powder bed temperature were also inspected. From this data, conclusions and trends were deduced relating local powder bed temperature variations seen during the SLS process to the mechanical properties of the produced parts.

3:20 PM

Additive Manufacturing Tools for Refrigeration Foaming Operations: ***Brian Post***[1]; Breanna Rhyne[1]; Alex Roschli[1]; Phillip Chesser[1]; Katherine Gaul[1]; Lonnie Love[1]; Michael Cukier[2]; Michael Hile[2]; [1]Oak Ridge National Laboratory; [2]Whirlpool Corporation

The time and material savings offered by additive manufacturing (AM) are monumental for the growth of the tooling industry. Molds that support the insulated foaming processes of refrigerator manufacturing are critical for reliable, accurate production. However, current foam supporting molds are complicated and expensive to manufacture. Foam supporting molds must be thermally conductive for proper heat transfer during assembly line production. This paper illustrates the advantages, processes, and analyses of how AM was used to fabricate a mold that was used to create the foaming support molds for the refrigeration foaming process. The foaming support molds were made from thermally conductive epoxy and house heat exchangers that aid steady heat transfer to critical surfaces of the part via water heating/cooling. The integration of heating components combined with consistent temperature profiles and high thermal conductivities of the molds could prove cheaper to produce and easier to modify.

3:40 PM

Mesoscopic Experimental Investigation on Surface Roughness of Powder Bed in Powder-bed-based Additive Manufacturing: ***Hui Chen***[1]; Qingsong Wei[1]; Yusheng Shi[1]; [1]Huazhong University of Science and Technology

This paper presents a mesoscopic experimental study on the powder-spreading, where a novel testing method with a laser detector was proposed to make non-destructively in-situ measurement on the surface roughness of packed powder bed at individual particle scale. Preliminary investigations show that, with the processing parameters considered here, the surface roughness of powder bed is not affected by the spreading height, but increases linearly with the increasing of spreading speed. Using powder particles with smaller size distribution makes the packed powder bed smoother, i.e., the surface roughness smaller. Meanwhile, comparisons between our experimental results and those obtained through DEM predictions in former literatures are discussed.

Applications 4

Tuesday PM — Room: 416AB
August 14, 2018 — Location: Hilton Austin

Session Chair: Xiayun Zhao, University of Pittsburgh

1:40 PM

4D Printing of Composites with Embedded Continuous Fibers: Qingrui Wang; Xiaoyong Tian[1]; ***Lan Huang***[1]; [1]Xi'an Jiao Tong University

Most of the current 4D printing technologies have the following defects: 1) the deformation shape is simple; 2) the deforming precision is poor; 3) the deformation process is always uncontinuous. In this study, a new 4D printing process based on the composites with embedded continuous fibers is proposed. In this process, a bilayer structure consisting of the top layer of continuous fibers and the bottom layer with resin is 3D printed. Due to the different thermal expansion coefficient and elastic modulus of the top and bottom layers, the structure will produce bending deformation when the temperature changes. It is found that the curvature value and the curvature direction of the composite structure can be precisely controlled by the angle of the intersecting fibers. The influence of fiber trajectory on curvature is studied, and then, the controllable deformation of any developable surface is achieved.

2:00 PM

An Investigation on Sound Characteristics of 3D-printed String Music Instruments: ***Joshua Riefer***[1]; [1]Texas A&M University

3D printing has become a subject of much industrial and scientific investigation. Additive manufacturing techniques involve layer-by-layer processes that introduce complex parameter control, delicate printing configurations, and ultimately relatively uncharted resulting material properties. Among the more up and coming applications of this versatile manufacturing approach is the realm of musical instrument fabrication. Guitars have been machined and handcrafted for years by skilled luthiers and continue in refinement as tools and techniques develop. It becomes important to realize the effects that using this this developing technology has on the sound quality of these traditional instrument layouts. In this study, acoustic resonating chambers were printed with three different filament types and configured according to soprano ukulele size and design. These specimens were then strung and recorded to obtain sound data for time and frequency analysis.

2:20 PM

3D Printable Lithium Ion Batteries as Energy Storage Devices: ***Hui Ying Yang***[1]; [1]SUTD

Compared to the conventional power sources, lithium ion batteries (LIBs) are highly anticipated to perform well in personal electronic devices in terms of high power density, short charging time and excellent cycling stability. In addition, recent advances in nanoscience and nanotechnologies provide new routes to increase the energy density and provide flexibility in operations of LIB systems. Here, we will report a 3D printable flexible solid LIB with high performance as the power source of wearable electronics especially for wearable medical or sports devices. Ultra-light, safe and flexible solid LIBs are an essential component of the wearable electronics, especially for the medical applications or sports wears. It is designed to replace the bulky, rigid and potentially dangerous conventional power sources. The revolutionary design of wearable LIBs will open up a new research direction for future electronic devices.

2:40 PM
Multimaterial Aerosol Jet Printing of Passive Circuit Elements: ***Seth Johannes***[1]; David Keicher[1]; Judith Lavin[1]; Shaun Whetten[1]; Marcelino Essien[1]; Ethan Secor[1]; [1]Sandia National Laboratories
Stable operation of the NanoJet(NJ) aerosol printing technology is enabling for development of printed electronic components. An area of considerable interest for electronic printing is the production of multi-layered, multi-material passive components. To demonstrate the NJ multi-layer, multi-material capability a miniature toroidal inductor structure provided a point of focus for this effort. The toroidal inductor used a planar coil design with a dielectric and core material printed in between the lower and upper halves of the planar coil. The results of this work will be discussed including requirements for successful printing with the multi-layer, multi-material component. Measured device performance of the printed structure will be discussed and compared to predicted values. This results of this work are meant to provide guidance for future work in this area.

3:00 PM
Additive Manufacturing of Liners for Shaped Charges: Jason Ho[1]; ***Cody Lough***[1]; Edward Kinzel[1]; Catherine Johnson[1]; [1]Missouri University of Science and Technology
A Shaped Charge (SC) is an explosive device used to focus a detonation in a desired direction, and has applications in oil extraction, weaponry and demolition. The focusing relies on a void in the explosive mass, shaped by a metal liner that becomes a super-heated projectile during detonation. Additive Manufacturing (AM) allows greater design freedom and geometric complexity for the liner portion of the SC. Specifically, hierarchical structuring and functional grading can potentially provide greater velocity, directionality, and efficiency. In this work, Selective Laser Melting (SLM) is used to explore different geometries for an SC liner made out of SS 304L. These are detonated using the explosive Composition C-4 to evaluate performance metrics, depth and stand off, and are observed using high-speed imaging. The effects of the SLM processed microstructure is also compared to conventionally formed liners. The work shows the potential for advanced shaped charges produced using SLM.

3:20 PM
Controlling Dispersion Characteristics of Ag-PDMS Conductive Composites: ***Mei Chee Tan***[1]; Yingsi Wu[1]; Zhaomin Wang[1]; Xinyu Zhao[1]; [1]Singapore University of Technology and Design
The general approaches to print nanometals during additive manufacturing are: (1) intermittent printing of matrix structures and nanometals, and (2) direct printing of pre-mixed nanometal-matrix composites. Poly(dimethylsiloxane) (PDMS) composites filled with Ag nanoparticles are created to allow direct printing of 3D non-planar electronic sensors with improved adhesion. The sensing performance and conductivity of these composites depend on the percolation threshold governed by filler morphology and dispersion characteristics. However, incompatible interfacial chemistries between PDMS and polyacrylic acid (PAA)-modified Ag nanoparticles lead to the undesirable poor dispersion and incomplete PDMS curing. Thus, surface modification of Ag-PAA particles was needed. In this presentation, a single-steps surface modification through PAA and PVP complexation is presented. The PAA-PVP chemistry and resultant increased thermal stability and particle interactions are discussed. The surface modification also allowed the Ag-PDMS mixture to cure at higher Ag loadings exceeding percolation threshold, resulting in a lowered constant resistivity of ~6 O.cm.

3:40 PM
Size and Topology Effects on Fracture Behavior of Cellular Structures: ***Yan Wu***[1]; Li Yang[1]; [1]University of Louisville
Cellular structures can deform by either the bending or stretching of the cell walls or cell struts. While most cellular structures are bending-dominated, those that are stretching-dominated are much more weight-efficient for structural applications. Some typical cellular structures that represent the bending-dominated structures and stretching-dominated structures have been investigated in this study. From this investigation, cellular structures are designed for varying cell topology, cell size and number of unit cells. The deformation and fracture behavior of these cellular structures is theoretically predicted through an analytical fracture model. The difference of fracture properties with increasing number of unit cells, as well as the effect of cellular topology on fracture behaviors are investigated in detail.

Applications: Biomedical 1

Tuesday PM	Room: Salon A
August 14, 2018	Location: Hilton Austin

Session Chair: Jingyuan Yan, Clemson University

1:40 PM
Development of Customized Cellular Structures to Match the Mechanical Properties of Human Trabecular Bone: ***Xuewei Ma***[1]; Ahmed Sherif El-Gizawy[1]; [1]University of Missouri
The significant mismatch of stiffness properties of patient trabecular bones and metallic implant materials in joint reconstruction surgery results in stress shielding phenomenon. Building cellular metallic implants with structure and properties closely matching those of patients' nature bone would reduce the potentials for artificial joint failures. The present work introduces Computed Tomography (CT) segmentation and Finite Element Analysis (FEA) techniques to capture the geometric and stiffness properties of patient joints. Cellular structures with interconnected pores will be built to match the stiffness properties of patient bone and allow bone ingrowth for a biological fixation. The Gibson-Ashby model and FEA will be used to predict the mechanical properties of the designed cellular structures. The designs that have properties close to trabecular bone will be manufactured by PBF using the biocompatible material Ti-6Al-4V. Mechanical testing will be done to validate the effectiveness of the design and analysis methodology.

2:00 PM
Near-Field Electrospinning of a Polymer Bioactive Glass Composite: ***Krishna Kolan***[1]; Jie Li[1]; Jonghyun Park[1]; Julie Semon[1]; Ming Leu[1]; [1]Missouri University of Science and Technology
Challenges for developing bioactive glass-based composite scaffolds for different tissues include controlling the glass dissolution and achieving the macroporous structure. In this study, we investigate the fabrication of scaffolds with a polymer/bioactive glass composite using near-filed electrospinning (NFES). An overall controlled three-dimensional scaffold with pores containing random nano fibers is created and aimed to provide superior cell proliferation. Highly angiogenic borate bioactive glass (13-93B3) is added to polycaprolactone at the ratio of 20:80 in wt.% for scaffold fabrication using the NFES technique. Scaffolds measuring 5x5x0.5 mm3 in overall dimensions with a filament width of ~250 µm and pore size of ~250 µm are fabricated. The glass dissolution and pH change of these scaffolds are measured and the results are compared with those of scaffolds fabricated by extrusion-based printing. The 3D structure formation dependence on process parameters and the integrity of fabricated scaffold in a cell culture environment are also investigated.

2:20 PM
Bone Tissue Engineering Scaffolds of Ti-6Al-4V with Variable Porosity: Design, Fabrication and Structural Evaluation: ***Xiang-yu Zhang***[1]; Gang Fang[1]; Jie Zhou[2]; Sander Leeflang[2]; Wei Liu[1]; Lei-lei Xing[1]; [1]Tsinghua University; [2]Delft University of Technology
Functionally graded scaffold (FGS) manufactured by additive manufacturing (AM) greatly mimics the morphology, mechanical and biological properties of the natural bone. In the present study, the FGSs with multiple porosity variation strategies along their length were proposed and geometrically designed through a self-developed program. The FGSs were fabricated through selective laser melting (SLM). The finite element analysis and experimental verification of the FGS compressive deformation were conducted. Consideration of the diameter variation and curvature of the scaffold strut resulted from SLM improved the simulation accuracy. The simulated and measured results all indicated that the thickness variation of struts significantly influenced the deformation and failure of the FGS. The variable porosity along the FGS length enhanced its bionic performance. The proposed design was further applied in the femur FGS. Compared to the mechanical properties of the natural bone, the deformation behavior also was superior to the scaffold with uniform porosity.

2:40 PM
Design Rules for Additively Manufactured Wrist Splints Created Using Design of Experiment Methods: ***Sarah Kelly***[1]; Abby Paterson[1]; Richard Bibb[1]; [1]Loughborough Design School
Research has shown that wrist splints (to treat conditions such as arthritis) can be made using Additive Manufacturing (AM) with a similar or greater performance than splints created using traditional manufacturing methods. Work to date reviews splints with singular pattern designs. While these designs could alleviate most of the problems associated with traditional splinting, it does not allow for the co-design of the splint between the clinician and patient. Design rules were created by investigating variables of cut out patterns using Design of Experiments (DOE) methods. Finite Element Analysis (FEA) of various combinations of cut out variables was conducted alongside physical validation of AM parts. It is hoped that through the use of AM many of the problems associated with traditional splinting such as poor aesthetics and poor ventilation will be mitigated. Using DOE methods, design rules were created to enable clinicians to confidently design splints alongside their patients.

3:00 PM
Evaluation of Fully Functional Specialised Software for the Production of Additive Manufactured Wrist Splints: ***Abby Paterson***[1]; [1]Loughborough University
Additive Manufacturing (AM) has been proposed by many researchers, clinicians and industry in recent years for the production of custom-made wrist splints. The intention is to offer improved fit to the wearer, whilst using opportunities such as multiple material printing to enhance the design features of wrist splints to improve overall function. Lattice structures can also be incorporated to improve aesthetics and comfort. However, whilst all these aspects are feasible, there are limitations on the usability of mainstream Computer Aided Design (CAD) software packages and the level of adoption by clinicians. This study describes the evolution of a specialised software designed specifically for use by hand therapists. Funded by Arthritis Research UK, the software was trialled and evaluated on clinicians working within the National Health Service. Feedback suggests usability and versatility was strong, but also indicated scope for improvement to support further research and commercial backing.

3:20 PM
Design and 3D printing of patient specific polymer hand splint concept: ***Mazher Mohammed***[1]; Pearse Fay[1]; [1]Deakin University
Traditionally, upper limb orthotics often falling short of being optimal with respect fit and patient expectations, resulting in a lack of use and no treatment of the underlying condition. In this study we address several current limitations and examine the feasibility of using 3D optical scanning, Computer Aided Design (CAD) and low cost 3D printing as a tool to create more ergonomic and efficacious splints for patients suffering from injured musculature or bone fracture of the thumb. Optical scanning allows a non-invasive and rapid means to reproduce the surface topology of a person's hand and we use this data as the template for the device design. We explore the use of CAD to create a more aesthetically pleasing and functional splint, enhancing both comfort and potential moisture release. Finally, we demonstrate that low cost polymer printing can allow for rapid design evaluation and production of a final, usable device.

3:40 PM
Mandibular Repositioning Appliance Following Resection Crossing the Midline- A 3D Printed Guide: Santosh Kumar Malyala[1]; Ravi Kumar Y[1]; Chitra Chakravarthy[2]; ***Ian Gibson***[3]; [1]National Institute of Technology Warangal; [2]Navodaya Dental College and Hospital,Raichur; [3]Deakin University
Additive Manufacturing (AM) is one of the latest manufacturing processes which has evolved dramatically over the past three decades. The medical and dental industries have benefitted the most in this regard. In the medical industry, every complex surgery has unique requirements in planning or execution, where it needs customized surgical guides or tools. In patients with mandibular tumors where a surgical resection is done crossing the midline, currently, there is no guide or tool available for repositioning the mandible to the patient's original anatomy. To overcome this, an attempt has been made to develop a customized repositioning appliance, which can guide the surgery at preplanning stage and same is used as a surgical guide during the surgical procedure. The repositioning appliance is developed using the patient's CT data which is then processed with the use of medical software. The final patient specific repositioning appliance is fabricated using the AM technology.

Broader Impacts

Tuesday PM	Room: 616AB
August 14, 2018	Location: Hilton Austin

Session Chair: Joy Gockel, Wright State University

1:40 PM
MAPP - Manufacture Using Advanced Powder Processes: ***Candice Majewski***[1]; [1]The University of Sheffield
Powder-based manufacturing, despite demonstrating promise for a wide range of applications, is yet to fulfil its full potential. Restrictions in processes, materials and quality control present increasingly significant challenges as we continue to push powder-based techniques to the extents of their abilities. The EPSRC Future Manufacturing Hub in Manufacture using Advanced Powder Processes (MAPP) is a £20 million research hub with an underlying vision to deliver on the promise of powder-based manufacturing to provide low energy, low cost, and low waste high value manufacturing routes and products. Within our programme we are addressing all stages of powder-based manufacture, including material design and characterisation, process modelling and monitoring, and quality assurance, working towards a new era of 'right first time' manufacturing. This presentation will present an overview of progress to date, future plans, and ways to engage with our research activities.

2:00 PM
Understanding the Process of Adopting Selective Laser Melting of Metallic Materials: ***Evren Yasa***[1]; [1]Eskisehir Osmangazi University
Additive manufacturing, considered as the future of manufacturing, presents many advantages over conventional manufacturing. These include manufacturing integrated parts eliminating joining processes, shortening lead times from design to testing, lightweight structures, being able to produce very complex geometries at almost no added cost, etc. Therefore, many industrial sectors are getting more excited about adopting these technologies into their production lines. However, the shortage of experienced personnel in the field of Additive Manufacturing may make the transition period difficult and troublesome. Many issues in terms of safety, environment, materials, process development, design guidelines as well as testing and validation arise. This paper will address and review the lessons learned as a result of implementing selective laser melting for serial production as well as for research and development purposes so that this valuable outcome can be used as a guideline by beginners in this field not to repeat the same mistakes.

2:20 PM
Real-time Pyrometer Feedback and Control in Metal Powder Bed Fusion: ***Ben Fulcher***[1]; David Leigh[1]; [1]Vulcan Labs
This presentation will explore aspects of the fabrication of metal PBF parts using pyrometer-controlled laser power in Inconel 718. Traditional processing techniques define fixed laser parameters that include laser scan speed, scan spacing, maximum vector length, and laser power. Fixed parameters generally yield varying melt pool temperatures depending on vector length, creating variance in microstructure based on geometry and slicing parameters. This team has developed a method of maintaining a consistent melt temperature by varying laser power to improve the microstructure and material property consistency. Part quality assurance is also improved as a result of melt pool monitoring and control.

2:40 PM
The Recycling of E-Waste ABS Plastics by Melt Extrusion and 3D Printing using Solar Powered Devices as a Transformative Tool for Humanitarian Aid: ***Mazher Mohammed***[1]; Daniel Wilson[1]; Eli Gomez-Kervin[1]; Callum Vidler[1]; Johannes Long[1]; Lucus Rosson[1]; [1]Deakin University
This study demonstrates the EcoPrinting principal as a tool for humanitarian aid delivery. EcoPrinting makes use of renewable energy to realise a low carbon footprint means of recycling waste plastics into feedstock for Fused Filament Fabrication (FFF) 3D printing. We apply this system in a remote location on the Solomon Islands to take reclaimed plastics from the local environment to form 3D printer filaments. We successfully demonstrate the efficacy of the system to operate using solar derived energy and use the resulting filament to 3D print functional pipe connectors and seals to fix failing water infrastructure in a remote village. We conclude Ecoprinting can be used as an effective tool to overcome limitations in supply chain logistics, providing timely and cost effective aid solutions to vulnerable communities in low socio-economic environments, while simultaneously addressing challenges relating to plastic waste management.

3:00 PM
Additive Manufacturing with Modular Support Structures: ***Ismail Yigit***[1]; Mohammed Isa[1]; Ismail Lazoglu[1]; [1]Koc University
Additive manufacturing is praised to have low material waste compared to conventional subtractive manufacturing methods. This is not always the case when the computer aided design (CAD) model consists of large overhangs. In such cases, fabrication of support structures are required to fill the space between the CAD model and the manufacturing bed. In post processing, these support structures must be removed from the model. These supports become waste and reduce the buy-to-fly ratio. In this paper, we present a pre-fabricated reusable modular support structure system which minimizes the fabrication of conventional support structures. The conventional supports are replaced with modular support blocks wherever possible. The blocks are stacked under the overhang with a robot arm until the overhang of the model is reached. Conventional supports can be fabricated on top when needed. This strategy reduces fabrication of conventional supports. Thus, faster fabrication times are obtained with higher buy-to-fly ratios.

3:20 PM
3D Printer Assisted Hands-on Education in Design and Manufacturing: ***Ankit Sahai***[1]; Ishant Singhal[1]; Shashank Kapoor[1]; Pushpendra Yadav[1]; Rahul Sharma[1]; [1]Dayalbagh Educational Institute
In general, engineering education is in 2D space that starts off with abstract theory and math-based problem solving showing the pictorial representations of concepts thus lacking practical measurement and quality outputs. We are proposing an instructional model successful at Dayalbagh Educational Institute, used to understand hard to grasp concept in machine design, manufacturing, and mechanics of machines by allowing physical realization of concepts via 3D printers thus encouraging students to get them interested in complex courses. This enables them verify visually different hypothesis/process-parameters and experience an entire product design cycle, allowing students to harness capability of 3D printers to enhance engineering concepts, experiment geometries in design not viable with traditional manufacturing. This approach encourages action based hands-on, eyes-on learning, exploration and innovation, in engineering by harnessing the capabilities 3D printing technologies to visualize concepts and turning own innovative ideas into reality which were constrained due to traditional pedagogy.

Materials: Composites 1

Tuesday PM	Room: 615AB
August 14, 2018	Location: Hilton Austin

Session Chair: Chad Duty, University of Tennessee

1:40 PM
A Review of Additive Manufacturing of Polymer Matrix Composites: ***Kivilcim Ersoy***[1]; Evren Yasa[2]; [1]FNSS Defense systems; [2]Eskisehir OsmanGazi University
Additive Manufacturing (AM), which is also considered as the future of manufacturing or the new industrial revolution, presents many advantages over conventional processes such as its capability of producing parts with high geometrical complexity, short manufacturing lead times and suitability for customization as well as for low volume production. Combining AM's advantages with promising materials such as composites may bring additional benefits for functional part production. This study is therefore focussed on reviewing the studies mainly on AM of polymer matrix composites involving many aspects spanning from design, process technology and applications to available equipment

2:00 PM
Additive Manufacturing of Sustainable Composites: Matthew Solle[1]; Flynn Murray[1]; Jesse Arroyo[1]; ***Cecily Ryan***[1]; [1]Montana State University
Biobased and biodegradable composite materials are of interest to enhance the sustainability of a variety of applications, such as automotive, biomedical, construction, and consumer electronics. In this work, we discuss tailoring composite materials to the additive manufacturing process by linking processing, materials properties, and performance for solid freeform manufacturing of biobased and biodegradable materials, while comparing to bulk material properties which can be used as inputs into constitutive models of manufactured parts. We focus on the rheology, printing direction, and tailored composition enabled by fused deposition modeling in our comparison. We will also present the hardware and software improvements to our printing process that were crucial to realizing complex material compositions and properties.

2:20 PM
Influence of Mesostructure on the Thermal and Mechanical Properties of Additively Manufactured Interpenetrating Phase Composites: ***Abdel Moustafa***[1]; Zachary Cordero[1]; [1]Rice University
Interpenetrating phase composites (IPCs) are multiphase materials in which the constituents form percolating interconnected networks. Along with advances in manufacturing processes of these materials, efforts are underway to investigate their properties. In this talk, we will present a novel two-step processing route for creating IPCs with periodic microstructure. The composite comprises a 316L lattice structure fabricated by selective laser melting, and A356 aluminum alloy infiltrated in the spaces between the lattice struts. Using experiments and finite element modeling, we will show how various mesostructural features affect the overall thermal and mechanical properties of these composites. Finally, we will propose design principles for optimizing these properties.

2:40 PM
Design and Robotic Fabrication of 3D Printed Moulds for Composites: Rajkumar Velu[1]; Nahaad Vaheed[1]; ***Felix Raspall***[1]; [1]Singapore University of Technology and Design
3D printing technologies have a direct impact on manufacturing the composite structures and in particular fabrication of moulds. Moulds produced through additive manufacturing methods would greatly improve product features. The material selection and process conditions involved in producing mould tooling, mainly towards Automated fibre placement (AFP) work cells. In this study, the main objective is to improve the design and fabrication of composite parts through complex moulds as well as to assess and improve the production workflow through the development of an effective design environment for the existing fiber placement operation. A robotic arm will be used to hold the print surface and to follow a pre-programmed print path with a stationary extruder to fabricate the mould tooling. This paper will present a review on the selection process for mould materials and the experimental work carried out to investigate structural properties, mechanical properties and dimensional accuracy of 3D printed moulds.

3:00 PM
Selective Laser Melting of Nickel Based Metal Matrix Nanocomposite Powder Produced by Electroless Plating: ***Ming Li***[1]; Chao Ma[1]; Alex Fang[1]; Zhijian Pei[1]; [1]Texas A&M University
Nanoparticle reinforced metals, also known as metal matrix nanocomposites (MMNCs), are important materials for additive manufacturing because of their improved properties compared with existing superalloys. However, the current fabrication methods (e.g. high-energy ball milling) of MMNC powder are usually costly and difficult to uniformly introduce high fraction reinforcements to metallic material. Electroless plating was used to successfully produce nickel/alumina MMNC powder containing a high fraction (66 vol.%) of alumina nanoparticles. The MMNC powder was then melted into single tracks using different process parameters on a selective laser melting system (Renishaw AM 400). Afterwards, the morphologies, microstructures, phase analysis and nanohardness of the products were characterized.

3:20 PM
Thermal Management of Li-ion Batteries Using Phase Change Composite Fabricated by Selective Laser Sintering: ***Malek Nofal***[1]; Yayue Pan[1]; [1]University of Illinois at Chicago
There has been a significant interest in powertrain electrification as an effort for United States energy independence. Electric vehicles industry has been growing rapidly due to it tremendous efficiency that are mostly powered by rechargeable batteries. One of the biggest challenges with these batteries is how the end user can safely fast-charge a battery that's is compact without the risk of degrading the life cycle or causing a server thermal event. Therefore, a thermal management system is required to insure a safe operation. In this research, we are employing additive manufacturing to produce composites that can integrated with lithium ion cells to achieve a thermal management scheme. The composite consists of thermally conductive graphite and paraffin wax that has high latent heat capacity. A matrix of 18650 lithium ion cells is assembled to construct a battery pack that is cycled under different charging and discharging profiles.

3:40 PM
Solid Free-form Fabrication of Mesh-reinforced Polymeric Composites: ***Hengky Eng***[1]; Saeed Maleksaeedi[1]; Jun Wei[1]; Suzhu Yu[1]; Florencia Edith Wiria[1]; [1]Singapore Institute of Manufacturing Technology
A new process was developed for producing mesh reinforced composites using additive manufacturing technology. Unlike the conventional method which requires a mould to form the geometry, this process is completely mouldless and is able to produce graded composites by controlling the reinforcement layers configuration. The new method uses the principles of stereolithography process in which a resin impregnated mesh is sandwiched between the bottom of a tank and a metal platform, and cured selectively using a scanning UV light. A significant improvement in the fracture toughness of the mesh reinforced 3D printed plastic was observed. The impact energy absorbed was increased from 2.2 to 23.9 kJ/m2. Flexural strain was enhanced more than 350% due to presence of fibres. To implement the method, a new concept was developed for full automation of mesh transfer during layered manufacturing.

Materials: Non-traditional in AM

Tuesday PM — Room: 602
August 14, 2018 — Location: Hilton Austin

Session Chair: Saniya LeBlanc, George Washington Univ

1:40 PM
Fiber-fed Printing of Free-form Free-standing Glass Structures: ***John Hostetler***[1]; Jonathan Goldstein[2]; Richard Brow[1]; Douglas Bristow[1]; Robert Landers[1]; Edward Kinzel[1]; [1]Missouri University of Science and Technology; [2]Air Force Research Laboratory
Additive Manufacturing (AM) of low-profile 2.5D glass structures has been demonstrated using a fiber-fed laser-heated process. In this process, glass fibers with diameters 90-125 µm are supported as they are fed into the intersection of the workpiece and a CO2 laser beam. The workpiece is positioned by a four-axis CNC stage with coordinated rotational/transitional kinematics. The laser energy at γ = 10.6 µm is couples to phonon modes in the glass, locally heating it above its working point. This rapid heating and cooling process allows for the deposition of various glasses into free-standing three-dimensional structures such as trusses and other complex geometries. Issues unique to the process are discussed, including the thermal breakdown of the glass and index inhomogeneity between the fiber core and cladding when using single-mode optical fiber feedstock.

2:00 PM
Additive Manufacturing of Energetic Materials: ***Maxime Chiroli***[1]; Fabrice Ciszek[2]; Barbara Baschung[1]; [1]French-German Research Institute of Saint-Louis; [2]French-German research institute of Saint-Louis
Over the last decade, additive manufacturing gained a lot of interest within the defense industry. However, printing energetic materials such as explosives or solid propellants remains a challenge. A research work with the aim to suggest appropriate materials and associated 3D printing techniques to produce energetic materials, is currently carried out. In interior ballistics, improved weapon performance ends in reaching higher muzzle kinetic energy. This can be achieved by adjusting the gas pressure released during the ballistic cycle by using specific propellant grains. A former study (Baschung, MRS Symposium H, Boston, 2005) highlighted the advantages of using co-layered propellant grains to achieve this goal. The difficulties in producing such kind of propellants can now be bypassed thanks to 3D printers. Our approach consists in deposing a viscous energetic paste, containing a solvent, with an adapted machine. The layer formation and the adhesion between them are investigated in this work.

2:20 PM
Evaluating the Relationship between Deposition and Layer Quality in Large-scale Additive Manufacturing of Concrete: Negar Ashrafi[1]; Jose Duarte[1]; Shadi Nazarian[1]; ***Nicholas Meisel***[1]; [1]Penn State University
Scaling up additive manufacturing (AM) for automated building construction requires expertise from different fields of knowledge, including architecture, material science, engineering, and manufacturing to develop processes that work for practical applications. While concrete is a viable candidate for printing due to its common use in building, it raises important challenges in deposition due to the material deformation that occurs as concrete transitions from fresh to hardened states. This study aims to experimentally quantify the deformation of printed concrete layers under the influence of different processing variables, including layer thickness, upper layer weight, pump and nozzle speed, and time interval between layers. A mixer-pump extrudes the material and an industrial 6-axis robotic arm, which provides various ranges of movement in different axes, layers the material. The results of this study can be used to develop a tool for predicting and accounting for the deformation of concrete layers during the AM process.

2:40 PM
Methods of Depositing Anti-reflective Coatings for Additively Manufactured Optics: ***Zachary Beller***[1]; David Keicher[1]; Ethan Secor[1]; Judith Lavin[1]; Marcelino Essien[2]; Shaun Whetten[1]; Seethambal Mani[1]; [1]Sandia National Laboratories; [2]Integrated Deposition Solutions, Inc.
Recent advancements in the field of additive manufacturing (AM) have enabled the production of high-fidelity optical components allowing for the design of novel fiber optic systems. In order to support this emerging technology, methods of depositing anti-reflective coatings (ARCs) onto these optical components must be developed. Work has begun to identify such coating materials; develop systems capable of accurately depositing controlled, uniform layers onto given substrates; establish deposition procedures for ensuring coating validity; and establish post-processing procedures to ensure the reliability of finished components. Areas of interest for finished components include their integration into high-bandwidth fiber optic systems, enabling further miniaturization of communication components. Methods of ARC deposition will be discussed along with final component performance and the identification of key process parameters affecting product performance.

3:00 PM
Transport Properties of Laser Processed Thermoelectric Materials: Haidong Zhang[1]; Panagiotis Rammos[1]; ***Saniya LeBlanc***[1]; [1]George Washington University
Thermoelectric generators can convert heat into electricity, but current manufacturing approaches limit thermoelectric device development. Laser powder bed fusion offers the possibility of customizing part geometry to maximize power generation performance. This work reports on laser powder bed fusion of semiconductor thermoelectric materials (bismuth telluride, zirconium nickel stannide, and magnesium silicide) for low and high temperature applications. The temperature-dependent electrical and thermal transport properties were characterized, and the Seebeck coefficient (electrical potential as a function of temperature gradient across the material), electrical conductivity, and thermal conductivity from room temperature to 500°C are used to determine the thermoelectric figure of merit. The transport measurements combined with electron microscopy results provide insight into the defect structures which influence carrier transport in laser-processed thermoelectric materials. The results provide insight into tuning transport properties via laser processing.

3:20 PM
Characterization of 3D Printing Properties of Vitamin-D Enriched Orange Concentrate Using Different Starches: ***S M Azam***[1]; Min Zhang[1]; [1]Jiangnan University
This study investigated the fused deposition modeling (FDM) of vitamin D orange concentrate (OC) with different starches viz. cornstarch (CS), potato starch (PS), sweet potato starch (SS), and wheat starch (WS). Rheological analysis suggests that adding starch with OC and steam cooking improvised required flow properties for FDM process. OC with WS exerts the most suitable conditions considering printing and post printing properties of the printed constructs. The water state, textural, microstructural, and color properties of the printed objects were measured and compared. Scanning electron microscopy images suggest that FDM process improved the microstructural homogeneity which led to firmness to the printed objects. Among the mixtures OC-WS exhibit exhibits the brightest color among the blends which is beneficial for higher consumer acceptance.

3:40 PM
Additively Manufactured Polyphenylene Sulfide: Structure and Properties of Composites and Blends: ***Nekoda van de Werken***[1]; [1]University of New Mexico
Polyphenylene sulfide (PPS) is an engineering grade thermoplastic that exhibits high tensile strength and stiffness, creep resistance, thermal stability, high dielectric strength, and is resistant to common solvents below 200 °C. We explored the thermal, mechanical and dielectric property development in loaded and unloaded PPS structures printed using Fused Filament Fabrication (FFF). Dielectric breakdown, DC leakage and impedance spectroscopy show that FFF PPS structures exhibit dielectric properties that are similar to injection and compression molded PPS. Mechanical behavior was investigated using a combination of ex situ and in situ ìCT tensile testing which clearly shows strong adhesion between adjacent beads and poor adhesion between deposition layers. Print quality was also assessed over a range of process conditions including extruder and bed temperatures, print speeds, and layer thicknesses using FFF printing artifacts. The observed properties and structures and print quality for these PPS materials will be presented. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Topology Optimization 2: Applications

Tuesday PM Room: 417AB
August 14, 2018 Location: Hilton Austin

Session Chair: Carl Hauser, TWI Ltd

1:40 PM
Topology Optimized Heat Transfer Using the Example of an Electronic Housing: ***Dennis Menge***[1]; Patrick Delfs[1]; Marcel Töws[1]; Hans-Joachim Schmid[1]; [1]Direct Manufacturing Research Center; Paderborn University
Function integration is a key issue for an efficient and economic usage of Additive Manufacturing. An efficient heat transfer by topology optimized structures is a rarely considered approach which will be outlined with a new designed housing. A commercial projector unit, whose electrical components produce 37,5 W, shall be integrated in the closed housing and passively cooled by natural convection by special housing geometries. Topology optimized structures shall be generated in the inner part of the housing to transfer the heat evenly from the projector components to the housing wall under the condition of minimizing the mass. At the outside of the housing walls, lattice and rib structures are applied to increase the effective surface for heat transfer by natural convection and radiation. Further, the housing geometry is optimized regarding a minimization of support structures to reduce the post-processing effort. Finally, the housing shall be built of AlSi10Mg by SLM.

2:00 PM
Design Optimization, Fabrication, and Testing of 3D Printed Aircraft Structure Using Fused Deposition Modeling: ***Nicholas Lira***[1]; Gavin Sabine[1]; Joakim Lea[1]; Craig Conklin[1]; Robert Taylor[1]; [1]University of Texas at Arlington
This paper discusses the design, analysis, optimization, and 3D printing of thin-walled aircraft structure for an existing aircraft design using Fused Deposition Modeling (FDM). Design and fabrication methodology is presented from inception to completion with discussion of numerous challenges experienced in the process and their resolution. Representative static approximations of design flight loads were used to perform topology and sizing optimization to create an optimal internal stiffening structure to achieve minimum weight. Joints were created to assemble aircraft components taller than maximum print height. A series of test joints and stiffeners were printed to ensure accurate modeling, print capability, and minimize future printing errors. The complete aircraft, integrated with an optimized stiffening structure and joints, was printed and assembled. Finally, fuselage and wing bending design loads were reproduced in mechanical testing to validate the quality of the design and printing process.

Transition to Modeling 1 - Process Planning session (below)

Modeling 1 - Process Planning

Tuesday PM Room: 417AB
August 14, 2018 Location: Hilton Austin

Session Chair: Richard Crawford, Univ of Texas

2:20 PM
A Path Planning Algorithm for the Design of Additively Manufactured Functionally Graded Materials: ***Tanner Kirk***[1]; Olga Eliseeva[1]; Richard Malak[1]; Raymundo Arroyave[1]; Ibrahim Karaman[1]; [1]Texas A&M University
Additive manufacturing has expanded the design potential of Functionally Graded Materials (FGMs) by enabling a near infinite set of gradient paths from one composition to another. However, the presence of certain phases in a gradient path could lead to undesirable properties, like increased brittleness, that reduce part performance or prevent manufacturing altogether. In this work, a path planning algorithm from the robotics community is adapted to plan gradient paths that avoid these undesirable phases at a range of temperatures. Gradient paths can be planned in any arbitrarily large alloy system and can also be optimized with respect to a cost function like path length or distance from undesirable phase regions. To illustrate the effectiveness of the methodology, FGMs in the Fe-Ni-Cr system were planned and subsequently manufactured. Future extensions of this work could enable the design of FGMs that are optimal with respect to financial cost, manufacturability, or part performance.

2:40 PM
5-Axis Path Planning for Direct Energy Deposition Using Deformed Centerline Transformation: ***Michael Dvorak***[1]; Michelle Gegel[1]; Douglas Bristow[1]; Robert Landers[1]; [1]Missouri University of Science and Technology
In 5-axis additive manufacturing, a machine can both translate and rotate on two of its axes and translate on the remaining three axes. This configuration is capable of building complex geometrical features without need of support structures, which is particularly advantageous for blown-powder processes such as direct energy deposition (DED). However, path planning is more complex for 5-axis additive machines than for 3-axis systems due to the multitude of orientations the deposition head can adopt at any given location. In this paper a novel method for 5-axis path planning is presented. First, the part is designed in CAD and sliced into layers of uniform thickness using off-the-shelf slicing software. The centerline of the part is then deformed to any custom path and each layer is transformed to be perpendicular to the custom path. Finally, the transformed points undergo an inverse kinematic transformation to generate joint motions for the machine.

