THE 33RD ANNUAL INTERNATIONAL

SOLID FREEFORM FABRICATION SYMPOSIUM 2022

– AN ADDITIVE MANUFACTURING CONFERENCE –

July 25-27, 2022
Hilton Austin Hotel
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:

NSF

Office of Naval Research
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sffsymposium.org

SCHEDULE AT-A-GLANCE

Sunday, July 24	Time	Location
Registration	1:00 p.m. - 6:30 p.m.	Grand Ballroom Foyer
Welcome Reception	5:30 p.m. - 6:30 p.m.	Grand Ballroom Foyer
Monday, July 25	**Time**	**Location**
Registration	7:00 a.m. - 5:00 p.m.	Grand Ballroom Foyer
Opening Remarks	8:00 a.m. - 8:15 a.m.	Salon HJK
Plenary Session and FAME Award Presentations	8:15 a.m. - 12:15 p.m.	Salon HJK
- Break	10:45 a.m. - 11:15 a.m.	Grand Ballroom Foyer
Lunch	12:15 p.m. - 1:30 p.m.	On Your Own
Panel Discussion: Emerging Women Leaders	12:45 p.m. - 1:30 p.m.	Salon G
Technical Sessions	1:30 p.m. - 5:20 p.m.	*See Technical Program*
- Break	3:10 p.m. - 3:40 p.m.	Grand Ballroom Foyer
Pre-Awards Program Reception	6:00 p.m. - 6:30 p.m.	Grand Ballroom Foyer
11th Annual Awards Program & Banquet	6:30 p.m. - 9:00 p.m.	Salon HJK
Tuesday, July 26	**Time**	**Location**
Registration	7:00 a.m. - 5:00 p.m.	Grand Ballroom Foyer
Technical Sessions	8:00 a.m. - 12:10 p.m.	*See Technical Program*
- Break	10:00 a.m. - 10:30 a.m.	Grand Ballroom Foyer
Student Attendee Lunch and Panel Discussion	12:10 p.m. - 1:40 p.m.	Salon F-G
General Attendee Lunch	12:10 p.m. - 1:40 p.m.	Salon H
Technical Sessions	1:40 p.m. - 4:00 p.m.	*See Technical Program*
Industrial Needs for AM Research and Development	1:40 p.m. - 4:00 p.m.	Room 408
Poster Session with Refreshments	4:00 p.m. - 5:30 p.m.	Salon JK
FAME Award Winners Reception (by invitation only)	5:00 p.m. - 6:30 p.m.	The Reverbery (Lobby Level)
Wednesday, July 27	**Time**	**Location**
Registration	7:00 a.m. - 5:00 p.m.	Grand Ballroom Foyer
Luggage Storage	7:00 a.m. - 5:00 p.m.	Salon G
Technical Sessions	8:00 a.m. - 11:50 a.m.	*See Technical Program*
Design for Additive Manufacturing Workshop	8:00 a.m. - 11:50 a.m.	Room 410
- Break	9:40 a.m. - 10:10 a.m.	Grand Ballroom Foyer
Lunch	11:50 a.m. - 1:10 p.m.	On Your Own
Technical Sessions	1:10 p.m. - 5:00 p.m.	*See Technical Program*
- Break	2:50 p.m. - 3:20 p.m.	Grand Ballroom Foyer

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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
- Access to a PDF eBook of the post-conference proceedings (available in November 2022)

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, July 24: 1:00 p.m. to 6:30 p.m.
- Monday, July 25: 7:00 a.m. to 5:00 p.m.
- Tuesday, July 26: 7:00 a.m. to 5:00 p.m.
- Wednesday, July 27: 7:00 a.m. to 5:00 p.m.

Technical Sessions

All technical and poster presentations will be located at the Hilton Austin. See the Technical Program on pages 14-109 for locations.

Luggage Storage

Luggage storage will be available at no cost to attendees on Wednesday, July 27, from 7:00 a.m. to 5:00 p.m. in Salon G. 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 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 and valet parking are both available at the hotel at guests' expense. Visit the Hilton Austin website for more details.

NETWORKING AND SOCIAL EVENTS

All networking and social events will be held at the Hilton Austin.

Pre-Conference Welcome Event

Sunday, July 24 · 5:30 p.m. to 6:30 p.m.
Hilton Sixth Floor Grand Ballroom Foyer
An informal pre-conference social event is scheduled for Sunday evening. The cost is included in the full registration fee for professionals and students. The purpose is to provide a venue where attendees can renew old friendships and meet new people prior to the start of technical sessions. Beverages and light refreshments will be served.

Photos from the Solid Freeform Fabrication 2019 event:

Awards Banquet

Monday · Salon HJK
6:00 p.m. Reception
6:30 p.m. Welcome Remarks
6:40 p.m. Dinner and Wine Service
7:45 p.m. The FAME Awards

- International Outstanding Young Researcher in Freeform and Additive Manufacturing Award: Filomeno Martina, CEO of WAAM3D Ltd and Visiting Lecturer at Cranfield University
- International Freeform and Additive Manufacturing Excellence Award: Behrokh Khoshnevis, University of Southern California

9:00 p.m. Event Concludes

Conference Lunch Event

General Attendee Lunch
Tuesday, 12:10 p.m. to 1:40 p.m. · Salon H
An informal networking lunch will be provided near the meeting rooms in Salon H at the Hilton Austin at the lunch break on Tuesday. The cost is included in the conference registration fee.

Student Lunch and Panel Discussion

Tuesday, 12:10 p.m. to 1:40 p.m. · Salon G
Lunch is provided for all attendees on Tuesday, July 26. Cost is included in the registration fee.

A special program and panel will be held during the Tuesday lunch period for students. The theme is: "**How to Be Prepared for Careers in Additive Manufacturing (AM) - A Panel Discussion with AM Experts Across Application Domains**". Professor Guha Manogharan from Penn State University will moderate the panel. See page 5 for details on these four panelists that represent various career paths and stages.

Sneha Narra

Sneha Narra received a master's degree in computational mechanics, and a master's and doctorate in mechanical engineering from Carnegie Mellon University (CMU). After receiving her doctorate, she worked as a postdoctoral research associate at the Next Manufacturing Center at CMU. She then served as an assistant professor in the materials and manufacturing program at Worcester Polytechnic Institute, before joining CMU as an assistant professor in the fall of 2021. Narra's additive manufacturing process design research lies at the intersection of process modeling including numerical, analytical, and semi-analytical methods, processing experiments, materials characterization, and data-driven analysis.

Maryna Lenina

Maryna Lenina is an AM Academy product and partnership manager. She joined EOS in summer 2016 as an applications engineer for metal AM, then transitioned to digitalization topics and currently supports development and delivery of training content. She believes that education plays a key role in implementing emerging technologies, including industrial 3D printing, and successfully transforming organizations.

Lenina earned her master's degrees in mechanical engineering from Texas A&M University, Korea Institute of Science and Technology (KIST), and the National Technical University of Ukraine Polytechnic Institute. At KIST she did research about the flexible floating ring seal that is used to reduce air leakage and increase compressor efficiency. Now together with EOS Additive Minds, she shares her expertise in facilitating innovation with industrial 3D printing. Lenina works on the development and delivery of Additive Manufacturing programs and products for professional development.

Nicholas Bass

Nicholas (Nick) Bass is the lead AM engineer at an AM service bureau. He holds a master's degree in additive manufacturing and design from Penn State. At Cumberland Additive, Bass supports manufacturing projects with powder bed fusion in rigorous industries like aerospace, defense, and energy. His focus is on the industrialization of AM technologies for the manufacture of end-use parts. Prior to Cumberland, Bass worked held roles at Arconic, Flex, and Lockheed Martin Space. Bass brings high tech, high volume, diverse industrial experience to advance AM applications and streamline the AM factory.

Chelsea Cummings

Chelsea Cummings is an AM consultant from The Barnes Global Advisers, contributing to a variety of projects mainly supporting design for the process and advising customers on digital tools available to support their AM strategy. She began her engineering career at Honeywell Aerospace, gaining experience in various roles, including AM. Her AM experience focused on developing metal parts built on powder bed machines for aerospace applications. Her experience qualifying production parts for AM with the FAA at Honeywell led her to a role in new product engineering at Arconic (formerly Alcoa) where she successfully qualified additively manufactured parts for aerospace production for a major aircraft manufacturer. Her work with various manufacturers for flight and space has honed her AM design skills for diverse applications. Lean certified by her alma mater, Arizona State University, and Honeywell, she cultivates streamlined AM designs, production, and applications.

DINING OPTIONS

VISIT Austin CONVENTION CENTER DISTRICT RESTAURANT GUIDE

MAP	RESTAURANT	ADDRESS	PHONE	WEBSITE	CUISINE
F14	III Forks D $$$ ♿	111 Lavaca St.	474-1776	3forks.com	Steakhouse
H10	1886 Bakery & Cafe, Driskill Hotel B L D $$ ♪ ♿	604 Brazos St.	391-7066	1886cafeandbakery.com	Bakery
N16	Anthem L D $$ ♿	91 Rainey St. #120	731-1411	eatdrinkanthem.com	Latin & Asian
H15	Arlo Grey, The LINE B D $$ ♿	111 E. Cesar Chavez St.	478-2991	thelinehotel.com/arlogrey	American
E13	ATX Cocina L D $$ ♿	110 San Antonio St. #170	263-2322	atxcocina.com	Mexican
L12	Austin Taco Project, Hilton TC	500 E. Fourth St.	682-2739	austintacoproject.com	New Texan
J11	The Backspace L D $$	507 San Jacinto Blvd.	474-9899	thebackspace-austin.com	Italian
N17	Banger's Sausage House & Beer Garden B L D $$ ♪ ♿	79 Rainey St.	386-1656	bangersaustin.com	American
F13	Bar Chi L D LN $$	206 Colorado St.	382-5557	barchisushiaustin.com	Sushi
F13	Bob's Steak and Chop D $$$	301 Lavaca St.	222-2627	bobs-steakandchop.com	Steakhouse
H13	Burger Bar, JW Marriott L D $ ♿	110 E. Second St.	608-4822	burgerbaraustin.com	Burgers
H11	Cabana Bar, Hotel ZaZa	400 Lavaca St.	880-3244	hotelzaza.com/austin	American
J13	Cafe Blue L D $$ ♿	340 E. Second St.	428-5796	cafebluetx.com	Seafood
L12	Cannon and Belle, Hilton D $$	500 E. Fourth St.	493-4900	cannonandbelle.com	American
G12	The Capital Grille L D $$$ ♿	117 W. Fourth St.	322-2005	thecapitalgrille.com	Steakhouse
H10	Caroline, Aloft B L D $$ ♪ ♿	621 Congress Ave.	982-6766	carolinerestaurant.com	American
H11	CAVA L D $$ ♿	515 Congress Ave.	256-8002	cava.com	Mediterranean
I13	Cedar Door B L D LN $ ♪ ♿	201 Brazos St.	473-3712	cedardooraustin.com	American
J11	Champions Sports Bar TC	300 E. Fourth St.	473-0450	hotelaustindowntown.com	American
K10	Chez Nous TC	510 Neches St.	473-2413	cheznousaustin.com	French
H7	Chi'Lantro TC	823 Congress Ave	593-6290	chilantrobbq.com	Korean BBQ
F12	Chispa's L D LN $ ♿	214 W. 4th St.	551-2554	chispasaustin.com	Mexican
I15	Ciclo, Four Seasons B L D LN $$ ♿	98 San Jacinto Blvd.	685-8300	cicloatx.com	Steakhouse
G11	Comedor	501 Colorado St	499-0977	comedortx.com	Mexican
H13	Cooper's Old Time Pit Bar-B-Que L D LN $$ ♪ ♿	217 Congress Ave.	474-4227	coopersbbqaustin.com	Barbeque
J14	Corinne, Marriott Downtown	304 E Cesar Chavez St.	787-7018	corinneatx.com	American
H13	Corner, JW Marriott L D $$$ ♿	110 E. Second St.	608-4488	cornerrestaurantaustin.com	New Texan
F13	CRÚ - A Wine Bar D $$ ♿	238 W. Second St. #13	472-9463	cruwinebar.com	New American
J12	Eddie V's Steakhouse D LN $$$ ♪	301 E. Fifth St.	472-1860	eddiev.com	Seafood/Steak
N17	Emmer & Rye B D $$ ♿	51 Rainey St., Ste. 110	366-5530	emmerandrye.com	New American
I10	Eureka! L D LN $$ ♿	200 E. Sixth St.	735-1144	eurekarestaurantgroup.com	American
I14	Foreground TC	111 Congress Ave.	-	fairgroundaustin.com	Assorted
C11	Fixe Austin's Southern House D $$$ ♿	500 W. Fifth St.	888-9133	austinfixe.com	New American
J13	Fleming's Prime Steakhouse D $$$ ♿	320 E. Second St.	457-1500	flemingssteakhouse.com	Steakhouse
C14	Flower Child L D $ ♿	500 W. Second St.	777-4132	iamaflowerchild.com	American
J13	Fogo de Chao L D $$$ ♿	309 E. Third St.	472-0220	fogodechao.com	South American
L13	Foxy's Proper Pub	201 Brazos St.	501-6713	foxysproperpub.com	Pub
O12	Gabriela's Austin	900 E 7th St.	840-1569	gabrielasdowntown.com	Mexican
L14	Garrison, Fairmont Hotel	101 Red River St.	600-2000	fairmont-austin.com	Assorted
M18	G'Raj Mahal D LN $$ ♿	73 Rainey St.	480-2255	grajmahalaustin.com	Indian
M16	Geraldine's, Hotel Van Zandt B L D LN $$	605 Davis St.	476-4755	geraldinesaustin.com	New American
E10	Gloria's L D $$	300 W. Sixth St.	236-1795	gloriasrestaurants.com	Mexican
C14	Goldie's, Austin Proper	600 W 2nd St.	628-1500	properhotel.com	Bar
E11	Group Therapy, Hotel ZaZa	400 Lavaca St.	542-9292	hotelzaza.com/austin	American
J14	Gus's Fried Chicken L D $	117 San Jacinto Blvd.	474-4877	gusfriedchicken.com	Chicken
J10	Iron Cactus L D LN $$	606 Trinity St.	472-9240	ironcactus.com	Mexican
L15	Iron Works L D $$ ♿	100 Red River St.	478-4855	ironworksbbq.com	Barbeque
F14	Jo's Coffee B L D $ ♪ ♿	242 W. Second St.	469-9003	joscoffee.com	Coffee House
M10	Koriente L D $	621 E. Seventh St.	275-0852	koriente.com	Asian
E14	La Condesa L D $$$	400 W. Second St.	499-0300	lacondesaaustin.com	Mexican

MAP	RESTAURANT	ADDRESS	PHONE	WEBSITE	CUISINE
G12	La Triviata L D $$ ♿	314 Congress Ave.	479-8131	latraviatatx.com	Italian
D14	Lamberts BBQ B L D LN $$ ♪	401 W. Second St.	494-1500	lambertsaustin.com	Barbeque
I14	La Café Crepe B L D $ ♿	200 San Jacinto Blvd.	480-0084	cafecrepeofaustin.com	French
C14	La Piscina, Austin Proper	600 W 2nd St.	628-1500	properhotel.com	Tex-Mex
N16	Little Brother D LN $$	89 Rainey St.	305-3133	littlebrotherbar.com	Mexican
C14	Le Politique TC	110 San Antonio St.	580-7651	lepolitiqueaustin.com	French
J14	Loaf + Vine, Marriott Downtown $	304 E Cesar Chavez	787-6969	coming soon	Coffee
F11	Lonesome Dove L D $$$ ♿	419 Colorado St.	271-2474	lonesomedoveaustin.com	New Texan
G10	Maiko Sushi Lounge L D $ ♿	311 W 6th St.	236-9888	maikoaustin.com	Sushi
I13	Mai Thai L D $$	207 San Jacinto Blvd., #201	482-8244	maithaiaustin.com	Asian
G13	Manuel's TC	310 Congress Ave.	472-7555	manuels.com	Mexican
I13	Max's Wine Dive TC	207 San Jacinto Blvd., #200	904-0111	maxswinedive.com/austin	American
J14	Michelada's L D $$ ♿	333 E. Second St.	320-0300	micheladasaustin.com	Mexican
C14	The Mockingbird, Austin Proper	600 W 2nd St.	628-1500	properhotel.com	Greek
L13	Moonshine L D $$	303 Red River St.	236-9599	moonshinegrill.com	American
D14	North Italia L D $$	500 W. Second St., #120	777-5062	northitalianrestaurant.com	Italian
D14	Numero 28 L D $$	452 W. Second St.	494-5510	numero28austin.com	Italian
H13	OP Italian Austin, JW Marriott TC	110 E. Second St.	608-4490	opitalianaustin.com	Italian
J14	P.F. Chang's China Bistro L D $$ ♿	201 San Jacinto Blvd.	457-8300	pfchangs.com	Asian
J10	Parkside D LN $$$	301 E. Sixth St.	474-9898	parkside-austin.com	American
C14	The Peacock Mediterranean Grill, Austin Proper	600 W 2nd St.	628-1500	properhotel.com	Mediterranean
F12	Péché D LN $$	208 W. Fourth St.	494-4011	pecheaustin.com	French
L8	Pelon's Tex Mex L D $$	802 Red River St.	243-7874	pelonstexmex.com	Mexican
E11	Perfect Strangers, Hotel ZaZa	400 Lavaca St.	542-9292	hotelzaza.com/austin	Coffee
G9	Perry's Steakhouse & Grille L D $$$	114 W. Seventh St.	474-6300	perryssteakhouse.com	Seafood & Steak
N16	Rainey Street Burgers	51 Rainey St. #140A	399-5710	raineystreetburgers.com	American
N16	Rainey Street Food Truck Lot	82 Rainey St.	-	-	Assorted
G12	RA Sushi L D $$ ♿	117 W. Fourth St., #300	726-2130	rasushi.com	Asian
G13	Red Ash D $$$ ♿	303 Colorado St., #200	379-2906	redashgrill.com	Italian
H9	Roaring Fork, InterContinental SFA L D $$$ ♿	701 Congress Ave.	583-0000	roaringfork.com	Southwestern
J11	Russian House L D LN $$ ♿	307 E. 5th St.	428-5442	russianhouseofaustin.com	Russian
G10	Ruth's Chris Steak House D $$$ ♿	107 W. Sixth St.	477-7884	ruthschris-austin.com	Steakhouse
J11	Stella San Jac, The Westin B L D $$ ♿	310 E. Fifth St.	792-5648	stellasanjac.com	New Texan
L8	Stubb's BBQ L D LN $$ ♪ ♿	801 Red River St.	480-8341	stubbsaustin.com	Barbeque
H13	Swift's Attic L D LN $$ ♪ ♿	315 Congress Ave.	482-8842	swiftsattic.com	American
H13	Taco Deli B L D LN $	301 Congress Ave.	601-6631	tacodeli.com	Mexican
F14	Taverna Ristorante B L D $$	258 W. Second St.	477-1001	tavernabylombardi.com	Italian
D14	Torchy's Taco B L D LN $	110 San Antonio St., #120	792-5909	torchystacos.com	Mexican
E13	Trace, W Hotel L D LN $$$	200 Lavaca St.	542-3660	traceaustin.com	American
F12	Truluck's D $$$ ♿	400 Colorado St.	482-9000	trulucks.com	Seafood & Steak
F12	Turf N' Surf L D LN $$ ♿	407 Lavaca St.	276-2763	lavacastreet.com	Cajun/Creole
H10	Velvet Taco L D $	522 Congress Ave. #100	298-5223	velvettaco.com	Mexican
H15	Veracruz All Natural, LINE hotel	111 E. Cesar Chavez St.	665-2713	veracruzallnatural.com	Mexican
C10	Verbena, Canopy Hilton L D LN $$	612 W 6th St.	991-3019	verbenaatx.com	Various
J13	Vince Young Steakhouse D $$$	301 San Jacinto Blvd.	457-8325	vinceyoungsteakhouse.com	Steakhouse
D11	Wu Chow L D $$ ♿	500 W. Fifth St.	476-2469	wuchowaustin.com	Asian
J14	Zanzibar, Marriott Downtown D LN $$	304 E Cesar Chavez	787-6969	zanzibaratx.com	Island

KEY B=Breakfast L=Lunch D=Dinner LN=Late Night $=$5-14 $$=$15-25 $$$=$26+ ♪=Live Music ♿=Wheelchair Accessible TC=Temporarily Closed *Area code is 512 for all phone numbers*

CONFERENCE POLICIES AND INFORMATION

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.

Americans with Disabilities Act

The 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

The organizers of the SFF Symposium are 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

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.

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.

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.

COVID-19 Update

The SFF organizing committee, working in partnership with conference and event venues, is complying with guidance from the U.S. Centers for Disease Control and Prevention and relevant state and local authorities in an effort to provide a safe and healthy environment for attendees during the ongoing COVID-19 pandemic. However, COVID-19 is an extremely contagious disease, and it is not possible to eliminate the risk of spreading or contracting COVID-19. An inherent risk of exposure to COVID-19 exists in any public place where people are present, and efforts to mitigate the risk of exposure to COVID-19 may not be sufficient to prevent spreading or contracting COVID-19.

The events, speakers, and services listed here are current as of July 2, but changes may occur due to circumstances beyond our control. We thank you for your flexibility as we plan the best possible event for you and the materials community.

COVID Guidelines in Austin, Texas

The new risk-based guidelines set out three Community Levels of risk, from the lowest threat, low, through the most serious, high, along with recommended behaviors for each level. Regardless of vaccination status or level, individuals need to continue to follow the additional requirements of local businesses, venues and schools.

As of July 2, the Austin-Travis County COVID-19 Community Level is Medium. This means that there is moderate impact on the healthcare system and moderate levels of disease severity.

The following are Community Level-based recommendations for people who are up to date with their COVID-19 vaccines:
Low: Masking optional when gathering, dining, and shopping.

Medium: Masking optional when gathering, dining, and shopping. Mask when social distancing is not possible. *[Current Status]*

High: Indoor masking regardless of vaccination/risk status when gathering, dining, and shopping.

Recommendations for people who are at risk:
Get up to date with your vaccines as soon as possible.
Low: Masking optional when gathering, dining, and shopping.

Medium: Indoor masking when gathering, dining, and shopping. *[Current Status]*

High: Indoor masking regardless of vaccination/risk status when gathering, dining, and shopping.

At all levels wearing a well-fitting mask and practicing social distancing are supported by the Austin Public Health office as additional layers of protection to prevent the spread of COVID-19.

Even at low levels, people can wear a mask based on personal preference, informed by their level of risk. People with symptoms, a positive test, or exposure to someone with COVID-19 should wear a mask.

A BIG THANK YOU TO:

The **National Science Foundation** for providing meeting support for students

The **Office of Naval Research** for providing meeting support

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Professor Guha Manogharan from Penn State University for serving as this year's coordinator for the NSF graduate student registration fee waiver program; also, for organizing and chairing the Tuesday student lunch event.

The University of Texas at Austin Center for Additive Manufacturing and Design Innovation (CAMDI) (Jared Allison, Carolyn Seepersad) for donating the FAME trophies.

Intl SFF Symposium Organizing Committee
Dave Bourell, Chair, UT-Austin
Joe Beaman, UT-Austin
Rich Crawford, UT-Austin
Carolyn Seepersad, UT-Austin
Mehran Tehrani, UT-Austin
Desi Kovar, UT-Austin

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Neil Hopkinson, Stratasys	Chris Williams, Virginia Tech
Bradley Jared, Sandia National Labs	

Intl SFF Symposium FAME Award Selection Committee	
Chad Duty (Chair), University of Tennessee at Knoxville	
April Cooke, Seurat Technologies	Adam Clare, University of Nottingham
Nathan Crane, Brigham Young University	Joy Gockel, Colorado School of Mines

The following undergraduate and graduate students applied for and received conference registration fee waivers. Most waivers are funded by a conference participant support grant from the National Science Foundation. Four awards were funded by this year's FAME award winner, Professor Behrokh Khoshnevis, University of Southern California. Congratulations to all award winners.

Khoshnevis Student Awardees

- Elizabeth Chang-Davidson, Carnegie Mellon University
- Christina Nissen, University of Texas at Austin
- Samantha Webster, Northwestern University
- Amanda Wei, Virginia Tech

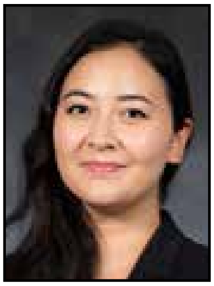
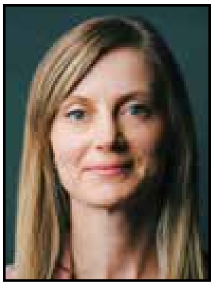
SFF Symposium Student Registration Fee Waiver Award Winners

- Marshall Allen, Texas A&M University
- Abdulmajeed Altassan, Georgia Institute of Technology
- Mohanish Andurkar, Kansas State University
- Md Shakil Arman, Texas A&M University
- Saeed Ataollahi, University of Tennessee - Chattanooga
- Maryam Avateffazeli , University of Toledo
- Aigbe E. Awenlimobor, Baylor University
- Saheed Babalola, Missouri University of Science and Technology
- Martha Baldwin, Carnegie Mellon University
- Alexander Belchou, Penn State University
- Jaime Berez, Georgia Institute of Technology
- Benjamin Bevans, University of Nebraska - Lincoln
- James Brackett, University of Tennessee - Knoxville
- Tosh Kaneala Brown-Mooew, University of Washington
- Scott Burlison, University of Texas at Austin
- Jannatul Bushra, University of Arizona
- Nicholas Capps, University of Notre Dame
- Roxana Carbonell, University of Texas at Austin
- Irving E. Ramirez Chavez, Arizona State University
- Kun-Chieh Chien, University of Texas at Austin
- Jeremy Cleeman, Rutgers University
- Caralyn Collins, Northwestern University
- Olivia Cool, Penn State University
- Christine Cummings, Penn State University
- Maia Delwiche, University of Wisconsin-Platteville
- Olivia DeNonno, Colorado School of Mines
- Gita Deonarain, Michigan Technological University
- Anannya Doris, University of Texas - El Paso
- Abdelrahman Elsayed, Texas A&M University
- Rachel Evans, Wright State University
- David P. Failla Jr., Mississippi State University
- Zipeng Guo, University of Buffalo
- Rodrigo Enriquez Gutierrez, Ohio State University
- Marwan Haddad, Texas A&M University
- Jakob Hamilton, Rochester Institute of Technology
- Connor Hammond, Texas State University
- Chuan He, University of Michigan
- Shawn Hinnebusch, University of Pittsburgh
- Nancy Huang, Penn State University
- Rafid Hussein, Kansas State University
- Shweta Hanmant Jagdale, University of Texas at Dallas
- Admas Kebede, University of Massachusetts Boston
- Philip King, Penn State University
- Pratik Koirala, University of Texas at Austin
- Naresh Koju, University of Louisville
- Satyanarayana Konala, North Carolina State University
- Nicholas Lamprinakos, Carnegie Mellon University
- Jacob Lawrence, Brigham Young University
- Gabriel Lipkowitz, Stanford University
- Siying Liu, Arizona State University
- Paula Logozzo, California State University Northridge
- MohammadBagher Mahtabi, University of South Alabama
- Nandana Menon, Penn State University
- Eduardo Miramontes, University of Tennessee - Knoxville
- Joshua Mochache, University of Texas - Arlington
- Gabriel Olaivar, University of Illinois Urbana-Champaign
- Arun Poudel, Auburn University
- Minglei Qu, University of Wisconsin-Madison
- Mithila Rajeshirke, Tennessee Technological University
- Aditya Ganesh Ram, University of Texas at Arlington
- Manoj Kumar Reddy Rangapuram, Missouri University of Science and Technology
- Byeong-Min Roh, Penn State University
- Clare Sabata, Missouri University of Science and Technology
- Matthew Schreiber, Colorado School of Mines
- Hossein Sehhat, Missouri University of Science and Technology
- Yujie Shan, Purdue University
- Scott E. Snarr, University of Texas at Austin
- Hongtao Song, University of Texas at Austin
- Subodh C Subedi, University of Wisconsin-Madison
- Chao Sui, University of Arkansas
- Tengteng Tang, Arizona State University
- Akshay Jacob Thomas, Purdue University
- Neil Thompson, Brigham Young University
- Nahid Tushar, University of Arkansas
- Justin Valenti, Penn State University
- Janely Villela, University of Texas - El Paso
- Joshua Wagner, Rice University
- Jenny Wang, Georgia Institute of Technology
- Xin Wang, Missouri University of Science and Technology
- Janith Wanni, Clarkson University
- Daniel Weber, University of Texas at Austin
- Ryan Welch, George Washington University
- Jade Welsh, University of North Florida
- Mianqing Yang, Missouri University of Science and Technology
- Jiahui Ye, Texas A&M University
- Rujing Zha, Northwestern University
- Runyu Zhang, University of Texas at Dallas
- Yue Zhang, University of Pittsburgh
- Yue Zhou, SUNY - Binghamton
- Khushbu Zope, Rochester Institute of Technology

Monday Morning Plenary (Hilton 6th floor, Salon HJK) and Noon Panel (Hilton 6th floor, Salon G)

The theme of the Monday morning plenary session is "Emerging Women Leaders in AM". Chaired by Professor Carolyn Seepersad at The University of Texas at Austin, six presentations will be made by outstanding women researchers early in their careers. You are encouraged to grab a quick lunch at the close of the session at 12:10 p.m., and then to return at 12:45 p.m. for a panel discussion dealing with issues related to becoming and being an emerging woman leader in AM. The panel will consist of the plenary session emerging women leaders. The panel moderators are Professor Seepersad and Dr. Cindy Waters from the NSWCCD-Carderock Division. The room location for the panel is Salon G, and the session will end in time for attendees to move to the afternoon parallel sessions at 1:30 p.m.

Plenary Speakers and Panelists


Pictured Left to Right:
- Sneha Prabha Narra, Carnegie Mellon University
- Sarah Wolff, Texas A&M University
- Mihaela Vlasea, University of Waterloo
- Yaoyao (Fiona) Zhao, McGill University
- Grace Gu, University of California–Berkeley
- Xiangjia L, Arizona State University

Special Session: Binder Jet AM

Organizers: C. Fred Higgs III, Rice University; Nathan Crane, Brigham Young University; and Chao Ma, Texas A&M University
- Session I - Advancements in Binder Jet AM: Monday at 1:30 p.m.
- Session II - Binder-Powder Interaction: Tuesday at 8:15 a.m.
- Session III - Part Densification and Strengthening: Tuesday at 1:40 p.m.

Special Session: Data Analytics

Organizers: Prahalada Rao, University of Nebraska-Lincoln; Brian Giera, Lawrence Livermore National Laboratory; and Subhrajit Roychowdhury, GE Global Research, Niskayuna, NY
- Session I - High-Dimensional Data Analytics: Monday at 1:30 p.m.
- Session II - Machine Learning in AM: Tuesday at 8:15 a.m.
- Session III - Sensing and Analytics: Wednesday at 8:00 a.m.

Special Session: Wire-Fed DED

Organizers: Andrzej Nycz, Oakridge National Laboratory; Sneha Narra, Carnegie Mellon University; and Bishal Silwal, Georgia Southern University
- Session I: Controls and Modeling: Monday at 1:30 p.m.
- Session II: Material Properties: Tuesday at 8:15 a.m.
- Session III - Systems and Processes: Tuesday at 1:40 p.m.

Industrial Needs for AM Research and Development

Chair: Todd Spurgeon, America Makes
Tuesday at 1:40 p.m. · Room 408
Developed in partnership with America Makes, this session will feature a cross section of diverse industrial perspectives (aerospace, oil and gas, energy, medical) to drive focus within the additive manufacturing research and development community to address needs of industry. Discussions will include not only a description of applied research opportunities but also identification of scientific and technological development opportunities to foster alignment between the needs of industry and the expertise, skills, and capabilities of the academic community.

Early-Stage Design for Additive Manufacturing Workshop

Lead: Dr. Nicholas Meisel, Associate Director of Engineering Design Graduate Programs and Assistant Professor of Engineering Design, Penn State University
Wednesday at 8:00 a.m. · Room 410
Additive manufacturing (AM) benefits from a range of design tools (e.g., topology optimization, lattice structure generation) during the later stages of design intended to improve part quality. However, how can we as engineers change our thinking generate with more ideal design candidates for AM earlier in the design process? In this special, hands-on workshop session, attendees will explore different tools for considering design for additive manufacturing (DfAM) in early-stage design. Special emphasis will be placed on the role of DfAM in concept generation. Through this workshop, participants will also be challenged to confront their own subconscious consideration of manufacturability throughout the design process. Participants from both academia and industry are encouraged to attend. There is no additional cost for to attend this workshop.

TECHNICAL PROGRAM - OVERVIEW

Location		Monday AM	Monday PM	Tuesday AM	Tusday PM	Tuesday Evening	Wednesday AM	Wednesday PM
		8:00 a.m. to 12:05 p.m.	1:30 p.m. to 5:30 p.m.	8:15 a.m. to 12:05 p.m.	1:40 p.m. to 4:00 p.m.	4:00 p.m. to 5:30 p.m.	8:00 a.m. to 11:50 a.m.	1:10 p.m. to 5:00 p.m.
Fourth Floor	400-402			Process Development - Emerging Techniques	Materials: Novel Materials		Process Development - Large-scale Processing	Materials: Ceramics and Glasses
	408			Process Development - Novel Methods and Processes I	Industrial Needs for Additive Manufacturing Research and Development		Process Development - Novel Methods and Processes II	Process Development - Novel Methods and Processes III
	410		Special Session: Wire-Fed DED - Controls and Modeling	Special Session: Wire-Fed DED - Material Properties	Special Session: Wire-Fed DED III - Systems and Processes		Design for Additive Manufacturing Workshop	Process Development - AM Control
	412		Process Development - Modeling and Control	Process Development - Deposition Processes	Modeling - Design and Analysis for AM		Modeling - Process Planning and Scanning Strategies	Physical Modeling - Analysis and Experiments
	415 AB		Broader Impacts	Applications - Polymers	Materials: Polymers - Powder Bed Fusion		Materials: Polymers - Material Extrusion	Materials: Polymers - Novel Materials and Processes
	416 AB		Physical Modeling - Melt Pool and Microstructure	Applications - Metrology and Defects	Applications - Topology Optimization		Applications - Aerospace	Applications - Hybrid Manufacturing and Composites
	417 AB		Applications: Lattices and Cellular - Fabrication and Testing	Applications - Metals	Applications - Biomedical		Applications: Lattices and Cellular - Lattice Structure Design	Applications: Lattices and Cellular - Heterogeneous Lattice Structures
	Salon A		Special Session: Data Analytics I - High-Dimensional Data Analytics	Special Session: Data Analytics II - Machine Learning in AM	Physical Modeling - Unique Processes		Special Session: Data Analytics III - Sensing and Analytics	Process Development - Process Monitoring
	Salon B		Special Session: Binder Jet AM I - Advancements in Binder Jet AM	Special Session: Binder Jet AM II - Binder-Powder interaction	Special Session: Binder Jet AM III - Part Densification and Strengthening		Physical Modeling - Novel Approaches	Physical Modeling - Part-Scale Modeling
Sixth Floor	615 AB		Materials: Composites - Novel Materials and Processes	Materials: Metals - Porosity and Processing	Materials: Metals - Powder and Processes		Materials: Composites - Polymer-Based Composites	Materials: Metals - Ferrous Metals including 17-4PH
	616 AB		Materials: Metals - 316L Stainless Steel	Materials: Metals - Nickel-based Superalloys	Materials: Composites - Metal-Based Composites		Materials: Metals - Aluminum	Materials: Metals - Titanium
	Salon F		Materials: Metals - Copper and Other Metals					
	Salon G		Process Development - Metal AM					
	Salon HJK	Plenary Session (Salon HJK)				Poster Session Salon JK		

Session Name	**Plenary Session**
Room	Salon HJK
Chair	Carolyn Seepersad, University of Texas at Austin
8:00 AM	Introductory Comments
8:15 AM	Use of Extreme Value Statistics for Establishing Process-Porosity-Fatigue Relationships in Laser Powder Bed Fusion Additive Manufacturing: Mihaela Vlasea, Carnegie Mellon University
8:40 AM	Accelerated Material Adoption in Laser Powder Bed Fusion: Xiangjia Li, University of Waterloo
9:05 AM	Fabrication of Biomimetic Functional Materials and Structures via Multiscale Nanocomposite Printing: Sarah Wolff, Arizona State University
9:30 AM	Operando Imaging of Directed Energy Deposition Additive Manufacturing: Yaoyao Fiona Zhao, Texas A&M University
9:55 AM	Design for Additive Manufacturing – from Pure Complexity to Multi-functionality: Grace Gu, McGill University
10:20 AM	Break
10:50 AM	Generative Design and Additive Manufacturing of Three-dimensional Architected Metamaterials : Filomeno Martina, University of California, Berkeley
11:15 AM	An Overview of Key Results in Wire-based DED in the WAAMMat Programme: Berok Khoshnevis, WAAM3D
11:45 AM	Invention and Development of Contour Crafting, Selective Inhibition Sintering, and Selective Separation Shaping: Irving E. Ramirez-Chavez, USC

Session Name	Special Session: Wire-Fed DED - Controls and Modeling	Process Development - Modeling and Control	Broader Impacts	Physical Modeling - Melt Pool and Microstructure	Applications: Lattices and Cellular - Fabrication and Testing	Special Session: Data Analytics I - High-Dimensional Data Analytics
Room	410	412	415 AB	416 AB	417 AB	Salon A
Chair	Bishal Silwal	Richard Hague	Robert Landers	Adam Clare	Li Yang	Subhrajit Roychowdhury
	Georgia Southern Univ	University of Nottingham	University of Notre Dame	University of Nottingham	University of Louisville	GE Global Research Center
1:30 PM	The Case for an End-to-end Software-hardware Stack in Wire Arc Additive Manufacturing: Rajat Gulabrao Kawalkar, WAAM3D	Towards Regulation of Build Height in a Directed Energy Deposition Additive Manufacturing using Adaptive Iterative Learning Control: Benjamin Bevans, Penn State University	Evaluation of the Ecological Footprint for Parts from AlSi10Mg manufactured by Laser Powder Bed Fusion: Dustin Seltzer, Fraunhofer Institute for Laser Technology (ILT)	A Data-driven Model for Reconstructing 3D Melt Pool Geometries in Additive Manufacturing: Roo Walker, Northwestern University	Digital Image Correlation of Architected Materials: Challenges, Lessons Learned and Opportunities: Shuheng Liao, Arizona State University	Multi-scale Shape Agnostic Flaw Detection and Monitoring in Laser Powder Bed Fusion using Heterogeneous In-process Sensor Data : Daniel Oropeza, University of Nebraska - Lincoln
1:50 PM	Robot-to-robot Collision Avoidance and Tool Path Recovery for A Multi-robot Wire-fed Ded System: Miguel Hoffmann, Oak Ridge National Laboratory	Towards Regulating Internal Temperature Distributions during Powder Bed Fusion Builds using Model Predictive Control: Laetitia Monnier, the Ohio State University	Comparative Life Cycle Environmental Assessment of aluminium, titanium and steel components manufactured by Wire Arc Additive Manufacturing: Nathaniel Wood, Cranfield University	A Computational Study Summarizing the Effects of Composition on the Melt Pool Geometry in Additive Manufacturing : Alexis Maurel, Pennsylvania State University	Insight into Compressive Behaviour of Schwarz-P Lattices Fabricated by Material Extrusion: Nandana Menon, Imperial College London	HDF5 Hierarchies for AM Digital Representations: Olivia Cook, NIST
2:10 PM	Geometric Challenges in Designing Parts for Machining using Wire-fed DED: Tim Lantzsch, Oak Ridge National Laboratory	In-Situ Monitoring of Wire Arc Additive Manufacturing for Defect Prediction: Luke Scime, University of Tennessee	The impact of measurement methodology on the diameter measurement of simple AM features: Eduardo Miramontes, National Institute of Standards and Technology	High-fidelity Modeling of Multi-material Additive Manufacturing: From Micro-/Nano-particle Reinforced Composites to In-situ Alloying: Scott Snarr, National University of Singapore	Beam Deletion in Square Honeycombs for Improved Energy Absorption Under Quasi-static In-Plane Compression: Wentao Yan, Arizona State University	Scalable Part Qualification for Powder Bed Additive Manufacturing: Mohammadamin Moghadasi, Oak Ridge National Laboratory
2:30 PM	Impacts of Sharpened Corner Path Geometry on Layer Topology in Wire Arc Additive Manufacturing: David Shoukr,	In-situ Monitoring of Laser Powder Bed Fusion using IR and NIR Emissions to Detect Thermal Anomalies: Sofia Sheikh, University of Tennessee, Knoxville	The Case for Flipping the Manufacturing Classroom: Matthew Roach, Arizona State University	Melt Pool Modelling of the LPBF-AM Process: A Comparison of Thermal Semi-analytic and Numerical Multi-phases Approaches: Ivo Kletetzka, Swansea University	Slender Energy Density for Improved Process Mapping with Lightweight Features Fabricated by Powder Bed Fusion: Jordan Rosser, University of louisville	Data-driven Approach for Printability Evaluation for Additively Manufactured Metal Alloys: Janely Villela, Texas A&M University
2:50 PM	Key Variables in Toolpath Generation for Wire-Arc Additive Manufacturing: Rujing Zha, Oak Ridge National Laboratory	Autonomous Error Detection and Correction Powered by Deep Neural Networks: Fred Carter, University of Cambridge	Using Solid Freeform Fabrication to develop a low cost Robotics experiment platform to complement classroom learning and exploring topics in STEM Education: Douglas Brion, STEM and Robotics Academy	Modelling of Microstructure Evolution in Wire-Based Laser Direct Energy Deposition with Ti-6Al-4V: Suhas Alkunte, Oak Ridge National Laboratory	The Effects of Powder Feedstock and Process Parameters on the Material Characteristics of Ti6Al4V Thin Strut Features Fabricated by Laser Powder Bed Fusion Additive Manufacturing: Yousub Lee, University of louisville	Evaluating the Effects of Geometry and Process Parameters in L-PBF using a High-Throughput CT Scanning Approach Within a Connected Machine, Monitoring, Geometry Data Framework : Hadi Miyanaji, Northwestern University
3:20 AM	BREAK	BREAK	BREAK	BREAK	BREAK	BREAK
3:40 PM	WAAM GPU-accelerated Process Simulation Using an Improved Modeling Workflow: Tayler Sundermann, University of Pittsburgh	Understanding Correlations between Processing Parameters and Part Geometry in Robotic Reactive Extrusion Additive Manufacturing (REAM): Conor Porter, UT Austin	AI-powered Augmented Reality Training for Metal Additive Manufacturing: Michael Fogg, California State University Northridge	Modeling of IN718 precipitates' growth in powder-bed fusion (in-situ and post-build aging): Andrew Rhodes, A*STAR	Optimization of Print Parameters for Ti-5553 Skinned Lattice: Jakub Mikula,	Generation and Analysis of AlSi10Mg L-PBF Single Track Data Set Enabling Deeper Process Insights.: Xavier Jimenez, Northwestern University
4:00 PM	Convolution Long-short Term Memory Autoencoders Applied to Process Monitoring Across Multiple Camera Types for Laser Hot Wire Additive Manufacturing: Laura Budde, Carnegie Mellon University	Developing a Universal Additive Manufacturing Parameter Transference Model: David Shoukr, Los Alamos National Laboratory	Examining Repeatability in Polymer Material Extrusion Additive Manufacturing Systems: Kevin Le, Naval Surface Warfare Center	Phase-field modeling of microstructure evolution in additive manufacturing with a physics-informed graph network approach: Neshat Sayah, Northwestern University	Manufacturability Thresholds for Powder Bed Fusion of Ti-6Al-4V Lattices: A Study of Defects and Dimensional Accuracy: Tianju Xue, Quad City Manufacturing Lab-Western Illinois University	Spatiotemporal Modeling of the L-PBF Thermal Field History: Brandon Abranovic, Texas A&M University
4:20 PM		A Model for Driving Signal Effects on Piezoelectric Inkjet Printing Speed : Zhuo Yang, University Arkansas	A Comprehensive Review and Discussion of Knowledge Graph and Ontology for Rapid Qualification of Metal Additive Manufactured Parts: Chao Sui, The University of Texas Rio Grande Valley	Process-specific Microstructure-sensitive Modeling of Fatigue in Additively Manufactured Ti-6Al-4V Alloys: John Obielodan, The University of Tennessee Chattanooga	Surface-based Lattice Structures as Candidates for Heat Exchangers: Lionardo Lado, University of Nottingham	Reconstructing 3D Melt Pool Geometry from Coaxial Melt Pool Image for Powder Bed Fusion Additive Manufacturing: Christine Cummings, Georgetown University
4:40 PM		Using Process Monitoring Signals to Identify Defects during Laser Powder Bed Fusion: Amanda Giam, Lawrence Livermore National Laboratory		Three-dimensional (3D) Simulation of Micro-Void Development within Large Scale Polymer Composite Deposition Beads: Orkhan Huseynov, Baylor University	Characterization of Thermophysical Properties for Additively Manufactured Porous Media : Aigbe Awenlimobor, Penn State University	Factorial design data analytics for material parameters in multi-physics modeling of additive manufacturing: Marwan Haddad, Integrative Sciences and Engineering Program, National University of Singapore
5:00 PM		Unified System Controller for a Powder Bed Fusion System Developed for an Open-source Framework : Jeffery Betts, Technical University of Denmark				Examining the GPU Acceleration Speed-up for Finite Element Modeling of Additive Manufacturing: Nathaniel Wood, Mississippi State University