3:00 PM
Reinforcement Learning for Generating Toolpaths in Additive Manufacturing: ***Steven Patrick***[1]; Andrzej Nycz[2]; Mark Noakes[2]; Andrew Messing[2]; Katherine Gaul[2]; [1]University of Tennessee, Knoxville; [2]Oak Ridge National Laboratory
Generating toolpaths plays a key role in additive manufacturing processes. In the case of 3-Dimensional (3D) printing, these toolpaths are the pathways the printhead will follow to fabricate a part in a layer-by-layer fashion. Most toolpath generators use nearest neighbor (NN), branch-and-bound, or linear programming algorithms to produce valid toolpaths. These algorithms often produce sub-optimal results or cannot handle large sets of traveling points. In this paper, the researchers at Oak Ridge National Laboratory's (ORNL) Manufacturing Demonstration Facility (MDF) propose using a machine learning (ML) approach called reinforcement learning (RL) to produce toolpaths for a print. RL is the process of two agents, the player and the critic, learning how to maximize a score based upon the actions of the player in a defined state space. In the context of 3D printing, the player will learn how to find the optimal toolpath that reduces printhead lifts and global print time.

3:20 PM
Control System Framework for Using G-Code-based 3D Printing Paths on a Multiple Degree-of-Freedom Robotic Arm: ***Andrzej Nycz***[1]; Mark Noakes[1]; Christopher Masuo[1]; Lonnie Love[1]; Katherine Gaul[1]; [1]Oak Ridge National Laboratory
This paper describes a control system framework of using G-Code-based 3D printing paths on a multiple degree-of-freedom (DOF) serial link robot manipulator. Usually, G-Code is created a using software application meant for gantry systems. Therefore, the generated G-Code does not address the kinematic complexity nor take advantage of the flexibility available in serial link robot manipulators. The presented framework can be used for a number of additive manufacturing (AM) methods, hybrid solutions, and applications not directly related to AM. The implementation was successfully tested on a seven DOF robot manipulator that successfully performed hundreds of hours of large-scale wire-arc metal deposition.

3:40 PM
3D Printed Electronics Design Software with Autorouting Capabilities: ***Jose Coronel***[1]; Jose Perez[1]; Carlos Tafoya[1]; Ryan Wicker[1]; David Espalin[1]; [1]The University of Texas at El Paso
Hybrid additive manufacturing (AM) uses multiple processes to directly deposit materials and components, which could include multiple material deposition, material removal (machining), conductor placement and deposition, component pick and place, and other automated processes. There is, however, a need for CAD software that considers these multiple processes. For instance, during the design of 3D printed electronics, designs must be generated to represent 3D printed parts and traces, which are composed of different materials and deposited by separate machine tools. This work presents a custom software and workflow within Autodesk Fusion 360 that programmatically transfers design data from PCB design software into the solid CAD modeling space, automatically creates cavities for electronic components, and autoroutes traces based on a net list. The performance of the software was evaluated based on time required to autoroute traces for a variety of conditions and geometries. The software was found to facilitate and expedite the design process for 3D printed electronics.

Residual Stress

Tuesday PM — Room: 412
August 14, 2018 — Location: Hilton Austin

Session Chair: Joseph Newkirk, Missouri University of Science and Technology

1:40 PM
Designing for Residual Stress with Glass: ***Nicholas Leathe***[1]; Kurtis Ford[1]; [1]Sandia National Laboratories
Conventional design philosophy focuses on the elimination or minimization of residual stresses in materials. A traditional approach to additive manufacturing has been to improve, characterize, and model the fabrication process to accommodate and adapt to this conventional design philosophy. Instead, we challenge this design paradigm to fully utilize advanced manufacturing techniques. Designing and modeling for residual stress dramatically opens the design space as engineers are not only able to design with materials, but to also influence material stress states. This can improve product performance, enable unique and novel designs, and revolutionize design for additive manufacturing.

2:00 PM
Understanding the Impact of Thermal Constraints on Residual Stress in 3D Metal Printed Parts: ***Shaun Whetten***[1]; David Keicher[1]; Joseph Bishop[1]; Kyle Johnson[1]; Phillip Reu[1]; Paul Farias[1]; Andrew Kustas[1]; [1]Sandia National Laboratories
Thermal cycling and repeated melting/solidification characteristics of layer-wise metal printing processes impart significant residual stress in 3D printed parts. In 3D metal printing processes such as Laser Engineered Net Shaping (LENS®) this is especially true. High residual stresses result in deformation and even cracking of printed metal components. Residual stress can affect print part accuracy, material properties, and possibly component lifetime. Thus, it is important to minimize the effects of the residual stress to avoid these and other undesirable characteristics. In this talk, benefits of substrate heating on residual stress reduction will be discussed. Digital image correlation and numerical FEA simulations were used to determine residual stress in LENS parts at various levels of substrate heating. Simulation results were utilized to understand observed effects of the heating.

2:20 PM
Residual Stress Simulations and Comparison against Experimental Measurements for Additively Manufactured Ti-6Al-4V: ***Rishi Ganeriwala***[1]; Maria Strantza[2]; Neil Hodge[1]; Wayne King[1]; Robert Ferencz[1]; Donald Brown[2]; [1]Lawrence Livermore National Laboratory; [2]Los Alamos National Laboratory
The production of metal parts via laser powder bed fusion (L-PBF) additive manufacturing is rapidly growing. However, in order for components produced via L-PBF to be used in safety critical applications, a high degree of confidence is required in their quality. An essential piece for such qualification is the ability to accurately know the stress state within a part. Since experimental measurement is often not feasible, having a validated model capable of reliably simulating these stresses would be extremely valuable. This presentation will focus on the approach used for part-scale simulations of the L-PBF process using the multiphysics finite element code Diablo. Experimental validation of the simulations is provided through x-ray diffraction measurements of the residual strains present in additively manufactured Ti-6Al-4V components. A detailed comparison between the experimental measurements and simulations will be presented. Additionally, the effects of part geometry on modeling strategy will be discussed.

2:40 PM
Correlations of Interlayer Time with Distortion of Large Ti-6Al-4V Component in Laser Metal Deposition with Wire: ***Yousub Lee***[1]; Yashwanth Bandari[1]; Srdjan Simunovic[1]; Bradley Richardson[1]; Lonnie Love[1]; Ryan Dehoff[1]; Katherine Gaul[1]; [1]Oak Ridge National Laboratory
Laser metal deposition with wire (LMD-w) is one of the processes for large aerospace component fabrication due to high deposition rates and material efficiency. However, it often results in large residual stress and undesired distortion. Hence, optimization of process parameters is necessary to reduce the distortion. The optimization essentially requires a solution based on thermo-mechanical analysis. In this study, a three-dimensional finite element method is developed for heat transfer and stress analyses. A progressive material activation method is used to describe the wire addition. A quantitative evaluation of energy during the LMD-w process is calculated to determine the amount of energy input from the wire and laser. The calculated energy is applied to the simulation to evaluate the effect of various interlayer times on the development of residual stress and distortion. Ultimately, we suggest a possible solution to mitigate the distortion in a large-scale component.

3:00 PM
Model Development for Residual Stress Consideration in Design for Laser Metal 3D Printing of Maraging Steel 300: ***Vedant Chahal***[1]; Robert Taylor[1]; [1]The University of Texas at Arlington
Design optimization of laser metal 3D printed structural components requires prediction of build-process induced residual stresses that vary with part geometry and affect distortion and support requirements during the build. Finite element residual stress state evaluation is not feasible within the computational constraints of iterative optimization. Alternatively, a simplified theoretical model is presented for predicting the residual stresses induced during Selective Laser Melting of maraging steel. Furthermore, a Design of Experiments (DOE) approach is implemented to verify the theoretical model and develop a response surface suitable for design optimization. The DOE uses cantilever geometry with length, thickness, and fillet radius as variables and shows overhang length to have the greatest influence on residual stresses. Geometries with high stiffness lead to lower deformations and tend to retain high stresses. The presented model can predict the trend of residual stresses for different geometries and can be used in shape optimization.

3:20 PM
A Modified Inherent Strain Model for Fast Prediction of Residual Stress and Deformation for Laser Metal Additive Manufacturing: ***Albert To***[1]; Xuan Liang[1]; Qian Chen[1]; Devlin Hayduke[2]; [1]University of Pittsburgh; [2]Materials Sciences Corporation
A modified inherent strain theory is proposed to enable faster prediction of the residual stress and deformation for laser powder bed additive manufacturing (AM). In this work, the detailed procedure for extracting inherent strain values based on a small-scale simulation of the representative volume of an AM component and applying them to a part-scale model are presented. In addition, the features of the inherent strains with respect to the influence by the process parameters of the DMLS process are investigated. To validate the accuracy of the proposed theory, residual deformation of the double cantilever beams and a complex canonical part are investigated. The predicted residual deformations match well with the results through the experiments. The two examples show excellent accuracy of the modified inherent strain method for prediction of the residual deformations of the large-scale metal components in the AM processes.

3:40 PM
Residual Stress Reduction of Laser Powder Bed Fusion Processes Using In Situ Laser Diode Annealing: ***William Smith***[1]; John Roehling[1]; Bey Vrancken[1]; Michael Hill[2]; Manyalibo Matthews[1]; [1]Lawrence Livermore National Laboratory; [2]University of California, Davis
Fabricating additively manufactured metal parts through laser powder bed fusion (LPBF) is of great interest to many technological fields, ranging from medical to aerospace. However, due to the extreme heating and cooling cycles experienced during LPBF, the resulting parts are often riddled with internal residual stresses which can cause warping and a deviation from original design specifications. In this work, we explore an in situ method of mitigating residual stress by integrating laser diode irradiation into the traditional LPBF fabrication process. The selective projection of diode light serves as a heat source for the build area, which reduces the temperature gradient experienced by the current layer, thus reducing residual stresses. By carefully controlling the diode distribution, we are able to study the influence of heating and cooling rates on the residual stress. Prepared by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS-749687-DRAFT

Special Session: Binder Jet AM 2 - Processing

Tuesday PM — Room: Salon E
August 14, 2018 — Location: Hilton Austin

Session Chair: Andrew Klein, ExOne

1:40 PM
Binder Jet Printing and Post-processing of Ni-Mn-based Functional Magnetic Materials: ***Markus Chmielus***[1]; Erica Stevens[1]; Katerina Kimes[1]; Pierangeli Rodriguez[1]; Jakub Toman[1]; Amir Mostafaei[1]; [1]University of Pittsburgh
While it is possible to additively manufacture Ni-Mn-based functional magnetic materials such as magnetic shape memory alloys and magnetocaloric materials using energy-beam-based additive manufacturing methods, rapid solidification and repeated heating result in unfavorable microstructures and properties. Here, the advantages and disadvantages of binder jet 3D printing for magnetic shape memory alloys and magnetocaloric materials will be introduced. Furthermore, the effect of sintering, annealing and ordering temperature and time will be correlated to final composition, defects, homogeneity, porosity, grain size, thermal, magnetic and functional properties. The dependencies between heat treatment parameters and microstructure are further used to develop a better understanding of the sintering kinetics and to categorized the sintering parameters into different regimes that result in different final microstructures and properties. Finally, the microstructure and properties of binder jet printed, and post-processed samples will be compared to those of laser metal deposited and traditionally-made functional magnetic samples.

2:00 PM
Densification of H13 Components Fabricated by Binder Jet Additive Manufacturing – Scaling up and Associated Challenges: ***Peeyush Nandwana***[1]; Derek Siddel[1]; Chris Shafer[1]; Amy Elliott[1]; [1]Oak Ridge National Laboratory
H13 is one of the most commonly used hot work tool steel alloys for applications ranging from injection molding to extrusion dies. Thermal checking is the common phenomena for failure of these components. Thus, there is a need for a high throughput and cost-effective solution for fabrication of H13 tool steel components. Binder jet additive manufacturing (BJAM) is one such technique. Apart from being cost-effective, it also enables the fabrication of complex geometries with embedded conformal cooling channels. We present the sintering schedule for densification of H13 components along with the challenges involved in scaling up of components. Furthermore, microstructure evolution and monotonic tensile behavior of the material will be discussed with respect to conventionally processed material.

2:20 PM
Binder Jetting Additive Manufacturing of Water-Atomized Iron: ***Issa Rishmawi***[1]; Mehrnaz Salarian[1]; Mihaela Vlasea[1]; [1]University of Waterloo
Binder jetting additive manufacturing (BJAM) was deployed to processing of low-cost, water-atomized pure iron powder. Surface morphology and particle size distribution of the powder were fully characterized using scanning electron microscopy (SEM) and particle dynamic image analysis via Retsch Camsizer X2. Cylindrical samples were fabricated, and in the AM process, the effects of powder compaction, layer thickness and liquid binder level on green part density were studied. Density analysis was performed using x-ray computed tomography (µCT). The potential application and future research work will be outlined based on the characterization results.

2:40 PM
Microstructural Evolution, Densification Kinetics and Sintering Mechanisms of Binder Jet 3D Printed of Different Size Alloy 625 Powders: Amir Mostafaei[1]; Pierangeli Rodriguez[1]; ***Markus Chmielus***[1]; [1]University of Pittsburgh
In binder jet 3D printing, infiltration or sintering are used to produce structurally sound and dense parts. In this study, alloy 625 powders with three different size distributions are used to quantify the densification kinetics and microstructural evolution and subsequently identify the dominant sintering mechanisms of binder jet 3D printed alloy 625 parts. Sintering was performed at different temperatures (e.g. 1240 °C, 1270 °C and 1285 °C) and holding times (e.g. 0, 0.5, 1, 2, 4, 8 and 12 h) in vacuum and relative and bulk density measured. Optical micrographs taken from cross sections of the sintered parts were used to analyze linear shrinkage, densification rate, volume strain rate, grain/pore intercept length, pore separation, and activation energy, all of which were then used to attain densification kinetics data. It is shown and discussed how sintering parameters affect initial, intermediate and final sintering stages.

3:00 PM
The Effect of Inkjetted Nanoparticles on Metal Part Properties in Binder Jetting Additive Manufacturing: ***Yun Bai***[1]; Christopher Williams[1]; [1]Virginia Polytechnic Institute
In the binder jetting additive manufacturing process, printed metal parts are created by first jetting a polymeric binder into a powder bed and then sintering the resulting green parts, wherein the binder is pyrolyzed and the metal particles are sintered via diffusion. Sintered metal part properties can be enhanced when nanoparticles are deposited into powder bed interstices via jetting a nanoparticle binder. In addition, nanoparticles can be used as a means for binding metal powder bed particles without organic adhesives. As the jetted nanoparticles are sintered at a temperature lower than the powder sintering temperature via a heated powder bed, strength is enabled to the printed green part. In this work, the effects of jetted nanoparticles on sintering densification and printed part structural integrity are investigated for three different types of nanoparticle binders: (i) nanoparticles suspended in an organic binder, (ii) inorganic nanosuspension, and (iii) particle-free Metal-Organic-Decomposition ink.

3:20 PM
Particle Encapsulation to Increase Powder Sinterability and Part Strength in Ceramic Binder Jetting Additive Manufacturing: ***Wenchao Du***[1]; Xiaorui Ren[1]; Chao Ma[1]; Zhijian Pei[1]; [1]Texas A&M University
Binder jetting additive manufacturing has demonstrated its considerable potential in fabricating ceramic parts. Currently, the density of the ceramic parts made by binder jetting is low and their mechanical properties are not satisfactory. The main reason is the low sinterability of powder feedstock. To ensure sufficient flowability to form the powder bed, microsized (50-100 µm) powder is usually used. However, microsized powder has poor sinterability because of the limited specific surface energy. A new particle modification method called powder encapsulation has been applied to increase the part density and strength. Specifically, coarse alumina powder (50 µm in average) was to act as the core and was encapsulated with an amorphous alumina shell. The microsized core can provide the high flowability and the shell can promote sintering due to its high activity. The printed samples showed enhancement in sintering and had significantly higher compression strength.

3:40 PM
Volumetric Sintering of a Selectively Doped Polymer Using RF Radiation: ***Jared Allison***[1]; Carolyn Seepersad[1]; John Pearce[1]; Joseph Beaman[1]; David Bourell[1]; Christopher Tuck[2]; Richard Hague[2]; [1]University of Texas at Austin; [2]University of Nottingham
Polymer parts produced by additive manufacturing are often characterized by lengthy processing times and poor mechanical properties due to the repeated heating and cooling of each layer. Volumetric sintering methods can address these issues by implementing a single stage heating process. Polymer powders behave as electrical insulators and are thermally unaffected by electric fields. Materials with high electrical conductivities such as graphite, however, generate heat under the influence of an electric field at radio frequencies. It is possible to selectively dope a powder bed with graphite through a jetting process. Volumetric sintering can be achieved by applying the dopant to successive powder layers, then casting RF waves through the resulting build volume. The doped regions of the powder bed generate heat and locally fuse the powder to create parts. The focus of this research is to compare the experimental results to computer simulations conducted in COMSOL.

Special Session: Data Analytics in AM 3 - Process Monitoring and Defect Mitigation

Tuesday PM	Room: Salon B
August 14, 2018	Location: Hilton Austin

Session Chair: Alaa Elwany, Texas A&M

1:40 PM
Crucial Measurements and Their Implications in Metal Powder Additive: ***Marshall Ling***[1]; [1]SLM Solutions NA
In an industry moving as quickly as additive manufacturing it is essential to take preemptive steps to assure that you don't fall behind. One critical example in laser powder bed fusion is the characterization of both the machine and the metal produced using data gathered through sensors, testing, and sampling. This presentation will draw upon the experience of SLM Solutions in Wixom, Michigan to discuss the importance of capturing specific pieces of data throughout the build process and how each can be applied to make key process improvements and troubleshoot.

2:00 PM
Machine Vision and Traditional Approaches for AM Process Monitoring and Control: Luke Scime[1]; Brian Fisher[1]; ***Jack Beuth***[1]; [1]Carnegie Mellon University
Process monitoring and control is an active area of AM research. In such studies, process monitoring for documenting part quality is the first goal, followed by efforts to achieve robust in situ control. Both can be performed at a variety of levels of detail. This talk will describe process monitoring at layer and melt pool scales. Layer monitoring will apply machine vision and machine learning approaches to address errors in powder spreading, which can lead to subsequent powder fusion errors. Two types of melt pool monitoring will be detailed, each involving high speed imaging with a stationary camera. One approach involves the extraction of information directly from melt pool emissions and the other involves machine vision and machine learning methods to link melt pool characteristics to flaw formation. The status of using each of these methods for real time control will be summarized.

2:20 PM Invited
Real-time Detection of Build Failures in Thin-wall Structures in Laser Powder Bed Fusion: ***Farhad Imani***[1]; Aniruddha Gaikwad[2]; Prahalad Rao[2]; Hui Yang[2]; Edward (Ted) Reutzel[3]; [1]Pennsylvania State University; [2]University of Nebraska; [3]Applied Research Laboratory, Pennsylvania State University
The objective of this work is to detect the onset of build failures during the sintering of thin-wall structures in laser powder bed fusion (L-PBF) process. Thin wall structures, in the form of 25 fins with varying thickness were built under different orientations, i.e., the angle at which the fins face the recoater. The powder bed was monitored continuously during the build using DSLR camera. Subsequently, the gray scale images of the powder bed were related to the build success assessed from offline X-Ray computed tomography. The connection between the powder bed images and part quality are made via a deep convolutional neural network.

2:40 PM Invited
Spatially Resolved Acoustic Spectroscopy for Additive Manufacturing: Towards Online Inspection: ***Paul Dryburgh***[1]; Rikesh Patel[1]; Don Milesh Pieris[1]; Wenqi Li[1]; Richard Smith[1]; Matt Clark[1]; Adam Clare[1]; [1]Faculty of Engineering, University of Nottingham

High-integrity engineering applications will not permit the incorporation of many defects observed in current the class of powder-bed fabrication systems. As such, there are limitations to the engineering context that this manufacturing method may be used in. Microstructure and defect interrogation are key aspects for pushing additive manufacturing forward, assuring part quality. In addition, online measurements allow for closed-loop feedback, where component measurements can inform remedial action, or vary processing parameters during fabrication. The acoustic microscopy technique spatially resolved acoustic spectroscopy is an exciting proposition for use in component integrity assessment, due to its ability to detect surface and subsurface defects, and probe material properties. This talk will introduce typical datasets from both prepared and as-deposited AM surfaces, and discuss the opportunity presented by collecting data online, focusing on rework of defects. The talk will conclude with an overview of progress made towards online integration and on-going challenges.

3:00 PM Invited
Toward Data- rich Additive Manufacturing: Jacob Williams[1]; ***Paul Dryburgh***[2]; Adam Clare[2]; Prahalad Rao[1]; [1]University of Nebraska; [2]University of Nottingham

Direct evaluation of additive manufacturing ((AM) processes represents one of the most significant challenges to this technology. The objective of this research is to use spatially resolved acoustic spectroscopy signatures for online detection of defects in parts made using laser powder bed fusion additive manufacturing process. Currently, the use of acoustic spectroscopy for online part quality monitoring in AM is limited due to signal noise. To overcome this challenge there is a need for obtaining enriched data sets from the information acquired in this way. Accordingly, we propose a so-called deep learning convolutional neural network that uses acoustic wave maps of the part as input data and translates them to an output form resembling an optical micrograph. Using this approach defects such as porosity can be accurately identified and characterised, The method devised here is able to process sets consistent with 100mm2 within 30 seconds.

Special Session: Hybrid AM Processes 3 - Hybrid Materials, Structures, Functions

Tuesday PM — Room: 404
August 14, 2018 — Location: Hilton Austin

Session Chair: Guha Manogharan, Pennsylvania State University

1:40 PM
Effect of Porosity on Electrical Insulation and Heat Dissipation of FDM Parts Containing Embedded Wires: ***Kazi Md Masum Billah***[1]; Jose Coronel Jr.[1]; Ryan Wicker[1]; David Espalin[1]; [1]W. M. Keck Center for 3D Innovation

While the effects of porosity on the mechanical strength of fused deposition modeling (FDM) parts have been thoroughly investigated, there exists a need for evaluating electrical and thermal properties. This work describes the design, fabrication, and test methodology of FDM parts with embedded wires, to determine the contribution of porosity to other properties. Beyond mechanical strength, identifying desirable electrical and thermal properties will allow the additive manufacturing community to fabricate power electronics components with reduced cost, in an automated process. For experimentation, three different sets of coupons were fabricated using Polycarbonate (PC) thermoplastic with embedded bare copper wire. Characterization included high electrical stress and thermal testing, to determine the effect of porosity on insulation and heat dissipation respectively. Electrical characterization showed higher wire density reduced breakdown strength. Comparisons between untreated and heat-treated specimen (heated above PC's glass transition temperature), showed that heat dissipation increased by an average of 15%.

2:00 PM
A New Digitally Driven Process for the Fabrication of Integrated Flex-rigid Electronics: ***Matthew Shuttleworth***[1]; Mohammadreza Nekouie Esfahani[1]; Jose Marques-Hueso[2]; Thomas Jones[2]; Assel Ryspayeva[2]; Marc Desmulliez[2]; Russell Harris[1]; Robert Kay[1]; [1]University of Leeds; [2]Heriot-Watt University

Conventionally, flexible and rigid electronics are produced separately using mask-based lithography techniques thus requiring connectors to join circuits together introducing potential failure modes and additional assembly. This work demonstrates the application of a novel manufacturing approach to generate bespoke, integrated flex-rigid electronics overcoming the need for connectors. This is achieved by hybridizing Polyetherimide fused filament fabrication with selective photosynthesis of silver nanoparticles and copper electroless plating. The performance and reliability of this approach has been experimentally validated via manufacturing and testing strain gauges. By printing thin layers (<50μm), Polyetherimide exhibits a high flexibility. Where part thicknesses exceed 0.2mm, components become rigid. A combination of various layer thicknesses allows rigid-flex substrates to be produced, with secondary processing to deposit the circuitry. Strain gauges with metalized feature sizes down to 160μm have been fabricated demonstrating a repeatable 2Ω change when deflected. This testing was performed over 10,000 cycles.

2:20 PM
Hybrid Manufacturing with FDM Technology for Enabling Power Electronics Component Fabrication: ***Jose Coronel***[1]; Kazi Md Billah[1]; Ryan Wicker[1]; David Espalin[1]; [1]University of Texas at El Paso

The introduction of Kapton coated wires within a printed substrate presents the opportunity to design and fabricate power electronics components. Preventing dielectric breakdown of the printed substrate, the ultrasonic embedding approach enables complex geometrical embedding through customized software. This work presents the effective embedding of Kapton coated Litz wire into polycarbonate (PC) substrate for stator fabrication. Custom software allowed for generation of embedding toolpaths directly from the CAD model of the stator. Results showed the most successful embedding paths were those that included pre-formed cavities in the substrate. Through characterization of a myriad of printed samples, an approach for determining cavity geometries was developed. Through the use of the Foundry Multi3D System, the increased complexity of embedded electronic parts can further impulse the implementation of hybrid additive manufacturing in large scale applications.

2:40 PM

Digitally-driven Micro Surface Patterning by Hybrid Manufacturing: ***Matthew Smith***[1]; Nicholas Fry[1]; Robert Kay[1]; Russell Harris[1]; [1]University of Leeds

Aerosol Jet printing is a versatile direct-write method allowing selective deposition and alteration of surface chemistry on a variety of substrates, making it suitable for incorporation in a range of hybrid manufacturing processes. The digitally controlled nature of the presented hybrid manufacturing process enables rapid turnaround of designs, and improvements in flexibility and complexity compared to established methods. The apparatus and instrumentation that has been created at the University of Leeds enables specific processing conditions that result in deposition of features with critical dimensions smaller than 20µm. In this study the analysis of the effect of process variables on deposition geometries is presented. The features were assessed by a combination of optical microscopy and white light interferometry. Using in-process machine vision, topographical compensation, and alignment capability the deposition of material into micropatterned features in poly(dimethylsiloxane) (PDMS) was demonstrated. High-value applications of this technology for surface functionalisation include electronics and bio-engineering.

3:00 PM

Hybrid Directed Energy Deposition for Smart Structural Elements: Michael Juhasz[1]; Rico Tiedemann[2]; ***Eric MacDonald***[1]; Brett Conner[1]; Jason Walker[1]; [1]Youngstown State University; [2]University of Bremen

Hybrid additive manufacturing combines traditional fabrication with the layer-by-layer deposition advantages of additive manufacturing. The integration of a wide variety of manufacturing processes enables the benefits of both AM - including complex geometries, part consolidation, and mass customization - with traditional processes providing superior surface finish and dimensional accuracies. One benefit of an integrated suite of manufacturing processes that has not been extensively leveraged is access to the structure at intermediate layers during fabrication. This access will enable the next generation of aerospace or biomedical devices capable of providing sensing data from within the structure, data which could be used for predictive maintenance, structural health management or for functionality not yet conceived. In this report, an Ambit™ system was optimized to deposit stainless steel and used to build a tensile bar with an internal strain sensor encapsulated within the structure.

3:20 PM

Hybrid Printing and Nanoimprint Fabrication of Functional Surfaces: ***Hong Yee Low***[1]; Jumiati Wu[1]; Wei Li Lee[1]; [1]Singapore University of Technology and Design

Functional micro and nanoscale surface texture is an emerging physical surface engineering technology. Unlike traditional physical surface engineering, the advancement of lithography has enabled a new suite of physical surface engineering with highly uniform surface textures that span across the length scale of micrometer to nanometer, generally between 10 micrometer and sub-100 nm.Due to the inherently 2-dimensional nature of lithographic processes, functional micro and nanoscale surface texturing has been mostly limited to flat substrate and films. On the other hand, although a variety of 3-D printing techniques offer rapid prototyping of highly customizable objects/products, the spatial resolution is limited to ~20 micrometer in most advanced 3-D printers. In this work, we report a prototyping technique to fabricate functional micro and nanoscale surface texture on 3-D printed objects. Hydrophobic surface texture with resolution of 200 nm has been achieved on a range of 3D printed curvatures.

3:40 PM

Harsh Environmental Testing of Conductive Links for Resilient Hybrid Electronics: ***Clayton Neff***[1]; Edwin Elston[2]; Matthew Burfeindt[2]; Nathan Crane[1]; Amanda Schrand[2]; [1]University of South Florida; [2]Air Force Research Laboratory, Fuzes Branch, Munitions Directorate

The manufacturing of resilient hybrid electronics (RHE) is an emerging defense technology area. The choice of materials ultimately dictates the resiliency of the product in harsh environments (i.e. high g impact, thermal cycling). In this study, we examined poly-ether-ether-ketone (PEEK) polymer substrates and two commercially available conductive inks (DuPont CB028 and KA801). The inks were 3D printed using micro-dispensing onto the PEEK substrates and resiliency was evaluated by measuring the mechanical (adhesion) and electrical (DC and RF) performance when subjected to the aforementioned harsh environments. Adhesion, DC and RF patch antennas samples each consist of their own respective configuration. The methods developed in this work provide the first standardized procedures for evaluating resiliency of hybrid electronics under harsh environmental conditions. Results show CB028 can survive at least 20,000 G's and exposure to extreme temperatures of +71 to -55ºC while KA801 has much more variability in performance under the same conditions.

Applications: Biomedical 2

Wednesday AM	Room: Salon A
August 15, 2018	Location: Hilton Austin

Session Chair: Candice Majewski, The University of Sheffield

8:00 AM

Interactions between Microbes and Laser Sintered Polymers: ***Robert Turner***[1]; James Wingham[1]; Thomas Paterson[1]; Joanna Shepherd[1]; Candice Majewski[1]; [1]University of Sheffield

Microbes are pervasive, colonizing the surfaces in our environment, our skin and digestive system. Medical implants (e.g. catheters) and contact surfaces in clinical environments (e.g. light switches) are at risk of unwanted microbial attachment. While in some situations microbes are essential symbiotes, in others they are lethal pathogens, an issue exacerbated by the growing problem of antimicrobial resistance (AMR). But these organisms are also critical for manufacturing many dairy goods, confectionery and alcoholic beverages. It has become imperative to develop an improved understanding of the interactions between microbes and products made using additive manufacturing, to control these favorably. Here, we present a suite of techniques for characterizing such interactions and exploring the functionality of antimicrobial materials for additive manufacturing. We use polyamide 12 based materials, and have selected pathogens known to cause hospital and community acquired infections, and with a propensity to develop antimicrobial resistance, as initial subjects.

8:20 AM

In Situ Monitoring and Printability Analysis of Hybrid Hydrogels for Tissue Engineering: ***Srikanthan Ramesh***[1]; Sam Gerdes[2]; Sharon Lau[1]; Azadeh Mostafavi[2]; Zhenyu Kong[3]; Blake Johnson[3]; Ali Tamayol[2]; Prahalada Rao[2]; Iris Rivero[1]; [1]Iowa State University; [2]University of Nebraska-Lincoln; [3]Virginia Tech

Advancements in additive manufacturing have made it possible to fabricate biologically relevant architectures from a variety of materials. Hydrogels have garnered increased attention for the fabrication of tissue engineering constructs due to their resemblance to living tissue and ability to function as cell carriers. However, there is currently a lack of standardized printability analysis techniques required to optimize the printing process. This study takes the critical first-step for connecting in-process sensor data with construct quality by studying the influence of printing pressure and needle diameter on the shape fidelity and mechanical performance of 3D printed constructs. Alginate-Chitosan hydrogels were synthesized with tunable mechanical properties and stability required to support cellular growth. In situ print layer photography and x-ray microtomography were utilized to characterize print quality and internal structure of the constructs respectively. Additionally, cell viability and proliferation were analyzed to confirm the suitability of the structures for tissue engineering applications.

8:40 AM
Effects of DOD 3D Bioprinting on the Formability of Microspheres: ***Ryan Meza***[1]; Matthew Moldthan[1]; Bingbing Li[1]; [1]California State University Northridge
Tissue engineering through freeform fabrication has provided an opportunity to print functional living tissues. Bioinks capable of maintaining high rates of cell viability are critical to the success of this process. To test the compatibility of Drop-on-Demand (DOD) bioinks under extreme conditions, hydrogels were printed through an inkjet based MicroFab PH-46 (MicroFab, Plano, TX) micro dispensing subsystem. Altering voltage, rise/fall time, and frequency have a significant effect on the printability and formability of microspheres, which are used to encapsulate cells during the printing process. The purpose of this experiment is to alter and measure the relation of these parameters to the size of the microspheres, bioink used, distance traveled, and droplet printability. Bioinks tested include: sodium alginate (0.25%-1%) and Hystem (a commercially available bioink).

9:00 AM
Digital Micromirror Device (DMD)-based Stereolithography of 3D Vascular-like Structures with Living Cells Encapsulated: ***Soham Wadnap***[1]; Changxue Xu[1]; [1]Texas Tech University
Bioprinting has been widely used to construct artificial tissues and organs layer by layer by precisely controlling the deposition of biological materials and living cells. Biofabrication of vasculature is not only a reasonable first step towards successful organ printing but also a critical indictor of the feasibility of envisioned organ printing technology. In this paper, a 3D bioprinting system based on dynamic optical projection stereolithography has been adopted to fabricate 3D vascular-like structures with fibroblasts encapsulated. The effects of operating conditions on the cure depth of single layer have been investigated, such as UV intensity, exposure time and cell concentration. A phase diagram had been constructed to identify optimal operating conditions. Post-printing mechanical properties of cell-laden hydrogel have been characterized, and cell viability has been assessed to be above 90%. As a proof of concept study, the resulting fabrication knowledge helps print tissue-engineered vascular network with complex geometry.

9:20 AM
Introduction of Antimicrobial Properties into Laser Sintered Polymers: ***James Wingham***[1]; Robert Turner[1]; Thomas Paterson[1]; Joanna Shepherd[1]; Candice Majewski[1]; [1]The University of Sheffield
Everyday objects often act as breeding grounds for bacteria and other microbes, which can easily be spread through human contact. Whilst many of these are relatively harmless, concerns about antimicrobial resistance (AMR) mean that preventing their growth on a product or surface is becoming increasingly desirable. With the rise in use of Additive Manufacturing to create end-use products, ranging from medical devices to consumer goods, it is timely to consider how we might incorporate antibacterial properties into these. This paper presents the results of preliminary work investigating the ability of a silver-based compound to prevent, slow or delay bacterial growth when used in the production of Laser Sintered polymer parts. Polyamide 12 / silver phosphate glass micro-composite materials were created using Laser Sintering and tested against Gram positive (***Staphylococcus aureus***), and Gram negative (***Pseudomonas aeruginosa***), bacteria; with early results indicating the potential for this approach to be effective.

9:40 AM Break

10:10 AM
On Demand Direct-write 3D Printing of Visible Light Crosslinkable GelMA Soft Tissue Scaffolds Using an Iterative Learning Control Method: ***Ali Asghari Adib***[1]; Amir Sheikhi[2]; Ali Khademhosseini[2]; David Hoelzle[1]; [1]Ohio State University; [2]University of California Los Angeles: Dept of Bioengineering, Center for Minimally Invasive Therapeutics, California NanoSystems Institute
Three-dimensional (3D) bioprinting of tissues holds a great promise in regenerative medicine wherein rapid fabrication of cell-laden scaffolds is highly demanded. In recent years, Direct-Write (DW) Additive Manufacturing has been successfully employed to print porous scaffolds to fit defects and promote tissue repair. Conventional inks typically require curing at non-physiological conditions, e.g., at high temperature or under long UV exposure time, preventing safe printing inside the body. Moreover, flowrate control continues to be a problem in DW due to system compliances, such as fluid capacitance. In this study, soft tissue scaffolds comprised of gelatin methacryloyl (GelMA) were 3D-printed in complex shapes using multiple material domains of different mechanical properties at physiologically relevant conditions, and crosslinked on-site with visible light. System compliances were assessed, and an iterative learning control method was employed to precisely control the material flowrate. This study paves the way for controlled ***in vivo*** 3D-printing of tissue scaffolds.

10:30 AM
Mechanical Property Characterization of Cell-laden Gelatin Methacrylate-based Hydrogels: ***Srikumar Krishnamoorthy***[1]; Changxue Xu[1]; [1]Texas Tech University
3D Bioprinting refers to fabrication of three-dimensional functional organs using a layer-by-layer mechanism, and is the most promising solution towards solving the problem of organ donor shortage. Hydrogels, such as gelatin methacrylate (GelMA), have been established as excellent materials for various 3D bioprinting applications. Post-printing mechanical behaviors of GelMA is essential for cell viability and proliferation as well as eventual functionality of bioprinted tissues/organs. In this paper, the mechanical properties of cell-laden GelMA-based hydrogels have been characterized immediately after fabrication and after 7-day incubation. Effect of GelMA degradation on mechanical properties has been investigated, and cell migration and distribution within the GelMA hydrogels have been quantified. The cell proliferation with time has shown to reduce cell-laden hydrogel mechanical properties significantly.

10:50 AM
Bioresorbable Vascular Scaffolds 3D Printed via microCLIP: ***Henry Oliver Ware***[1]; Banu Akar[1]; Guillermo Ameer[1]; Cheng Sun[1]; [1]Northwestern University
Recent development of high-resolution Micro-Continuous Liquid Interface Production (microCLIP) process has enabled 3D printing of biomedical devices with 10 micron-scale precision. 3D bioresorbable vascular scaffolds (BVS) were printed using an antioxidant, photopolymerizable citric acid-based material (B-Ink). Despite demonstrating BVS fabrication feasibility, challenges remained. Specifically, to improve material strength/ stiffness of our 3D printed BVSs, microCLIP process parameters (UV power and stage speed) and pre-polymer composition (inclusion of secondary radical generators) were optimized to increase BVS radial stiffness. According to literature, a vascular stent when placed in the body must be able to sustain a pressure loading between 10.67kPa and 13.34kPa of pressure loading. Process and material optimization yielded BVSs with 150um strut thickness that could be fabricated in the 15-20 minute range and could sustain the necessary biological radial pressure loadings . This technology and photopolymerizable material is a large step forward toward on-the-spot and on-demand fabrication of patient specific BVSs.

11:10 AM
A Sustainable Additive Approach for the Achievement of Tunable Porosity: ***Sharon Lau***[1]; Taylor Yeazel[1]; Ana Miller[1]; Nathan Pfister[1]; Iris Rivero[1]; [1]Iowa State University
This study aims to design a green additive approach for the fabrication of controlled porosity on hydrogels. Hydrogels are commonly used for tissue engineering however, the generation of controllable porosity in hydrogels remains an issue due to its swelling and degradation properties. The hydrogel was fabricated by physical cross-linking and subsequently, the porosity was generated by casting the solution in a 3D printed mold prior to physical crosslinking. This approach eliminates the use of chemical cross-linking compounds which are often toxic and not environmentally friendly. Polyvinyl alcohol was selected to validate this technique due to its biocompatibility and adequate mechanical properties. The microstructure, mechanical properties and deformation of the porous hydrogels were characterized. Results revealed that the proposed bioplotting technique reduced variation of pore size and allotted for the realization controlled and tunable pore structures.

11:30 AM
Binder Jetting of Piezoelectric Ceramic: ***Luis Chavez***; Jaime Regos[1]; Carlos Diaz[1]; David Espalin[1]; Ryan Wicker[1]; Yirong Lin[1]; [1]The University of Texas at El Paso
This paper explores binder jetting printing of piezoelectric ceramic BaTiO3 with bimodal particle size distribution. Ceramics have excellent mechanical, electrical, and biological properties for mechanical, biological, and electrical applications. Compared with metals and polymers, 3D printing of ceramics has seen limited progress due to difficulty processing in printing and sintering. Binder jetting is one potential promising solution. However, the density of the final ceramic part is typically far from the material's theoretical fully dense value; thus limiting their application due to poor mechanical and electrical properties. As a possible solution, this paper investigates the feasibility of using bi-modal ceramic particles to increase printed ceramic density. A mixture of micro-particle and nano-particle BaTiO3 was used to consider both sinter-ability and powder bed flow-ability. It was shown that the density, dielectric, and piezoelectric properties of printed BaTiO3 using bimodal particle size distributions increased more than 60%, 50%, and 90%, respectively.

Lattices and Cellular 2

Wednesday AM	Room: 412
August 15, 2018	Location: Hilton Austin

Session Chair: Li Yang, University of Louisville

8:00 AM
X-ray Tomographic Imaging of 3D Printed Cellular Materials during In Situ Mechanical Deformation: ***Brian Patterson***[1]; Kevin Henderson[1]; Matthew Herman[1]; Paul Welch[1]; Cynthia Welch[1]; Axinte Ionita[1]; Xianghui Xiao[2]; Tao Sun[2]; Kamel Fezzaa[2]; Jason Williams[3]; Nikhilesh Chawla[3]; [1]Los Alamos National Laboratory; [2]Argonne National Laboratory; [3]Arizona State University
Typical cellular foams are created through a stochastic process that creates a morphology that is not easily controllable or repeatable. Additive manufacturing allows for the controlled morphology of materials to systematically probe the mechanical response of cellular materials. AM is used to create hyper elastic materials that have structures and mechanical responses to deformation that can be systematically investigated. Using both laboratory-based, and synchrotron-based in situ 3D tomographic imaging, the examination of deformation and damage on several size and time scales is critical to understanding how these soft materials behave as a result of loading. Advanced processing, including eigenvector centrality and finite element modeling, is required to understand these mechanical responses. Eigenvector centrality predicts the mechanical properties of lattice-structured materials as a function of structural completeness and FEM modeled performance can be compared to the in situ 3D X-ray tomographic imaging to probe deformation as a result of loading.

8:20 AM
Fabrication of Support-less Engineered Lattice Structures via Jetting of Molten Aluminum Droplets: Dinesh Jayabal[1]; ***Khushbu Zope***[1]; Denis Cormier[1]; [1]Rochester Institute of Technology
On-demand magnetohydrodynamic (MHD) jetting of molten metal droplets is a unique metal additive manufacturing process capable of printing down-facing features without the need for support structures. By carefully controlling the metal temperature, droplet jetting frequency and droplet stepover distance, it is possible to ensure that one droplet has solidified prior to impact of the next molten metal droplet. The incoming droplet rapidly solidifies upon impact, and the droplet step-over distance then dictates the slope of the down-facing printed feature. In this paper, we describe initial results in which complete lattice structures have been printed in 4043 aluminum using this approach. A parametric study that maps jetting frequency and droplet step-over distance with the resulting strut angle is presented. With careful control of jetting parameters, we show that it is possible to print nearly horizontal lines without any support. Lastly, mechanical properties of the lattice structures are presented.

8:40 AM
Additive Manufacturing of Lightweight Mirrors: ***Nikola Dudukovic***[1]; Logan Bekker[1]; Wen Chen[1]; Bryan Moran[1]; Eric Duoss[1]; Christopher Spadaccini[1]; William Steele[1]; Tayyab Suratwala[1]; Rebecca Dylla-Spears[1]; [1]Lawrence Livermore National Laboratory
Additive manufacturing offers new routes to lightweight optics inaccessible by conventional methods. Predictive lattice design combined with the ability to 3D print complex structures allows for the creation of low-density metamaterials with high global and local stiffness, providing a path to fabrication of lightweight optical supports with tuned geometric and mechanical properties. Our approach involves the simulation and optimization of lightweight lattices for anticipated stresses due to polishing and mounting loads via adaptive mesh refinement. The designed lattices 3D printed using large area projection microstereolithography (LAPuSL), coated with a metallic plating, and bonded to a thin fused silica substrate. This lightweight assembly can be brought to a desired flatness using full aperture polishing and treated with a reflective coating, resulting in a lightweight mirror. *This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 within the LDRD program. LLNL-ABS-738806.

9:00 AM
Ballistic Evaluation of Additively Manufactured Metallic Lattice Structures: ***Brandon Mcwilliams***[1]; Jian Yu[1]; Andelle Kudzal[1]; Josh Taggart-Scarff[2]; [1]US Army Research Laboratory; [2]Oak Ridge Institute for Science and Education
Powder Bed Fusion (PBF) enables production of complex, hierarchical structures not producible through other means to create unique mechanical properties by design through process modeling and topology optimization. Structures with reduced weight that have unique energy absorption and deformation mechanisms could allow soldiers to adapt to mission-specific requirements in the field. In this work, the ballistic performance of PBF AlSi12 and Ti-6Al-4V structures are evaluated using impact experiments with a fragment simulating projectile. Solid and lattice truss structures of equal areal density with variations on number of cells, truss diameter, and cell size are evaluated. Geometric influence on defect characteristics in lattice specimens and bulk parts are quantified using micro-computed tomography and microscopy. Implications of this work on modeling for design and manufacturing of mass-efficient structures for high strain rate loading applications will also be discussed.

9:20 AM
Cellular Structures for Blast and Impact Protection with Selective Laser Melting: ***Jonathan Harris***[1]; Graham McShane[1]; [1]University of Cambridge
Additive manufacturing offers unprecedented scope for creating novel and complex cellular structures from high-performance materials. Such a production capability is especially pertinent to the design of lightweight protective structures for blast and impact loading, where intricate low-density geometries can be beneficial. This study uses a novel origami-inspired core structure to investigate the effect of material alignment (with respect to loadingdirection) on protective performance. These structures were produced with selective laser melted steel and tested at strain rates from 10^{-3} to 10^{4} s^{-1}. The experimental results were used to validate a series of finite element models, which in turn were used to optimize the origami geometry to specific loading scenarios. A detailed metallurgical and defect analysis was conducted with X-ray tomography and microscopy, revealing significant advantages and disadvantages inherent to laser-based additive manufacturing processes. This study demonstrates the ability of additive manufacturing to create structures optimized to dynamic loading scenarios.

9:40 AM Break

10:10 AM
Design and Optimization of Spatially-varying, Multi-material 3D Printed Soft Lattice Structures: ***Oliver Weeger***[1]; Narasimha Boddeti[1]; Sai-Kit Yeung[1]; David Rosen[1]; Martin Dunn[2]; [1]Singapore University of Technology and Design; [2]University of Colorado Denver
Lattice structures are frequently found in nature and engineering due to their myriad attractive properties, with applications ranging from molecular to architectural scales. Lattices have also become a key concept in additive manufacturing, enabling also the fabrication of soft lattices subject to large deformations and instabilities. Here, we present a design, optimization and manufacturing approach for soft lattices structures with tailored, spatially varying material and geometric properties. We model the lattice members as curved rods and use a spline-based isogeometric method to simulate their nonlinear mechanical behavior. Material and geometric parameters of the members, e.g., radius and Young's modulus, are also parameterized using splines and optimized to tailor the mechanical response of the structure.Computational results are verified against experiments realized by inkjet multi-material 3D printing, highlighting the potential for rapidly emerging applications of soft lattice structures with tailored properties in soft robotics, healthcare, personal protection, energy absorption, and design.

10:30 AM
Dissipative Non-linear Topology: ***Nicholas Leathe***[1]; Brad Boyce[1]; Bradley Jared[1]; William Mook[1]; Zachary Casias[1]; Erich Schwaller[1]; Jarett Tigges[1]; [1]Sandia National Laboratories
This research demonstrates a new, fundamental application of lattices designed for energy dissipation. It builds off the commonly accepted hexagonal honeycomb shape, and incorporates internal functional elements to provide added behaviors. The functional elements can vary in behavior, but in the research presented here, they enable a material agnostic energy damping. Energy dissipating topologies utilizing Coulombic friction are demonstrated across length scales and material sets, specifically metallic, ceramic, and polymer based topologies. Finally, the conducted research explores the application of functional elements at the individual unit cell and builds into larger lattice networks for more complex applications and environments.

10:50 AM
Demonstration of Two-photon Polymerization Printing for Inertial Confined Fusion Capsules: ***Matthew Herman***[1]; Dominic Peterson[1]; Kevin Henderson[1]; Tana Cardenas[1]; Christopher Hamilton[1]; John Oertel[1]; Brian Patterson[1]; [1]Los Alamos National Laboratory
Understanding fuel mix within Inertial Confined Fusion (ICF) capsules is critical to achieving experimental fusion. Two-photon polymerization (TPP) microfabrication process has emerged as a technique for construction of three-dimensional (3D) microstructures that will allow for greater control of capsule manufacturing. The process allows feature sizes on the order of tens of nanometers with relatively high processing speeds. This extreme control of spatial resolution is currently being applied in our efforts to manufacture polymer foam structures, lattice foam systems, and microcapsules. Demonstrated here are proof-of-concept microlattices produced using two-photon polymerization. The ability to direct laser write a 3D foam which has controllable hierarchical structure from the meso-scale to the macro-scale, coupled with control of the chemical makeup of the material will allow for greater confidence in future ICF experiments. With this technology, better control of fuel mixing is possible, amenable to modeling and easily modified for tailored target design.LA-UR-18-23175

11:10 AM
Flexure and Twist of Fused Deposited Lattice Materials: ***Enrique Cuan-Urquizo***[1]; Atul Bhaskar[2]; [1]Tecnológico de Monterrey; [2]University of Southampton
The structure-property relation of fused deposited (FDM) lattices were studied analytically, computationally and experimentally under bending and torsion. While most of the works have been focused on characterising through tension and compression, other practical loadings, i.e. flexure and twist, are addressed here. The deformation mechanisms of the filaments were identified, as stretch-flexure for bending and flexure-torsion for twist. These micromechanics of the filaments were employed to develop models to predict the apparent (macro) properties. The theoretical models were then compared with finite element simulations and experimental tests. The transverse deflection of FDM lattice beams resulted to be highly shear sensitive as opposed to homogenous beams, errors-up to 1200% for the worst cases. Moreover, the bonding between layers strongly influences the twist response. This structured material comprises the infill of FDM components, thus influencing the mechanical properties. Understanding the structure-property relationship becomes important before more potential applications are explored.

Materials: Composites 2 - Extrusion-based Processes

Wednesday AM Room: 615AB
August 15, 2018 Location: Hilton Austin

Session Chair: Chao Ma, Texas A&M University

8:00 AM
Characterizing Compositional Transitions in Pellet-based 3D Printing of Functionally Graded Materials: ***James Brackett***[1]; Zeke Sudbury[1]; John Lindahl[2]; Vlastamil Kunc[2]; Chad Duty[1]; [1]University of Tennessee Knoxville; [2]Oak Ridge National Laboratory
Large scale additive manufacturing systems such as Big Area Additive Manufacturing (BAAM) often use a pelletized feedstock and mixing screw capable of blending specific ratios of polymers during the deposition process to meet given structural requirements. Such structures are known as Functionally Graded Materials (FGM), which typically combine a commodity material base with an engineering material at specified points to improve mechanical performance. To accurately produce FGM parts using BAAM, an understanding of the transitional behavior from one material to another is needed. This study documents characteristic shape functions that describe such transitions based on processing conditions and screw design with a focus on the transitions between acrylonitrile butadiene styrene (ABS), carbon fiber reinforced ABS, and glass fiber reinforced ABS. Using the characteristic shape functions as a design guide, an FGM cantilever beam is printed, and the mechanical performance is compared to similar beams printed with a single material.

8:20 AM
Continuously Reinforced and Wholly Thermoplastic Composite Filaments for Application in Fused Filament Fabrication: ***Mubashir Ansari***[1]; Donald Baird[1]; [1]Virginia Tech
One of the major limitations of Fused Filament Fabrication is poor mechanical properties of the filaments. This work addresses this problem by continuously reinforcing the matrices such as acrylonitrile butadiene styrene (ABS) and polyphenylene sulfide (PPS), using thermotropic liquid crystalline polymers (TLCP's). The reinforcing fibrils are generated using a novel dual extrusion technology, which allows continuous injection of the TLCP's into polymer matrices. The resulting filaments have excellent tensile properties with the 40.2 wt.% TLCP/ABS filaments exhibiting 169.2±4.0 MPa and 39.9±3.7 GPa in tensile strength and modulus, respectively, and the 67.0 wt.% TLCP/PPS filaments exhibiting 155.0±24.2 MPa and 40.4±7.5 GPa in tensile strength and modulus, respectively. On printing using the ABS composite filaments, the printed parts had tensile strength and modulus values of 72.2±1.2 MPa and 11.7±2.1 GPa, respectively. The samples printed using the PPS composite filaments showed tensile strength and modulus of 108.5±19.4 MPa and 25.9±1.1 GPa, respectively.

8:40 AM
Fabricating Functionally Graded Materials by Ceramic On-demand Extrusion with Dynamic Mixing: ***Wenbin Li***[1]; Austin Martin[1]; Tieshu Huang[2]; Alexander Henderson[1]; Ming Leu[1]; Jeremy Watts[1]; Gregory Hilmas[1]; [1]Missouri University of Science and Technology; [2]NNSA's Kansas City National Security Campus
Ceramic On-Demand Extrusion (CODE) is an extrusion-based additive manufacturing process recently developed for fabricating dense, functional ceramic components. Presented in this paper is a further development of this process focusing on fabrication of functionally graded materials (FGMs). A dynamic mixing mechanism was developed for mixing constituent ceramic pastes, and an extrusion control scheme was developed for fabricating specimens with desired material compositions graded in real time. FGM specimens with compositions graded between Al_2O_3 and ZrO_2 were fabricated and ultimately densified by sintering to validate the effectiveness of the CODE process for FGM fabrication. Energy dispersive spectroscopy (EDS) was used to compare final compositions to the original material designs. The specimen's hardness and fracture toughness at different locations along the gradients were examined by micro-indentation tests. The dimensions of sintered specimens were measured, and the effects of material composition gradients on the distortions of sintered FGM specimens were analyzed.

9:00 AM
The Effect of Pre-shear Processing Conditions on 3D Printing of Reinforced Polymers: ***Dylan Hoskins***[1]; Christine Ajinjeru[1]; Chad Duty[1]; Vlastimil Kunc[2]; John Lindahl[2]; [1]University of Tennessee; [2]Oak Ridge National Laboratory- Manufacturing Demonstration Facility
Material printed with large scale additive manufacturing systems such as the Big Area Additive Manufacturing (BAAM) system experience a wide range of shear rates during the extrusion process. The shear rate can vary over five orders of magnitude as the material passes through the single screw extruder and is deposited onto previous layers. Since the polymer structure requires some time to recover from high shear rates, the upstream flow conditions can significantly impact the extrusion conditions. When fiber reinforced materials are deposited, the fibers can also become highly aligned in the direction of flow due to the high shear stresses. Therefore, accurate analysis of the viscoelastic response of a polymer during extrusion requires that these pre-shear conditions are appropriately understood. This study evaluates the pre-conditioning effects of high degrees of both shear rate and shear strain on the extrusion viscosity of carbon fiber reinforced acrylonitrile butadiene styrene (ABS).

9:20 AM
Multi-material Printing of Structural Components: Process Conditions and Bond Strength: ***Christine Ajinjeru***[1]; Chad Duty[1]; [1]University of Tennessee Knoxville
The goal of this study is to investigate the mechanisms governing the bond formation process in multi-layered composite structures printed using two or more discrete polymers, also referred to as multi-material systems. Structural components made with multi-material systems such as alternating layers of thermoplastic/thermoplastic or thermoplastic/thermoset can greatly expand the range of applications of printed parts while capitalizing on the properties of these hybrid structures not found in a single polymer. However, depositing alternating layers of materials with differing thermo-mechanical properties presents unique processing challenges. As such, this study determines the print conditions for thermoplastic/thermoplastic and thermoplastic/thermoset material combinations on extrusion-based 3D printing systems while minimizing instabilities. The contribution of viscosity, density and interfacial tension to interlayer stability is analyzed. The interlayer bond formation process, cure kinetics, and mechanical properties evolution during printing of a multi-material system is also presented.

9:40 AM Break

10:10 AM
Processing Short Fiber Reinforced Polymers in the Fused Deposition Modeling Process: ***Christian Schumacher***[1]; Volker Schöppner[2]; Stefan Gnaase[3]; [1]Paderborn University / Direct Manufacturing Research Center; [2]Paderborn University / Kunststofftechnik Paderborn; [3]Paderborn University
By adding fibers to a polymer matrix a reinforcement of the material can be achieved. Short fiber reinforced polymers can easily be processed in the Fused Deposition Modeling (FDM) process without major modifications of the processing machine. For instance short fiber reinforced filaments can be processed to produce short fiber reinforced components. In many other additive manufacturing processes this is not possible so easily. The choice of the matrix material, the fiber type, fiber length and fiber alignment have great influences on the properties of the produced component. In this paper short fiber reinforced filaments are processed in the FDM process. Afterwards the resulting part properties are analyzed regarding to fiber specific influences.

10:30 AM
Dynamic Mechanical Characterization of Additively Manufactured Fiber Reinforced Thermoplastic Composites with Respect to Toolpath Orientation: ***John Lindahl***[1]; Rachel Evans[1]; Christine Ajinjeru[2]; Chad Duty[2]; Peng Liu[1]; Ahmed Hassen[1]; Seokpum Kim[1]; Vlastimil Kunc[1]; [1]Oak Ridge National Laboratory; [2]University of Tennessee
Extrusion deposition of thermoplastic composite materials generates a part with anisotropic thermal and anisotropic mechanical properties. This is due to the high alignment of second phase reinforcements in the extruded material from simple shear flow in the nozzle. To obtain the viscoelastic properties of additive manufactured (AM) composites through a temperature range, three dynamic mechanical analysis testing methods were performed: torsion, three-point bend, and linear tension. This paper details the viscoelastic properties of AM composites in the X-Z, Y-Z, and X-Y planes relation to toolpaths aligned with the X-axis. Moreover, it also compares the results of the three different testing methods against each other. A comparison between the properties shown on desktop AM and Big Area Additive Manufacturing (BAAM) of similar materials is also explored.

10:50 AM
Impact Testing of 3D Printed Kevlar-reinforced Onyx Material: Mackenzie Scrocco[1]; Logan Weinreber[1]; Edward Ellks[1]; Timothy Chamberlain[1]; Pedro Cortes[1]; ***Brett Conner***[1]; [1]Youngstown State University
Kevlar reinforcement is commonly used in impact resistance applications. This research evaluated the performance of 3D printed Kevlar continuous fiber reinforcement of 3D printed nylon containing chopped carbon fiber (CCF). The 3D printer used was a Markforged Mark Two material extrusion system. Onyx is the name of Markforged's nylon/CCF material. Composite architecture designs include type of infill pattern, number of Kevlar layers, location of Kevlar layers, etc. Several composite architectures were designed and then evaluated. Specimens were characterized using Charpy impact testing and gas gun ballistic testing. Results are compared on the basis of weight and estimated part cost.

11:10 AM
Deposition Controlled Magnetic Alignment in Iron-PLA Composites: ***Nathan Watson***[1]; Paris von Lockette[1]; [1]Penn State University
By manipulating the print plane, infill direction, and geometry of Fused Filament Fabricated (FFF) iron-PLA composite parts, the alignment of their magnetic axes can be influenced. FFF printing allows control of deposition direction, which affects arrangement of the iron within the composite part in ways that induce preferred magnetic orientation, the so called easy axis. Qualitative results show the direction of deposition of the composite iron-PLA filament has significant effects on the response of the printed parts to an external magnetic field. Results further show that across different geometries, the easy axis of a printed part can be proscribed by setting the print plane and infill direction parallel to the desired orientation. Expected part geometry effects, along with the print plane and infill influences, suggest the phenomenon can be modeled using multi-scale demagnetizing field theories to print magneto-sensitive devices that can perform localized, controlled actuation in a uniform magnetic field.

Materials: Metals 5 - Aluminum and Copper

Wednesday AM	Room: 415AB
August 15, 2018	Location: Hilton Austin

Session Chair: Anton du Plessis, CT Scanner facility

8:00 AM
Microstructure Influence on the Strain-rate and Stress-state Behavior of Solid-state AM AFS-Depostion Aluminum Alloy 6061: ***Brandon Phillips***[1]; Dustin Avery[1]; C. J. T. Mason[1]; Paul Allison[1]; J. B. Jordon[1]; [1]The University of Alabama
The Solid-State Additive Manufacturing process referred to as Additive Friction Stir - Deposition (AFS-Deposition) provides a new path for coating, joining, and additively manufacturing materials such as Aluminum Alloy 6061. Metal powder or solid rod is fed through a non-consumable rotating cylindrical tool generating heat and plastically deforming the feedstock material through controlled pressure from the tool as successive layers are built upon a substrate. In this research, the dynamic recrystallization (DRX) and grain refinement is characterized for the successive layers in as-deposited samples using Electron Backscattered Diffraction. Tensile behavior is also characterized at both quasi-static (0.001/s) and high strain-rates (1500/s) using a direct-tension split-Hopkinson pressure bar. Fractography of quasi-static and high strain-rate tensile specimens using a Tescan Lyra FIB-FESEM showed traditional ductile fracture morphology. Internal StateVariable (ISV) plasticity-damage model was calibrated to capture material behavior over a range of stress-states and strain-rates with one set of material constants.

8:20 AM
The Effect of Processing Parameter on Zirconium Modified Al-Cu-Mg Alloys Fabricated by Selective Laser Melting: ***Xiaojia Nie***[1]; Hu Zhang[1]; Haihong Zhu[1]; Zhiheng Hu[1]; Xiaoyan Zeng[1]; [1]Wuhan National Laboratory for Optoelectronics
The newly designed alloy compositions for selective laser melting (SLM) have aroused great interest. In this study, the Zirconium modified Al-Cu-Mg alloys was fabricated by SLM. Results show that crack-free samples with relative density of nearly 100% were obtained by optimizing the processing parameters. The morphology of surfaces and microstructure of cubic samples were varied with different scanning speed and hatching space.

8:40 AM
Selective Laser Melting of Al6061 Alloy: Processing, Microstructure, and Mechanical Properties: ***Jinliang Zhang***[1]; Bo Song[1]; Lei Zhang[1]; Jie Liu[1]; Yusheng Shi[1]; [1]Huazhong University of Science and Technology
Selective laser melting (SLM) is considered as one of the most promising additive manufacturing (AM) technologies. Aluminum alloy is of wide application potentiality due to their high specific strength and heat resistance. In this study, Al6061 alloy was prepared via selective laser melting (SLM) and densification, microstructure and properties were investigated systematically. It was found that process parameters including laser power and scanning rate have a great effect on the forming quality and the porosity of the samples. The a-Al phase is observed in XRD results and (200) is the preferable orientations of a-Al crystal in the SLM process. The microstructure can be divided into three areas: fine grained area, coarse grained area and heat affected area. As for the nanohardness, with the increase of laser power, the elastic modulus and hardness of SLM aluminum alloy show the trend of increasing first and then decreasing, and with the increase of scanning speed, the hardness of SLMed aluminum alloy is gradually reduced. With the increasing laser power and decreasing scanning rate, the elastic modulus and hardness of the samples increased first and then decreased.

9:00 AM
Effect of Process Parameters on Mechanical Properties of Wire and Arc Additive Manufactured AlCu6Mn: ***Yazhou Zhang***[1]; Ming Gao[1]; Xiaoyan Zeng[1]; [1]Wuhan National Laboratory for Optoelectronics
Wire and arc additive manufacturing (WAAM) is an additive manufacturing technique that can directly fabricate large 3D parts. In this study, a variable polarity cold metal transfer (CMT) pulse arc was employed to melt the mental wire onto a substrate. Tensile tests and microscopy were conducted for investigating the effects of process parameters on the mechanical properties and microstructure of AlCu6Mn after WAAM deposition. The highest tensile strength of 295 MPa and tensile elongation of 18% were obtained with appropriate heat input. Also, the bottom region of the sample has the best mechanical properties, followed by the middle and top region under the same parameters. This is mainly due to the increasing of over-burn defects and grain size in the top region with the accumulation of heat in the repeated thermal cycle.

9:20 AM
Small-scale Characterization of Additively Manufactured Aluminum Alloys through Depth-sensing Indentation: ***Farwan Alghamdi***[1]; Devendra Verma[2]; Meysam Haghshenas[1]; [1]University of North Dakota; [2]Nanoscience Instruments

Selective laser melting (SLM) can be considered a suitable additive manufacturing method for printing complex-in-shape aluminum components. However, in order to adopt the SLM for mass production of aluminum components for automotive and aerospace applications, one needs to fully understand the correlations between SLM parameters, produced microstructure, and local mechanical properties of the printed parts. In the present paper, along with microstructural assessments (optical and scanning electron microscopy), small scale properties of two additively manufactured aluminum alloys, AlSi10Mg and A205.0, were examined using an instrumented (depth-sensing) indentation testing technique. An instrumented indentation testing approach is a semi-destructive, reliable and convenient method which enables us to study the variations and distributions of the mechanical properties (i.e. hardness) as a function of distance from build plate. The variations in properties are then compared in AlSi10Mg and A205.0 alloys and are correlated to the generated microstructures in the printed alloys.

9:40 AM Break

10:10 AM
Visualization and Measurement with Dynamic X-ray Radiography of Laser Melting in 3D Printing: ***Anthony Rollett***[1]; Ross Cunningham[1]; Christopher Kantzos[1]; Tao Sun[2]; Cang Zhao[2]; Niranjan Parab[3]; [1]Carnegie Mellon University; [2]Argonne National Laboratory; [3].Argonne National Laboratory

A brief overview is given of the capabilities of synchrotrons for research in additive. High speed radiography at frame rates of 50 kHz and above has proven to be invaluable for enabling measurement of various phenomena relevant to selective laser melting (SLM). The size and shape of keyholes has been quantified, which defines the effective shape of the heat source and accounts for the variation in effective absorptivity. The keyhole depth appears to follow the rules for laser drilling. Instability of the keyhole leads to trapping of vapor bubbles. Voids (pores) inside powder particles sometimes are frozen into the melt pool, which results in a irreducible pore content in the printed part. Time dependent transitions are evident from conduction-mode to keyhole, which are strongly dependent on the power density. Solidification cracking can be observed in real time in materials with low resistance to cracking such as AA 6061.

10:30 AM
Process Optimization, Microstructures and Mechanical Properties of the Cu-13.5Al-4Ni-0.5Ti Copper-based Shape Memory Alloy Produced by Selective Laser Melting: ***Wenzhi Zhu***[1]; Qingsong Wei[1]; Jian Tain[1]; [1]State Key Laboratory of Materials processing and Die&Mould Technology, Huazhong University of Science and Technology

The Cu-13.5Al-4Ni-0.5Ti copper-based shape memory alloy (SMA) with near full density, elevated strength and hardness was produced by selective laser melting with optimized processing parameters. The phase and microstructures were characterized by XRD, OM and SEM, and the hardness and tensile measurements were conducted. The results showed that the maximum relative density of 99.9% was obtained when the laser input energy was about 110 J/mm3. Too high and too low energy densities both led to a decline in the density of as-SLM alloy. The XRD results show that only ß1’ phase (AlNi2Ti) was detected in as-SLM samples, different from that (γand γ2 phases) concluded by the Cu-Al-Ni phase diagram. The OM and SEM observations display that elongated strip-like grains in parallel grow across melting tracks. The average grain size is approximate 43μm. The hardness ranges from 267.1HV to 289.1HV, with strength of 536MPa and elongation of 8.56%, respectively.

10:50 AM
Microstructure and Physical Properties of Pure Copper Fabricated via Electron Beam Melting: ***Christopher Ledford***[1]; Prithwish Tarafder[1]; Harvey West[1]; Christopher Rock[1]; Diana Gamzina[2]; David Marsden[3]; Lawrence Ives[3]; Timothy Horn[1]; [1]North Carolina State Universty; [2]SLAC National Accelerator Laboratory; [3]Calabazas Creek Research, Inc.

Fabrication of pure copper components utilizing additive manufacturing allows for unique applications in the areas such as heat transfer, electrical connections, and radio frequency devices. In this study, pure copper was fabricated utilizing electron beam melting (Arcam S12). Microstructure and physical properties such as density, electrical conductivity, thermal conductivity, and chemical composition were analyzed among various powder size distributions and oxygen contents. Mechanical properties such as hardness, tensile and yield strength, and elongation were also studied.

11:10 AM
Composite Cu-C and Cu-W Thermal Concentrator Design Using LENS: ***Tim Price***[1]; Andrew Kustas[1]; Shaun Whetten[1]; David Keicher[1]; [1]Sandia National Laboratories

Multi-process and multi-material additive manufacturing have the potential to create new devices with tailored thermal performance. One area of interest is thermal concentration and heatsink applications. Recent work has focused on understanding the resulting properties of powderbed AM parts with LENS-produced features added separately. Thermal concentrator test plates were produced with a powderbed stainless steel substrate along with LENS-produced copper/carbon and copper/tungsten thermal concentrator composite elements. The objective of the carbon/tungsten additive is to improve the coupling between the LENS laser and copper matrix for enhanced local melting. The resultant grain structure and interface of the LENS copper composite and powderbed AM stainless substrate were evaluated using a suite of microscopy methods. Results show multi-material LENS continues to show promise as a thermal management technique.

Materials: Metals 6 - Titanium Alloys 1

Wednesday AM Room: 416AB
August 15, 2018 Location: Hilton Austin

Session Chair: Evren Yasa, Eskisehir Osmangazi University

8:00 AM
Development of Titanium and Steel Alloys Optimized for AM: Yining He[1]; ***Bryan Webler***[1]; Jack Beuth[1]; [1]Carnegie Mellon University
Experimental investigations into alloy development for laser powder bed AM are constrained by the cost of fabricating powders with customized compositions. To minimize the impact of powder fabrication cost, this study applies a powderless methodology to rapidly screen inferior compositions. Single laser tracks and multi-track pads are made on arc-melted alloy buttons across ranges of beam power and travel speed. Optimal compositions are then determined by melt pool characterization. This methodology has been applied to two alloy systems: (1) Ti6Al4V + B, with Ti6Al4V-xB compositions (x = 0, 1, 2, 5, 10, wt%) tested under 14 process settings. (2) three tool steel grades (M2, D2, P20) tested under 28 process settings. Single track results show trends in melt pool dimensions, microstructure and hardness across beam power, travel speed, and composition space. The multi-track pads also enable initial characterization of the effects of thermal cycling by adjacent melt pools.

8:20 AM
Effect of Powder Degradation on the Fatigue Behavior of Additively Manufactured As-Built Ti-6Al-4V: ***Patricio Carrion***[1]; Arash Soltani-Tehrani[1]; Nima Shamsaei[1]; [1]Auburn University
Additive manufacturing (AM) technology has enabled many industries to generate functional parts with an increased level of complexity via a layer-by-layer melting and solidifying process. In laser-powder bed fusion (L-PBF), the most commonly used AM process, metal powder is often recycled due to its high cost. However, there is no comprehensive study on how recycling powder affects its rheological properties, and the mechanical and fatigue behavior of the final manufactured part. In this study, a comparison of new and used Ti-6Al-4V powder characteristics was made. The comparison includes morphology, size distribution, as well as monotonic tensile and fatigue behavior of fabricated specimens. Finally, conclusions and suggestions on powder recycling are made. It was shown that the powder size distribution (PSD) becomes narrower after recycling, and the morphology of the particles change with recycling. No comparable effect was observed on the monotonic tensile and fatigue behavior of the AM as-built Ti-6Al-4V specimens.

8:40 AM
Volume Effects on the Fatigue Behavior of Additively Manufactured Ti-6Al-4V Parts: ***Jonathan Pegues***[1]; Michael Roach[2]; R. Scott Williamson[2]; Nima Shamsaei[1]; [1]Auburn University; [2]University of Mississippi Medical Center
Recent interest to implement additive manufactured parts into structural applications has created a critical need to better understand the fatigue behavior of these parts. Alloys such as Ti-6Al-4V are popular in the aerospace and biomedical industries due to their superior strength to weight ratio and biocompatibility. In these two industries, part sizes can range from very small surgical implants to large structural components, all of which are subjected to cyclic loading conditions. The fatigue behavior of additively manufactured parts may show more sensitivity to part size than their wrought counterparts due to the defects that are inherent to the fabrication process. This research investigates the sensitivity of additively manufactured Ti-6Al-4V parts to volume size by comparing the stress-life fatigue curves of three geometries with increasing gage volumes. Results indicate that additive Ti-6Al-4V parts show reduced fatigue lives because of an increase in surface or near-surface defects.

9:00 AM
LPBF Powder Feedstock Effects: A Study in Ti6Al4V: ***Ajay Krishnan***[1]; Scott Volk[1]; [1]Incodema3D
This study was carried out as part of Incodema3D's qualification process for new powder suppliers. Four different samples of Ti6Al4V powder were procured from various manufacturers and were subjected to a uniform analysis and build process to select the best-performing powder for LPBF applications. In the process of qualifying the powders, differences in their behavior were noted and presented a great opportunity to identify key powder characteristics. The powders were characterized by SEM, sieve analysis to determine their morphology, size and size distribution. Precautionary checks for flowability were carried on the Mercury Scientific Revolution Powder Analyser, before the powders were used to build tensile dogbone specimens in the 3D Systems ProX DMP 320. The in-process build quality for each powder sample was monitored, and subsequent mechanical properties of the built dog-bones were determined. The results were analysed and the best-performing feedstock was selected.

9:20 AM
Effect of Heat Treatment on the Phase Transformation and Mechanical Properties of Ti6Al4V Fabricated by Selective Laser Melting: ***Xingchen Yan***[1]; Chaoyue Chen[1]; Wenyou Ma[2]; Min Kuang[2]; Rodolphe Bolot[3]; Hanlin Liao[1]; Christian Coddet[1]; Min Liu[2]; [1]Universite de Technologie de Belfort-Montbeliard; [2]Guangdong Institute of New Materials; [3]Université de Bourgogne Franche-Comté
In this work, Ti6Al4V ELI (Extra Low Interstitials) samples were fabricated by selective laser melting (SLM) technology with optimized parameters. The manufactured samples were then treated by a series of vacuum heat treatments (HT, based on the phase diagram) and hot isostatic pressing treatment (HIP). Defects especially refer to the residual pores were measured by Micro-CT. The test of microhardness, tensile and high cycle fatigue for all samples were conducted. Besides, the microstructure and phase content in different condition were analyzed and compared by EBSD and TEM. The influence of different post treatment on the as-built samples was evaluated and discussed. As a result, HIP treatment was found to improve the ductility in comparison with as-built samples but resulted in a decrease of the maximum strength. The best fatigue resistance was achieved with HIP treatment due to the elimination of defects.

9:40 AM Break

10:10 AM
Characterization of Electron Beam Melted Parts Produced by Coarse Ti6Al4V Powders with Large Layer Thicknesses: ***Hengfeng Gu***[1]; Harvey West[1]; Ola Harrysson[1]; [1]North Carolina State University
In the current Electron Beam Melting (EBM) process, the particle size distribution (PSD) for the powder feedstock is often limited to 45-106µm. The small powder size not only increases the powder cost, but also leads to a low build speed due to thin build layers. The fine powder is also prone to oxidation and beam interaction. This paper investigated the properties of EBM parts fabricated using coarse Ti6Al4V powders (65-250µm) with multiple levels of thicker build layers and compared them to parts fabricated using standard PSD powders with 50µm layer thickness. Part density, chemistry, microstructure, and mechanical properties were characterized. It was found that parts manufactured using coarse powders achieved similar properties compared to those manufactured using standard size powders while reducing the build time significantly. This could potentially lead to faster and cheaper builds for large components that need finish machining.

10:30 AM
Toward Location-specific Control of Mechanical Properties in Ti-6Al-4V via Electron Beam Melting Process: ***Rahi Patel***[1]; Sneha Narra[1]; Jack Beuth[1]; [1]Carnegie Mellon University
The relationship between microstructure and mechanical properties of electron beam powder bed fusion (EB-PBF) fabricated Ti-6Al-4V (Ti64) parts is explored. Parts, which consist of tensile specimens, charpy blocks, and the dovetail region of a generic compressor blade were fabricated with different solidification conditions by varying processing parameters. These parts were then mechanically tested to characterize tensile properties, toughness, and hardness. Previous work has shown that there is a relationship between cooling rates at solidification and resulting prior beta grain widths. In addition, alpha grain size has been shown to be proportional to the solid state cooling rate, which also varies with processing parameters. Thermal models were developed to link thermal history to ex-situ images of prior beta grain width and alpha size. This work will further our understanding of the link between process parameters and final part properties and enable the implementation of location-specific control of properties in additive manufacturing.

10:50 AM
Microstructure, Mechanical Properties, and Fatigue Behavior of Electron Beam Additive Manufactured Ti-6Al-4V: ***Andrew Chern***[1]; Peeyush Nandwana[2]; Robert McDaniels[3]; Peter Liaw[1]; Ryan Dehoff[2]; Robert Tryon[3]; Chad Duty[1]; [1]University of Tennessee Knoxville; [2]Oak Ridge National Laboratory; [3]VEXTEC
Electron beam melting (EBM) presents the opportunity to reduce the buy-to-fly ratio of components for the aerospace industry, specifically for difficult to machine alloys like Ti-6Al-4V. However, a lack of knowledge surrounding how critical process parameters influence the microstructure and fatigue life prevents its widespread use today. This study investigates how the EBM process affects Ti-6Al-4V components by documenting the effect of build orientation, scan path, part size volume, and local surface finish on microstructure, tensile properties, and fatigue behavior. Four-point-bend fatigue tests, tensile tests, Vickers microindentation hardness, scanning electron microscopy, and optical microscopy revealed anisotropy in both the microstructure and fatigue behavior. These results are discussed with respect to other fatigue data available in the literature for various processing and post-processing conditions (such as machining and hot isostatic pressing).

11:10 AM
Understanding the Correlation between Mechanical Properties and Porosity Formation of 3D-printed TNM-B1 by Means of High-performance Computer Tomography: ***Elena Lopez***[1]; Axel Marquardt[2]; Mirko Riede[1]; André Seidel[1]; Frank Brückner[1]; Christoph Leyens[1]; [1]Fraunhofer IWS; [2]Technical University of Dresden
γ-TiAl have been used in low-pressure turbines to increase the efficiency of aircraft engines.These γ-TiAl can be used in the range 500 – 800 °C and replace conventional nickel-based superalloys.One of the major challenges of γ-TiAl is its inherent brittleness. The very high degrees of deformation that occur in the conventional production of components severely restrict the processing window and make the processing of this alloy class difficult.Using SEBM at temperatures above BDTT, complex components have been made of Ti-43.5Al-4Nb-1Mo-0.1B[at.-%] (TNM-B1).The process parameters have a decisive influence on the mechanical properties of the components and on the controlling of aluminium loss caused by its high vapour pressure.This has a considerable effect on the developing microstructure. The microstructural states and component properties can be furthermore influenced by a post processing heat treatment.The relationships between pore morphology (determined with a µ-CT) and the resulting mechanical properties are evaluated and discussed in detail.