Special Session: Binder Jet AM I - Advancements in Binder Jet AM	Materials: Composites - Novel Materials and Processes	Materials: Metals - 316L Stainless Steel	Materials: Metals - Copper and Other Metals	Process Development - Metal AM	Session Name
Salon B	615 AB	616 AB	Salon F	Salon G	Room
Joshua Wagner Rice University	Chad Duty University of Tennessee	Ola Harrysson North Carolina State University	Frank Liou Missouri University of Science and Tech	Abdalla Nassar Penn State University	Chair
Mechanized Spreading of Ceramic Powder Layers for Additive Manufacturing Characterized by Transmission X-ray Imaging: Filomeno Martina, University of California, Santa Barbara	Using Recycled Carbon Fiber Reinforced Polycarbonate as a Feedstock Material for Large Format Additive Manufacturing: Yue Zhou, University of Tennessee, Knoxville	Effects of Feeding Rates on the Microstructure of SS 316L Fabricated via Directed Energy Deposition with Coaxial Wire-Powder Feeding : Philip Depond, Binghamton University	Surface Nanotextured Powders for 3D Printing of High Reflectivity Metals: Christian Weiss, Lawrence Livermore National Laboratory	The Next Step with Additive Manufacturing of Steel and Iron Alloys: Ajit Panesar, Uppsala University	1:30 PM
Nondestructive Evaluation of Porosity in Binder Jet SS316L Components using Ultrasound and X-ray Computed Tomography: Christopher Masuo, Pennsylvania State University	3D Printing of Batteries from Lunar and Martian Regolith: Seungjong Lee, University of Texas at El Paso	Additively Manufactured 316L Stainless Steel: Effect of Heat Treatment on Microstructure and Tensile Properties: Michael Cullinan, Auburn University	A Study of the Electrical Resistivity of Sintered Copper Nanoparticles: Emanuele Pagone, University of Texas at Austin	Printability Studies of 316L Stainless Steel by Paste Deposition Modeling: Irving E Ramirez-Chavez, Texas A&M University	1:50 PM
Effect of Printing Orientation on Ceramic Binder Jetting Additive Manufacturing: Derek Vaughan, Department of Materials Science and Engineering, Texas A&M University, TX, USA	Development of Processing Parameters for the Selective Laser Sintering of Carbon Fiber Reinforced Polyphenylene Sulfide with a Tooling Application: Janith Wanni, Univ of Texas At Austin	Cellular Subgrain Features in Directed Energy Deposited Stainless Steel 316L: The Influence of Morphology on Mechanical Properties : Fankai Meng, Clarkson University	Fused Filament Fabrication of highly Dense Copper Parts: Maxwell Praniewicz, KU Leuven	Potential of Dual Laser Array Powder Bed Fusion for the Processing of Nickel-base Alloy 625: Naresh Koju, Fraunhofer Institute for Laser Technology ILT	2:10 PM
Embedded Sensors to Experimental Evaluate Binder Curing in 3D Printed Sand Molds for Metal Casting: Harold Walters, University of Texas at El Paso	Effects of Spherical Fillers on the Processability and Mechanical Properties of PA613 and PP-based LS Dry Blends: Jiahui Ye, Paderborn University (DMRC)	Uncertainty Quantification of Response Surface Methodology to Establish an Efficient Printability Assessment Framework in Directed Energy Deposition: M. Hossein Sehhat, Texas A&M University	Improving the Copper Powder through Plasma Spheroidization for use in the Additive Manufacturing: Dhruv Bhate, Missouri University of Science and Technology	Printability of Nickel Alloy 718 Using a Systematic Process Optimization Framework with Different Layer Thicknesses: Naresh Koju, Texas A&M University	2:30 PM
Binder Jetting of Tungsten Carbide with Low Metallic Binder Contents: Challenges and Solutions : Luke Meyer, Kennametal Inc.	Experimental Analysis of Functionally Graded Materials produced by Fused Filament Fabrication: Rebecca Kurfess, Tennessee Tech University	Towards directed energy deposition of metals using polymer-based supports: porosity of 316L stainless steel deposited on carbon-fiber-reinforced ABS: Rachel Paddock,	Structure-Property Relationships in Copper Made via Laser Powder Bed Fusion : Rajeev Dwivedi, University of Texas at Austin	In-situ Measurement of Melt Pool Emissions via Coaxial Spectrometry in Powder-blown Directed-energy Deposition: Mohammadamin Moghadasi, Northwestern University	2:50 PM
BREAK	BREAK	BREAK	BREAK	BREAK	3:10 PM
Compaction-assisted Binder Jetting of Textured Ceramics: Gabe Guss, Department of Materials Science and Engineering, Texas A&M University, TX, USA	Analysis of Fiber Attrition and Mechanical Performance in Large-Format Additive Manufacturing of Long-Fiber Reinforced Polymer Composites: Nancy Huang,	Investigating the Effects of Infiltration Conditions on the Microstructure and Mechanical Properties of Binder Jet Fabricated Stainless Steel/Bronze through Ultrasonic Testing: Kellen Traxel, Pennsylvania State University	Processing of Cu-Al-Fe Bronze via Liquid Metal Jetting Based Additive Manufacturing: Donald Palomino, Lawrence Livermore National Laboratory	Designing an Industrially Implementable Framework to Design Additive Recycling Invariant Powder LPBF Feedstocks via Alloy 718 : Mohammad Reza Vaziri Sereshk, Texas A&M University	3:40 PM
	Effect of Process Parameters on Voids within Short Carbon Fiber/ABS Beads Produced via Large Area Additive Manufacturing: Bethany Lettiere, Baylor university	Local Modification of Composition and Hardness in Stainless Steel by Hybrid Inkjet-Laser Additive Manufacturing: Yongkun Sui, Massachusetts Institute of Technology	Assessing Aerosol-jet Printed Gold Inks for Printed Electronics Applications: Evan Handler, Sandia National Labs	Combination of Cladding Processes with Subsequent Hot Forming as a New Approach for the Production of Hybrid Components: Daniel Padrao, Laser Zentrum Hannover e.V.	4:00 PM
	Mechanical Properties Characterization for Polyamide Matrix Dairy Protein Composites Fabricated Using Selective Laser Sintering Process: Bethany Lettiere, University of Wisconsin-Platteville	Tailoring Porosity in Laser Powder Bed Fusion by Spatial Manipulation of Feedstock Composition: Christopher Ledford, Massachusetts Institute of Technology	Fabrication of Refractory Alloys using Electron Beam Powder Bed Fusion: Zhaohui Geng, Oak Ridge National Laboratory	Assessment of In-situ Defect Mitigation Strategies in Metal Laser Powder Bed Fusion Additive Manufacturing: Alden Packer, Pennsylvania State University	4:20 PM
	Influence of the Different Matrix Materials on the Thermal Properties of Short Carbon Fiber Reinforced Composites Manufactured by Fused Filament Fabrication: Matthew Schreiber, Tennessee Technological University	Influence of Annealing on Microstructure and Mechanical Properties of Additively Manufactured 316L: Abdelrahman Elsayed, Colorado School of Mines	Laser Powder Bed Fusion of Defect-Free NiTi Shape Memory Alloy Parts with Superior Mechanical Response: Nicholas Calta, Texas A&M University	A Comparison of Thermal History and Porosity Formation for Different Laser Melting Toolpath: Shweta Hanmant Jagdale, Texas A&M University	4:40 PM
		Surface Morphology and Hardness of Powder Bed Fused Ss316l as a Function of Process Parameters: Matthew Ritchie, University of texas at dallas	In-situ Modification of a High Entropy Alloy With 2.4% Molybdenum Using LPBF, and its Effect on Microstructure and Corrosion Resistance: Sebastian Aagaard Andersen, Swansea University	Sampling Internal Temperature Distributions Within Parts Being Manufactured by the Metal Laser Powder Bed Fusion Process: Abhishek Shrivastava, the Ohio State University	5:00 PM

NOTES

Session Name	Process Development - Emerging Techniques	Process Development - Novel Methods and Processes I	Special Session: Wire-Fed DED - Material Properties	Process Development - Deposition Processes	Applications - Polymers	Applications - Metrology and Defects
Room	400-402	408	410	412	415AB	416AB
Chair	Francesco Sillani	David Rosen	Sneha Prabha Narra	Hadi Miyanaji	Xiangjia Li	Ismail Fidan
	Inspire AG	Georgia Institute of Technology	Carnegie Mellon University	Kennametal Inc.	Arizona State University	Tennessee Tech University
8:15 AM	Investigation into Effect of Beam Defocusing in Low Temperature Laser Sintering of PEEK: Ankit Saxena, Tokyo Metropolitan Industrial Technology Research Institute	From Neutron Diffraction to Tool Repair: How Fundamental Scientific Research Translates to Industrial Impact for Hybrid AM Processes : Mohanish Andurkar, Oak Ridge National Laboratory	Heat Treatment Effects on Mechanical Properties of Wire Arc Additive Manufactured Ti-6Al-4V : Brian Post, Sandia National Laboratories	AutoPrint: An Affordable and Automated Fused Filament Fabrication Based Additive Manufacturing System: Hyunwoong Ko, California State University - Chico	Additively Manufactured Conformal Fluidic Circuits as Non-destructive Pressure - Strain Transducers: Hasan Bank, Penn State	Characterizing The Distortion of Large-scale Polymer Composite Printed Structures: Allison Beese, University of Tennessee
8:35 AM	In-situ Interferometry for Vat Photopolymerization Additive Manufacturing: Junyu Hua, University of Pittsburgh	Evaluating Concepts for the Integration of Milled Components into the Additive Manufacturing Process: Xinyi Xiao, Technical University Darmstadt	Qualification of Low-criticality AM Components in an Expeditionary Environment: Jannik Reichwein, NSWCCD	Build Plate Design for Extrusion-Based Additive Manufacturing: John Pike,	3D Printing Diffractive Axicons and Zone Plates: Alex Roschli, Purdue University	Investigation of the Process Parameters and Geometry Dependent Shrinkage Behavior of Raster Lines in the Fused Deposition Modeling Process: Seyed Mohammad Hojjatzadeh, Paderborn University, Direct Manufacturing Research Center (DMRC)
8:55 AM	Revealing Melt Flow Instabilities in Laser Powder Bed Fusion Additive Manufacturing of Aluminum Alloy via In-situ High Speed X-ray Imaging: Amiee Jackson, University Of Wisconsin Madison	Validation of Ensemble Kalman Filter Estimations of Internal Temperature Fields During the Powder Bed Fusion Process: Adnen Mezghani, the Ohio State University	Effects Due to Variations in Thermal Properties of Maraging Steel for Finite Element Modeling of the WAAM Process: Nathaniel Wood, Mississippi State University	Hybrid DED Process Parameter Development and Translation across Spot Size: Vivek Patel, Oak Ridge National Laboratory	Multifunctional Design in Additive Manufacturing: Process Intensification for Enhanced CO2 Capture : Kenton Fillingim, Oak Ridge National Laboratory	A Novel Test Artifact Design for Conformal Printing via Material Extrusion: Seyed Mohammad Hojjatzadeh, The Pennsylvania State University
9:15 AM	Towards an Automated Methodology for Optically Cured, High Thickness Composite Polymer Pastes: an ISO-based Approach for Large Area Additive Manufacturing: Jeffrey Lipton, Newcastle University	Usability and Limitations for Predicting Melt Pool Dimensions via Dimensionless Numbers in Laser Powder Bed Fusion (LPBF): Wen Dong, EOS GmbH Electro Optical Systems	Impact of Composition and Solidification Pathway on Additively Manufactured 316L Printed via a Laser-wire Directed Energy Deposition Process: Theresa Hanemann, Colorado School of Mines	Impact of Nozzle Condition on Powder Catchment Efficiency for Coaxial Powder Direct Energy Deposition: Jia Liu, Georgia Institute of Technology	Vibration Reduction using Material Jetted Parts for Sander Grips: Lauren Heinrich, University of washington	The Impact of the Printed Part Geometry on the Shrinkage and Density of 316L Stainless Steel Parts Printed by FFF/FDM Technology: Wei Li, Sam Houston State University/ Engineering Technology Department
9:35 AM	Verification Process for Laser Powder Bed Fusion Machine Health: Francisco Gonzalez-Castill, Honeywell FM&T	Powder Spread Flaws in Polymer Laser Sintering and its Influences on Mechanical Performance: alexander reinchenbach, Paderborn University	The Failure of Wire-arc Additive Manufactured Aluminum Alloys With Porosities Under Loadings as Observed by In-situ X-ray Micro-computed Tomography: Helge Klippstein, University of Texas at Dallas	Impingement and Solidification Morphology of Liquid Metal Droplets in Additive Manufacturing via Magnetohydrodynamic Liquid Metal Jetting: Sebastian Larsen, Lawrence Livermore National Laboratory	Characterization of Material Jetting Processes to Develop Design Guidelines in Support of Model Based Definition for Additive Manufacturing: Viktor Sukhotskiy, UT Austin	Reducing Part Distortion in Laser Powder Bed Fusion Through Data-driven Topology Optimization: Mohanish Andurkar, University of Pittsburgh
9:55 AM	Break	Break	Wire Arc Additive Manufacturing of Reduced Activation Ferritic Martensitic (RAFM) Steel: Rachel Evans, Georgia Southern University	Break	Break	Break
10:25 AM	Bioinspired Smart Nanocomposite Fabrication via Liquid Crystal Templating-assisted 3D Printing: Elliott Jost, Arizona State University	The Resilience of Laser Powder Bed Fusion to Power Perturbations: Alexander P. Belchou, Pennsylvania State University		Intelligent Process Planning and Control of an Aerosol Jet Printing Process: Sumanth Theeda, University of Notre Dame	A Case Study in Component Redesign for Additive Manufacturing Process Workflows: Robert Landers, Georgia Institute of Technology	Predicting Geometric Accuracy via Image-to-image Machine Learning: Ziyad Smoqi, UT Austin
10:45 AM	Spatial Variations in Horizontal and Vertical Composition Grading using Laser Powder Bed Fusion: Patrizia Gartner, Colorado School of Mines	Thermally Switchable Build Surface Bond by Mechanical Interlocking for Hybrid Manufacturing: Jordan Yaple, Iowa State University		Material Jetting Developing Platforms for R&D: Ziyad Smoqi, Added Scientific Ltd	Single-part Tracking Enabled by Fluorescent Polysecure Tracing Particles in AM Parts: Craig Sturgess, wbk, KIT	Examining Repeatability in Powder Bed Fusion Additive Manufacturing Systems: M. Hossein Sehhat, Naval Surface Warfare Center
11:05 AM	Defect Lean Metal Additive Manufacturing: Philip King, University of Wisconsin-Madison	Regional Porosity Measurement in Laser Powder Bed Fusion: Chaitanya Mahajan,		Establishing a Machine-Agnostic Energy Density Model for Laser, Powder-blown Directed Energy Deposition: Haolin Zhang, Northwestern University	Effects of Chemical Treatment of Additively Manufactured Tooling on Surface Quality in Investment Casting : Samantha Webster, Penn State University	Effect of Additive and Subtractive Sequence on Distortion During Hybrid Directed Energy Deposition: Jiandong Yuan, Oak Ridge National Lab
11:25 AM	Use of a Penetrating Deposition Nozzle for Z-Pinning Additive Manufacturing: Miriam Seiti, University of Tennessee	Laser Calibration for Powder Bed Fusion Additive Manufacturing Process: Seth Dennison, National Institute of Standards and Technology		Material-independent Flowrate Control in Extrusion-based Additive Manufacturing: Nandana Menon, Ohio State University	Role of Pre-treatments in Printed Flexible and Stretchable (Bio-) Electronics: Ali Asghari Adib, KU LEUVEN	Physics-based Feedforward Control of Laser Powder Bed Fusion Process: Negar Gilani,
11:45 AM	Printing Multifunctional High Performance Polymer Parts via the Hybridization of Direct Ink Write and High Temperature Fused Filament Fabrication: Felix Hecker,	Experimental Analysis and Optimization of Gas Flow in an Open-Architecture Metal L-PBF System: Arun Poudel, Technical university of Denmark		Closed-loop Recycling of Low Friction Polymers in Fused Granule Fabrication Additive Manufacturing Processes: Ehsan Dehghan Niri, Brigham Young University	Validation and Comparison of FEM-Simulation Results of the Fused Deposition Modeling Process under Consideration of Different Mesh Resolutions: Neil Thompson, Paderborn University, Direct Manufacturing Research Center (DMRC)	In-situ Integration of Weldable Strain Gauges in Components Manufactured by Laser-based Powder Bed Fusion: Nicholas Watkins, Fraunhofer IGCV
12:05 PM	Cooling Rate Measurement in Directed Energy Deposition using Photodiode-based Thermometry: Gaius Nzebuka, Northwestern University			Development of Laser Cladding Procedure through Experiment and Analysis Using Powder-blown Directed-energy Deposition: Rongxuan Wang, University of Texas at El Paso	Numerical Transient Thermal Development of Melting a Solid Filament in the Hot-end in Material Extrusion Additive Manufacturing: Dajalma Garcia, Texas A&M University	Assessing the Feasibility of Process Window Estimation for L-PBF Ti-6Al-4V through Hardness Measurements: Minglei Qu, Auburn University
12:25 PM					Thin-walled Part Properties in PBF-LB/P — Experimental Understanding and Nonlocal Material Model : Ming C. Leu, Collaborative Research Center 814 - Additive Manufacturing	

Applications - Metals	Special Session: Data Analytics II - Machine Learning in AM	Special Session: Binder Jet AM II - Binder-Powder interaction	Materials: Metals - Porosity and Processing	Materials: Metals - Nickel-based Superalloys	Session Name
417AB	Salon A	Salon B	615AB	616AB	Room
Eric Fodran Northrop Grumman	Jia Liu Auburn University	Chao Ma Texas A&M University	Sarah Wolff Texas A&M University	Sneha Prabha Narra Carnegie Mellon University	Chair
Influence of Biodegradable Additives on the Surface Finish of Additively Manufactured Part: a Green Surface Manufacturing Approach: Tyler Corum, Indian Institute of Technology Jammu	A Review on Machine Learning Interpretation for Additive Manufacturing: Jacob Lawrence, Arizona State University	Observations of Binder Jetting Defect Formation Using High-Speed Synchrotron X-Ray Imaging: Natalia Saiz, Brigham Young University	Effects of Pores and Stress State on Fracture of Additively Manufactured Metals: Indrajit Nandi, Pennsylvania State University	Investigating the effect of defects on the crack initiation of additively manufactured IN718 using crystal plasticity simulations: Takashi Kigure, Auburn University	8:15 AM
Effect of Build Orientation on Residual Stress and Microstructure in Inconel 625 Fabricated via Laser Powder Bed Fusion: Felix Hecker, Kansas State University	Applications of Machine Learning in Additive Manufacturing: Joshua Wagner, University of Tennessee	Computational Modeling and Experimental Validation of Primitive Formation in Binder Jet 3D Printing: Jacob Aljundi, Rice University	Mechanisms of Pore Elimination During 3D Printing of Metals: Seungjong Lee, University of Wisconsin-Madison	Effect of Laser Polishing on Fatigue Behavior of Additively Manufactured IN718: Yue Zhang, Auburn University	8:35 AM
Physics-Informed Learning of Real-time Residual Stress in Laser Powder Bed Fusion: Sagar Jalui, Miami University	Additive Manufacturing Process State Inference with Convolutional LSTM: Kazi Moshiur Rahman, University of Massachusetts Boston	Influence of Binder-powder Interaction on Accuracy and Resolution of Binder Jetting Parts: Matthew Register, Virginia Tech	Direct Observation of Pore Formation Mechanisms During LPBF Additive Manufacturing Process: Anna Dunn, University of Wisconsin-Madison	Size and Processing Parameter Effects in Laser Powder Bed Fusion of Inconel 718: Qilin Guo, Wright State University	8:55 AM
Laser Powder Bed Fusion Additive Manufacturing of wicking structures for Heat Pipes: design, fabrication, and application.: Suleiman Obeidat, The Pennsylvania State University	Defects Classification via Hierarchical Graph Convolutional Network in L-PBF Additive Manufacturing: Arielle Torres, Auburn University	Functional Polyurethane Composites via Reactive Binder Jetting (RBJ) of a Dual-ink Binding System: Olivia Denonno, University of Nottingham	Fabricating Functionally Gradient Material with Hybrid Manufacturing: Directed Energy Deposition & Machining: Shaharyar Baig, The University of Texas at Dallas	Microstructure and mechanical properties of additively manufactured Inconel 718: A comparative study between L-PBF and LP-DED: Chris Kerr, Auburn University	9:15 AM
Preventing Recoater Crash in Laser Powder Bed Fusion via Modified Inherent Strain Modeling: Praveen Vulimiri, University of Pittsburgh	Graph Neural Networks for 3D Defect Mapping in Laser Powder Bed Fusion: Akash Verma, Imperial College London	Fundamental Study of Aerosol Jet® Printing by Means of Phase Doppler Anemometry: Runyu Zhang, KU Leuven	Effects of Fast Neutron Irradiation on the Microhardness of Inconel 625 and Inconel 718 Materials Fabricated via Laser Powder Bed Fusion : Anannya Doris, Kansas State University	Microstructural Characterization of Laser Powder Bed Fusion (L-PBF) Additively Manufactured Inconel 718 for Aerospace Application: Zachary Hilton, University of Texas at El Paso	9:35 AM
Break	Break	Break	Break	Break	9:55 AM
The Impact of as-built Surface Roughness on Vibration Bending Fatigue of Additively Manufactured Nickel Alloy 718: Daphne Lin, Wright State Universtiy	Optimization of Laser Process Parametres using Machine Learning Algorithms and Performance Comparison: Joshua Wagner, University of texas at dallas	An Experimental Apparatus for High-speed Imaging and Analysis of Powder Primitive Formation in Binder Jet 3D Printing : Christine Cummings, Rice University	Nondestructive Ultrasound Evaluation of Additively Manufactured Wear Coatings: Dhruv Bhate, University of Nebraska-Lincoln	Effects of HIP on the Quasi-static and High Cycle Fatigue Behavior of Thin-Walled Inconel 718 by Laser Bed Powder Fusion: Tengteng Tang, Arizona State University	10:25 AM
Studies on Thin and Thick-walled SS316L Overhanging Specimens Manufactured Using Powder-fed Laser-based Directed Energy Deposition: Evan Handler, The Pennsylvania State University	In-situ Monitoring and Prediction of Porosity in Laser Powder Bed Fusion using Physics-informed Meltpool Signature and Machine Learning: Guha Manogharan, University of Nebraska-Lincoln	A Computational Study on Pore Networks in Binder Jet Additively Manufactured Components with Bimodal Powder Distribution: Eric Weflen, The Pennsylvania State University	Effects of Recoating Velocity and Layer Thickness on the Powder-bed Surface Roughness in the Laser Powder Bed Fusion (LPBF) Process: Peter Morcos, Missouri University of Science and Technology	A Study on the Effect of VED, Particle Size Distribution, Moisture Content, and Powder Reuse on the Densification and Mechanical Properties of L-PBFed Nickel Alloy 718 Using Design of Experiment and ANOVA: Joy Gockel, Texas A&M University	10:45 AM
Design and Additive Manufacturing of Bio-inspired Copper Heat Sinks for Microelectronics Cooling: Guru Charan Reddy Madireddy, Arizona State University	Porosity Prediction for Multiple Processing Regimes in Laser Powder Bed Fusion via Machine Learning of In-situ Multi-modal Monitoring Data: Daniel Oropeza, University of Pittsburgh	Design, Fabrication, and Validation of a Laboratory-scale Binder Jet Additive Manufacturing Testbed: Henry de Winton, University of California, Santa Barbara	In-situ Characterization of Laser-Material Interaction Dynamics in Ring-shaped Beam Laser Powder Bed Fusion: Victoria Luna, University of Wisconsin-Madison	Comparative Study of Additively Manufactured Inconel 625 in the As-built and Heat-treated Condition: Lianyi Chen, University of Texas, El Paso	11:05 AM
Experimental Study on the Electropolishing of Additive Manufactured Copper Parts: Alexander Riensche, Kettering University	Transferring Printability Knowledge Across SS316L and IN718 in Laser Directed Energy Deposition using Machine Learning : Ho Yeung, Pennsylvania State University		Insights into the Droplets' Behaviour to Control the Quality Of 3D Parts: MetalJet : Jordan Rosser, University of Nottingham	Controlling Grain Evolution of IN625 Parts Produced by LPBF-AM: Brenin Bales, Swansea University	11:25 AM
Comparative study of Mechanical Properties of Aluminum Alloy A356 (Al-12Si) Fabricated by Directed Energy Deposition Method and Pressure Die Casting : Maximilian Binder, NAVAJO TECHNICAL UNIVERSITY			A Process - Structure - Property - Performance Study of Liquid Metal Jetted Parts: Shaharyar Baig, Lawrence Livermore National Laboratory	The Effect of Heat Treatment on the Microstructure and Tensile Properties of L-PBF Haynes 214: Ian Ho, Auburn University	11:45 AM
			Controlling Process Instability for Defect Lean Metal Additive Manufacturing: Muztahid Muhammad, University of Wisconsin-Madison	Microstructure and mechanical properties of additively manufactured Haynes 230: a comparative study of L-PBF vs. LP-DED: Jihoon Jeong, Auburn University	12:05 PM
					12:25 PM

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Session Name	Materials: Novel Materials	Industrial Needs for Additive Manufacturing Research and Development	Special Session: Wire-Fed DED III - Systems and Processes	Modeling - Design and Analysis for AM	Materials: Polymers - Powder Bed Fusion	Applications - Topology Optimization
Room	400-402	408	410	412	415AB	416AB
Chair	Joseph Bartolai	Todd Spurgeon	Bradley Jared	Albert To	Toshiki Niino	Christopher Williams
	Pennsylvania State University	Pennsylvania State University	University of Tennessee, Knoxville	University of Pittsburgh	Univ of Tokyo	Virginia Tech
1:40 PM	An Investigation of Laser Powder Bed Fusion Process-Structure Relationship of the High Temperature Thermoelectric Material Silicon Germanium: Aurelien Neveu, George Washington University		Advanced Robotic Gantry Directed Energy Deposition (DED) System for Large Format Structures with Multi-Process Capabilities: Shantanab Dinda, EWI	Advances in the Modeling of Additive Manufacturing Process Simulation : Ali Nabaa, Clarkson University	Recycling of Polymer Powders in SLS: Consequences on Flowability and Electrostatic Properties: Nipun Wijesinghe, GranuTools	A Framework for Interactive Structural Design for AM: Amm Hasib, UT Austin
2:00 PM	Fabrication of Liquid-Filled Voronoi Foams For Impact Absorption Using Material Jetting Technology: Camden Chatham, University of Washington		Creating Large-scale Metal Parts with Multi-arm High Deposition Wire-arc System: Axel Fernandes, Oak Ridge National Laboratory	Hybrid Curve Fitting for Accurate Object Construction: Akshay Jacob Thomas, Oak Ridge National Laboratory	A framework with examples for printing thermosetting polymers using laser powder bed fusion additive manufacturing: Charles Wade, Savannah River National Lab	Generative Design for Additive Manufacturing of Satellite Optical Tracker Mount: Connor Hammond, California State University Northridge
2:20 PM	Additive Manufacturing of Graphite Structures : Simon Cholewa, UT Austin		High Deposition Rate Wire Arc Additive Manufacturing: Keegan Ocorr, Oak Ridge National Laboratory	Application of Field-driven CAD System for Design for Additive Manufacturing: Ziheng Wu, Incheon National University	Coalescence Behavior of Polyamide 12 as Function of Molecular Weight and Influence on Mechanical Performance: Sang-in Park, Institute of Polymer Technology	Design and Testing of a Topology Optimized Transtibial Socket: Ethan Parsons,
2:40 PM	A Calibration-Free Physics-based Framework to Predict Printability Maps in Additive Manufacturing Process: Yuki Yamauchi, Texas A&M University	Industrial Needs for Additive Manufacturing Research and Development	Feasibility Study of Large-sized Aluminum Facades by Using Wire Arc Additive Manufacturing: Tosh Brown-Moore, Shimizu Corporation	Boosting Artificial Intelligence in Design Processes by the Use of Additive Manufacturing: Jason Pierce, Paderborn University	Optimization of Penetration Depth and Powder Layer Thickness for Proper Interlayer Adhesion in Polymer Laser Sintering: Manuel Ott, Tokyo Metro Ind Tech Research Inst	Mechanical Evaluation of Topology- and Toolpath-Optimized Composite Structures Manufactured via Multi-Axis Material Extrusion: Ranger Buchanan, Virginia Tech
3:00 PM	Photothermal bleaching of nickel dithiolene for bright multi-colored 3D printed parts multi-colored 3D printed parts : Ivo Kletetzka,		Large-scale Hybrid Manufacturing of Freeform Metal Components: Rodrigo Enriquez Gutierrez, University of Tennessee, Knoxville	The Effect of a Gas Stagnation Region on Nanoparticle Impact Velocity during Micro-Cold Spray: Marshall Allen, The University of Texas at Austin	Shelf Life of Polyamide 12 (PA2200) Laser Sintering Powder: Stephen Bierschenk, Paderborn University (DMRC)	Strength Comparison of a Topology Optimized Truss Structure from Printed SLA Resin, Electroplated Resin and DMLS Aluminum: Patxi Fernandez-Zelaia, REPLIFORM, INC.
3:20 PM	Influence of Powder Properties and Process Parameters on the High Temperature PBF-LB/M Manufacturability of Filigree Tungsten Components: Christian Budden, Fraunhofer IGCV		Process Development and Thermomechanical Modeling of Laser Hot Wire Additive Manufacturing Process: Caralyn Collins, Carnegie Mellon University	ORNL Large-scale Metal Slicer: A Custom Software that Meets the Challenges brought by Growing Complexity of Parts in Wire Arc Additive Manufacturing: Berin Seta, ORNL	Process optimisation of PA11 in fiber-laser powder-bed fusion through loading of an optical absorber: Canhai Lai, DTU Construct	
3:40 PM			Mitigating Thermal Distortion in Wire Arc Additive Manufacturing thru Integrating Topology Optimization and Modified Inherent Strain Modeling: Kevin Caballero, University of Pittsburgh	Z-Chunking for Cooperative 3D Printing of Large and Tall Objects: Chao Li, University of Texas at Austin	Powder Bed Fusion of Polypropylene Produced via Thermally Induced Phase Separation: Daniel Weber, N/A	
4:00 PM			Process Response of Martensitic 250 Stainless Steel Alloy + Wire Arc Additive Manufacturing with Cold Metal Transfer: Joseph Fisher, Center for Advanced Vehicular Systems			

Applications - Biomedical	Physical Modeling - Unique Processes	Special Session: Binder Jet AM III - Part Densification and Strengthening	Materials: Metals - Powder and Processes	Materials: Composites - Metal-Based Composites	Session Name
417AB	Salon A	Salon B	615AB	616AB	Room
David Hoelzle	Emanuele Pagone	C.Fred Higgs III	Emilie Valente	Denis Cormier	Chair
Ohio State University	Cranfield University	Rice Univ	Technical University of Denmark	Rochester Institute Of Technology	
3D Printed Bioactive Glass-Hydrogel Scaffolds for Craniofacial Bone Defects : Sofia Valdez, Missouri University of Science and Technology	A Pore-elimination Approach for Manufacturing Pore-free Feedstock Powders: Patrick Dougherty, UW-Madison	Binder Jetting of Aluminum 6061 and Ti64: Highlights in Reactive Metal Sintering and Distortion Control using LiveSinter: James McNeil, ExOne	Repeatability and Sensitivity of a Rotating Drum Method for Rheological Characterization of Stainless Steel Powders Used for Additive Manufacturing: Ryan Welch, NIST	3D Printing of Nanoporous Metals via Fused Filament Fabrication: Rheological Considerations: Justin Whiting, Arizona State University	1:40 PM
3D Printing and Application of Lattice-based Biodegradable Metal Implants for Bone Regeneration in Load-Bearing Bone Defects: Paula Logozzo, The Pennsylvania State University	Relationship between Flow-controlled Fiber Orientation and Spring-in Deformation in Extrusion Deposition Additive Manufacturing: Amanda Wei, Purdue University	Increasing Part Strength and Density in Binder Jetting with Lattice Infill Patterning: Andrzej Nycz, Virginia Polytechnic Institute and State University	Rheological Characterization of Room Temperature Powder Metal Paste for Extruded Material Modeling: Srivatsan Balaji, Tennessee Tech University	Optimization of SLA Photopolymers' Thermal Expansion for Nickel Plating: Marshall Norris, Texas State University	2:00 PM
Magnetic Surface Finishing for Additively Manufactured Titanium Scaffolds of Bone to Reduce Surface Roughness and Improve Osseointegration: Roxana Carbonell, California State University Northridge	Understand Powder Deposition Behaviors of a Novel Electrostatic Powder Spreading Technique using Molecular Dynamics Simulation: MD Shakil Arman, Lawrence Livermore National Security.LLC	Comparison of Nanopowder and Granulated Powder in Compaction-assisted Binder Jetting: Riley Wallace, Texas A&M University	Enhancement of Gas-Atomized 304L Stainless Steel Powder by Plasma Spheroidization for use in the Laser Powder Bed Fusion (LPBF) Process: Moein Mohammadi, Missouri University of Science and Technology	Laser Powder Bed Fusion of Highly-Reinforced Aluminum Matrix Composites: M. Hossein Sehhat, MIT Lincoln Laboratory	2:20 PM
Characterizing Hydrodynamic Shear Stress and Cell Viability of Algal Cells during Extrusion Bioprinting: Joseph Kubalak, RIT	Carbon Fiber Suspension Dynamics Analysis via Coupled CFD - DEM Simulations for Additive Manufacturing Polymer Melt Flows: Basil Paudel, Baylor University	A Data-driven Reverse Shape Compensation Method to Reduce Large Deformation in Binder Jet Parts: Yuka Yamagata, University of Pittsburgh	Design of Intrinsically Balling-Resistant Alloys: A Physics-informed and Data-enabled Approach: Sofia Sheikh, Texas A&M University	Knowledge Base Development for Mechanical Properties and Energy Consumption of Iron-PLA Composite Filaments in Additive Manufacturing: Brent Vela,	2:40 PM
Optimizing 3D Printed Tourniquets for Immediate Aid in Ukraine: Sean Wise, University of Washington	Robotic Path Planning for the Automated Design of Compositionally Graded Alloys: Daniel Oropeza, Texas A&M University	Reactive Binder Jet Additive Manufacturing for Microstructural Control of Ceramic Components: Bradley Jared, University of California, Santa Barbara	Additively Manufactured Mesoscale Composites: Kyle Wycoff, Oak Ridge National Laboratory		3:00 PM
Shared Teleoperation Architecture for Endoscopic Additive Manufacturing: Frank Liou, The Ohio State University	Modelling Fiber Orientation during Additive Manufacturing Compression Molding Processes: Markus Chmielus, Technical University of Denmark	From Porous to Solid and Back: Densification of Binder Jet 3D Printed Materials: Elizabeth Chang-Davidson, University of Pittsburgh	A Framework for Digital Materials Fabrication Using Directed Energy Deposition Process : Maximilian Binder, Missouri University of Science and Technology		3:20 PM
Stent Design Investigation for Polymeric and Metallic Materials using Finite Element Modeling of the Crimping Process: Richard J Smith, Northwestern University	Validation of Simulation Based Predictions of Recoater Interference in Laser Powder Bed Fusion : John Samuel Dilip Jangam, Autodesk Inc.	Support-free Sintering of 3D Printed Binder Jet Copper Parts and Stainless Steel Parts : Wen Dong, HP Labs	The Measurement of Orientation and Elasticity by Spatially Resolved Acoustic Spectroscopy (SRAS): Jackson Bryant, University of Nottingham		3:40 PM
		Binder Jetting of 316L Process Simulation Tools Evaluation: Ryan Stokes, W.M. Keck Center for 3D Innovation			4:00 PM

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Session Name	Process Development - Large-scale Processing	Process Development - Novel Methods and Processes II	Design for Additive Manufacturing Workshop	Modeling - Process Planning and Scanning Strategies	Materials: Polymers - Material Extrusion	Applications - Aerospace
Room	400-402	408	410	412	415AB	416AB
Chair	Brian Post	Frank Liou	Nicholas Meisel	Brent Stucker	Eric MacDonald	Edward Kinzel
	Oak Ridge National Laboratory	Missouri University of Science and Technology	Pennsylvania State University		University of Texas-El Paso	Univ. of Notre Dame
8:00 AM	A Review of Extrudate Shaping For Large-Scale Additive Manufacturing: Darren Scruggs, Oak Ridge National Lab	High-Resolution Reactive Extrusion Additive Manufacturing: Ruiqi Chen, The University of Texas at Austin		Toolpath Planning for Multiple Build Points using K-Means Clustering: Michael Kirka, Oak Ridge National Laboratory	Recycling PET Bottles in a Fused Granule Fabrication Additive Manufacturing System: Breanne Crockett, Brigham Young University	On-Orbit Fabrication of Spacecraft Structures by Direct Solar Photopolymerization: Abdulmajeed Altassan, Mitsubishi Electric Research Laboratories
8:20 AM	Large-volume, High-viscosity Masked Stereolithography: Jasim Uddin, The University of Texas at Austin	Impact of Zirconia Slurry Doping on 316L Stainless Steel prepared by Laser Powder Bed Fusion for biological/high corrosion applications: Martha Baldwin, Brigham Young University		Intelligent Scan Sequence Generation for Reduced Hot Spots, Residual Stress and Distortion in Multi-laser PBF: Benjamin Bevans, University of Michigan	Induction Initiated Curing of Additively Manufactured Thermoset Composites: Chinedum Okwudire, Texas State University	Lightweight Additively Manufactured Bell Crank: Pratik Koirala, W.M. Keck Center
8:40 AM	Post-processing Volumetric Additive Manufacturing Components: Akash Nivarthi, Technical University of Denmark - Department of Mechanical Engineering	Copper Tape Manipulation for Additive Manufacturing: Ajit Panesar, University of Arkansas		Automated Path Planning for Wire Feeding in Large Format Polymer Additive Manufacturing: Sam Gerdes, Oak Ridge National Laboratory	Ultrasonic Characterization of Sound Speeds in 3D-printed Polymers: Michael Borish, Applied Research Laboratories, The University of Texas at Austin	Experimental Study of Wing Structure Geometry to Mitigate Process-Induced Deformation: Nidhi Munaganuru, Pennsylvania State University
9:00 AM	Robot-guided Electrophotographic Powder Application System for Powder Bed Fusion of Metals by means of Laser Beam: Kazi Md Masum Billah, Fraunhofer IGCV	Continuous Sculpting as a Novel Method to Reduce the Staircase Effect in Solidfreeform Fabrication Processes that are Dependent on Phase Transformation: Joseph Bartolai, STEM and Robotics Academy		Hybrid AM Toolpath Planning via Signed Distance Functions: Alexander Nettekoven, Virginia Tech	Improved Interfacial Bonding of Multimaterial-fused Filament Fabrication Parts: Sam Pratt, University of Houston - Clear Lake	Autonomous Manufacturing of Aerial Vehicles via Robotic Additive Manufacturing and Embedding: Nathaniel Heathman, Virginia Tech
9:20 AM	Evaluating the Mechanical Properties within the Transition Region of Multi-Material Large-Format Extrusion Additive Manufacturing : Camden Chatham, University of Tennessee - Knoxville	High-power Microwave Irradiation for Localized Curing of Opaque Polymer Composites: Mohammad Alshaikh Ali, Lawrence Livermore National Laboratory		Discontinuity-free Additive Manufacturing Strategy for Axisymmetric Components: Michael Juhasz, Oak Ridge National Laboratory	Layerwise Modification of Material Chemistry via UV and Reactive Gas Exposure during Fused Filament Fabrication Additive Manufacturing: Thomas Feldhausen, Savannah River National Lab	Additive Manufacturing of Compliant Mechanisms for Deployable Space Structures: Nadia Hannon, NASA Jet Propulsion Laboratory
9:40 AM	Break	Break	Design for Additive Manufacturing Workshop	Break	Break	Break
10:10 AM	Integration of Plasma-Arc Directed Energy Deposition (PA-DED) system to drive higher fidelity Large Scale Additive Manufacturing of Metals (LSAMM): Yifeng Lin, EWI	Experimental Study for Improved Productivity of Laser-Foil-Printing Additive Manufacturing: Andrew Swanson, Missouri University of Science and Technology		Maxel Framework for Representing and Process Planning of Functionally Graded Materials: Prahalad Rao, STEM and Robotics Academy	FFF Printing of Semi-crystalline PET: Exploring the Effects of Layer Specific Area and Build Rate on Crystallinity and Mechanical Properties: Rajeev Dwivedi, Virginia Tech	Additive Manufacturing Development of an Aerospike Breadboard Engine: Deepak Kumar Pokkalla, Fraunhofer IWS Dresden
10:30 AM	Detecting Layerwise Build Defects Using Low-Cost Imaging and Machine Learning: Gabriel Olaivar, University of Tennessee, Knoxville	Optimizing Build Plate Adhesion of Polymers in Fused Granule Fabrication Processes: Joseph Fisher, Brigham Young University		Cad-To-Scan Planning For Hybrid Manufacturing: Rongxuan Wang, University of Tennessee	Size Effects on Elastic Moduli of Polymers 3D Printed by Fused Deposition Modeling: Tiffany Quigley, University of Illinois Urbana-Champaign	3D Metal Printing of Pure Copper Antenna using Ultrafast Pulse Laser: Mithila Rajeshirke, Korea Polytechnics
10:50 AM	Volumetric Sintering of Polymers via Radio Frequency Additive Manufacturing: Haijun Gong, UT Austin	Use of a Fluid Interface to Reduce Support Structures in Top-down Stereolithography: Joseph Bartolai, Georgia Institute of Technology		Expanding Laser Powder Bed Fusion Processing Space Using Alternative Scan Strategies: Andrew Lang, Carnegie Mellon University	Moisture Absorption of 3D Printing Nylon Filament in Humid Environment: Elizabeth Chang-Davidson, Georgia Southern University	Hybrid Laser Powder Bed Fusion Additive Manufacturing: Application to Microwave Radio Frequency Quarter Wave Cavity Resonators: Amir Asadi,
11:10 AM	Use of a Static Mixing Nozzle to Homogenize Material in Large-Format Extrusion Additive Manufacturing : John Will, University of Tennessee - Knoxville	Infrastructure Scale Additive Manufacturing: Contemporary Concepts and Challenges in Concrete 3D Printing: Sumit Paul, Oak Ridge National Laboratory		Conformal Additive Manufacturing on A Curved Substrate Using Isothermal Surface Slicing: Grant King, Purdue University	High Fidelity Additive Manufacturing of PMDA-ODA Polyimide via Supramolecular Salts: Yujie Shan, Virginia Tech	
11:30 AM	Swarm Manufacturing of a Robotic Vehicle: Joshua Wagner, University of Arkansas	Thermal-Imaging Feedback Control of Glass Additive Manufacturing Deposition Products: Jan-Hendrik Groth, Precision Motion Control Laboratory at Missouri S&T				

Applications: Lattices and Cellular - Lattice Structure Design	Special Session: Data Analytics III - Sensing and Analytics	Physical Modeling - Novel Approaches	Materials: Composites - Polymer-Based Composites	Materials: Metals - Aluminum	Session Name
417AB	Salon A	Salon B	615AB	616AB	Room
Ajit Panesar	Ehsan Dehghan Niri	Wentao Yan	John Obielodan	Mihaela Vlasea	Chair
Imperial College London	New Mexico State University	National University of Singapore	University of Wisconsin-Platteville	University of Waterloo	
Application of Systems Engineering to Lattice Structure Design: A Framework for Requirements Flow Down: William Yerazunis, The Pennsylvania State University	Holistic Development of the Electron Beam Melting Process for Ni-base Superalloys: Feedstock, Process Optimization, Data Analytics, to Component Evaluation: Mohit Yadav, Oak Ridge National Laboratory	A Finite Element Modelling of Densification and Distortion Behaviour of Laser Powder Bed Fusion Processed Inconel 718 Product: Robert Pavlovic, Indian Institute of Technology JAMMU	Additive Manufacturing of Fiber-Reinforced Polymer Composites: A Technical Review and Status of Design Methodologies: Eric Elton, Georgia Institute of Technology	Droplet on Demand Printing of Al-6061 and Pure Aluminum : Phillip Chesser, Lawrence Livermore National Laboratory	8:00 AM
Carbon Design Engine: Powerful Lattice Design Software for Precisely Tuned, High-Performance Products: Alejandro Hernandez, Carbon, Inc.	Monitoring and Flaw Detection during Wire-based Directed Energy Deposition using In-situ Acoustic Sensing and Wavelet Graph Signal Analysis: Subodh Subedi, University of Nebraska - Lincoln	Optimal Truss-Type Supports for Minimal Part Deformation in LPBF: McKay Sperry, University of Wisconsin Madison	Reactive Extrusion Additive Manufacturing of a Highly Loaded Carbon Fiber Reinforced Epoxy: Usama Rifat, University of Texas at Austin	Liquid Metal Droplet Jetting of 4008 Aluminum Alloy: Nicholas Rodriguez, Rochester Institute of Technology	8:20 AM
A Data-driven Approach for Multi-Topology Lattice Transitions: Justin Valenti, Carnegie Mellon University	In-Process Quality Monitoring of Biological Additive Manufacturing Using Machine Learning: Albert To, University of Nebraska-Lincoln	Modified Inherent Strain Method : Nahid Tushar, University of Pittsburgh	Towards Non-Planar Woven Carbon Fiber Composite Surfaces: Johannes Geis, Rochester Institute of Technology	Process-controlled Grading of the Young's Modulus of AlSi10Mg Components Using L PBF: Daniel Meile, Technical University Darmstadt - Product Development and Machine Elements	8:40 AM
Machine Learning-assisted Additive Manufactured Sandwich Structure Design : Joseph Kubalak, Imperial College London	Towards Online Monitoring and Data-driven Control: A Study of Segmentation Algorithms for Laser Powder Bed Fusion Processes: Nandana Menon, University of Texas Austin	Machine Learning-Assisted Prediction of Thermophysical Properties of Nickel-Base Alloys over a Temperature Range : Rajeev Dwivedi, Pennsylvania State University	Investigating the Directed Energy Deposition Additive Manufacturing of Thermoplastic Composites: Md Faysal Khan, The University of Texas at Austin	Investigate the height dependency of the micro-/defect-structure and mechanical properties of additively manufactured AlF357 aluminum alloy: Maximilian Binder, Auburn University	9:00 AM
Load Alignment Ratio – A Novel Lattice Evaluation and Optimization Metric: Christine Gebara, Pennsylvania State University	In- and Ex-situ Optical Signal Correlation in LPBF: Sofia Sheikh, Lawrence Livermore National Laboratory	Designing Calibration-Free Physics-Based Printability Maps for Additively Manufactured Cantor Alloys: Saptarshi Mukherjee, Texas A&M University	Robotic Additive Manufacturing of Thermoplastic Composite Assistive Technology: Guru Charan Reddy Madireddy, University of Texas at Austin	Characterization Techniques for Quantifying Effect of Interlayer Surface Peening on AlSi10Mg: James Brackett, Oak Ridge National Lab	9:20 AM
Break	Break	Break	Break	Break	9:40 AM
Utilizing Lattice Infill Structures to Optimize Weight with Structural Integrity Investigation for Commonly Used 3D Printing Technologies: Frank Brueckner, Tennessee Tech University	Multi-Phenomena Data Fusion for Enhanced Process Monitoring in Laser Powder Bed Fusion (LPBF): Indrajit Nandi, University of Nebraska	Revealing Texture-induced Abnormal Tensile Deformation Behavior in Additively Manufactured Haynes 282 using Crystal Plasticity Simulations: Tunay Turk, Auburn University	Effect of Z-Pin Geometric Parameters on Mechanical Properties of Z-Pinned Additively Manufacturing Composites: Julio Diaz, Oak Ridge National Laboratory	Comparison of Multiple Heat Treatments by Observing Mechanical Properties and Microstructure of LPBF Fabricated Aluminum F357: James McNeil, W.M. Keck Center for 3D Innovation	10:10 AM
Enhancing Aircraft Acoustic Liner Performance with Lattices and Cellular Structures : Chiyen Kim, Pennsylvania State University	In-process Multi-physical Melt Pool Characteristics Sensing and Data Correlation in Laser Powder Bed Fusion : Seth Strayer, Virginia Tech	Computational Fluid Dynamics Data-driven Heat Source Model for Finite Element Process Simulation in Laser Powder Bed Fusion Additive Manufacturing: Alexander K Schroeder, University Of Pittsburgh	Fatigue Analysis of Short Carbon Fiber Reinforced Composite Components Manufactured using Fiber-Reinforced Additive Manufacturing: Shadman Tahsin Nabil, Tennessee Tech University	Effect of Thermal Aging in the Fatigue Life of Hot Isostatic Pressed AlSi10Mg Alloy fabricated from Laser Powder Bed Fusion: Devon Goodspeed, The University of Texas at El Paso	10:30 AM
Using Mean Curvature of Implicitly Defined Minimal Surface Approximations to Generate New Unit Cells for Lattice Design: Alexander Riensche, The Pennsylvania State University	Logistic regression classification to predict regional anomalies in nominally printed volume of separate test pieces : Juan Francisco Reyes Luna, The Boeing Company	An Efficient Surrogate-based Model Optimisation to Predict the Morphology of Inkjet-printed Dielectric Tracks: Jenny Wang, University of Nottingham	Carbon Nanotube-induced Crystallinity in PEEK Nanocomposite Filaments for Additive Manufacturing: Md Faysal Khan, Texas A&M University	Effect of thermal post-processing on microstructure and tensile behavior of additively manufactured aluminum alloys (AlSi10Mg and Scalmalloy) via L-PBF: A comparative study: Hongtao Song, Auburn University	10:50 AM
Exploration and Evaluation of Offset Equation-Based Lattices: Mathew Marinelli, Pennsylvania State University	Prediction of Microstructure in LPBF using Part-level Thermal Simulations, In-process Sensor Data, and Machine Learning: Manoj Kumar Reddy Rangapuram, University of Nebraska–Lincoln	A Multiphysics Modeling Approach to Assess the Powder Bed Characteristics of High Strength Steel in Selective Laser Melting: Brian Post, Missouri University of Science and Technology	A Preliminary Study of Composite-Based Additive Manufacturing (CBAM) Material Properties: Victor Medrano, Rochester Institute of Technology	Study of Different Aging Conditions for Analysis of Microstructure and Mechanical Properties of F357 Alloy Fabricatd in LPBF printer: James Brackett, W.M. Keck Center	11:10 AM
An Experimental Study of Cellular Mechanical Interface in a Bi-material Structure Fabricated by Material Extrusion Additive Manufacturing : Maryam Avateffazeli, University of Louisville		A Multiphysics Computational Framework for Interfacial Fluid - Particle Interaction in Binder Jet 3D Printing: Aidan Brooks, Rice University		The Effect of Heat Treatment on Microstructural and Mechanical Performance of a Laser Powder Bed-fused Al-Cu-Mg-Ag-Ti-B Alloy: As-built Versus T7 Heat Treated : Rencheng Wu, University of Toledo	11:30 AM