11:30 AM
The Behavior of Phase Transformation for Ti-Ta Alloy in Laser Powder-bed Fusion: ***Leilei Xing***[1]; Yafei Wang[1]; Congcong Zhao[1]; Dianzheng Wang[1]; Kailun Li[1]; Wei Liu[1]; Zhijian Shen[1]; [1]Tsinghua university
The Ti-Ta alloy has been widely studied for biomedical applications due to its high biocompatibility, corrosion resistance. ß phase is preferable to good mechanical properties, which may be time consuming and costly to traditional casting technique. In this work, nearly full dense and in-situ alloyed Ti-Ta samples were fabricated by laser powder-bed fusion (LPBF). Unmelted Ta particles were observed in the samples due to its high melting point. However, the percentage of the unmelted Ta particles decreased as the laser exposure time increased. With the increase of Ta, the majority of a' phase transferred to ß phase. Meanwhile, microsegregation were observed in the Ti-50%Ta, and it would cause phase transformation from ß to a". All in all, this research will be instructive to in-situ fabrication and phase regulation of Ti-Ta alloy by laser powder-bed fusion.

Materials: Polymers 2 - Extrusion-based Polymers

Wednesday AM — Room: Salon J
August 15, 2018 — Location: Hilton Austin

Session Chair: Abby Paterson, Loughborough University

8:00 AM
Full Field Strain Measurement of Material Extrusion AM Parts with Both Solid and Sparse Infill Geometry: ***Joseph Bartolai***[1]; Alexander Wilson-Heid[1]; Jordan Kruse[1]; Allison Beese[1]; Timothy Simpson[1]; [1]Penn State University
Full field strain, during tensile deformation, is measured in parts produced by Material Extrusion Additive Manufacturing (MEAM) using Digital Image Correlation (DIC). Much has been done to study stress and strain at the part level; however, local levels of stress and strain within MEAM parts remain largely unexplored. This study documents the effects of tensile loading on MEAM parts of both solid and sparse infill geometry. Local effects of tensile strain on different toolpath orientations are also studied. A novel build strategy for creating sparse infill geometry is also introduced and tested.

8:20 AM
A Novel Thermoplastic Polymer Weld Strength Theory for Material Extrusion AM: ***Joseph Bartolai***[1]; Timothy Simpson[1]; [1]Penn State University
It is well known that the weakest points in thermoplastic polymer parts produced by Material Extrusion Additive Manufacturing (MEAM) are the weld interfaces between adjacent roads and layers of deposited extrudate. These weld interfaces develop strength as polymer molecules diffuse across the interface and become entangled with molecules on the other side of the interface. The rate at which molecular diffusion occurs is highly dependent on the temperature of the interface. Contemporary thermoplastic polymer welding theories do not accurately account for the cyclic thermal histories common in MEAM. The novel theory introduced herein estimates the strength of the weld throughout the deposition process, successfully capturing changes caused by temperature variation using an Arrhenius-like reaction. Both flat-plate welded specimens cut from extruded sheet and AM specimens are tested against the proposed theory.

8:40 AM
Inter-bead Bond Strength Improvement of FDM Parts by Isothermal Heating: ***Rhugdhrivya Rane***[1]; Robert Taylor[1]; [1]University of Texas at Arlington
This work aims to increase inter-bead bond strength of parts printed using Fused Deposition Modeling (FDM) 3D printing. FDM printed parts were subjected to heat treatment for specified durations thus increasing the healing and reptation at the bonds to eventually increase inter-bead strength, including z-direction strength. Heat treatment was performed at multiple temperature values and times to characterize bond strength effects and investigate part deformation and geometric accuracy. Experimental testing was done by subjecting the FDM parts to static and fatigue tensile loading and an increase in the values of strength was observed. The bond quality was analyzed under a microscope by observing the changes in the mesostructure and the degree to which healing is achieved at the adjacent polymer interfaces. The results of this study provide information to increase the structural strength of parts manufactured using FDM and also open prospects for higher strength applications.

9:00 AM
Conductive Polymer Options for Multi-material FFF Additive Designs: ***Louisa Orton***[1]; Emily Hardy[1]; Jason Weaver[1]; [1]Brigham Young University
Fused filament fabrication has the ability to print a wide range of filaments, including conductive filament. Multi-material designs including both conductive and insulating polymers can enable novel applications across many fields, from customized gaming and music equipment to electronics-embedded toys, gadgets, and medical devices. Several different solutions exist on the market for incorporating conductive pathways into additive manufactured products, including inks, paints, and filaments. This paper examines the electrical and material properties of several of these conductive polymers. It also considers the relative strengths and weaknesses of each regarding printability, effectiveness, and usability, including possible effects due to process and design parameters such as infill pattern and percentage, layer thickness, and contact methods.

9:20 AM
Using Fillers to Improve Printability of a Water Soluble Semi-crystalline Polymer for Material Extrusion Additive Manufacturing: ***Callie Zawaski***[1]; Camden Chatham[1]; Emily Wilts[1]; Tim Long[1]; Christopher Williams[1]; [1]Virginia Tech
Additive manufacturing (AM) applications are currently constrained by the limited selection of processable materials. The authors' have previously investigated the influence of divalent counter-ions on sulfonated poly(ethylene glycol) (PEG). These polymers were evaluated based on the criteria of (i) fast dissolution and (ii) manufacturability via fused filament fabrication (FFF) at low temperatures (<100 °C) to allow for the incorporation of active ingredients for personalized medicine. However, the ion exchange following the synthesis of the sulfonated PEG is expensive in production scale-up. To circumvent this limitation, this work explores the use of filler materials (CaCl2, SiO2, and starch) in the precursor sulfonated PEG sodium ion containing polymer, poly(PEG8k-co-NaSIP), to achieve the desired properties enabling FFF. Changes in the viscosity and the crystal percent, growth, size, and structure allows for improved processing via FFF without using an ion exchange.

9:40 AM Break

10:10 AM
The Effect of Crystallinity on Mechanical Properties of High Temperature Semi-crystalline Printed Thermoplastics: ***Vidya Kishore***[1]; Ahmed Hassen[2]; Vlastimil Kunc[2]; Chad Duty[1]; [1]University of Tennessee Knoxville; [2]Oak Ridge National Laboratory
Achieving good interlayer bonding between printed layers remains to be one of the primary challenges in additive manufacturing, typically causing significant mechanical anisotropy in printed components. For the majority of amorphous thermoplastics used in 3D printing, bonding between layers is primarily driven by thermal fusion and polymer inter-diffusion processes. However, for semi-crystalline polymers, the degree of crystallinity that is achieved across the interface can also determine the final mechanical properties of printed components. This work investigates the effect of processing conditions on the development of crystallinity within a printed part, and the resulting mechanical properties of some high temperature thermoplastics.

10:30 AM
Influences of Printing Parameters on Semi-crystalline Microstructure of Fused Filament Fabrication Polyvinylidene Fluoride (PVDF) Components: ***Niknam Momenzadeh***[1]; Thomas Berfield[1]; [1]University of Louisville
Piezoelectric polymers have garnered wide interest for sensing, actuation, and energy harvesting applications due to their unique combination of high strain tolerance and electro-mechanical coupling. Compared to other piezoelectric polymers, polyvinylidene fluoride (PVDF) and its copolymer and terpolymer variations demonstrate some of the strongest piezoelectric responses. One of the primary challenges associated with PVDF is that its piezoelectric response is highly dependent on its microstructure, which varies greatly with manufacturing-associated stresses. This work investigates Fused Filament Fabrication (FFF) of PVDF polymers, and the effects of processing parameters such as layer thickness, infill pattern, infill density, nozzle diameter, perimeter shells on its microstructure development. Fourier-Transform Infrared Spectroscopy (FTIR) measurements are used to assess the relative phase content of the semi-crystalline microstructure arrangement primary related with significant piezoelectric response in PVDF (ß-phase). In addition, these measurements are corroborated with a direct evaluation of the piezoelectric response of 3D printed PVDF structures.

10:50 AM
Low-temperature Powder Bed Fusion Processing of Poly(Phenylene Sulfide): ***Camden Chatham***[1]; Christopher Williams[1]; Timothy Long[2]; [1]DREAMS Lab at Virginia Tech; [2]Long Research Group at Virginia Tech
Poly(phenylene sulfide) (PPS) is a high-performance polymer with an equilibrium melting-crystallization temperature of 328 °C, which is above the maximum build chamber temperature for most commercial powder bed fusion (PBF) printers. Other high-temperature polymers often require expensive, high-temperature printers for their manufacture. In this paper, the authors present evidence of PPS printing using a bed temperature of 180 °C, which is below the equilibrium melting temperature for PPS and opposes the existing material screening guidelines. The presented process parameters result in final part density upwards of 1.19 g/cc (-11 % of injection molding), ultimate tensile strength of 62 MPa (80 MPa for injection molding), and elongation of 3.3 % (4% for injection molding). The presented work outlines the manufacturing parameters and the resultant part properties along with hypotheses on the generalizability of low-temperature PBF printing of high-performance polymers, and steps towards updating materials and process parameter selection guidelines for PBF.

11:10 AM

Characterization of Stiffness Properties of Fused Deposition Modeling Thermoplastic Components: ***Ahmed Sherif El-Gizawy***[1]; Thao Phan[1]; Timothy Staat[1]; Ryan Zvanut[2]; [1]University of Missouri; [2]National Security Campus-US DOE

Fused Deposition Modeling (FDM), is an additive manufacturing (AM) technique used to build rapid prototypes out of thermoplastic materials. As AM, printing technology continues to mature from a rapid prototyping process to rapid manufacturing functional products, predicting 3D printed part behavior has become increasingly desirable. The present paper presents an integrated approach for characterization of the process-induced stiffness properties of FDM printed materials. The use of polycarbonate (PC) and ULTEM 9085 materials in this technology for building functional products is growing very rapidly. This is because of their superior mechanical and physical properties. The standard testing methods and specimen design for FDM build components are revised and corrected for results that are more reliable. The results obtained on both materials indicate reduction of strength and ductility of FDM processed materials compared with the properties of feedstock material. This is attributed to thermal degradation of thermoplastics mechanical properties during FDM processing.

11:30 AM

Effects of Defects on the Mechanical and Electrical Properties of AM Parts: ***Sai Sri Nidhi Munaganuru***[1]; Hari Adluru[1]; Kenneth Reifsnider[1]; Rassel Raihan[1]; Vamsee Vadlamudi[1]; Muthu Ram Prabhu Elenchezhian[1]; Rauhon Ahmed Shaik[1]; [1]University of Texas at Arlington Research Institute

Additive manufacturing revolutionized many industries, i.e., automotive, biomedical, aerospace and defense. As opposed to traditional manufacturing methods, in Fused Deposition Modeling (FDM) a part is manufactured layer by layer from three-dimensional CAD models by the 3D printers. Though the vision of AM is impressive, there are many challenges that are hindering the widespread use of these complex material system. One of the challenge in these parts is defects in the form of discontinuous material, directional properties in print direction (raster orientation), different interface strength due to variations in the manufacturing process etc. In this work, the effect of manufacturing defects and their orientation on the mechanical and electrical properties of the additively manufactured parts will be investigated. The di-electrical properties will be studied to find out the material state of additively manufactured parts. Numerical multi-physics analysis will be performed further to understand how these defects effect the complex material system.

Modeling 2: Design and Process Planning

Wednesday AM	Room: 417AB
August 15, 2018	Location: Hilton Austin

Session Chair: Nicholas Meisel, Penn State

8:00 AM

Analysis of Additive Manufacturing Build Direction on Overhang Structures: ***Mohammed Isa***[1]; Ismail Yigit[1]; Ismail Lazoglu[1]; [1]Koc University

Additive manufacturing (AM) has gained repute as a direct method of fabrication of complex parts. However, the requirement for each layer to be structurally supported can make parts with overhangs hard to produce without alterations to the parts. This work proposes using multi-axis additive manufacturing to fabricate and analyze freeform overhangs such as bridge structures. Multi-axis AM allows reorientation of the build direction so that overhangs can be 3D printed. Consequently, decision on the build orientation is necessary and its result should be analyzed. The effect of the AM build direction with respect to the overhang's local surface directions will be studied. A Rhinoceros® plugin is designed to generate the path of the multi-axis AM for the unsupported components like roofs, bridges and protrusions. The effects of the build direction on the surface quality and deformation of the components are studied.

8:20 AM

Topology-aware Routing of Electric Wires in FDM-printed Objects: ***Florens Wasserfall***[1]; [1]University of Hamburg

The direct integration of electric connections into AM-fabricated plastic parts at printing time has recently attracted increasing attention. To make efficient use of such techniques, appropriate design and routing software is required. In prior work, we proposed the integration of SMD-component placement and wiring into a slicing-software for FDM-based processes, to consider parameters, e.g. extrusion-width or layer-thickness for each specific printjob. The trace-width of a printed wire roughly equates to the typical extrusion width of FDM-printers and the pitch of larger SMD-packages. For curved object surfaces and regions with high wire density, linear routing produces a high number of small islands and gaps. To mitigate this effect, we attempt to align wires with object perimeters and perimeters of already routed wires. A weighted graph representation is generated from all printable perimeters of each layer and direct connections between wire waypoints. An A*-based search is then employed to find optimal routes.

8:40 AM

Predicting Part Mass, Required Support Material, and Build Time via Autoencoded Voxel Patterns: Christian Murphy[1]; ***Nicholas Meisel***[1]; Timothy Simpson[1]; Christopher McComb[1]; [1]Penn State

Additive Manufacturing (AM) allows designers to create complex geometries that were once too complex or expensive to achieve through traditional manufacturing processes. Currently, Design for Additive Manufacturing (DfAM) is restricted to experts in the field, and novices may overlook potentially transformational design capabilities. This project aims to make DfAM accessible to a broader audience through deep learning, enabling designers of all skill levels to leverage AM-specific geometries create new designs. To demonstrate such an approach, a database of files was acquired from industry-sponsored AM challenges focused on lightweight design. These files were converted to a voxelized format which provides more robust information for machine learning applications. Next, a convolutional autoencoder was constructed to extract common voxel patterns from the files. Finally, the autoencoder was used to construct a deep neural network capable of predicting various DfAM attributes. This work demonstrates an initial foray towards a more extensive DfAM support system.

9:00 AM

Modeling a Scanning-mask Projection Vat Photopolymerization System For Large-area, High-resolution Additive Manufacturing: ***Viswanath Meenakshisundaram***[1]; Logan Sturm[1]; Christopher Williams[1]; [1]DREAMS Lab, Virginia Tech

Among the three critical manufacturing parameters: cycle time, build volume and feature resolution, current vat photopolymerization platforms allow for the maximization of two parameters only. A scanning-mask projection vat photopolymerization (S-MPVP) system addresses this shortcoming. Instead of creating layers by projecting a static 2D pattern on the resin surface, the S-MPVP scans the 2D pattern across the resin surface. During scanning, the mask must be dynamically altered to ensure geometric accuracy and uniform energy distribution. In this work, the construction of a S-MPVP machine and the development of a system model is presented. Specifically, a numerical model to determine the relationship between the process parameters such as scan speed and mask projection rate and the resulting cure profile is presented. The accuracy of the S-MPVP model is demonstrated by comparing the dimensions of fabricated specimens with the predictions from the numerical simulations.

9:20 AM
Continuous Property Gradation for Multi-material 3D-printed Objects: ***Christian Altenhofen***[1]; Thu Huong Luu[1]; Johannes Mueller-Roemer[1]; Marco Dennstädt[1]; Tim Grasser[1]; Daniel Weber[1]; André Stork[1]; [1]Fraunhofer IGD
Modern AM processes allow for printing multiple materials. The resulting objects can be stiff/dense in some areas and soft/porous in others, resulting in distinct physical properties. However, modeling material gradients is still tedious with current approaches, especially when smooth transitions are required. Current approaches can be distinguished into a) NURBS-BReps-based and b) voxel-based. In case of NURBS-BReps, discrete material distributions can be modeled by manually introducing separate shells inside the object; smooth gradation can only be approximated in discrete steps. For voxel representations, gradation is discrete by design and comes along with an approximation error. Also, interacting on a per-voxel basis is tedious for the designer/engineer. We present a novel approach for representing material gradients in volumetric models using subdivision schemes, supporting continuity and providing elegant ways for interactive modeling of locally varying properties. Additionally, the continuous volumetric representation allows for on-demand sampling at any resolution required by the 3D printer.

9:40 AM Break

10:10 AM
Novel Scanning Strategies to Replicate Processing Conditions across Laser Powder Bed and Directed Energy Deposition Processes: ***Nicholas Jones***[1]; Jack Beuth[1]; Sneha Narra[1]; Maarten de Boer[1]; [1]Carnegie Mellon University
Laser powder bed fusion (EOS) and direct energy deposition (LENS) are both widely used methods in additive manufacturing but produce very different melt pool morphologies and microstructures. When designing structures for fabrication with one AM process (e.g. LENS), it can be an advantage to replicate its melt pool dimensions and cooling rates through another process (e.g. EOS laser powder bed). Novel scanning strategies are proposed for laser powder bed fusion that utilize specific process parameter combinations to generate melt pool sizes, melt pool shapes, and cooling rates replicating those seen in direct energy deposition. In-situ measurements using high-speed imaging and ex-situ melt pool measurements using optical microscopy are taken from these scan patterns and are compared to simulation results. This work is establishing methods for replicating melt pool dimensions and cooling rates in processes that nominally operate in very different regions of processing space.

10:30 AM
Towards Development of Simulation Based Scan Pattern Optimization Scheme: ***Gaurav Ameta***[1]; Wentao Yan[1]; Paul Witherell[1]; [1]National Institute of Standards and Technology
Simulations of AM processes are improving every year. AM processes, specifically powder bed fusion (PBF), have numerous process parameters affecting the outcome. In this paper, the effect of laser scan path on multiple layers of laser powder bed fusion (L-PBF) process is studied through a simplified thermal conduction model based on finite difference method. The output quantity of interest is temperature fluctuations across the solid-state phase transformation temperature (900°C) for the Inconel625, which could influence the residual stress. Temperature fluctuations for several different scan speeds (0.2, 0.5 and 0.9 m/sec), scan patterns (zigzag and contour) and hatch distances on a square and circular slice are studied. It was found that the strain and stress accumulated in each layer is slightly correlated with the temperature fluctuations in the layer. Therefore, temperature fluctuation can be a metric for scan path optimization and will be used to develop an optimal laser scan path.

Process Development 6 - Novel Methods 1

Wednesday AM	Room: 616AB
August 15, 2018	Location: Hilton Austin

Session Chair: Abdalla Nassar, Applied Research Lab at Penn State

8:00 AM
A New Method of Improving Inkjet Printing Speed for Additive Manufacturing: ***Chao Sui***[1]; Lucas Marques[1]; Wenchao Zhou[1]; [1]University Arkansas
Although inkjet has been widely used in 3D printing for its high resolution and natural support of multiple materials, it remains uncompetitive for high volume production due to its relatively slow printing speed when compared to the traditional manufacturing methods. In this paper, we present a new method for significantly improving inkjet printing speed by increasing the printing frequency using a multi-pulse driving signal. Firstly, we simulated the droplet ejection process using an experimentally validated numerical model and demonstrated that a multi-pulse driving signal can increase the printing frequency and the overall printing speed by eight times through a benchmark inkjet printhead comparison. Then a high-speed drop-on-demand (DOD) droplet generation system was built. Experimental tests were performed to study the effects of the multi-pulse driving signal. Results show that the printing frequency can be significantly increased, which shows great promise of this new method for increasing inkjet printing speed.

8:20 AM
Multiple Collaborative Printing Heads in FDM: The Issues in Process Planning: ***Marco Leite***[1]; Nuno Frutuoso[1]; Bruno Soares[2]; Rodrigo Ventura[3]; [1]IDMEC, Instituto Superior Técnico, Universidade de Lisboa; [2]UNIDEMI, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Campus da Caparica; [3]ISR, Instituto Superior Técnico, Universidade de Lisboa
One of the main drawbacks of large-scale FDM is fabrication time, due to the use of a single deposition head. In this paper we propose a novel approach to tool-path generation for a system with multiple collaborative independent deposition heads. This system allows the size of the parts to increase considerably in comparison to regular FDM systems without the corresponding time increase. However, to enable the tool-path generation, the conventional process planning must be changed. Once the machine configuration is defined, (e.g. number and size of heads), the regions are attributed to each head as either static or dynamic. Then the layer is divided into domains, assigned to each head. A centralized tool-path planner then generates tool-paths, accounting for collisions and optimizing the fabrication time in the layer. The process repeating for all layers. Examples of this approach show reduced fabrication time and larger part dimensions than conventional systems.

8:40 AM
On the Nature of Stochastic Process Anomalies: ***Abdalla Nassar***[1]; Edward Reutzel[1]; Paul Guerrier[2]; Matthew Weldon[3]; Michael Krane[3]; [1]ARL Penn State / CIMP-3D; [2]Moog; [3]ARL Penn State
Particles much larger than the feedstock powder have been observed in commercial powder bed fusion processes, both during post-process sieving and embedded within built components. Such large particulates are often observed in close-proximity to lack-of-fusion defects in built components. However, their origin has not been adequately explained. Here, we provide a hypothesis on the origin of large (>>D50) particulate—that they emanate from stochastic agglomeration of ejected melt by multi-particle collisions. High-speed imaging during processing within a commercial laser powder bed fusion process, together with metallographic analyses are provided as evidence for the proposed hypothesis.

9:00 AM
Conduction-based Laser Power Control for Overhang Structures: ***Ho Yeung***[1]; Brandon Lane[1]; [1]National Institute of Standards and Technology
Overhang structures are difficult to build on a laser powder bed fusion system due to large variation in local thermal conductivities between powder and solidified regions. Traditionally this is addressed by either adding support structures to improve the local thermal conductivity, re-orienting the part with respect to the build direction, or changing the structure design itself. A new method is developed here which adjusts the laser power according to a geometric-based thermal conductivity model derived simultaneously during the laser scan path planning. This approach does not require any structural changes, hence is a more generic solution and is easy to automate. It also captures the relative thermal conduction variability due to the scan sequence, impossible for any traditional approaches applying before path planning. Special designed samples are built, and the effects of this unique scan strategy are investigated by in-situ melt-pool monitoring in combination with post-process part quality measurements.

9:20 AM
Pick and Place Robotic Actuator for Big Area Additive Manufacturing: ***Alex Boulger***[1]; Phillip Chesser[1]; Brian Post[1]; Alex Roschli[1]; Joshua Hilton[1]; Connor Welcome[1]; Nikolaos Tsiamis[1]; Lonnie Love[1]; Katherine Gaul[1]; Breanna Rhyne[1]; [1]Oak Ridge National Laboratory
Oak Ridge National Laboratory's Manufacturing Demonstration Facility has created a system that works in tandem with an existing large-scale additive manufacturing (AM) system to 'pick and place' custom components into a part as it is printed. Large-scale AM leaves a layered surface finish and is typically post-processed through 5-axis CNC machining. Each surface must be accurately recorded into a laser tracking system. This process can be simplified with the use of fiducials, which are small location indicators placed on the surface of a part. Additionally, the ability to monitor an AM tool via wireless sensors is advantageous to gauge part health as it is fabricated and later used. The 'pick and place' system allows thermocouples, fiducials, and other sensors to be accurately placed throughout the tool as it is fabricated. This solution has the potential to reduce time, labor, and cost associated with fabricating, post-processing, and using AM parts.

9:40 AM Break

10:10 AM
3D Printed Electronics: ***Mwamba Bowa***[1]; [1]The University of Tennessee
Additive manufacturing is revolutionizing the way we build and produce a plethora of products spanning many industries. It has shown strong potential in reduced energy use, sustainability and cost effectiveness. Exploring avenues that this technology can be utilized is key to improve productivity and efficiencies in various applications including electronic systems and devices manufacturing. Electronic systems and sub-systems are built using a variety of material and processes, which require a large carbon footprint, significant waste material and high production time. We propose the application of 3D printing technology to support an integrative process for combining circuit board fabrication, solder mask process, electronic component pick and place and enclosure manufacturing. The integration of these separate processes into a single high efficiency additive manufacturing process will yield significant savings in energy use, carbon footprint, waste product and production time and cost.

10:30 AM
Additive Manufacturing of Soft Electronics & 3D Microfluidics Using Liquid Metal Patterning Processes: ***Dishit Parekh***[1]; [1]North Carolina State University
Existing methods for metal additive manufacturing, unlike polymers, tend to be expensive and energy-intensive requiring elevated sintering temperatures and vacuum, making them difficult to integrate with soft materials. We present a simple approach that utilizes low melting point alloys that offer the electrical and thermal benefits of metals like gallium and indium, with the ease of printing due to its low viscosity. Due to the instantaneous formation of a thin, passivating surface nano-oxide skin, we can direct-write planar and out-of-plane, mechanically stable, high resolution, conductive microstructures down to ~10 microns, on-demand, at room temperature using a customized pneumatic dispensing robot. We have demonstrated functional electronics such as flexible and stretchable radio-frequency antennas for communication and wearable thermoelectric generators for energy harvesting applications. We have patterned 3D microchannels with vasculature using printed liquid metals as a sacrificial template, that can be employed in lab-on-a-chip systems enabling inexpensive fabrication of healthcare sensors.

10:50 AM
Fiber Pulling Printing--A Novel Additive Manufacturing Process of Continuous Fiber Reinforced Metal Matrix Composite: ***xin wang***[1]; Xiaoyong Tian[1]; Dichen Li[1]; [1]Xi'an Jiaotong University
Metal matrix composites (MMCs) are materials which have been widely used in the aerospace and automobile industries since the 1980s and have been classified as hard-tomachine materials. This manuscript proposes a novel additive manufacturing process of continuous fiber reinforced metal matrix composite--fiber pulling printing (FPP). The composites with complex structures can be directly manufactured via FPP which utilizes the wetting force and capillarity force to control the flow of melting matrix. The craft is proceeding without extra pressure device and atmosphere protection device and substantially decreases the cost. This manuscript introduces the proof-of-concept prototype and the ability to control the flow of melting matrix and fiber distribution through this process yields a flexible manufacturing route to fabricating 3D metal matrix composite parts with full density and complex geometries.

Process Development 7 - Powder Bed Fusion 1

Wednesday AM — Room: Salon K
August 15, 2018 — Location: Hilton Austin

Session Chair: Robert Landers

8:00 AM
Investigating Laser Beam Operations in Laser-powder Bed Fusion: ***Josh Koepke***[1]; Bradley Jared[1]; David Saiz[1]; Erich Schwaller[1]; [1]Sandia National Labratories
Additive manufacturing (AM) printers are delivered with nominal settings the manufacturer believes are best. Some AM printers allow the nominal settings to be adjusted allowing the user to determine how optimized these settings are. Understanding how a laser beam performs during the build process is crucial to building an acceptable part. In this experiment, the laser beam diameter was measured over time at different power levels and offsets from the build plate to determine an optimized beam profile. The dynamic performance of the laser beam at varied power and offset settings, and implications for process performance will be discussed. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. SAND2018-3875 C

8:20 AM
Two-dimensional Characterization of Window Contamination in Selective Laser Sintering: ***Doug Sassaman***[1]; Joe Beaman[1]; Peter Hall[2]; Scott Fish[1]; [1]University of Texas at Austin; [2]Stratasys Direct Manufacturing
Most Laser Sintering machines suffer from an issue where it is hypothesized that hot gases produced during the laser sintering process collect on the Zinc selenide window separating the build chamber from the environment. This contamination has previously been shown to reduce delivered laser power by up to 10%, and necessitate frequent cleaning and replacement of the windows. A power meter was constructed in order to perform ex-situ measurements of laser attenuation at various locations on the window. Identical builds were performed using fire-retardant nylon 11 on a DTM Sinterstation 2500, and the windows were measured before and after each build. Results indicate that contamination is not uniform on the window, and may cause a variation in laser attenuation up to 3.5%±0.25% depending on scanning location. It is also shown here that the contamination patterns are not repeatable from build to build, even if performed on the same machine.

8:40 AM
Effects of Inter-layer Dwell Time in Laser Powder Bed Fusion: ***Richard Williams***[1]; Paul Hooper[1]; Catrin Davies[1]; [1]Imperial College London
Parts are frequently nested together in powder bed fusion additive manufacturing processes (PBFAM) as a means to maximise productivity and minimise cost. As a result, the dwell time between successive layer scans experienced by a component will vary according to the other components being processed in the same build. In turn, this affects the temperature profile in the part as it is being built up and gives rise to defects and variation in microstructure and properties. This has significant implications where the certification of components for safety critical applications is concerned. In this work, sample components with variation in the inter-layer dwell time were manufactured in an instrumented build chamber with multi-scale thermal imaging capability. This data, along with microscopy and mechanical testing techniques, are used to characterise the defects and property variability associated with the phenomenon.

9:00 AM
Laser Metal Additive Manufacturing on Graphite: ***Arad Azizi***[1]; Scott Schiffres[1]; [1]SUNY Binghamton
This presentation will analyze the challenges to two-material additive manufacturing of dissimilar materials, and present research findings for several dissimilar materials made with powder bed laser fusion additive manufacturing. The issues of material-material wettability will be analyzed, and the thermal and mechanical strength of various two-material bondings will be presented (shear-lap testing). The underlying physics of the two-material bonding will be analyzed with thermo-mechanical transport models.

9:20 AM
Laser Reflectometry and Its Potential for LPBF In-situ Process Monitoring and Optimization: ***Brandon Lane***[1]; Ivan Zhirnov[2]; Steven Grantham[2]; Sergey Mekhontsev[2]; [1]National Institute of Standards and Technology ; [2]National Institute of Standards and Technology
Recent studies have demonstrated significant variability of laser coupling (absorption) with changing the process parameters, leading to non-linear impact on the melt pool energy balance before and during the onset of keyhole mode. In this paper, we demonstrate a new method for measuring laser absorption using a calibrated hemispherical reflectometer. The reflectometer enables measurement of the total reflected laser energy. In conjunction with a calibrated laser energy input, an energy balance provides the laser absorption (excluding evaporation and conductive losses). Simultaneously, a high speed, co-axial melt pool monitoring camera captures the radiant emission from the melt pool at a wavelength separate from the laser. A direct comparison is made between laser absorption measurements via the reflectometer, and radiant emission measurements via the high-speed camera. Discussion is also provided that compares our results to similar studies, and evaluates the viability of in-situ monitoring of laser absorption for process optimization

9:40 AM Break

10:10 AM
Predictive Iterative Learning Control with Surrogate Model for Optimal Laser Power in Selective Laser Sintering: ***Alexander Nettekoven***[1]; Scott Fish[1]; Ufuk Topcu[1]; Joseph Beaman[1]; [1]University of Texas at Austin
Previous research in Selective Laser Sintering (SLS) has shown that variable laser power can improve melt pool temperature uniformity by minimizing the anticipated deviation of the melt pool temperatures from the desired post-melting temperature caused by repetitive and random disturbances. This can significantly improve melting consistency of the melt pool and hereby, lead to better part quality. In order to appropriately feedforward control the laser power for each layer, a Predictive Iterative Learning Control algorithm (PILC) is proposed that will iteratively learn and output an optimal laser power profile. The PILC will train offline with a data-driven model of the SLS process that is based on in-situ measurement data from the machine. It also has the capability of updating itself online during build operations.

10:30 AM
Realtime Control-oriented Modeling and Distributed Sensing for Smart and Reliable Powder Bed Fusion: ***Xu Chen***[1]; Tianyu Jiang[1]; Dan Wang[1]; Hui Xiao[1]; [1]University of Connecticut
The vision of sustainable mass customization calls for additive manufacturing (AM) processes that are resilient to process variations and interruptions. This work concerns a system-theoretical approach towards such a smart, reliable AM. Specifically, one focused example is laser-aided powder bed fusion for fabricating metallic and high-performance polymeric parts. By capitalizing on the fundamental precision heating and solidification, together with the layer-by-layer iterations of energy source, feedstock, and toolpath, we will discuss mathematical abstractions of process imperfections that understand the intricate thermomechanical interactions and are tractable under realtime computation budgets. A model-based decentralized sensing is then proposed to discard unnecessary information to make full use of data-intensive sensor sources like streaming videos. Finally, we discuss our results of controlling the proper energy deposition to ensure quality and reproducibility in a closed loop. Simulation and experimentation with industrial laser scanning and an in-house built PBF testbed validate the theoretic and algorithmic results.

10:50 AM
Microwave Assisted Selective Laser Melting of Technical Ceramics: ***Sam Buls***[1]; Jef Vleugels[1]; Jean-Pierre Kruth[1]; Brecht Van Hooreweder[1]; [1]KU Leuven
Direct processing of technical ceramics is not possible with conventional additive manufacturing (AM) processes due to the very high temperatures that are required. Therefore, indirect AM approaches are often used. These indirect processes show great potential but require extensive post processing (e.g. debinding and sintering) leading to shrinkage, limited geometrical accuracy and eventually limiting overall part quality. To overcome these limitations, this paper presents a novel Microwave Assisted Selective Laser Melting process that enables direct processing of technical ceramics.

11:10 AM
Experimental Study of the Sub-systems in a Microscale Additive Manufacturing Process: Nilabh Roy[1]; ***Dipankar Behera***[1]; Obehi Dibua[1]; Chee Foong[2]; Michael Cullinan[1]; [1]University of Texas at Austin; [2]NXP Semiconductors
High throughput miniaturization and scalability of complex 3D architectures in microproducts is often limited by the resolution of the existing additive manufacturing (AM) processes. We are developing a microscale selective laser sintering (μ-SLS) machine for fabricating true-3D metallic microarchitectures with submicron feature size resolutions. This paper presents experimental testing and validation of the major sub-systems in the machine. A comprehensive study of the precision and accuracy of the optical subsystem, the global positioning stage, local XY nanopositioning stage, powder bed dispense system, and the control mechanisms largely determines the fidelity and throughput of the sintering process. Preliminary sintering results with optimized process parameters have also been discussed in this paper. The objective of these analyses is to develop mathematical models for an optimized microscale sintering process.

11:30 AM
Research on Relationship between Depth of Fusion and Process Parameters in Low-temperature Laser Sintering Process: ***Takashi Kigure***[1]; Yuki Yamauchi[1]; Toshiki Niino[2]; [1]Tokyo Metropolitan Industrial Technology Research Institute; [2]Institute of Industrial Science the University of Tokyo
The authors have been introducing a modified laser sintering process, namely low-temperature process. The process allows powder bed temperature being lower than those in normal laser sintering process which suppresses part warpage by preheating powder bed above its recrystallization temperature. This paper discusses fusion depth obtained by single layer scan and relating process parameters in low-temperature process. In stereolithography, relationship between cure depth and supplied energy per unit area is known as “working curve.” In this research, similar relationship in low-temperature process was searched for. Working curves in a variety of powder bed temperature were obtained from measurement. The results show a similarity to working curves obtained from stereolithography. It is found that fusion depth and light dose have exponential relationship, and we can define critical exposure and penetration depth. This fact allows us optimizing laser irradiation parameter setting in low-temperature process.

Special Session: Data Analytics in AM 4 - Quality and Modeling 3

Wednesday AM Room: Salon B
August 15, 2018 Location: Hilton Austin

Session Chair: Linkan Bian, Mississippi State Univ

8:00 AM
Machine Learning based Monitoring of Advanced Manufacturing Technologies: ***Brian Giera***[1]; Bodi Yuan[2]; Albert Chu[1]; Gabriel Guss[1]; Stefan Hau-Riege[1]; Philip DePond[1]; Sara McMains[3]; Manyalibo Matthews[1]; [1]Lawrence Livermore National Laboratory; [2]Lawrence Livermore National Laboratory & University of California, Berkeley; [3]University of California, Berkeley
As with most additive manufacturing systems, analysis of sensor data currently occurs post-build, rendering process monitoring and rectification impossible. Supervised machine learning offers a route to convert sensor data into real-time assessments; however, this requires a wealth of labeled data that traditionally is too time-consuming and/or expensive to assemble. In this work, we propose solutions to this critical issue for a variety of advanced manufacturing technologies such as Selective Laser Melting, Direct Ink Write, and microfluidic-based microencapsulation. We demonstrate a suite of approaches to apply machine learning that result in labeled datasets, e.g. high-speed video or images, we can leverage to train a Convolutional Neural Network. Machine learning-based models generated with this approach can enable in situ quality detection and real-time process monitoring essential to rapid closed-loop control. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

8:20 AM
Precision Enhancement of 3D Printing via In Situ Metrology: ***Ling Li***[1]; Ryan McGuan[1]; Pirouz Kavehpour[1]; Robert Candler[1]; [1]University of California, Los Angeles
The field of additive manufacturing, especially 3D printing, has gained growing attention in the research and commercial sectors in recent years. Notwithstanding that the capabilities of 3D printing have moved on to enhanced resolution, higher deposition rate, and a wide variety of materials, the crucial challenge of verifying that the component manufactured is within the dimensional tolerance as designed continues to exist. This work developed and demonstrated an approach for layer-by-layer mapping of 3D printed parts, which can be used for validation of printed models and in situ adjustment of print parameters. A high-speed optical scanning system was integrated with a Fused Deposition Modeling (FDM) type 3D printer and algorithms were developed to optimally scan during the print process.

8:40 AM Invited
Layer-wise Profile Monitoring of Laser-based Additive Manufacturing: Seyyed Seifi[1]; Wenmeng Tian[1]; Haley Doude[1]; Mark Tschopp[2]; ***Linkan Bian***[1]; [1]Mississippi State University; [2]Army Research Laboratory
The objective of this study is to build a new layer-wise process signature model to create the thermal-microstructure relationship. Additive manufacturing is a novel fabrication technique which is capable of producing highly complex part. Nevertheless, the main challenge is improvement of quality of fabricated part which has be studied thoroughly in literature. Existing numerical methods like FEMs are time consuming and inefficient and data-driven methods basically focus on local prediction of anomalies. In this study, we derive novel key process signatures for each layer which are directly correlated with layer-wise quality of the part. Having key signatures in hand, a classifier is trained to detect the existence of anomalies inside a layer. The proposed models are validated through a case study of real-world direct laser deposition experiment where the layer-wise quality of part is being predicted. Prediction accuracy is calculated using three measures, i.e. recall, precision and f-score, which validates the effectiveness of the proposed methodology in predicting layer-wise quality.

9:00 AM
Interferometry Sensing Data Mining for Real-time Geometric Profile Measurement in Photopolymer Based Additive Manufacturing: ***Xiayun Zhao***[1]; David Rosen[2]; [1]University of Pittsburgh; [2]Georgia Institute of Technology
An in-situ interferometry system is developed to infer the output of geometric profile in a self-designed photopolymer based additive manufacturing process. Data acquisition and analysis for retrieving sensory information is central to the success of real-time measurement and control for the process. As the photopolymerization phenomena occur continuously over a range of space and time scales, the sensor data analysis is complicated with computation speed and cost. The large amount of video data, which is usually noisy and cumbersome, requires efficient data analysis methods to unleash the measurement capability. Algorithms are strengthened by incorporating empirical values obtained from experimental observations to guarantee realistic solutions for online computation. Experimental results indicate that the data-enabled interferometry method could estimate the height profile of cured parts with accuracy and precision. Furthermore, the study exemplifies that data mining techniques can help unveil more insights about the real-time dynamics for advanced process modeling and control.

9:20 AM
In Situ Physics-based Monitoring of the Reliability of Printed, Flexible Electronics during Tensile Testing Using Digital Image Correlation: ***Roozbeh (Ross) Salary***[1]; Darshana Weerawarne[1]; Jack Lombardi[1]; Mark Poliks[1]; [1]State University of New York at Binghamton
The goal of this work is to monitor the reliability of flexible electronics – fabricated using aerosol jet printing, an additive manufacturing process – during tensile cycling. The objective is to forward an in situ framework, based on the concept of digital image correlation, to explain the underlying failure mechanisms behind tensile loading. To realize this objective, our experimental setup was instrumented with a high-resolution imaging system, mounted on a motorized linear stage. This allows for successive, synchronized image acquisition from a specimen during tensile testing. Subsequently, the acquired images were stitched together to obtain a full-field image, capturing the whole geometry of the specimen. The full-field images were processed using digital image correlation to map the displacement and strain fields, which pinpoint the onset of crack formation, and also allow for modeling of crack propagation as a function of the applied load. The experimental results were corroborated using finite element analysis.

9:40 AM Break

10:10 AM
Correlative Beam Path and Pore Defect Space Analysis for Modulated Powder Bed Fusion Process: ***Deniz Ertay***[1]; Henry Ma[1]; Mihaela Vlasea[1]; [1]University of Waterloo
There are ongoing challenges in achieving full density metal parts via laser powder bed fusion (LPBF). Numerous of studies have shown that the part density depends on the process parameters, the powder characteristics, and the process environment conditions. The scan strategy and the interactions of scan paths at discontinuities such as borders create regions with high probability of pore occurrence. In this work, the complex relation between the defects and the toolpath at border discontinuities is investigated for a print recipe which gives >99.95% solid fraction in the core of the part. Samples are scanned by X-ray Computed Tomography (CT). The pore space was analyzed to extract the pore frequency, size, shape, and location with respect to the scan path, border and contour strategies. A machine learning algorithm is presented to predict the probability of pore occurrence for a given scan path and strategy.

10:30 AM Invited
Uncertainty Quantification and the Additive Manufacturing Digital Twin: ***Alaa Elwany***[1]; Raymundo Arroyave[1]; Ibrahim Karaman[1]; Ji Ma[1]; [1]Texas A&M University
Qualification and certification of metal additive manufacturing (AM) parts still pose a serious barrier against adoption of the technology. Purely experimental approaches are not practical. Modeling and simulation through computational ICME models have been proposed as alternatives, with the goal of accelerating the development of processing recipes as well as Q&C, based on variable powder, design, energy input, path/layer sequencing and post-processing heat treatments. Within the ICME framework, establishment of quantitative PSPP relationships can provide the means to realize the concept of AM "Digital Twins". Two key challenges need to be addressed first: (1) these models are extremely complex, let alone a system of hierarchical or coupled models. This makes them impractical for part-level simulation, and (2) they are also characterized with multiple layers of uncertainty in model predictions. This presentation will present three studies that employ tools of the well-established field of uncertainty quantification (UQ) to address these challenges.

10:50 AM
A Study of L-PBF Process Parameters on Martensitic Phase Transformation Temperature of NiTi Shape Memory Alloys via Taguchi's Robust Design Methodology: ***Bing Zhang***[1]; Alaa Elwany[1]; Raymundo Arroyave[1]; Ibrahim Karaman[1]; Ji Ma[1]; Brian Franco[1]; [1]Texas A&M University
Several research roadmaps for Laser Powder-Bed Fusion (L-PBF) metal-based Additive Manufacturing technologies have pointed out the need for quality control and certification in parts prior to their use on applications with rigorous requirements such as aerospace or medical devices. Therefore, deeper understanding and identification of manufacturing parameters that make the build process less sensitive to the effects of environmental variables, deterioration, and manufacturing variations is desired. This study describes a framework for Nickel-Titanium alloys which utilizes Taguchi's Robust Design methodology to reduce the variability of the shape-memory effect as well as to optimize the martensitic transformation temperatures in printed parts by constructing a response surface insensitive to identified noise factors. The findings demonstrate that conducting a systematic robust formal analysis on L-PBF process is beneficial and cost-effective since it only utilizes a reduced amount of experiments and provides insightful results to better understand the behavior of the manufacturing process.

Special Session: Hybrid AM Processes 4 - Direct/Indirect Build Strategies

Wednesday AM — Room: 404
August 15, 2018 — Location: Hilton Austin

Session Chair: Michael Sealy, University of Nebraska-Lincoln

8:00 AM
Potentials and Challenges of Multi-material Processing by Laser-based Powder Bed Fusion: ***Maximilian Binder***[1]; Christine Anstaett[1]; Max Horn[1]; Fabian Herzer[1]; Georg Schlick[1]; Christian Seidel[1]; Johannes Schilp[1]; Gunther Reinhart[1]; [1]Fraunhofer Research Institution for Casting, Composite and Processing Technology IGCV
Multi-material additive manufacturing offers a multitude of opportunities for increasing functional integration beyond the current state of the art. However, the real potential is only vaguely described and there are also challenges alongside the new opportunities. This paper presents a systematic collection of the challenges to be overcome by laser-based powder bed fusion before it can provide industrially relevant multi-material processes. Amongst others, parameter adaptation to avoid micro-cracking, relevant process monitoring technologies (e.g., thermography-based layer monitoring) and potential approaches for powder separation (e.g., using ferromagnetism) are described. Furthermore, to exploit the full potential of multi-material designs, possible concepts for the integration of fully functioning mechatronic devices into multi-material parts are also presented.

8:20 AM
Omni-directional Cladding for Hybrid Layered Manufacturing: ***Karunakara Karuppasamy Poolan***[1]; Sajan Kapil[1]; Seema Negi[1]; Michael Sealy[2]; Alain Bernard[3]; Shengyong Pang[4]; Dmitriy Trushnikov[5]; [1]Indian Institute of Technology Bombay; [2]University of Nebraska–Lincoln; [3]IRCCyN, Ecole Centrale de Nantes; [4]Huazhong University of Science and Technology; [5]Perm National Research Polytechnic University
Cladding-based AM has higher deposition rates, larger working envelopes and *Functionally Gradient Matrix (FGM)* capability. Additive and subtractive manufacturing routes have their own advantages and limitations. Our *Hybrid Layered Manufacturing (HLM)* synergically combines addition (cladding) and subtraction (machining). Soon, we realized the need for hybridization in other aspects of cladding, viz., energy sources, slicing strategies and kinematics. *Omni-directionality*, the independence of the geometry and quality with the trajectory of cladding, is essential in cladding-based AM as the trajectories vary widely. Most cladding methods except *Metal Inert Gas (MIG)* lack this property as feedstock, energy beam and trajectory are at different angles. We report our investigations of the ill effects of this and present various ways of achieving Omni-directionality in *Tungsten Inert Gas (TIG)*, laser and *Electron Beam (EB)* cladding. We have omni-directional TIG and laser: the former is our own development and the latter is that of Fraunhofer IWS.

8:40 AM
Part Decompositions for 3+2 5-Axis Hybrid Manufacturing: ***Xinyi Xiao***[1]; Sanjay Joshi[1]; [1]Penn State
Traditional Additive Manufacturing (AM) is often limited to 3-axis deposition of the layers, with the restriction forces the requirement for support structures for overhanging areas of the part, often necessitating the need for additional work to remove the support structures. Allowing for multi-axis machines has the potential to reorient the parts and create parts by eliminating the support structures. Successful automated implementation of this strategy requires that the part be decomposed into volumes such that individual volumes can still be processed by slicing in the X-Y plane and building in the z-direction, while allowing for reorientation of the part for each decomposed volume. This research presents a decomposition algorithm that determines orientation and the decomposition sequence and for the decomposed volumes using a 5-axis machine. Constraints on the machine, such as limits on positioning and collision detection are incorporated into the algorithm to generate feasibly manufacturable solutions.

9:00 AM
A Digitally Driven Hybrid Manufacturing Process for the Flexible Production of Engineering Ceramic Components: ***Jack Hinton***[1]; David Flynn[2]; Russell Harris[1]; Robert Kay[1]; [1]University of Leeds; [2]Heriot-Watt University
Predominant techniques for manufacturing ceramic components use template-driven methods, which hampers responsiveness and impose significant design constraints. This has driven significant interest towards using additive manufacturing approaches. When used in isolation these techniques are restricted by uncontrollable porosity, high shrinkages during firing plus a lack of process-compatible materials. This paper presents the research and development of a new hybrid manufacturing process chain for the agile production of engineering grade ceramics components. The combination of high viscosity ceramic paste extrusion, sacrificial support deposition and subtractive micro-machining has yielded complex monolithic ceramic components with feature sizes of 100µm, part densities of ~99.7%, surface roughness down to ~1µm Ra and 3-point bend strength of 218MPa. Since a wide range of materials can be formulated into visco-elastic pastes they can be readily deposited using this approach.

9:20 AM
A Novel Study on EDM Processing of Support Structures in Metal AM: *Gregory Bicknell*[1]; Guha Manogharan[1]; [1]Penn State University
Wire electric discharge machining (EDM) is a non-traditional machining method that has the ability to machine hard, conductive materials, with no force and high precision. Wire EDM is commonly used in additive manufacturing (AM) applications to remove printed parts from the base-plates onto which they are printed. One persistent problem in wire EDM is wire breakage. Wire breakage leads to longer machining times and wastes wire material. One important factor that leads to wire breakage is variance in workpiece thickness. The interaction between wire EDM and AM support structures is not well understood, due to the interrupted cuts and variance of cut thickness posed by supports. This paper studies the effect of different types of AM support structures on EDM wire breakage and machining time. Findings from this study will enable identification of optimal parameters based on design of support structures.

9:40 AM Break

10:10 AM
Effect of Substrate Surface Finish and Process Parameters on Dimensional and Geometrical Deviations of Additively Manufactured Stainless Steel Components: ***Mohamed Eldakroury***[1]; Jakob Croghan[1]; Matthew Frank[1]; [1]Iowa State University
The objective of this study is to investigate the effect of different surface qualities in Directed Energy Deposition (DED) on final product distortions. DED is an AM process where metal powder is delivered into a melt pool initiated by a laser beam from a coaxial nozzle. A substrate is a piece of metal that could take any shape and is used as a base for printing. In this study, The substrate surface finish, bead overlap, and number of layers were varied.Casted, machined and sandblasted 10”x10” Stainless Steel plates were used as substrates and a pattern of 2”x2” Stainless Steel cubes with different number of layers were printed. After printing, the partS were left cool down in the air and the total height of the parts as well as substrate overall flatness were measured and the deviations from the original part design and substrate dimensions were quantified and investigated.

10:30 AM
Hybrid Manufacturing Process for Controlling Grain Structure in Directionally Solidified Castings: Andrew Catalanotto[1]; Daniel Suzuki[1]; Logan Ware[1]; ***Zachary Cordero***[1]; [1]Rice University
We demonstrate a hybrid process for fabricating composite molds to directionally solidify net shape castings of reactive metals and alloys. Our technique employs a consumer off-the-shelf stereolithography 3D printer to make patterns with tight tolerances at low cost. Using these patterns, we create composite molds, combining an inert ceramic shell with an investment mold reinforcement to effect a sharp contrast in thermal conductivity between the molten metal and the mold. With this contrast and the mold geometry, we manipulate the heat flux throughout the mold, controlling the grain structure of the metal during directional solidification. To substantiate our method, we create an integrally-cored mold, and use it to directionally solidify a single crystal gas turbine blade.

10:50 AM
Parametric Optimization of a Hybrid Process Combining Wire Arc Additive Manufacturing with Milling: ***Fang Li***[1]; Shujun Chen[1]; Junbiao Shi[1]; Jun Xiao[1]; [1]Beijing University of Technology
Hybrid manufacturing, integrating additive and subtractive processes into a single setup, has been gaining popularity recently due to the ability to take full use of the advantages of each individual process while minimizing their disadvantages. This paper proposes a hybrid wire arc additive manufacturing and milling process (HWMP) based on a multi-robot cooperative platform. The key performances of HWMP including surface quality, material utilization and efficiency are evaluated systematically, which are the results of the comprehensive effects of both the deposition parameters (e.g. travel speed, wire-feed rate) and the milling parameters (e.g. spindle speed, tool-feed rate). The case study shows that HWMP with the optimal parameters improves the material utilization by 57% and the efficiency by 32% while reaching the same level of surface quality compared against the traditional machining method.

11:10 AM
Examination of the Connection between Selective Laser-melted Components Made of 316L Steel Powder on Conventionally Fabricated Base Bodies: ***Martin Link***[1]; Tobias Haefele[1]; Eberhard Abele[1]; [1]TU-Darmstadt (PTW)
The advantages of selective laser melting lie in the production of complex, small components with small batch sizes. For large-volume components, the use of SLM is limited by the available installation space, the low build rates and the high material costs. For the production of large and less complex workpieces conventional manufacturing processes like milling are more economic. The aim of this article is to combine both processes to decrease manufacturing times. For this purpose, a body made of 316L steel powder is printed using SLM on conventionally manufactured base bodies made of various stainless and tool steels. The use of multi-materials enables optimized machinability in accordance with the respective manufacturing process. The mechanical properties of the multi-material samples are examined. The microstructure at the connection is analysed using micrographs. The results are used to develop design guidelines and recommendations for material selection.

Applications 5

Wednesday PM August 15, 2018 | Room: 415AB | Location: Hilton Austin

Session Chair: John Turner, UT-Battelle / Oak Ridge National Lab

1:10 PM
A Brief History of the 3D Printed Car: Failures, Successes, and Future Opportunities: ***Brian Post***[1]; Scott Curran[1]; Lonnie Love[1]; Robert Wagner[1]; Phillip Chesser[1]; Alex Roschli[1]; Katherine Gaul[1]; [1]Oak Ridge National Laboratory
The automobile is a hallmark of the American experience; it symbolizes freedom and personal expression in a way few other inanimate objects can. When the first cars appeared, there were many varieties, and prior to the advent of the assembly line, they were each hand crafted to the specifications of the future owner. Additive manufacturing (AM) is ushering in a new wave of mass customization by enabling automated construction of one-of-a-kind prototypes and end use components. A few people, the present authors included, have sought to extend the capabilities of AM systems to the production of full-scale automobiles. In doing so, custom vehicles can be produced for specific aesthetic or ergonomic functions. This paper demonstrates the potential of AM to enable new models in automobile manufacturing through examination of the failures, celebration of the successes, and looking toward the future capabilities of AM in the production of 3D printed cars.

1:30 PM
Using Post-tensioning in Large Scale Additive Parts for Load Bearing Structures: ***Phillip Chesser***[1]; Randall Lind[1]; Brian Post[1]; Alex Roschli[1]; Lonnie Love[1]; Katherine Gaul[1]; [1]Oak Ridge National Laboratory
One of the perennial problems with additive manufacturing (AM) is the lack of inter-laminar bond strength between the layers, also known as z-strength. This can make the use of AM fabricated parts in load bearing applications problematic. This problem can be solved in some applications with post-tensioning. The use of post-tensioning in structures can be used to ensure that layer interfaces only see compressive stresses. This method is commonly used to strengthen concrete structures since concrete is weak in tension while strong in compression. This paper explores the successful application of post-tensioning to improve z-strength of large structures made with Big Area Additive Manufacturing (BAAM) where loads are significant. Theory and examples are presented herein.

1:50 PM
Using Big Area Additive Manufacturing to Directly Manufacture a Boat Hull Mold: ***Brian Post***[1]; Phillip Chesser[1]; Randall Lind[1]; Alex Roschli[1]; Lonnie Love[1]; Matthew Sallas[1]; Katherine Gaul[1]; Fletcher Blue[1]; Stephen Wu[2]; [1]Oak Ridge National Laboratory; [2]AllianceMC
Big Area Additive Manufacturing (BAAM) is a large-scale, 3D printing technology developed by Oak Ridge National Laboratory's Manufacturing Demonstration Facility and Cincinnati Inc. The ability to quickly and cost-effectively manufacture unique molds and tools is currently one of the most significant applications of BAAM. This work details the application of BAAM to fabricate a 34' catamaran boat hull mold. The goal of this project was to explore the feasibility of using BAAM to directly manufacture the mold without the need for thick coatings. The mold was printed in 12 individual sections over a five-day period. After printing, the critical surfaces of the mold were CNC-machined, and the sections were assembled. The success of this project illustrates the time and cost savings of BAAM in the fabrication of large molds.

2:10 PM
Precast Concrete Molds Fabricated with Big Area Additive Manufacturing: ***Alex Roschli***[1]; Brian Post[1]; Phillip Chesser[1]; Matthew Sallas[1]; Lonnie Love[1]; Katherine Gaul[1]; [1]Oak Ridge National Laboratory
The traditional process of making precast concrete molds requires significant manual labor. The molds are made using hardwood, cost tens of thousands of dollars, and take weeks to build. Once built, a mold will last 5-10 pulls before becoming too heavily degraded to continue use. With additive manufacturing, the same mold can be built in eight hours, post-machined in eight hours, costs about $9000, and is project to last nearly 200 pulls. Oak Ridge National Laboratory has been working with Big Area Additive Manufacturing (BAAM) to fabricate concrete molds for a new high-rise apartment complex in New York. The molded pieces will form structural window supports for the hundreds of windows in building façade. The magnitude of window molds is where additive manufacturing can shine when producing the geometry. This paper will discuss the methods and findings of using BAAM to replace conventional precast concrete pattern making.

2:30 PM
3D Printed Fastener-free Connections for Non-structural and Structural Applications – An Exploratory Investigation: Daniel Delgado Camacho[1]; ***Patricia Clayton***[1]; William O'Brien[1]; Kee Young Jung[1]; [1]University of Texas at Austin
The construction industry has shown increasing interest in AM technologies and has successfully implemented various proof of concept projects using different AM processes. Much of the research on AM in the construction industry has focused on development of new large-scale extrusion printing systems and on development of cementitious materials for AM applications, whereas research exploring new applications of already existing AM technologies and materials suitable for construction applications has been scarce. This paper explores the use of existing, small-scale material extrusion 3D printers to create fastener-free connections that could be used in structural or non-structural applications. These connections, inspired by traditional wood joinery and modern proprietary connections were printed using polylactic acid (PLA) material. The flexural strength of the connections were then tested using a four-point bending test to evaluate their potential structural performance and to identify connection types that warrant further research in this exploratory proof of concept study.

2:50 PM Break

3:20 PM
Lattice Structure Support Fabrication Using Binder Jetting For Thin-Walled Features: ***Sebastian Vargas***[1]; Steven Ambriz[1]; Ryan Wicker[1]; David Espalin[1]; [1]The University of Texas at El Paso
Metallic parts fabricated with binder jetting are generally self-supporting within the powder bed, although when fabricating fragile, thin features, support structures are required. The goal of this work was to quantify the compression properties of metallic green support structures containing lattice elements. The Magics Structures Module was used to design the lattice structures that were fabricated using 316L Stainless Steel and an ExOne M-Flex machine. The green parts were cured and depowdered followed by compression testing. The maximum compression stress was measured at 1.9 MPa, which is comparable to a ½ inch gypsum board or dry wall (maximum stress for gypsum is reported as 2.4 MPa). Further strengthening of metallic parts will be explored in future work through using finer powder precursor and modified process parameters.

3:40 PM
Binder Jetting of High Temperature and Thermally Conductive (Aluminum Nitride) Ceramic: ***Carlos Diaz-Moreno***[1]; Christian Rodarte[1]; Steven Ambriz[1]; Diego Bermudez[1]; David Roberson[1]; Cesar Terrazas[1]; David Espalin[1]; R. Ferguson[1]; Evgeny Shafirovich[1]; Ryan Wicker[1]; Yirong Lin[1]; [1]The University of Texas at El Paso
This work reports on the fabrication of aluminum nitride (AlN) complex components using binder jetting printing, on the use of hot isostatic pressing (HIPing) to increase their density, and on the characterization of the printed material, including thermal conductivity. The HIP parameters employed were a temperature of 1900°C using a rich N2 atmosphere at a pressure of 30,000 psi during 8 hours. Results show that the printed and HIPed AlN components had a 1.96 g/cm (60.12 %) of density when compared to theoretical values. Measurements of the thermal conductivity at 23°C and 500°C were 4.82 W/m*K and 3.17 W/m*K, respectively. Characterization using scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDS), X-ray diffraction (XRD) and Raman spectroscopy were used to investigate the ceramic structural morphology of the sintered and HIPed material, its chemical composition, crystal structure, and vibrations modes of the binder jetting printed AlN.

Lattices and Cellular 3

Wednesday PM — Room: 412
August 15, 2018 — Location: Hilton Austin

Session Chair: Maggie Yuan, Beijing Institute of Technology

1:10 PM
Efficient Topology Optimization of Variable-density Lattice Structure for Convective Heat Transfer: ***Albert To***[1]; Lin Cheng[1]; Kevin Laux[1]; Matthew Lynch[2]; [1]University of Pittsburgh; [2]United Technologies Research Center
In this presentation, a topology optimization method is proposed to enhance the convective heat transfer by optimizing the relative density field of lattice structure. To precisely describe thermal performance of lattice material, a multiscale model is employed to derive the heat convection of lattice structure in terms of design variables. At microscale, a full scale simulation is conducted on the lattice unit to obtain the forced convection heat transfer coefficients, while at macroscale a homogenized model is set up to characterize the thermal performance of lattice material using the analysis of micro-model. Once the homogenized model is obtained, it is embedded into a coupled thermal-fluid governing equation and the optimization is conducted to iteratively optimize the density distribution of lattice structure until the convergence is satisfied. In order to demonstrate the efficiency of the proposed method, several numerical examples are provided to compare with result of full scale simulation.

1:30 PM
Topology Optimization Using Tailorable Free form Lattice Structures for Additive Manufacturing: ***Archak Goel***[1]; Botao Zhang[1]; Sam Anand[1]; [1]University of Cincinnati, Department of Mechanical and Materials Engineering
Additive Manufacturing method have recently being used to make light-weight parts for various applications. Manufacturing a part with a lattice structures based on a topologically optimized design space is one of the popular methods to achieve weight reduction. Conventional strategies for designing commonly used lattices such as a BCC, lack flexibility for modifying the unit cell shape for achieving intricate design goals. This paper proposes a new strategy for an automated geometric design of a unit cell using B- Spline based free-form surfaces and its implementation using a SIMP based topology optimization algorithm. Such topology optimization algorithms output a voxelized design space with varying material density values. This calls for a method that can fill those voxels with variable density lattice structures while ensuring a smooth connectivity between cells. This paper addresses this issue and discusses case studies to show the implementation using tailorable BCC unit cells as an example.

1:50 PM
On the Mechanical Behavior of Additively Manufactured Asymmetric Honeycombs: Lucas Casanova[1]; Vineeth Anitha[1]; Nikhil Kadway[1]; Arpit Gandhi[1]; Thao Le[1]; Christine Lee[1]; ***Dhruv Bhate***[1]; [1]Arizona State University
From a design perspective, there are three decisions that need to be made when integrating cellular materials such as lattices and honeycombs into a structure: selection of the unit cell type, distribution of the size of the cells across the structure, and optimization of individual cell walls/struts and junction thicknesses. In this paper, we take a closer look at the second of these for 2-dimensional square honeycombs of uniform thickness, starting from a regular, periodic square. We gradually reduce the symmetry of the structure both locally as well as globally, to end in a purely stochastic shape consisting of Voronoi cells. We report results of compression testing of specimens made with the Fused Deposition Modeling process, and study the effective specific properties of the honeycombs with regard to their elastic modulus, yield and energy absorption. Finally, we demonstrate how asymmetry may be used as a design principle.

2:10 PM
Finite Element Modeling of Metal Lattice Using Commercial FEA Platforms: ***Edel Arrieta***[1]; Jorge Mireles[1]; Calvin Stewart[1]; Cesar Carrasco[1]; Ryan Wicker[1]; [1]University of Texas El Paso
The introduction of geometrical features into standard solids result in cellular materials with unique performances. The deformation mechanisms originated by the introduced geometry may not be entirely captured by the current commercial FEM software; resulting in inaccuracies in predicting the performance of cellular metals. Additionally, the inconsistency on AM materials properties will result in material models with uncertainty, thus, contributing to the inaccuracy of simulations. The present work shows a process for modeling the strength of EBM Ti-6Al-4V lattices structures; starting from the definition of the convenient experiments to the generate the data for the development of material models at different orientation and finalizes with the assignment of these material models to the lattice FEMs. MSC Patran/Nastran is used in this work. Experimental results of the compressive strength of lattice structures are compared with those from the FEM utilizing the different material models created from the experiments.

2:30 PM
A CAD-based Workflow and Mechanical Characterization for Additive Manufacturing of Tailored Lattice Structures: ***Peter Koch***[1]; Hannes Korn[2]; Richard Kordass[2]; Stefan Holtzhausen[1]; Christine Schoene[1]; Bernhard Mueller[2]; Ralph Stelzer[1]; [1]Technische Universität Dresden; [2]Fraunhofer IWU
Lattice structures are highly recommended for lightweight applications and cost reduction in additive manufacturing (AM). Currently, parts with lattice structures are still mainly used for illustrative purposes and rarely in industrial products. One important reason is that, due to their high dependency on macro- and micro-geometry, the mechanical properties of manufactured structures are difficult to predict. Thus, even and precise struts are needed. In this paper, a workflow for fabrication of lattice structures with strut-diameters from 150 µm to 400 µm on commercial LBM systems is presented. Based on a CAD-integrated user-interface for lattice design, a customized slicing algorithm determines database-aided suitable exposure parameters which ensure that the properties of the manufactured struts will precisely be as specified upon design. Subsequently, compression tests are performed in order to verify the established workflow. The developed tool enables designers to integrate AM-specific geometries into their components without specific experience in AM.

2:50 PM Break

3:20 PM

A Comparison of Modeling Approaches for Predicting the Elastic-plastic Response of Additively Manufactured Honeycomb Structures: ***Raghav Sharma***[1]; Thao Le[1]; Ethaniel Harms[1]; Jiaxu Song[1]; Daniel Sowa[1]; Alex Grishin[2]; Dhruv Bhate[1]; [1]Arizona State University; [2]Phoenix Analysis & Design Technologies, Inc. (PADT)

Valid and accurate models describing the mechanical behavior of additively manufactured cellular materials are crucial to enabling their implementation in critical-to-function parts. Broadly speaking, the modeling approaches commonly used in the literature fall into three categories. Each of these differs in the level of discretization at which the cellular behavior is modeled: at the level of each material point, at the level of the unit cell or at the level of a connecting member that constitutes a unit cell. Each of these three approaches relies on different characterization techniques and the way in which the resulting data is leveraged in the development of the model. In this work, we critically examine all three modeling approaches using FEA and compare their accuracy in the prediction of the elastic and plastic behavior of experimentally characterized hexagonal honeycomb structures made with Fused Deposition Modeling, and discuss the pros and cons of each method.

3:40 PM

Adaptive Shape Conforming Honeycomb Lattice Infill for 3D Printing of Thin Wall Objects: ***AMM Nazmul Ahsan***[1]; Bashir Khoda[1]; [1]North Dakota State University

Additive manufacturing offers the capability of making lattice infills resulting in light weigh thin wall objects with higher strength to weight ratio. The self-supporting honeycomb lattice is a promising candidate for infill as it eliminates the emergence of support material. Conventionally the uniform porosity infills are trimmed by the object external geometry to fit it inside the object. However, the trimmed sides of the uniform lattice infill structures become weak due to lack of support. In this paper, we propose a continuity based adaptive honeycomb lattice infill construction methodology. The design domain is first adaptively discretized into non-uniform voxels. The voxels adjacent to the external geometry are densified compared to the inner voxels. Then the hexagonal honeycomb lattice unit cells are fitted inside the voxels following a proposed continuity based toolpath plan. Such adaptive conformal honeycomb infill ensures adequate contact of the external cells to the thin wall boundary.

4:00 PM

Design for Additive Manufacturing (DfAM): Mixed Integer Non-linear Problem (MINLP) for Design of Aperiodic Metamaterial Objects: Siddhant Aphale[1]; Amir Behjat[1]; Jun Wang[1]; ***Rahul Rai***[1]; [1]University at Buffalo-SUNY

Metamaterials are structured materials which can achieve unique mechanical properties without using expensive substance by optimizing the underlying unit cells. The prospect of fabricating by additive manufacturing and realizing the unique properties has generated recent interest in the design of metamaterials. Besides optimizing the inner structure, additional possibilities might be achieved by optimizing the combination of non-similar unit cells (aperiodic). In this paper, a novel design optimization framework for designing aperiodic metamaterials to obtain the desired properties is studied. The metamaterial structure and combination are optimized using Genetic Algorithm. The capability of the proposed algorithm is demonstrated on a cantilever beam design which is optimized to achieve any desired deflection distribution under defined loading condition. The combinatorial pattern of unit cells (discrete optimization) and unit cell-specific parameters (continuous optimization) are simultaneously optimized. The numerical results demonstrate the promise of the proposed approach in solving this Mixed Integer Non-Linear problem (MINLP).

4:20 PM

Numerical and Experimental Study of the Effect of Artificial Porosity in a Lattice Structure: ***Anton du Plessis***[1]; Ina Yadroitsava[2]; Dean Kouprianoff[2]; Igor Yadroitsev[2]; [1]CT Scanner Facility; [2]Central University of Technology

Additively manufactured lattice structures are used in various applications due to their unique properties, especially low weight with relatively good strength and stiffness. While lattices have been investigated widely, the effect of manufacturing flaws on the lattice performance was not yet analyzed in detail. One important type of manufacturing flaw which can be relatively easily analyzed numerically and experimentally is unwanted voids or porosity. In this work, using a simple cubic lattice structure as test case, pores with varying sizes were induced in a single strut and compressive loading simulated. Ti6Al4V lattices produced by powder bed fusion, with and without such induced pores, were subjected to mechanical compression tests. MicroCT images validated the presence and size of the induced voids in produced samples. The mechanical compression tests show that even large pores in individual load-bearing struts do not affect the ultimate compressive strength of the lattices.

Materials: Composites 3 - Direct Write, UV Curing, Nanomaterials

Wednesday PM Room: 615AB
August 15, 2018 Location: Hilton Austin

Session Chair: Denis Cormier, Rochester Institute of Technology

1:10 PM

Effects of in-situ Compaction and UV-curing on the Performance of Glass Fiber-reinforced Polymer Composite Cured Layer by Layer: ***Shiferaw Beyene***[1]; Beshah Ayalew[1]; Srikanth Pilla[1]; [1]CU-ICAR

In this paper, the effect of in-situ compaction and UV-induced curing on the performance of fiber-reinforced DGEBA based epoxy is studied for a layer-by-layer curing process. The optimum percentage of photo-initiator concentration and UV-intensity were obtained by conducting a different experiment for each of them. Fourier Transform Infrared (FTIR) spectroscopy method is used to determine the degree of cure. Then, short beam shear (SBS) test is conducted to measure the inter-laminar shear strength of the cured product under different compaction load. The UV intensity and Photo-initiator concentration were kept constant during the test. The result showed that thick composite parts fabricated with in-situ compaction and UV curing process have showed increased inter-laminar shear strength with increased compaction load up to a certain point. An increase in compaction beyond this point decreased the interlaminar-shear strength.

1:30 PM

UV-assisted Direct Write of Polymer-bonded Permanent Magnets: ***Callum Bailey***[1]; Alan Shen[2]; Anson Ma[2]; Sameh Dardona[1]; [1]United Technologies Research Center; [2]University of Connecticut

Polymer-bonded permanent magnets, formed by injection and compression molding, are an industrially-important class of magnets with applications in automotive, sensing, hard disk drives, and medical devices. In recent years, a variety of additive manufacturing techniques have been used to fabricate polymer-bonded magnets: including material extrusion, Big Area Additive Manufacturing (BAAM), binder jet, stereolithography, and extrusion-based direct write. This presentation reports the use of a UV-assisted extrusion-based direct write (UVADW) process to fabricate polymer-bonded permanent magnets at room temperature. The formulation of the magnetic ink will be presented, as well as mechanical and magnetic characterization of the printed magnets, and comparison with other additive manufacturing and conventional manufacturing techniques.

1:50 PM
3D Printing of Hybrid Core-shell Architectures via Direct Write: ***Robert Pack***[1]; Stian Romberg[1]; Brett Compton[1]; [1]University of Tennessee Knoxville
Direct deposition and a broad range of feedstock materials make direct write (DW) 3D printing ideal for fabricating multi-material hybrid architectures for structural or functional components that cannot be achieved through traditional processes or vat- or powder bed-based additive manufacturing (AM). In this work, we explore the use of a core-shell nozzle motif with various structural feedstock materials to create and characterize multi-material hybrid cellular structures. A stochastic foam core with a carbon fiber/epoxy shell system was studied for production of cellular materials with improved stiffness and buckling resistance over single-material lattices. Opportunities in ceramic-metal systems for potential use in biomedical and wear applications (e.g. stainless steel/hydroxyapatite and nickel/titanium carbide, respectively) will also be discussed.

2:10 PM
Effects of Filler Morphology and Nozzle Size on Anisotropy in 3D Printed Epoxy Composites: ***Nadim Hmeidat***[1]; Liam Page[1]; Jackson Wilt[1]; Brett Compton[1]; [1]University of Tennessee Knoxville
Extrusion-based additive manufacturing approaches have advanced considerably in recent years, allowing the fabrication of new high-performance polymer composite materials. Specifically, recent work has demonstrated great potential for the use of direct ink writing (DIW) technology to 3D-print nanoclay-reinforced epoxy-based systems with high strength and stiffness that can serve as matrix materials for printed short fiber composites. This talk will focus on recent efforts investigating the effects of nozzle size, shape, and flow rate on the anisotropy of printed epoxy composite components as characterized by mechanical testing and polarized light microscopy. Formulations utilizing nanoclay filler will be compared to those using fumed silica, and potential methods for controlling the anisotropy in printed components will be discussed.

2:30 PM
Additive Manufactured Stainless Steel Nanocomposites with Uniform Dispersion of Nanoparticles: ***Minglei Qu***[1]; Khalid Hussain Solangi[1]; Qilin Guo[1]; Lianyi Chen[1]; [1]Missouri University of Science and Technology
Metal matrix nanocomposites (MMNCs) with uniform distribution of nanoscale ceramic particles can show dramatically improved mechanical properties as compared to the matrix materials. However, when the size of the nanoparticles is small and the volume fraction of nanoparticles is high, it is very difficult to disperse them uniformly in the metal matrices. Here we report the fabrication of 304L-TiN nanocomposites with uniform dispersion of TiN nanoparticles by high energy ball milling and selective laser melting (SLM). The 304L-TiN nanocomposites with uniformly dispersed TiN nanoparticles exhibit significantly enhanced mechanical properties. Detailed microstructure characterization and analysis reveal that the dispersion of nanoparticles in the SLMed sample strongly depends on the dispersion of nanoparticles in the feedstock powders. Our research provides a promising approach to manufacture MMNCs with uniform dispersion of nanoparticles by additive manufacturing process.

2:50 PM
3D Printing of Nanocomposites for Multifunctional Materials: ***Hoejin Kim***[1]; Luis Chavez[1]; Jaime Regis[1]; Ryan Wicker[1]; Yirong Lin[1]; [1]The University of Texas at El Paso
This research studies multifunctional sensing capabilities of nanocomposites fabricated by fused-deposition modeling 3D printing technique. The nanocomposites are composed of BaTiO3 (BT), multi-walled carbon nanotubes (MWCNTs), and poly(vinylidene) fluoride (PVDF). It is demonstrated that by utilizing unique advantages of this material combination and in-situ poling process, sensing capabilities for temperature and strain can be tuned with content variations of BT and MWCNTs. It is observed that the sensitivity of temperature sensing can be improved as the active inclusions increase and is maximal 1.7wt.% of MWCNTs and 60wt.%-BT in composites. In addition, the mechanical toughness of nanocomposites can be increased by 579 % with the use of CNTs and BT inclusions. These results demonstrated not only technique to 3D print multifunctional nanocomposites with temperature and strain sensing capabilities, but also the feasibility for large-scale multifunctional sensor device manufacturing with freedom of design, low cost, and faster processing.

3:10 PM Break

Materials: Metals 7 - Non-traditional Materials

Wednesday PM　　Room: 404
August 15, 2018　　Location: Hilton Austin

Session Chair: Wayne King, Lawrence Livermore National Laboratory

1:10 PM
Mechanical Properties of Zr-based Bulk Metallic Glass Parts Fabricated by Laser-foil-printing Additive Manufacturing: ***Yingqi Li***[1]; Ming C. Leu[1]; Hai-Lung Tsai[1]; [1]Missouri University of Science & Technology
The application of bulk metallic glasses (BMGs) has been limited to parts with small dimensions and simple geometries, due to the requirement of high cooling rates during casting. This work exemplifies a promising method, i.e., laser-foil-printing (LFP) additive manufacturing, to fabricate high-quality BMG parts with large dimensions and complex geometries. In this study, Zr52.5Ti5Al10Ni14.6Cu17.9 BMG parts were fabricated by LFP technology in which BMG foils are laser welded layer-by-layer. The mechanical properties of the fabricated BMG parts were measured using micro-indentation, tensile test and four-point bending test, and then compared with as-cast BMG parts. Through LFP, fully amorphous BMG parts without porosity and cracking have been successfully made. The glass transition temperature and crystallization temperature of the printed parts are nearly the same as those of the as-cast parts. Additionally, the printed BMG parts exhibit mechanical properties, e.g., micro-hardness, tensile strength, flexural strength, etc., comparable to the as-cast BMG parts.

1:30 PM
Effect of Cooling Rate on the Microstructure Mechanical Properties of Zr-based Bulk Metallic Glasses by Selective Laser Melting: ***Yujing Liu***[1]; [1]University of Western Australia
The different interval time between scanning layers will lead to different temperature of substrate and the cooling rate in SLM-produced Zr-based samples. FEM results revealed that the cooling rate can reach 10^6 K/s during the building process. The shorter interval time between layers during SLM process results in higher substrate temperature and lower cooling rate, therefore promoting the formation of nanocrystals and large defect pores. Meanwhile, the generation of large defect pores leads to rough top surface and oxidation. The longer interval time provide a lower temperature substrate and a higher cooling rate, which could accelerate the amorphization process and the smooth top surface. The defects and oxidation can affect the morphology of fracture surface, but have a limited influence on the ultra-compressive stress, while the local region crystallization leads to a greater ductility.

1:50 PM
Influence of Light Elements on the Properties of Bulk Metallic Glass Parts Produced by Laser Beam Melting: ***Moritz Stolpe***[1]; [1]Heraeus Additive Manufacturing GmbH
Due to their amorphous structure, metallic glasses combine a unique spectrum of properties, making them promising candidates for various fields of technological applications. Recently, it has been demonstrated that the limitations in size and shape inherent to conventional processing methods, e.g. die casting or injection moulding, can be overcome by additive manufacturing. The layer-wise formation of parts produced by selective laser beam melting normally results in cooling rates that are high enough to avoid crystallization. However, new challenges are encountered by the powder-route. Often metallic glass forming alloys are highly sensitive to impurities putting high requirements for powder production and handling. In particular light elements, e.g. oxygen, nitrogen, and carbon, can be detrimental for the properties of the printed parts. Here, we report on a systematic study on the influence of light element impurities on the mechanical performance, glass forming ability and thermal properties of printed bulk metallic glass components.