NOTES

Session Name	Materials: Ceramics and Glasses	Process Development - Novel Methods and Processes III	Process Development - AM Control	Physical Modeling - Analysis and Experiments	Materials: Polymers - Novel Materials and Processes	Applications - Hybrid Manufacturing and Composites
Room	400-402	408	410	412	415AB	416AB
Chair	Joy Gockel	Guha Manogharan	David Hoelzle	Viktor Sukhotskiy	Johanna Schwartz	Yaoyao Fiona Zhao
	Colorado School of Mines	Pennsylvania State University	Ohio State University	Lawrence Livermore National Laboratory	Lawrence Livermore National Laboratory	McGill University
1:10 PM	Laser Additive Manufacturing of Thermoelectric Bismuth Telluride (Bi2Te3), Earth-Abundant Copper Sulfide (Cu2S) and Silver Selenide (Ag2Se): Geoffrey Rivers, Northrop Grumman	Reducing Porosity of Extruded Fiber Reinforced Thermoplastics with a Vacuum-Assisted Pellet Hopper: Auston Clemens,	Electrostatic Powder Spreading (ESPS) as a Method to Build Multi-Material Powder Bed Fusion Parts: Frye Mattingly, Lawrence Livermore National Laboratory	A Dislocation Mechanism Based Constitutive Model for Hierarchical Anisotropic Materials : Holger Merschroth, Clarkson University	Reliable PEDOT:PSS inks using bio-renewable green co-solvents for Inkjet 3D-printed electronics: Chamara Herath, University of Nottingham	Inserting Components into Geometries Contructed onto Non-standard Substrates for Electronics Packaging: Arun Poudel, Nottingham University
1:30 PM	Additive Manufacturing of Zirconium Carbide by Ceramic On-Demand Extrusion : Lok-kun Tsui, Missouri University of Science and Technology	Active Control of Selective Laser Flash Sintering of Ceramics: Callie Zawaski, UT Austin	A Comparison Of Additive Layer Deposition And Open Molding Of PETG By Fused Pellet Fabrication In A Hybrid Manufacturing System.: David Khanan, Brigham Young University	Characterization of Microscopic Deformation of Materials Using Deep Learning Methods : Tao Liu, Clarkson University	Aerosol Jet Printing of Carbon Nanotubes for Electronic Interconnects: Kavindu Wijesinghe, University of New Mexico	Rapid Three-dimensional Printing of Architected Piezoelectric Structures Using Micro-CLIP: Indrajit Nandi, Arizona State University
1:50 PM	Laser Powder Bed Fusion Additive Manufacturing of Zirconium Carbide: Aja Hartman, Lawrence Livermore National Laboratory	An Ultrasonic Technique to Determine the Onset of Select Laser Flash Sintering: Guoying Dong, University of Texas at Austin	Investigating the Relationship Between In-Process Quality Metrics and Mechanical Response in the L-PBF Process : Christina Nissen, Center for Advanced Vehicular Systems	A Preliminary Study of Microstructural Evolution Modeling for Liquid Metal Droplet Jetting: Francesco Sillani, Rochester Institute of Technology	Opacity Modulation in Additive Manufacturing: Khushbu Zope, HP Labs	Additive Manufacturing of LiNi1/3Mn1/3Co1/3O2 battery electrode material via vat photopolymerization precursor approach: Deniz Ebeperi, UTEP
2:10 PM	Ceramic On-Demand Extrusion of ZrB₂-SiC Microchannels for Ultra High-Temperature Compact Heat Exchanger : Lindsey Bezek, Missouri University of Science and Technology	A Study on the Effect of Heating on the Ceramic Suspension for Maximizing the Solid Loading in the Vat Polymerization Process: Li Yang, Chung-Ang university	Influence of Micro-scale Zig-zag Interlock on the Adhesion Strength of Multi-material Interface Printed by Material Extrusion Additive Manufacturing: Seungjae Han, Université de lorraine, CNRS, Arts et Métiers ParisTech, LEM3	CalPhaD Method Contribution to Optimize Heat Treatments on a Ti-6Al-4V Additive Manufactured Alloy: Hui Wang, CEA	Effects of UV Overcuring in Multi-Material Jetting Additive Manufacturing : Christophe Voltz, Virginia Tech	Design and Fabrication of Cost-Effective, Light-Weight Bipolar Plate for PEM Fuel Cells using FDM Process: Austin Whitt, Indian Institute of Technology Jammu
2:30 PM	Printed Photonics Using Single Mode Optical Fiber: Yizhen Zhu, Univ. of Notre Dame	Multiplexed 3D Printing of Thermoplastics: Nikola Dudukovic, Rutgers University	Laser Line Profile Scanning for Powder Bed Measurement: Jeremy Cleeman, Georgia Institute of Technology	Digitally Twinned Additive Manufacturing: Real-time Detection of Flaws in Laser Powder Bed Fusion by Combining Thermal Simulations with In-Situ Meltpool Sensor Data: Kun-Chieh Chien, University of Nebraska	Investigation of Mechanical Properties of Structures fabricated by Continuous Volumetric Photopolymerization based 3D Printing: Prahalad Rao, Arizona State University	Additive Manufacturing of Mixed Potential Sensors for Natural Gas Emissions Monitoring: Jakob Hamilton, University of New Mexico
2:50 PM	Break	Break	Break	Break	Break	Break
3:20 PM	Direct-Writing SiC with Micro-Cold Spray: Effect of Particle Impact Velocity on Film Morphology: Hongtao Song, University of Texas at Austin	Effects of Varied Support Structure Strategies on the Melt Pool Temperature and Mechanical Properties of SS316L in Laser Powder Bed Fusion: Shawn Hinnebusch, Mississippi State Univ	Melt Pool Feature Extraction, Spatial Registration and Layer-to-Layer Control in Powder Bed Fusion: William Young, Missouri University of Science & Technology	Incorporating Physical Property Measurements in DEM for Modeling AM Powders: Ioannis Bitharas, Rice University	Aging Behavior of UV Curable PDMS Developed for Large-scale, High Viscosity Stereolithography: C. Fred Higgs III, UT Austin	Reactive Extrusion Additive Manufacturing (REAM) of Functionally Graded Field-Responsive Thermoset Composites : Mianqing Yang, University of Texas at Austin
3:40 PM	Direct Write of Zinc Oxide Films by Micro Cold Spray: Kubra Sekmen, University of Texas at Austin	Decoupling Control of Processing Conditions for Hybrid Manufacturing Systems with ROS: Celeste Atkins, Oak Ridge National Lab	A Hierarchical V-Network Framework for Part Qualification in Metal Additive Manufacturing: Kyle Saleeby, Pennsylvania State University	Calibration of the Johnson-Cook Material Model for Additively Manufactured 304LSS Parts: Modeling and Experiments: Joerg Volpp, Missouri University of Science and Technology	Material Modelling of the Photopolymers for Additive Manufacturing Processes: Siva Sai Krishna Dasari, Laboratoire de Mécanique des Solides (LMS), CNRS, Ecole Polytechnique	Concrete Additive Manufacturing and Its Use in Energy Storage: Emilie Valente, Oak Ridge National Laboratory
4:00 PM	Single Particle Impacts in Micro Cold Spray: Aditya Chivate , The University of Texas at Austin	Convolutional Autoencoder for Image Denoising AM Process Monitoring: Eric Weflen, University of Massachusetts Boston	Characterization of Defects within AM Fabricated Metal Components: Jaison Mneyergi, University of Massachusetts Boston	Numerical and Experimental Characterization of the Dynamic Properties of As-built 316L Components Produced via Laser Powder Bed Fusion: Sanam Gorgannejad, Mississippi State University	Study of Proximity Effect in Projection-based Micro Stereolithography Process: David Failla, University at Buffalo	Comparing Additive Approaches: Manufacturing a Wind Turbine Structural Component: Joseph Bartolai, Oak Ridge National Laboratory
4:20 PM	Lightweight, Electrically Conductive, and Thermally Insulating porous ceramics through Stereolithography 3D Printing: Krzysztof Nauka, State University of New York at Buffalo	Closed Loop Control Utilizing in Situ Pattern Printing and Reading for Quality Level Determination in Additive Manufacturing: Stefan Mischliwski, HP Labs	Design of an In-situ Microscope for Selective Laser Sintering: Aja Hartman, University of Texas Austin	Anticipating Build Risk of Complex Geometries Using Commercial Additive Manufacturing Simulation Tools: Aiden Martin, Naval Surface Warfare Center, Carderock Division	Powder Bed Fusion of Polymers with Ultraviolet Light Emitting Diode Energy Sources: Adam Gershen, HP Inc	Hybrid Additive and Subtractive Manufacturing of Self-Heating Tooling: Katherine Fowler, Iowa State University
4:40 PM	Study on Development of DLP Printed Metal - Ceramic Structures: Wenqi Li, Youngstown state university	As-built Mechanical Property Estimation and Control of Laser Powder Bed Fusion SS-316L Parts: , Miami University				Clamping Concept for 6-side Hybrid Manufacturing: Qilin Guo, Carolinum, Goethe University Frankfurt

Applications: Lattices and Cellular - Heterogeneous Lattice Structures	Process Development - Process Monitoring	Physical Modeling - Part-Scale Modeling	Materials: Metals - Ferrous Metals including 17-4PH	Materials: Metals - Titanium	Session Name
417AB	Salon A	Salon B	615AB	616AB	Room
Grace Gu	Douglas Bristow	Bradley Jared	Dhruv Bhate	Allison Beese	Chair
University of California, Berkeley	Missouri Univ of Science & Technology	University of Tennessee, Knoxville	Arizona State University	Pennsylvania State University	
Evaluation of Functionally Graded Lattice Properties of Laser Powder Bed Fused Stainless Steel 316l: Robert Plant, University of texas at dallas	Evaluation of Solidification in PBF-LB Using a High Speed Camera: Daniel Moser, Institute of Production Management, Technology and Machine Tools, TU Darmstadt	Towards Tractable, Fully Time-resolved Simulations of Engineering Scale Parts Built using the Laser Powder Bed Fusion Process: Eric Elton, Sandia National Laboratories	Effect of Powder Characteristics on Fatigue Performance of Additively Manufactured 17-4 PH Stainless Steel: Muztahid Muhammad, Auburn University	Effect of defects on the mechanical properties of laser powder bed fused Ti-6Al-4V: Eric Fodran, Auburn University	1:10 PM
Electrodeposition of Metals onto 3D-Printed Lattices: Siying Liu, Lawrence Livermore National Laboratory	In-Situ Infrared Thermographic Measurement of Powder Properties in Laser Powder Bed Fusion: Nicholas Piercy, Missouri University of Science and Technology	Thermal Modeling of Wire Arc Additive Manufacturing using Spectral Graph Theory: Alex Gibson, University Of Nebraska - Lincoln	Defect-sensitive Fatigue Modeling for L-PBF Parts in Very High Cycle Regime : Aditya Krishna Ganesh Ram, Auburn University	Development of Composite-like Parts using SLM: Clare Sabata, University of Texas at Arlington	1:30 PM
Fused Filament Fabrication of a Multi-material Metamaterial for Tailored Compliance: Ana Martinez, Penn State	In-situ Microwave Tomography for Temperature Monitoring during Powder Bed Fusion of Polymers: Saad Khairallah, Inspire AG	Fundamental physics effects of background gas species and pressure on vapor plume structure and spatter entrainment in laser melting: Bradley Sampson, Lawrence Livermore National Laboratory	Embedding Information in Additively Manufactured Metals via Magnetic Property Grading for Traceability and Counterfeiting Prevention: Arun Poudel, Texas A&M University Department of Materials Science and Engineering	Key Process Variable Drifts and their Impact on Defect Structure and Tensile Behavior of L-PBF Ti-6Al-4V: Alexander Wilson-Heid, Auburn University	1:50 PM
Experimental and Numerical Analysis of Lattice Structures with Different Heterogeneities: Rajkumar Velu, University of Colorado Denver	In Situ High-speed X-ray Imaging of the Alloying Process via Laser-based Directed Energy Deposition with Dissimilar Powders: Md. Tusher Mollah, Texas A&M University	Investigation on corner precision at different corner angles in material extrusion additive manufacturing: An experimental and computational fluid dynamics analysis: Fangkai Xue, Technical University of Denmark	A Process Optimization Framework for Direct Energy Deposition: Densification, Microstructure, and Mechanical Properties of an Iron-chromium Alloy: Mohammad Bagher Mahtabi, Texas A&M	Effect of Powder Reuse on Microstructural and Fatigue Properties of Ti-6Al-4V Fabricated via Directed Energy Deposition: Abid Hasan Rafi, University of South Alabama	2:10 PM
A Limited-scale Experimental Investigation of the Unit Cell Topology Effects of Interpenetrating Compound Cellular Structure Designs: Lok-kun Tsui, University of Louisville	Key Wavelength Selection for Optical Emission Spectroscopy Metrology of Direct Metal Laser Sintering: Amit Verma, UT Austin	Rapid Qualification of Wire Feed Direct Energy Deposition Process Builds using ICME Approach: Jaime Berez, Carnegie Mellon University	Visualization of Melt Pool Stability for Wire- and Powder-based Directed Energy Deposition Repair of Gray Cast Iron: Shaun Whetten, Rochester Institute of Technology	Hot Isostatic Pressing to Increase Isotropic Behavior of Wire DED Ti6Al4V: Edward Kinzel, Sandia National Labs	2:30 PM
Break	Break	Break	Break	Break	2:50 PM
Cellular Fluidics: Tuning Multiphase Interfaces in 3D Using Architected Porous Media: Carolyn Seepersad, Lawrence Livermore National Laboratory	Laser-material Interactions in LPBF, Visualised through Simultaneous X-ray and Schlieren High-speed Imaging: Albert To, Heriot-Watt University	Effect of Scanning Strategies on Defects Generated by Lack of Fusion during Laser Power Bed Fusion: A Part-Scale Finite Element Simulation Study : Xin Wang, University of Pittsburgh	Directed Energy Deposition Processing-Performance Relationship of AF9628: Jonathan Pegues, Missouri University of Science and Technology	Heat Treatment Effects on Mechanical Properties of Electron Beam Additive Manufactured Ti-6Al-4V: Derek Davies, Sandia National Laboratories	3:20 PM
Optimized Dissolvable Support Design for 316L Stainless Steel Produced by Laser Powder Bed Fusion : Celeste Atkins, University of Pittsburgh	Powder Movement and Spattering during Green Laser Powder Bed Fusion of Copper: Albert To, Luleå University of Technology	Enabling Part-Scale Scanwise Process Simulation of Laser Powder Bed Fusion by Combining Matrix-free Finite Element Modeling, Adaptive Remeshing, and GPU Computing: Byeong-Min Roh, University of Pittsburgh	Alternative Stainless Tool Steels for Additive Manufacturing: Joshua Mochache, Technical University of Denmark	Characterization of the Fatigue Strength of Additively Manufactured Ti-6Al-4V Specimens with Residual Stress and Recoater Blade Interference Flaws : Scott Burlison, University of Texas Arlington	3:40 PM
	Process Monitoring for Pore Detection using in situ X-ray Imaging and Pyrometry Signal: Roozbeh Salajeghe, Lawrence Livermore National Laboratory	Investigating the Influence of Thermal and Mechanical Properties of Resin on the Sedimentation Rate of Components Produced by Volumetric Additive Manufacturing: Admas Kedebe, Technical University of Denmark	Effect of Surface Preparation on LPBF 17-4PH Mechanical Properties: Mohammad Bagher Mahtabi, Pennsylvania State University	Effects of Process Interruption during Laser Powder Bed Fusion on the Microstructural and Mechanical Properties of Fabricated Parts: Aidan Moyers, University of South Alabama	4:00 PM
	Process Monitoring of Laser Powder Bed Fusion Additive Manufacturing using Thermionic Emission Detection: Santosh Rauniyar, Lawrence Livermore National Laboratory	Transient Nature of the Raster Scan Areas in the Laser Powder Bed Fusion Process: Doug Sassaman, University of Louisville	Comparison of Tensile Properties and Microstructure of Laser-Powder Bed Fusion 17-4PH Stainless Steel: Zipeng Guo, Naval Surface Warfare Center, Carderock Division		4:20 PM
	Towards Inline Material Microstructure Imaging using Spatially Resolved Acoustic Spectroscopy (SRAS): Shawn Hinnebusch, University of Nottingham	Layerwise Thermal Process Simulation for Laser Powder Bed Fusion: Calibration and Validation with Infrared Camera: Xinyi Xiao, University of Pittsburgh	Phase Transformation Dynamics-guided Alloy Design for Additive Manufacturing: Bharat Yelamanchi, University Of Wisconsin Madison		4:40 PM

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Poster Session	
Salon JK	
Multi-Stage Additive Manufacturing Process for Multi-Scale Porous Structures: Zipeng Guo, State University of New York at Buffalo	Support Free Directed Energy Deposition: William Dong, University of Wisconsin-Madison
Computational Fluid Dynamics Data-driven Heat Source Model for Finite Element Process Simulation in Laser Powder Bed Fusion Additive Manufacturing: Seth Strayer, University Of Pittsburgh	Wire-arc Fabrication of Topology Optimized Aviation Components: Sam Pratt, Virginia Tech
Layerwise Thermal Process Simulation for Laser Powder Bed Fusion: Calibration and Validation with Infrared Camera: Shawn Hinnebusch, University of Pittsburgh	Biopolymer Composites with Dairy Protein for Use in Additive Manufacturing: Maia Delwiche, University of Wisconsin-Platteville
GPU-accelerated WAAM Process Simulation using an Improved Modeling Workflow: Xavier Jimenez, University of Pittsburgh	Construction of Laboratory-Scale Binder Jetting System for High-Speed Synchrotron X-Ray Imaging: Jacob Lawrence, Brigham Young University
Evaluation of Direct Ink-write Additive Manufacturing: Sidney Scott, Los Alamos National Laboratory	Origami Expandable Printing using Fused Granular Fabrication and Fabric Substrates: Victoria Stone, Brigham Young University
Reducing Part Distortion in Laser Powder Bed Fusion through Data-driven Topology Optimization: Praveen Vulimiri, University of Pittsburgh	Computational Modeling and Experimental Validation of Primitive Formation in Binder Jet 3D Printing: Joshua Wagner, Rice University
Processing Evaluation of Al-4008 (Al-Si-Mg) Alloy via Liquid Metal Jetting-based Additive Manufacturing: Kellen Traxel, Lawrence Livermore National Laboratory	Data-driven Surrogate Model for Laser Powder Bed Fusion Part - Process Design : Jannatul Bushra, University of Arizona
Preventing Recoater Crash in Laser Powder Bed Fusion via Modified Inherent Strain Modeling: Wen Dong, University of Pittsburgh	Characterization and Validation Experiments for a Binder Jet 3D Printing Modeling Framework: Wesley Combs, Rice University
X-ray Tomography as a 3D Metrology Technique for AM Materials: Bryan Hunter, Materials Science and Technology Division, Los Alamos National Laboratory	Developing a Roadmap to Manufacture Feedstocks for Selective Laser Sintering: Peter Braegelmann, Los Alamos National Laboratory
Localized Curing of Thermoset Composites via Microwave Irradiation: Johanna Schwartz, Lawrence Livermore National Laboratory	Intelligent Scan Sequence Optimization for PBF Additive Manufacturing of Complex Geometries: Chuan He, University of Michigan
Optimization of Vat Photopolymerization Parameters for LiCoO₂ Battery Electrode Manufacturing : Ana Aranzola, University of Texas at El Paso	Monitoring and Flaw Detection during Wire-based Directed Energy Deposition using In-situ Acoustic Sensing and Wavelet Graph Signal Analysis: Benjamin Bevans, University of Nebraska - Lincoln
Interlayer Mechanical Properties of Thermoset Components Produced by Material Extrusion Additive Manufacturing: Jonathan Pedersen-Bjergaard, Technical University of Denmark	Prediction of Microstructure in LPBF using Part-level Thermal Simulations, In-process Sensor Data, and Machine Learning: Grant King, University of Nebraska–Lincoln
A Literature Review of the Application of M300 Maraging Steel for Laser Powder Bed Fusion : Haley Petersen, Center of Advanced Vehicular Systems	In-situ Monitoring and Prediction of Porosity in Laser Powder Bed Fusion using Physics-informed Meltpool Signature and Machine Learning: Ziyad Smoqi, University of Nebraska-Lincoln
X-ray Analysis of Magnetically Induced Additive Manufacturing: Ronald Sellers, Texas A&M University	Feedforward Control of Laser Powder Bed Fusion Process: Alexander Riensche,
A Data-driven Reverse Shape Compensation Method to Reduce Large Deformation in Binder Jet Parts: Basil Paudel, University of Pittsburgh	Immersed Electrohydrodynamic Direct Writing: Fabrication of Nanofiber-reinforced Composites with Spatially Controlled Distribution: Ping Guo, Northwest Institute for Nonferrous Metal Research
A Low Cost, Flexible Sensor Architecture for Process Monitoring in Metal Casting with 3D Printed Sand Molds: Janely Villela, University of Texas at El Paso	Melt Pool Size Control in LENS Direct Metal Deposition : Douglas Bristow, Missouri Univ of Science & Technology
Investigation of Wear Behavior of Centrifugal Disc Finishing on Additively Manufactured Ti6Al4V Samples : Foxian Fan, Penn State University	Digital Twin Research and Development for an Additive Manufacturing Cell: Frank Liou, Missouri University of Science and Technology
Finite Element Modeling of Material Deposition for 5-axis Additive Manufacturing: Liv Russell, Mississippi State University	Development of a Hybrid Carbon Fiber Composites Additive Manufacturing Machine: Xiangyang Dong, Missouri University of Science and Technology
Thermal History Validation of Directed Energy Deposition Process: Usman Tariq, MISSOURI UNIVERSITY OF S&T	Print Initiation and Termination in Glass Additive Manufacturing: Douglas Bristow, Missouri Univ of Science & Technology
Simulation of Curing Behavior with Temperature Dependent Kinetic Constants in Vat Photopolymerization: Yue Zhang, University of Pittsburgh	Four-Axis Coordinated Motion for Glass Additive Manufacturing: Douglas Bristow, Missouri Univ of Science & Technology
Development of Standards Education Modules for Robotics and Additive Manufacturing : Haijun Gong, Georgia Southern University	Metal Additive Manufacturing for Advanced Materials by Laser Foil Printing: Jonghyun Park, Missouri University of Science and Technology
Direct Writing of Thick, Patterned Films of Ag by Micro Cold Spray: Aditya Goyal, University of Texas at Austin	Soybean-Derived Printed Graphene Structures via Aerosol Jet Printing Process : Jonghyun Park, Missouri University of Science and Technology
Investigations for the Optimization of Metal Freeforming using the ARBURG freeformer: Nikolai Krischke, Karlsruhe Institute of Technology - wbk	Additive Manufacturing of Embedded Sensors with Laser Foil Printing Method: Ming Leu, Missouri University of Science and Technology
Feedback Control Development for Glass Additive Manufacturing: Andre Bos, Los Alamos National Laboratory	

Plenary Session

Monday AM — Room: Salon HJK
July 25, 2022 — Location: Hilton Austin Hotel

8:00 AM Introductory Comments

8:15 AM
Use of Extreme Value Statistics for Establishing Process-Porosity-Fatigue Relationships in Laser Powder Bed Fusion Additive Manufacturing: *Sneha Prabha Narra*[1]; [1]Carnegie Mellon University

The process-induced defects and microstructural inhomogeneities in laser powder bed fusion processed parts contribute to undesirable variation in fatigue properties. We introduce a process qualification framework for Ti-6Al-4V that involves process mapping, characterization, fatigue testing, and statistical analysis. We apply concepts from the statistics of extremes to model the upper tail of the pore size distribution, a major determinant of fatigue performance and scatter. During analysis, we apply the peaks-over-threshold method to identify the upper tail of a pore size distribution and then estimate the critical defect size in the material. Furthermore, we present the effects of varying processing parameters on the critical defect size and compare those with crack initiating defect size and fatigue life from four-point bending fatigue tests. The results demonstrate the existence of a fatigue-based process window and accurate estimation of critical defect size determining the fatigue life.

8:40 AM
Accelerated Material Adoption in Laser Powder Bed Fusion: *Mihaela Vlasea*[1]; Sagar Patel[1]; Jigar Patel[1]; [1]University of Waterloo

The complexities of laser-material interaction for laser powder bed fusion require innovative approaches to accelerate material adoption. A combination of physics-driven LPBF processing diagrams, melt pool simulations, beam path planning, and advanced material characterization including X-ray computed tomography, in situ optical tomography, and in situ powder bed imaging can be used in the process parameter development cycle. An example of this workflow is illustrated for LPBF of high reflectivity materials such as Cu and Al alloys, which poses processing challenges of porosity and cracking. Our efforts to careful control of vaporization during LPBF are expected to lead to high density parts for such challenging alloys.

9:05 AM
Fabrication of Biomimetic Functional Materials and Structures via Multiscale Nanocomposite Printing: *Xiangjia Li*[1]; [1]Arizona State University

After billions of years' evolution, nature has developed high-performance biological structures and smart material systems, providing inspiration for the design of next-generation smart materials, as well as a variety of excellent mechanical, hydrodynamic, optical, and electrical properties. However, traditional design and fabrication technologies show significant disadvantages in reproducing sophisticated structural architectures in nature and therefore hinder the progress of biomimetic study and its applications in engineering systems. Additive manufacturing (AM), in contrast, has created new opportunities for producing products with complex geometric designs. This talk will introduce a novel nanocomposite printing method and outline major methods to mimic nature's material systems with superior functional properties, covering topics about composite material, design, simulation, optimization, AM, and performance validation. Additionally, this talk will highlight ongoing issues in the area of bioinspired design and manufacturing and put forward the potential future approach to tackle demanding engineering challenges.

9:30 AM
Operando Imaging of Directed Energy Deposition Additive Manufacturing: *Sarah Wolff*[1]; [1]Texas A&M University

The laser-based powder-blown directed energy deposition (L-DED) additive manufacturing process is promising for its fabrication of complex, multi-material metallic parts with superior mechanical parts for a wide range of applications. However, porosity in L-DED parts is common due to rapid solidification and can pose obstacles in qualification and certification. This talk will discuss the fundamental interactions between in-flight powder particles and the underlying melt pool that lead to porosity in the process. High-speed synchrotron X-ray imaging (up to 80,000 fps) experiments at the 32-ID beamline at the Advanced Photon Source in Argonne National Laboratory show porosity mechanisms that originate from feedstock powders, laser attenuation during deposition, the interplay between the kinetic and surface energies during deposition, as well as particle characteristics of shape, size, and chemical composition. In addition, work with external magnetic fields and mixing dissimilar materials for both porosity control and alloy development will be discussed.

9:55 AM
Design for Additive Manufacturing – from Pure Complexity to Multi-functionality: *Yaoyao Fiona Zhao*[1]; [1]McGill University

Since Additive Manufacturing (AM) processes can fabricate complex part shapes and material compositions, it released significant amount of freedom for designers to design innovative products. In general, parts that are good candidates for AM tend to have complex geometries, low production volumes, special combinations of properties or characteristics. Most of existing design methods and approaches are well established for conventional manufacturing processes which tend to limit the complexity and potential multi-functionalities of products considerably. Given the unique characteristics of AM, Prof. Zhao and her team have conducted pioneering research in Design for AM (DFAM) field. In this talk, Prof. Zhao will report her recent work on developing novel design strategies and geometric modeling techniques to support multi-functional design concept generation and multi-scale highly complex CAD model realization with manufacturability analysis applied at early design stage.

10:20 AM Break

10:50 AM
Generative Design and Additive Manufacturing of Three-dimensional Architected Metamaterials: *Grace Gu*[1]; [1]University of California, Berkeley

Architected cellular structures are oftentimes known for their superior mechanical properties such as high strength-to-weight ratio and damage tolerance. The mechanical properties of architected cellular materials are governed by their base materials and multi-scale hierarchical structures. We will first present novel computational approaches based on advanced optimization algorithms and machine learning techniques to design architected cellular materials at multiple length scales, from several nanometers to centimeters. Additive manufacturing (AM) is a promising technology to create architected cellular materials with complex structures. However, current AM techniques are not robust when it comes to defects. In the second part of this talk, we will discuss how to improve the printing quality of AM by incorporating sensor technologies and machine learning algorithms to adaptively adjust process parameters in real-time. This framework will ultimately lead to the discovery of highly versatile metamaterials, opening up unexplored possibilities in the field of materials design and manufacturing.

11:15 AM
An Overview of Key Results in Wire-based DED in the WAAMMat Programme: *Filomeno Martina*[1]; Stewart Williams[2]; J Ding[3]; W Suder[4]; Alec Davis[5]; Philip Prangnell[6]; [1]WAAM3D Limited; [2]Cranfield Univ; [3]WAAM3D Limited and Cranfield University; [4]Cranfield University; [5]University Of Manchester; [6]The University of Manchester

The talk will cover some of the key aspects of the work on large-scale metal AM carried out at Cranfield University (within the WAAMMat programme) and WAAM3D. Firstly in-process cold-work via rolling and machine hammer peening, which has an instrumental role in achieving forged-like microstructure in alloys of titanium, iron and nickel; as well as its effect on residual stress and mechanical properties. Secondly, a new Wire Arc Additive Manufacturing variant based on multiple wire feeds, which has enabled deposition rates of 15kg/h whilst resulting in improved microstructures thanks to better control of the thermal field. Finally, future research directions, featuring the new multi-energy source concept using both of arc and laser sources to achieve even higher deposition rates without compromising accuracy and structural integrity.

11:45 AM

Invention and Development of Contour Crafting, Selective Inhibition Sintering, and Selective Separation Shaping: *Berok Khoshnevis*[1]; [1]Unviersity of Southern California

Three Additive Manufacturing technologies, Contour Crafting (CC), Selective Inhibition Sintering (SIS), and Selective Separation Shaping (SSS) have been conceived, developed and offered to the commercial market by the speaker. The tale of CC is that of a passionate effort which started from its simple beginning and continued to home building, to building on the Moon and Mars and more. SIS started with polymeric part printing and evolved to a technology for printing metallic parts. SSS was inspired by a specific NASA project need for construction of Lunar landing pads and quickly expanded into a general AM technology for printing with high temperature metals and ceramics. The presentation will show that traversing such paths has only been made possible by strong belief in the essence of each idea and its potential impact, as well as a passion which provided the energy to hold on and sustain in spite of unfavorable circumstances.

Applications: Lattices and Cellular - Fabrication and Testing

Monday PM	Room: 417 AB
July 25, 2022	Location: Hilton Austin Hotel

1:30 PM

Digital Image Correlation of Architected Materials: Challenges, Lessons Learned and Opportunities: *Irving Ramirez-Chavez*[1]; Jarom Hatch[2]; Charles-Olivier Amyot[2]; Dhruv Bhate[1]; [1]Arizona State University; [2]Trillion Quality Systems

Digital Image Correlation (DIC) is a non-contact, optical technique for the measurement of full-field displacements and strains, most typically during a mechanical test. The benefit of DIC in the study of additively manufactured architected materials such as honeycombs, lattices, and sheet-based cellular structures, stems from the heterogeneous state of strain in these structures that is a result of their complex geometry and its interaction with applied loads. However, architected materials, with their small feature sizes and large deformation capabilities, present some challenges for DIC. These include sensitivity to speckle pattern, loss of data at large global strains, and handling of noise during post-processing. In this presentation, we discuss our efforts in applying DIC to the study of compression behavior in several studies spanning honeycombs and sheet-based architected materials, with single and dual-phases. This forms the basis for a discussion of lessons learned, and for identifying opportunities for further study.

1:50 PM

Insight into Compressive Behaviour of Schwarz-P Lattices Fabricated by Material Extrusion: Piyapat Jameekornkul[1]; *Ajit Panesar*[1]; [1]Imperial College London

Lattice structures are increasingly being chosen for lightweight applications due to their high strength-to-weight ratio and energy absorption capability. This work investigates the mechanical performance of the Schwarz-P (SP) lattices with a range of unit-cell sizes and densities. The SP lattices were fabricated using material extrusion with ASA (industrial grade) material and tested along different orientations to build plate. A new shear test method adapted from the standard rail shear method was used for reporting shear properties. The Digital Image Correlation (DIC) was utilised to measure the local strain and deformation mechanism. The preliminary results indicate that stiffness and strength were related to densities abiding the Ashby-Gibson model in well-controlled tight bands which will help inform design decisions for future adoption. Further experiments will be conducted to improve the accuracy of the results, gain better understanding of graded lattices and provide insights on possible use of fibre-reinforcement in lattices.

2:10 PM

Beam Deletion in Square Honeycombs for Improved Energy Absorption Under Quasi-static In-Plane Compression: *Irving Ramirez-Chavez*[1]; Christine Lee[2]; Dhruv Bhate[1]; [1]Arizona State University; [2]Interwoven Labs

When selecting cellular materials for energy absorption applications, there have traditionally been two choices: a periodic structure such as a honeycomb, or a stochastic one, as seen in foams. Both choices involve a global definition governing the allocation of the members of the structure, be they beams or surfaces. With Additive Manufacturing, the exploration of more complex structures enables the creation of aperiodicity through the local perturbation of periodic structures. This paper explores one application of this approach by deleting beams in square honeycombs, with the aim of avoiding localization of failure that generates significant undulations in the stress plateau under in-plane quasi-static compression. These perturbed structures show improved energy absorption behavior by generating higher Specific Energy Absorption for a given transmitted stress and relative density than their periodic counterparts. This work thus argues for further exploration of localized aperiodicity as an approach to finely tune energy absorption performance.

2:30 PM

Slender Energy Density for Improved Process Mapping with Lightweight Features Fabricated by Powder Bed Fusion: *Naresh Koju*[1]; Li Yang[1]; [1]University of Louisville

Conventional energy density is the most used parameter for optimizing the process and quality of the PBF-AM process. However, this energy density requires more careful evaluation for thin features (< 1 mm). Generally, the effect of contour scanning can be neglected, and energy density for bulk parts can be calculated with hatch scanning only. On the contrary, for thin features, the energy applied during both contour and hatch scanning can be significant as their dimension are close to laser spot size, and hatch spacing values. The slender energy density (Es) is proposed to incorporate energy from both contour and hatch scans in the energy density equation. The significance of slender energy density for thin struts is explored in this study by evaluating its effects on geometry, porosities, microstructures, and mechanical properties. The results suggest better consistency of slender energy density with existing knowledge of material energy density during PBF-AM processing.

2:50 PM

The Effects of Powder Feedstock and Process Parameters on the Material Characteristics of Ti6Al4V Thin Strut Features Fabricated by Laser Powder Bed Fusion Additive Manufacturing: *Naresh Koju*[1]; Jonah Hermes[1]; Sumit Paul[1]; Sayed Saghaian[1]; Li Yang[1]; [1]University of Louisville

In this work, three different types of Ti6Al4V powder feedstock of different particle size ranges (fine, medium, and coarse) were utilized to fabricate thin strut lightweight features using laser powder bed fusion additive manufacturing (L-PBF-AM) using different process parameter settings. Thin strut features of varying dimensions from 0.1mm to 0.5mm were fabricated. The resulting sample sets allow for the analysis of the compound powder feedstock-process-geometry-material (PPG-M) characteristics for lightweight features fabricated by L-PBF-AM, which have not been previously explored. Various material characteristics, including porosity, grain size, geometry quality, and mechanical properties of the thin strut samples were experimentally determined and analyzed. The results clearly demonstrated the significance of the compound PPG-M relationships for lightweight structures, which calls for further studies to "re-establish" the knowledge base for L-PBF-AM materials at small dimension scales.

3:10 PM Break

3:40 PM
Optimization of Print Parameters for Ti-5553 Skinned Lattice: *Gabe Guss*[1]; Steven Hoover[1]; Ava Ashby[1]; Gabriel Balensiefer[1]; Jenny Wang[1]; Nick Calta[1]; [1]Lawrence Livermore National Laboratory

Ti-5553 is an important alloy for complex LPBF geometries, due to its beta phase stabilization resulting in lower residual stresses. Aerospace parts are being light-weighted, by replacing bulk parts with lattice using topology optimization approaches. These parts consist of bulk regions, skin regions and strut regions, all of which require different printing parameters to generate the correct qualities. In this presentation, I will show iterative DOE's (Design Of Experiments), for 1 cm^3 cubes, 0.2x1 cm thin walls, and 1x1x0.5 cm 10% dense octet truss unit cell lattices. Measurements of dimensionality, porosity and surface roughness are used to build a response surface against power, speed, spot size and hatch spacing, along with scan path type allowing the ability to narrow in on a set of printing parameters for a required application. A comparison of traditional DOE approaches versus commercially available DOE tools, Senvol and Intelligens.ai will be evaluated.

4:00 PM
Manufacturability Thresholds for Powder Bed Fusion of Ti-6Al-4V Lattices: A Study of Defects and Dimensional Accuracy: *Mohammad Reza Vaziri Sereshk*[1]; Eric Faierson[1]; [1]Quad City Manufacturing Lab- Western Illinois University

Applications for Ti-6Al-4V lattice structures produced through additive manufacturing are growing in defense and biomedical industries. Lattice structures can reduce weight and improve energy-absorption capacity in protection applications, or match properties with surrounding bone, and function as tissue scaffolds in biomedical applications. The degree to which 3D-printed lattice structure matches the original solid model depends on a number of factors, some of which include: type of additive manufacturing process utilized, orientation of lattice structure on build plate, type of lattice structure, and material utilized. Although some thresholds on dimension and orientation for 3D-printing of simple rod or plate can be found in literature, the large number of variables that influence lattice 3D-printing require thorough investigation. In this study, a wide range of strut-based and surface-based lattices were designed and fabricated in order to study defects and dimensional accuracy. Manufacturability limitations and mechanical properties for 3D-printed Ti-6Al-4V lattices will be presented.

4:20 PM
Surface-based Lattice Structures as Candidates for Heat Exchangers: *Daniel Padrao*[1]; David Hancock[2]; Frank Schoofs[2]; James Paterson[2]; Christopher Tuck[1]; Ian Maskery[1]; [1]University of Nottingham; [2]United Kingdom Atomic Energy Authority

Heat exchangers are integral for many different fields. Their performance can be enhanced through the inclusion of non-conventional designs. Additive manufacturing enables the creation of complex structures with greater surface-to-volume ratios than standard pin/fin arrays and pipes. Here, the hydraulic and thermal performance of gyroid and primitive lattice structures were examined numerically. They exhibited volumetric heat transfer coefficients an order of magnitude greater than a cooling pipe, but also exhibited much larger pressure drops. The primitive lattice was determined to be a poorer candidate for heat exchangers due to the large variation of channel diameter, which impeded fluid mixing. This was quantified by maximum volumetric heat transfer coefficients of 1.3 Wm-3K-1 and 2.1 Wm-3K-1 for the primitive and gyroid lattice structures, respectively. Finally, predictive models for pressure drop and volumetric heat transfer coefficient were determined, which can be used to design heat exchangers with pre-defined performance requirements.

4:40 PM
Characterization of Thermophysical Properties for Additively Manufactured Porous Media: *Alden Packer*[1]; [1]Penn State University

Porous structures are broadly applicable in many applications such as heat pipes, light-weight structures, bio-mimetic surfaces, batteries, and fuel cells. Each application has unique material and geometry requirements for these structures. Traditional porous materials are fabricated by casting, small fiber arranging, controlled material foaming, and other methods. However, additive manufacturing (AM) of porous structures may offer unique advantages such as material selection, process control, and tunable properties to meet application-specific requirements. Advancements in AM allow printing porous structures across multiple orders of magnitude, from millimeter to nanometer pore sizes. Limited experimental validations have been done for the resultant material properties. In this work, thermophysical properties, such as thermal and electrical conductivity, porosity, permeability, and wettability will be characterized and implications on AM process control will be concluded.

Broader Impacts

Monday PM	Room: 415 AB
July 25, 2022	Location: Hilton Austin Hotel

1:30 PM
Evaluation of the Ecological Footprint for Parts from AlSi10Mg manufactured by Laser Powder Bed Fusion: *Christian Weiss*[1]; Christian Boedger[2]; Ekkehard Schiefer[3]; Daniel Heussen[1]; Constantin Haefner[1]; [1]Fraunhofer Institute for Laser Technology (ILT); [2]Paderborn University; [3]Frankfurt University of Applied Sciences

The manufacturing industry contributes immensely to the global emissions and therefore is a key factor that has to be addressed when a more sustainable production is desired. Laser Powder Bed Fusion (LPBF) is an AM technique that offers the possibility to manufacture metal parts in a more material efficient way due to the layer-by-layer build-up. Nevertheless, the processing chain for parts from LPBF contains additional steps like powder atomization, which also influence the ecological footprint of the production chain. Within this work, a life-cycle model for the production step of parts from AlSi10Mg powder material is developed. The model is supplied with data from the powder atomization up to the production step, either by literature, database or experimental measurements during production. The footprint in terms of CO2 emissions is then analyzed and emission-intense steps are identified. Two manufacturing scenarios are considered to evaluate the sensitivity on the emissions.

1:50 PM
Comparative Life Cycle Environmental Assessment of aluminium, titanium and steel components manufactured by Wire Arc Additive Manufacturing: *Emanuele Pagone*[1]; Filomeno Martina[2]; Eloise Eimer[1]; [1]Cranfield University; [2]WAAM3D

Wire Arc Additive Manufacturing (WAAM) produces large, metallic, near-net-shape components depositing a wire using an electric arc. It has shown great potential in terms of cost savings, material wastage reduction, lead time compression, and supply chain simplification. This work will compare the environmental impact of several competing manufacturing routes (subtractive, together with a few WAAM variants) for the production of components in aluminium, steel and titanium of interest to the aerospace and energy industries. The comparison is carried out in a product life cycle perspective estimating the embodied energy and carbon dioxide equivalent emissions from the primary production of raw materials until the shipment of the finished product to the customer (i.e. a "cradle-to-gate" approach). Repair cases will also be discussed. In most cases WAAM is shown to substantially improve the environmental impact of like-for-like components.

2:10 PM
The impact of measurement methodology on the diameter measurement of simple AM features: *Maxwell Praniewicz*[1]; Jason Fox[1]; Christopher Saldana[2]; [1]National Institute of Standards and Technology; [2]Georgia Institute of Technology

Dimensional qualification of AM components is a continuing research problem. Different measurement techniques implemented on the same feature can yield different measurement results. While this can also be true for components made from more traditional manufacturing processes, the deviations between measurement techniques are often increased by an order of magnitude due to a larger degree of form and surface texture variations which occur on AM components. Understanding the origins of deviations and comparability of measurement processes is crucial to the measurement of AM components. In this work, 30 identically designed components are produced using a laser powder-bed fusion process. The components are then measured using manual gaging and a coordinate measurement machine. Two different measurands are evaluated and the deviations between two measurement and various feature fitting methods are contrasted. Statistical analysis is performed to determine the comparability between the measurement techniques.

2:30 PM
The Case for Flipping the Manufacturing Classroom: *Dhruv Bhate*[1]; Cameron Noe[1]; Kyle Brim[1]; Ryan Sparks[1]; Nicholas Lindquist[1]; [1]Arizona State University

There are arguably few technical domains that demand hands-on engagement more than manufacturing. In this work, we focus on providing five reasons why manufacturing classrooms should be taught in flipped format, backed by our experiences gained during a five-year effort at Arizona State University to flip three courses in Additive Manufacturing (AM). These reasons are: (i) enabling continuous improvement of the course by freeing instructor time from a lecture-only paradigm; (ii) extending manufacturing into adjacent domains such as materials science; (iii) supporting students in the creation of real-world value; (iv) providing content for use beyond the on-campus student body, and (v) enhancing student choice by leveraging content across multiple courses. We report on student feedback, as well as the unexpected resilience the flipped model provided during the pandemic. We identify challenges with teaching in a flipped classroom model, such as dealing with larger classroom sizes, and enabling meaningful student assessment.

2:50 PM
Using Solid Freeform Fabrication to develop a low cost Robotics experiment platform to complement classroom learning and exploring topics in STEM Education: *Rajeev Dwivedi*[1]; Ravi Bhupathiraju[1]; Surya Rebbapragada[1]; [1]STEM and Robotics Academy

Educational and competitive robotics provide avenue for hands on experimentation and hence effective tools for STEM education. Cost of physical components continues to be a limiting factor. Within the Educational Robotics, the kits (LEGO, VEX, REV, etc.) are beyond the reach of most of the communities across the world. “Robotics for All” is an initiative to enable a versatile cost effective platform to provides a minimum set of parts that students can integrate with general purpose as well as custom controller/microcomputers (Arduino, Raspberry-Pi, BBC microbit) to perform range of experiments. Various sensors and camera modules can be easily integrated to further learning and experimentation. It will be possible to perform experiments in Robot Navigation, Process planning, object manipulation, industrial architectures, Machine Learning etc. Solid Freeform Fabrication was used to enable manufacturing, verification and improve the design of piece parts with emphasis on low cost without compromise on learning opportunities.

3:10 PM Break

3:40 PM
AI-powered Augmented Reality Training for Metal Additive Manufacturing: *Donald Palomino*[1]; Shijie Bian[1]; Pedro Salcedo[1]; Erick Navarro[2]; Bharath Gopalaiah[1]; Richard Otis[3]; Bingbing Li[1]; [1]California State University Northridge; [2]SimInsights Inc; [3]California Institute of Technology

The Metal Additive Manufacturing (AM) training can cost a company a considerable amount of time, cost, and resources. To resolve this challenge, The NSF funded HyperSkill platform will be applied to create an innovative immersive training program that will integrate the AI-powered object detection and text recognition into a comprehensive digital twin of the metal AM processes. This immersive digital twin will support the delivery of just-in-time guidance to trainees, while also monitoring their actions and providing contextual and personalized feedback to accelerate training, foster retention and maximize transfer to the actual job. The Augmented Reality (AR) training supports the import of 3D assets, no-code authoring of workflows, SOPs and step by step instructions as well as delivery across a wide variety of AR devices. The specific metal AM operation is based on the Renishaw AM400 with its reduced build volume (RBV) configuration.

4:00 PM
Examining Repeatability in Polymer Material Extrusion Additive Manufacturing Systems: *Evan Handler*[1]; Akeel Channer[1]; Caroline Vail[1]; [1]Naval Surface Warfare Center Carderock Division

The naval enterprise faces ongoing readiness challenges with rapidly obtaining parts. Digital manufacturing technologies such as additive manufacturing (AM) offer the unique ability to produce parts of tailored needs and complex geometries from a digital file. This presentation examines the repeatability of production quality polymer AM systems over multiple builds at multiple sites both within a single system and across multiple systems. Mechanical properties tested include tensile, short beam shear, flexural, and compression in different orientations. The variation seen at different sites, mimicking differences in handling and internal procedures when printing occurs at different naval locations, will also be discussed.

4:20 PM
A Comprehensive Review and Discussion of Knowledge Graph and Ontology for Rapid Qualification of Metal Additive Manufactured Parts: Farzana Yeasmin[1]; Md Riyad Hossain[1]; *Zhaohui Geng*[1]; Jianzhi Li[1]; [1]The University of Texas Rio Grande Valley

Additive manufacturing (AM), especially metal-AM, has become a popular manufacturing process in high-value-added industries, such as aerospace, defense, etc., because of its flexibility in design and fabrication. However, the quality of parts is still debatable in critical applications, which prevents its wider adoption by the industry. Conventional testing and qualification procedure can be time- and cost-consuming, which prolongs the throughput time of AM-printed parts. This study provides a detailed review of the key considerations and process map concerning the part quality of the metal AM processes. Prior studies on the knowledge graph and ontology of the metal-AM are surveyed and the potential research gaps to build a complete framework using knowledge graph and ontology for rapid validation and verification of the AM-printed parts are discussed. Future studies on building a rapid qualification framework for metal AM are presented.

Materials: Composites - Novel Materials and Processes

Monday PM
July 25, 2022

Room: 615 AB
Location: Hilton Austin Hotel

1:30 PM
Using Recycled Carbon Fiber Reinforced Polycarbonate as a Feedstock Material for Large Format Additive Manufacturing: *Roo Walker*[1]; Vidya Kishore[2]; Tyler Smith[2]; Matthew Korey[2]; Soydan Ozcan[2]; Vlastimil Kunc[2]; Chad Duty[1]; [1]University of Tennessee, Knoxville; [2]Oak Ridge National Laboratory

Additive manufacturing (AM) is often regarded as a sustainable manufacturing process because it is known for its ability to reduce material waste. But as the scale of AM processes increase, the amount of waste generated by large format AM (LFAM) processes increases accordingly. Additionally, LFAM typically depends on secondary mechanical shaping techniques, such as machining, creating additional waste streams. These "waste" materials can be a valuable resource if they are determined to be a viable secondary LFAM feedstock material. This study investigates the potential for using recycled carbon-fiber reinforced polycarbonate (CF-PC) as a feedstock for the Big Area Additive Manufacturing (BAAM) system. The CF-PC material was mechanically recycled then re-pelletized. The mass flow rate and rheological behavior of the recycled materials were investigated to quantify the change in extrusion behavior.

1:50 PM
3D Printing of Batteries from Lunar and Martian Regolith: *Alexis Maurel*[1]; Ana C. Martinez[1]; Pedro Cortes[2]; Bharat Yelamanchi[2]; Sina Bakhtar Chavari[2]; Ana Aranzola[1]; Sreeprasad Sreenivasan[1]; Cameroun Sherrard[3]; Eric MacDonald[1]; [1]University of Texas at El Paso; [2]Youngstown State University; [3]NASA Marshall Space Flight Center

Additive manufacturing paves the way towards the in-space/on-surface development of shape-conformable energy storage devices for applications that will support Human's mission on the Moon and Mars: spacecraft, portable power devices, robots, and large-scale power systems. Batteries will be able to better fill unique volumes, taking advantage of the dead space, with a view to maximize the energy storage capability. Although lithium-ion batteries are currently the most common choice on Earth, sodium-ion batteries are of particular interest for NASA due to the relative abundance of their materials and precursors in the Lunar and Martian regolith. In this presentation, the development of a composite photocurable resin loaded with TiO_2 negative electrode material and conductive additives, to feed a vat photopolymerization printer, will be discussed. The influence of the printing parameters and additional thermal post processing step on the resulting electrochemical performances and mechanical integrity of the printed items will be reviewed.

2:10 PM
Development of Processing Parameters for the Selective Laser Sintering of Carbon Fiber Reinforced Polyphenylene Sulfide with a Tooling Application: *Scott Snarr*[1]; Patrick Snarr[1]; Joseph Beaman Jr.[1]; [1]Univ of Texas At Austin

The ongoing development of processing parameters for advanced thermoplastic materials to be fabricated via selective laser sintering (SLS) is rapidly advancing the potential industrial applications of the manufacturing method. This research focuses on the development of SLS processing parameters and a tooling application for carbon fiber reinforced Polyphenylene Sulfide (CF-PPS), a composite material that is novel to SLS. A high temperature SLS research machine was used to identify suitable processing parameters for the material along with the tensile strength and geometrical accuracy associated with those parameters. Utilizing the previously identified parameters, a repair mold for an electronic cable assembly was fabricated. Mechanical tests were performed on fabricated CF-PPS parts to evaluate the performance of the material under the mold's normal operating conditions. The additively manufactured CF-PPS mold was deemed viable for production and was shipped to our sponsor for further evaluation.

2:30 PM
Effects of Spherical Fillers on the Processability and Mechanical Properties of PA613 and PP-based LS Dry Blends: *Ivo Kletetzka*[1]; Roland Gawlikowicz[1]; Hans-Joachim Schmid[1]; [1]Paderborn University (DMRC)

In this work, the influences of spherical fillers on the processing properties and the resulting mechanical properties of laser sintered components are investigated. For this purpose, micro glass spheres, hollow glass bubbles and mineral spheres are dry blended to the matrix polymers polyamide 613 and polypropylene with a filling ratio of 20 and 40 vol%. First, relevant properties of the blends, such as powder flowability, thermal behavior and melt viscosity, are investigated. Based on the results, processing parameters are then developed for the LS process and the mechanical properties of the components are investigated. The aim is to be able to tailor the mechanical properties of LS components by adding fillers and thus to create new application areas for additively manufactured components.

2:50 PM
Experimental Analysis of Functionally Graded Materials produced by Fused Filament Fabrication: *Suhas Alkunte*[1]; Ismail Fidan[1]; Seymur Hasanov[2]; [1]Tennessee Tech University; [2]The University of Alabama

Multi-material additive manufacturing has grabbed tremendous attention in the research community. In this investigation, a multi-material single extrusion system was used to fabricate the combination of chopped carbon fiber reinforced Polyethylene Terephthalate Glycol (CCF-PETG) and Thermoplastic Polyurethane (TPU) materials with gradient transition for a more robust material interface. Various patterns such as the 20, 40, 60, and 80% by volume blend of CCF-PETG and TPU materials are designed, printed, and analysed to understand their tensile and fatigue behaviors. Tensile–tensile fatigue tests with a stress ratio of 0.1 were performed on each specimen at 80% of UTS. The characterization of functionally gradient material interface and direct transition patterns were conducted for comparison. The results showed that gradient change in material concentrations from soft to hard material has significantly enhanced the interface strength. Overall, the fabrication of soft-hard/mechanically-tunable material properties has a potential application in several fields (i.e. robotic grippers).

3:10 PM Break

3:40 PM
Analysis of Fiber Attrition and Mechanical Performance in Large-Format Additive Manufacturing of Long-Fiber Reinforced Polymer Composites: *Andrew Rhodes*[1]; Tyler Smith[2]; Christian Sharpe[1]; Vlastimil Kunc[2]; Chad Duty[3]; John Lindahl; [1]University of Tennessee; [2]Oak Ridge National Laboratory; [3]University of Tennessee / Oak Ridge National Laboratory

Preserving the initial fiber length of fiber-reinforced thermoplastics during large-format additive manufacturing is of significant interest since the residual fiber length influences the mechanical properties of the final part. Currently, the attrition of long fiber reinforcement during large-format, single screw extrusion additive manufacturing is not well understood. This study evaluates the relationship between printing speed, the final fiber length, and resultant mechanical properties for pelletized TPU feedstock containing glass fiber of lengths 4 mm, 6mm, and 12 mm. Samples were printed at several processing speeds and subjected to fiber length analysis and tensile testing. Fiber length analysis was performed using the epoxy-plug method, where an improved down-sampling method was implemented for increased repeatability. This study will improve understanding in the choice of machine design, material selection, and processing parameters for optimal mechanical properties.

4:00 PM

Effect of Process Parameters on Voids within Short Carbon Fiber/ABS Beads Produced via Large Area Additive Manufacturing: *Neshat Sayah*[1]; Douglas E. Smith[1]; [1]Baylor University

Short carbon fiber reinforced composite materials produced with Large Area Additive Manufacturing (LAAM) are attractive due to their lightweight, favorable mechanical properties, multifunctional application, and low manufacturing costs. However, the physical and mechanical properties of short carbon fiber reinforced composites 3D printed via LAAM systems remain below expectations due to the void formation. This study aims to investigate the effect of the 3D printing process parameters (including nozzle's height above the printing surface, nozzle temperature, and extrusion rate) on void distribution and volume fraction within the microstructure of a single bead of short carbon fiber/acrylonitrile butadiene styrene (CF/ABS) composite. In this work, high-resolution-3D micro-computed tomography (µCT) is used to evaluate the microstructure of the printed bead. Preliminary results reveal that among the parameters considered here, the nozzle's height has the most effect on void volume fraction within the printed part and void volume fraction decreases with increasing extrusion rate.

4:20 PM

Mechanical Properties Characterization for Polyamide Matrix Dairy Protein Composites Fabricated Using Selective Laser Sintering Process: *John Obielodan*[1]; Maia Delwiche[1]; [1]University of Wisconsin-Platteville

This work investigates the viability of casein protein for manufacturing engineering structures. Polyamide 12 (PA12) was used as a matrix for different compositions of casein up to 15%. Test samples were fabricated for neat PA12 and the composites using selective laser sintering for tensile, impact, and flexural strengths comparisons. The results show significant increases of the tensile strengths up to 71% for the composite materials over the neat PA12. Stiffnesses also increased up 157% while the ductility reduced by at least 45%. Flexural strengths increased significantly for all casein compositions and treatments up to 135%. However, impact strengths reduced significantly for all the composites, except for the plasticized samples that demonstrated marginal differences with the neat PA12. This investigation shows the dependencies of mechanical properties on the type of filler casein and treatments.

4:40 PM

Influence of the Different Matrix Materials on the Thermal Properties of Short Carbon Fiber Reinforced Composites Manufactured by Fused Filament Fabrication: *Orkhan Huseynov*[1]; Ismail Fidan[1]; [1]Tennessee Technological University

A considerable amount of literature has been published on the thermal properties of the short carbon fiber reinforced composites (SCFRC) however, there has been no study exploring the effect of various matrix materials on the thermal properties of the SCFRC. The aim of this study is to investigate the thermal conductivity and thermal diffusivity of neat and composite Polyethylene Terephthalate Glycol (PETG), Polycarbonate/Polybutylene terephthalate (PC/PBT), Acrylonitrile Butadiene Styrene (ABS) and Nylon filled with short carbon fibers. Thermogravimetric and differential scanning calorimetry analysis were performed to study degradation, glass transition temperature and specific heat value. The results obtained from this research study are important in reporting the relationships between the SCFRCs and commonly used polymer materials.

Materials: Metals - 316L Stainless Steel

Monday PM — Room: 616 AB
July 25, 2022 — Location: Hilton Austin Hotel

1:30 PM

Effects of Feeding Rates on the Microstructure of SS 316L Fabricated via Directed Energy Deposition with Coaxial Wire-Powder Feeding: *Yue Zhou*[1]; Fuda Ning[1]; [1]Binghamton University

Directed energy deposition (DED) technology with coincident wire-powder feeding has great potential to efficiently fabricate metallic alloy/composite with great comprehensive performance. In this study, we investigated the effects of feed rates on the microstructure of DED-built parts fabricated with coaxial wire-powder feeding via numerical and experimental methods. In particular, the thermal contribution of dual feedstock to the melt pool was calculated based on quasi-stationary analytical models. The results found that the melt pool temperature decreased initially and then increased with the powder feed rate, which was then experimentally verified by an IR camera. Moreover, a lower melt pool temperature corresponded to the finer grains with thinner boundaries due to the higher cooling rate. In addition, Electron Backscatter Diffraction (EBSD) was employed to analyze the grain morphology and orientations. The relations among process parameters, thermal variation, and microstructure of DED-built parts with coaxial wire-powder feeding were revealed in this paper.

1:50 PM

Additively Manufactured 316L Stainless Steel: Effect of Heat Treatment on Microstructure and Tensile Properties: *Seungjong Lee*[1]; Reza Ghiaasiaan[1]; Shuai Shao[1]; Paul Gradl[2]; Nima Shamsaei[1]; [1]Auburn University; [2]NASA

The microstructure and tensile properties of 316L stainless steel (SS) fabricated using the laser powder directed energy deposition (LP-DED) after various heat treatment (HT) steps such as stress-relief (SR), solutionizing (SOL), and hot isostatic pressing (HIP) are characterized. Microstructures before and after HTs are analyzed using both optical and scanning electron microscopy (SEM). Both quasi-static uniaxial tensile and hardness tests are performed to measure mechanical properties. The tensile results indicate that the non-heat treated (NHT) condition possesses higher strengths but lower ductility as compared to the other HT conditions (i.e., SR, SOL, HIP, SR+SOL, and SR+HIP). By employing the multi-step HT conditions (i.e., SR+SOL and SR+HIP), no significant changes on tensile properties as compared to the individual single-step HT conditions (i.e., SOL or HIP) are observed. The findings suggest that multi-step HTs are not required for LP-DED 316L SS unless HIP is needed to minimize volumetric defect contents.

2:10 PM

Cellular Subgrain Features in Directed Energy Deposited Stainless Steel 316L: The Influence of Morphology on Mechanical Properties: *Janith Wanni*[1]; Ajit Achuthan[1]; [1]Clarkson University

While the influence of cellular subgrain feature in directed energy deposited stainless steel 316L (DED 316L) has been established as the dominant factor in the observed exceptional combination of strength and ductility of AM 316L, the specific role of morphologies is not well understood. The present study on the mechanism of formation, microstructural characteristics, and the influence on mechanical properties of cellular subgrain features reveal many new insights. Microstructural analysis of the DED 316L specimens containing cellular subgrain features of tubular and vermicular morphologies show very different element segregation and secondary phase distribution. The mechanism responsible for the formation of the two different morphologies is the differences in the solidification modes due to different solidification conditions. Irrespective of the widely different morphologies the two builds exhibited similar mechanical behavior indicating that it is the overall barrier that determines their influence on the mechanical properties, not the differences in their morphologies.

2:30 PM
Uncertainty Quantification of Response Surface Methodology to Establish an Efficient Printability Assessment Framework in Directed Energy Deposition: *Jiahui Ye*[1]; Matthew Vaughan[1]; Ibrahim Karaman[1]; Raymundo Arroyave[1]; Alaa Elwany[1]; [1]Texas A&M University

Increasing impact of metal additive manufacturing (AM) on wider industrial sectors has motivated the development of new alloys specifically designed for AM. To efficiently assess whether a tailored alloy is a good candidate for metal AM, as well as identify process windows for defect-free parts, the AM community has gradually realized the significance of printability assessment frameworks. However, such a framework is still lacking for the complex powder-based laser directed energy deposition (L-DED) processes. In this presentation, we highlight an efficient printability assessment framework for L-DED demonstrated by the case study of 316 stainless steel. For printability maps establishment, a statistical model based on response surface methodology (RSM) is initially built to predict melt pool characteristics, followed by uncertainty quantification and Bayesian calibration to future improve model prediction accuracy. The proposed methodology provides a time- and cost-efficient solution to determine printability of both existing and newly designed alloys for L-DED.

2:50 PM
Towards directed energy deposition of metals using polymer-based supports: porosity of 316L stainless steel deposited on carbon-fiber-reinforced ABS: *Rebecca Kurfess*; Kyle Saleeby[1]; Thomas Feldhausen[1]; Kenton Fillingim[1]; A. John Hart[2]; David Hardt[2]; [1]Oak Ridge National Laboratory; [2]Massachusetts Institute of Technology

Directed energy deposition (DED) is increasingly valuable to many industries because of its high deposition rates relative to other metal additive manufacturing processes, but the design space of DED is limited. For instance, steep overhangs are difficult or impossible to manufacture. Polymer-based support structures could help address this challenge. The viability of DED on polymer composite substrates has begun to be explored, specifically with 316L stainless steel on carbon-fiber-reinforced ABS substrates. Monolithic metal components can be deposited on the polymer, but it was found that gas release during polymer degradation causes porosity due to gas entrapment in the metal. An interlayer cooling time was introduced to reduce polymer degradation and decrease the porosity due to gas entrapment, but this led to porosity from lack of fusion. Here, an analysis of these mechanisms, resulting mechanical properties, and the parameter space enabling effective DED of metals using polymer supports are presented.

3:10 PM Break

3:40 PM
Investigating the Effects of Infiltration Conditions on the Microstructure and Mechanical Properties of Binder Jet Fabricated Stainless Steel/Bronze through Ultrasonic Testing: *Nancy Huang*[1]; Olivia Cook[1]; Robert Smithson[2]; Christopher Kube[1]; Andrea Argüelles[1]; Allison Beese[1]; [1]Pennsylvania State University; [2]3M Company

In this study on binder jet fabricated 316 stainless steel infiltrated with bronze, infiltration environment, bronze infiltrant amount, and infiltration configuration were varied to study the effects of infiltration conditions on resultant microstructure and mechanical properties. Microstructures were characterized through ultrasonic testing and optical and scanning electron microscope imaging, while mechanical properties were evaluated with uniaxial tension and hardness testing. Samples infiltrated in N2-based environments had Cr2N precipitates throughout the microstructure, which resulted in increased hardness and tensile strength compared to samples infiltrated in an Ar-based environment. Ultrasonic attenuation and wave speed measurements were linked to porosity and mechanical properties, and most samples failed near regions with high local attenuation and low local wave speed values, which indicated regions of higher porosity. This study demonstrates the potential for ultrasonic testing to be used as a nondestructive evaluation technique to assess porosity and mechanical properties of binder jet additively manufactured metals.

4:00 PM
Local Modification of Composition and Hardness in Stainless Steel by Hybrid Inkjet-Laser Additive Manufacturing: *Bethany Lettiere*[1]; S. Mohadeseh Taheri-Mousavi[1]; A. John Hart[1]; [1]Massachusetts Institute of Technology

The design space of additive manufacturing (AM) is broadened by techniques for local manipulation of microstructure and/or composition. We are developing a new approach toward this goal for metal AM, using inkjet printing to spatially deposit additives prior to laser melting of each layer of the metal powder. As a model system, we choose to study the deposition of a carbon-based ink onto 316L stainless steel. Using stainless steel plate substrates, we assess the influence of ink concentration and laser scan parameters on the local composition and microstructure of the steel. Mechanical properties are measured locally via hardness testing, and globally via tensile testing of designed tensile specimens with gradient composition. These findings, in combination with insights from numerical modeling, suggest the capabilities and limitations of the hybrid inkjet-laser technique for high-resolution, spatially graded metal AM.

4:20 PM
Tailoring Porosity in Laser Powder Bed Fusion by Spatial Manipulation of Feedstock Composition: *Bethany Lettiere*[1]; A. John Hart[1]; [1]Massachusetts Institute of Technology

Metallic foams can provide tailored thermal management, absorb impact energy, and enhance the adhesion or biocompatibility of surfaces. In additive manufacturing (AM), lattice structures are the typical means to tune effective material density and therefore mimic these effects. Yet, intentionally incomplete fusion of powder feedstock in laser melting, or the addition of foaming agents can result in finely tuned porosity with cell sizes smaller than typical architected lattice structures. We are developing a hybrid AM process, whereby inkjet printing is used to spatially deposit additives prior to laser melting. Here, we study the ability to locally control subsurface pore size and density within 316L stainless steel using a polymer foaming agent. Etched metal plates are used for single-layer print studies to assess the influence of polymer concentration, laser power, hatch spacing, and scan speed; results are related to a simplified thermal model of the heating and cooling rates during LPBF.

4:40 PM
Influence of Annealing on Microstructure and Mechanical Properties of Additively Manufactured 316L: *Matthew Schreiber*[1]; Charles Smith[1]; Olivia Denonno[1]; Kip Findley[1]; John Speer[1]; Jonah Klemm-Toole[1]; Zhenzhen Yu[1]; Amy Clarke[1]; Craig Brice[1]; Joy Gockel[1]; [1]Colorado School of Mines

In this presentation, the annealing response of 316L manufactured with both laser powder bed fusion (LPBF) and wire-arc additive manufacturing (WAAM) is discussed in the context of microstructural evolution and mechanical properties. Because AM comprises several technologies that differ in heat source, feedstock, and scan strategy, among other build variables, the final products can exhibit a range of thermal histories. These unique thermal histories can subsequently influence as-built properties and annealing response of AM materials, most notably those manufactured with different AM deposition processes. Characterization methods including differential scanning calorimetry (DSC), optical microscopy, x-ray diffraction (XRD), and tensile testing are utilized to better understand how deposition history affects the extent of annealing. Comprehensive characterization results are presented to provide insight into the necessary post-build processing required to achieve desired properties for AM materials

5:00 PM

Surface Morphology and Hardness of Powder Bed Fused Ss316l as a Function of Process Parameters: *Shweta Hanmant Jagdale*[1]; Sumanth Theeda[1]; Bharath Bhushan Ravichander[1]; Golden Kumar[1]; [1]University of texas at dallas

Laser powder bed fusion is an emerging additive manufacturing process to fabricate fully dense complex metal parts with high accuracy. Laser process parameters such as, laser power, hatch distance, scan speed, scan strategy and layer thickness play a major role in defining the quality of the as-printed parts. Stainless steel 316L (SS316L) is known for its excellent corrosion resistance, high tensile strength, and high-performance at elevated temperatures. SS316L is used in many applications in the field of automotive, aerospace, medical and heavy equipment industries. In the current study, experiments are designed using Taguchi method to understand the effect of process parameters on the properties of as-built SS316L parts. Surface roughness of as-printed parts is characterized by using digital optical microscopy. The relative density and Vickers microhardness are measured for the as-built parts. Finally, an optimal processing region for laser process parameters is identified.

Materials: Metals - Copper and Other Metals

Monday PM — Room: Salon F
July 25, 2022 — Location: Hilton Austin Hotel

1:30 PM

Surface Nanotextured Powders for 3D Printing of High Reflectivity Metals: Ottman Tertuliano[1]; *Philip Depond*[2]; Andrew Lee[2]; David Doan[2]; X. Gu[2]; Manyalibo Matthews[3]; Wei Cai[2]; Adrian Lew[2]; [1]University of Pennsylvania; [2]Stanford University; [3]Lawrence Livermore National Lab

The widespread application of additive manufacturing is hindered by an inability to control the complex interaction between the energy source and feedstock. Here we develop a process to introduce nanoscale features to the surface of copper (Cu) powders which increases powder absorptivity by ~70% during laser powder bed fusion. The absorptivity increase enables printing of pure Cu structures with densities >90% using low laser powers down to 100W. The nanotextured powders uniquely improve absorptivity and printing conditions at low energy density, reducing machine damage induced by high reflectivity metals. Ray tracing simulations show the measured improved absorptivity is mostly described by increased local absorptivity at the nanoscale features of etched surfaces. High speed video of single-layer hatches is performed to observe modified powder dynamics. The approach taken here demonstrates a generalized approach to modifying the absorptivity and printability of metal powders by only changing the surface texture of the feedstock.

1:50 PM

A Study of the Electrical Resistivity of Sintered Copper Nanoparticles: Obehi Dibua[1]; Aaron Liao[1]; Joshua Grose[1]; Dipankar Behera[2]; Chee Foong[3]; *Michael Cullinan*[1]; [1]Univ of Texas Austin; [2]Fathom Radiant; [3]NXP Semiconductors

Microscale Selective Laser Sintering is a novel Additive Manufacturing process being built to fabricate parts with microscale resolution for applications in the microelectronics industry where small feature sizes are critical. This process works by sintering nanoparticles to give a better control on feature sizes. To get an idea of the mechanical strength of the parts fabricated with this process, it is important to be able to quantify the density in the manufactured parts. However, the parts fabricated with this process are too thin to physically handle enough to measure the density, but it is possible to measure the electrical resistance of these parts. So, in order to get the density of these parts, the relationship between electrical resistance and density has to be known. As such this paper presents an experimental study done on sintered copper nanoparticles to relate density to electrical resistance.

2:10 PM

Fused Filament Fabrication of highly Dense Copper Parts: *Fankai Meng*[1]; Margherita Beretta[1]; Jozef Vleugels[1]; Frederik Desplentere[1]; Eleonora Ferraris[1]; [1]KU Leuven

Fused Filament Fabrication (FFF) is an additive manufacturing technology also applied to indirect printing of metal parts recently. This involves the use of composite filaments compounded with metal powder and polymer binders. The as-printed samples (green parts) are then debinded and sintered to obtain a fully dense metal component. In this study, we investigate FFF printing of copper. The target is to reach = 96% relative density in the sintered state. A full factorial design of experiments with layer thickness, flowrate multiplier and nozzle travelling speed was conducted to investigate the printing process. Debinding and sintering were applied subsequently. Multiple tests, including Archimedes method, micro- CT, SEM inspection, analysis of variance, TGA, etc. were applied at different stages to study the quality of filament, printing and post processing. As a result, it was feasible to fabricate 96% dense copper component with FFF.

2:30 PM

Improving the Copper Powder through Plasma Spheroidization for use in the Additive Manufacturing: *M. Hossein Sehhat*[1]; Tristan Cullom[2]; Ming Leu[1]; Joseph Newkirk[1]; [1]University of Missouri, Science and Technology; [2]Kansas City National Security Campus

Efficient fabrication of high-quality copper parts, especially for components with complex geometries, could be accomplished by Additive Manufacturing (AM) processes, such as the Electron Beam Powder Bed Fusion (EB-PBF). The feedstock material to the EB-PBF process is in powder form with specific characteristics, one of which is powder flowability, which influences the quality of final fabricated products. Powder flowability strongly depends on the geometry of powder particles. It has been well-documented that spherical geometries result in better powder flowability. In this study, the copper powder was spheroidized using an induction plasma spheroidization process. The resulted powder (spheroidized) was compared to the as-received powder in terms of morphology and powder flowability to elucidate the impact of the plasma spheroidization process on powder characteristics. The morphology of both as-received and spheroidized powders was characterized by measuring particle size and shape distribution. The Revolution Powder Analyzer was used to quantify the powder flowability.

2:50 PM

Structure-Property Relationships in Copper Made via Laser Powder Bed Fusion: *Rachel Paddock*[1]; Mehran Tehrani[1]; [1]The University of Texas at Austin

Additive manufacturing (AM) of pure copper brings the potential to enable high-performance thermal and electrical components in microelectronics, aerospace vehicles, and thermal/power systems. Advances in AM have recently enabled laser-based powder bed fusion (LPBF) of copper. This work investigates the effects of printing parameters on the electrical and mechanical properties of additively manufactured pure copper coupons made via LPBF. These properties are correlated to the microstructure and chemical composition of copper samples. Our results can guide the design of denser AM copper parts for different applications and be used to improve the properties of LPBF copper.

3:10 PM Break

3:40 PM
Processing of Cu-Al-Fe Bronze via Liquid Metal Jetting Based Additive Manufacturing: *Kellen Traxel*[1]; Chinthaka Silva[1]; Eric Elton[1]; Viktor Sukhotskiy[1]; Luke Thornley[1]; Andrew Pascall[1]; Jason Jeffries[1]; [1]Lawrence Livermore National Laboratory

Metal-AM processes involve inherent thermal transients and phase transformations during processing that can lead to cracking, print failure, and variation in mechanical properties. These areas have been minimally explored for liquid metal jetting (LMJ) based-AM, which requires only raw ingot and involves different thermal processing characteristics in comparison to other metal-AM methods. Bronze alloys based on Cu-Al-Fe parent alloy system exhibit several solid-state phase transformations from the molten state down to room temperature, which makes them an interesting candidate for study via LMJ. We present results of printing studies where bronze alloy C954 (Cu-Al-Fe) is jetted onto metallic substrates at various processing parameters. High-magnification imaging, analysis, and characterization of the printed material demonstrates the vast differences in microstructure and processing characteristics at various input processing parameters, leading to a better understanding of the properties of these materials when processed via LMJ. Prepared by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS-833716.

4:00 PM
Assessing Aerosol-jet Printed Gold Inks for Printed Electronics Applications: *Yongkun Sui*[1]; Lok-kun Tsui[2]; Chowdary Koripella[1]; Andrew Sanford[1]; Judith Lavin[1]; [1]Sandia National Labs; [2]University of New Mexico

Aerosol-jet printing (AJP) capable of depositing high-resolution conductive, resistive, and dielectric films on various rigid and flexible substrates has demonstrated its potential for printed electronics applications. Here, we will assess commercial off-the-shelf gold nanoparticle inks for electrical interconnects using AJP. Firstly, printing quality in terms of line width, line height and overspray for three different inks from UTDots and NovaCentrix will be evaluated and optimized by tuning AJP operation parameters. Next, sintering of these inks will be optimized based on in-situ resistance measurement. Then, conductivities will be calculated based on 4-point probe sheet resistance measurement. Finally, adhesion of these ink printed on various rigid and flexible polymer substrates will be tested. The assessment of these inks and printing process optimization provide some insights to ink selection for printed gold interconnects.SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

4:20 PM
Fabrication of Refractory Alloys using Electron Beam Powder Bed Fusion: *Christopher Ledford*[1]; Patxi Fernandez-Zelaia[1]; Michael Kirka[1]; [1]Oak Ridge National Laboratory

Refractory materials are well suited to benefit from additive manufacturing due to existing limitations in processing these materials via conventional means. Nonetheless, obtaining high density and defect free material is a nontrivial task which requires high processing temperatures along with clean inert environments. Here we present our work on the processing of various refractory alloys using electron beam powder bed fusion to produce fully dense, crack-free material. In addition, we investigate the resulting process-sensitive microstructures and corresponding property relationships.

4:40 PM
Laser Powder Bed Fusion of Defect-Free NiTi Shape Memory Alloy Parts with Superior Mechanical Response: *Abdelrahman Elsayed*[1]; Ibrahim Karaman[1]; Kadri Can Atli[1]; Raymundo Arroyave[1]; Alaa Elwany[1]; Chen Zhang[1]; Lei Xue[1]; [1]Texas A and M

Laser powder bed fusion (L-PBF) is a promising additive manufacturing (AM) technique for the fabrication of NiTi shape memory alloy (SMA) parts with complex geometries that are otherwise difficult to fabricate through traditional processing methods. In this study, NiTi parts were fabricated using L-PBF and consistently exhibited room temperature tensile superelasticity up to 6% in the as-printed condition, almost twice the maximum reported value in the literature. The use of optimized processing parameters, carefully tailoring the evaporation of Ni from a Ni-rich NiTi powder feedstock, and controlling the printing chamber oxygen content eliminated porosity and cracks. Crystallographic texture analysis demonstrated that the as-printed NiTi parts had a strong preferential texture for superelasticity. Transmission electron microscopy investigations revealed the presence of nano-sized oxide particles and Ni-rich precipitates in the as-printed parts, which play a role in the improved SE by suppressing inelastic accommodation mechanisms for martensitic transformation.

5:00 PM
In-situ Modification of a High Entropy Alloy With 2.4% Molybdenum Using LPBF, and its Effect on Microstructure and Corrosion Resistance: *Matthew Ritchie*[1]; Shahin Mehraban[1]; Steve Brown[1]; Daniel Butcher[1]; Jonathan Cullen[1]; Monique Calvo-Dahlborg[1]; Nicholas Lavery[1]; [1]Swansea University

Laser powder bed fusion (LPBF) components display higher porosity compared to parts made by other processes and these pores act as preferential initiation sites for pitting corrosion to occur. In stainless steels such as 316L, molybdenum is 3.5X more effective at enhancing the pitting resistance than chromium, without adding unwanted nitrides to the alloy. In this work, the effect on corrosion resistance is reported for a high entropy alloy (Al-Cr-Mn-Ni-Fe) gas atomised specifically for LPBF, as well as the effects of modifying the alloy by blending the HEA with molybdenum. In-situ LPBF processing, even for low levels of additions has made the comparison difficult, as the pitting resistance is so strongly linked to the porosity, which is higher in the in-situ process. Pitting resistance for both the original HEA and the doped HEA will be compared between samples processed by casting and by LPBF.

Physical Modeling - Melt Pool and Microstructure

Monday PM
July 25, 2022

Room: 416 AB
Location: Hilton Austin Hotel

1:30 PM
A Data-driven Model for Reconstructing 3D Melt Pool Geometries in Additive Manufacturing: *Shuheng Liao*[1]; Jian Cao[1]; [1]Northwestern University

In metal additive manufacturing processes, melt pool size can influence the geometric accuracy and material properties of the fabricated part. While online monitoring and control of the 2D melt pool size have been successfully developed, controlling the 3D melt pool characteristic, i.e., melt pool depth or melt pool volume is still challenging because the 3D melt pool geometry cannot be directly monitored during the process. In this study, a data-driven model is proposed to reconstruct the 3D melt pool geometries from the 2D melt pool images. Synthetic data generated from FEM simulation are generated and used to train the proposed model. Experimental validation of the developed model will be provided.

1:50 PM
A Computational Study Summarizing the Effects of Composition on the Melt Pool Geometry in Additive Manufacturing: Daniel Gwynn[1]; Sree Gundimeda[2]; Amrita Basak[1]; *Nandana Menon*[1]; [1]Pennsylvania State University; [2]Green Valley School, Gujarat

Thermophysical properties play a crucial role in controlling the evolution of melt pool dimensions in metal Additive Manufacturing (AM). It is, therefore, imperative to understand the impact of thermophysical properties on the melt pool dimensions for critical materials such as nickel-based superalloys. In this paper, a three-dimensional analytical model is used to predict the transient melt pool dimension over a range of process parameters for several nickel-based superalloys. The model is then interrogated to evaluate the effects of composition on the melt pool dimensions. The results show that the melt pool dimensions correlate well with the liquidus temperature, density, and thermal conductivity of the alloy. By exploring the impact of process variables and compositions on the melt pool dimension evolution, a framework can be established to maintain the desired melt pool dimensions during fabrication of functionally-graded parts with different alloys belonging to the same material class.

2:10 PM
High-fidelity Modeling of Multi-material Additive Manufacturing: From Micro-/Nano-particle Reinforced Composites to In-situ Alloying: *Wentao Yan*[1]; [1]National University of Singapore

Additive manufacturing possesses promising capabilities of fabricating new materials by mixing multi-material powders and manipulating chemical compositions. In this talk, we will present our latest work on high-fidelity modeling of the complex additive manufacturing process: from powder spreading to melting. To evaluate the mixture uniformity of the powder layer/stream, we employ the computational fluid dynamics (CFD) and discrete element method (DEM) coupling method to simulate the powder spreading/blowing processes of mixed multi-material powders. To thoroughly understand the material composition distribution in the melting procedure, we develop a multi-physics thermal-fluid flow model to simulate the different melting/flow/solidification behaviours of different powders as well as the interactions between solid powders and molten pool. Various scinarios are simulated from micro-/nano-particle reinforced composites to in-situ alloying for new materials. All these models are validated against experiments, and show appealing potentials to provide guidance for additive manufacturing of mixed powders.

2:30 PM
Melt Pool Modelling of the LPBF-AM Process: A Comparison of Thermal Semi-analytic and Numerical Multi-phases Approaches: *Jordan Rosser*[1]; Asela Uyanwaththa[1]; Yi Nie[1]; Steve Brown[1]; Mustafa Megahed[2]; Nicholas Lavery[1]; [1]Swansea University; [2]ESI Group

Laser powder bed fusion additive manufacturing can be used to create intricate geometries with superior mechanical performance. At the scale of the laser spot size, the process of melting powders has a chaotic nature with complex and interacting physics, which can be attributed to defects which reduce mechanical properties. Modelling across various length and time scales can provide insight, better our understanding, and optimise the process, but it is important to find a balance between computational effort and outcomes. To this extent three thermal approaches are considered and evaluated by comparison. The first is a low-fidelity semi-analytical approach utilising the Eagar-Tsai model to simulate the thermal history at the part-scale. The second is a medium-fidelity model developed using OpenFOAM's solver to simulate melt pool dynamics at the microscale. Finally, a high-fidelity thermo-fluidic model, as part of ESI-AM, which considers all major aspects of during processing, including recoil pressure and evaporation.

2:50 PM
Modelling of Microstructure Evolution in Wire-Based Laser Direct Energy Deposition with Ti-6Al-4V: *Yousub Lee*[1]; Srdjan Simunovic[1]; Brian Gibson[1]; Paritosh Mhatre[1]; Alex Roschli[1]; [1]Oak Ridge National Laboratory

Over the past years, large-scale metal additive manufacturing (AM) has been transitioning from rapid prototyping to mass production. However, a wide market penetration of the AM has not happened yet. The difficulties for wide-scale market adoption to critical structural components are related to the development cost for process optimization and for manufacturing of high-quality parts. For metallic components, the process conditions control the material and mechanical properties/performance of the printed part. The thermal history strongly determines the phase fraction, morphology, growth pattern, size of microstructure and nature of defects. In this study, we: 1) developed a thermal simulation using finite element method, 2) experimentally measured thermal histories from a U-shaped part with four tool paths of horizontal, vertical, raster, and contour to calibrate and validate the thermal model, and 3) investigated the effect of thermal history on microstructure evolution and composition and quantified the microstructural variation during the printing process.

3:10 PM Break

3:40 PM
Modeling of IN718 Precipitates' Growth in Powder-bed Fusion (In-situ and Post-build Aging): *Jakub Mikula*[1]; Rajeev Ahluwalia[1]; Robert Laskowski[1]; Kun Wang[1]; Guglielmo Vastola[1]; Yong-Wei Zhang[1]; [1]A*STAR

Nano-sized γ' and γ'' precipitates form the backbone of Inconel 718 alloy, allowing the material to operate under extreme thermo-mechanical conditions. Interestingly, in additive manufacturing of IN718, the formation of precipitates is rarely observed and usually, a post-build heat treatment process is required to achieve the desired mechanical response. This holds true for the case of standard printing conditions. However, exerting more unconventional control over the printing process may unlock the potential of additive manufacturing to induce precipitate formation also in the as-built state and develop gradual microstructural changes within the printed part. Here, we aim to investigate the amenability of various printing conditions to formation of precipitates during the printing stage by developing a two-scale finite element / phase-field simulation framework. We apply the framework to the geometry of centrifugal impeller and explicitly show precipitate nucleation and growth driven by the local thermal history within the printed part.

4:00 PM
Phase-field Modeling of Microstructure Evolution in Additive Manufacturing with a Physics-informed Graph Network Approach: *Tianju Xue*[1]; Zhengtao Gan[1]; Shuheng Liao[1]; Jian Cao[1]; [1]Northwestern University

The phase-field (PF) method is considered as an accurate method for the simulation of microstructure evolution. Recently, there has been an increasing interest in applying the phase-field method to metal additive manufacturing processes for the simulation of power melting, solidification, and grain growth. Due to the high computational cost, most existing simulations are either in 2D, or easily takes weeks for a moderate-size 3D problem. In this work, we propose a reduced-order modeling method for phase-field simulation by employing graph networks from machine learning. Our method solves temperature field, liquid/solid phase field, and grain orientation variables simultaneously in a set of coupled partial differential equations. We compare the reduce-order approach with traditional direct numerical simulation based on the finite difference method and show that the reduce-order approach is at least 10x faster while stilling capturing key outcomes such as melt pool evolution, post-process grain size distribution, etc.

4:20 PM
Process-specific Microstructure-sensitive Modeling of Fatigue in Additively Manufactured Ti-6Al-4V Alloys: *Lionardo Lado*[1]; Saeed Ataollahi[1]; Aref Yadollahi[2]; Mohammad J. Mahtabi[1]; [1]The University of Tennessee Chattanooga; [2]University of South Alabama

In this study, fatigue behavior of Ti-6Al-4V alloy fabricated via different additive manufacturing (AM) methods was modeled using a microstructure-sensitive approach. Microstructural data — including characteristics of defects, as well as mechanical and crack-growth properties — were collected from the literature. Scanning electron microscope images were used to measure the size of the defects responsible for fatigue. A Multistage fatigue model was used to predict the fatigue lives by fixing the material-related variables and limiting the parameters to those dictated by the AM process, i.e. pore size, pore nearest neighbor distance, total porosity, and grain size. The fatigue curves for the different materials were successfully estimated only by appropriately determining the four mentioned variables, shedding light on a more efficient microstructure-sensitive fatigue modeling of AM materials.

4:40 PM
Three-dimensional (3D) Simulation of Micro-Void Development within Large Scale Polymer Composite Deposition Beads: *Aigbe Awenlimobor*[1]; Douglas Smith[1]; Zhaogui Wang[2]; [1]Baylor University; [2]Dalian Maritime University

Structural integrity and quality of short fiber composite parts produced by Big Area Additive Manufacturing (BAAM) are largely affected by inherent bead microstructural features such as voids. Unfortunately, our understanding of void nucleation and evolution during polymer deposition process is lacking. Our prior computational effort that investigated mechanisms that may promote micro-void formation was based on 2-dimensional planar models of a single ellipsoidal fiber motion in purely viscous polymer extrusion/deposition flow through a BAAM nozzle. Here we propose a 3D finite element modeling approach to simulate single fiber out-of-plane rotations utilizing velocity and velocity gradient values computed along streamlines obtained from a 3D extrusion/deposition simulation of the BAAM polymer deposition process. The pressure distribution on the fiber's surface along the flow path provides new insight into potential micro-void nucleation mechanism. Results show low-pressure regions occur near the fiber's surface which varies across the printed bead and through its thickness.

Process Development - Metal AM

Monday PM
July 25, 2022

Room: Salon G
Location: Hilton Austin Hotel

1:30 PM
The Next Step with Additive Manufacturing of Steel and Iron Alloys: *Rajat Gulabrao Kawalkar*[1]; Harrsh Dubey[2]; Satish Lokhande[2]; [1]Uppsala University; [2]Priyadarshini College of Engineering, Nagpur

A common trait of utilizing additive manufacturing process with other existing manufacturing processes in manufacturing chain to make products is the future cycle in industrial manufacturing. This type of techniques usually involves producing parts on different substrates which are conventionally manufactured from processes such as casting, milling, turning and etc. This complex manufacturing setup that uses the positives of different manufacturing technology helps in achieving manufacturing large parts within effective production time while ensuring superior finish. This paper discusses the state of art technologies used with additive manufacturing for making steel alloy parts while also discussing existing innovation setup with powder bed fusion and directed energy depositional techniques which can be associated with additive manufacturing of steel components.

1:50 PM
Printability Studies of 316L Stainless Steel by Paste Deposition Modeling: *Miguel Hoffmann*[1]; Alaa Elwany[1]; [1]Texas A&M University

Indirect metal additive manufacturing (AM) processes that employ metal-polymer composites to 3D print 'green' parts offer an economical and user-friendly alternative to melt-based AM. Leveraging knowledge in powder metallurgy permits functional parts with predictable microstructures and properties to be manufactured; however, the large fractions of binder introduce the need for specialized debinding procedures that significantly prolong manufacturing time and can negatively impact mechanical properties and geometrical capabilities. We introduce paste deposition modeling, an AM process for making 316L stainless steel parts using a high solid loading (90.1 wt %) paste with just 3.5 vol % binder. Response surface methodology experiments were conducted to study the effects of process parameters on green density and surface roughness. Multi-objective optimization enabled printing parts with 4.67 g/cc green density and 21.54 um surface roughness. Thermal studies were conducted to investigate ideal debinding and sintering conditions. Microstructures were analyzed through optical and scanning electron microscopy.

2:10 PM
Potential of Dual Laser Array Powder Bed Fusion for the Processing of Nickel-base Alloy 625: *Tim Lantzsch*[1]; Norbert Pirch[1]; Thomas Laag[1]; Thomas Westphahlen[1]; Constantin Haefner[1]; [1]Fraunhofer Institute for Laser Technology ILT

Laser Powder Bed Fusion (LPBF) has become an industrially established manufacturing technique due to its' capability to produce highly complex components. To increase the productivity of industrial LPBF machines the number of laser scanner systems (LSS) is often multiplied, which causes an almost linear increase of machine costs. In contrast, within this study a novel LPBF machine concept with a flexible dual fiber laser array is investigated. LPBF processing experiments are carried out for nickel-base alloy 625. The manufactured test specimens using this approach are characterized regarding melt pool formation, part quality (density, surface roughness, micro hardness) and build-up rate. The obtained results are compared with a state-of-the-art single laser LPBF machine. The results indicate comparable part quality while the dual laser array LPBF approach yields a productivity increase by up to 100% compared to the single laser reference.

2:30 PM
Printability of Nickel Alloy 718 Using a Systematic Process Optimization Framework with Different Layer Thicknesses: *David Shoukr*[1]; Peter Morcos[1]; Tayler Sundermann[1]; Raymundo Arroyave[1]; Ibrahim Karaman[1]; Alaa Elwany[1]; [1]Texas A&M University

Laser-powder bed fusion is used in the literature to fabricate nickel alloy 718 successfully. However, the selection of the process parameters was based on experimentally-intensive methods or computationally-expensive simulations. Hence, these methods can test only a small region of the parameter space. Moreover, studies combine the process parameters into linear or volumetric energy densities. Both factors have proven to provide partial information about the part and inconsistent mechanical properties and microstructures. The current framework covers the entire scanning speed-laser power space, determines the hatch spacing, and detects the printability region which is the porosity-free region determined by the elimination of the porosity defects. Furthermore, layer thicknesses of 60 and 90 \956m are investigated to increase the volumetric build rate (VBR).Printability is assessed using porosity measurements while performance is evaluated using tensile tests. Fully-dense parts were fabricated with tensile strengths and VBR of up to 1063.5 MPa and 7.10 mm^3/s.

2:50 PM
In-situ Measurement of Melt Pool Emissions via Coaxial Spectrometry in Powder-blown Directed-energy Deposition: *Rujing Zha*[1]; Samantha Webster[1]; Jihoon Jeong[1]; Alberto Castro[2]; Jian Cao[1]; [1]Northwestern; [2]Sigma Labs

Laser powder blown directed-energy deposition (LPB-DED) is a highly flexible metal additive manufacturing technique with applications in aerospace and automotive fabrication and repair. Coaxial monitoring of the melt pool using a photodiode array provides a high-frequency, inexpensive data stream that will enable open- and closed-loop control of the process. However, photodiode readings have not yet been compared with spectrometer measurements to better connect photodiode readings with melt pool conditions. While past work has used spectrometers to monitor LPB-DED, none have correlated results from a coaxially mounted spectrometer with photodiode readings to the authors' knowledge. To fill this gap, cladding of alloy 718 on 1045 carbon steel was coaxially monitored with a photodiode array and a spectrometer (200-1120 nm range). Laser power, powder flow rate, scan speed, laser focus, and standoff distance were varied across the clads. Correlations were found between spectrometer readings, photodiode readings, and clad dimensions.