2:10 PM
Laser Engineered Net Shaping of the CoCrFeMnNi High Entropy Alloy: ***Andrew Kustas***[1]; Michael Chandross[1]; Mark Wilson[1]; Shaun Whetten[1]; David Keicher[1]; Ping Lu[1]; Joseph Michael[1]; Nicolas Argibay[1]; [1]Sandia National Laboratories
High Entropy Alloys (HEAs), typically consisting of five or more alloying constituents in equal or nearly-equal concentrations, often show extraordinary mechanical properties. However, detailed descriptions of their process-structure-property relationships are lacking. We utilized the Laser Engineered Net Shaping (LENS) additive manufacturing method to produce samples for rapid and systematic study of these relationships. We use high-fidelity characterization of microstructure, composition, and mechanical properties of LENS-created parts to help inform strengthening and thermodynamic stability models for these materials. The promise of HEAs as a materials-based approach to realizing the full potential of AM, enabling widespread commercial adoption, is also discussed. Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525

2:30 PM
A Novel Self Dispersion Reinforcement High Entropy Alloy Prepared by Selective Laser Melting: ***Jizhan Li***[1]; [1]Huazhong University of Science and Technology
A high entropy alloy with the chemical composition of 35 at.% Fe, 30 at.% Cr,15 at.% Mn, 10 at.% Ni, 5 at.% Al and 5 at.% Cu was prepared by selective laser melting. The results show the nano size self dispersion phase uniformly precipitated on the matrix. In this study, the effect of the various processes of selective laser melting on the self dispersion phase was investigated in detail. The various processes of selective laser melting were designed via the change of the laser scanning velocity, the layerthickness and the energy density according to the orthogonal experiment.

2:50 PM Break

3:20 PM
Microstructure Evolution during Solid-state Ambient Condition Metal Additive Manufacturing: ***Anagh Deshpande***[1]; Keng Hsu[1]; [1]University of Louisville
Acoustoplastic metal direct-write (AMD) is a recently demonstrated solid-state additive manufacturing process which uses acoustic energy to deposit voxels of metal to construct net-shape 3D-geometries in ambient condition and at room temperature. During the process, two simultaneous physical phenomenon, acoustic softening and acoustic energy assisted diffusion, result in shaping of the voxel and bonding to the lower layer or substrate. The interaction of acoustic energy with pure aluminium and gold and the subsequent stress and microstructure evolution has been well documented in the literature but such materials have limited manufacturing applications. To that end, in this study, the after-deformation microstructure of aluminium alloys under the presence of acoustic energy has been discussed in detail along with the deformation mechanism. The study will provide insight into the microstructure evolution during AMD process and also during other acoustic energy assisted manufacturing processes.

3:40 PM
Fabrication and Microstructural Characterisation of Additively Manufactured Nickel Aluminum Bronze Parts: ***Mohsen Mohammadi***[1]; [1]University of New Brunswick
Nickel aluminum bronze (NAB) alloy in its cast form exhibit unique combination of superior stress corrosion properties, excellent mechanical properties, and high resistance to corrosion and biofouling. NAB alloys are widely used for engineering components in landing gear bushing and bearings of commercial aircrafts, as seawater pumps and valves in marine applications, and as propellers for naval and commercial shipping. NAB is a quaternary alloy that typically contains 8.5-11 wt% Al, 4-5 wt% Ni, 2-5 wt% Fe, 0.8-1.5 wt% Mn, and Cu as remainder. Porosity and coarse grain microstructure in the cast NAB are detrimental to mechanical properties. Heat treatment, fusion welding techniques, and friction stir processing were employed in the past for the purpose of cast microstructural refinement. However, additive manufacturing (AM) technology that uses a layer-by-layer technique offers great potential to fabricate complex shapes and also in overcoming the defects that arise during casting. Till date, there has been not much work reported on producing NAB components through wire arc additive manufacturing (WAAM) technique. The research in this study is first of its kind, which is focused on fabricating the NAB alloy in both cuboidal ($l = b \neq h$) and cylindrical forms, analyzing the microstructure and mechanical properties, and then comparing with the as-cast NAB.

4:00 PM
Direct Writing of Films from High Speed Aerosol Deposition of Ag: ***Jeremiah McCallister***[1]; Michael Becker[1]; John Keto[1]; Desiderio Kovar[1]; [1]The University of Texas at Austin
The Laser Ablation of Microparticle Aerosol (LAMA) process is capable of producing an aerosol of nanoparticles from a microparticle aerosol. The nanoparticles are then accelerated to high velocities (400-1400 m/s) and sprayed onto substrates at room temperature to produce patterned thick films of variable thickness (2 - 150 µm). The process allows for the use of a broad range of inorganic materials to be directly written onto almost any organic or inorganic substrate. Experiments have been conducted by impacting silver particles at a constant velocity but varying the particle diameter producing dense silver films. The films were analyzed for their microstructure, densities, and surface finish and compared to films deposited with constant particle size and varying velocities.

4:20 PM
Additive Manufacturing of Soft Ferromagnetic Alloys Using Laser Engineered Net Shaping: ***Andrew Kustas***[1]; Donald Susan[1]; Kyle Johnson[1]; Shaun Whetten[1]; Mark Rodriguez[1]; Daryl Dagel[1]; Joseph Michael[1]; David Keicher[1]; Nicolas Argibay[1]; [1]Sandia National Laboratories
Soft ferromagnetic alloys possess exceptional magnetic properties for a variety of electromagnetic applications. However, the intrinsic poor workability of these materials can lead to cracking during conventional manufacturing. We explored an innovative solidification-based processing approach to produce bulk forms of select soft ferromagnetic alloys using Laser Engineered Net Shaping (LENS). Atomic ordering, grain size, and crystallographic texture of samples were characterized using a suite of microscopy methods, along with mechanical and magnetic properties. Implications of using LENS for future processing of soft ferromagnetic alloys are also discussed. Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525

4:40 PM
High-speed, In-situ Monitoring of Microcracking of W for Different SLM Scan Strategies: ***Bey Vrancken***[1]; Aiden Martin[1]; Brian Giera[1]; Wayne King[1]; Manyalibo Matthews[1]; [1]Lawrence Livermore National Laboratory

Because of its high melting point, high thermal conductivity, low thermal expansion and other favorable properties, tungsten is receiving a lot of attention as a potential plasma-facing material in fusion reactors. Additive Manufacturing is one of several candidate advanced manufacturing techniques to process tungsten, but tungsten's poor thermal shock resistance and above room temperature ductile-to-brittle transition cause microcracking during production. In this research, high-speed in-situ monitoring is used to visualize the cracks as they form. The influence of the laser power, scan speed, and scan strategy on the crack initiation, crack type, and crack density are discussed to generate guidelines to reduce microcracking. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344. This work was funded by the Laboratory Directed Research and Development Program at LLNL under project tracking code 18-ERD-057, 18-SI-003, and 17-ERD-042.

Materials: Metals 8 - Titanium Alloys 2

Wednesday PM — Room: 416AB
August 15, 2018 — Location: Hilton Austin

Session Chair: Hari Kishore Adluru, University of Texas Research Institute

1:10 PM
Effects of Layer Orientation on the Multiaxial Fatigue Behavior of Additively Manufactured Ti-6Al-4V: ***Patricio Carrion***[1]; Aidin Imandoust[1]; Jutima Simsiriwong[2]; Nima Shamsaei[1]; [1]Auburn University; [2]University of North Florida

Additive manufacturing (AM) allows for fabrication of components with complex geometries that cannot be fabricated using conventional manufacturing techniques. These components are often subjected to multiaxial stress states due to their typically complex design accompanied by residual stresses and/or multiaxial external loading. Therefore, understanding the fatigue behavior of AM materials under multiaxial-type loadings is necessary for ensuring reliable in-service component performance. In this study, the effects of layer orientation on the multiaxial fatigue behavior of Ti-6Al-4V fabricated via a laser-powder bed fusion (L-PBF) process was investigated. Tubular thin-walled multiaxial specimens were fabricated in vertical and diagonal orientations with respect to the build plate. Specimens were tested under axial, torsional, in-phase axial/torsional, and 90° out-of-phase axial-torsional cyclic loadings. Upon failure, the crack orientation of vertical and diagonal specimens was correlated to the type of loading, which illustrated the failure mechanism of L-PBF Ti-6Al-4V and justified the variations in the fatigue lives of specimens.

1:30 PM
Depth-sensing Rate-dependent Deformation of an Additively Manufactured Ti-6Al-4V Alloy: ***Muztahid Muhammad***[1]; Mohammad Masoomi[2]; Brian Torries[2]; Nima Shamsaei[2]; Meysam Haghshenas[1]; [1]University of North Dakota; [2]Auburn University

Depth-sensing (instrumented) indentation testing technique is a robust, convenient and reliable characterization method to study rate-dependent plastic deformation in metals and alloys at ambient and elevated temperatures. In the current research, the depth-sensing indentation creep behavior of additively manufactured Ti-6Al-4V and its mechanism were studied at room temperature for different additive manufacturing build direction. Indentation creep tests were conducted through a dual-stage scheme (loading followed by a constant load-holding) at different maximum load ranging from 250, 350, and 450 mN with holding time of 400 s. Effect of maximum indenter load and creep parameters, i.e. creep rate, creep stress exponent, strain rate sensitivity, and indentation size effect (ISE) were investigated in detail. In addition, microstructural quantitative analyses, using optical microscopy and scanning electron microscopy, were performed on the materials. Microstructural assessments and depth-sensing creep characterizations were then used to assess processing parameter/ microstructure/ creep properties relationships for this alloy.

1:50 PM
Individual and Coupled Contributions of Laser Power and Scanning Speed towards Process-induced Porosity in Selective Laser Melting: ***Subin Shrestha***[1]; Thomas Starr[1]; Kevin Chou[1]; [1]University of Louisville

Porosity is an undesired characteristic in selective laser melting (SLM) parts. Of different mechanisms, keyhole pores are formed when the energy density is very high. In this study, single-track SLM experiments using Ti-6Al-4V powder were designed and conducted with combinations of varied levels of the laser power and the scanning speed, intended to maintain the same energy density. Three energy densities: 0.32 J/mm, 0.4 J/mm and 0.48 J/mm, were tested to investigate the influence of the laser power versus the scanning speed to porosity. Pore numbers and volumes were analyzed using micro-scale computed tomography. The results indicate that the keyhole pore formation is affected more distinctively by the change in the power rather than the scanning speed, while keeping the energy density constant. As the power increases, from 20 W to 140 W, the total pore volume increases. However, the pore volume decreases, when the power increases beyond 140 W.

2:10 PM
Stress Corrosion Cracking Behavior of Additively Manufactured Ti-6Al-4V Parts Fabricated Using New and Heavily Recycled Powder: ***Jonathan Pegues***[1]; Michael Roach[2]; R. Scott Williamson[2]; Nima Shamsaei[1]; [1]Auburn University; [2]University of Mississippi Medical Center

Additive manufacturing (AM) is becoming an increasingly popular method in both aerospace and biomedical industries. Titanium alloys are common in several applications due to their excellent strength-to-weight ratio and biocompatibility. Traditional wrought Ti-6Al-4V alloys show little sensitivity to stress corrosion cracking (SCC) when subjected to in-vitro conditions. For AM, alloy powder is often sifted and reused multiple times which can result in degradation of the powder's shape. Recent studies have also shown that the oxygen content of AM powder increases with repeated use which may increase the susceptibility of AM parts to SCC. This research compares the microstructural characteristics and tensile SCC behavior of AM Ti-6Al-4V parts fabricated from new and recycled powder in distilled H2O, salt water, and Ringers solution. Additionally, the effect of surface finish is investigated for each microstructure - comparing the as-built surfaces to machined and polished surfaces.

2:30 PM
Influence of Atmospheric Control in Laser Powder Bed Additive Manufacturing, on Part Quality and Long Term Powder Life: ***Youssef Gaber***[1]; Jonathan Munday[1]; Lucy Grainger[1]; [1]Renishaw

A study of the influence of the processing environment on the structural integrity of additively manufactured parts was carried out using a Renishaw 500M machine. The oxygen and moisture contents were strictly controlled leading to a significant improvement to the mechanical properties. The influence on powder life was also investigated by measuring the Oxygen and Hydrogen contents of the powder used in this study, which showed that re-used powder under these operating conditions was in better condition than its virgin counterpart. These findings not only address concerns about the costs of adopting additive manufacturing due to powder re-use limitations but also demonstrates the significance of using the correct hardware to achieve the desired part quality

2:50 PM
Effect of Energy Density on the Consolidation Mechanism and Microstructural Evolution of Laser Cladded Functionally-graded Composite Ti-Al System: ***Eyitayo Olatunde Olakanmi***[1]; Motheo Sepako[1]; Joseph Morake[1]; Said Kutua[1]; Shaik Hoosain[2]; Sisa Pityana[2]; [1]Botswana International University of Science & Technology,; [2]Council for Scientific & Industrial Research
The engagement of additive manufacturing (AM) technology in developing intermetallic coatings involves additional heat treatment with a view to obtaining desirable microstructure and mechanical properties. This eventually increases the lead time and the manufacturing cost. To address these challenges, this study explores the fabrication of gradient and laminar structures of titanium aluminide (Ti-Al) composite coatings deposited on Ti-6Al-4V substrate via a single step laser cladding (LC). The alterations in microstructural properties, chemical composition and phase analysis of the coatings reinforced with TiC were investigated as a function of laser energy density. Evaluation of the deposited samples reveals that FGM composite clads were fabricated from Ti-Al blended with TiC when LED was set at 17.50 J/mm2. At the selected LED, a thermo-positive reaction between the constituents' materials was induced and it resulted in the formation of intermetallic compounds (e.g. Ti2AlC, γ and γ_2 matrix phases). This study provides new insights on the selection of process parameters for the coating manufacturers while employing low cost- and time-effective LC process for fabricating functional graded Ti-Al coatings.

3:10 PM Break

Materials: Polymers 3 - Powder Bed Fusion

Wednesday PM — Room: Salon J
August 15, 2018 — Location: Hilton Austin

Session Chair: David Leigh, Vulcan Labs

1:10 PM
Optimization of Optical Permeability of Powder Bed in Low-temperature Laser Sintering Process: ***Toshiki Niino***[1]; K Ohma[2]; [1]Institute of Industrial Science, The University of Tokyo; [2]Shibaura Institute of Technology
Up to now, optical permeability of powder for laser sintering has been seldom discussed since light of CO2 laser, which is installed in most commercial systems, is absorbed by polymers so sufficiently that we do not have to control absorption of the powder bed. On the other hand, difficulty of focusing the laser due to its long wavelength of 10.6ìm degrades the precision of the process. To reduce the spot diameter, a few systems are equipped with fiber laser with a shorter wavelength of 1.1ìm. Since the light is rarely absorbed most neat polymer, in contrast, we have to add an absorbent. Here, we have to decide the amount of the agent that gives the optimal permeability of powder bed. In this research, relationship between relative part density as an index of mechanical performance and optical permeability in low-temperature laser sintering, which the authors have introduced, is investigated.

1:30 PM
Surface Modification of Polymer Particles for Laser Sintering Applications: ***Sam Irving***[1]; Chris Tuck[1]; Steven Howdle[1]; Ruth Goodridge[1]; [1]University of Nottingham
Laser sintering (LS) is an additive manufacturing process in which polymeric particles are fused together by the energy of a laser. Although potentially applicable to a wide range of polymers, to date very few amorphous polymers are processed in this manner, due to poor part strength resulting from their low melt viscosities. In this work poly(methyl methacrylate) particles are surface-functionalised with vinyl groups as a means of producing cross-linked particles in situ. This is intended to provide added mechanical strength by the production of a cross-linked polymer network throughout the part – with the added benefit of generating cross-linked materials in a LS system, which is currently difficult to achieve. This system employs a supercritical CO2 polymerisation medium to facilitate a one-pot synthesis. The research presented herein details the synthesis of these particles, along with structural confirmation, followed by application testing in a laser sintering environment.

1:50 PM
Laser Sintering of PA12/PA4,6 Polymer Composites: ***Dieter Strobbe***[1]; Peter Van Puyvelde[1]; Jean-Pierre Kruth[1]; Brecht Van Hooreweder[1]; [1]KU Leuven
This work investigates the laser sintering (LS) processing of PA12/PA4,6 composites and the performance of resulting parts. The coalescence and consolidation of powder mixture with bimodal melting behavior are characterized. This shows a sufficiently low shear viscosity can be achieved at processing temperature where PA12 melts but PA4,6 remains solid. This enables Additive Manufacturing of the higher melting PA4,6 thermoplastic using the processing window of the lower melting PA12. After laser sintering of the composites, the microstructure and the mechanical properties of the resulting parts are characterized. This illustrates that PA4,6 establishes a good interfacial adhesion and remains as a secondary phase in the matrix during the melting and crystallization. As a result, PA12/PA4,6 LS composite parts demonstrate different mechanical properties than that of PA12 parts. This processing approach opens up new perspectives for LS of advanced engineering thermoplastics.

2:10 PM
Understanding Hatch-dependent Part Properties in SLS: *Andreas Wörz*[1]; Dietmar Drummer[1]; [1]Institute of Polymer Technology
Selective laser sintering of polymers (SLS) is on the verge from pure prototyping to producing individualized complex parts for series application. As the parts are generated layerwise and the influence of process-parameters as well as part orientations are well-known, the aim of the paper is to point out the influence of the layerwise manufacturing in dependence of the hatching strategy on the resulting part properties as these are constant process-steps. Therefore, tensile bars with different amounts of layers but constant layer-thickness were produced using different hatching strategies and investigated depending density, surface roughness and mechanical properties. The results showed a strong increase of the mechanical properties, ductile breaking behavior and part density as well as decreasing surface roughness with higher layer numbers as well as the hatching strategies. Therefore, the results point out significant interaction between constant process steps and resulting part properties.

2:30 PM
Effect of Thermal Exposure to Mechanical Properties of Laser Sintered Polyamide 11: ***David Leigh***[1]; David Bourell[2]; [1]Vulcan Labs; [2]University of Texas
In this presentation, observations are made regarding the effect of time at temperature on polyamide 11 end-use parts produced using the laser sintering process. More than 80,000 tensile coupons were created to qualify production builds and the resulting data is used to evaluate the mechanical properties with respect to thermal exposure during production. Analysis of the machine thermal profile, thermal modeling, and mechanical test data is used to quantify the sensitivity of the mechanical properties on part bed temperature over time in addition to the laser energy used to fuse the material.

2:50 PM Break

3:20 PM
Impact of Extended Sintering Times on Mechanical Properties in PA-12 Parts Produced by Powderbed Fusion Processes: ***Justin Nussbaum***[1]; Nathan Crane[1]; Garrett Craft[1]; Julie Harmon[1]; [1]University of South Florida
Additive manufacturing provides many advantages in reduced lead times and increased geometric freedom compared to traditional manufacturing methods, but the material properties are typically inferior to their traditionally manufactured counterpart. This paper considers powder bed fusion of polyamide 12 (PA12, Nylon 12) produced by three different processes: laser sintering (LS), Multi Jet Fusion (MJF)/High Speed Sintering (HSS), and Large Area Projection Sintering (LAPS). While all utilize similar PA12 materials, they are found to differ significantly in mechanical properties especially in ductility. The slower heating methods provided by MJF/HSS and LAPS produce a considerably increased elongation at break. The LAPS process exhibits a 10x elongation while MJF/HSS exhibits a 2.5x elongation when compared to commercial LS samples. While there are small differences in crystallinity between these samples, the difference may be attributed to changes in the heating and cooling rates of the samples.

3:40 PM
Investigation into the Crystalline Structure and sub-Tpm Exotherm of Selective Laser Sintered Polyamide 6: ***Peng Chen***; [1]
Selective Laser Sintering (SLS) has achieved a wide acceptance for direct manufacture of complex functional components. However, the performance of SLS part still needs to be improved, in which the crystalline structure plays an important role. Every crystalline form has specific properties, and the whole material behaviors have great relationships with the various species and crystalline structure. Therefore, this paper investigates crystalline structure of laser sintered Polyamide 6 (PA6) and quantifies the different HT-a and LT-a phases using thermal analysis. The results show that the sintered parts are uniformly characterized by a relatively stronger (2 0 0) and a weaker (0 0 2) diffraction peak. This crystalline structure variation is basically consistent for all SLS parts and independent of laser power. In addition, the sub-Tpm crystallization transition concerning a phase was found for SLS PA6 part, which is derived from the release of strain energy absorbed during SLS processing.

4:00 PM
Laser Sintering of Polyamide 6 for Advanced Industrial Applications: ***Stefan Josupeit***[1]; [1]BASF 3D Printing Solutions GmbH
The industrialization of polymer powder bed fusion technologies requires high performance materials, reproducible part qualities and high throughput at competitive cost. The powder market has started to change: As material selection was very limited in past years, typical injection molding materials such as Polyamide 6 are now becoming state-of-the-art for selective laser sintering as well. The talk discusses the processing behavior of polyamide 6 in laser sintering, the functionalization of powder materials for advanced applications as well as selected use cases based on process and application developments.

4:20 PM
The Influence of Contour Scanning Parameters and Strategy on Selective Laser Sintering PA613 Build Part Properties: ***Christina Kummert***; Hans-Joachim Schmid[1]; [1]Paderborn University
Qualification of new materials for the laser sintering (SLS) process includes a development of suitable parameters in terms of optimal part properties. Especially laser scanning parameters influence part porosity and therewith mechanical performance. In the present work tensile specimens were built of PA613 a new LS Polyamide delivered by Evonik and processed on an EOSINT P396. As build parameters have to be developed for the new material, scanning parameters and strategy of the PA613 specimen contour was varied in different ways. Resulting part properties were investigated by CT-analysis as well as by tensile tests. The three-dimensional part porosity, pore size, shape, count and arrangement are analysed in dependent of used laser scanning parameters and resulting mechanical properties are regarded. The investigations help to understand the existent relations between laser energy input, part porosity and mechanical performance and therewith to find optimized build parameters for the new material.

4:40 PM
Processing of High Performance Fluoropolymers by Laser Sintering: ***Carlo Campanelli***[1]; Chris Tuck[1]; Ricky Wildman[1]; [1]University of Nottingham
One of the main limitations of additive manufacturing is its narrow material portfolio. Fluoropolymers are a family of polymers with outstanding properties such as wide service temperatures (-260 °C - +260 °C), excellent resistance to chemicals, sunlight, flames, and weathering without the addition of stabilizers, plasticizers or fillers. In this study, fluoropolymers such as perfluoroalkoxy (PFA) and polychlorotrifluoroethylene (PCTFE) have been used in Laser Sintering. PFA and PCTFE have melting temperatures of 304 °C and 210 °C respectively which make them challenging to process. Our results demonstrate the feasibility of these materials in LS and that warping was the major issue encountered due to the relatively low powder bed temperature of 182 °C. We illustrate how particle size, additives, and thermal conditioning affect the powder flow and how the warping can be decreased by utilizing a modified build plate, and different scan strategies and part orientations. Flat sheets are successfully produced with potential use in membrane-based applications.

Physical Modeling 5 - AM Modeling Innovations

Wednesday PM — Room: Salon B
August 15, 2018 — Location: Hilton Austin

Session Chair: Travis Mayberry, Raytheon Integrated Defense Systems

1:10 PM
Where Next for AM Simulation?: Brent Stucker[1]; ***Chong Teng***[1]; [1]ANSYS
Over the past few years, many start-ups as well as existing software companies have begun releasing additive manufacturing simulation tools. The majority of these tools are focused on predicting and correcting for part distortion during metal laser sintering. Although much can now be accomplished with AM simulation, there are still many things that AM users and researchers hope to simulate in the future. The additive manufacturing software team at ANSYS, the world's leading provider of engineering simulation software, is actively engaged in building and delivering new AM simulation functionality. Current development efforts are focused on linking thermal process simulations to microstructure and property predictions, including the effects of post-process heat treatment. Through this talk ANSYS' approach to filling these gaps in AM simulation will be presented.

1:30 PM
Characterizing Additive Manufacturing Models: From High-fidelity to Low-fidelity: ***Wentao Yan***[1]; Yan Lu[2]; Jason Fox[2]; Kevontrez Jones[1]; Paul Witherell[2]; Wing Liu[1]; [1]Northwestern University; [2]National Institute of Standards and Technology
Computational modeling for additive manufacturing has proven to be a powerful tool to understand the physical mechanisms, and predict fabrication quality. However, various models have been developed with different assumptions and purposes, and appropriate models are often difficult to choose, especially for end-users, due to the lack of quantitative comparison and standardization. Thus, this study is focused on quantifying the uncertainty due to the modeling assumptions and evaluating the influence of major physical factors. Multiple models with different assumptions, from high-fidelity to low-fidelity, including thermal-fluid flow models, finite element heat transfer models, and an analytical thermal model, are run, while experiments are performed as validation. Data-analytics methodology is utilized to quantify the uncertainties, and to characterize and represent the models. This study can provide guidance on model selection and the corresponding accuracy, and more importantly facilitate the development and integration of AM models.

1:50 PM
Assessing the Utility of a Superposition-based Finite Element Approach for Part-scale Thermal Simulations: ***Terrence Moran***[1]; Peipei Li[1]; Derek Warner[1]; Nam Phan[2]; [1]Cornell University; [2]Naval Air Systems Command
The utility of a superposition-based finite element approach is explored for part-scale thermal simulation in additive manufacturing. The approach consists of summing an analytic solution for a moving heat source in a semi-infinite medium with a correcting finite domain field computed with finite element analysis. The accuracy and computational expense of the approach are compared against a fully converged traditional finite element approach. Through efficient implementation of the analytic solution and the use of a coarse finite element mesh away from surfaces, part-scale thermal modeling appears possible without sacrifices in accuracy, within the context of the linear heat equation.

2:10 PM
Visualisation and MHD Modelling of Shielding Gas Flow and Coverage in WAAM: ***Ioannis Bitharas***[1]; Anthony McAndrew[2]; Sergio Rios[3]; Philippe Bridgeman[2]; Jialuo Ding[2]; Stewart Williams[2]; Andrew Moore[1]; [1]Heriot Watt University; [2]Cranfield University; [3]University of Magallanes
We present magneto-hydrodynamic (MHD) flow modelling of plasma arc welding (PAW) in the context of WAAM to analyse the local shielding of Ti-6Al-4V parts. The model was used to characterise the effect process settings have on the inert gas coverage and the 3D printing conditions. Visualisation of the plasma and shielding gas flows through schlieren imaging is presented. The observed flow features and turbulence levels show good agreement between experiment and simulation. The predicted variables in the MHD model promote process understanding and enable meaningful interpretation of the imaged refractive index gradients. Through these diagnostics, the extent of air entrainment in the plasma jet was determined for different part geometries as well as torch and trailing shield configurations. In addition, the changes in heat input into the component due to the varying interactions between the fluid flow and 3D printed wall structures are discussed.

2:30 PM
Smoothed Particle Hydrodynamics Simulation of Additive Friction Stir Manufacturing of Aluminum Alloy 6061: ***George Stubblefield***[1]; Kirk Fraser[2]; Paul Allison[1]; Brian Jordon[1]; [1]University of Alabama; [2]National Research Council Canada
Additive Friction Stir (AFS) or MELD is a relatively new additive manufacturing process with physics similar to Friction Stir Welding (FSW). Early research has shown that MELD produces refined grains and higher yield strength and ultimate tensile strength than wrought material. Since MELD is a solid-state process, the normal issues associated with fusion-based processes, such as porosity and hot cracking, are eliminated. Due to the excessive deformation in the MELD process, traditional finite element schemes are insufficient. As such, in this work, a meshfree coupled thermomechanical approach is used to model the MELD process. The meshfree method, Smoothed Particle Hydrodynamics (SPH), is used to discretize the set of continuum conservation equations. To calibrate the model, experimental data, including phase characterization and grain morphology correlated to plastic and thermal loading, was gathered from thermomechanical simulations and MELD depositions.

2:50 PM Break

3:20 PM
Non-equilibrium Phase Field Model Using Thermodynamics Data Estimated by Machine Learning for Additive Manufacturing Solidification: ***Sukeharu Nomoto***[1]; Masahito Segawa[1]; Hiroshi Hiroshi[1]; [1]ITOCHU Techno-Solutions Corp.
A multi-phase field (MPF) method using finite interface dissipation model proposed by Steinbach et al. is applied to simulate solidification microstructure evolution of stainless steel composition in the non-equilibrium condition of high cooling rate and temperature gradient of additive manufacturing. The calculation is performed for quinary system in order to simulate solidification of engineering composition. Thermodynamic calculation using CALPHAD database in this MPF calculation is replaced by machine learning prediction procedure to reduce calculation time. The microstructure evaluated by using machine learning parameter is good agreement with one directly coupled with CALPHAD database. This calculation is approximately five times faster than the direct CALPHAD calculation method. Finally, it is confirmed that this MPFM can be applicable to simulate non-equilibrium phase transformation of additive manufacturing condition with high numerical stabilization.

3:40 PM
Multi-physics Modeling of Single Track Scanning in Selective Laser Melting: ***Bo Cheng***[1]; Xiaobai Li[1]; Charles Tuffile[1]; Alexander Ilin[2]; Hannes Willeck[2]; Udo Hartel[2]; [1]Robert Bosch LLC; [2]Robert Bosch GmbH
In this work, a microscale computational fluid dynamics (CFD) model was developed for selective laser melting (SLM) process simulation using FLOW3D to study the effect of powder bed recoating methods on melt pool characteristics. The discrete element method (DEM) was used to simulate both the blade and the roller-compaction recoating processes, where layers of powder particles with different sizes were generated on a solid substrate. Melt pools propagating through the powder beds were simulated using the Volume of Fluid (VOF) method that tracks the free surface evolution of melt pools that are produced when a Gaussian distributed moving laser heat source, with given process parameters, irradiates the powder bed. Thermal and fluid material properties were incorporated in the model to improve simulation accuracy, and melt pool validation from single-track laser scanning simulation was performed.

4:00 PM
Towards an Open-source, Preprocessing Framework for Simulating Material Deposition for a Directed Energy Deposition Process: ***Matthew Dantin***[1]; Will Furr[1]; Matthew Priddy[1]; [1]Mississippi State University
This work focuses on the development of an open-source framework to simulate material deposition for arbitrary geometries with respect to desired process parameters during a Directed Energy Deposition process. This framework allows the flexibility to define the element activation criteria used in conjunction with Abaqus. A Python script was developed to generate G-code and implement an element activation sequence that is unique to a specific CAD drawing. This is quite important for simulating the additive manufacturing construction of complex geometries because the thermal history of the component is dependent on laser path, which has a significant effect on residual stresses and distortion. Initial process monitoring experiments have been conducted using a dual-wave pyrometer and a high-rate camera to inform the element activation criteria, and the results of varying the criteria are presented and compared with simulated temperature profiles.

4:20 PM
High Speed Visualisation and Multiphysics Modelling of Laser PBF: ***Ioannis Bitharas***[1]; Prveen Bidare[1]; Mark Ward[2]; Moataz Attallah[2]; Andrew Moore[1]; [1]Heriot Watt University; [2]University of Birmingham
An open architecture laser powder bed fusion (LPBF) system was used for high-speed imaging of the dynamics of the process under varying pressure and using different inert gases. Experiments were carried out in argon and helium under sub-atmospheric [1], atmospheric [2] and high-pressure conditions. Long standoff microscopy results showed the motion of particles in the powder bed and schlieren imaging visualised the fluid dynamics of the inert atmosphere. Multiphysics modelling, validated by the experiments, was carried out to understand the complex interactions between laser, metal powder/vapour/plasma and inert gas. These results provide useful information for process planning, including on powder denudation, dynamic packing density, the production of metal vapour and spatter, and variations in laser absorption in to the powder bed. [1] P. Bidare, I. Bitharas et al., 130-131 65–72 Int. J. of Machine Tools and Manufacture (2018)[2] P. Bidare, I. Bitharas et al., 142 107-120 Acta Materialia (2018)

Physical Modeling 6 - Improvements in AM Modeling

Wednesday PM Room: Salon A
August 15, 2018 Location: Hilton Austin

Session Chair: Aref Yadollahi, Mississippi State Univ

1:10 PM
Quantifying Uncertainty in Laser Powder Bed Fusion Additive Manufacturing Models and Simulations: ***Tesfaye Moges***[1]; Wentao Yan[1]; Stephen Lin[2]; Gaurav Ameta[1]; Jason Fox[1]; Paul Witherell[1]; [1]National Institute of Standards and Technology; [2]Northwestern University
Various sources of uncertainty that can potentially cause variability in the product quality exist at different stages of the laser powder bed fusion (L-PBF) process. To implement computational models and simulations for quality control and process optimization, quantitative representation of their predictive accuracy is required. In this study, a methodology to estimate uncertainties in L-PBF models and simulations is presented. The sources of uncertainty, including those due to modeling assumptions, numerical approximation, input parameters, and measurement error, are discussed in detail and quantified for low and high-fidelity melt pool simulation models. A design of experiment (DOE) approach, which is suitable for examining many factors, is leveraged to quantify uncertainty due to input parameters and investigate their effects on output quantity of interests (QoIs). The result of this work is essential for understanding the tradeoffs in model fidelity and guiding the selection of a model suitable for its intended purpose.

1:30 PM
Mechanistic Examination of Post Processing to Improve the Fatigue Performance of Powder Bed Fused Ti-6Al-4V: ***Peipei Li***[1]; Derek Warner[1]; Nam Phan[2]; [1]Cornell University; [2]Naval Air Systems Command
Post processing is often needed to obtain powder bed fused (PBF) Ti-6Al-4V parts with good fatigue performance. In fatigue critical applications, post processing treatment usually involves hot isostatic pressing (HIP) and subsequent surface machining. This manuscript attempts to clarify the mechanisms associated with benefits of HIP for high cycle fatigue performance. Several mechanisms are considered and examined against the experimental data sets available in the literature. The results suggest that HIP may act most significantly by decreasing the fraction of the defect population that can initiate fatigue cracks, both by decreasing defect sizes below a threshold and by changing the microstructure around defects. Following this conclusion, a first attempt is made to predict thresholds of HIP soak parameters (Temperature-Pressure-Time) required for improving high cycle fatigue performance in PBF Ti-6Al-4V.

1:50 PM
Optimization of Inert Gas Flow inside Laser Powder-bed Fusion Chamber with Computational Fluid Dynamics: ***Chen Yu***[1]; Guglielmo Vastola[1]; Yong-Wei Zhang[1]; [1]Institute of High Performance Computing
It is crucial to maintain a uniform and fast enough inert gas flow inside build chamber to obtain high-quality final products (e.g. low porosity) without oxidation. The current study investigated the behaviors of the inert gas flow inside a chamber with CFD simulations, as well as its evaluation and optimization. The gas flow pattern inside the chamber was evaluated in terms of the uniformity of velocity across the build plate and shear force on the powders. It was shown that the gas channels and locations of inlet openings significantly affected the inside the chamber. So the design of gas channels/inlets and flow rates was carefully adjusted to generate gas flow patterns uniform gas flow across the chamber to remove emissions from the melt pool efficiently. Furthermore, the re-circulation of emission inside chamber was significantly reduced to keep the chamber walls clean and minimize the damage to the optical surface. In conclusion, CFD benefits in improving quality of products and reducing life-cycle cost for laser powder-bed fusion process.

2:10 PM
An Improved Vat Photopolymerization Cure Model Demonstrates Photobleaching Effects: ***Mohammad Mahdi Emami***[1]; David Rosen[1]; [1]Singapore University of Technology and Design, Digital Manufacturing and Design Centre
An improved high-fidelity simulation model for a grayscale projection micro-stereolithography process has been developed. The modeling purpose is to accurately predict cured part shapes and dimensions, given a radiation intensity distribution. The model employs COMSOL to solve a series of chemical reaction differential equations that model the evolution of chemical species (photoinitiator, monomer, and polymer) concentrations. Additionally, the model incorporates the effects of oxygen inhibition and species diffusion. This research offers two primary contributions to the cure model: the consideration of volumetric intensity to model variations in photoinitiator absorbance as a function of depth into the resin, and a change to the rate model for photoinitiator to free radical conversion. The effects of these changes demonstrate observed photobleaching effects. Simulated cured part profiles are compared to experiments and demonstrate good agreement. Additionally, initial results are presented on the usage of the simulation model in a new process planning method.

2:30 PM
Effects of Elemental Segregation during SLM from Atomistic Simulations: ***Mark Wilson***[1]; Andrew Kustas[1]; Michael Chandross[1]; [1]Sandia National Laboratories
Variability in mechanical performance of selective laser melting (SLM) processed metal components is attributed to microstructural defects (e.g., voids, lack-of-fusion). Recent experimental results have shown evidence of chromium microsegregation during the high cooling rates associated with SLM. Atomistic simulations offer a method to explore solute segregation or trapping during solidification and to understand the effects on material properties. We employ non-equilibrium molecular dynamics to simulate a single pass of a laser source. Similar to experimental results, our model shows microsegregation upon solidification. We compare elastic and mechanical properties of a segregated simulation to that of a homogeneous alloy. Results are compared with experiments and predictions from rapid solidification models. Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

2:50 PM Break

3:20 PM
Conceptual Modelling of Bi-directional Bead Geometry Prediction in Laser Metal Wire Deposition (LMD-w): ***Adeola Adediran***[1]; Andrzej Nycz[1]; Yashwanth Bandari[1]; Bradley Richardson[1]; Lonnie Love[1]; [1]Oak Ridge National Laboratory
The knowledge of how process parameters affect bead geometry is important in automatic control of the laser metal wire deposition (LMD-w) process where optimal selection of input parameters is required for high productivity and cost effectiveness. The quality of the printed part is also dependent on the bead geometry, because it determines the mechanical properties of the part. This work proposes a predictive model of bead cross-sectional profiles for single-bead, single-layer deposition, via experimental analyses of process variables in an LMD-w process. Thus, given a set of known input parameters, i.e. laser power, robot travel speed and wire speed, the model predicts an estimate of the resulting bead cross-sectional width and height, and vice versa. An adequate understanding of individual bead profiles and a defined relationship with respect to input parameters will enable effective modelling of multi-bead, multi-layer and overlapping bead profiles for fabrication of solid parts with desirable properties.

3:40 PM
Nonlinear and Linearized Gray Box Models of Direct-write Printing Dynamics: ***Andrej Simeunovic***[1]; David Hoelzle[1]; [1]Ohio State University
Control of material metering in direct-write (DW) additive manufacturing modalities, such as piston-driven DW, is critical for manufacturing accuracy. However, in piston-driven DW, transient flowrate is poorly controlled due to capacitive pressure dynamics - pressure is stored and slowly released over time from compliant system elements. Thus far, modeling of these dynamics has ranged from simplistic, potentially omitting key contributors to the observed phenomena, to highly complex, making usage in control schemes difficult. Here, we present nonlinear and linearized models that seek to capture the complex dynamic elements of piston-driven DW systems and pose them as ordinary differential equations for eventual integration into control schemes. We validate our models with flowrate measurements for a diverse set of materials, as well as a range of extrusion nozzles to address different feature sizes. As part of this experimental work, we explore the contributions of various system elements to the compliance observed.