3:10 PM Break

3:40 PM
Designing an Industrially Implementable Framework to Design Additive Recycling Invariant Powder LPBF Feedstocks via Alloy 718: *Tayler Sundermann*[1]; Raymundo Arroyave[1]; Alaa Elwany[1]; Ibrahim Karaman[1]; [1]Texas A&M University

Precision metal additive manufacturing is a high growth industrial technology, however, cost represents a significant roadblock for widespread adoption. In powder bed fusion technologies powder feedstock constitutes the bulk of machine operation cost, and the entire volume of a powder bed must be filled regardless of volume consumed by the part; additionally, off-the-shelf powders are overwhelmingly considered as single use consumable materials. To decrease the cost and drive efficiency, a practical solution is to recycle powder used in previous builds. Unfortunately, recycling of powders is not trivial. Measurement techniques that are staples from powder metallurgy are not ideal for additively manufactured powders, and do not reliably inform build outcomes. The present work offers a detailed framework on powder feedstock characterization considering powder morphology, composition, and behavior and dictating cost effective testing strategies to determine differences, physically normalize, and reintroduce powder to create feedstocks recyclable until they're consumed in a build.

4:00 PM
Combination of Cladding Processes with Subsequent Hot Forming as a New Approach for the Production of Hybrid Components: *Laura Budde*[1]; Paulina Merkel[2]; Vannila Prasanthan[3]; Susanne Bährisch[4]; Mohamad Yusuf Faqiri[5]; Marius Lammers[1]; Jörg Hermsdorf[1]; Thomas Hassel[5]; Johanna Uhe[4]; Bernd-Arno Behrens[4]; Bernd Breidenstein[3]; Malte Stonis[2]; Ludger Overmeyer[1]; [1]Laser Zentrum Hannover e.V.; [2]IPH – Institut für Integrierte Produktion Hannover gGmbH,; [3]Institute of Production Engineering and Machine Tools, Leibniz University Hannover; [4]Institute of Forming Technology and Machines, Leibniz University Hannover; [5]Institute of Materials Science, Leibniz University Hannover

A new process chain for the manufacturing of load-adapted hybrid components is presented. The "Tailored Forming" process chain consists of a deposition welding process, hot forming, machining and an optional heat treatment. This paper focuses on the combination of laser hot-wire cladding with subsequent hot forming to produce hybrid components. The applicability is investigated for different material combinations and component geometries, e.g. a shaft with a bearing seat or a bevel gear. Austenitic stainless steel 316L and martensitic valve steel AISI HNV3 are used as cladding materials, mild steel AISI 1022M and case hardening steel AISI 5120 are used as base materials. The resulting component properties after laser hot-wire cladding and hot forming such as hardness, microstructure and residual stress state are presented. In the cladding and the heat-affected zone, the hot forming process caused a transformation from a welding microstructure to a fine-grained forming microstructure.

4:20 PM
Assessment of In-situ Defect Mitigation Strategies in Metal Laser Powder Bed Fusion Additive Manufacturing: *Christine Cummings*[1]; David Corbin[1]; [1]Pennsylvania State University

Recent advancements to in-situ process monitoring of laser powder bed fusion (LPBF) additive manufacturing (AM) have enabled localized defect detection. Research into defect mitigation methods, however, is limited to post-processing techniques. This study investigates in-situ defect mitigation methods through localized laser re-melting of defect areas during Ti-6Al-4V builds and takes a first look at the parameters required for successful defect elimination. Mitigation parameters include the mitigation size, the laser power, and the number of layers mitigated. Eliminating defects mid-process reduces energy and material expense, limits the need for post-processing, and improves reliability and consistency in LPBF. To systematically assess mitigation success, process anomalies were seeded into AM parts, generating surrogate defects at known locations. Optimal mitigation parameters, resulted in defect volume reduction by a minimum of 98% compared to predicted defect volumes. These results indicate that in-situ re-melting is a promising method for the elimination of defects in LPBF AM.

4:40 PM
A Comparison of Thermal History and Porosity Formation for Different Laser Melting Toolpath: *Marwan Haddad*[1]; Ronald Sellers[1]; Hui Wang[1]; Benjamin Gould[2]; Sarah Wolff[1]; [1]Texas A&M University; [2]The Chemours Company

Experiments on laser melting of Ti-6Al-4V powder beds and powderless Ti-6Al-4V substrates were conducted at the Advanced Photon Source at Argonne National Laboratory. In situ monitoring via synchronized X-ray and infrared (IR) imaging systems enabled the capture of real-time images of the process. Our methodology consisted of measuring the melt pool dimensions from the X-ray images and correcting and calibrating the temperatures in the IR images by estimating an emissivity value using a simplified equation based on Planck's law. Our objectives are to estimate the melt pool dimension from IR images and to analyze and compare thermal history and porosity formation for different laser melting toolpath under different process parameters.

5:00 PM
Sampling Internal Temperature Distributions Within Parts Being Manufactured by the Metal Laser Powder Bed Fusion Process: *Nathaniel Wood*[1]; David Hoelzle[1]; [1]the Ohio State University

Metal Powder Bed Fusion (PBF) is a type of additive manufacturing (AM) process that builds parts out of a bed of metal power. PBF parts frequently exhibit defects, many of which can be traced to an improperly-evolving temperature field during the build. Validating algorithms which estimate these temperature fields is critical for their quality control, as direct measurement of internal temperatures is impossible in production. This work describes an experiment that measures the temperatures within parts being subjected to the PBF build process at select locations therein. Data is generated for three levels of processing complexity: first, sufficiently low laser powers to not induce melting; Second, melting the top surface of the parts but not building material; Third, building five layers of material. Relevant PBF process input signals, and infrared camera measurements, are also recorded. We anticipate this dataset will be useful for researchers validating a variety of estimation algorithms.

Process Development - Modeling and Control

Monday PM — Room: 412
July 25, 2022 — Location: Hilton Austin Hotel

1:30 PM
Towards Regulation of Build Height in a Directed Energy Deposition Additive Manufacturing using Adaptive Iterative Learning Control: *Dustin Seltzer*[1]; Jeffrey Schiano[1]; [1]Penn State University

Additive manufacturing presents a more cost-effective method of repair for components instead of remanufacturing. However, some components, such as turbine blades, have narrow tolerances that can not be guaranteed when processing parameters are chosen prior to the build. Instead, we propose an algorithm that uses past build height measurements to update the scan speed command for the next deposition. The proposed method uses an adaptive iterative learning control (AILC) method, based on sensitivity point tuning, to update scan speed. The solidified deposition is imaged using a line scan profilometer camera that obtains a build height measurement every 0.01 inches. The scan speed sequence for the next layer deposition is adjusted based on the error between the measured and desired build height. Details of the control design methodology and simulation results using a 2D repetitive process model identified from experimental data is discussed.

1:50 PM
Towards Regulating Internal Temperature Distributions during Powder Bed Fusion Builds using Model Predictive Control: *Nathaniel Wood*[1]; David Hoelzle[1]; [1]the Ohio State University

A large body of literature exists on regulating melt pool width in powder bed fusion (PBF) through feedback control of process parameters like laser power and scan speed. These algorithms dynamically vary the process parameters so that the features track desired trajectories. Deciding appropriate process parameter trajectories is challenging because determining defect-free regimes requires extensive heuristics and experiments. Directly regulating the feature which controls defects, which is oftentimes the temperature field, would be optimal. This paper contributes to this goal. In simulation, we use a feedback control algorithm called Model Predictive Control (MPC) to cause a PBF temperature build, with simplified physics, to track a reference trajectory. At each time step, MPC generates locally-optimal process inputs to correct forecasted discrepancies between the reference trajectory and build temperature in the future. MPC is able to remove 76% of error in tracking a reference temperature field, relative to the process without control.

2:10 PM
In-Situ Monitoring of Wire Arc Additive Manufacturing for Defect Prediction: *Eduardo Miramontes*[1]; Joshua Penney[1]; William Hamel[1]; Bradley Jared[1]; Ethan Rummel[1]; [1]University of Tennessee

Wire Arc Additive Manufacturing is a promising metal additive manufacturing technology that confers significant advantages over established alternatives. Benefits include high deposition rate, improved material utilization, low equipment costs, and increased part size. However, the mechanical properties of the parts are often sub-standard due to common defects such as porosity, residual stresses, and cracks. Mitigation requires online detection and prediction capabilities. A multi-sensor framework comprising arc current, arc voltage, wire feed speed, robot position and orientation, motor current, thermal imaging, and acoustics has been developed. The data obtained with this framework will be utilized to train a random forest ensemble model to predict defects in real time. Different metrics for classifying defects will be investigated, including visual inspection, dimensional measurements, and pore density. The trained model will provide the basis for a closed loop control system that can adjust the process parameters in response to defect detection.

2:30 PM
In-situ Monitoring of Laser Powder Bed Fusion using IR and NIR Emissions to Detect Thermal Anomalies: *Matthew Roach*[1]; Bennett Fowler[1]; Darshan Thakkar[2]; Charles Babbitt[2]; Shuchi Khurana[2]; Bradley Jared[1]; [1]University of Tennessee, Knoxville; [2]Addiguru

Process monitoring of laser-powder-bed-fusion (L-PBF) has advanced significantly since the beginning of the technology as a means for additive manufacturing. Many methods exist to date for in-situ process monitoring using the collection and analysis of certain useful emission wavelengths given off by the manufacturing process; however, these methods can be costly to implement in all situations and certain systems do not collect data at high resolution, or high enough framerate to provide meaningful data. This research aims to develop a method of low-cost thermal monitoring using near-infrared (NIR) and infrared (IR) wavelength band emission monitoring to create a system to detect anomalies. These anomalies can then be compared to printed material to verify the detection of a printed anomaly. This research will explore the use of IR along with NIR wavelengths to inform the process and other drawbacks brought about by monitoring one wavelength band over the other.

2:50 PM
Autonomous Error Detection and Correction Powered by Deep Neural Networks: *Douglas Brion*[1]; Sebastian Pattinson[1]; [1]University of Cambridge

Material extrusion is the most widely used additive manufacturing method, but its use in many applications is limited by its vulnerability to diverse errors. Expert human operators can detect errors but cannot provide continuous monitoring or real-time correction. This has led to much research into automated methods for error detection. However, current approaches can often only detect limited error modalities across a narrow range of parts and materials. Additionally, errors remain particularly challenging to correct, primarily requiring manual intervention. This talk will describe our recent work on addressing these limitations through a novel combination of in situ imaging and deep neural networks. This enables closed-loop feedback through real-time error detection and autonomous correction to aid in the extrusion-based manufacture of end-use parts in demanding applications.

3:10 PM Break

3:40 PM
Understanding Correlations between Processing Parameters and Part Geometry in Robotic Reactive Extrusion Additive Manufacturing (REAM): *Michael Fogg*[1]; Robert Pavlovic[1]; Pratik Koirala[1]; Mehran Tehrani[1]; Carolyn Seepersad[1]; [1]University of Texas at Austin

Reactive extrusion additive manufacturing (REAM) is an AM method in which a liquid thermoset feedstock is deposited and cured in situ by mixing it with a catalyst as it is extruded, initiating an exothermic curing reaction. The robotic REAM system investigated here couples this extrusion system to a six-degree-of-freedom robotic arm for actuation and utilizes a path-planning software that converts g-codes into robotic trajectories. The REAM process has many advantages, such as fabricating parts with isotropic material properties, initiating curing without external energy input, and utilizing high extrusion rates, but curing kinetics, thermal gradients, deposition time, feed and extrusion rates can affect the accuracy and resolution of the deposition. This work focuses on understanding these variables and their effects, so the system can be tuned, improving part accuracy and repeatability. Ultimately, real-time data could be used to adjust these parameters during the printing process to mitigate defects as they occur.

4:00 PM
Developing a Universal Additive Manufacturing Parameter Transference Model: *Kevin Le*[1]; Colt Montgomery[1]; William Winter[1]; Robin Pacheco[1]; Kevin Shay[2]; Kevin Lamb[2]; Mike Boice[2]; Dale Cillessen[3]; Maria Strantza[4]; Nicholas Calta[4]; Gabe Guss[4]; Guadalupe Rivero[5]; Tek Ferguson[5]; Cody Lough[6]; Ashley Schmid[6]; Brian Ferguson[6]; Andy Deal[6]; [1]Los Alamos National Laboratory; [2]Y-12 National Security Complex; [3]Sandia National Laboratories; [4]Lawrence Livermore National Laboratory; [5]Pantex Plant; [6]Kansas City National Security Campus

Comparable laser powder bed fusion machines, when parameters and material powder are held consistent, will produce different quality components. To achieve a similar quality component, optimized parameters must be established for each machine resulting in wasted material, lost time, and excess cost. To solve this problem, a model will be developed which allows for transference of existing parameters to another machine thus ensuring the same quality components regardless of machine or vendor and preventing redundant work efforts relating to parameter development and optimization.To create this model, data will be gathered from multiple additive manufacturing machines across multiple sites. Each machine will produce a plate of single bead weld tracks, eventually resulting in bead cross sectional images. After characterization, the beads will be used to develop a unique representative metric. This metric will be used in a machine learning algorithm to find a relationship between parameters on different machines.

4:20 PM
A Model for Driving Signal Effects on Piezoelectric Inkjet Printing Speed: *Chao Sui*[1]; Wenchao Zhou[1]; [1]University Arkansas

Piezo drop-on-demand (DOD) inkjet is a non-contact and direct forming technique for pattern fabrication, which has been widely used in additive manufacturing, biochip, flexible displays, MEMS components, and optical devices. It is known that the droplet ejection behavior differs by ink properties and the driving waveform. In this paper, we present a model for the droplet formation dynamics from a single nozzle with a bipolar driving signal, which provides a quantitative relationship between the waveform of the driving signal and the average jetting velocity at the nozzle exit, droplet ejection frequency, and droplet volume. An experimental setup is developed for calibration and validation of the model. Results show the model agrees well with experiments and can be used to predict inkjet printing speed based on the parameters of the driving signal.

4:40 PM
Using Process Monitoring Signals to Identify Defects during Laser Powder Bed Fusion: *Nicholas Calta*[1]; Jean Baptiste Forien[1]; Gabe Guss[1]; Saad Khairallah[1]; William Smith[1]; Philip Depond[1]; Manyalibo Matthews[1]; [1]Lawrence Livermore National Lab

In situ process monitoring tools are a powerful approach for quality assurance in laser powder bed fusion to compliment post-build inspections. While such approaches provide a great deal of information about process stability, detailed links between process monitoring signals and defect formation remain challenging to quantify. In this talk, I will describe efforts to correlate high speed melt pool thermal emission measurements to defects in an octet truss microlattice. We correlate high speed pyrometry measurements over two wavelength ranges, 500 – 900 nm and 1500 – 1700 nm, to the presence of intentionally introduced defects. From these correlations, we develop a metric to predict the probability that a given strut is defective. We also use finite element modelling and high-speed thermal and optical imaging to describe the physical mechanism that underlies this correlation. Prepared by LLNL under Contract DE-AC52-07NA27344.

5:00 PM
Unified System Controller for a Powder Bed Fusion System Developed for an Open-source Framework: *Sebastian Aagaard Andersen*[1]; Magnus Bolt Kjer[1]; Venkata Karthik Nadimpalli[1]; David Bue Pedersen[1]; [1]Technical University of Denmark

A unified system controller was developed to facilitate an open-source framework relevant to Laser Powder Bed Fusion (L-PBF). The controller seeks to bridge the gap, between system and researcher, often invoked by the proprietary nature of commercial L-PBF systems. As part of the open-source framework, the bespoke controller provides an open and customizable way of controlling the governing subsystems, e.g. scanner (XY2-100), laser, flow, and actuation. Furthermore, the unified system controller was designed to retrieve feedback from the scanner and designated process sensors. Utilizing the process feedback the unified system controller demonstrates its capabilities to support both open and closed-loop control routines. The embedded firmware and custom PCB allow the unified systems controller to serve as a versatile controller for L-PBF systems, and a powerful tool when investigating and coupling process effects to system behavior.

Special Session: Binder Jet AM I - Advancements in Binder Jet AM

Monday PM
July 25, 2022

Room: Salon B
Location: Hilton Austin Hotel

1:30 PM
Mechanized Spreading of Ceramic Powder Layers for Additive Manufacturing Characterized by Transmission X-ray Imaging: *Daniel Oropeza*[1]; Ryan Penny[2]; Daniel Gilbert[2]; John Hart[2]; [1]NASA JPL; [2]MIT

Spreading of uniform, dense powder layers is a critical requirement for powder bed additive manufacturing (AM) processes, and layer quality is influenced by powder feedstock selection and spreading parameters. In prior work, quantification of powder layer density has required disruption of the powder layer after spreading, or compromise in the precision and/or design of the spreading mechanism compared to actual AM equipment. This work demonstrates the use of a precision, mechanized powder spreading testbed coupled with transmission x-ray imaging for spatially-resolved, non-contact powder layer density measurements. Specifically, the influence of several variables on the spreading of aluminum oxide powders is studied: powder size and shape, spreading tool choice (i.e., blade versus roller), traverse speed and/or rotation rate, and powder dispensing methodology (i.e., piston-fed vs hopper).

1:50 PM
Nondestructive Evaluation of Porosity in Binder Jet SS316L Components using Ultrasound and X-ray Computed Tomography: *Olivia Cook*[1]; Nancy Huang[1]; Robert Smithson[2]; Christopher Kube[1]; Allison Beese[1]; Andrea Argüelles[1]; [1]Pennsylvania State University; [2]The 3M Company

The progression of additive manufacturing technologies hinges on their ability to produce defect-free parts with ideal properties. Binder jet printing (BJP) has many advantages over fusion-based AM methods, such as no thermal cycling, increased geometric freedom, and lower energy consumption. However, part porosity has been shown to compromise properties in BJP components. In this study, NDE methods, which are well suited to evaluate components containing spatially varying characteristics, were applied in this study to examine porosity. X-ray computed tomography was used to obtain 3D reconstructions of the pores present in binder jet printed SS316L tensile samples. Subsequently, samples were scanned in an ultrasonic immersion system, and wave speed and attenuation spatial maps were extracted. These ultrasonic testing results were analyzed against XCT results to explore deeper linkages between pore morphology and wave speed and attenuation beyond the known sensitivity to the volume fraction of porosity.

2:10 PM
Effect of Printing Orientation on Ceramic Binder Jetting Additive Manufacturing: *Mohammadamin Moghadasi*[1]; Zhijian Pei[2]; Chao Ma[3]; [1]Department of Materials Science and Engineering, Texas A&M University; [2]Department of Industrial and Systems Engineering, Texas A&M University; [3]Department of Engineering Technology and Industrial Distribution, Texas A&M University

In this study, the effect of printing orientation on ceramic binder jetting additive manufacturing was investigated. Flexural samples were printed with six different orientations using commercially available alumina powder. Then, the samples were cured, debound, and finally sintered in a furnace. Afterward, three-point bending, Archimedes method, and microscopy were used to study the mechanical behavior, density, and pore distribution, respectively. The results showed that although there was no considerable change in the density, the flexural strength varied significantly in a wide range from 82.8±6.1 MPa to 151.6±4.6 MPa among different printing orientations. The microscopy showed that the different distributions of interlayer pores were the main reason for the large variation in the flexural strength.

2:30 PM
Embedded Sensors to Experimental Evaluate Binder Curing in 3D Printed Sand Molds for Metal Casting: Eric MacDonald[1]; Nathaniel Bryant[2]; Jerry Thiel[2]; *Janely Villela*[1]; Juan Owen Villela[1]; [1]University of Texas at El Paso; [2]University of Northern Iowa

The benefits of additive manufacturing for fabricating complex sacrificial sand molds for geometrically-complex metal castings is revolutionizing the foundry industry driven by a digital manufacturing paradigm. The design freedom of 3D printing allows for new mold designs, not possible with traditional approaches. However, research on the curing time, including the aging of printed molds, requires more exploration. This study describes the experimental exploration of 3D printed specimens in which embedded environmental sensors were integrated into sand blocks during an interruption and fully encapsulated in bound sand. After 28 days, humidity, volatile organic compounds, and temperature were captured and accumulated metrics for three environmental treatments were calculated. Mechanical testing of the blocks along with standard test specimens subjected to the same conditions were conducted. The sand structures held in high humidity were statistically significantly weaker than the other treatments based on the hypothesis that humidity impedes curing.

2:50 PM
Binder Jetting of Tungsten Carbide with Low Metallic Binder Contents: Challenges and Solutions: *Hadi Miyanaji*[1]; Paul Prichard[1]; Zhuqing Wang[1]; Martin Perez[1]; [1]Kennametal Inc.

Cemented tungsten carbide (WC-Co) plays a major role in many industrial applications including high-speed cutting turning tools and wear components. Currently, tungsten carbide material is manufactured into desired geometries using conventional powder processes. In the recent years, a promising additive manufacturing technology, Binder Jetting (BJ) process, has demonstrated success in converting WC powders into components. Unlike ductile materials, cemented tungsten carbide has more demanding quality requirements for manufacturing with Binder Jetting technology to achieve comparable properties to conventionally processed material. Engineered powder materials, flaw-less printing, and optimal sintering are all required for successful binder jetting of tungsten carbide powder materials, and become even more critical for WC with low metallic binder contents. Controlling the size and distribution of the pores within printed artifacts is crucial and determines the final part mechanical properties. In this work, the material-process-property correlations of binder jetted tungsten carbide with low cobalt content are assessed.

3:10 PM
Compaction-assisted Binder Jetting of Textured Ceramics: *Mohammadamin Moghadasi*[1]; Anna-Katharina Hofer[2]; Raul Bermejo[2]; Zhijian Pei[3]; Chao Ma[4]; [1]Department of Materials Science and Engineering, Texas A&M University, TX, USA; [2]Department of Materials Science, University of Leoben, Leoben, Austria; [3]Department of Industrial and Systems Engineering, Texas A&M University, College Station, TX, USA; [4]Department of Engineering Technology and Industrial Distribution, Texas A&M University, College Station, TX, USA

In this work, for the first time, a binder jetting process was used to fabricate textured ceramics. This was achieved by using the mixture of alumina nanoparticles and nanoplatelets as the feedstock powder. The fraction of nanoplatelets in the feedstock powder was varied across 0 wt.%, 1 wt.%, 5 wt.%, 10 wt.%, 15 wt.%, 25 wt.%, and 50 wt.%. Green samples were prepared with a lab-design machine for compaction-assisted binder jetting. In this machine, the feedstock powder was spread and compacted layer by layer. Then the green samples were sintered in a furnace. The green density, sintered density, and sintering shrinkage were measured. Furthermore, a scanning electron microscope and X-ray diffractometer were used to investigate the degree of texture in the sintered parts. The results showed that increasing the fraction of nanoplatelets increased the degree of texture; however, this increase led to a decline in the sintered density.

3:30 PM Break

Special Session: Data Analytics I - High-Dimensional Data Analytics

Monday PM	Room: Salon A
July 25, 2022	Location: Hilton Austin Hotel

1:30 PM
Multi-scale Shape Agnostic Flaw Detection and Monitoring in Laser Powder Bed Fusion using Heterogeneous In-process Sensor Data: *Benjamin Bevans*[1]; Chris Barrett[2]; Tom Spears[2]; Aniruddha Gaikwad[1]; Alex Riensche[1]; Ziyad Smoqi[1]; Scott Holliday[3]; Prahalada Rao[1]; [1]University of Nebraska-Lincoln; [2]Open Additive; [3]Navajo Technical University

The goal of this work is the flaw free production of metal additive manufactured (AM) parts made using the laser powder bed fusion process (LPBF). As a step towards this goal, we develop and apply machine learning approaches to detect multi-level flaws ranging from the micro-scale porosity, meso-scale layer deformation, and macro-scale flaws, using data acquired from multiple sensors targeted at each level. Data from a near infrared meltpool monitoring- , high speed- , and optical powder bed imaging-cameras are analyzed using graph theory to extract monitoring features. Then machine learning models are trained to detect the onset of multi-scale flaw formations and are tested across different part geometries and build plates. The approach detects porosity, layer-level distortion (warpage), and geometry (scan path) related flaws with statistical fidelity exceeding 90% (F1-score). Thus this work takes the first step towards shape agnostic, multi-sensor, detection of multi-scale flaws in LPBF.

1:50 PM
HDF5 Hierarchies for AM Digital Representations: *Laetitia Monnier*[1]; Paul Witherell[1]; Hyunwoong Ko[2]; Vincenzo Ferrero[1]; Sebti Foufou[3]; [1]NIST; [2]Arizona State University; [3]Universite de Bourgogne Franche-Comte

Advancement in Additive Manufacturing (AM) technologies and data acquisition techniques have led to an increase in AM data generated. However, due to the large volume and the diversity of AM data available it is becoming challenging to efficiently store, analyze, and represent AM processes. HDF5 have the potential to allow an easy access to big data by offering a hierarchical data catalog. Thus, AM processes could be represented through a hierarchy based on the data analytic needs and directly link the corresponding AM data.This paper investigates the use of data formats to represents big data and AM dataset. Existing AM ontologies and models are reviewed in order to effectively encapsulate AM information and incorporate the hierarchy into an HDF5 AM wrapper. Three hierarchies are proposed to represent specifics perspectives of AM processes: the digital twin of AM Product Lifecycle, the AM V model representation, and the material centric characteristics.

2:10 PM
Scalable Part Qualification for Powder Bed Additive Manufacturing: *Luke Scime*[1]; Alka Singh[1]; William Halsey[1]; Michael Sprayberry[1]; Zackary Snow[1]; Vincent Paquit[1]; [1]Oak Ridge National Laboratory

In this presentation we will discuss our successful efforts to scale an Artificial Intelligence enabled process monitoring solution across multiple powder bed printing technologies at Oak Ridge National Laboratory's Manufacturing Demonstration Facility. Specifically, we have integrated multiple sensor modalities from 13 different powder bed systems (Laser Powder Bed Fusion, Electron Beam Powder Bed Fusion, and Binder Jetting), spanning six printer manufacturers, into our workflows. Meta- and in-situ data from these printers are collected, processed, and visualized using a common software stack called "Peregrine." Data collection and analysis are performed in real-time on 11 of these systems and approximately 50 builds are analyzed each month across the facility. Peregrine has over 20 active users and developers, located across the DOE laboratory system and at the facilities of several industry partners. Lessons learned during this process will be shared, along with a vision for scalable part qualification and real time process control.

2:30 PM
Data-driven Approach for Printability Evaluation for Additively Manufactured Metal Alloys: *Sofia Sheikh*[1]; David Shoukr[1]; Raymundo Arroyave[1]; Alaa Elwany[1]; Ibrahim Karaman[1]; [1]Texas A&M University

To design a part specific to AM, many of the variables need to be controlled due to the larger amount of material and processing parameters that need to be optimized. To capture the material and process space needed to fabricate builds using AM, an AM database is introduced. The database tool is a structural way of capturing data to build models that can simulate the AM process and accelerate materials design in metal AM. Using a subset of the data and features, a modern machine learning approach is used to construct printability maps to build porosity-free parts. Printability maps of material systems, AF9628, NiNb5, and Ni50.3Ti were produced with distinct areas of defects, namely lack of fusion, keyholing, and balling. Furthermore, the printability maps constructed were compared to maps that were obtained using an analytical thermal model called the Eagar-Tsai model and calibrated with experiments.

2:50 PM
Evaluating the Effects of Geometry and Process Parameters in L-PBF using a High-Throughput CT Scanning Approach Within a Connected Machine, Monitoring, Geometry Data Framework: *Fred Carter*[1]; Conor Porter[1]; Dominik Kozjek[1]; Paul Brackman[2]; Jian Cao[1]; Kornel Ehmann[1]; [1]Northwestern University; [2]Zeiss Industrial Metrology

The Laser Power Bed Fusion (L-PBF) process is well suited for manufacturing a wide range of complex geometries across a range of different processing conditions and alloys. Similarly advances in on- and off-axis monitoring techniques, machine sensors, and toolpath generation enable the concurrent creation of high-fidelity digital data as parts are produced. Unfortunately, the traditional evaluation methods for L-PBF components are often time consuming, segmented, and in certain cases lower resolution than the digital data. This work offers a new approach using high throughput CT-scanning method that is capable of analyzing a wide range of geometries and process conditions in a similar time to which the parts were produced. This technique provides the ability to map geometric and material quality data directly to the machine, monitoring, geometry framework. This data is used in a first step to show the impact of geometry and processing conditions on the resultant material.

3:10 PM Break

3:40 PM
Generation and Analysis of AlSi10Mg L-PBF Single Track Data Set Enabling Deeper Process Insights.: *Conor Porter*[1]; Fred Carter[2]; Dominik Kozjek[1]; Andrea Cardona[1]; Jon-Erik Mogonye[3]; Kornel Ehmann[1]; Jian Cao[1]; [1]Northwestern University; [2]Northwestern University/ DMG Mori; [3]Army Research Laboratory

The stability of the melt pool in Laser Powder Bed Fusion (L-PBF), especially with process perturbations, is a key factor underpinning the success of a build. In metal Additive Manufacturing, single tracks are widely used to verify and validate simulation and process models. This work describes the creation of a holistic L-PBF single track data set incorporating a large domain of process conditions for AlSi10Mg. The 352 single tracks are characterized through a series of high throughput methods including white light interferometry, automated microstructure analysis, and in-situ high-frequency (up to 200 kHz) coaxial melt pool monitoring. This data constitutes a large database of process parameters, high-resolution measurements, and geometry information for data driven analysis, including machine learning. In one approach this data is used to correlate track shape and melt pool characteristics to in-situ measurements.

4:00 PM
Spatiotemporal Modeling of the L-PBF Thermal Field History: *David Shoukr*[1]; Peter Morcos[1]; Ibrahim Karaman[1]; Raymundo Arroyave[1]; Alaa Elwany[1]; [1]Texas A&M University

Modeling the thermal field histories in additive manufacturing (AM) is the first step in understanding the process-structure-properties-performance relationships. Thermal histories provide information about the melt-pool dynamics, solidification growth rate, and temperature gradients. These parameters can help understand crack susceptibility and formation as well as microstructure and dendritic arm spacing. Moreover, due to the thermodynamics of the AM process, understanding the structure, properties, and performance of a part requires the simulation of the thermal field history of the entire part. Current thermal models, including simplified analytical models, are extremely expensive.In this study, spatiotemporal statistical methods are used to provide a fast and accurate description of the evolution of the thermal fields. This model takes into consideration the thermal field spatial and temporal rate of change, temperature-dependent material properties, and part geometry. The model is found to produce results equivalent to thermal models that require orders of magnitude greater computational cost.

4:20 PM
Reconstructing 3D Melt Pool Geometry from Coaxial Melt Pool Image for Powder Bed Fusion Additive Manufacturing: *Zhuo Yang*[1]; Yan Lu[1]; Ho Yeung[1]; Brandon Lane[1]; Jaehyuk Kim[1]; [1]NIST

Coaxial camera of powder bed fusion machine records real-time melt pool surface during the build. Those images provide insight into melting conditions such as melting area, shape, intensity, and spatters. However, the optical melt pool image can only capture the information at the 2D level. This intrinsic disadvantage is limited to further layerwise analysis. This paper develops a method to reconstruct the 3D melt pool geometry from 2D optical melt pool images. First, it estimates the melt pool depth based on the width-depth ratio measured from historical data under different process conditions. Secondly, the method generates the melt pool cross-sections based on previous morphological analysis. The reconstruction also uses image pre-processing to remove noise and distinguish spatters from the melt pool. This paper investigates the practical way to estimate the melt pool depth based on accessible information. Future work would design an single-track experiment to fully validate the proposed method.

4:40 PM
Factorial Design Data Analytics for Material Parameters in Multi-physics Modeling of Additive Manufacturing: *Amanda Giam*[1]; Zhisheng Ye[2]; Wentao Yan[2]; [1]Integrative Sciences and Engineering Program, National University of Singapore; [2]National University of Singapore

A bottleneck in Laser Powder-Bed Fusion (L-PBF) metal additive manufacturing (AM) is the quality inconsistency of its products. To avoid costly experimentation, efforts have been invested in computational multi-physics modeling, but effectiveness is limited by parameter uncertainties in the models. In this study, statistical techniques are used to analyze main and interaction effects due to input factor uncertainties on the response melt pool depth in multi-physics models. Data is gleaned from high-fidelity thermal-fluid simulations. A full factorial design, the analysis of variance, half-normal probability plots and multiple linear regression are implemented for screening and sensitivity analysis. Crucial physical phenomena of the L-PBF process related to material parameters are analysed to validate the statistical results with domain knowledge. The consistent results achieved from both statistical and physical analyses provide practical guidance for simulation and experimental communities.

5:00 PM
Examining the GPU Acceleration Speed-up for Finite Element Modeling of Additive Manufacturing: *Jeffery Betts*[1]; Will Downs[1]; Matthew Dantin[2]; Matthew Priddy[1]; [1]Mississippi State University; [2]Naval Surface Warfare Center

Using a graphics processing unit (GPU) in addition to a central processing unit (CPU) has demonstrated promise for the acceleration of processing-intensive operations such as finite element (FE) simulations. Commercial FE solvers have begun to utilize GPU acceleration for classical multi-physics applications, but the speed-up for additive manufacturing (AM) simulations is not well understood. There is a significant need for GPU acceleration for metal-based AM FE simulations, which are computationally expensive, because of the high mesh densities and the large number of time increments employed. This study examines the efficacy of GPU acceleration for Abaqus AM simulations, where benchmark simulations using a sequentially coupled FE thermo-mechanical model are run both with and without GPU acceleration. The speed up is compared across the AM process for the thermal and mechanical analysis, as well as a subsequent mechanical analysis performed on the final part to compare with existing data.

Special Session: Wire-Fed DED - Controls and Modeling

Monday PM Room: 410
July 25, 2022 Location: Hilton Austin Hotel

1:30 PM
The Case for an End-to-end Software-hardware Stack in Wire Arc Additive Manufacturing: *Filomeno Martina*[1]; Stewart Williams[2]; Jialuo Ding[2]; [1]WAAM3D; [2]Cranfield University

The control of thermal effects and residual stress, and the assurance of structural integrity are key limiting factor for those critical applications that would benefit from Wire Arc Additive Manufacturing (WAAM) the most. Moreover, in terms of build rates, and for large structures, despite speeds that are substantially larger than powder-based technologies, the current limitations associated with power sources borrowed from the welding world make WAAM still an impractical choice.This presentation will focus on how hardware and software designed for WAAM help overcome these challenges, including solutions for tool path planning and parameters calculation; the development and integration of brand-new sensing systems; auxiliary automation systems around an ideal WAAM system; the validation of build rates up to 15kg/h; and control software that offers a fully-auditable trail for part manufacture. Case studies from the aerospace and energy worlds will support and demonstrate the solutions covered.

1:50 PM

Robot-to-robot Collision Avoidance and Tool Path Recovery for A Multi-robot Wire-fed Ded System: *Christopher Masuo*[1]; Andrzej Nycz[1]; Mark Noakes[1]; Alex Arbogast[1]; Peter Wang[1]; Joshua Vaughan[1]; Alex Walters[1]; Derek Vaughan[1]; William Carter[1]; Luke Meyer[1]; Jonathan Paul[2]; Jason Flamm[2]; [1]Oak Ridge National Laboratory; [2]Lincoln Electric

Large metal additive parts can be manufactured rapidly through utilizing a wire-fed DED process. Production rate can be further improved by integrating multiple deposition heads to collaborate on building the same part. An approach of this implementation is to incorporate multiple robots equipped with wire-arc deposition capabilities. Multiple robots, however, necessitates control algorithms that focus on assigning print tool paths for each robot to ensure high throughput in productivity. These assigned tool paths would minimize robot-to-robot interference. Inevitably, robot collisions can occur based on the geometry of the part. Additionally, equipment failures on a robot can also arise during operation. These interruptions drastically hinder productivity and weaken the utilization of a multi-robot platform. In this work, a robot collision avoidance algorithm and tool path recovery framework for unexpected equipment failures were developed. Productivity was compared between the unimplemented and implemented methods. A multi-robot wire-arc system was used for benchmark testing.

2:10 PM

Geometric Challenges in Designing Parts for Machining using Wire-fed DED: *Derek Vaughan*[1]; Luke Meyer[1]; Chris Masuo[1]; Andrzej Nycz[1]; Mark Noakes[1]; Josh Vaughan[1]; Alex Walters[1]; Bill Carter[1]; Riley Wallace[1]; [1]Oak Ridge National Laboratory

Wire-fed DED using MIG welding systems allows for high deposition rates above 30lbs/hr, enabling much larger parts to be printed than would be possible on other DED systems. However, a drawback to this high deposition rate is a relatively low bead resolution on the printed part. Post-processing using machining is usually required on any mating surfaces printed using Wire-fed DED. Problems such as residual stress in the build plate, underbuilding, and path interpolations can all lead to insufficient material deposition and deviation from the desired shape. These areas where the printed part varies from the model can leave defects on post-processed surfaces. This paper will cover common geometry issues that can arise from wire-fed DED and design changes that can be made to ensure that the printed design contains the required material to achieve the finished part.

2:30 PM

Impacts of Sharpened Corner Path Geometry on Layer Topology in Wire Arc Additive Manufacturing: *Harold Walters*; Lai Canhai; Andrzej Nycz; Mark Noakes; Joshua Vaughan; Chris Masuo; Derek Vaughan; Luke Meyer; William Carter; Riley Wallace; [1]

In wire arc additive manufacturing, adjacent weld beads typically use a constant offset between the bead centerlines. This can lead to material-filling issues when printing corner geometries with acute angles due to the tool path being restricted from reaching points of interior corners. Issues such as voids and uneven layer height compound on consecutively printed layer cross sections, resulting in increasingly undesired layer topologies. These effects can be mitigated by manipulating the bead geometry to move interior corner points closer to exterior corner points, "corner sharpening"; thus, closing the gap but also deviating from the standard constant offset at the tip of the interior corners. This work explores the experimental effects of utilizing different cases of sharpened corner geometries to address this issue and focuses on the topological results.

2:50 PM

Key Variables in Toolpath Generation for Wire-Arc Additive Manufacturing: *Luke Meyer*[1]; Lai Canhai[1]; Derek Vaughan[1]; Chris Masuo[1]; Alex Walters[1]; Bill Carter[1]; Mark Noakes[1]; Andrzej Nycz[1]; [1]Oak Ridge National Laboratory

Creating large-scale metal parts using wire-arc additive manufacturing typically entails creating a 3-dimensional model of a part, distilling this model down to a series of 2-dimensional cross sections or "layers," then using these cross sections to create toolpaths for a machine to read and ultimately build the desired part. The process of creating cross sections and toolpaths, termed "slicing," is dependent on each layer being almost perfectly flat during printing to create a part with successfully stacked layers, reasonable dimensional accuracy, and a lack of voids or inclusions. Often overlooked, choices made during toolpath generation determine the quality of a printed part through variables such as bead spacing, number of concentric loops around the perimeter, direction of printing, start position, and use of infill paths. In this analysis, selected toolpath generation variables will be detailed with representative printed examples and recommendations for a successful additively manufactured part.

3:10 PM Break

3:40 PM

WAAM GPU-accelerated Process Simulation Using an Improved Modeling Workflow: *Xavier Jimenez*[1]; Alaa Olleak[1]; Albert To[1]; [1]University of Pittsburgh

Several studies have been published on using computational methods to simulate wire arc additive manufacturing (WAAM). Most of those studies focus on a specific geometry with a hard-coded model that is difficult to implement on a new geometry. This paper focuses on an improved workflow that combines slicing and simulation to create a WAAM part with a digital twin. The model is solved using a GPU-accelerated process simulator and the parts are printed on a Gefertec Arc605 system. The model calibration process and challenges associated with it are also discussed. The improved workflow helps to accelerate the manufacturing process of new parts using WAAM, through thermal history prediction at the part scale level.

4:00 PM

Convolution Long-short Term Memory Autoencoders Applied to Process Monitoring Across Multiple Camera Types for Laser Hot Wire Additive Manufacturing: *Brandon Abranovic*[1]; Elizabeth Chang-Davidson[1]; Sulagna Sarkar[1]; Jack Beuth[1]; [1]Carnegie Mellon University

In order to reliably print quality parts using additive manufacturing, process monitoring is a crucial step in the build process. During the deposition period, large quantities of data are collected and must be analyzed in order to detect and eliminate process anomalies. Unsupervised deep learning techniques are valuable in executing this analysis due to their ability to recognize flaws without the need for vast quantities of labeled data. A convolutional long-short term memory autoencoder model was trained on process data from a laser hot wire additive manufacturing process. This model used, as input, data from both a visible-light camera and an infrared camera, to encompass melt pool disturbances as well as near-melt pool part temperatures. This model is shown to be feasible as a realtime monitoring technique capable of detecting known characteristic process flaws, as well as a post-deposition data analysis tool for directing part testing towards suspected flaw areas.

Applications - Metals

Tuesday AM Room: 417 AB
July 26, 2022 Location: Hilton Austin Hotel

8:15 AM

Influence of Biodegradable Additives on the Surface Finish of Additively Manufactured Part: a Green Surface Manufacturing Approach: Shivam Kumar[1]; Rishika Jaiswal[1]; Ashish Meena[1]; *Abhishek Shrivastava*[1]; Rajkumar V[1]; Anand Kumar[1]; [1]IIT Jammu

Additively manufactured components have a high degree of surface roughness inherent to the nature of the process. AM components find their applications in aerospace, defence etc., made from Inconel 718. Post-processing is necessary to improve the functionality of such high-value components to bring down surface roughness within the permissible limits. Various techniques are available to achieve the required surface finish, such as electro-polishing, buffing, and lapping. However, these techniques require synthetic additives and lubricants, posing a threat to the environment and increasing the overall operational cost. Natural additives can offer an alternative to ease the process and reduce the operation cost. In this work, natural additives (citric acid from lemon) and natural abrasives (rock-stone) have been used to enhance the surface finish of AM blocks. A 40% reduction in the surface roughness (Sa) has been obtained using citric acid over Inconel 718, indicating a step towards realizing green surface manufacturing.

8:35 AM

Effect of Build Orientation on Residual Stress and Microstructure in Inconel 625 Fabricated via Laser Powder Bed Fusion: *Mohanish Andurkar*[1]; Bart Prorok[2]; Scott Thompson[1]; [1]Kansas State University; [2]Auburn University

The structural integrity of parts produced by Laser Powder Bed Fusion (L-PBF) is still not at a great acceptance level. One of the major defects inherited in parts fabricated from L-PBF is high level of residual stress. In this study, three different stress relief temperatures were performed on L-PBF Inconel 625 specimens to observe effects on the residual stress magnitude and grain growth. The evolution in residual stress after heat treatment is supported by microstructure characterization via Electron Backscattered Diffraction (EBSD) and measuring mechanical properties using nano-hardness mapping. The results indicate that the as-printed samples possessed a high tensile residual stress that was subsequently relieved via the employed heat treatments. EBSD results indicate the presence of twining phenomenon in the microstructure after heat treatment thus implying recrystallization. The kernel average misorientation (KAM) map of the as-printed sample showed more pronounced local misorientation compared to heat treated samples.

8:55 AM

Physics-Informed Learning of Real-time Residual Stress in Laser Powder Bed Fusion: *Xinyi Xiao*[1]; [1]Miami University

Metal additive manufacturing (AM) process recently predominately gained attention by providing flexibility in design and manufacturability, but its rapid heating and cooling lead to deviations in the as-built properties far from the desired. Residual stress is prone to cause build failure and further affect the part functionality performing. However, in-situ residual stress cannot be easily measured and examined for controlling as-built properties in real-time. The recent development of the in-situ monitoring sensors can contribute to carefully examining the process anomalies, such as porosity and cracking issues. However, the quantitative consequences between the observed physical phenomena and the residual stress have not yet been developed. To solve the aforementioned issues, we propose a quantitative method that integrates process-related physical phenomena and a novel neural networks framework to predict and control the in-situ residual stress during the real-time fabrication process.

9:15 AM

Laser Powder Bed Fusion Additive Manufacturing of Wicking Structures for Heat Pipes: Design, Fabrication, and Application: *Adnen Mezghani*[1]; Edward Reutzel[2]; Abdalla Nassar[2]; [1]The Pennsylvania State University; [2]The Applied Research Laboratory

Heat pipes (HP) are high-performing two-phase thermal management components. A porous wicking structure inside HPs provides capillary pressure, which in turn drives the two-phase fluid flow in the system. Recently, laser powder bed fusion (LPBF) additive manufacturing (AM) has received increasing consideration as a manufacturing medium for heat pipes. This is because AM offers increased design freedom and opportunities for cost reduction. However, the main problems that additively manufactured wicks face are (1) anisotropy in porosity and the presence of trapped pores, and (2) the difficulty in achieving a combination of small effective pore size and large porosity comparable to conventionally sintered wicks, leading to inferior performance. In this work, we present useful fabrication strategies for wicking structures, recent preliminary work on the implementation in hypersonic leading edges, common issues facing the design and fabrication of wicks for LPBF AM, and guidance for future research.

9:35 AM

Preventing Recoater Crash in Laser Powder Bed Fusion via Modified Inherent Strain Modeling: *Wen Dong*[1]; Albert To[1]; [1]University of Pittsburgh

When fabricating overhang structures with the laser powder bed fusion (L-PBF) process, the recoater blade is prone to stoppage during printing if the overhang tip significantly deforms, which is often referred to as the recoater crash. In the present work, the modified inherent strain (MIS) method, as a fast modeling approach, is implemented to predict the distortion of a part with overhangs during printing. Through experimental measurement and simulation results, we investigate the relationships between multiple geometrical parameters and the height of the part immediately before a recoater crash. After that, the critical criterion is found to predict the recoater crash. The proposed criterion can be applied in the design stage of a part to reduce the possibility of a recoater crash, thus saving cost and increasing manufacturing efficiency.

9:55 AM Break

10:25 AM

The Impact of as-built Surface Roughness on Vibration Bending Fatigue of Additively Manufactured Nickel Alloy 718: *Rachel Evans*[1]; Joy Gockel[2]; Nathan Klingbeil[1]; Luke Sheridan[3]; Onome Scott-Emuakpor[3]; [1]Wright State Universtiy; [2]Colorado School of Mines; [3]Air Force Research Laboratory

Surface roughness has been shown in literature to be a dominating factor in the fatigue life of structural components. This is especially true in additive manufacturing, where as-built surfaces are significantly rough. The impact of surface roughness on fatigue life is still not fully understood in as-built additively manufactured parts, and thus must be studied more extensively. Using a novel vibration bending fatigue testing method, this work has investigated the effects of surface roughness on fatigue life in as-built additively manufactured nickel superalloy 718 fabricated using different additive manufacturing processing conditions. Additionally, fracture surface analysis has been performed to determine the location of crack initiation for each test, highlighting geometrical effects in fatigue testing. The outcome of this work is an enhanced understanding of the surface roughness impact in additively manufactured parts, which is necessary in increasing the efficiency and reliability of additive manufacturing for applications involving fatigue loading conditions.

10:45 AM

Studies on Thin and Thick-walled SS316L Overhanging Specimens Manufactured Using Powder-fed Laser-based Directed Energy Deposition: *Alexander Belchou*[1]; Ashish Jacob[1]; Sanjay Joshi[1]; Edward Reutzel[1]; Peter Coutts[1]; [1]The Pennsylvania State University

Effective Design for Additive Manufacturing (DfAM) requires accurate knowledge of a machine's capabilities and limitations. One important factor is the machine's ability to deposit unsupported overhanging features. A general method was devised to characterize the ability of a powder-fed Laser-Based Directed Energy Deposition (LB-DED) system to deposit overhanging features with various overhang angles, wall thicknesses, and scan strategies, which was then investigated on a DMG Mori Lasertec 65 3D Hybrid LB-DED system using 3-axis toolpaths. To assess the accuracy of the manufactured overhang angle, for each specimen the angle of the downward facing surface and upward facing surface were measured and compared to the target overhang angle. It was observed that for the longitudinal scan strategy, overhang accuracy substantially degraded as wall thickness increased. For the transverse and cross hatch patterns there is no observable trend between the achievable overhang angle and the wall thickness. In addition, it was observed that in general increasing the target overhang angle degrades the accuracy of the manufactured overhang angle. The most accurate overhang angles overall were achieved for the longitudinal 1 bead thick specimens. These results will help inform future DfAM and path planning strategies. This research fills a gap in the literature by providing a general method to assess overhang capabilities for LB-DED systems.

11:05 AM

Design and Additive Manufacturing of Bio-inspired Copper Heat Sinks for Microelectronics Cooling: *Jordan Yaple*[1]; Cameron Noe[1]; Abdulmajeed Alenezi[1]; Patrick Phelan[1]; Dhruv Bhate[1]; [1]Arizona State University

The heat sink is a key component in thermal management of microelectronics and is traditionally designed with arrays of pins or fins. In this work, a bio-inspired approach to designing heat sinks was evaluated. A process was first developed on a 100W Laser Powder Bed Fusion (LPBF) system for the copper alloy CuNi2SiCr, which was found to have a tenfold reduction in thermal conductivity relative to commercially pure Copper. This process was then used to fabricate four heat sinks: two of these replicates of commercial heat sink designs, and two leveraging bio-inspired design approaches with the aim of increasing the available surface area per unit volume. The four designs were tested on a microelectronics package placed on a hot plate and their performance compared against commercially available heat sinks. The results demonstrated that despite their poor thermal conductivity, the bio-inspired heat sinks had equivalent performance to the commercial heat sinks.

11:25 AM

Experimental Study on the Electropolishing of Additive Manufactured Copper Parts: Jonathan Eby[1]; Kianna Lucas[1]; Parker Jensen[1]; Matthew Reinert[1]; Abishek Kamaraj[1]; *Chaitanya Mahajan*[1]; [1]Kettering University

Low-cost metal-polymer filaments are being widely used in material extrusion printers to manufacture parts for a wide range of applications in the automotive and biomedical industries. These filaments can be used to produce parts with intricate details and complex internal geometries. Parts printed with such filaments have rough surfaces with a poor surface finish after the de-binding and sintering process. The high surface roughness affects aesthetics, corrosion behavior, and mechanical properties. Traditional finishing techniques such as sandblasting are limited to the external surfaces, and it is a challenge to polish the internal surfaces of these printed parts. Electropolishing offers an alternate method to reduce the surface roughness of both external and internal surfaces. We present a parametric study of electropolishing parts printed using the copper filament material extrusion process. The influence of current density, deposition time, and other electrochemical process parameters on the surface finish will be presented.

11:45 AM

Comparative study of Mechanical Properties of Aluminum Alloy A356 (Al-12Si) Fabricated by Directed Energy Deposition Method and Pressure Die Casting: Ragavanantham Shanmugam[1]; Jishu Chandran[2]; Mohanavel Vinayagam[3]; Osama Fakron[1]; *Seth Dennison*[1]; Seth Romine[1]; [1]NAVAJO TECHNICAL UNIVERSITY; [2]Vel Tech Rangarajan Dr.Sagunthala R&D Institute of Science and Technology; [3]Bharath Institute of Higher Education and Research

Additive Manufacturing (AM) is a rapidly growing manufacturing technique. Direct energy deposition (DED) is an important method in additive manufacturing. This research compares the Mechanical Properties like tensile strength and hardness of additively manufactured Al-12Si Aluminum alloy by DED method and pressure die casting (PDC) method. The DED and PDC fabricated parts showed similar ultimate tensile strength and young's modulus if load direction in UTM machine is same as building directions, although other mechanical properties are slightly differing in their values. Mechanical properties of fabricated objects made by reused powders also exhibited similar values to those manufactured by unused powder. Hardness comparison of both the modes has yet to be carried out. Also, the analysis of influence of print orientation in these properties will also be carried out through various experiments. Keywords: Direct energy deposition (DED), AlSi12 alloy, Pressure die casting, ultimate tensile strength, hardness, building directions

Applications - Metrology and Defects

Tuesday AM	Room: 416 AB
July 26, 2022	Location: Hilton Austin Hotel

8:15 AM

Characterizing The Distortion of Large-scale Polymer Composite Printed Structures: *Tyler Corum*[1]; Johnna O'Connell[1]; Ryan Spencer[1]; Ahmed Hassen[2]; Chad Duty[1]; [1]University of Tennessee; [2]Manufacturing Demonstrstion Facility Oak Ridge National Laboratory

The Big Area Additive Manufacturing (BAAM) system at Oak Ridge National Laboratory (ORNL) can print large-scale parts with carbon fiber-reinforced acrylonitrile butadiene styrene (CF-ABS). Incorporating reinforcing fibers improves stiffness and strength, but also introduces significant anisotropy in the thermomechanical performance. Understanding the distortion experienced during thermal cycling of a printed tool is crucial to maintaining tolerances and avoiding part failure. This study uses digital image correlation (DIC) to measure the coefficient of thermal expansion (CTE) of a printed part between room temperature and a known steady-state temperature. Various samples were evaluated to determine the impact of different print parameters, nozzle geometries, and orientations with the intent to minimize thermally-induced distortion.

8:35 AM

Investigation of the Process Parameters and Geometry Dependent Shrinkage Behavior of Raster Lines in the Fused Deposition Modeling Process: Elmar Moritzer[1]; *Felix Hecker*[2]; [1]Paderborn University, Kunststofftechnik Paderborn (KTP); [2]Paderborn University, Direct Manufacturing Research Center (DMRC)

Additive manufacturing processes are able to generate components from raw material (filament, powder etc.) without the need of tools or conventional machining. One of the most common additive manufacturing processes is the Fused Deposition Modeling (FDM). Here, a thermoplastic polymer filament is fed into a heated nozzle, where the filament is plasticized. The plasticized material is then deposited, layer-by-layer, onto the building platform or the already existing component structure in a defined way. Thermoplastic polymers show a material specific shrinkage induced by the cooling process. The recurring heat input by depositing adjacent strands results in a complex cooling situation which contributes to the non-uniform shrinkage of the component. In the investigations, first, a DoE is carried out to determine the influence of selected process parameters on the shrinkage behavior of the raster lines. Following, the geometrical deviations of simple geometries under consideration of different process parameters are determined and analyzed.

8:55 AM
A Novel Test Artifact Design for Conformal Printing via Material Extrusion: *Sagar Jalui*[1]; Seyed Zargar[1]; Sheila Moroney[1]; Marcus Putz[1]; Mychal Taylor[1]; Serah Hatch[1]; Guha Manogharan[1]; [1]The Pennsylvania State University

It has been well documented that Additive manufacturing (AM) offers unparalleled design complexity. However, the layer-by-layer manufacturing method involves 2D planar slices of each layer, which eventually combines to represent the net-shape 3D geometry. In recent years, there have been significant developments in non-planar (conformal) printing, specifically in polymeric material extrusion process. Although there are several test artifacts currently developed to evaluate print quality, they have not been designed for conformal printing. This study presents a novel test artifact specifically for conformal printing by creating a design matrix for any given machine-nozzle configuration. Based on non-STL NURBS and trigonometric (sine) surfaces, this test artifact would allow for deeper insights into the print quality of organic shapes that could be fabricated via material extrusion 3D printers. It would also enable the creation of novel Design for Additive Manufacturing (DfAM) rules specifically for conformal printing.

9:15 AM
The Impact of the Printed Part Geometry on the Shrinkage and Density of 316L Stainless Steel Parts Printed by FFF/FDM Technology: *Suleiman Obeidat*[1]; Joe Nervis Jr[1]; Junkun Ma[1]; [1]Sam Houston State University/ Engineering Technology Department

Additive manufacturing has been used extensively for the last decade in making different parts of different complexities. One of the additive manufacturing methods discussed in this work is Free Form Fabrication/ Fused Deposition Modeling (FFF/FDM). FDM is used to fabricated stainless steel using BASF Ultrafuse 316L Metal 3D Printing Filament which is made of 80% 316L stainless steel particles in polymer base. In this work, we study the impact of the part geometry on the shrinkage percentage and density of 3D printed parts. Four basic geometries are printed: cylinders, rectangular blocks, spheres, and cones. These geometries have the same volume with the same height in the printing direction for the cylinders, rectangular blocks, and the cones. The size of the parts before and after sintering are compared with the CAD model of those parts and the density of those parts are also compared before and after sintering.

9:35 AM
Reducing Part Distortion in Laser Powder Bed Fusion Through Data-driven Topology Optimization: *Praveen Vulimiri*[1]; Florian Dugast[1]; Shane Riley[1]; Albert To[1]; [1]University of Pittsburgh

Laser powder bed fusion (LPBF) is a popular method to produce complex metal additive manufactured (AM) parts. However, during the process, the laser melting of the metal powder introduces thermal stresses which distort the part from the desired dimensions. If the stress is large, it could lead to cracking, recoater blade crash, or other build failures. A new data-driven model has been developed based on the modified inherent strain method to provide a near instantaneous approximation of the residual stress and strain in a part. The model is used in topology optimization to optimize the part for end use application and constrain the distortion during the build process simultaneously. A computational example of the method will be shown followed by a plan for experimental validation of the method.

9:55 AM Break

10:25 AM
Predicting Geometric Accuracy via Image-to-image Machine Learning: *Daphne Lin*[1]; Tim Phillips[1]; Jared Allison[1]; Carolyn Seepersad[1]; [1]University of Texas at Austin

As AM technologies become more widespread, gaps in process control also become more apparent. While previous research primarily focuses on the effects of adjusting process parameters, there is a lack of process control tools for monitoring and ensuring accuracy in part geometry during a print. Our goal is to demonstrate the possible use of image-to-image machine learning algorithms to monitor and update process parameters in polymer selective laser sintering (SLS). We first train the image-to-image conditional generative adversarial network (cGAN) on a dataset of layer-by-layer thermal images and physical dimensions of the final part. Aftr the cGAN model is trained, it can accurately predict the physical dimensions of a layer based on input thermal images. The ultimate goal of the research is to integrate the model into the controls of the polymer SLS machine and update process parameters in real time to ensure accurate prints with little manual parameter adjustment.

10:45 AM
Examining Repeatability in Powder Bed Fusion Additive Manufacturing Systems: *Evan Handler*[1]; Aidan Cowhig[1]; Katherine Fowler[1]; Caroline Vail[1]; [1]Naval Surface Warfare Center

The naval enterprise faces ongoing readiness challenges in their ability to rapidly obtain repair or replacement components. Among the different additive manufacturing methods, Laser Powder Bed Fusion (LPBF) has garnered interest for its ability to create geometrically accurate, complex, and critical parts out of various metal powders. However, questions remain among approvers regarding the repeatability of these systems, both among different builds on the same system and the variability when moving to a different system. Leveraging the Naval Sea Systems Command Additive Manufacturing Warfare Center Working Group, a consistent set of coupons was printed multiple times on six LPBF systems from three different manufacturers. Process variables, including energy source parameters, scan paths, and operator procedures, were kept as constant as possible within and across each site. Specimens produced were used for tensile and hardness testing, optical microscopy, and surface roughness measurements, in order to detect process control limits and allowables.

11:05 AM
Effect of Additive and Subtractive Sequence on Distortion During Hybrid Directed Energy Deposition: *Guru Charan Reddy Madireddy*[1]; Yousub Lee[1]; Rangasayee Kannan[1]; Kyle Saleeby[1]; Eric MacDonald[2]; Thomas Feldhausen[1]; [1]Oak Ridge National Lab; [2]University of Texas at El Paso

Hybrid additive manufacturing combines additive manufacturing and subtractive processing intertwined during fabrication for the simultaneous benefits of both additive manufacturing (complex geometries and mass customization) and traditional processes (improved surface finish and dimensional accuracies). However, two processes that are otherwise identical except for the sequencing of additive and subtractive steps can lead to different results as differences in distortion can result in process-to-process registration. In this work, a single identical geometry was fabricated with two hybrid process orderings and the resulting geometric compliance is compared both experimentally and through finite element modeling. By fabricating support features first before machining and tool change-out cooling, subsequent geometric features can be successfully printed which would otherwise be susceptible to excessive distortion. The study found that final distortion in geometry is dependent on additive and subtractive process sequencing in hybrid additive manufacturing and the FE model was validated for distortion prediction.

11:25 AM
Physics-based Feedforward Control of Laser Powder Bed Fusion Process: *Alexander Riensche*; Benjamin Bevans[1]; Ziyad Smoqi[1]; Reza Yavari[1]; Josie Gilligan[2]; Ajay Krishnan[3]; Kevin Cole[1]; Prahalada Rao[1]; [1]University of Nebraska-Lincoln; [2]Lincoln High School; [3]Edison Welding Institue

In this work we mitigated flaw formation in laser powder bed fusion (LPBF) additive manufacturing by introducing feedforward process control. In LPBF the spatiotemporal temperature distribution in the part during processing, called thermal history, is the root cause of flaw formation such as distortion, poor geometric integrity, microstructure heterogeneity, and degraded surface finish. The key idea is to use physics-based thermal simulation to optimally adjust the processing parameters layer-by-layer before the part is printed. The effectiveness of this smart additive manufacturing approach is demonstrated in the context of several LPBF parts (Inconel 718) built on two separate build plates. The results demonstrate that controlled processing improves surface finish, geometric inaccuracy, and resolution of fine features.

11:45 AM
In-situ Integration of Weldable Strain Gauges in Components Manufactured by Laser-based Powder Bed Fusion: *Maximilian Binder*[1]; Andreas Machnik[1]; Maximilian Bosch[1]; Katharina Kreitz[1]; Georg Schlick[1]; Christian Seidel[1]; [1]Fraunhofer IGCV

The integration of sensors in components made by PBF-LB/M facilitates promising new possibilities for component monitoring. It enables the collection of relevant measurement data at previously inaccessible component regions, which are needed for the determination of maintenance strategies. Therefore, the following research deals with the development of a concept, with which weldable strain gauges (WSG) can be weld-on by the laser-scanner-system of a PBF-LB/M system to the manufactured component. The examinations show that the arrangement of so-called weld seams has a decisive influence on a correct metal carrier connection of the WSG. It can be deduced from the study that WSGs can be integrated within components manufactured by PBF-LB and completely welded to it with the laser-scanning-system. Following measurement validations demonstrate that the WSG provides complete and correct measurement data and can therefore be considered as sufficiently connected to the component.

12:05 PM
Assessing the Feasibility of Process Window Estimation for L-PBF Ti-6Al-4V through Hardness Measurements: *Arun Poudel*[1]; Mohammad Yasin[1]; Shuai Shao[1]; Nima Shamsaei[1]; [1]Auburn University

Optimizing the process window for an additively manufactured material using X-ray computed tomography (XCT) is a time-, labor-, and capital-intensive process where a large number of coupons need to be analyzed in the process parameter space. Hence, as an alternative, this study aims to assess the relationship between the relative density and hardness of laser powder bed fused (L-PBF) Ti-6Al-4V. Coupons with different levels of porosity are fabricated in underheating (i.e., energy input lower than recommended), recommended, and overheating (i.e., energy input higher than recommended) conditions. These coupons are used for Rockwell hardness measurements and the results are analyzed to develop a relationship with the process window obtained via the XCT method.

Applications - Polymers

Tuesday AM	Room: 415 AB
July 26, 2022	Location: Hilton Austin Hotel

8:15 AM
Additively Manufactured Conformal Fluidic Circuits as Non-destructive Pressure - Strain Transducers: *Ankit Saxena*[1]; Philip King[1]; George Rai[1]; Christopher Rahn[1]; Guha Manogharan[1]; [1]Penn State

Strain measurement methods such as Strain Gauges and DIC (Digital Image Correlation) are restricted by the shape and location of the structure under evaluation and may require wiring through confined, inaccessible, exposed, and/or high-temperature environments. This paper presents a novel approach for measuring mechanical strain via additively manufactured fluid circuits that conform to the structure under evaluation. Structural deformation changes the volume inside the fluid circuits, varying the pressure. Static analysis will be performed to reveal the relationship between change in pressure and strain. To validate the static analysis, experiments will be conducted on metal structures with additively manufactured conformal fluid circuits. These results will serve as building blocks for a novel non-destructive strain evaluation method with applications such as long-term monitoring of safety-critical structures such as aircraft and bridges.

8:35 AM
3D Printing Diffractive Axicons and Zone Plates: *Junyu Hua*[1]; Huachao Mao[1]; [1]Purdue University

Diffractive optical elements (DOEs) are important optics for light phase modulation and are widely used in sensors, spectrometers, and feature detection. Fabrication of DOEs requires high precision and clean environment, which is mainly fulfilled by nanofabrication in clean rooms. This paper reports two typical DOEs, diffractive axicons, and zone plates which were 3D printed in minutes with low-cost 3D printers. Diffractive axicons could transform laser into a ring-shaped distribution while zone plates could work as lens to converge beams. A collimated and filtered 520 nm laser beam passed through the printed samples successfully generated the designed patterns. The phase mask of the DOEs was measured by off-axis digital holography and agreed with the designed phase. This method makes it possible to fabricate DOEs with lower cost and easier procedures.

8:55 AM
Multifunctional Design in Additive Manufacturing: Process Intensification for Enhanced CO2 Capture: *Amiee Jackson*[1]; Costas Tsouris[1]; Dhruba Deka[1]; Gyoung Gug Jang[1]; Josh Thompson[1]; Lonnie Love[1]; [1]Oak Ridge National Laboratory

Capture and removal of carbon dioxide is necessary to mitigate and counterbalance “hard-to-abate” emissions in the planetary quest toward drawdown. For chemical methods of CO2 capture, process intensification through device multifunctionality can yield greater energy efficiency and reduce plant complexity and footprint, which in turn can reduce overall cost. An additively manufactured intensified structured packing device which co-locates the mass transfer and heat exchange functions enables increases in CO2 capture rates with lower solvent temperatures. The device features embedded channels for coolant flow within a crossflow structured packing device comparable to Sulzer’s Mellapack 250 to balance the constraints of manufacturability with flow rate requirements for heat and mass transfer. By leveraging additive manufacturing for process intensification in point-source CO2 capture with solvents, this device demonstrates the utility and value that advanced manufacturing methods enable in multifunctional products.

9:15 AM
Vibration Reduction using Material Jetted Parts for Sander Grips: Shruthika Kandukuri[1]; Atharva Kashyap[1]; *Jeffrey Lipton*[1]; [1]University of washington

Workers in many industries are exposed to harmful vibrations that negatively impact their comfort and long-term health through tools such as hand-held sanders. Here we show that using material jetting we can produce durable and effective vibration protection equipment that reduces vibrations felt by the user by an average of 50% to 80%. We developed 3D printed vibration absorbing grips made from a blend of TangoBlack+ and uncured liquid. The grips were deployed at a Boeing factory and survived 1 month of usage. The grips were best at absorbing higher-frequency vibrations, reducing a first resonance at 250Hz by 10dB but able to reduce frequencies above 4kHz by over 20dB. Our results demonstrate promising capabilities of material jetting viscoelastic materials for direct part production of ergonomic components. Moreover, these grips could be improved and used to dampen vibrations on other tools such as bucking bars and used in various other industries.

9:35 AM
Characterization of Material Jetting Processes to Develop Design Guidelines in Support of Model Based Definition for Additive Manufacturing: *Francisco Gonzalez-Castill*[1]; Carolyn Seepersad[1]; [1]University of Texas at Austin

Model Based Definition (MBD) is an emerging practice for communicating product and manufacturing information for all stages of the product life cycle. MBD presents an interesting opportunity for AM processes, which disrupt traditional product information communication with complex designs, machine process parameters, and design features that are not easily communicated with traditional 2D drawings. To implement MBD for AM comprehensively, the limitations, opportunities, and capabilities associated with each individual AM process must be characterized using metrology studies. These studies can be used to formulate comprehensive designer guidelines for a given AM process to ensure designers conform to process limitations and take advantage of the unique capabilities afforded by AM. In this paper, a summary of metrology studies performed on a variety of material jetting AM processes and machines is presented, and opportunities for additional studies are discussed. A framework for incorporating this knowledge into MBD is illustrated.

9:55 AM Break

10:25 AM
A Case Study in Component Redesign for Additive Manufacturing Process Workflows: *Elliott Jost*[1]; Jaime Berez[1]; Christopher Saldana[1]; [1]Georgia Institute of Technology

Additive manufacturing (AM) has matured beyond limited use-cases in rapid prototyping into a process capable of competing with conventional manufacturing methods for production of end-use components. As such, many manufacturers are evaluating candidate products for redesign for AM (rDFAM), with interest in improving component performance, streamlining manufacturing, and reducing costs. Herein a bicycle stem is used as an exemplar case study of component redesign for AM. Design constraints, AM process selection, and material selection are considered. Generative design is used to optimize the component's weight given the design constraints. An end-to-end manufacturing process chain is consequently developed and analyzed for viability, covering DFAM and post processing. Through this comprehensive case study, it is shown that significant weight savings, greater than 25% in the present case, can be achieved through the rDFAM process. Guidelines from the rDFAM process are generalized for application to further cases.

10:45 AM
Single-part Tracking Enabled by Fluorescent Polysecure Tracing Particles in AM Parts: *Patrizia Gartner*[1]; Nikolai Krischke[1]; Martin Benfer[1]; Matthias Bender[1]; Gisela Lanza[1]; Jürgen Fleischer[1]; Georg Dost[2]; [1]wbk, KIT; [2]Polysecure GmbH

Traceability is widely recognized as a core enabler of many industry 4.0 technologies. The necessary identification of products is often realized through label-based systems, but tracing products with particular geometric constraints that prohibit the use of such systems remains an issue. A promising alternative of label based identification is the pattern based identification. This contribution portrays a novel method to utilize fluorescent particles integrated in polymer-based products and optical pattern recognition to facilitate the identification of products with specific geometric constraints. The particles are integrated into the polymer and the unique random distribution of fluorescent particles triggered by an LED flash is used to recognize individual products. To demonstrate the approach, polymer-based gear wheels were printed using ARBURG plastic freeforming and an automatic identification system was designed. The presented approach could be a reliable alternative to other surface-structure-based approaches for product identification and enable comprehensive tracing of components throughout value-chains.

11:05 AM
Effects of Chemical Treatment of Additively Manufactured Tooling on Surface Quality in Investment Casting: *Philip King*[1]; Ankit Saxena[1]; Guha Manogharan[1]; [1]Penn State University

Polymer additive manufacturing (AM) has been employed to produce metal parts indirectly via printed tooling (e.g., wax patterns) for investment casting. In investment casting, every feature of the pattern is transferred to the final part, leading to printed patterns having poorer surface finish than traditionally manufactured patterns. Additionally, AM patterns with surface pores can lead to slurry infiltration. Improving the surface finish and sealing the pattern's surface can significantly improve the surface finish of the final metal part. This study investigates chemically treated printed wax patterns for indirect metal AM via investment casting. In this study, 36 patterns with two different geometries were printed with varying print conditions and surface treated with acetone for different durations. The surface quality of the metal casting was measured using a contact profilometer. These results will help establish a new process chart for surface treatment of increasingly complex AM patterns in indirect metal AM.

11:25 AM
Role of Pre-treatments in Printed Flexible and Stretchable (Bio-) Electronics: *Miriam Seiti*[1]; Akash Verma[1]; Eleonora Ferraris[1]; [1]KU LEUVEN

Pre-treatment methods, like plasma and corona discharges, are often used to functionalize, activate, or clean any surfaces in many industries, including printed (bio-)electronics. Prior printing step, those methods can increase the wettability of the ink on hydrophobic substrates, such as silicones (PDMS) and TPU. New inks formulations that are compatible with such substrates can mitigate pre-treatments, but usually, they are inevitable with common, available commercial inks. In this work, the wettability and adhesion of silver ink and conductive polymer ink (PEDOT:PSS) developed for Aerosol Jet® Printing (AJ®P) are investigated on TPUs, PET, and PDMS substrates, with and without the influence of corona and spot-plasma pre-treatments. Each method was investigated with two different settings. Contact angle measurements, AJ®P and adhesion tape tests, are performed to investigate the best substrate-treatment combination. Such fundamental study can be critical in printed (bio-)electronics pilot lines for prototyping and serial manufacturing of smart electronics.

11:45 AM
Validation and Comparison of FEM-Simulation Results of the Fused Deposition Modeling Process under Consideration of Different Mesh Resolutions: *Felix Hecker*[1]; Elmar Moritzer[2]; [1]Paderborn University, Direct Manufacturing Research Center (DMRC); [2]Paderborn University, Kunststofftechnik Paderborn (KTP)

The Fused Deposition Modeling (FDM) process is an additive manufacturing (AM) technology. In the FDM process, components are generated by feeding a thermoplastic polymer filament into a heated nozzle and depositing the molten material layer-by-layer in a defined way onto the building platform or an already existing component structure. The strand-by-strand deposition leads to a complex cooling situation which contributes to the non-uniform shrinkage of components in the FDM-process. Using an AM plug-in for the FEM-simulation software Abaqus, the thermal and mechanical aspects of a component can be simulated according to the temporal sequence of the manufacturing process. For this, the birth-death-method is used in the simulations. During the investigations, the simulation results regarding geometrical deviations are compared to the actual deviation of the manufactured specimens. Furthermore, the influences of the mesh resolution on the simulation results and the required time for the simulations are considered.

12:05 PM
Numerical Transient Thermal Development of Melting a Solid Filament in the Hot-end in Material Extrusion Additive Manufacturing: *Gaius Nzebuka*[1]; Chukwuzubelu Ufodike[1]; [1]Texas A&M University

To Be Announced.

12:25 PM
Thin-walled Part Properties in PBF-LB/P — Experimental Understanding and Nonlocal Material Model: *Andreas Jaksch*[1]; Michele Spinola[2]; Simon Cholewa[3]; Lukas Pflug[4]; Michael Stingl[2]; Dietmar Drummer[3]; [1]Collaborative Reserach Center 814 - Additive Manufacturing; [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Department of Mathematics, Chair of Applied Mathematics (Continuous Optimization); [3]Friedrich-Alexander-Universität Erlangen-Nürnberg, Institute of Polymer Technology; [4]Friedrich-Alexander-Universität Erlangen-Nürnberg, Competence Unit for Scientific Computing

Understanding the mechanics, geometry effects, and process behavior of thin-walled components is critical to fully utilize the potential of lightweight design of powder bed fusion of polymers (PBF-LB/P). In this work, parts built with rectangular cross sections of different sizes and orientations are described by their geometry, surface roughness, mechanical characteristics, and on specific component geometry depending energy input. Experimental findings are supported by a nonlocal material model developed to adequately describe weakened material behavior at the surface of PBF-LB/P parts. This approach allows the simulation of the elastic modulus and density for complex part geometries while considering boundary effects. Furthermore, the volume-surface ratio for thin-walled components follows a linear behavior correlated to the rectangular cross sections in different building orientations. This uniformity indicates that this ratio is a suitable quantity to consider. Therefore, the process knowledge is improved, especially in new design standards for thin-walled structures in PBF-LB/P.

Materials: Metals - Nickel-based Superalloys

Tuesday AM July 26, 2022 | Room: 616 AB | Location: Hilton Austin Hotel

8:15 AM
Investigating the Effect of Defects on the Crack Initiation of Additively Manufactured IN718 using Crystal Plasticity Simulations: *Indrajit Nandi*[1]; Nima Shamsaei[1]; Shuai Shao[1]; [1]Auburn University

This study aims to analyze the effect of defects location on the fatigue behavior of additively manufactured IN718. A competing mechanism exists between persistent slip bands (PSBs) and volumetric defects on the initiation of fatigue cracks in AM IN718 under cyclic loading. Crystal plasticity simulations were performed to reveal the relative importance in crack initiation due to defects and PSBs. Cyclic loading was applied on a defect laden polycrystalline aggregate and the defect locations were systematically varied. The crack nucleation cycles and locations were captured using a strain contrast-based crack initiation criterion. The findings suggest that the presence of large defects affects the cyclic strain localization and crack initiation behavior of the AM IN718 material.

8:35 AM
Effect of Laser Polishing on Fatigue Behavior of Additively Manufactured IN718: *Seungjong Lee*[1]; Martin Bureš[2]; Shuai Shao[1]; Douglas Wells[3]; Miroslav Zetek[2]; Miloslav Kepka[2]; Nima Shamsaei[1]; [1]Auburn University; [2]University of West Bohemia; [3]NASA

This study investigates the effect of laser polishing on the fatigue behavior of IN718 fabricated using laser powder bed fusion process. Four different conditions including as-built, laser-polished using two different process parameters, and laser-polishing followed by secondary stress relief are considered. Uniaxial tension-compression fatigue tests are conducted in strain-controlled mode to examine the fatigue behavior for each condition. In addition, surface roughness measurements, microstructure analysis, and porosity measurements are also performed for all conditions. The results indicate that laser-polishing alone does not improve fatigue performance, even though it can significantly reduce surface roughness. The beneficial effects of the smoother surfaces may have been countered by the tensile residual stresses induced by laser-polishing. It is also observed that while the secondary stress relief reduces tensile residual stresses, it dissolves the precipitates and weakens the material, and therefore, fatigue behavior is not improved.

8:55 AM
Size and Processing Parameter Effects in Laser Powder Bed Fusion of Inconel 718: *Anna Dunn*[1]; Henry Young[1]; Joy Gockel[2]; [1]Wright State Univ; [2]Colorado School of Mines

Processing parameter and part size effects can have a profound effect on microstructure development during laser powder bed fusion (LPBF). We utilized LPBF to fabricate Inconel 718 tensile and fatigue specimens, at varying laser powers and part sizes. We compare mechanical testing (fatigue, tensile, microhardness array) to microstructural data (SEM, EDS, EBSD). Higher laser powers produce larger grains and more Laves phase segregation. Samples with larger diameters exhibit smaller grains. Lower bulk laser power produces fatigue bars with higher cycles to failure, with exceptions for samples with large surface pores or surface notches.

9:15 AM
Microstructure and mechanical properties of additively manufactured Inconel 718: A comparative study between L-PBF and LP-DED: Nabeel Ahmad[1]; *Shaharyar Baig*[1]; Reza Ghiaasiaan[1]; Paul Gradl[2]; Shuai Shao[1]; Nima Shamsaei[1]; [1]Auburn University; [2]NASA Marshall Space Flight Center, Propulsion Department

This study aims to characterize the microstructure and mechanical properties of Inconel 718 fabricated using two different additive manufacturing processes: laser powder bed fusion (L-PBF) and laser powder directed energy deposition (LP-DED). Similar heat treatments (HTs) including stress-relief (1065ºC for 1.5 hr), hot isostatic pressing (1162 ºC under 100 MPa isostatic pressure of Ar gas for 3 hr), solution annealing (1065 ºC for 1 hr), and two-step ageing (760 ºC for 10 hr + 650 ºC for 10 hr) are applied to both batches. Scanning electron microscopy is utilized to characterize microstructural evolution during each step of HTs for both samples. Tensile tests are performed to evaluate the mechanical properties at room temperature. Elongation to failure of L-PBF specimens is measured to be 16% lower than that of the LP-DED ones, while the ultimate tensile and yield strengths of L-PBF specimens are, respectively, 9% and 6% higher, compared to the LP-DED ones. The differences in tensile properties between two specimens are explained using microstructural and fracture surfaces analysis.

9:35 AM
Microstructural Characterization of Laser Powder Bed Fusion (L-PBF) Additively Manufactured Inconel 718 for Aerospace Application: *Anannya Doris*[1]; Leslie Trujillo[1]; Dana Godinez[1]; Edel Arrieta[1]; Ryan Wicker[1]; Paul Gradl[2]; Francisco Medina[1]; [1]W.M. Keck Center for 3D Innovation at The University of Texas at El Paso; [2]Marshall Space Flight Center, NASA

Inconel Alloy 718 is used for aerospace applications because of its excellent corrosion resistance and mechanical properties. This alloy is particularly applicable in manufacturing components subjected to high temperatures in aero-engines and gas turbines. However, properties for the same alloy when processing it on systems from the same and different machine manufacturers give subtle differences in process parameters, feedstock, and machine configurations. A series of sixteen Laser Powder Bed Fusion (L-PBF) AM Inconel 718 geometric feature build plates have been evaluated with microstructural characterization. This study presents the details of the microstructure analysis concerning the geometry and machine platforms. Microstructural analyses of these samples included average grain width measurement for all the X-Y and Y-Z build layers and are accompanied by process parameters and powder characterization. The present work concludes with a discussion on the importance of captured differences among builds to understand the practical limitations among AM platforms.

9:55 AM Break

10:25 AM
Effects of HIP on the Quasi-static and High Cycle Fatigue Behavior of Thin-Walled Inconel 718 by Laser Bed Powder Fusion: Paul Paradise[1]; Chad Beamer[2]; *Dhruv Bhate*[1]; [1]Arizona State University; [2]Quintus Technologies LLC

Mechanical properties of as-printed specimens fabricated with the Laser Powder Bed Fusion (LPBF) process have been shown to experience reductions as their thickness reduces, particularly below 1mm. In this work, we report on results obtained from quasi-static and High Cycle Fatigue (HCF) tests conducted on LPBF Inconel 718 specimens manufactured with a thickness range of 0.3 – 2 mm, and heat treated with and without a Hot Isostatic Pressing (HIP) step, in order to identify what effects HIP has on the thickness dependence. We report that for quasi-static properties, HIP almost eliminates thickness dependency observed for yield strength, while preserving the dependency for elongation and UTS. For HCF, HIP preserves thickness dependence, but only outperforms non-HIP specimens at high stresses. Through a combination of microstructural and Finite Element Analysis studies, as well as leveraging comparisons to a sheet metal baseline, we explore the underlying reasons for these HIP-induced effects.

10:45 AM
A Study on the Effect of VED, Particle Size Distribution, Moisture Content, and Powder Reuse on the Densification and Mechanical Properties of L-PBFed Nickel Alloy 718 Using Design of Experiment and ANOVA: *Peter Morcos*[1]; David Shoukr[1]; Tayler Sundermann[1]; Raymundo Arroyave[1]; Ibrahim Karaman[1]; Alaa Elwany[1]; [1]Texas A&M University

Laser-Powder bed fusion of nickel alloy 718 has been widely studied in the literature. However, the effect of powder characteristics such as particle size distribution (PSD), inclusion of fine particles, moisture content, and powder reuse was not studied comprehensively. In this study, two levels of powder type, particle size distribution, (includes particle size range and median particle size), moisture content, VED, and powder type were used. Statistical design of experiment (DOE) techniques was implemented to reduce the experimental cost and burden. The observed results were analyzed using analysis of variance to determine the effect of the different powder characteristics on the quantities of interest (QoI). The QoI in this study are the densification and mechanical properties. The study reveals that VED, powder type, and range are the commonly significant factor for the QoI, while moisture content was significant for Charpy impact energy test only.

11:05 AM
Comparative Study of Additively Manufactured Inconel 625 in the As-built and Heat-treated Condition: *Victoria Luna*[1]; Leslie Trujillo[1]; Ariel Gamon[1]; Edel Arrieta[1]; Ryan Wicker[1]; Colton Katsarelis[2]; Paul Gradl[2]; Francisco Medina[1]; [1]University of Texas, El Paso; [2]NASA, Marshall Space Flight Center

This study was conducted to characterize the microstructure and mechanical properties of inconel 625 manufactured with laser powder bed fusion (L-PBF), electron beam melting (EBM), wire arc additive manufacturing (WAAM), electron beam directed energy deposition (EB-DED), laser powder directed energy deposition (LP-DED), and laser wire directed energy deposition (LW-DED) in both the as built and heat-treated condition. The heat treatment in this study included stress relieving, hot isostatic pressure (HIP), and solution treatment. The effects of the heat treatment on the grain widths and hardness of the alloy will be observed across the technologies before and after heat-treatment. At the end of this study there will be a comparative analysis of the alloy inconel 625 across the six technologies.

11:25 AM
Controlling Grain Evolution of IN625 Parts Produced by LPBF-AM: *Jordan Rosser*[1]; Edward Palmer[1]; Steve Brown[1]; Nicholas Lavery[1]; [1]Swansea University

Laser Powder Bed Fusion (LPBF) Additive Manufacturing (AM) is rapidly being adopted globally due to its capability of producing complex net-shape parts in a range of alloys with mechanical properties as good as, or better than conventional processes. The alluring possibility is in controlling microstructural features during processing such as grain size, solidification morphology and texture, giving mechanical properties tailored for intended applications. LPBF-AM microstructures are dominated by sizable columnar growth, which along with even small levels porosity contribute to lower fatigue and creep strength in comparison to wrought. This would limit high temperature applications where IN625 is used in aeroengine exhaust sections. In contrast, the less dominating equiaxed grains lead to a reduction in crack propagation and improve fatigue performance at the surface.In this work a combination of physical experiments and modelling is used to study the controllability of grain growth and orientation of IN625 made by LPBF-AM.

11:45 AM
The Effect of Heat Treatment on the Microstructure and Tensile Properties of L-PBF Haynes 214: *Shaharyar Baig*[1]; Shuai Shao[1]; Paul Gradl[2]; Nima Shamsaei[1]; [1]Auburn University; [2]NASA

The as-fabricated microstructure of Haynes 214 by laser powder bed fusion (L-PBF) is dendritic due to the high cooling rates, which is generally considered undesirable and removed via heat treatments. In this study, the effects of various heat treatments on the microstructure and tensile properties of L-PBF Haynes 214 are investigated. Test specimens are fabricated on a L-PBF system in the vertical orientation. Multi-step heat treatments are performed including stress-relief, hot isostatic pressing, solution annealing and ageing. The resultant microstructures are examined after each step using a scanning electron microscope (SEM). Room temperature tensile tests are performed for some of the conditions according to ASTM E8. Finally, the tensile fracture surfaces are examined via SEM to understand the fracture mechanisms.

12:05 PM
Microstructure and mechanical properties of additively manufactured Haynes 230: a comparative study of L-PBF vs. LP-DED: *Muztahid Muhammad*[1]; Rukesh Gusain[1]; Reza Ghiaasiaan[1]; Paul Gradl[2]; Shuai Shao[1]; Nima Shamsaei[1]; [1]Auburn University; [2]NASA Marshall Space Flight Center

This study investigates the microstructure and room temperature mechanical properties of Haynes 230 fabricated via laser powder bed fusion (L-PBF) and laser powder directed energy deposition (LP-DED). The same multiple-step heat treatments (HT); stress-relieving (1066°C for 1.5 hours), followed by hot isostatic pressing (HIP at 1163°C and 103 MPa for 3 hours), and solution annealing (1177°C for 3 hours), are applied to both L-PBF and LP-DED specimens. Microstructural analysis is conducted employing a scanning electron microscope. Uniaxial tensile tests at room temperature are conducted to evaluate the mechanical properties. The microstructures after HT and tensile results for both L-PBF and LP-DED specimens are found to be comparable. Upon post-processing HTs, the micro-segregation and dendritic microstructure observed in non-heat-treated conditions are fully dissolved, and carbide phases (M6C/M23C6) are formed within both grain interiors and grain boundaries. Finally, the failure mechanisms under tensile load are studied and compared by fractography.

Materials: Metals - Porosity and Processing

Tuesday AM — Room: 615 AB
July 26, 2022 — Location: Hilton Austin Hotel

8:15 AM
Effects of Pores and Stress State on Fracture of Additively Manufactured Metals: *Allison Beese*[1]; Alexander Wilson-Heid[1]; Nancy Huang[1]; Olivia Cook[1]; Robert Smithson[2]; Christopher Kube[1]; Andrea Arguelles[1]; [1]Pennsylvania State University; [2]3M

Pores are present in additively manufactured metals made using methods ranging from laser powder bed fusion (L-PBF) to binder jetting. The impact of these pores on the load-bearing capacity, or failure behavior, of components made by additive manufacturing (AM) must be understood for wider-scale adoption of AM for structural components. This talk will present methods for introducing pores into additively manufactured parts, and characterizing these pores, in order to study their impact on failure behavior of additively manufactured stainless steel 316 (made by binder jet AM and L-PBF) and Ti-6Al-4V (made by L-PBF). Additionally, as AM is ideally suited for the fabrication of complex geometries, different locations within components will be subjected to different stress states (e.g., shear, biaxial tension); thus, the measured and modeled combined effect of stress state and pores on the failure behavior of these alloys will be discussed.

8:35 AM

Mechanisms of Pore Elimination During 3D Printing of Metals: *Seyed Mohammad Hojjatzadeh*[1]; Niranjan D. Parab[2]; Wentao Yan[3]; Qilin Guo[4]; Lianghua Xiong[5]; Cang Zhao[2]; Luis I. Escano[1]; Minglei Qu[1]; Xianghui Xiao[2]; Kamel Fezzaa[2]; Wes Everhart[6]; Tao Sun[7]; Lianyi Chen[4]; [1]Department of Mechanical Engineering, University of Wisconsin-Madison; [2]Advanced Photon Source, Argonne National Laboratory; [3]Department of Mechanical Engineering, National University of Singapore; [4]Department of Mechanical Engineering, University of Wisconsin-Madison, Madison; [5]Department of Materials Science and Engineering, Missouri University of Science and Technology; [6]Department of Energy's Kansas City National Security Campus Managed by Honeywell FM&T; [7]Department of Materials Science and Engineering, University of Virginia

Laser powder bed fusion (LPBF) is a 3D printing technology that can print metal parts with complex geometries without the design constraints of traditional manufacturing routes. However, the parts printed by LPBF normally contain many more pores than those made by conventional methods, which severely deteriorates their properties. Here, by combining in-situ high-speed high-resolution synchrotron x-ray imaging experiments and multi-physics modeling, we unveil the dynamics and mechanisms of pore motion and elimination in the LPBF process. We discovered a new mechanism based on thermocapillary force that can rapidly eliminate pores from the melt pool during the LPBF process. The pore elimination mechanisms reported here may inspire and guide the design of 3D printing approaches to achieve pore-free 3D printing of metals.

8:55 AM

Direct Observation of Pore Formation Mechanisms During LPBF Additive Manufacturing Process: *Seyed Mohammad Hojjatzadeh*[1]; Niranjan D. Parab[2]; Qilin Guo[3]; Minglei[3]; Lianghua Xiong[4]; Cang Zhao[2]; Luis I. Escano[3]; Kamel Fezzaa[2]; Wes Everhart[5]; Tao[6]; Tao Sun[6]; Lianyi Chen[3]; [1] University of Wisconsin-Madison; [2]Advanced Photon Source, Argonne National Laboratory, Lemont, IL; [3]University of Wisconsin-Madison; [4]1Department of Mechanical and Aerospace Engineering, Missouri University of Science and Technology; [5]Department of Energy's Kansas City National Security Campus Managed by Honeywell FM&T, Kansas City, Missouri ; [6]Department of Materials Science and Engineering, University of Virginia

Laser powder bed fusion (LPBF) is a 3D printing technology that can print parts with complex geometries that are unachievable by conventional manufacturing technologies. However, pore formation during metal LPBF process can deteriorate the mechanical performance of the printed parts. In this research, we study pore formation mechanisms during continuous wave (CW) LPBF and pulsed wave (PW) LPBF processes by using in-situ high-speed synchrotron x-ray imaging technique in real time. We report six pore formation mechanisms during the CW-LPBF process and one main pore formation mechanism during PW-LPBF process. In addition, we demonstrated the mechanism of cavity pattern and pore pattern formation during pulsed-wave laser melting. The results presented here provide direct evidence and insight into pore formation mechanisms during the LPBF process, which may guide the development of pore elimination/mitigation approaches during 3D printing of metals.

9:15 AM

Fabricating Functionally Gradient Material with Hybrid Manufacturing: Directed Energy Deposition & Machining: *Wei Li*[1]; Runyu Zhang[1]; Kishore Nagaraja[1]; Ning Bian[1]; Hongbing Lu[1]; [1]The University of Texas at Dallas

Directed energy deposition (DED) is commonly used to fabricate metallic functionally gradient materials (FGMs). Due to unsatisfied surface finish and dimensional accuracy, DED is always combined with machining. The combined process is named hybrid manufacturing. Different mechanical properties of two materials generate heterogeneous mechanical properties in FGM, which can seriously influence the cutting mechanism, such as cutting force, cutting temperature, surface roughness, and tool wear, especially if one material is a hard-to-cut material. In this study, SS316L and IN718 are fabricated into the FGM specimen with DED process. Various material tests are performed to characterize material properties of the FGM specimen. After that, a tungsten carbide (WC) milling cutter is used to machine the FGM specimen with dry peripheral milling. The surface roughness, cutting force, cutting temperature, and the tool wear are studied to investigate the machining mechanism. Additionally, a multi-physics and multi-materials modeling framework is being established for simulating the hybrid manufacturing.

9:35 AM

Effects of Fast Neutron Irradiation on the Microhardness of Inconel 625 and Inconel 718 Materials Fabricated via Laser Powder Bed Fusion: *Mohanish Andurkar*[1]; Valentina O'Donnell[2]; Tahmina Keya[3]; Bart Prorok[3]; John Gahl[2]; Scott Thompson[1]; [1]Kansas State University; [2]University of Missouri; [3]Auburn University

The demand for advanced materials for next generation nuclear reactors has intensified the need to explore additive manufacturing (AM) processes as an alternate means of fabricating components. In this study, Inconel 625 and Inconel 718 samples fabricated using Laser Powder Bed Fusion (L-PBF) were irradiated using fast neutrons at the research cyclotron at University of Missouri. Samples were as-printed or heat treated at 700, 900, or 1050 □ for 1 hour to understand the impact of heat treatment any radiation hardening. Wrought Inconel 625 and Inconel 718 samples were also inspected for experimental control. All samples were irradiated for either 5 or 10 weeks resulting in a total fluence of $4x10^{15}$ and $6x10^{15}$ neutrons/cm^2, respectively. To quantify radiation damage, the Vickers microhardness was measured before and after fast neutron irradiation. Results show that the additively manufactured samples possessed a higher tolerance to any radiation hardening.

9:55 AM Break

10:25 AM

Nondestructive Ultrasound Evaluation of Additively Manufactured Wear Coatings: *Ziyad Smoqi*[1]; Luz Sotelo[1]; Aniruddha Gaikwad[1]; Joseph Turner[1]; Prahalada Rao[1]; [1]University of Nebraska-Lincoln

In this work, ultrasound surface waves were used to evaluate coatings deposited via directed energy deposition (DED) additive manufacturing process. Specifically, we evaluated the quality of Stellite 21 coated on Inconel 718 substrate. The surface wave speed and diffuse backscattered amplitude of the ultrasound waves were correlated with the microstructure heterogeneity, cracking, and warpage of the coating. Three different frequencies were used to excite surface waves with different penetration depths. The signals obtained were used to quantify and compare the surface wave speed and surface wave-diffuse ultrasonic backscatter from five different DED-processed Stellite coated samples. Considering destructive metallurgical characterization as a reference, surface wave measurements were found to be effective for examining coating integrity; the backscatter amplitude of the surface waves was correlated with the microstructure and crack density. These flaws also change the stress state of the coating and consequently the surface wave propagation speed and its scattering behavior.