4:00 PM
Predictive Model Based Curing Process Control in Selective Separation Shaping (SSS) Process for Fabrication of High Quality Cementitious Part: ***Xiang Gao***[1]; Behrokh Khoshnevis[1]; [1]University of Southern California
Selective separation shaping is a new additive manufacturing technique with the capability of fabricating polymeric, metallic, ceramic and cementitious materials. In earlier research, the potential of SSS to fabricate large-scale cementitious parts has been demonstrated. The final strength of cementitious products is sensitive to water-cement ratio, curing humidity and temperature. In this paper, a strength predictive model for cementitious parts fabricated by SSS under different processing parameters is shown and explained. Based on this model, a modified curing process control strategy in SSS is shown. The strength test results on cementitious parts are presented.

Process Development 8 - Novel Methods 2

Wednesday PM — Room: 616AB
August 15, 2018 — Location: Hilton Austin

Session Chair: Jason Weaver, Brigham Young University

1:10 PM
Mechanical Properties of Polymer Additive Manufactured Samples Using ARBURG Freeformer and Ultimaker 2+ Compared with a Conventional Injection Molding Process: ***Pascal Pinter***[1]; Sascha Baumann[2]; Christoph Lohr[2]; Kay Weidenmann[1]; [1]Karlsruhe Institute of Technology; [2]Fraunhofer ICT
In polymer additive manufacturing, many processes have been developed and optimized in order to reach decent mechanical properties in recent years. Nonetheless, it is hardly possible to reach the reference properties given by the injection moulding process using the same base material. Within this contribution, the process of the ARBURG freeformer (ARBURG Plastic Freeforming (APF)) was compared with an ordinary FDM process, which was carried out by an Ultimaker 2+ printer, and the injection moulding process. The ARBURG freeformer device can theoretically process any thermoplastic granulate using an integrated injection molding unit. In order to compare the three processes mentioned, a filament for the Ultimaker was extruded using the same ABS granulate as for the freeformer and the injection moulding process. Results show that quasi-static mechanical properties depend more on the achievable density than on the manufacturing process itself while dynamic tests offer room for optimizations.

1:30 PM
Immiscible-interface Assisted Direct Metal Drawing: ***Li He***[1]; Fan Fei[1]; Wenbo Wang[1]; Jinhui Yan[2]; Xuan Song[1]; [1]University of Iowa; [2]University of Illinois at Urbana–Champaign
State-of-the-art metal additive manufacturing (AM) techniques construct a three-dimensional (3D) structure through sintering or melting dry metal powders in a layer-by-layer fashion, which consequently results in some typical manufacturing defects in the final structure, such as residual stress and highly-orientated microstructures. To overcome these defects, we present a new low-cost metal AM process, named Immiscible-interface assisted Direct Metal Drawing (II-DMD), which fabricates self-supported and isotropic 3D metal structures by continuously extruding a metal colloidal suspension within a second immiscible matrix colloidal suspension. The shape of the metal colloid is stabilized due to the presence of an immiscible interface between the two colloidal systems. Dense metal structures can be achieved via post-consolidation of the self-stabilized metal-matrix colloidal systems, including liquid-phase drying and metal-phase sintering. In this article, the immiscible-interface-assisted self-stabilization mechanism is studied by both experiments and numerical simulations. The post-consolidation processes are discussed. Several test cases were fabricated and characterized.

1:50 PM
High-efficiency, High-resolution Multimaterial Fabrication for Digital Light Processing-based Three-dimensional Printing: ***Kavin Kowsari***[1]; Qi (Kevin) Ge[1]; [1]Singapore University of Technology and Design
We developed and constructed a novel digital light processing (DLP)-based micro-stereolithography three-dimensional (3D) printing system capable of producing high-resolution components made of multiple materials in a fully automated, efficient, layer-by-layer manner. A high-contrast digital micro display (DMD) with a pixel size of 15 µm was used to project customized 405 nm images through a borosilicate glass plate coated with optically-clear PTFE to induce polymerization in a variety of acrylate-based photocurable polymeric resins, where each layer contained multiple resin types. The new minimal-waste material exchange mechanism involves an air jet to remove residual liquid resin attached to the substrate after each exposure, which eliminated the need to use cleaning solutions that have been known to damage printed features. Complex, multimaterial micro-lattice structures were printed about 58% faster than existing studies which used cleaning solutions.

2:10 PM
Exploring Additive Manufacturing via Semi-solid Metal Formation Process: ***Qing Dong***[1]; Xiao Dong[1]; [1]Advanced Technology and Innovation Institute
Additive manufacturing with melted metal can be challenging due to the harsh requirements for the manufacturing environment, the material solidification defects and the limited selection and high price of the materials. This paper presents a process and the corresponding experiments which take the concept of semi-solid metal forming process that is widely used in friction stir welding but makes necessary modification to the device as well as the process so that it is viable for additive manufacturing. This new process is referred to as Advanced Friction Additive Manufacturing (AFAM). AFAM provides a micro environment for semi-solid metal formation which greatly relaxes the requirements to the additive manufacturing environment and the materials. Early experiments have shown great results in the mechanical properties of the metal product obtained via AFAM method.

2:30 PM
Tool-path Generation for Hybrid Additive Manufacturing: ***Marco Leite***[1]; João Cunha[1]; Manuel Sardinha[1]; Bruno Soares[2]; Luis Reis[1]; António Ribeiro[1]; [1]IDMEC, Instituto Superior Técnico, Universidade de Lisboa; [2]UNIDEMI, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Campus da Caparica
In this paper we propose a new approach to tool-path generation for hybrid additive subtractive manufacturing apparatus. The goal is the development of an integrated hybrid process, based on additive and subtractive manufacturing, to produce complex geometries with continuous fiber reinforced thermoplastics. The authors propose a system that can handle two heads: a filament deposition head and a milling head. The system allows for just additive, just subtractive, first additive followed by subtractive and finally additive and subtractive at each layer. For each strategy, the tool-path trajectories will be different depending on part geometry due to the need to maintain the integrity of the fiber reinforcement of the final part. To evaluate the proposed strategies, examples are provided on how to take an .stl file with a final geometry and generate the necessary adjustments to enable the subtractive process.

2:50 PM Break

3:20 PM
Coaxial Imaging of Directed Energy Deposition Processes—What Are We Actually Measuring?: ***Christopher Stutzman***[1]; Abdalla Nassar[1]; Wesley Mitchell[1]; Edward Reutzel[1]; [1]Penn State University
Coaxial imaging of visible emissions is a common technique for sensing and control of directed energy deposition (DED) additive manufacturing. It is thought a camera system focused on the surface of the melt pool and sensitive to visible wavelengths, can be used to estimate the size and shape of the melt pool. Here, we demonstrate that coaxial "meltpool imaging" of DED processes does not accurately measure deposit width and test the hypothesis, as typically employed, such techniques measure geometries that are actually correlated to plume emissions during DED of Ti-6Al-4V. The proposed hypothesis is tested for multi-track, multi-layer builds under varying laser power, powder flow rate, and hatch pattern.

3:40 PM
Structural Health Monitoring (SHM) of 3D Printed Structures: ***Tyler Smith***[1]; Seokpum Kim[1]; Jordan Failla[1]; John Lindahl[1]; Ahmed Hassen[1]; Chad Duty[2]; Pooran Joshi[1]; Christopher Stevens[1]; Vlastimil Kunc[1]; [1]Oak Ridge National Laboratory; [2]University of Tennessee at Knoxville
This paper introduces an innovative method for Structural Health Monitoring (SHM) of polymer/composite based 3D printed parts. In this work, we propose a method to integrate SHM sensors into the printed part during the printing process itself. These sensors detect micro and macro cracks by measuring the changes in the output signals measured throughout the printed structure itself. Multiple samples were printed and tested to demonstrate that the output signals identified when cracks were formed inside the structure. 3D printed components are gaining a wide interest by different industries such as aerospace, automotive, and medical. However, the lack of standardized quality control procedures for 3D printed processes has deterred the broader adoption of polymer/composite based 3D printed parts for use in end-user applications. Results demonstrated in this paper could allow broader adoption of custom 3D printed parts.

4:00 PM
Development of an Indigenous and Innovative Sand 3D Printer: Ashik Kumar Patel[1]; Yogesh Patil[1]; Subodh Chavan[1]; Amisha Goutam[1]; Sameer Kelkar[1]; Ranjeet Bhagchandani[1]; Pushkar Kamble[1]; ***K P Karunakaran***[1]; [1]Indian Institute of Technology
3D printing is a disruptive technology owing to its unique geometric and matrix capabilities. If the sand molds and cores are 3D printed, sand casting can approach the quality of investment casting. Despite these benefits, its prohibitively high cost of imports discourage its acceptance. This paper describes our sand 3D printer costing a tenth in capital and consumables through indigenization and innovations. Both multi-jet binder and Selective Laser Sintering (SLS) approaches were studied and the latter was chosen. The existing SLS machine with RF CO2 laser is an overkill for foundry applications. We modified a glass tube DC laser engraving machine by adding a novel sand dispenser, suitable CNC/PLC controller and custom-built software. Its build speed is 5 l/hr. Despite full sintering, warpage will be minimum through appropriate path planning. The next release will aim at 100 l/hr by varying speed, laser power, beam diameter & layer thickness and hybridization.

Process Development 9 - Powder Bed Fusion 2

Wednesday PM Room: Salon K
August 15, 2018 Location: Hilton Austin

Session Chair: Phill Dickens, University of Nottingham

1:10 PM
Dynamic Defect Detection in AM Parts: Jason Blough[1]; ***Kevin Johnson***[1]; Andrew Barnard[1]; Troy Hartwig[2]; Ben Brown[2]; Tristan Cullom[3]; Robert Landers[3]; Douglas Bristow[3]; Edward Kinzel[3]; [1]Michigan Technological University; [2]Kansas City National Security Campus; [3]Missouri University of Science and Technology
The goal of this paper is to evaluated internal defects in AM parts using dynamic measurements. The natural frequencies of AM parts can be identified by measuring the response of the part(s) to a dynamic input. Different excitation methods such as a modal impact hammer or shaker can be used to excite the parts. This paper will investigate the use of Doppler lasers, accelerometers and Digital Image Correlation. The parts evaluated in this work include sets of parts that are still attached to the build plate, this makes the identification of a faulty part more difficult, as parts on a build plate interact with each other as well as the build plate complicating the responses. Several approaches to these issues will be presented. This work has been funded by Honeywell Federal Manufacturing & Technologies under Contract No. DE-NA0002839 with the U.S. Department of Energy.

1:30 PM
In-situ Defect Detection through Monitoring and Modeling of Plume Characteristics: ***Joe Walker***[1]; Andrew Drieling[1]; John Middendorf[2]; Glen Perram[3]; Nathan KlingBeil[1]; Joy Gockel[1]; [1]Wright State University; [2]Universal Technology Corporation; [3]Air Force Institute of Technology
Additive manufacturing (AM) fabricates highly complex components, but occasionally produces unpredictable defects that negatively affect part quality and performance. In-situ monitoring can provide early defect detection in order to save time and resources. This work uses a multi-sensor approach in-situ to identify the types of defects formed. A high-speed camera, thermal camera, and spectrometer are used to collect data simultaneously on a custom-built laser powder bed fusion (LPBF) machine. This work focuses on monitoring and modeling the plume characteristics through the spectrometer output, an approach that is commonly used in laser welding for defect detection. Processing parameters, and feature geometries are varied in order to obtain a variety of defects such as keyholing, balling, lack of fusion and microstructural inconsistencies. By correlating all sensor data anomalies, it is possible to locate defects mid-build which will allow for early identification of scrap parts or potential for in-situ correction of defects.

1:50 PM
Fault Detection in Selective Laser Sintering with Optical Coherence Tomography: ***Adam Lewis***[1]; Scott Fish[1]; Joseph Beaman[1]; [1]The University of Texas at Austin
The selective laser sintering (SLS) process suffers from inconsistent part properties. Because of this, improved part validation and process control continue to be identified as critical areas of improvement in industry roadmaps. Recently, optical coherence tomography (OCT) has shown promise as a new process sensor in SLS due to its ability to yield high resolution, depth resolved spatial data not attainable with conventional sensors. Due to OCT's unique capabilities, it has shown to be adept in identification of faults in the SLS process. This work reports on common faults in the SLS process that have been identified with an in-situ OCT sensor. Mitigation of the detected faults is also explored.

2:10 PM
Investigating Melt Pool Dynamics in Laser-powder Bed Fusion Using a Two-color Pyrometer: ***Josh Koepke***[1]; Bradley Jared[1]; David Saiz[1]; Erich Schwaller[1]; Dan Tung[1]; Laura Swiler[1]; [1]Sandia National Labratories
In-situ process monitoring using a two-color pyrometer is being used to investigate the dynamics and temperature of the melt pool during laser-powder bed fusion (L-PBF). A key challenge is the accuracy of reported measurement temperatures. To better understand the temperature data being generated, line scans were performed while varying laser power and speed on flat plate and powder. Data for the melt pools were analyzed to look for process trends and measurement variations. The temperature data was also compared to the surface topography and metallography of each line scan to investigate trends in the melt pool dynamics. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. SAND2018-3808 C

2:30 PM
Accurate Determination of Laser Spot Position during LPBF Process Thermography: ***Ivan Zhirnov***[1]; Sergey Mekhontsev[1]; Brandon Lane[1]; Steven Grantham[1]; [1]National Institue of Standards and Technology
Thermography and high-speed imaging are useful tools for researching the additive manufacturing process by providing transient, spatial, and thermal information in and around the melt pool. However, it is not directly possible to ascertain the position of the laser spot with respect to the imaged melt pool, which could provide key information regarding how laser energy is distributed and absorbed. In this paper, we demonstrate a procedure for registering the laser spot position with the melt pool using a bright illumination source co-axially aligned with the laser to project a sharp spot on the build plane. This spot fixed to the laser position and used as a reference frame for registering the laser spot with the melt pool thermal field. Measurement results demonstrate the effect of varying process parameters (laser power and scan speed) on the melt pool thermal field and respective position of the laser spot.

2:50 PM Break

3:20 PM
Nanoparticle Bed Deposition by Slot Die Coating for Microscale Selective Laser Sintering Applications: ***Dipankar Behera***[1]; Nilabh Roy[1]; Chee Foong[2]; Michael Cullinan[1]; [1]Department of Mechanical Engineering, The University of Texas at Austin; [2]NXP Semiconductors
The minimum feature size in most commercially available metal additive manufacturing processes is limited to ~100 microns which pose a challenge in fabricating complex 3D microarchitectures. We are developing a microscale selective laser sintering (µ-SLS) process with the goal of fabricating these microarchitectures with 1 µm resolution. To achieve near-net shaped features, the powder bed thickness should not be more than one micron. This paper presents the development and testing of a powder bed deposition mechanism using a slot-die coater. Metallic nanoparticles uniformly dispersed in a solvent are used in this study. A viscocapillary model is used to predict the wet thickness based on coating gap. Experimental results reveal that sub-micron layer thicknesses can be achieved by tuning the process parameters like flow rate, coating speed, coating gap, and die gap etc. The novel approach discussed in this paper enables implementing a robust dispense mechanism for high throughput additive manufacturing.

3:40 PM
Off-nominal Laser Power Testing in Selective Laser Sintering: ***Samantha Taylor***[1]; Alexander Nettekoven[1]; Scott Fish[1]; Joseph Beaman[1]; [1]University of Texas at Austin
Selective laser sintering (SLS) parts are becoming increasingly popular for safety critical systems and applications such as aircrafts and medical devices. In order to build parts that will meet strict customer specifications, current research at UT Austin is looking to improve process control by developing data driven methods that can interpret in-situ measurements from sensors, such as infrared cameras, and effectively utilize different actuators. As a first step for improving process control, an analysis of in-situ data from SLS builds is performed for the purpose of flaw detection and uncertainty quantification. The recorded data will stem from builds with induced flaws due to off-nominal conditions of laser power as well as other parameters. The investigation will provide information about the source and signature of flaws in our temperature measurements. The goal is to eventually answer the question of how small of a change in off-nominal conditions will be detectable.

4:00 PM
A Guideline for Additively Manufacturing New Materials Using Laser Powder Bed Fusion: Hannah Boon[1]; Bing Zhang[1]; Luke Johnson[1]; Kubra Karayagiz[1]; Alaa Elwany[1]; Ji Ma[1]; Raymundo Arroyave[1]; ***Ibrahim Karaman***[1]; [1]Texas A&M University
As new materials are designed for metal additive manufacturing (AM), there is a need for a systematic approach to determining and optimizing process parameters. The purpose of this paper is to present a guideline for laser-based powder bed fusion (LPBF) operators that will accelerate build times for new materials while lowering costs. The guideline illustrates a two-step optimization problem based on the following four process parameters: laser power (P), scan speed (v), layer thickness (t), and hatch distance (h). The first step focuses on optimizing P and v in order to achieve desirable melt pool dimensions. Eagar-Tsai and Finite element models were employed to predict the width and depth of the melt pool. The second step optimizes t and h by considering the melt pool geometry and calculating the optimal hatch distance in order to fabricate with a maximum layer thickness.

4:20 PM
Beam Shaping in Powder Bed Based Additive Manufacturing: A Numerical Approach to Determine Adjusted Beam Shapes: ***Jan Frederik Hagen***[1]; Stefanie Kohl[1]; Michael Schmidt[1]; [1]Institute of Photonic Technologies, Friedrich-Alexander University Erlangen-Nürnberg
Most powder bed based laser beam melting machines today use a quasi-Gaussian beam profile. It has been shown though that changing the beam profile alters solidification conditions and thus has the potential to allow the tailoring of microstructures without a change in laser power or scan speed. We show a numerical approach that allows the determination of adjusted beam profiles for a vast number of applications. An inverse problem is solved to determine these shapes. Adjusted profiles are tested in a high fidelity melt pool simulation to validate the applicability of this approach. Results show that adjusted profiles can be used to increase hatch distance or reduce the necessary laser power for a certain melt pool depth compared to a standard quasi-Gaussian beam profile and thus improve the efficiency of the process.

4:40 PM
Characterizing Laser Coupling Efficiency during Additive Manufacturing: ***Dan Tung***[1]; Jeff Rodelas[1]; Alex Barr[1]; Matt Vieira[1]; [1]Sandia National Laboratories
Coupling efficiency during laser powder bed additive manufacturing was characterized by scanning a laser on a plate and on a single powder layer inside an integrating sphere to provide measurements with both high spatial and temporal resolution. Efficiency was calculated using the reflected (uncoupled) light as a fraction of the laser output power; laser output power was calibrated separately from the laser command power. After correlation to defect presence and location, efficiency data was used to produce constant absorbed energy by intentionally varying laser power in an attempt to mitigate defect formation compared to traditional constant command power scenarios. ***Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.***

Process Development 10 - Spinning, Pinning, and Stereolithography

Wednesday PM	Room: 417AB
August 15, 2018	Location: Hilton Austin

Session Chair: Bahram Asiabanpour, Texas State Univ

1:10 PM
Study of Charge Effect during Melt Electrospinning Writing Process: ***Houzhu Ding***[1]; Kai Cao[1]; William Boettcher[1]; Robert Chang[1]; [1]Stevens Institute of Technology
Melt-electrospinning writing (MEW) is an electrohydrodynamics (EHD)-based additive manufacturing (AM) paradigm that enable printing high resolution microscale scaffold where a significant challenge lies in the charge analysis. This paper advances measurements and analysis to determine the effect of charge on the MEW resolution. First, the accumulated MEW fibers with different cone shapes on 3 substrates at different conductivities by stationary deposition demonstrates the existence of charge effect during MEW. By seting different inter-fiber distance (Sf) on coverslips with different conductivities, fiber repulsion (measured Sf > set Sf) and attraction (fibers stick together) are observed during printing, evidenced by dynamic fiber deformation using high resolution images. Preliminary mathematical model based on point charge interaction is proposed to explain the attraction-repulsion phenomenon. Finally, current form collector is measured by a double-picoammeter denoising system. Current collected on non-conductive coverslip has higher amplitude than on conductive coverslip during extrusion when voltage and temperature varies.

1:30 PM
Fabrication of Aligned Nanofibers along Z-axis – A Novel 3D Electrospinning Technique: Yingge Zhou[1]; ***George Tan***[1]; [1]Texas Tech University
This study presents a 3D fabrication technique of nanofibrous scaffold for tissue engineering. A divergence static electric field was introduced in an electrospinning system to induce a self-assembly of aligned nanofibers into a tunable 3D architecture with thickness ranging from 2-12 mm. The effects of collector configuration on polycaprolactone (PCL) nanofiber attributes were investigated. Human fibroblast cells were cultured on the nanofiber scaffold in vitro for 7 days. It was found that the width and inclination angle of the collector influenced the nanofiber density distribution. The cells proliferated on the scaffold and organized as a fibrous matrix which mimicked the microstructure of native musculoskeletal tissues.

1:50 PM

Z-Pinning Approach for Reducing Mechanical Anisotropy of 3D Printed Parts: ***Chad Duty***[1]; Jordan Failla[2]; Seokpum Kim[2]; Tyler Smith[1]; John Lindahl[2]; Alex Roschli[2]; Brian Post[2]; Lonnie Love[2]; Vlastimil Kunc[2]; [1]University of Tennessee; [2]Manufacturing Demonstration Facility (ORNL)

The mechanical strength of extrusion-based printed parts is often reduced (25-50%) in the build direction (z-direction) compared to the in-plane strength due to poor bonding between deposited layers. This effect can be magnified (75-90% difference) when depositing fiber-reinforced materials or larger print areas with long layer times. Therefore, a patent-pending approach has been developed that deposits material into intentionally aligned voids in the z-direction, allowing continuous material to span multiple layers. The "z-pinning" approach presented will cover several concepts for improving the interlaminar strength of extrusion-based 3D printed parts as well as techniques for applying the technology across a broad spectrum of deposition platforms and material systems. Experimental results will demonstrate a significant improvement (2-3x) in mechanical properties for neat and fiber reinforced components on various platforms (desktop to large scale). The impact of z-pins on the thermal expansion of printed parts during thermal cycling will also be demonstrated.

2:10 PM

Improved Mechanical Bond of Printed Dissimilar Materials Using Z-Pinning Approach: ***Jordan Failla***[1]; Tyler Smith[1]; Chad Duty[2]; Seokpum Kim[1]; John Lindahl[1]; Alex Roschli[1]; Brian Post[1]; Lonnie Love[1]; Vlastimil Kunc[1]; [1]Manufacturing Demonstration Facility, Oak Ridge National Laboratory; [2]University of Tennessee

3D printing of dissimilar materials is inherently challenging due to a weak interlayer bond that results from differing thermal, chemical, or mechanical properties. A patent-pending z-pinning approach is presented that creates a strong interlayer bond between the two materials based primarily on mechanical interlocking. Rather than printing the two materials directly on top of one another, the Z-pinning approach creates a multi-layer transition, where tapered holes in the first material are filled with the second material to create an interlocking grid-like scaffold. The z-pinning method has shown significant improvement in the mechanical bonding of dissimilar materials such as nylon and poly-lactic acid for extrusion-based 3D printing.

2:30 PM

Structurally Intelligent 3D Layer Generation for Active-Z Printing: ***Jivtesh Khurana***[1]; Timothy Simpson[1]; Mary Frecker[1]; [1]Pennsylvania State University

Active-Z Printing offers the ability to deposit material along non-planar layers to control the mechanical behavior of parts produced by material extrusion additive manufacturing. These non-planar layers can be exploited to incorporate a part's loading conditions into the slicing process by aligning deposited layers with predicted localized stress tensors. In this work, we demonstrate that superior structural performance can be achieved by taking advantage of layer shapes derived from principal stress trajectories. A slicing method incorporating stress field data is developed to generate 3D layers from principal stress trajectories. As a demonstration, a 3-point bend specimen is manufactured with 3D layers derived from principal stress trajectories developed in a deformed specimen. Mechanical tests are conducted and 3-point bend specimens are shown to have superior mechanical response. This novel approach introduces new capabilities to Additive Manufacturing for structurally intelligent fabrication.

2:50 PM Break

3:20 PM

Parallel Two-photon Lithography with Sub-diffraction Voxel Shaping: ***Sourabh Saha***[1]; Vu Nguyen[1]; Shih-Chi Chen[2]; James Oakdale[1]; [1]Lawrence Livermore National Laboratory; [2]Chinese University of Hong Kong

Two-photon lithography (TPL) is a photo-polymerization technique that enables fabrication of 3D structures with submicron features. TPL relies on nonlinear photoabsorption to generate features smaller than the diffraction-limited light spot. Traditionally, a tightly focused laser spot is serially scanned to generate 3D parts by assembling "voxels" (volumetric pixels). This serial scheme severely hinders process scalability and limits the geometry of voxels to an ovoid shape. Here, we present a parallel TPL technique that increases the rate by at least 50 times and also enables tuning the voxel shape. In our technique, a patterned 2D "light sheet" (comprising a million focused points) is projected off a digital micromirror device to polymerize 2D layers in parallel. Voxel shaping is achieved by projecting multiple points within the span of a diffraction-limited light spot to generate non-Gaussian intensity distributions. Our technique enables writing structures with complex sub-diffraction features at an unprecedented rate and resolution.

3:40 PM

High-Temperature Vat-Photopolymerization: ***Viswanath Meenakshisundaram***[1]; Nicholas Chartrain[1]; Xi Chen[2]; Mingtao Chen[2]; Keyton Feller[1]; Timothy Long[2]; Christopher Williams[1]; [1]DREAMS Lab, Virginia Tech; [2]Long Research Group, Virginia Tech

Vat Photopolymerization (VP) offers superior feature resolution, surface finish and isotropic mechanical properties. However, the mechanical performance of VP parts is typically poor due to the low-molecular weight of the printed photopolymers. Using high-molecular weight polymers in VP systems is a process challenge because they exhibit high viscosity, which leads to the deformation and damage of intricate features during the recoating process. While heating the photopolymer can lower the viscosity, it increases the risk of thermal-polymerization during fabrication. In this work, the authors present the design of a high-temperature VP machine capable of handling photopolymers with viscosities up to 30 Pa*s. Results from printing two high-temperature compatible photopolymer systems are presented. Generalized methods for formulating photopolymers that can be photocured at elevated temperatures without the risk of thermal-polymerization are discussed. The designed high-temperature VP system unlocks the possibility of using temperature-modulated polymerization strategies for additive manufacturing of high-performance polymers.

4:00 PM

microCLIP Ceramic High-resolution Fabrication and Dimensional Accuracy Requirements: ***Henry Oliver Ware***[1]; Cheng Sun[1]; [1]Northwestern University

Ceramics have been broadly used as structural and functional materials with a wide range of engineering applications. Recent introduction of Continuous Liquid Interface Production (CLIP) uses projection UV photopolymerization and oxygen inhibition to tremendously reduce fabrication time. In addition to 3D printing polymeric materials, it has demonstrated the feasibility of fabricating ceramic parts using the photo-curable ceramic resins. However, the associated ceramic particle light-scattering significantly alters the process characteristics of the CLIP process, resulting in broadening of the lateral dimensions in associated with the reduction in the curing depth. Varying the exposure conditions to accommodate the scattering effect further affects the deadzone thickness, which introduces a systematic defocusing error to further complicate the process control. In this work we show that careful characterization and balance of both effects yields an optimal set of process parameters (UV Power and stage speed) for high-resolution 3D fabrication with a given photo-curable ceramic resin.

4:20 PM
Investigation on Constrained Surface for Continuous Projection Stereolithography: ***Haiyang He***[1]; Yilong Wang[1]; Alan Feinerman[1]; Yayue Pan[1]; [1]University of Illinois at Chicago
The objective of this paper is to investigate continuous projection stereolithography using two novel constrained surfaces. One is characterized by embedded micro-air-channel with liquid filling surface textures. The embedded micro-air-channel supplies oxygen to form a thin oxygen inhibition layer during stereolithography process and surface textures effectively reduces the separation force. The other constrained surface is based on the diffusion of oxygen at a highly air-permeable constrained surface, which is characterized by the central polymerization window and its surrounding oxygen supplying window. The surrounding oxygen supplying window could help maintain a thin uncured liquid layer and enable continuous printing. Experiments were performed to verify and compare the effectiveness of the two constrained surface designs in performing continuous printing of both hollowed structures and solid structures. The printable cross-section size, maximum build speed, and reliability of these two constrained surface designs were analyzed and discussed in this work.

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Investigation of Acoustic Field for Localized Particle Manipulation in Vat Photopolymerization Additive Manufacturing of Anisotropic Nanocomposites: ***Lu Lu***[1]; Xiaohui Tang[2]; Shan Hu[2]; Yayue Pan[1]; [1]University of Illinois At Chicago; [2]Iowa State University
By assembling and orienting particle/fiber fillers with an appropriate pattern in a polymer matrix, superior anisotropic properties and functionalities can be coded in composites. Vat photopolymerization Additive Manufacturing processes, especially the projection stereolithography, have been used for fabricating such anisotropic nanocomposites. Various methods for manipulating fillers in the liquid resin, including the filler location, local orientation and filler assembly, have been investigated. This study investigated the use of acoustic field for particle redistribution, alignment, and self-assembly. A multi-physics numerical model has been developed to predict the particle movement dynamics and distributions. The acoustic radiation force, drag force, and gravity during the particle patterning process were analyzed. Experiments have been performed and the capability of the proposed method was characterized. In-situ manipulation of particle dispersions within the liquid resin was demonstrated and 3D anisotropic composites were printed.

Poster Session

Tuesday PM	Room: Salon JK
August 14, 2018	Location: Hilton Austin

Comparison of Ex Situ X-ray Tomography and In Situ Monitoring to Gain Control Over Defects during Laser Powder Bed Fusion: ***Jean-Baptiste Forien***[1]; Philip Depond[1]; Gabe Guss[1]; Bradley Jared[2]; Jonathan Madison[2]; Elena Garlea[3]; Hahn Choo[4]; Manyalibo Matthews[1]; [1]Lawrence Livermore National Laboratory; [2]Sandia National Laboratories; [3]Y-12 National Security Complex; [4]University of Tennessee
As in any other laser welding technique, creation of pores and defects during laser powder bed fusion can lead to component failure and thus cannot be tolerated. Post-build inspection is required to ensure the printed parts are defects-free. These inspections can take time and are complicated particularly for large parts. A solution is to use in situ process monitoring to detect the creation of defects, which could in turn be corrected during the printing itself. However, the relationship between pore creation and in situ monitoring still needs to be understood. In this work, we use x-ray computed tomography to detect pores and correlate them to pyrometry and high speed thermal imaging signals collected during laser welding. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

An Aerospace-integrated Component Application based on Selective Laser Melting: Design, Fabrication and FE Simulation: ***Fei Liu***[1]; Jingchao Wang[2]; Zhi Tan[2]; Bin Liu[2]; Yue Guo[2]; David Z. Zhang[1]; [1]Chongqing University; [2]Beijing Institute of Aerospace Systems Engineering
Developments in Additive Manufacturing (AM) technologies have enabled the integrated manufacturing of complex structures with multifunctional performances. Selective Laser Melting (SLM), as one of them, becomes the candidate for production of metallic aviation spaceflight structures because of its high precision for controlling architecture and excellent performance. An aerospace component named Upper-stage Cabin was selected for integrated design without connectors, and then manufactured by a SLM system using Ti-6Al-4V powder. The dimensional accuracy of the component was verified through testing; It's mechanical response was analyzed under compressive loading test, compared with the results of numerical simulation. The study found that SLM technology is an effective means for integrated design and manufacture of Upper-stage Cabin structures for aerospace. The dimensional precision of the complex integrated structures formed by SLM meets the application requirements. The formed integrated components have achieved good mechanical properties, which promote the application of this technology in aerospace field.

Development of a Thermoplastic Biocomposite for 3D Printing: ***John Obielodan***[1]; Joshua Helman[1]; Andrew Grumbles[1]; [1]University of Wisconsin-Platteville
Organosolv lignin, a natural cross-linked phenolic wood polymer is a by-product of the pulping process in the paper industry. It is a renewable organic natural product with many application areas. It has attractive properties that make it a potential candidate for fabricating useful parts using 3D printing. Also, polylactic acid (PLA), a biodegradable thermoplastic derived from renewable sources has been widely used in 3D printing polymer parts. In this work, organosolv lignin is blended with PLA in different proportions and extruded into filaments for extrusion-based 3D printing. The qualities of both the filament extrusions and printed study samples are being evaluated to determine viable optimal compositions for specific applications.

EBSM Online Monitoring System Based on Machine Vision: ***Xulong Ma***[1]; Feng Lin[2]; Chao Guo[1]; [1]Tianjin SciTsinghua QuickBeam Tech. Co., Ltd.; [2]Tsinghua University
Electron beam selective melting(EBSM) additive manufacturing is a technology for metal materials processing layer by layer to manufacture three dimensional solid parts. At present, surface defects such as surface deformation and porosity in EBSM process cannot be monitored online and can only be diagnosed after manufacturing is completed, which is time-consuming and laborious. We uses machine vision to implement online monitoring defects in EBSM process, including the detection of surface deformation and pore defects, and also including monitoring the printing for backtracking the process. Furthermore we use deep learning method to process the monitor images and try to learn more abstract features of defects such as a region missed, dropped in or deformed. This shortens the traditional "first-form, post- check" process and avoids time wastage and material waste. Using machine vision monitoring in metal EBSM process, the level of intelligentized EBSM additive manufacturing technology has been enhanced.

Experimental Characterization of Direct Metal Deposited Cobalt-based Alloy on Tool Steel for Component Repair: ***Xinchang Zhang***[1]; Tan Pan[1]; Wei Li[1]; Frank Liou[1]; [1]Missouri University of Science and Technology
Die casting dies made of tool steel is subject to impact, abrasion and cyclic thermo-mechanical loading that delivers damage such as wear, corrosion, and cracking. To repair such defects, materials enveloping the damage need to be machined and refilled. In this study, V-shape defects with varied sidewall inclination angles were prepared on H13 tool steel substrates and refilled with cobalt-based alloy for superior hardness and wear resistance. The microstructure of rebuild samples was characterized using an optical microscope (OM) and scanning electron microscope (SEM). Elemental distribution from the substrate to deposits was analyzed using energy dispersive spectrometry (EDS). Mechanical properties of repaired samples were evaluated by tensile test and microhardness measurement. Fracture mechanism in tensile testing was analyzed by observing the fracture surface. The experiment reveals that V-shape defects with sidewall beyond certain angles can be successfully remanufactured. The deposits were fully dense and free of defects. The microstructure and tensile test confirm the solid bonding along the interface. The tensile test shows the mean ultimate tensile strength (UTS) of repaired samples is approximated 620 MPa, where samples fractured at the deposits region. Hardness measurement reveals the hardness of deposits is around 810 HV which is much higher than that of the substrate.

Incorporation of Automated Ball Indentation Methodology for Studying Powder Bed Fabricated 304L Stainless Steel: Sreekar Karnati[1]; Jack Hoerchler[1]; ***Aaron Flood***[1]; Frank Liou[1]; [1]Missouri University of Science and Technology
Automated Ball Indentation (ABI) is a viable method for estimating the ductility, yield stress, and ultimate stress, among other metrics, in different materials. Currently, ABI data analysis utilizes Holloman's Power Law to model the plastic region of the true stress-true strain curve. While this formulation is accurate for some materials, its relevance for austenitic stainless steels, such as 304L, needed investigation. The deviation of the material's plastic behavior from the Power Law was investigated. In order to better model this behavior, both the Voce and Ludwigson formulation were investigated. These formulations were tested for both wrought and additively manufactured 304L stainless steel. Regression analysis was used to choose the appropriate fit. The chosen formulation was then used to generate a material model to simulate the ABI process. These simulations were validated through experimental analysis.

Multi-color Thermal Imaging in Laser Powder Bed Fusion Additive Manufacturing: ***Dong-Xia Qu***[1]; Nicholas Calta[1]; Gabe Guss[1]; Manyalibo Matthews[1]; [1]Lawrence Livermore National Laboratory
A multi-color pyrometry technique is developed to measure the temperature of melt pool dynamics in laser powder bed fusion additive manufacturing. We employ an eight-band hyperspectral camera to carry out the experiments and to determine the object temperature by fitting to the Wien's approximation. A detailed analysis of a number of key parameters influencing the accuracy of the temperature measurement using hyperspectral thermal imaging will be given—the influence of spectrally-dependent emissivity, the effect of the vapor plume, and the influence of the scattered background radiation from the laser beam. Based on this analysis, we develop the optimum measurement conditions, and discuss the potentials and the limits of multi-color pyrometry method for additive manufacturing applications. This work was performed under auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. The project was supported by the Laboratory Directed Research and Development programs of LLNL (18-SI-003).

The Sidewall Inclination Angle's Influence on Repairing V-shape Defect in Ti6Al4V Metallic Components with Direct Energy Deposition Process: ***Wei Li***[1]; Xinchang Zhang[1]; Frank Liou[1]; [1]Missouri University of Science & Technology
Ti6Al4V has excellent mechanical and metallurgical properties and is considered as an ideal engineering material in aerospace and nuclear industries. The defects on Ti6Al4V metallic components are often repaired through Laser based direct energy deposition due to its merits of accuracy, high-efficiency, low-cost, etc. However, various defect shapes, especially for some concave defects, fundamentally affect the repairing property and quality. In this study, the concave defects were simplified as V-shape defects in Ti6Al4V samples. The sidewall inclination angle's influence on repairing V-shape defects was investigated. Seven sidewall inclination angles (30°, 45°, 60°, 75°, 80°, 85°, and 90°) were cut in Ti6Al4V samples as V-shape defects. The repairing was done with laser based DED process under same processing parameters. Then the micro-morphology and microstructure near repair interface were characterized using optical microscope and scanning electron microscope. Mechanical properties of repaired samples were evaluated by tensile test and microhardness measurement.

Additive Manufacturing of Metal Functionally Graded Materials: A Review: ***Yitao Chen***[1]; Frank Liou[1]; [1]Missouri University of Science and Technology
Functionally graded materials (FGMs) have attracted a lot of research interest due to their gradual variation in material properties that result from the non-homogeneous composition or structure. Metal FGMs have been widely researched in recent years, and additive manufacturing has become one of the most important approaches to fabricate metal FGMs. The aim of this paper is to review the research progress in metal FGMs by additive manufacturing. It will first introduce the unique properties and the advantages of FGMs. Then, typical recent findings in research and development of two major types of metal additive manufacturing methods, namely laser metal deposition (LMD) and selective laser melting (SLM), for manufacturing different types of metal FGMs will be discussed. Finally, the major technical concerns in additive manufacturing of metal FGMs which are closely related to mechanical properties, and industrial applications of metal FGMs will be covered.