10:45 AM

Effects of Recoating Velocity and Layer Thickness on the Powder-bed Surface Roughness in the Laser Powder Bed Fusion (LPBF) Process: *M. Hossein Sehhat*[1]; Austin Sutton[2]; Zane Yates[1]; Ming Leu[1]; [1]University of Missouri, Science and Technology; [2]Los Alamos National Laboratory

Laser Powder Bed Fusion (LPBF) process is composed of a recursive operation of spreading a powder layer followed by melting particles through laser scanning. The properties of fabricated components, such as density, tensile strength, and elongation, significantly depend on the quality of spread powder. A powder that is deemed flowable through traditional flowability tests, such as the Hausner ratio or angle of repose, may display poor spreadability in LPBF, creating defects in the fabricated components. This research investigated the effects of layer thickness and recoating velocity on the powder-bed surface roughness in the LPBF process. A high-accuracy powder spreading setup was constructed to perform the powder spreadability experiments. The powder-bed surface roughness was measured using a laser profiler. Gas-atomized 304L stainless steel powder was used in this study. The results show that by increasing the layer thickness, the surface roughness decreases while increasing the recoating velocity worsens the surface roughness.

11:05 AM
In-situ Characterization of Laser-Material Interaction Dynamics in Ring-shaped Beam Laser Powder Bed Fusion: *Jiandong Yuan*[1]; Qilin Guo[1]; Minglei Qu[1]; Luis Escano[1]; Ali Nabba[1]; Lianyi Chen[1]; [1]University of Wisconsin-Madison

High-speed synchrotron x-ray imaging is used to characterize the transient dynamics of the laser-material interaction dynamics in ring-shaped beam laser powder bed fusion process. The dynamics of powder spattering, vapor cavity evolution, melt pool evolution, pore formation and evolution and surface wave propagation will be presented. The potential mechanisms of defect mitigation by ring-shaped laser beam will be discussed. The results obtained in this research may guide the development of beam shaping approach for process instability control and defect mitigation.

11:25 AM
Insights into the Droplets' Behaviour to Control the Quality Of 3D Parts: MetalJet: *Negar Gilani*[1]; Nesma Aboulkhair[1]; Marco Simonelli[1]; Ian Ashcroft[1]; Richard Hague[1]; [1]University of Nottingham

Metal jetting is a promising Additive Manufacturing technology that has the potential to fabricate intricate single and multi-metal components at a resolution not achievable with the more common AM techniques. Due to the droplet-by-droplet nature of the fabrication, insight into the individual droplets' behaviour, which defines the consistency and quality of printed parts, is of fundamental importance and yet not fully understood. Here, we present an integrated computational and experimental approach to investigate this research question. Our study shows that the droplets' morphologies result from a complex interplay between the droplets impact hydrodynamics and solidification dynamics. Furthermore, we explore how the substrate temperature influences the droplets' morphology, microstructure, inter-droplet, and droplet-to-substrate bonding. Based on these findings, a solution is proposed and successfully tested to eradicate the previously-reported lack of consolidation between medium temperature (600°C–1000°C) droplets. Our results represent a step forward in the direct printing of functional multi-metal components.

11:45 AM
A Process - Structure - Property - Performance Study of Liquid Metal Jetted Parts: *Nicholas Watkins*[1]; Thomas Reeve[1]; Alexander Wilson-Heid[1]; Kellen Traxel[1]; Jason Jeffries[1]; Andrew Pascall[1]; [1]Lawrence Livermore National Laboratory

Liquid metal jetting droplet-on-demand (LMJ-DoD) additive manufacturing is an attractive alternative to the industry standard, laser-based techniques: low feedstock footprint, low overbuild quantity, less contamination and inclusions, and compatible with a larger range of materials. However, little has been reported on the crucial process-structure-properties-performance (PSPP) relationships for the LMJ-DoD process to consistently produce robust metal parts. We investigate the effects of various build plate temperatures and fill patterns on the microstructure, density, hardness, and tensile strength of tin parts created with our custom LMJ-DoD setup. The results and methods of this study will help guide future work in optimizing the liquid metal jetting process to reliably print parts using a wide variety of metal feedstocks.Prepared by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS-833275.

12:05 PM
Controlling Process Instability for Defect Lean Metal Additive Manufacturing: *Minglei Qu*[1]; Qilin Guo[1]; Luis Izet Escano[1]; Ali Nabaa[1]; S. Mohammad H. Hojjatzadeh[1]; Zackary Young[1]; Lianyi Chen[1]; [1]University of Wisconsin-Madison

The process instabilities intrinsic to the localized laser-powder bed interaction cause the formation of various defects in laser powder bed fusion (LPBF) additive manufacturing process. Particularly, the stochastic formation of large spatters leads to unpredictable defects in the as-printed parts. Here we report the elimination of large spatters through controlling laser-powder bed interaction instabilities by using nanoparticles. The elimination of large spatters results in 3D printing of defect lean sample with good consistency and enhanced properties. We reveal that two mechanisms work synergistically to eliminate all types of large spatters: (1) nanoparticle-enabled control of molten pool fluctuation eliminates the liquid breakup induced large spatters; (2) nanoparticle-enabled control of the liquid droplet coalescence eliminates liquid droplet colliding induced large spatters. The nanoparticle-enabled simultaneous stabilization of molten pool fluctuation and prevention of liquid droplet coalescence discovered here provide a potential way to achieve defect lean metal additive manufacturing.

Process Development - Deposition Processes

Tuesday AM	Room: 412
July 26, 2022	Location: Hilton Austin Hotel

8:15 AM
AutoPrint: An Affordable and Automated Fused Filament Fabrication Based Additive Manufacturing System: *Hasan Bank*[1]; [1]California State University - Chico

Additive Manufacturing (AM) has been advancing rapidly since its democratization by academia and the following adoption by the people who would like to realize their design. Despite its capabilities of manufacturing highly complex geometries, AM is a discrete and relatively low-volume production method. Needless to highlight, there is a vast potential to enhance productivity at every individual step of the production pipeline in AM. In this paper, we aim to create a guideline for streamlining the production and providing an automating use case for the FFF-based additive manufacturing process via open-source software such as Octoprint, Octofarm, Cura as well as proprietary –and optional– Computer-Aided Design (CAD) add-on for offline planning of the 3D printing queues under 500 USD per printer.

8:35 AM
Build Plate Design for Extrusion-Based Additive Manufacturing: *Alex Roschli*; Brian Post[1]; Celeste Atkins[1]; Phillip Chesser[1]; Adam Stevens[1]; Kristin Zaloudek[1]; [1]ORNL

A fundamental part of machine design for large format polymer extrusion-based additive manufacturing (AM) systems is the substrate where the object is to be constructed, often referred to as the build plate. A good build plate is imperative for a successful build as it is used for supporting and positioning the part during the entire construction. For planar 3D printing, this build plate needs to be flat and in-plane with the X/Y motion of the 3D printer. Additional functionality can include heaters for preventing delamination or warping, vacuum to help prevent warping, removable build surfaces for quick part removal, and mounting features for helping position a part for subtractive operations. This paper reviews existing build plate designs and discusses the design considerations and materials for build plate fabrication.

8:55 AM
Hybrid DED Process Parameter Development and Translation across Spot Size: *Kenton Fillingim*[1]; Thomas Feldhausen[1]; Rangasayee Kannan[1]; Peeyush Nandwana[1]; Kyle Saleeby[1]; Rebecca Kurfess[1]; [1]Oak Ridge National Laboratory

Directed Energy Deposition (DED) systems now allow for variable laser spot size potential. However, a method should be developed for easier parameter development and translation across a range of spot sizes. A strategy was formed to produce 316L stainless steel walls for beam diameters ranging from 1.5mm – 3.5mm. The developed method keeps energy density constant while varying power, speed, and powder flow rates. Starting with a known 3.5mm spot size parameter set, scan speed and powder flowrate are modified proportionally to the decrease in spot size. Five walls at different beam diameters produced acceptable porosity and hardness values, giving validation to the proposed rule of thumb. Differences in hardness and grain size will be discussed. Time, material, and net shape considerations are discussed from a DED hybrid manufacturing context. This study provides insight towards the influence of both energy density and spot sizes on build outcomes.

9:15 AM
Impact of Nozzle Condition on Powder Catchment Efficiency for Coaxial Powder Direct Energy Deposition: *Lauren Heinrich*[1]; Joseph Fletcher[1]; Thomas Feldhausen[2]; Thomas Kurfess[1]; Christopher Saldaña[1]; [1]Georgia Institute of Technology; [2]Oak Ridge National Laboratory

Blown powder directed energy deposition is well-designed for fine resolution additive manufacturing processing. Coaxial powder deposition heads use an outer layer of shielding gas directed by an outer nozzle to prevent oxidation occurring during the powder melting process. Powder blown feedstock catchment efficiency can be as low as 50-80% whereas wire deposition systems are closer to 98% efficient. The present study evaluates the impact of directed energy deposition nozzle condition on catchment efficiency. Changes in the overall outer shielding gas nozzle length has been found to increase material usage efficiency by 10% through convergence of the powder flow. The results of this experiment show that for coaxial powder deposition head design, if the standoff distance can safely be decreased, powder catchment efficiency can be increased as the outer shielding gas nozzle is increased in length, or the standoff distance is decreased.

9:35 AM
Impingement and Solidification Morphology of Liquid Metal Droplets in Additive Manufacturing via Magnetohydrodynamic Liquid Metal Jetting: *Viktor Sukhotskiy*[1]; Nicholas Watkins[1]; Kellen Traxel[1]; Andrew Pascall[1]; Erik Einarsson[2]; Jason Jeffries[1]; [1]Lawrence Livermore National Lab; [2]University at Buffalo

Powderless and beamless metal additive manufacturing (AM) processes continue to gain importance as low-cost alternatives to conventional techniques. Inspired by aqueous inkjetting and metal spray forming, liquid metal jetting (LMJ) uses propelled submillimeter liquid metal droplets to rapidly build high density metal parts. In an LMJ-AM process, the control of droplet patterning, coalescence and solidification is critical to ensure dimensional accuracy, low porosity and minimized surface roughness. Post-deposition droplet shape and grain structure are very sensitive to simultaneous drop spreading, rapid solidification, and freezing of the contact line. Therefore, it is important to understand key process variables and their effect on droplet solidification dynamics. We present a combined numerical-experimental analysis of key process parameters such as droplet velocity, size, droplet temperature, substrate temperature and thermofluidic properties. The results are presented in a dimensionless Weber vs. Freezing number space, with emphasis on droplet aspect ratio.Prepared by LLNL under contract DE-AC52-07NA27344/IM-1052413

9:55 AM Break

10:25 AM
Intelligent Process Planning and Control of an Aerosol Jet Printing Process: Yipu Du[1]; *Robert Landers*[1]; Yanliang Zhang[1]; Meng Jiang[1]; [1]University of Notre Dame

Aerosol Jet Printing (AJP) is a versatile microscale additive manufacturing process capable of fabricating a wide variety of materials. This process is hindered by variations due to such factors as transport losses, changes in nozzle condition and ink consistency, etc. This variability makes it difficult to plan the process (i.e., properly select the process parameters) and ensure quality deposition. In this paper we will introduce a method based on machine learning to quickly determine process parameters for a given ink composition. The method combines active learning and reinforcement learning algorithms to efficiently estimate process parameters to produce desired part properties. We will also introduce a run-to-run controller that adjusts the ink flow rate to regulate the electrical resistance of fabricated leads. A lead is deposited, its resistance is measured, and ink flow rate is adjusted for the subsequent lead. Experimental studies are conducted to examine the effectiveness of these methods.

10:45 AM
Material Jetting Developing Platforms for R&D: *Craig Sturgess*[1]; [1]Added Scientific Ltd

Material Jetting (MJ) equipment currently on the market is dominated by systems which often do not support custom formulations. Unlike the latest generation of Extrusion and Vat-Polymerisation systems there is no easy to access open source solution for MJ development and therefore the market is limited to those who can afford to adapt equipment on the market, often putting warranties at risk. We describe the challenges of developing new inks and inkjet printing systems based on the available architecture (i.e. Dimatix DMP, Suss PixDro LP50 and Image expert) and the limitations that they bring for 3D Printing. To support our projects, we have developed understanding around the build and design of open MJ systems that enable our material and process development whilst reducing costs. This presentation describes the pitfalls and challenges around this, about how systems can be made and how critical the material, process and hardware are in MJ.

11:05 AM
Establishing a Machine-Agnostic Energy Density Model for Laser, Powder-blown Directed Energy Deposition: *Samantha Webster*[1]; Jihoon Jeong[1]; Jian Cao[1]; [1]Northwestern University

Laser powder-blown directed energy deposition (LP-DED) is an additive manufacturing process that utilizes a coaxial powder nozzle and laser to melt metal powders onto a substrate in a line-by-line fashion. This coupling gives rise to interactions between the laser, powder, and melt pool. Processing maps of individual parameters as well as energy density are typically correlated with the presence of defects (e.g., pores, cracks) to identify appropriate processing windows or optimal build conditions. While these solutions have been successful in their individual experiments, it is difficult to compare results from different machines since each has a different laser and powder flow distribution. In this study an analytical energy density model is presented that accounts for different laser and powder distributions as well as their alignment. Coaxial CCD imaging and clad cross sections are used to validate the model and connect melt pool volume to energy density.

11:25 AM
Material-independent Flowrate Control in Extrusion-based Additive Manufacturing: *Ali Asghari Adib*[1]; David Hoelzle[1]; [1]Ohio State University

Precise control of the material flowrate is important for shape fidelity of manufactured parts in material extrusion (MEX). Existing ad hoc and learning-based flowrate control schemes are dependent on the rheological properties of the build material and the extrusion parameters, requiring recalibration with any changes in the set parameters. Previously, we have reported on a pressure-based proportional feedback control scheme for flowrate control in direct-write (DW) MEX. However, proportional control is model-free, has a non-zero steady-state error in reference tracking, and might induce instability at high gains by reducing the gain margin. Here, we utilize loop shaping control design to guarantee consistent flowrate control regardless of the rheological properties of MEX build material. Classical frequency-based methods are used to design controllers for the desired loop shape in simulation. The control schemes are validated experimentally on a DW MEX system to manufacture multi-material parts demonstrating enhanced material- and nozzle size-independent performance.

11:45 AM
Closed-loop Recycling of Low Friction Polymers in Fused Granule Fabrication Additive Manufacturing Processes: *Neil Thompson*[1]; Jason Weaver[1]; [1]Brigham Young University

Plastic waste is a critical worldwide problem, and an important issue facing additive manufacturing (AM). Extensive research has explored how plastic waste in AM can be reduced by recycling prints into new filament, with varying success. An alternative to filament-based extrusion is "fused granule fabrication" (FGF), which extrudes from pellets or granules. This paper examines extent to which low friction polymers (such as PETG) can be recycled and reprinted through the same FGF tool without significant loss to material properties. We developed a double filtration, cleaning and dehydrating process that allowed us to effectively print using recycled plastic, and we found our recycled samples reached 70-80% of the ultimate tensile strength of virgin plastic. Incorporating this technology into printing facilities can significantly decrease plastic waste with greater ease than most filament recycling methods.

12:05 PM
Development of Laser Cladding Procedure through Experiment and Analysis Using Powder-blown Directed-energy Deposition: *Dajalma Garcia*[1]; [1]University of Texas at El Paso

Directed Energy Deposition (DED) is one of the categories in Additive Manufacturing (AM) that has increased our attention due to the technological advancements in recent years. Mainly, with advancements in laser power, application of multi-materials, and capability to print greater dimensions. We are experimenting with a particular process in DED, cladding. Cladding is the process of applying a metal coating to a substrate with the purpose of improving its properties, such as corrosion and material strength. For our experiment, we implemented a powdered feedstock (Inconel 718) which was tested in different types of substrates. This, in an effort to reduce the time spent on trial-and-error development of cladding parameters. We develop a procedure on how to determine a good clad interaction after an examination of the microstructure and interaction of single beads and a hatched area.

Process Development - Emerging Techniques

Tuesday AM	Room: 400-402
July 26, 2022	Location: Hilton Austin Hotel

8:15 AM
Investigation into Effect of Beam Defocusing in Low Temperature Laser Sintering of PEEK: *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

Laser sintering of PEEK with the same powder bed temperature as PA12, which is lower than recrystallization temperature of PEEK, has been achieved at pervious study. However, the process at low bed temperatures requires a greater energy supply to melt the material, and it increases the risk of thermal decomposition. Expansion of spot size by defocusing is one of the effective ways to reduce the peak intensity of beam and allow providing more energy to the same laser irradiation range as avoiding the decomposition. In this study, specimens were prepared with the same amount of energy and difference beam diameters, to observe difference in internal voids and thermal decomposition of specimens. As a result, it was indicated that large spot size is effective on high energy supply without thermal decomposition and suppressing internal voids.

8:35 AM
In-situ Interferometry for Vat Photopolymerization Additive Manufacturing: *Yue Zhang*[1]; Chaitanya Vallabh[1]; Xiayun Zhao[1]; [1]University of Pittsburgh

Current digital light processing (DLP) based vat photopolymerization (VPP) processes lacks in-situ monitoring approaches to understand and control the photopolymerization process along with the evolution of the print part properties. To achieve an insightful understanding of the physical curing process during VPP, an in-situ monitoring system is desired to visualize the curing dynamics and estimate the printed part's properties, especially the cured height and degree of conversion (DoC). To realize this, we develop an in-situ interferometric curing monitoring (ICM) system for measuring the cured height and DoC profiles of the printed part during a DLP based VPP process. A sensor model is developed to analyze the interferogram data for estimating each voxel's cured height and DoC across the print area. It has the potential to provide real-time, close-loop feedback control for VPP, thus improving the overall accuracy and reproducibility of the parts being printed

8:55 AM
Revealing Melt Flow Instabilities in Laser Powder Bed Fusion Additive Manufacturing of Aluminum Alloy via In-situ High Speed X-ray Imaging: *Qilin Guo*[1]; Minglei Qu[1]; S. Mohammad H. Hojjatzadeh[1]; Luis I. Escano[1]; Zachary Young[1]; Kamel Fezzaa[2]; Lianyi Chen[1]; [1]University Of Wisconsin Madison; [2]Argonne National Laboratory

Laser metal additive manufacturing technologies enable the fabrication of geometrically and compositionally complex parts unachievable by conventional manufacturing methods. However, the certification and qualification of AM parts are greatly hindered by the stochastic melt flow instabilities intrinsic to the process, which have not been explicitly revealed by direct observation. Here, we report the mechanisms of the melt flow instabilities in LPBF-AM process revealed by in-situ high-speed high-resolution X-ray imaging. We identified powder/droplet impact, significant keyhole oscillation, and melting-mode switching as three major mechanisms for causing melt flow instabilities. We demonstrated the detrimental consequences of these instabilities brought to the process, and projected new understanding on the melt flow evolution and keyhole oscillation. This work provides critical insights into process instabilities during laser metal additive manufacturing, which may guide the development of instability mitigation approaches. The results reported here are also important for the development and validation of high-fidelity computational models.

9:15 AM
Towards an Automated Methodology for Optically Cured, High Thickness Composite Polymer Pastes: an ISO-based Approach for Large Area Additive Manufacturing: *Chris Kerr*[1]; Javier Munguia Valenzuela[1]; Oliver Nixon-Pearson[2]; Mark Forrest[2]; Peter Gosling[1]; [1]Newcastle University; [2]ORE Catapult

Optically cured polymer composites can offer numerous advantages over thermally processed composites. This is especially applicable with large beads generated using Large Area Additive Manufacturing (LAAM) extrusion. This paper proposes a low-cost, semi-automated, off-the-shelf desktop system to quickly and precisely cure 8 mm thick, glass-filled (di-)methacrylate composite specimens for three-point flexural testing. In the absence of a clear preparation method for specimens of this thickness, we integrate aspects of two existing ISO Standards: ISO 178:2019, and ISO 4049:2019, to provide a rapid and reliable basis for specimen preparation and flexure testing. We propose two distinct curing strategies and compare these in terms of the flexural performance of prepared specimens, and the total cure time. Flexural data is critical to understanding the structural performance of light-activated composite pastes; and the curing methodology can be applied to potential future technologies which involve high-speed *in-situ* curing, from direct part/feature repair to functional production.

9:35 AM
Verification Process for Laser Powder Bed Fusion Machine Health: *Zachary Hilton*[1]; [1]Honeywell FM&T

Laser powder bed fusion machines are complex systems comprised of a number of interconnected sub-systems which work in concert during the laser powder bed fusion process. The health, i.e. consistency in performance, of these complex systems must be monitored and verified to ensure consistency in the process during long-term production. If a system is 'unhealthy' the process becomes less controlled and can lead to decreased part quality. To monitor and validate that a machine is healthy, a number of tests were developed. The tests discussed are: laser power, multi-laser alignment, laser position, laser beam characteristics, cover gas flow, z-axis verification, and overall machine condition. The methodology and efficacy of each test is discussed along with additional potential tests and next steps. This work was funded by The Department of Energy's Kansas City National Security Campus is operated and managed by Honeywell Federal Manufacturing & Technologies, LLC under contract number DE-NA0002839.

9:55 AM Break

10:25 AM
Bioinspired Smart Nanocomposite Fabrication via Liquid Crystal Templating-assisted 3D Printing: *Tengteng Tang*[1]; Saleh Alfarhan[1]; Kailong Jin[1]; Xiangjia Li[1]; [1]Arizona State University

The creatures in nature exhibit unique functional performances due to hierarchical architectures composed of nanofillers and the polymer-based matrix. Traditional manufacturing and 3D printing methods have been previously used to fabricate biomimetic anisotropic composites by aligning cellulose fillers in a polymer or ceramic matrix, using external directional physical fields or shear forces. However, only certain types of functional fillers, which are responsible for external physical fields or shear forces, can be aligned with simple orientations and patterns using the aforementioned techniques. Here, we present a versatile 3D printing technology, named liquid crystal templating assisted 3D printing (LCT-3DP), that can fabricate nanocomposites by distributing nanofillers inside the polymer-based matrix in a programmable fashion. In this study, the properties of LCT-3D printed polymer matrix composites (PMCs) were evaluated, and the design of bioinspired hierarchical architectures of such printed PMCs was further optimized through physics-based multiscale modeling, simulation, and testing.

10:45 AM
Spatial Variations in Horizontal and Vertical Composition Grading using Laser Powder Bed Fusion: Cherish Lesko[1]; Joe Walker[2]; John Middendorf[2]; *Joy Gockel*[3]; [1]Wright State University; [2]Open Additive, LLC; [3]Colorado School of Mines

Spatially varying composition can be achieved through novel laser powder bed fusion (LPBF) machine technology designed to place location specific material. The binary Titanium -Tantalum alloy system is of great interest to many fields of engineering because of the unique thermal and mechanical properties it possesses. Intentional compositional changes along with unintentional variations from the AM processing results in spatial differences impacting the material structure and the resulting properties. Machine process strategy impacts composition control and influences phase evolution. Elemental segregation occurs due to incomplete mixing in the melt pool and remelting at the interfaces. It is also established that the interfaces are structurally sound in both the vertical and horizontal grading directions, but phase transformations and microstructure differences result from thermal effects of the LPBF process when building different geometries. Through a fundamental understanding of the composition-processing-structure-properties-performance relationships, AM composition grading can be realized for many applications.

11:05 AM
Defect Lean Metal Additive Manufacturing: *Lianyi Chen*[1]; [1]University of Wisconsin-Madison

Defects and part quality uncertainties are prominent barriers for adoption of metal additive manufacturing for mission critical applications. Guided by a deeper understanding of the dynamics and mechanisms of defect formation and evolution (revealed by our in-situ high-speed synchrotron x-ray imaging and diffraction research in the past seven years) in laser powder bed fusion process (LPBF), we developed different approaches to mitigate and eliminate defects in LPBF metal additive manufacturing process. In this presentation, I will give an overview of the approaches my group developed to (1) eliminate pores from feedstock powders, (2) eliminate larger spatters, (3) mitigate pore formation, (4) eliminate pores from melt pool, and (5) eliminate undesirable phases in the as-printed parts for achieving defect lean metal additive manufacturing.

11:25 AM
Use of a Penetrating Deposition Nozzle for Z-Pinning Additive Manufacturing: *Brenin Bales*[1]; Roo Walker[2]; Vlastimil Kunc[3]; Chad Duty[1]; [1]University of Tennessee; [2]Bredesen Center for Interdisciplinary Research and Graduate Studies; [3]Oak Ridge National Laboratory

Fused Filament Fabrication involves depositing material layer-by-layer to create a three-dimensional object. This method often demonstrates high mechanical anisotropy in the printed structure, leading to a drop in the material strength of the part when comparing structures along the deposition path (X/Y-Axis) versus build direction (Z-Axis). Initial research has led to the development of the Z-Pinning process, where continuous pins are deposited in the Z-Axis. This process has led to significant gains in toughness and inter-layer strength, particularly in fiber-reinforced materials. However, this process can create flaws in the structure that increase in severity and frequency as the pins grow in length and diameter. To mitigate the flaws, a penetrating nozzle has been developed that extends a fine-tipped extrusion nozzle into the pin cavity and simultaneously extrudes material as it retracts. This study will investigate the printability of the penetrating nozzle for simple geometries and evaluates the resulting Z-pinning mesostructure.

11:45 AM
Printing Multifunctional High Performance Polymer Parts via the Hybridization of Direct Ink Write and High Temperature Fused Filament Fabrication: *Ian Ho*; Jacob Viar; [1]

Direct manufacturing of multifunctional, high-performance components is an aspirational goal for additive manufacturing technologies. Prior research has shown that hybrid DIW/FFF systems, where the DIW tool selectively deposits conductive traces within layers of FFF-printed parts, can fabricate multifunctional parts. However, these prior efforts are limited to DIW/FFF systems operating at ambient conditions, due to concerns over premature curing of conductive inks, and thus has been limited to printing with commodity polymers. To enable fabricating multifunctional high-performance polymers, a hybrid DIW/FFF system with an actively cooled DIW head was created that enabled FFF printing in chamber temperatures of up to 110°C. Nylon parts with embedded conductive silver traces were fabricated using this novel process. Because switching print modalities interrupts the FFF print, which weakens the interlayer bond at the pause interface, the effects of the duration of pause on interlayer bond strength in the part were also studied through mechanical testing.

12:05 PM
Cooling Rate Measurement in Directed Energy Deposition using Photodiode-based Thermometry: *Jihoon Jeong*[1]; Samantha Webster[1]; Shuheng Liao[1]; Jian Cao[1]; [1]Northwestern University

Laser powder blown Directed Energy Deposition (DED) is a rapidly emerging additive manufacturing (AM) technology for repairing and producing net-shaped components. Rapid cooling rates and variation in microstructure across a part are unique features of the DED process. This is due to heat accumulation during layer-by-layer deposition and periodic reheating and cooling of layers, which ultimately result in mechanical property gradients. In our open-architecture DED system, we utilize photodiode-based thermometry to monitor in-situ melt pool temperature and quantify the cooling rate at a 100 kHz acquisition rate. The measurement of the cooling rate at various process parameters will be discussed. Additionally, the use of photodiode-based thermometry in the DED system will be presented.

Process Development - Novel Methods and Processes I

Tuesday AM
July 26, 2022

Room: 408
Location: Hilton Austin Hotel

8:15 AM
From Neutron Diffraction to Tool Repair: How Fundamental Scientific Research Translates to Industrial Impact for Hybrid AM Processes: *Brian Post*[1]; Tom Feldhausen[1]; Kyle Saleeby[1]; Yousub Lee[1]; Alex Plotkowski[1]; Peeyush Nandwana[1]; Rangasayee Kannan[1]; [1]Oak Ridge National Laboratory

Hybrid manufacturing systems combining directed energy deposition and subtractive capabilities in the same machine envelope were initially debuted in 2014. However, these systems have seen little industrial adoption. Given that most additive parts are preforms with required conventional post-processing to make them functional, it seems like hybrid systems would offer significant advantages. While more capable, the science of interleaving AM and conventional machining operations is complex. Fundamental understanding of factors like residual stress, microstructural evolution, and geometric distortion in these complex processes remains the primary barrier to success. This presentation details how research into the fundamental thermophysical properties of hybrid processes is being translated to real-world applications. Covering specific developments like a wire-arc hybrid machine installed in ORNL's Spallation Neutron Source and the development of the world's largest metal-wire laser DED hybrid system, the audience will gain an appreciation of the challenges and future opportunities for hybrid AM systems.

8:35 AM
Evaluating Concepts for the Integration of Milled Components into the Additive Manufacturing Process: *Jannik Reichwein*[1]; Johannes Geis[1]; Eckhard Kirchner[1]; [1]Technische Universität Darmstadt

Laser Powder Bed Fusion (L-PBF) has specific advantages over conventional manufacturing processes. These include high freedom in the design of components and cost-efficient production of small quantities. However, the surface quality of components is low compared to milling and the production of large components is often associated with high costs. These challenges are addressed by integrating milled components into the L-PBF process. Therefore, various concepts are presented for positioning, aligning and fastening machined components in the build space of the L-PBF system with the goal to provide a reliable way to start the L-PBF process on top of these components. Thus, allowing the potential of additive and subtractive manufacturing to be exploited without requiring an additional joining operation. Finally, these concepts are applied to a steering shaft bracket and the costs for manufacturing are evaluated. A 25% reduction in manufacturing costs was achieved compared to the purely additively manufactured component.

8:55 AM
Validation of Ensemble Kalman Filter Estimations of Internal Temperature Fields During the Powder Bed Fusion Process: *Nathaniel Wood*[1]; David Hoelzle[1]; [1]the Ohio State University

This paper validates the accuracy of an Ensemble Kalman Filter (EnKF) when estimating internal temperature fields within the powder bed fusion (PBF) process. The EnKF is a type of state estimator algorithm, which supplies approximately 2-norm optimal estimates of the process state (here, internal temperatures) conditioned on available process input/output measurements. Accurate temperature field estimates are important for quality control of defects controlled by improper heat transfer. Critically, the EnKF works without any a priori training data, making it more convenient and cost-effective relative to machine learning algorithms which are the current state of the art for this task. We generate EnKF estimations using input/output data from a set of mock PBF builds on an open architecture PBF. Thermocouples are embedded within these builds, and their internal temperature measurements are the basis for validating EnKF estimation accuracy. We show that the EnKF estimates match the thermocouple measurements with 70% accuracy.

9:15 AM
Usability and Limitations for Predicting Melt Pool Dimensions via Dimensionless Numbers in Laser Powder Bed Fusion (LPBF): *Theresa Hanemann*[1]; Christoph Seyfert[2]; Astrid Rota[1]; Martin Heilmaier[3]; [1]EOS GmbH Electro Optical Systems; [2]AMCM GmbH; [3]Karlsruhe Institute Of Technology

Recently the use of dimensionless numbers to estimate melt pool geometries in LPBF for different alloys has been seen increased research interest. In contrast to common energy density relations based on process parameters only, dimensionless numbers consider the difference in laser-material interaction by incorporating material thermophysical properties. In this study, two dimensionless numbers, namely dimensionless enthalpy and Peclet number, are introduced and proposed to predict melt pool dimensions of single scan tracks for five different alloys (In718, 316L, Ti6Al4V, M300, AlSi10Mg). Dimensionless enthalpy characterizes the energy input in relation to the energy needed for melting, while the Peclet number, giving a ratio of heat convection to conduction, represents the heat loss during the interaction. Both dimensionless numbers had to be considered to accurately predict melt pool dimensions over a wide range of processing parameters. Corresponding limitations to the validity of the proposed scaling relations will be presented.

9:35 AM
Powder Spread Flaws in Polymer Laser Sintering and its Influences on Mechanical Performance: *Helge Klippstein*[1]; Hans-Joachim Schmid[1]; [1]Paderborn University

By monitoring the recoating process within polymer laser sintering production, it was shown that several powder-spread-flaws can be detected. Those groove-like flaws are expected to be the result of agglomerates jamming between the recoater and the last powder layer. Analyzing the interaction between powder-spread-flaws and part properties shows the influence of the recoating process on the performance of laser sintering part. Therefore, artificial powder-spread-flaws are applied to the build jobs of tensile test specimens and measured. For the characteristic of the flaws, the artificial grooves are variated in depth and width. Furthermore, the position of the flaw is changed form mid part to close to surface areas. By correlating the flaws with the mechanical part properties, the critical flaw size and position was determined, which enables the recently developed powder spread monitoring system to deliver better information and alerts on critical recoating failures.

9:55 AM Break

10:25 AM
The Resilience of Laser Powder Bed Fusion to Power Perturbations: *Christine Cummings*[1]; David Corbin[1]; [1]Pennsylvania State University

Stochastic defect creation in laser powder bed fusion additive manufacturing (AM) limits trust in and reliability of AM parts for critical applications. This work aims to better understand the situations in which defects persist and the situations in which defects self-heal, without auxiliary defect mitigation methods whether post-process or in-situ. Prior research has established that small defects self-heal as subsequent layers are processed. This research investigates how the scale of process anomalies (power perturbations) impacts the persistence and size of formed defects. Process anomalies were seeded at known locations throughout Ti-6Al-4V specimens with layer heights spanning 1-6 layers (0.06-0.36 mm) and diameters ranging from 150-450 µm. Process anomalies as tall as two layers or with a maximum diameter of 150 µm self-healed to a size undetectable using commercial X-ray computed tomography (CT) analytical tools. This research indicates the correlations between process anomalies and resultant defect size.

10:45 AM

Thermally Switchable Build Surface Bond by Mechanical Interlocking for Hybrid Manufacturing: *Eric Weflen*[1]; Frank Peters[1]; Matthew Frank[1]; [1]Iowa State University

This work presents a method for achieving a thermally switchable bond on a build surface for large-scale pellet extrusion AM using mechanically interlocking features. Removal of multi-meters objects from the build surface remains a challenge. Furthermore, the residual stress that develops as the multiple millimeter thick layers are deposited in an ambient environment can lead to the object detaching from the build surface if bonding is insufficient. To achieve ample object to build surface bonding, undercut features are machined into an aluminum build surface onto which the molten polymer is extruded. Upon solidification, a mechanical bond is formed. Object removal is facilitated through rapid heating of the undercut features, resulting in a loss of mechanical bonding. We present results from our lab-scale setup allowing fundamental studies of the core physics. The method can scale to fit the requirements of large-scale AM equipment and has the potential to be scaled down.

11:05 AM

Regional Porosity Measurement in Laser Powder Bed Fusion: *Henry de Winton*; Richard Williams[1]; Paul Hooper[1]; [1]Imperial College London

High performance applications require all parts to meet rigorous quality standards. Currently this requires extensive Non-Destructive Evaluation which can cost as much as manufacturing the part itself. In-situ monitoring offers an additive manufacturing specific opportunity to reduce the costs of measuring quality. In this work we use high speed melt pool monitoring and x-ray computed tomography as validation to demonstrate state of the art porosity detection in laser powder bed fusion (POD: 0.74, PFA: 0.06) at a never-before-seen level of localisation (2mm voxels). Furthermore, we find that as localisation decreases below this level the concept of "porosity" breaks down as we approach the length scale of the pores. Our approach to quality measurement is designed to yield actionable information to aid industry in meeting quality standards required for aerospace and nuclear applications.

11:25 AM

Laser Calibration for Powder Bed Fusion Additive Manufacturing Process: *Ho Yeung*[1]; Steven Grantham[1]; [1]National Institute of Standards and Technology

Laser speed, position, spot size, and response time are critical for the laser powder bed fusion process. This study demonstrates an effective approach for laser calibration by using two low-cost CMOS cameras. The cameras are set up to look up directly at the attenuated laser beam. The laser speed and position are calibrated by commanding the laser to travel through known distances between the two cameras. The laser spot sizes are calibrated by laser beam images taken by the camera at different heights and locations on the build plane. The laser response time is compared by looking at the laser command input, laser power monitoring output, and camera images. The results are compared with traditional calibration methods. Build experiments are also conducted and show the system can be used effectively to conduct a pre-build check/calibration.

11:45 AM

Experimental Analysis and Optimization of Gas Flow in an Open-Architecture Metal L-PBF System: *Magnus Bolt*[1]; Moritz Zwicker[1]; Venkata Nadimpalli[1]; Sebastian Andersen[1]; David Pedersen[1]; [1]Technical university of Denmark

The crossflow is a crucial subsystem in the metal laser powder bed fusion process. It ensures process stability and minimizes contamination of the finished component. The flow removes spatter and condensate from the process area - and it removes the plume that otherwise clouds the laser leading to a decrease in the laser power leading to a non-uniform energy density. The flow is measured in-situ in 3D space using an XYZ gantry inside a custom-built L-PBF machine. The effect of the gas inlet geometry, as well as the impact of the in-line filter, are studied. The clogging of the filter over time necessitates closed-loop control of the main blower while the process is running. The main blower is controlled by the central control unit via a variable frequency drive. The control input comes from the thin-film anemometer which is also used to measure the flow field.

12:05 PM

Real-time Process Monitoring and Closed-loop Laser Power Control in Powder Bed Fusion: *Rongxuan Wang*[1]; Benjamin Standfield[1]; Chaoran Dou[1]; Zhenyu Kong[1]; [1]Virginia Tech

Laser powder bed fusion is one of the most effective ways to achieve 3D printing. However, this method still suffers from quality issues, especially for small features. Generally, the laser power is assumed to be constant, resulting in heat accumulation and an oversize melt pool during the small feature printings. This work develops a closed-loop control system to regulate the laser power based on the thermal camera's real-time monitoring to address this issue. The desired printing temperature is found by correlating the laser power, the printing accuracy (assessed by an in-house built high-spatial-resolution 3d scanner), and the thermal signatures from a set of thin-wall structure printing trails. The control system is built upon a self-designed multi-sensing laser powder bed fusion platform. The result shows the laser power can be successfully controlled with 1.8 KHz, and a significant improvement in small feature printing accuracy has been observed.

Special Session: Binder Jet AM II - Binder-Powder interaction

Tuesday AM	Room: Salon B
July 26, 2022	Location: Hilton Austin Hotel

8:15 AM

Observations of Binder Jetting Defect Formation Using High-Speed Synchrotron X-Ray Imaging: *Jacob Lawrence*[1]; Colton Inkley[1]; Kamel Fezza[2]; Samuel Clark[2]; Nathan Crane[1]; [1]Brigham Young University; [2]Argonne National Laboratory

The Binder Jetting (BJ) process is capable of producing parts at high speeds from a variety of materials, but performance is limited by defects in the final parts. An improved understanding of fundamental phenomena in the printing process is needed to understand the source of these defects. This work presents initial findings from high-speed imaging of the BJ process using synchrotron X-rays. High-speed X-ray imaging allows for direct observation of key physical mechanisms in the printing process that may introduce defects including binder droplet impact on the powder bed, powder rearrangement below and above the powder bed surface, and balling formation. Testing was performed with multiple materials and droplet spacings to compare the effect on observed phenomena. Multiple lines were printed on packed and loose powder beds to further explore factors that affect defect formation and to better simulate industrially relevant conditions.

8:35 AM

Computational Modeling and Experimental Validation of Primitive Formation in Binder Jet 3D Printing: *Joshua Wagner*[1]; C. Fred Higgs III[1]; [1]Rice University

While significant advancements in binder jet 3D printing (BJ3DP) technology have been realized through experimental approaches, various physical limitations, such as exceedingly small length and time scales, often make direct empirical observations intractable. Consequently, there remains an incomplete understanding of the fluid and particle dynamics governing the agglomeration of powder during liquid binder deposition. This cluster of bound particles, known as a *primitive*, is the fundamental building element of the part and its characteristics have important implications on the quality of the final component. In this work, we present fully resolved simulations of primitive formation events modeled with a novel computational fluid dynamics (CFD) and discrete element method (DEM) framework. The volume-of-fluid (VOF) method is used to capture the dynamic binder-air interface and the resulting capillary forces responsible for primitive formation. The framework is deployed for parametric studies to determine optimal combinations of process parameters with various powder systems.

8:55 AM
Influence of Binder-powder Interaction on Accuracy and Resolution of Binder Jetting Parts: *Kazi Moshiur Rahman*[1]; Christopher Williams[1]; [1]Virginia Tech

The interaction of the jetted binder and the powder particles is the primary determinant of the quality of binder jetting parts. Understanding the interaction in the context of green part accuracy is critical to fabricating dimensionally accurate final parts. Prior studies on accuracy have focused on processing parameters such as binder saturation, layer thickness, and printing speed. However, the study of accuracy in the context of binder-powder interaction is limited. In this study, the authors propose a standard benchmark artifact containing features uniquely designed to quantify binder-powder interaction effects on green part accuracy and resolution. To explore the effects of binder and powder size on part resolution and accuracy, the benchmark artifacts are printed with varying powder size (30 µm and 5 µm), binder droplet size (10 pL and 30 pL), and binder saturation ratio (75%, 100%, and 150%); measurements of dimensional variation are reported.

9:15 AM
Functional Polyurethane Composites via Reactive Binder Jetting (RBJ) of a Dual-ink Binding System: *Arielle Torres*[1]; Yinfeng He[1]; Richard Hague[1]; Christopher Tuck[1]; [1]University of Nottingham

Powder consolidation via additive manufacturing (AM) requires high processing temperatures. Repeated exposure at elevated temperatures causes degradation in unused polymer powders leading to poor part performance and limited recyclability for powder-based AM processes, such as Selective Laser Sintering. This work focuses on Reactive Binder Jetting (RBJ), a novel AM process which forms three-dimensional (3D) composite parts without lasers or other high temperature elements. Powder consolidation occurs when the reactive dual-ink binding system polymerises to form strong covalent bonds between particles. A custom inkjet printer equipped with dual-printhead and integrated powder bed is used to fabricate 3D composite polyurethane structures with tuneable mechanical properties. This work demonstrates the versatility and control RBJ offers the manufacturing industry by enabling users to tailor ink formulations and printing parameters to fabricate functional polymeric parts that elicit a range of properties.

9:35 AM
Fundamental Study of Aerosol Jet® Printing by Means of Phase Doppler Anemometry: *Akash Verma*[1]; Eleonora Ferraris[1]; Maria Vetrano[1]; [1]KU Leuven

Aerosol Jet® Printing (AJP) is a widely known printing method for Printed Electronics. The process can be divided into 4 fundamental sub-steps: atomization, transport of aerosol, collimation, and in-flight jet. Fundamental studies regarding these processes are rare to find. Hereby, in-flight jet visualization of silver and PEDOT:PSS inks after exiting the nozzle and before hitting the substrate, was performed by Phase Doppler Anemometry (PDA) to analyze the particle size and speed of an aerosol jet at different gas flows combinations (Focusing Ratio). Test structures of the same inks were also printed and their linewidth was measured by optical microscope. The results were analyzed and correlated each other when possible. Such fundamental study can help to predict printing output as width of the printed pattern, concentration, etc. Such parametric studies can also help to optimize process parameters and ink development. Keywords: Aerosol Jet Printing, Phase Doppler Anemometry, Fundamental study

9:55 AM Break

10:25 AM
An Experimental Apparatus for High-speed Imaging and Analysis of Powder Primitive Formation in Binder Jet 3D Printing: *Joshua Wagner*[1]; Wesley Combs[1]; C. Fred Higgs III[1]; [1]Rice University

Wide scale adoption of binder jet 3D printing (BJ3DP) for high-performance components in aerospace, biomedical, defense, and other demanding applications requires improvement in mechanical properties and performance characteristics of end-use parts. Increased fidelity may be achieved with better understanding of the interfacial physics and complex fluid-particle interactions fundamental to the process. In this work, an experimental testing apparatus is presented that isolates the primary operation of the binder deposition step in BJ3DP. This allows for direct observation of the formation of primitives, which are the elemental bound particle agglomerations that compose the final part. High-speed, microscopic imaging is used to capture short time scale phenomena such as ballistic particle ejection and capillary-induced particle granulation. A dimensional analysis of the experimental setup is given, and the effects of various dimensionless process parameter groupings and particle size distributions on primitive formation are discussed.

10:45 AM
A Computational Study on Pore Networks in Binder Jet Additively Manufactured Components with Bimodal Powder Distribution: Willem Groeneveld-Meijer[1]; Paula Clares[1]; William Carsky[1]; Jeremy Schreiber[1]; Matthew Lear[1]; *Guha Manogharan*[1]; [1]Pennsylvania State University

Binder jet additive manufacturing (AM) allows for manufacturing of complex geometries with traditionally difficult to manufacture materials. Ceramic materials such as alumina, Al2O3, and SiO2, silica, inherently lend themselves to binder jet AM for the purpose of manufacturing complex precursor geometries for metal ceramic composites (MCCs). The toughness and ultimate tensile strength of these MCCs relies upon the liquid metal infiltration into the ceramic precursor pore network. This paper presents a discrete element model (DEM) simulation for settling, spreading, and binder droplet saturation of bimodal particles in order to most efficiently tailor pore networks for MCCs. Specifically, effects of powder particle size distribution, binder saturation of the powder during printing, and resulting pore network mapping. Findings from this study will inform the AM community on the unique interplay between bimodal powders and locally varying binder saturation.

11:05 AM
Design, Fabrication, and Validation of a Laboratory-scale Binder Jet Additive Manufacturing Testbed: *Daniel Oropeza*[1]; Ricardo Roberts[2]; John Hart[3]; [1]NASA JPL; [2]Tecnologico de Monterrey; [3]MIT

Understanding binder jetting additive manufacturing (BJAM) fundamentals, including spreading of thin powder layers, powder-binder interactions, and post-processing is critical to develop robust process parameters. Toward meeting these needs, the design, fabrication, and qualification of a BJAM testbed is presented. The testbed replicates operating conditions of commercial AM equipment and features fully programmable motion control including powder spreading using a precision roller mechanism, powder supply via a vibrating hopper, and gantry positioning of an inkjet dispenser. The inkjet system allows for the exploration of novel binder compositions and full control of jetting parameters. Validation of the accuracy and repeatability of the machine and its subsystems, as well as the fabrication of exemplary BJAM stainless steel components are discussed. The precision engineered testbed can therefore enable the study of the BJAM process fundamentals, exploration of novel binder compositions, and processing of custom powders to further scientific research and industrial applicability of BJAM.

Special Session: Data Analytics II - Machine Learning in AM

Tuesday AM
July 26, 2022

Room: Salon A
Location: Hilton Austin Hotel

8:15 AM

A Review on Machine Learning Interpretation for Additive Manufacturing: *Hyunwoong Ko*[1]; [1]Arizona State University

Machine Learning (ML) using big data and physics knowledge provides Additive Manufacturing (AM) with high potential to extract newfound knowledge, such as causality between processes, structures, and properties, from real-world data. However, this potential often relies on increased model complexity for a surge in performance, which turns ML models into "black boxes". Such black-box models lead to uncertainty regarding the knowledge ML extracts and, eventually, decisions the knowledge supports for AM. This uncertainty is a challenge in adopting ML in high-value yet critical AM applications. To tackle the challenge, this study addresses interpretation of ML models for AM in the perspective of explainable AI. This study focuses on a literature review to classify related methods and identify their potential in design, process control, and part evaluation for AM. This study sheds light on extraction of knowledge from ML models and transfer of the knowledge at multiple scales in various applications.

8:35 AM

Applications of Machine Learning in Additive Manufacturing: *John Pike*[1]; James Klett[2]; Vlastimil Kunc[2]; Chad Duty[1]; [1]University of Tennessee; [2]Oak Ridge National Laboratory

Due to recent advances, Machine Learning (ML) has gained attention in the Additive Manufacturing (AM) community as new ways to improve AM with ML are explored. The capability of ML to solve tasks such as classification, regression, and clustering provide possibilities to improve AM in every step of the process. In the design phase, ML can be used to optimize part design with respect to topology, material selection, and shape deviation compensation. AM processing can benefit from process parameter optimization and the prediction of part properties. Lastly, one of the main areas ML can impact AM is through in-situ process monitoring to detect defects and determine part quality. This presentation aims to describe some of the ML techniques being employed in AM, and demonstrate how they can be used.