Development of an Automated Laser Control System for Improving Temperature Uniformity in Selective Laser Sintering: ***Timothy Phillips***[1]; Scott Fish[1]; Joseph Beaman[1]; [1]University of Texas at Austin
It is believed that the temperatures achieved during the build process of selective laser sintering (SLS) components strongly affect the quality of those components and temperature fluctuations of a few degrees can alter mechanical properties. Therefore, reducing the thermal fluctuations during the build process is a key step to improving part uniformity. One potential solution is a feed-forward laser fluence controller based on infrared temperature measurements. In this system, controlling the amount of energy deposited by the laser yields a high level of control over the final part temperatures, reducing component non-uniformity. This poster will cover development of such a controller and will present preliminary results showing a higher level of control over the uniformity of specimen when using active laser control.

CNTs/CF Reinforced Composites for Programmable Deformation by Fused Deposition Modelling 3D Printing: ***Lan Huang***[1]; Xiaoyong Tian[1]; Qingrui Wang[1]; [1]Xi'an Jiao Tong University

In recent years, with the great progress in the field of 3D printing and 4D printing, the coding design for artificial materials in the preparation process has been realized, making the materials possess controllable self-folding, self-evolving, and self-assembly characteristics. Carbon fiber (CF) is the common reinforcement phase for increasing the mechanical properties of composites, such as strength, modulus, and interfacial shear strength. In this paper, CF reinforced composite (CF/PA) with precisely controllable deformation has been already fabricated by Fused Deposition Modelling Techonology (FDM), in the research of our group, due to the large difference between thermal coefficient of CF and that of resin. Further more CF can be used as the basic material for electrical actuator for programmable deformation, as a result of its conductivity, and week electroresistive effect. To enhance the electroresistive effect for practical application, CNTs/CF hybrid material was fabricated through layer by layer self assembly technology (LBL), and showed an excellent electroresistive performance and a high gauge factor (GF). Then the CNTs/CF/PA composites manufactured by FDM display good properties of controlled deformation compared with pure CF/PLA composites, and the FDM method provides much flexibility of pattern design simultaneously.

Elucidating the Role of Fluid-particle Interaction in Binder Jet Additive Manufacturing: ***Joshua Wagner***[1]; C. Fred Higgs III[1]; [1]Rice University

In binder jet additive manufacturing, coupled fluid-particle interaction is a primary factor governing the final quality of a 3D printed part; thus, better understanding of this complex physics will allow for improved printing performance and resolution. In this work, we seek to elucidate the fluid and particle dynamics occurring when a liquid droplet impinges a powder bed and forms a bonded particle agglomeration – effects of ballistic impact, capillarity, and surface tension are studied. The investigation is carried out through the use of high-speed, microscopic imaging to examine a liquid droplet impacting a particle bed. Ultimately, we show how this experimental work will be used to validate a multiphase (solid-liquid-gas) numerical framework that is currently being developed to model the phenomenon.

Evaluation of Thermal Metrics for the Comparison of Finite Element Models with In-situ Thermal Images for Laser-based Additive Manufacturing: ***William Furr***[1]; Matthew Dantin[1]; Matthew Priddy[1]; [1]Center for Advanced Vehicular Systems

Given the spatiotemporal variance of the AM process, comparison of simulation results with thermal imaging can be helpful in accurately modeling the phenomena present in AM. Thermal metrics are evaluated for their efficacy as well as employed for the comparison of FE model results of LBAM processes with thermal images captured in-situ. Comparisons are made using thermal images from a coaxially mounted dual wavelength pyrometer and side-mounted infrared camera during the LENS construction of a Ti-6Al-4V thin wall. Comparison metrics, specific to the melt pool, include: (i) thermal gradient in multiple directions, (ii) maximum temperature, (iii) length-to-width ratio, and (iv) linear comparisons of the spatial temperature distributions between the simulation and process data. These types of comparisons can be extremely beneficial in the production of an accurate FE model for extending to microstructure prediction because of its dependence on the spatial temperature distribution during solidification and cooling.

3D Printed Aircraft Competition at the University of Texas at Arlington: ***Gavin Sabine***[1]; Robert Taylor[1]; [1]University of Texas at Arlington

As 3D printing technologies have expanded the design space for many applications, the challenge of leveraging this design freedom for improved performance while satisfying fabrication process constraints has likewise increased. The University of Texas at Arlington (UTA) hosts the 2nd Annual 3D Printed Aircraft Competition on July 14, 2018 at the UTA Football Stadium to give undergraduate and graduate students the opportunity to innovatively design a purely 3D printed aircraft for the longest flight given limited propulsion allowance. The competition is divided into two categories, fixed wing and rotary wing, with awards given in each category for longest flight duration and most innovative design. The competition rules challenge students to integrate design and advanced manufacturing to maximize mission performance, design within 3D printing process and material constraints, develop lightweight 3D printable airframe configurations, leverage direct digital manufacturing technologies, and develop team and hands-on design experience.

Experimental Investigation of Build Direction Thermal Conductivity of PLA with Process Structure Relationship: ***Darshan Ravoori***; Ankur Jain[1]; [1]University of Texas at Arlington

Additive manufacturing offers advantages of tailored physical properties of built parts. A significant amount of research work has been conducted to link process parameters to structural properties parts produced through polymer extrusion 3D printing. However, relatively less research has been carried out to understand the relationships between thermal properties and process parameters such as print speed, layer height and Infill density. This research develops this understanding through a combination of in-situ high speed imaging and thermal conductivity measurements. Measurements are conducted by one-dimensional heat flux method. These results are correlated with in situ high speed images of process as well as cross section images of the built part. Experiments in a wide range of process parameters indicate that thermal conductivity of build direction is a strong function of print speed and layer height. The present work enables such optimization by understanding the key relationships between process parameters and thermal properties.

Fast Prediction of Thermal History in Large-scale Part Fabricated via a Laser Metal Deposition Process: ***Lei Yan***[1]; Joseph Newkirk[1]; frank Liou[1]; Eric Thomas[2]; Andrew Baker[2]; James Castle[2]; [1]Missouri University of Science and Technology; [2]The Boeing Company

Laser metal deposition (LMD) has become a popular choice for the fabrication of near net shape complex parts. Plastic deformation and residual stresses are common phenomena that generated from the intrinsic large thermal gradient and high cooling rate in the process. Finite element analysis (FEA) is often used to predict the transient thermal cycle and optimize processing parameters. But the predicting of thermal history in the LMD process with FEA method is usually time-consuming, especially for the large-scale part. Herein, multiple three-dimensional FEA models with simple assumptions on the heat source and its loading methods are compared and validated with experimental thermocouple data.

Fatigue Behavior of EBM Ti-6Al-4V after Surface Processing: A Preliminary Study: ***Carter Keough***[1]; Harvey West[1]; Richard Wysk[1]; Ola Harrysson[1]; [1]North Carolina State University

The fatigue behavior of a functional component is affected by the quality of its surface. Components made via electron beam melting (EBM) are known to have unique, rough surfaces which often results in parts that do not meet the desired geometric or dimensional tolerances for many final applications. For this reason, surface processing is often utilized to achieve a desired geometric tolerance or to enhance the mechanical performance. The understanding of surface modification effect on fatigue response is limited and far from complete. A study investigating the effects of surface quality and surface defects on the fatigue performance of additively built Ti-6Al-4V has been conducted. The objective of this work is to develop a series of post processing guidelines for finishing metal AM components. Both mechanical and chemical conditioning methods have been compared to as-built EBM surfaces and the fatigue results described.

General Rules for the Powder Bed Build Setup - A Review: ***Tan Pan***[1]; Sreekar Karnati[1]; Frank Liou[1]; [1]Missouri University of Science and Technology
Powder bed fusion (PBF) is one of the current additive manufacturing techniques that can fabricate fully dense functional metal components. Through a layer by layer fabrication methodology, complex geometries to meet the requirements of aerospace, automotive, biomedicine industries etc. can be easily produced. The success of a build largely depends on having a flawless start. Ensuring a proper setup is vital during the build planning process, which closely relates to the quality of the final products. Geometric inaccuracy, distortion, and poor surface quality can occur due to a bad build plan setup. This review presents some of the most crucial general setup rules for the powder bed build process. Rules concerning orientation selection, support structure optimization, and residual stress reduction have been surveyed and discussed. The overall objective of this work is to help setup build plans that can ensure precise dimensions and high quality among the built components.

Improving EBM Processability of Metallic Glass Using an Electrically Conductive Powder Coating: ***Zaynab Mahbooba***[1]; Lena Thorsson[2]; Peter Skoglund[2]; Ola Harrysson[1]; Mattias Unosson[2]; [1]North Carolina State University; [2]Exmet AB
Powder charging negatively affects productivity during EBM parameter development and can prevent successful EBM production of electrically resistive materials. In this work, we complete EBM parameter development on an electrically resistive Fe-based metallic glass alloy. To help reduce powder charging, the powder batch was coated with a nano-sized layer of chromium to provide a conductive path for charge dissipation; this should improve the processability of the metallic glass powder without drastically altering the chemistry or structure. We report the effect of the coating on the powder bed conductivity and the final microstructure and chemical homogeneity.

Design and Additive Manufacture of Quadcopter Drone Components: ***Ifeanyi Echeta***[1]; Emma Woods[1]; Karolina Rokita[1]; Christopher Strong[1]; Marcin Kotlarz[1]; [1]University of Nottingham
Unmanned Aerial Vehicles (UAVs) and additive manufacturing (AM) are two popular and rapidly growing areas of technology. As such, UAVs provide an interesting background to explore the possibilities of AM. Three AM process were implemented in the production of a quadcopter UAV: material extrusion, vat photopolymerisation and material jetting for the frame, propellers and landing gear respectively. Other areas of investigation included infiltrating sheet laminated paper for propeller guards, and extruding conductive paste for electronic tracks. Designs sought to improve upon components from a purchased drone kit. Part consolidation was achieved, resulting in a reduction of 8 components. Further work will include investigating means of weight reduction and utilising additional AM processes such as SLS for the frame. This project was part of the first year of training at the EPSRC Centre for Doctoral Training in additive manufacturing at the University of Nottingham, UK.

Investigating Emissivity Dependence on Surface Roughness: ***Samantha Taylor***[1]; Eric Forrest[2]; [1]University of Texas at Austin; [2]Sandia National Laboratories
Thermal monitoring of additively manufactured parts is becoming increasingly popular. The issue that arises from non-contact thermal sensing, specifically infrared imaging, is that a set of environmental parameters must be known. The most critical parameter is the emissivity of the object of interest. The difficulty in determining this parameter is its dependence on not only temperature, material, and wavelength, but also surface roughness. This study focuses on the dependence of directional emissivity on surface roughness for additively manufactured parts. Metal parts were manufactured with selective laser melting and laser engineered net shaping, generating a range of surface textures. Parts were heated to a range of temperatures and observed with a long-wave infrared (LWIR) camera to determine directional emissivity of the samples for the LWIR band-integrated response of the camera. The general tendency was that rougher surfaces had higher emissivity. This relationship is key to reduce errors in thermal imaging measurements.

Low-cost Bio-printer Gantry Design and Prototyping Process Control for Future Medical Application: ***Xiao Zhang***[1]; Eric Weflen[1]; Iris V Rivero[1]; Hantang Qin[1]; [1]Iowa State University
The development of human tissue and organ engineering technique relied on the advancement of the bio-printer which can deliver a repeatable and flexible printing process. This paper provided a new approach to design bio-printer from a low-cost printer by redesigning the structure and controlling with Python program which shown an innovative ideal to further develop bio-printing technique. The dispensing system would be redesigned and the material dispensing rate and nozzle moving speed would be calibrated and programmed to provide a shorter printing time cycle and relatively accurate, repeatable printing resolution. Polymer scaffolds had a wide application in tissue engineering and one of the most popular usages was to organize cells and placed into the body or container to grow into the desired tissue. In this research, the printer fabricated the scaffold to prove the accessibility of this approach.

Mechanical Challenges of 3d Printing Ceramics Using Digital Light Processing: ***Matthew Roach***[1]; David Keicher[1]; Erin Maines[1]; B. Wall[1]; C. Wall[1]; Judith Lavin[1]; Shaun Whetten[1]; Lindsey Evans[1]; [1]Sandia National Laboratories
Digital light processing (DLP) 3D printing can be used for manufacturing complex structures using a variety of materials, which would be nearly impossible using traditional manufacturing methods. Recent work at Sandia National Laboratories uses DLP technology for additive manufacturing of complex alumina structures, using photocurable resins loaded with micron or submicron alumina particles. These resins are printed using a DLP 3D printer to produce a "green part." The work presented here will discuss the mechanical challenges associated with printing alumina using commercially available DLP and stereolithography 3D printers, including the design of a custom DLP 3D printer to address identified mechanical challenges, thereby leading to improved print versatility and quality.

Mitigation of Hypervelocity Impact Damage in Additively Manufactured Composites: ***Lauren Poole***[1]; Matthew French[1]; William Yarberry[1]; Zachary Cordero[1]; [1]Rice University
Additive manufacturing offers a new approach for creating high-performance shielding elements with spatial gradients in composition and structure that help mitigate impact damage. In this research, we used hypervelocity impact testing to compare the impact response of additively manufactured A356/316L interpenetrating composites with those of monolithic metals and lamellar composites. We experimentally determine that our additively manufactured composites offer superior spall resistance, have lower areal densities, and are more spatially efficient when compared to monolithic metals and traditionally processed composites. We then show using hydrocode simulations that this improved shielding performance results from attenuation of the shock front due to internal reflections at the heterophase interfaces.

Modeling Strategies and Optimization of Additive-manufactured Structural Elements: ***Flynn Murray***; Michael Berry[1]; Cecily Ryan[1]; [1]Montana State University
Recent advances in additive manufacturing (AM) have opened the door to creating optimized structural elements that minimize the quantity of material used in these elements while maximizing performance. Further, AM allows for the use of environmentally-friendly materials in these elements. This research was focused on using topology optimization to optimize structural elements under specific loading conditions, using a variety of materials including bio-based polymers with natural fibers. The models used in this optimization incorporated constitutive models that accounted for the anisotropic material behavior inherent in AM. These elements were then constructed using fused deposition modeling under various build orientations with designated layer properties, and then tested to failure under the specified loading conditions. The behavior of these specimens was then compared to the predicted behavior to determine the efficacy of the modeling/optimization strategies. This research demonstrated the potential of using AM to optimize structural members made of bio-based polymers.

Active Learning for Engineering Students at the Wind Lab 3D Printing Initiative: ***Alejandra Flores Sifuentes***[1]; Clara Novoa[1]; [1]Texas State University
A pilot study using data in a case study methodology demonstrates a successful start to understanding the impact of 3D maker tools and space for engineering students. The students in this study completed five collaborative student projects that have been used for cybersecurity, aerospace, robotics and oil industry applications. The initial participants in this initiative have been sophomore, junior, and senior engineering students. Future plans are to include more underclassmen through one-day summer orientations and VizStars training. Data will be collected in the future on students' perceptions about the effect of design activities on their career motivation. These activities introduced students in their careers to concepts in design and to the types of challenges that define the field of engineering.

NASA EPDC Additive Manufacturing Badge Development: ***Riley Horner***[1]; Alec Chamberlian[1]; Olaoluwa Aina[1]; Bahram Asiabanpour[1]; [1]Texas State University
The NASA STEM Educator Professional Development Collaborative (NASA-EDPC) digital badge programs facilitates students and teachers with innovative methods and models to quickly gain new skills. NASA describes digital badging as an online professional development process for certifying learning. It allows selection from a wide variety of STEM topics, engage in exciting learning opportunities, and demonstrate mastery of the topic. This method is being applied to create a certification badge for Additive Manufacturing fundamental skills for High School teachers and Undergraduate students with no prior knowledge of the field. Additive Manufacturing is a broad STEM discipline; by introducing and demonstrating the skills needed basic concepts can be easily portrayed and assessed through a 3-hour online course. This badge utilizes Next Generation Science Standard (NGSS) lesson plans within a Biological Sciences Curriculum Study (BSCS) 5E framework. This structure summarizes large amounts of information into easily understood and applicable concepts using interactive lessons.

NASA Sounding Rocket Additive Manufacturing Payload: ***Jarett Tigges***[1]; Nicholas Leathe[1]; Shaun Whetten[1]; David Keicher[1]; Seethambal Mani[1]; [1]Sandia National Laboratories
In the early morning of March 25th, 2018, a Terrier-Improved Malemute sounding rocket launched off the coast of Virginia carrying a handful of experiments. One of those payloads contained a set of additively manufactured samples designed to fail in the launch environment. These samples were fabricated at Sandia National Laboratories using direct energy deposition with final machining to achieve tight tolerances in critical regions. Prior to launch, the specimens were inspected with a CT scanner to identify possible defects in the critical region. After launch, the payload was recovered and the specimens were analyzed to determine the effect defects had on part performance.

Quantifying the Effects of Varied Laser Scan Velocity on Part Quality in Selective Laser Melting Process: ***Matthew White***[1]; Harvey West[1]; Ola Harrysson[1]; [1]Center for Additive Manufacturing and Logistics at NC State University
Additively manufactured part qualities are highly dependent on machine parameters. The velocity at which the laser raster scans across the powder layer is an influential parameter in the selective laser melting (SLM) process. Laser speed not only influences physical properties, but some materials are further influenced on a compositional level as well. A preliminary study has been conducted utilizing Ti-6Al-4V to develop a comprehensive understanding of impacts of the laser speed parameter. The objective of this study is to quantify the effects of the varied laser scan velocities under constant laser power and develop a mathematical regression of part properties versus the laser speed. To do this, density measurements were obtained through pyncometry, porosity was analyzed through optical microscopy and scanning electron microscopy (SEM), and compositional change maps were made from energy dispersive X-ray spectroscopy (EDS) to observe compositional changes throughout the part surfaces.

Simulation of the Thermal Behavior and Analysis of Solidification Process during Selective Laser Melting of Alumina: ***Kai Zhang***[1]; Tingting Liu[1]; Wenhe Liao[1]; Changdong Zhang[1]; Yi Zheng[1]; Huang Shao[1]; [1]Nanjing University of Science and Technology
Selective laser melting (SLM) has rapidly developed in the past decade. High precision-complex ceramics parts can be directly fabricated using this technology. To study the thermal behavior of molten pools in the selective laser melting of alumina, we established a three-dimensional model based on ANSYS. Then, combined with simulation results, the physical phenomena during the rapid solidification process were discussed. The simulation results showed that the laser power and scanning speed exerts a marked influence on the maximum temperature, liquid lifetime, dimensions, and temperature gradient of the molten pool. Owing to the different temperature gradients in the molten pool, the thermal capillary force on the free surface varies. As a result, a slight difference exists between the stripy solidification structures. Different orientations of columnar crystals can be obtained. The underlying mechanism controls the direction of the temperature gradient with suitable processing routes, such as decreasing the scanning speed.

Tactile Sensor for Shear and Pressure Sensing Manufactured through Additive Manufacturing of Silicone Elastomer: ***Ketut Putra***[1]; [1]University of Michigan
Shear and pressure on prosthetic and orthotic devices are some of the main contributors to tissue breakdown for patients. In this study, we report a novel tactile sensor manufactured through an additive manufacturing (AM) process that was intended for measuring shear and pressure applied to prosthetic and orthotic devices. The design of the sensor consisted of a receptor, a sensor body, and two liquid metal filled channels. The channels for the liquid metal were made possible through a novel AM process of silicone elastomer. The manufacturing parameters of the progressive cavity pump system enabled geometrical accuracy up to 200 microns. The sensor was able to decouple a given force into normal and shear forces due to the distinct deformation of the two channels. The calibrated sensor could measure normal pressure up to 437.5 kPa and shear pressure up to 75 kPa with root mean square error below 1%.

Development of a Customized CPAP Mask using Reverse Engineering and Additive Manufacturing: ***Zhichao Ma***[1]; Javier Munguia[1]; Philip Hyde[1]; Michael Drinnan[1]; [1]Newcastle University
Continuous Positive Airway Pressure (CPAP) therapy has been commonly used to treat Obstructive Sleep Apnoea (OSA) syndrome. Unfortunately, conventional CPAP masks induced side effects, such as interface non-adherence, non-intentional air leaks, facial skin damages, have considerably affected the overall effectiveness of CPAP therapy. Take the individual characteristics of patients, including face topology, skin sensitivity, severity of OSA syndrome, breath and sleep pattern, and personal preference, into consideration to minimise the mask interface related side effects by creating a methodology that produces bespoke masks for every patient. Reverse engineering and 3D scanning technology were performed to acquire 3D facial datasets. Finite Element Analysis (ANSYS) approach was applied to study the interaction at mask/face interface by simulating the actual environment of CPAP treatment. Customized mask was designed and will further be fabricated using Additive Manufacturing.

Using Additive Manufacturing in the Development and Manufacture of a Fixed Wing Drone: Maria CrespoCuadrado[1]; George Hall[1]; Simon Mitchell[1]; ***William Reynolds***[1]; Kieran Smith[1]; [1]University of Nottingham
additive Manufacturing (am) has demonstrated to allow more freedom when designing components with more optimised structures with lower design to manufacture times. as part of the epsrc centre for doctoral training in additive manufacturing, we have explored the possibilities that come from combining am technologies in the development of a fixed wing drone. the implementation of structural optimisation within the aircraft frame has highlighted some of the biggest advantages within am, i.e., reducing the number of parts, reducing weight and enhancing the drone performance. the incorporation of an am motor will also be presented as one of the major improvements, that can tailor power to the needs of the specific aircraft. in this poster, we will explore the possibilities of incorporating conductive tracks and light novel graphene oxide batteries, looking at the challenges associated with prospective new materials and printers.

Utilising Additive Manufacturing Techniques for the Design and Manufacture of an Airship: Alice Brettle[1]; ***Richard Finch***[1]; Alexander Sieberath[1]; George Gayton[1]; Dan Burton[1]; [1]Advanced Manufacture Building
Additive Manufacturing is a broad term used to describe a process that builds a part by selectively adding material layer-by-layer. It has numerous advantages over conventional manufacturing methods (for example lathing and casting) as it can produce complex geometries and allows for customisation and bespoke designs. Using AM allowed for the design of components that would otherwise be costly and time consuming to make, particularly when designing a fuel cell where complex geometries are necessary. Manufacturing this complex design was achieved easily and accurately using an SLA printer. The limitations of AM will also be explored, and the realities of using AM techniques versus conventional methods will be discussed. This project was part of the first year of training at the EPSRC Centre for Doctoral Training in additive manufacturing at the University of Nottingham, UK.

Weakly Coupled Thermomechanical Topology Optimization and Large-scale Polymer Deposition: ***Jackson Ramsey***[1]; [1]Baylor University
Topology optimization can determine the material distribution that optimizes the stiffness of parts under mechanical loading. The structures generated are difficult to create but can be made with additive manufacturing techniques like large-scale polymer deposition. However, large-scale polymer deposition introduces thermal loading, which creates stresses in the part, as well as anisotropic material properties. A topology optimization algorithm was created to model these conditions. The optimality criterion-based algorithm was created to optimize the stiffness of a two-dimensional design space over both material density and direction. The steady-state thermal problem was solved to give a temperature field, which was used to generate thermal stresses that were included in the mechanical optimization. This weakly coupled thermal analysis and material direction optimization reflects the anisotropic Young's modulus and thermal stresses present in large-scale polymer deposition. The algorithm optimizes stiffness more accurately than standard topology optimization programs.

Laser-Aided Additive Manufacturing of Glass: ***Caroline Ketterer***[1]; Edward Kinzel[1]; Douglas Bristow[1]; Robert Landers[1]; [1]Missouri University of Science and Technology
A CO2 laser can be used to 3D print with various diameter glass filaments. 3D printing allows for greater design freedom than is available with other manufacturing methods. A substrate is placed on a four axis stage, which is heated to temperatures in the range of 550°C. This is to decrease the risk of cracking in the substrate due to thermal shock when the laser is in use. Windows 3D Builder, Slic3r, and MATLAB are used to generate G-code to print intricate shapes. Process parameters such as filament diameter, feeder speed, scan speed, and laser power can be adjusted to change the contact angle of printed tracks. With a contact angle of 90 degrees or less, parts with multiple layers can be printed with smooth sides.

Layer Height Measurement for In-situ Monitoring of Selective Laser Melting: ***Aleksandr Shkoruta***[1]; Sandipan Mishra[1]; [1]Rensselaer Polytechnic Institute
Typically, SLM process control has concentrated on temperature because of its influence on residual stresses, microstructure evolution, and part geometry. On the other hand, surface measurement is an additional abundant source of information that is yet to be fully explored. In this paper, use of a laser height profile measurement sensor is investigated for in-situ surface characterization of SLM. Test samples were built using different process variable (power and scan speed) settings. Analysis of these measurements shows that surface roughness was heavily influenced by the process parameters. A 2D Fourier analysis of the test surfaces clearly shows operational mode transitions. The profile spectrum along one of the axes has a consistent peak at the spatial frequency that does not correlate to either hatch distance or other pre-set process parameters. This peak in the observed spectrum might indicate the melt pool size, which will be corroborated by optical imaging post build.

Path Planning for Glass Laser Additive Manufacturing: ***Andrew Moore***[1]; Douglas Bristow[1]; Edward Kinzel[1]; Robert Landers[1]; [1]Missouri University of Science and Technology
To print a 3D model, a slicing program is used to convert the model's STL file into g-code. Almost all slicer programs are made for plastic printers and the g-code is specific to those types of printers. In order to obtain code that can be used on the glass printer, the g-code from the slicer must be converted. A matlab program is used to parse the code for all the points that need to be printed and a new g-code file is created with the proper format for the glass printer. The matlab program also searches for discontinuous sections in the part geometry where a plastic printer would stop printing. At these spots, a disconnect is added to separate the feed from the printed part and a reconnect is added if the print is to continue at another point. During disconnecting, a neck can form on the end of the feed, which can be problematic for reconnecting. A study was done to find the effects of certain printing parameters on the length of the neck in order to achieve the shortest possible neck.

Research on 3D Scanning for Remanufacturing Automation Using Additive Manufacturing: ***Brenna Scott***[1]; Xinchang Zhang[2]; Wenyuan Cui[2]; Frank Liou[2]; [1]Lincoln University of Missouri; [2]Missouri University of Science and Technology
Completely replacing damaged parts can be expensive. With the available technology it is becoming possible to compare 3D scans of damaged parts to their CAD files and repair the parts by using additive manufacturing to deposit material on a damaged part so that part can be repaired and reused. Two challenges that have prevented this solution being implemented are how to create quality scans of metal parts and how to automate the repair process.Quality scans can easily be made of objects that have diffuse reflection but it is still difficult to create quality scans of objects that have specular reflection, such as metal objects. An existing solution to this problem is covering reflective parts with a powder coating. However this increases the time and money spent preparing the part for scanning and removing the powder afterwards, as well as reducing the scan quality if improperly applied.There is no existing automated repair process. There are a few 3D scanners that are marketed as being automated, but the entire repair process needs automation, from the scanning, to aligning the scan with the model of the original part, to finding the missing volume of the part, to generating a tool path, and making the repairs using additive manufacturing.

Additive Manufacturing of Metal Bandpass Filters for Future Radar Applications: ***Bradley Grothaus***[1]; Austin Sutton[1]; Ming Leu[1]; Ben Brown[2]; [1]Missouri University of Science and Technology; [2]Missouri University of Science and Technology; Department of Energy's Kansas City National Security Campus Managed by Honeywell FM&T

Selective laser melting (SLM) is a powder-bed fusion based additive manufacturing process that bonds successive layers of powder with a laser to create components directly from computer-aided design (CAD) files. The additive nature of the SLM process in addition to the use of fine powders facilitates the construction of complex geometries with good resolution, which has captured the attention of those involved in the design of bandpass filters for radar applications. However, a significant drawback of SLM is its difficulty in fabricating parts with overhangs necessitating the use of support structures, which, if not removed, can greatly impact the performance of bandpass filters. Therefore, in this study bandpass filters are manufactured in two stages with 304L stainless steel where each builds only a portion of the part to improve the reliability in manufacturing the overhangs present. The results show that the versatility of SLM can produce difficult-to-manufacture bandpass filters with high dimensional accuracy. This work was funded by Honeywell Federal Manufacturing & Technologies under Contract No. DE-NA0002839 with the U.S. Department of Energy.

Fiber-Fed Glass Additive Manufacturing: ***Jason Johnson***[1]; Edward Kinzel[1]; Robert Landers[1]; Douglas Bristow[1]; [1]Missouri University of Science and Technology

Glass has properties that make it an essential engineering material. These include transparency, chemical resistance, hardness, and low temperature sensitivity. From containers to displays to architectural applications, glasses' uses are pervasive. While artisans can realize complex geometries, mass manufactured goods are constrained by tooling abilities. Additive Manufacturing (AM) expands the design space for glass. However, 3D printing transparent glass poses significant challenges due to its thermophysical properties. This poster presents a process for depositing arbitrary 3D structures using a laser-heated additive manufacturing process. Optical fiber, supported by a hypodermic tube, is fed into the intersection of a CO2 laser and the workpiece. The laser locally heats the glass depositing it onto a translating workpiece, controlled by a four-axis CNC stage. The wide-range of abilities and difficulties unique to this process are discussed and displayed.

Effects of Thermal Camera Spatial and Temporal Resolution on Feature Extraction in Selective Laser Melting: ***Xin Wang***[1]; Douglas Bristow[1]; Robert Landers; [1]Missouri University of Science and Technology

Selective Laser Melting (SLM) is a common additive manufacturing process which uses a laser energy source to fuse metal powder layer by layer. A common measurement tool for measuring the thermal history is a thermal camera that records the thermal emission of the part's surface. The temperature history in the melt region in an SLM process is characterized by high temporal and spatial gradients. This study investigates the effects of sampling frequency and spatial resolution of thermal cameras when monitoring the temperature in SLM processes. High fidelity simulation data for a single track in an SLM process is used to quantify the effects of the camera's spatial and temporal resolution. Next, the effect these resolutions have on feature extraction, namely peak temperature and melt pool morphology, is investigated by applying feature extraction methodologies to the down sampled simulation data. Finally, the feature extraction methodologies are applied to experimental data.

3D Bioprinting with Alginate Hydrogel and Polymer Bioactive Glass Composite: ***Krishna Kolan***[1]; Sonya Roberts[1]; August Bindbeutel[1]; Michael Khayat[1]; Julie Semon[1]; Delbert Day; Ming Leu; [1]Missouri University of Science and Technology

Bioactive glasses have recently gained attention in tissue engineering and 3D bioprinting because of their osteogenic and angiogenic properties. The glasses doped with trace elements elicit desirable responses from different cell types for different tissues. In this study, scaffolds are 3D printed with polymer/bioactive glass composites using different combinations of silicate-based 45S5 glass, borate-based 13-93B3 bioactive glass, and two biocompatible polymers, polycaprolactone (PCL) and polylactic acid (PLA). Alginate hydrogel is used to encapsulate human mesenchymal stem cells (MSCs), and bioink filaments are printed between the polymer composite filaments to fabricate cellularized scaffolds. Scaffolds are fabricated with ~300µm filament width and pores with varying glass content (25% to 75% in weight) in the composite. The scaffold's mechanical properties are measured with the addition of glass and hydrogel, and its weight loss and bioactivity are investigated over a period of 28 days. The results indicated increased scaffold stiffness (200%) with addition of glass (50 wt.%) and a faster glass dissolution from PLA in comparison to PCL. The viability and proliferation of MSCs are compared when printed with different material combinations. This study demonstrates a high potential to create a highly bioactive and tailored 3D environment for complex and dynamic interactions that govern the cell's behavior in vitro and in vivo.

Application of SWIR Camera in the Monitoring and Control of Overhang Quality in Selective Laser Melting: ***Olaseni Adeniji***[1]; Cody Lough[2]; Xin Wang[2]; Edward Kinzel[2]; Douglas Bristow; Robert Landers; [1]University of the District of Columbia; [2]Missouri University of Science and Technology

Selective Laser Melting (SLM) is an Additive Manufacturing (AM) process where parts are made directly from 3D models and printed layer-by-layer from different powder material fused by a laser. The continuous progression in SLM has allowed for increased flexibility and complexity of parts to be manufactured for various industries. However, limiting factors in SLM, including the occurrence of overhang geometries, lead to poor surface quality finishes of different parts and potential failure during manufacturing. This poster details the application of a shortwave infrared camera to record thermal data during a build of overhang geometries with a Renishaw AM250. This is done to understand the evolving thermal history of overhang parts and attempt to correct failures by using features from the thermal data as feedback in layer-to-layer control. The resulting part produced with layer-to-layer control is compared to parts manufactured with open loop and no control by analyzing microstructure and microhardness in the part cross-section.

Corrosion Behavior of Selective Laser Melted 304L Stainless Steel: ***Michael Anderson***[1]; Lianghua Xiong[1]; Lianyi Chen[1]; [1]Missouri University of Science and Technology

Selective laser melting process has gained much interest from both the scientific and industry communities because it prints 3D components with complex and customized geometries from computer aided design models. However, the microstructure of the metals made by selective laser melting are different from those made by conventional ways, which may result in different corrosion behavior. This research aims to reveal the corrosion behavior of 304L stainless steel made by selective laser melting and correlate the corrosion behavior with microstructure. The corrosion behavior was characterized via electrochemical measurements, including open circuit potential, potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) tests. The microstructure was investigated by optical and scanning electron microscopy techniques. The correlation between corrosion behavior and microstructure features is discussed.

Additive Manufacturing of Electrical Conductors: ***Juvani Downer***[1]; Heng Pan[1]; I-Meng Chen[1]; [1]Missouri University of Science and Technology

Aerosol Jet printing is an additive manufacturing technique that enables deposition of a variety of materials onto both 2D and 3D substrates. This research study focuses on the understanding of aerosol printing of copper nanoparticles (ink), and the photonic sintering of these nanoparticles for the fabrication of an electrical conductor onto a 2D substrate (planar). The copper ink particles are usually stored in a gas chamber connected to the aerosol printer but can only be deposited onto a substrate via a nozzle connected to the end of the printer. This study will determine a copper particle aerosol printing design (electrical conductors) that when sintered will produce relative conductivity to that of bulk copper. Photonic sintering parameters such as pattern length, sintering distance and voltage are investigated. Our research will seek to determine the relationships between aerosol jet printing of copper electrical conductors onto planar surfaces to determine if the samples generated would be good in the potential manufacturing of conductors. The work could be considered as the elements of the printed electronics. The data gathered thus far seems promising as it shows a comparable linear relationship between the small and large-scale electrical conductors as it relates to conductivity when the pattern length parameter was investigated.

Additive Manufacturing of Stainless Steel Nanocomposites: ***Javel Wilson***[1]; Minglei Qu[1]; Lianyi Chen[1]; [1]Missouri University of Science and Technology

Metal matrix nanocomposites (MMNCs) with uniform distribution of nanoscale ceramic particles can show dramatically improved mechanical properties as compared to the matrix materials. However, when the size of the nanoparticles is small and the volume fraction of nanoparticles is high, it is very difficult to disperse them uniformly in the metal matrices. Here we report the fabrication of stainless steel based nanocomposites with uniform dispersion ceramic nanoparticles by high energy ball milling and selective laser melting (SLM). The stainless steel matrix nanocomposites with uniformly dispersed nanoparticles exhibit significantly enhanced mechanical properties. Our research provides a promising approach to manufacture MMNCs with uniform dispersion of nanoparticles by additive manufacturing process.

Investigation into Mechanical Property Variation in Overhang Geometries Manufactured by Selective Laser Melting: ***Christopher Smith***[1]; Cody Lough[1]; Xin Wang[1]; Edward Kinzel[1]; Douglas Bristow; Robert Landers; [1]Missouri University of Science and Technology

Selective Laser Melting (SLM) additive manufacturing (AM) can be used to create parts with geometries difficult to produce with traditional machining. However, certain geometries, including overhangs, must have support material to increase heat transfer away from the melt pool and ensure parts are manufactured correctly. This creates the disadvantage of adding post processing operations to remove the supports from the part. Manufacturing parts without supports eliminates post processing but can result in greater differences in cooling rates at overhangs since they are freely supported by powder. These uneven cooling rates result in variance in the mechanical properties across parts. In this poster the differences in mechanical properties are mapped across overhang geometries using the Vickers Microhardness test. The correlation between the thermal history and hardness of the parts is determined. Methods to create uniform properties within an overhang sample are evaluated by microhardness mapping. This research is aimed at finding a way to control the physical properties, regardless of geometry, by adjusting process parameters to result in uniform properties or purposeful changes in properties to exist within printed parts.

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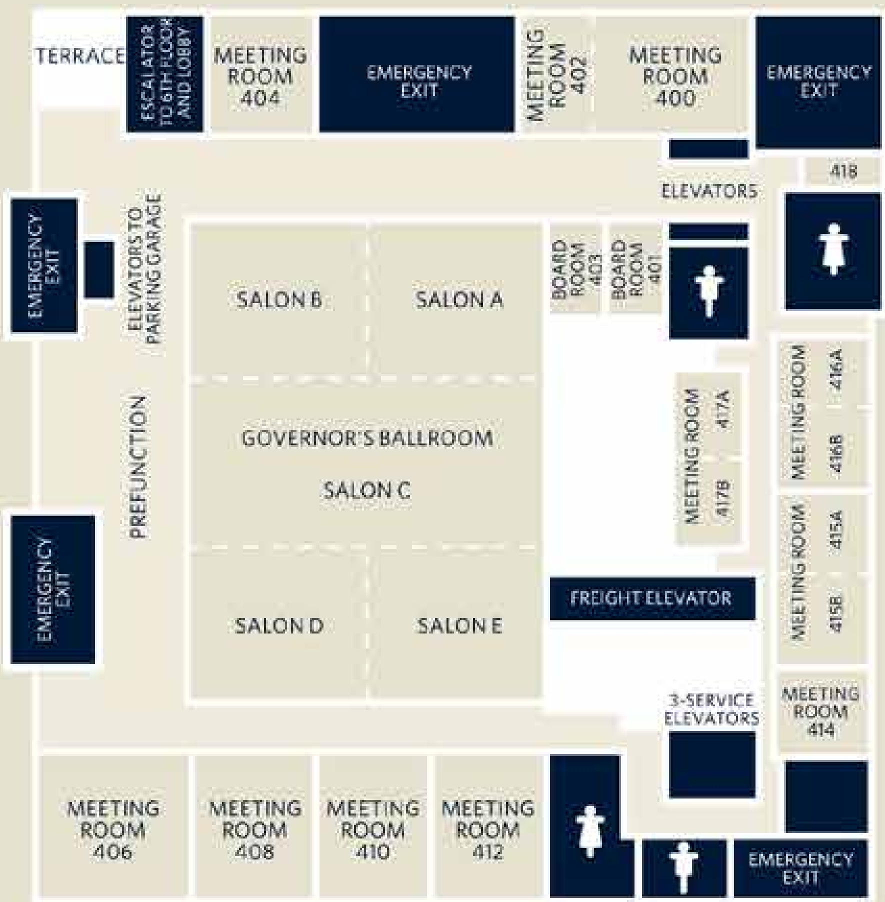

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