8:55 AM

Additive Manufacturing Process State Inference with Convolutional LSTM: *Vivek Patel*[1]; Richard Anarfi[1]; Benjamin Kwapong[1]; Kenneth Fletcher[1]; Todd Sparks[2]; Aaron Flood[2]; [1]University of Massachusetts Boston; [2]Product Innovation and Engineering LLC

Simulation of the melt pool physics during directed energy deposition (DED) or laser powder bed fusion (LBPF) processes can be a computationally onerous task. If such a model is needed for real time control, the problem can be intractable, leading to the usage of reduced-fidelity models. Machine learning (ML) offers methods to use high-fidelity models as a training data source to infer solution results quickly. In this paper we propose a ML method based on convolutional long short-term memory (LSTM) network trained on rendered images from a metal AM process simulation and CAM data. The convolutional LSTM architectures bring together time series processing and computer vision by introducing a convolutional recurrent cell in a LSTM layer. The proposed method is used to predict images of an AM process given tool path and process information. Such a prediction can be an important first step in a ML-based process control schema.

9:15 AM

Defects Classification via Hierarchical Graph Convolutional Network in L-PBF Additive Manufacturing: Anyi Li[1]; *Jia Liu*[1]; Shuai Shao[1]; Nima Shamsaei[1]; [1]Auburn University

Three typical types of defects, i.e., lack of fusions, keyholes, and gas-entrapped pores, characterized by various features (e.g., area, volume, perimeter, etc.), are generated under different fabrication conditions of laser beam powder bed fusion (L-PBF) processes. However, there is a lack of recognized approaches to automatically and accurately classify the defects in L-PBF components. This work presents a novel hierarchical graph convolutional network (H-GCN) to classify different types of defects by a cascading GCN structure with a low-level features (defect features) layer and a high-level features (fabrication conditions) layer. Such an H-GCN not only leverages the information from different hierarchies to classify the defects but also explores the impact of fabrication conditions on defect features. The H-GCN is evaluated through simulation and a real case study with L-PBF defect datasets and compared with the neural network (NN) and GCN.

9:35 AM

Graph Neural Networks for 3D Defect Mapping in Laser Powder Bed Fusion: *Sebastian Larsen*[1]; Paul Hooper[1]; [1]Imperial College

Since defects form due to the stochastic nature of the LPBF process, stringent post-build inspection regulations are a required burden. However, locating defects in-situ would enable a component to be qualified in real time, automating this requirement. A graph neural network model was developed to provide a geometric invariant method for localising defects in the material. The model was trained on high-speed melt pool monitoring data, collected from a component manufactured with seeded defects. A k-fold cross validation was performed where each seeded defect was detected and localised. The defect sizes were correlated with the 3D probability map which showed positive correlation with number of detections. Graph neural networks provide an efficient way to locate defects in a component, while remaining invariant to geometry. We believe the effectiveness comes from incorporating this physical structure into a machine learning model.

9:55 AM Break

10:25 AM

Optimization of Laser Process Parametres using Machine Learning Algorithms and Performance Comparison: *Sumanth Theeda*[1]; Bharath Bhushan Ravichander[1]; Shweta Hanmant Jagdale[1]; Golden Kumar[1]; [1]University of texas at dallas

Laser powder bed fusion (L-PBF) can be used to produce near net-shaped functional metal components. Despite offering high flexibility in producing components with intricate geometries, L-PBF has many constraints in terms of controllability and repeatability because of large number of processing parameters. There is a need for a robust computational model which can predict the properties of L-PBF parts using a wide range of processing parameters. In this work, several Machine learning-based algorithms like Random Forest, k Nearest Neighbors, XGBOOST, Support Vector Machine (SVM), and Deep Neural Networks are used to model the property-processing parameters relation for SS 316L samples prepared by LPBF. Laser power, scan speed, hatch spacing, scan strategy, volumetric energy density, and density are used as the input to these models. The developed model is then used to predict and analyze the surface roughness of as-fabricated SS 316L specimens. The prediction and experimental results are compared for the above-mentioned models to evaluate the capabilities and accuracy of each model.

10:45 AM

In-situ Monitoring and Prediction of Porosity in Laser Powder Bed Fusion using Physics-informed Meltpool Signature and Machine Learning: *Ziyad Smoqi*[1]; Aniruddha Gaikwad[1]; Benjamin Bevans[1]; Md Humaun Kobir[1]; James Craig[1]; Alan Abul-Haj[1]; Alonso Peralta[1]; Prahalada Rao[1]; [1]University of Nebraska-Lincoln

The goal of this research is the in-situ monitoring and detection of porosity formation in LPBF using a two-wavelength imaging pyrometer (ThermaViz). To realize this goal, a large cuboid of ATI 718Plus Alloy part (10 mm × 10 mm × 137 mm) was built under different conditions of laser powers and scanning speeds. During the process, meltpool temperature and shape measurements were acquired using the two-wavelength imaging pyrometer. The porosity analysis of the part was performed offline using X-ray computed tomography (XCT). The porosity in different segments of the part was correlated with physically relevant meltpool signatures, such as meltpool length, temperature distribution, and ejecta (spatter) characteristics, using simple machine learning approaches. Both the severity of porosity and its type were predicted with an accuracy exceeding 95% (statistical F1-score).

11:05 AM

Porosity Prediction for Multiple Processing Regimes in Laser Powder Bed Fusion via Machine Learning of In-situ Multi-modal Monitoring Data: *Haolin Zhang*[1]; Chaitanya Vallabh[1]; Alexander Caputo[2]; Richard Neu[2]; Xiayun Zhao[1]; [1]University of Pittsburgh; [2]Georgia Institute of Technology

In metal additive manufacturing (AM) processes, such as Laser Powder Bed Fusion (LPBF), complex laser-powder interactions make the process difficult to monitor and qualify. One such major challenge is the quantification of process-induced porosity. Porosity is detrimental to the mechanical properties and the life-cycle of the manufactured part. In this work, we develop a machine learning aided porosity prediction framework utilizing the in-situ monitored, multi-modal, melt pool (MP) and powder bed signatures as input to predict the process-induced porosity in the final printed part. The proposed input signatures are our in-house 1) single camera two wavelength imaging pyrometry (STWIP) measured MP temperature and MP area, and 2) Fringe Projection profilometry (FPP) measured surface topography. A machine learning based porosity correlation framework will be developed to derive quantitative metrics of the porosity from the multiple in-situ MP signatures. Further, this framework has the potential to be implemented for online defect detection.

11:25 AM

Transferring Printability Knowledge Across SS316L and IN718 in Laser Directed Energy Deposition using Machine Learning: Sudeepta Mondal[1]; *Nandana Menon*[1]; Amrita Basak[1]; [1]Pennsylvania State University

Laser-directed energy deposition additive manufacturing processes have several parameters that impact the melt pool properties, which in turn affect the microstructure of the part. Computational investigations are regularly implemented; however, these investigations must be repeated for each material of interest. In this paper, a transfer learning approach is proposed to address this challenge. Using an analytical model, input-output data pairs are generated for a nickel-based alloy, IN718, and an iron-based alloy, SS316L. A baseline neural network is trained for each alloy. The capability of these baseline networks is interchangeably analyzed with a parametric retraining of the percentage of data used and the number of retrained layers of the baseline network. With just 10% data, and one retrained layer, accuracies above 90% are observed. The results show that the acquired printability knowledge can be transferred across material systems without requiring a significant amount of data from the second material system.

11:45 AM

Simplified Unsupervised Statistical Anomaly Detection for In-situ Quality Control of Directed Energy Deposition (DED) Additive Manufacturing: *Ehsan Dehghan Niri*[1]; Steven Hespeler[1]; Michael Juhasz[2]; Harold Halliday[3]; Melanie Lang[4]; [1]New Mexico State University; [2]Lawrence Livermore National Laboratory; [3]Navajo Technical University; [4]FormAlloy Company

The leading reason for parts rejected during metal Additive Manufacturing is the creation of unacceptable defects. Post-process nondestructive testing methods are either time-consuming or impractical for quality control of AM parts with complex geometries. The slow nature of the AM process provides a unique opportunity to collect certain data in real-time to be used for in-situ quality control. The first step is to develop an automated unsupervised statistical anomaly detection algorithm that can detect abnormalities in both measured parameters and sensing features. In this paper, to detect anomalies, a simple unsupervised statistical method is developed to detect outliers in the collected data during the laser-based Directed Energy Deposition process. The results show, while the algorithm could successfully detect the creation of large porosities it could not reliably detect creation of smaller defects. It is concluded that additional sensing data is critical for reliable in-situ quality control to detect small defects.

Special Session: Wire-Fed DED - Material Properties

Tuesday AM — Room: 410
July 26, 2022 — Location: Hilton Austin Hotel

8:15 AM

Heat Treatment Effects on Mechanical Properties of Wire Arc Additive Manufactured Ti-6Al-4V: *Natalia Saiz*[1]; Jonathan Pegues[1]; Shaun Whetten[1]; Andrew Kustas[1]; Tyler Chilson[1]; [1]Sandia National Laboratories

Directed energy deposition (DED) is an attractive additive manufacturing (AM) process for large structural components. The rapid solidification and layer-by-layer process associated with DED results in non-ideal microstructures, such as large grains with strong crystallographic textures, resulting in severe anisotropy and low ductility. Despite these challenges, DED has been identified as a potential solution for the manufacturing of near net shape Ti-6Al-4V preforms. In this work, we explore several heat treatments processes, including HIP, and their effects on tensile properties of wire arc additively manufactured (WAAM) Ti-6Al-4V. A high throughput tensile testing procedure was utilized to generate statistically relevant data sets related to each specific heat treatment and sample orientation. Results are discussed in the context of microstructural evolution and the resulting fracture behavior for each condition as compared to conventionally processed Ti-6Al-4V. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525

8:35 AM

Qualification of Low-criticality AM Components in an Expeditionary Environment: *Jacob Aljundi*[1]; Jonathan Torres[2]; Zach Heinkel[1]; Sam Pratt[1]; [1]NSWCCD; [2]Bucknell University

The Department of the Navy has interest in the adaptability of additive manufacturing (AM) for custom small volume production. Tactical environments often have limited margin for delays in receiving needed parts. By implementing AM, fleet users can fabricate mission-specific components in expeditionary environments while maintaining minimal delays. Naval Surface Warfare Center Carderock Division (NSWCCD) seeks to develop techniques to qualify low-critical AM components. Production of metal components in expeditionary environments requires increased confidence in the mechanical performance of AM materials. Qualification for low-critical AM components should be affordable and simple while still rigorous enough to provide field users with confidence that low-criticality parts will perform as intended. To address the lack of qualification process for low criticality, field generated AM components, the project team seeks to assess existing methods for field qualification of welded structural components, as well as reduced-sized sample test methods such as the small punch test.

8:55 AM

Effects Due to Variations in Thermal Properties of Maraging Steel for Finite Element Modeling of the WAAM Process: *Matthew Register*[1]; Matthew Priddy[1]; [1]Mississippi State University

Finite element (FE) thermal simulations of the wire arc additive manufacturing (WAAM) process have been widely used to predict the temperature history of as-built parts. Temperature-dependent thermal properties like density, conductivity, specific heat, and latent heat are required to accurately simulate the solidus to liquidus transition seen in the heat affected zone. Current research has shown that thermal properties measured experimentally or simulated using material database software can be used for thermal modeling; however, there has been no direct comparison shown to determine which is most appropriate for WAAM modeling. The focus of this research is to compare the temperature variation of the FE thermal simulations with experimentally measured and computer-generated properties for M250 grade maraging steel. The thermal history for thin wall builds at various lengths and heights will be compared with differing temperature-dependent thermal properties to examine the relationship between thermal properties and history.

9:15 AM

Impact of Composition and Solidification Pathway on Additively Manufactured 316L Printed via a Laser-wire Directed Energy Deposition Process: *Olivia Denonno*[1]; Matthew Schreiber[1]; Charles Smith[1]; Kip Findley[1]; John Speer[1]; Anthony Petrella[1]; Craig Brice[1]; Amy Clarke[1]; Joy Gockel[1]; Jonah Klemm-Toole[1]; Zhenzhen Yu[1]; [1]Colorado School Of Mines

Wire-fed laser directed energy deposition is a high deposition rate process ideal for large structures and simple geometries utilizing low-cost feedstock material. Understanding the solidification behavior and microstructure evolution of additively manufactured wire-fed DED austenitic stainless steel is essential for the qualification of the alloy across additive manufacturing platforms. In this study, it was determined that solidification conditions and composition can affect the stability of austenite as the primary solidifying phase relative to delta ferrite. The impacts of solidification pathway, thermal gradients and solidification velocities, and composition on solidification behavior of thin and thick laser-wire DED 316L parts will be discussed and compared. The observed shift in solidification modes among these two builds can be modeled and understood via a comprehensive microstructure map developed using analytical solidification models. This microstructure map can be used to predict microstructure morphology and size as well as solidification mode across additive manufacturing platforms.

9:35 AM

The Failure of Wire-arc Additive Manufactured Aluminum Alloys With Porosities Under Loadings as Observed by In-situ X-ray Micro-computed Tomography: *Runyu Zhang*[1]; Yuxin Jiao[1]; Christopher Paniagua[1]; Yi Tian[1]; Hongbing Lu[1]; Wei Li[1]; [1]University of Texas at Dallas

Wire-arc additive manufactured aluminum alloys (WAAM 4043 Aluminum) are widely used in many industries. Porosities are known to exist within the WAAM aluminum alloys, which greatly reduces the usability and reliability of such parts. In this study, WAAM aluminum alloy specimens with porosities are manufactured using a Fronius (TPS 320i) MIG/MAG welding and ABB (IRB 140) robot system. The mechanical performance of the specimens with porosities is evaluated under the three-point bending and tension using in-situ X-ray micro-computed tomography (μCT). The μCT system with an integrated mechanical loading frame provides in-situ volumetric images of the specimens while loadings are applied. The failure of the WAAM aluminum specimens and the propagation of the internal porosities are observed and assessed. This work provides direct experimental observations and evaluations of the influence of porosities on the mechanical behavior of WAAM aluminum alloys under loadings.

9:55 AM

Wire Arc Additive Manufacturing of Reduced Activation Ferritic Martensitic (RAFM) Steel: Bishal Silwal[1]; *alexander reinchenbach*[1]; [1]Georgia Southern Univ

RAFM steel has been considered the candidate material for an in-vessel component of the fusion wall reactor. The goal of this research project is to fabricate and study the technical feasibility of wire arc additive manufacturing. A metal-cored wire is a tubular electrode comprised of an outer metal sheath with alloying powdered materials inside the core. The advantage of using the metal-cored wire is that a higher deposition rate, and higher side-wall fusion, can be achieved, and more important, special alloys such as RAFM steels can be manufactured at a relatively lower cost. Moreover, any undesirable elements can be excluded. A preliminary investigation of WAAM RAFM was carried out at the Georgia Southern AM lab. A design of experiments with different waveforms using the metal-cored wire was conducted to study the printability. The microstructure and mechanical properties were tested, analyzed, and compared with the available data from the literature.

10:15 AM Break

A Panel Discussion with Emerging Women Leaders in AM

Tuesday PM	Room: Salon G
July 26, 2022	Location: Hilton Austin Hotel

12:45 PM Panel Discussion

Applications - Biomedical

Tuesday PM	Room: 417 AB
July 26, 2022	Location: Hilton Austin Hotel

1:40 PM

3D Printed Bioactive Glass-Hydrogel Scaffolds for Craniofacial Bone Defects: Fateme Fayyazbakhsh[1]; Nathan Hirsch[1]; Yue-Wern Huang[1]; Delbert Day[1]; *Ming Leu*[1]; [1]Missouri University of Science and Technology

Gelatin/alginate-based hydrogels are widely used as tissue engineering matrices for bone regeneration. Recent studies employed inorganic phases to enhance mechanical strength by mimicking the normal bone's biphasic structure. In this study, we examined the tunable functionality of 3D printed scaffolds using gelatin, alginate, and bioactive glass in terms of mechanical properties, biodegradation, and bioactivity for craniofacial defects. To evaluate printability, the rheological behavior and shape fidelity of the 3D printed scaffolds were analyzed and related to the scaffold composition. The results demonstrated that alginate has a positive effect on flowability, shape fidelity, and mechanical strength by forming crosslinks between the hydrogel network and ions released from glass. Biological tests showed the 3D printed scaffolds with higher gelatin content had higher cell viability and proliferation. The results from this research showed that the 3D printed bioactive glass-hydrogel scaffolds are promising candidates for craniofacial bone regeneration with tunable biodegradation and mechanical properties.

2:00 PM
3D Printing and Application of Lattice-based Biodegradable Metal Implants for Bone Regeneration in Load-Bearing Bone Defects: *Shantanab Dinda*[1]; Timothy Simpson[1]; Ibrahim Ozbolat[1]; [1]The Pennsylvania State University

Human bones have naturally evolved ways to repair small fractures quickly; however, fractures below the waste require mechanical aids to help bear loading while healing. These techniques are effective but tend to cause a lack of mobility. 3D printed biodegradable metallic implants are now showing promise as an ideal alternative for expediting recovery and increasing mobility, especially with the growth of lattice-based design and better osseointegration techniques. This study discusses the development and testing of a functional 3D printed implant that integrates such properties, with an eye toward clinical translation. Materials selection and implant design have been done based on printability, load-bearing, biocompatibility, controlled degradation, and osseointegration. An iron-manganese mixture with dopants is used with lattice-based design to minimize material and printed using binder jetting. After fabrication, experiment analysis to evaluate load-bearing, degradation, in-vitro performance, and microstructure has been performed for validation, achieving a functional 3D printed biodegradable metal implant.

2:20 PM
Magnetic Surface Finishing for Additively Manufactured Titanium Scaffolds of Bone to Reduce Surface Roughness and Improve Osseointegration: Runrun Chen[1]; *Axel Fernandes*[1]; Shiqi Zheng[2]; Shuyi Huang[1]; Natan Barros[3]; HanJun Kim[3]; Bingbing Li[1]; [1]California State University Northridge; [2]University of California Los Angeles; [3]Terasaki Institute for Biomedical Innovation

Our research focuses on the additively manufacture of Ti6Al4V alloy scaffolds for bone implants and tissue engineering, with varying lattice structures and pore sizes in the range of 200-500 microns using a powder bed fusion (PBF) system Renishaw AM 250. The additive manufacturing process results in high surface roughness on the scaffolds and loose powder inside. Our aim is to polish the lattice and achieve a low surface roughness on the scaffolds by using magnetic field-assisted polishing (MAP). Then, we shall test the osseointegration and osteoblast viability of the lattice structures by infusing the lattice structure with osteoblast cells and studying the cell growth over a period. We will present our various validation using SEM imaging, TEM surface analysis, Algorithmic CAD processing, MAP, and other data analysis tools to be able to recommend a lattice structure that has lower apoptosis rates, better cell proliferation, and good osseointegration.

2:40 PM
Characterizing Hydrodynamic Shear Stress and Cell Viability of Algal Cells during Extrusion Bioprinting: *Keegan Ocorr*[1]; Srikanthan Ramesh[1]; Ke Du[1]; Iris Rivero[1]; [1]RIT

The encapsulation of algal cells into a soft material and deposition into 3D structures has numerous applications, such as improving tissue oxygenation, producing metabolites, and aiding in the forming synthetic coral reefs. Protecting the algae contained in the hydrogels from the shear stresses experienced during extrusion remains an obstacle to maximizing the functionality of the printed structures. This research evaluates the influence of shear stress on the viability and function of the encapsulated algal cells. We use ANSYS-Fluent to simulate the flow of algae-laden hydrogels through printer nozzles and determine the shear stress range that allows for continued algae growth and function. A 2D axisymmetric model was used to simulate the flow of cell hydrogels through conical nozzles, and numerical predictions were empirically validated. Our results suggest that optimization of the printing process must be carried while remaining within the maximum limit of shear stress that the cells can handle.

3:00 PM
Optimizing 3D Printed Tourniquets for Immediate Aid in Ukraine: *Tosh Brown-Moore*[1]; Srivatsan Balaji[1]; Jeff Lipton[1]; [1]University of Washington

The outbreak of conflict in Ukraine has been met with a drastic increase in demand for medical devices like the COVID pandemic. Additive manufacturing enables the on-demand onsite manufacturing of medical devices, such as tourniquets, necessary to save lives in emergency situations where delivery isn't an option. Here we show the relative performance of open-source 3D printed GLIA tourniquet components made from ABS and PETG and compare them to a commercially available combat application tourniquet (CAT). Using a variety of mechanical tests, our results demonstrate that tourniquet components printed with PETG are the best alternative to commercially available tourniquets in terms of cost and mechanical properties. We used this work to guide aid efforts for Ukraine through the Open-Source Medical Supply Organization.

3:20 PM
Shared Teleoperation Architecture for Endoscopic Additive Manufacturing: *Rodrigo Enriquez Gutierrez*[1]; David Hoelzle[1]; Andrej Simeunovic[1]; Ali Asghari Adib[1]; [1]The Ohio State University

In this paper we explain the framework for a robot architecture for real-time shared teleoperation intended to be used for in-situ and in-vivo additive manufacturing of tissue engineering constructs and show its performance under laboratory conditions. The quasi-static environment inside the human body presents a challenge for 3D printing tissue engineering constructs endoscopically. The shared architecture allows surgeons to introduce real-time modifications to the trajectories for a small biological mesh, without the need to generate a new trajectory or stop the current process. Offline trajectory generation and bilateral teleoperation of robotic manipulators each present different strengths and weaknesses. This approach aims to balance both strategies while at the same time being more palatable to the medical community that has valid concerns about autonomous surgical procedures. This architecture is demonstrated on the EndoAM system, a replica of the current professional robotic surgery platform da Vinci, manufactured by Intuitive Surgical.

3:40 PM
Stent Design Investigation for Polymeric and Metallic Materials using Finite Element Modeling of the Crimping Process: *Caralyn Collins*[1]; Cheng Sun[1]; Rao Fu[1]; Yonghui Ding[1]; Guillermo Ameer[1]; [1]Northwestern University

Driven by the need for bioresorbable vascular scaffolds (BVS), interest in the use of polymers as primary stent materials has increased dramatically in recent years. Such stents are highly compatible with recent advances in additive manufacturing, enhancing ease of geometric customization and offering additional drug elution potential. Contrasting with existing metal stent literature, there is an apparent lack of literature regarding systematic, optimized stent design specifically for polymer profiles. To ensure optimal performance of the BVS in crimping, a step involving large mechanical deformation, topology of the stent must be considered in tandem with the selected material profile. This study uses ABAQUS to establish a framework for predicting BVS performance during crimping, taking into consideration differences in BVS topology alongside both representative metal and polymer material profiles. Stress profile and deformation analysis is completed to inform future stent design and to fully harness the potential of additive manufacturing processes.

Applications - Topology Optimization

Tuesday PM	Room: 416 AB
July 26, 2022	Location: Hilton Austin Hotel

1:40 PM
A Framework for Interactive Structural Design for AM: *Sofia Valdez*[1]; Nicholas Rodriguez[1]; Carolyn Seepersad[1]; [1]University of Texas at Austin

Additive manufacturing paired with topology optimization results in expansive design spaces that cannot be searched effectively by either human designers or computational algorithms alone. Our goal is to establish a machine learning based interactive design framework that combines the intuitive guidance of a designer and the generative ability of a computer. Specifically, the goal is to enable designers to guide the algorithm towards design features that are significant and desirable to them for reasons that are difficult to embed within the optimization itself (e.g. aesthetics) while maintaining satisfactory structural performance. The foundation of the framework consists of the latent representation of a library of designs generated by training a generative adversarial network (GAN) on a diverse set of topology optimized designs. The framework utilizes latent-based interactive functionalities that allow users to efficiently visualize, search, and alter designs within an expansive structural design space by manipulating their latent variable representations.

2:00 PM
Generative Design for Additive Manufacturing of Satellite Optical Tracker Mount: *Paula Logozzo*[1]; Abraham Meiszner[1]; Donald Palomino[1]; Bingbing Li[1]; [1]California State University Northridge

Technology such as Generative Design allows users to generate numerous, high-quality component candidates that are often lighter and stronger than traditionally designed parts. However, the organic and intricate nature of machine generated parts is problematic during the manufacturing phase, resulting in high costs and slow manufacturing times with traditional manufacturing techniques. An alternative manufacturing technique, metal additive manufacturing, is explored as a potential solution for the construction of machine generated components. This paper addresses the process of designing and load testing a satellite optical instrument mounting bracket using the generative design and thermal simulation capabilities of Autodesk Fusion 360. The workflow pipeline begins with the creation of generative design studies for the instrument bracket in accordance with the design criteria outlined in the optical instrument design challenge, where it is then thermally load tested using FEA in Fusion 360 and analyzed for its mechanical behavior.

2:20 PM
Design and Testing of a Topology Optimized Transtibial Socket: *Roxana Carbonell*; Richard Crawford[1]; [1]University of Texas at Austin

This paper presents a design and testing protocol for an optimized transtibial prosthetic socket using the ground structure method of topology optimization. The bulk of the socket is replaced with an optimized Michell truss geometry developed using semi-static analysis of a surrogate socket and limb geometry. Separate trusses were developed for the loading of three stances: heel strike, vertical (standing), and toe off. The truss models were combined to create the final design. The final design volume was 5.8121 e-4 cubic meters compared to the original model volume of 8.2963 e-4 cubic meters. Additionally, it is theorized that the truss design will allow for airflow minimizing overheating within the socket. After computational analysis of the finished design, the socket was manufactured using SLS Nylon-12 and tested using a dummy limb. The socket successfully supported 2240 newtons, the load required by ISO standard 10328 the standard for lower limb prostheses.

2:40 PM
Mechanical Evaluation of Topology- and Toolpath-Optimized Composite Structures Manufactured via Multi-Axis Material Extrusion: *Joseph Kubalak*[1]; Christopher Williams[1]; [1]Virginia Tech

Unlike conventional, gantry-based additive manufacturing (AM), multi-axis AM enables continuous variation of deposition path direction and tool orientation throughout the part. Material can be deposited outside of the XY-plane, enabling 3D tailoring of a composite material's direction and placement to the part's manufacturing and end-use requirements. This removes the relatively weak layer-interfaces from the load paths, applying more load to the fiber and increasing mechanical properties. To enable design and fabrication in this context, the authors have created the topology and toolpath optimization (TTO) workflow. TTO uses a topology and orientation optimization algorithm to determine 3D material distribution and orientation relative to input loading conditions, aligns material depositions (i.e., the composite reinforcement) to those orientations, and orders the deposition paths for collision-free fabrication to maximize part performance. In this presentation, multi-axis TTO parts are fabricated and mechanically evaluated relative to planar AM parts and demonstrate significant improvement in structural efficiency.

3:00 PM
Strength Comparison of a Topology Optimized Truss Structure from Printed SLA Resin, Electroplated Resin and DMLS Aluminum: *Sean Wise*[1]; Allison Beese[2]; Analisa Russo[3]; Lourdes Bobbio[2]; Timothy Simpson[2]; [1]REPLIFORM, INC.; [2]Pennsylvania State University; [3]Formlabs Inc.

Given the high cost of metal components made with DMLS, we compare the strength of two electroplated resin components against monolithic SLA polymer and DMLS aluminum versions of the same geometry. Using ROM, validated by ASTM tensile strength measurements, two coating sequences were designed to provide electroplated samples with half the tensile strength and equivalent tensile strength of DMLS Al, respectively. All four sets were subjected to 3-point bending. The monolithic materials had higher proportionate maximum load with respect to tensile strength; however, the electroplated polymer part displayed enhanced bending response relative to its designed tensile strength. The plated part with weaker coating bore 85% of the load of DMLS aluminum part while the parts with a stronger coating bore almost twice the load. The enhanced performance is due to the surface reinforcement from the high strength coating, which better resists bending and buckling in this type of design.

Industrial Needs for AM Research and Development

Tuesday PM — Room: 408
July 26, 2022 — Location: Hilton Austin Hotel

1:40 PM
About the Session: Developed in partnership with America Makes, this session will feature a cross section of diverse industrial perspectives (aerospace, oil and gas, energy, medical) to drive focus within the additive manufacturing research and development community to address needs of industry. Discussions will include not only a description of applied research opportunities but also identification of scientific and technological development opportunities to foster alignment between the needs of industry and the expertise, skills, and capabilities of the academic community.

Materials: Composites - Metal-Based Composites

Tuesday PM — Room: 616 AB
July 26, 2022 — Location: Hilton Austin Hotel

1:40 PM
3D Printing of Nanoporous Metals via Fused Filament Fabrication: Rheological Considerations: *Amm Hasib*[1]; Stanislau Niauzorau[1]; Natalya Kublik[1]; Bruno Azeredo[1]; [1]Arizona State University

Nanoporous metals are a distinct class of materials with inherent size-dependent properties and high surface area, relevant for designing high-performing materials for catalysis, energetics, environmental, and energy applications. In an attempt to integrate it into additive manufacturing processes, this work (i) synthesizes dense polymer-matrix metal composites reinforced with metallic nanofoams whose pore size range from 5-20 nm, (ii) studies the role of capillary imbibition, and its rheology, extrudability and printability via fused filament fabrication. The following integration challenges are discussed: (a) uniform mixing and infiltration of thermoplastics into porous metals, and (b) nano-confined polymer chains and its effect on its rheological behavior. This is accomplished by examining the wetting characteristics, phase exchange (i.e., between solvent and polymer) and capillary imbibition of polymeric solution as a function of different polymer chain radius of gyration, Rg. It was found that the molecular weight and Rg regulates its wettability, viscosity, density and printability.

2:00 PM
Optimization of SLA Photopolymers' Thermal Expansion for Nickel Plating: *Connor Hammond*[1]; Jitendra Tate[1]; [1]Texas State University

Stereolithography additive manufacturing is a method of producing parts by stacking layers of a photopolymer resin cured by exposure to UV light . This method of additive manufacturing gives great resolution, but often lacks the material properties of other techniques. One method to increase part performance is the addition of a thin nickel plating to increase strength, heat deflection, and chemical resistance. No solution has been proposed for using nickel coated parts in harsh environments where the large difference in thermal expansion rates between the nickel plating and base resin cause internal stresses to form. The excellent chemical resistance of the nickel plating would also allow these parts to be used in high temperature, oxygen rich environments such as those presented in life support systems. Through the development of a high-performance nanocomposite SLA resin, we hope to achieve parts with good mechanical properties and a CTE similar to nickel.

2:20 PM
Laser Powder Bed Fusion of Highly-Reinforced Aluminum Matrix Composites: *Ethan Parsons*[1]; [1]MIT Lincoln Laboratory

The mechanical and thermal properties of particle-reinforced metal matrix composites (MMCs) are attractive for high-performance defense and space applications, but fabrication of MMC components with conventional methods is difficult, costly, and typically limited to components with simple geometry. Additively manufacturing particulate MMCs with laser powder bed fusion (LPBF) would be an ideal method, but the laser consolidation of these materials has been largely unsuccessful in matching the properties of conventionally-produced MMCs. The challenges include spreading the heterogeneous powder, distributing small ceramic particles, and forming a strong bond between the metal and the ceramic. Here, by mechanically alloying AlSi10Mg powder and ceramic microparticles, we manufacture highly-reinforced aluminum composite powders with morphology tuned for AM process conditions. Using LPBF, we achieve dense consolidation of these powders at ceramic contents of over 30% and demonstrate tensile properties matching the properties of aluminum matrix composites made by conventional methods.

2:40 PM
Knowledge Base Development for Mechanical Properties and Energy Consumption of Iron-PLA Composite Filaments in Additive Manufacturing: *Ranger Buchanan*; Joji Dasari; Ismail Fidan; Khalid Tantawi[1]; Indranil Bhattacharya[2]; Michael Allen[2]; [1]University of Tennessee Chattanooga; [2]Tennessee Technological University

Additive Manufacturing (AM) is the process of manufacturing where materials are constructively added to create an object. AM allows for some designs that are impossible to produce with traditional methods. One of the most common AM process is Fused Filament Fabrication (FFF) process, which utilizes layers of extruded materials to fabricate objects. While 3D printers commonly use plastics, composite materials can also be used.The power consumption of electronics are related to run time, though power consumption is also influenced by how much energy electronics need to operate. 3D printers can reduce run time by increasing layer height, decreasing infill density, or increasing print speed, but all of these factors will affect the quality of the print. This research intends to develop a knowledge base to manufacture Iron-PLA composites and analyze the mechanical and electrical properties in addition to the energy consumption of the prints based upon print parameters.

Materials: Metals - Powder and Processes

Tuesday PM — Room: 615 AB
July 26, 2022 — Location: Hilton Austin Hotel

1:40 PM
Repeatability and Sensitivity of a Rotating Drum Method for Rheological Characterization of Stainless Steel Powders Used for Additive Manufacturing: *Justin Whiting*[1]; Vipin Tondare[1]; Shawn Moylan[1]; [1]NIST

There remains a need for rheological characterization that is relevant for powder-based additive manufacturing (AM). While there have been novel powder rheometers introduced to the commercial market, each must first be rigorously evaluated prior to widespread adoption for predicting AM powder performance. The work presented here focuses on the quantification of the repeatability and reproducibility from two commercially available rotating drum powder rheometers for testing metal AM powder. The repeatability assessment is accomplished via a robust set of tests that include the following independent variables: cleaning method, mass of the sample, particle size distribution, material, and hysteresis. The reproducibility of the method is evaluated via an interlaboratory study comprised of a total of 13 laboratories from industry, academia, and one National Laboratory. Samples are produced following ASTM B215-20. Results from ANOVA conducted on the data collected from the interlaboratory study are presented with results from both device's repeatability analysis.

2:00 PM
Rheological Characterization of Room Temperature Powder Metal Paste for Extruded Material Modeling: *Marshall Norris*[1]; Ismail Fidan[1]; [1]Tennessee Tech University

Powder metals have been used in Additive Manufacturing processes such as injection molding, extrusion, and slip casting for decades. Innovations in the Fused Filament Fabrication (FFF) process have provided the opportunity to mix powder metals with a binding thermoplastic at elevated temperatures to create good quality components. This research attempts to define the rheological characteristics of amalgam materials used to produce components at room temperature using powder metals that will provide the following three outcomes: 1. material that will flow under low shear stress, 2. green strength to provide structural support of material deposited on top and prevent deformation under gravitational load, and 3. once cured to provide material properties that are comparable to those of materials produced by traditional means. The purpose of this research is to determine if powder metal components can be produced by FFF at room temperature while maximizing the powder metal composition in the mixture.

2:20 PM
Enhancement of Gas-Atomized 304L Stainless Steel Powder by Plasma Spheroidization for use in the Laser Powder Bed Fusion (LPBF) Process: *M. Hossein Sehhat*[1]; Austin Sutton[1]; Ming Leu[1]; [1]University of Missouri, Science and Technology

Particles of AISI 304L stainless steel powder, produced using the gas-atomization method, were spheroidized by the induction plasma spheroidization process (TekSphero-15 spheroidization system) to assess the effects of plasma spheroidization on powder and part properties. The morphology of both as-received and spheroidized powders was characterized by measuring particle size and shape distribution. The Revolution Powder Analyzer was used to quantify powder flowability. After building several parts with both the as-received and spheroidized powders using the Laser Powder Bed Fusion (LPBF) process, the mechanical properties of parts fabricated with these two kinds of powders were measured and compared. After the plasma spheroidization process, the particles reshaped to spheres while their particle size remained essentially unchanged. The parts fabricated by the LPBF process with the plasma spheroidized powder showed lower tensile strength but higher ductility, which is due to change in the solidification mode after the spheroidization process.

2:40 PM
Design of Intrinsically Balling-Resistant Alloys: A Physics-informed and Data-enabled Approach: *Brent Vela*[1]; Seth Mehalic[1]; Sofia Sheikh[1]; Alaa Elwany[1]; Ibrahim Karaman[1]; Raymundo Arroyave[1]; [1]Texas A&M University

Historically, additive manufacturing (AM) has been framed in terms of the need to tune processing conditions for a particular AM technology in order to print conventional alloys, oftentimes developed for fabrication methods other than AM. There are significant opportunities to design alloys specifically for AM. A key challenge in realizing this is that alloy design requires optimizable composition-based performance metrics to guide the exploration of the alloy chemistry space. We propose a novel composition-based indicator of balling based on intrinsic thermophysical properties at AM-relevant conditions, namely the ratio between the characteristic spreading and solidification times of a molten alloy droplet. By identifying these intrinsic properties, it is possible to incorporate 'intrinsic printability', specifically 'intrinsic resistance to balling', into AM-focused alloy design. The proposed indicator is used to train machine learning classifiers to predict balling and validated against an experimental dataset mined from the literature, demonstrating the utility of said indicator.

3:00 PM
Additively Manufactured Mesoscale Composites: *Patxi Fernandez-Zelaia*[1]; Chris Ledford[1]; Jiahao Cheng[1]; Xiaohua Hu[1]; Seokpum Kim[1]; Sebastien Dryepondt[1]; Michael Kirka[1]; [1]Oak Ridge National Laboratory

Fusion based additive manufacturing enables site specific microstructure control via control of the local solidification physics. The mesoscale structure, both morphological features and crystallographic texture, can be controlled to some degree. In this work we share recent results using electron beam melting to fabricate 'mesoscale composites' in both a Ni-based superalloy and pure molybdenum. Experiments and microstructure-scale simulations indicate that both macro-scale and localized material behavior may be tailored in these engineered structures. This strategy is potentially suitable for synthesizing optimized materials for use in high temperature applications.

3:20 PM
A Framework for Digital Materials Fabrication Using Directed Energy Deposition Process: *Frank Liou*[1]; Wei Li[2]; [1]Missouri University of Science and Technology; [2]University of Texas at Dallas

Digital materials, or Functionally Gradient Materials (FGMs), feature smooth transition from one material to another within a single object. Digital materials afford the engineer the ability to highly customize the properties of a single object by modifying the object's material composition independently in different regions. For example, a particular region of the object might need an increased Young's modulus, wear resistance, or thermal properties. This paper will present a framework for digital materials fabrication using the powder-based Directed Energy Deposition (DED) process. To achieve such a system, issues and some initial investigations will be discussed. To implement such digital materials fabrication, the digital materials will first need to be digitally modeled. To ensure the compatibility of digital materials, the analysis of material selection routes will need to be conducted. To ensure powder ratio consistency, some powder analysis is needed.

3:40 PM
The Measurement of Orientation and Elasticity by Spatially Resolved Acoustic Spectroscopy (SRAS): *Richard Smith*[1]; Paul Dryburgh[1]; Wenqi Li[1]; Rikesh Patel[1]; Matt Clark[1]; [1]University of Nottingham

Spatially resolved acoustic spectroscopy (SRAS) is an acoustic microscopy technique, that can rapidly image the microstructure and measure the crystallographic orientation of grains of material. This talk will begin by demonstrating the ability to map the microstructure in L-PBF and wire-arc specimens, along with inferring the crystallographic texture and build information. Traditionally, elasticity measurements are challenging to undertake, requiring a single crystal of known orientation. This is incompatible with the ability to create spatially-varying microstructures and alloy in-situ inherent to AM. This talk will proceed to demonstrate that by combining the measurement of the acoustic velocity from multiple grains from SRAS, it is possible to determine both the elastic constants of the sample and the crystallographic orientation of each grain for the first time. The talk will conclude by discussing the outlook for elasticity measurements in AM, covering the challenges and outlining the future steps towards realising real-time measurements.

Materials: Novel Materials

Tuesday PM — Room: 400-402
July 26, 2022 — Location: Hilton Austin Hotel

1:40 PM
An Investigation of Laser Powder Bed Fusion Process-Structure Relationship of the High Temperature Thermoelectric Material Silicon Germanium: *Ryan Welch*[1]; Bengisu Sisik[1]; Saniya LeBlanc[1]; [1]The George Washington University

Silicon Germanium, a low band-gap semiconductor, is commonly used in thermoelectric devices to convert heat to electricity at high temperatures (above 1000°C). Traditional thermoelectric device manufacturing methods limit device shapes to planar geometries which hinder thermal transport on curved surfaces. To address this issue, we explored laser powder bed fusion of silicon germanium by scanning single melt-lines on powder compacts while varying the laser power, scan speed, substrate temperature, and number of scans. Experimental results of melt line geometry agreed with finite element simulations at higher scan speeds (>100 mm/s). Discontinuities in melt lines remained pervasive while processing with a combination of a high line-energy density, preheated substrate, and repetitive laser scanning. The propensity for melt-line separation is attributed to a large temperature gradient, oxidation, low viscosity, and the subsequent Marangoni effect. The results guide future experiments to enable laser additive manufacturing of semiconductors.

2:00 PM
Fabrication of Liquid-Filled Voronoi Foams For Impact Absorption Using Material Jetting Technology: Tosh Brown-Moore[1]; *Srivatsan Balaji*[1]; Tyler Williams[1]; Jeff Lipton[1]; [1]University of Washington

An important consideration in the design of any mechanical system is its ability to isolate and dissipate vibrational and impact energy. Closed-cell foams utilize cell crumpling to absorb energy, relying solely on viscoelastic effects for damping. Liquids, however, can generate large amounts of damping from fluid channel friction and turbulence. We produced closed-cell foams that are liquid filled, resulting in tunable materials that absorb energy better than either component on their own, using a Voronoi generation model and a J750 printer that could jet curable and incurable liquids. We found that by changing wall thickness, cell density, and liquid percentage, we achieve a stiffness range of 4.1 N/mm to 80 N/mm. Our work introduces this new class of damping metamaterial that can absorb tunable amounts of energy per unit volume. These impact-absorbing structures may benefit applications such as protective equipment, healthcare, and automotive industries.

2:20 PM
Additive Manufacturing of Graphite Structures: *Moein Mohammadi*[1]; Samuel Choi[1]; Prarik Koirala[1]; Gehan Jayatilaka[1]; Mehran Tehrani[1]; [1]UT Austin

This presentation discusses the design and use of a printable, sustainable, aqueous paste for room-temperature, direct ink writing (DIW) of complex structures. Graphite-containing pastes with controlled rheology were formulated, additively manufactured (AM), and then dried in air at three drying rates (slow, medium, fast). They were then characterized using spectroscopy and microscopy analysis. The compressive strength of AM graphite structures reached 5.8±0.6 MPa with almost no significant effect from drying rates. Carbonization of the AM parts increased the electrical conductivity by more than an order of magnitude to ~2.4×103 S m-1. In addition, it enabled the fabrication of nearly pure graphite structures for possible use in electrical discharge machining (EDM), electrochemical machining (ECM), high-temperature customized sealing, and energy conversion and storage.

2:40 PM
A Calibration-Free Physics-based Framework to Predict Printability Maps in Additive Manufacturing Process: *Sofia Sheikh*[1]; Pejman Honarmandi[1]; Brent Vela[1]; Peter Morcos[1]; David Shoukr[1]; Raymundo Arroyave[1]; Alaa Elwany[1]; Ibrahim Karaman[1]; [1]Texas A&M University

In additive manufacturing (AM), to fabricate porosity-free parts, the optimal processing conditions need to be determined. To do so, the design space for an arbitrary alloy must be analyzed to identify areas of defects for different power-velocity combinations, which can be visualized using a printability map, which can be costly. To reduce the cost and effort to construct printability maps, we have created a fully computational framework. The framework predicts material properties using CALPHAD models and a reduced-order model. Then, the analytical Eagar-Tsai thermal model uses the material properties to calculate the melt pool geometry during the AM processing. Finally, the printability maps are constructed using material properties, melt pool dimensions, and criteria for lack of fusion, keyholing, and balling defects. Using NiTi-based alloys, the framework is validated with experimental observations to compare and benchmark the defect criteria and find the optimal criterion set with the maximum accuracy.

3:00 PM
Photothermal Bleaching of Nickel Dithiolene for Bright Multi-colored 3D-printed Parts: *Kyle Wycoff*; Adekunle Olubummo[1]; Lihua Zhao[1]; Aja Hartman[1]; [1]HP Labs

HP's Multi Jet Fusion (MJF) 3D printing technology utilizes a carbon-based radiation absorber called the "fusing agent" in combination with a near infrared (NIR) light source to facilitate the fusion of polymer powder in a layer-by-layer fashion to generate 3D parts. Most available carbon-based and NIR radiation absorbers have an intrinsic dark color, which as a result will only produce black/gray and dark colored parts. To create white and bright colored parts with MJF, a visibly transparent and colorless radiation absorber is required. In this paper, we designed an activating fusing agent (AFA) that contains a red, strong NIR absorbing dye that can become colorless after harvesting irradiation energy during the MJF 3D printing process. Such a method will not only enable MJF 3D printing of white objects with good performance, but also provide a bright colored part when working with other color agents.

3:20 PM
Influence of Powder Properties and Process Parameters on the High Temperature PBF-LB/M Manufacturability of Filigree Tungsten Components: *Maximilian Binder*[1]; Olgu Yücel[1]; Thomas Bareth[2]; Georg Schlick[2]; Alexander von Mueller[3]; Jeong-Ha You[3]; Christian Seidel[2]; [1]Fraunhofer IGCV and Technical University of Munich; [2]Fraunhofer IGCV; [3]Max Planck Institute for Plasma Physics

The production of complex lattice structures from pure tungsten is of great interest for various fields of application like the energy industry or medical technology. For nuclear fusion filigree tungsten structures can be used as plasma-facing materials (so called limiters) and can therefore serve as a partial enabler for the future provision of low-risk and sustainable energy through nuclear fusion. Due to the very high melting point of tungsten, its great susceptibility to cracking and hardness, and its high density, the material is difficult to process to a satisfactory degree. This paper therefore presents how tungsten can be processed into fine lattice structures by means of high-temperature laser-based powder bed fusion and to what extent the metal powder and the exposure strategy used have a significant influence on pores and component defects. It is discussed how particle size distribution and sphericity of the powders have a major impact on the basic processability of the material. Furthermore, it is presented to what extent the laser exposure parameters such as the laser hatch distance can have a great influence on the resulting density of the material and with which methods the actual mate-rial density of lattice cubes can be determined in the first place. Finally, the elec-trical conductivity of the fabricated AM structures is measured and presented, as this is of great interest for many application areas.

Materials: Polymers - Powder Bed Fusion

Tuesday PM — Room: 415 AB
July 26, 2022 — Location: Hilton Austin Hotel

1:40 PM
Recycling of Polymer Powders in SLS: Consequences on Flowability and Electrostatic Properties: *Aurelien Neveu*[1]; Kerstin Michalke[2]; Filip Francqui[1]; [1]GranuTools; [2]University of Applied Science Jena

The reuse of polymer powders is common in powder bed-based additive manufacturing to reduce the cost associated with feedstock supply. However, in such processes, the powder bed is heated at a temperature close to the melting point of the material, which can lead to an alteration of its properties. In this study, the influence of the reuse of polymer in a SLS process has been investigated. Several mixes (50%/50%) of fresh (unused) and used PA12 have been produced and characterized. Especially, the change in powder flowability, a key characteristic for a good spreadability, has been highlighted by a rotating drum method (GranuDrum, GranuTools). Furthermore, the electrostatics (tribocharging) properties of the fresh and used powders are assessed (GranuCharge, GranuTools). We show that the influence of the processing conditions on the powder properties has to be taken into account to define a reliable reuse strategy guaranteeing the quality of the final parts.

2:00 PM
A Framework with Examples for Printing Thermosetting Polymers using Laser Powder Bed Fusion Additive Manufacturing: *Camden Chatham*[1]; Aaron Washington[1]; [1]Savannah River National Lab

Thermoset polymers share traits arising from their covalently crosslinked network structure that are distinct from thermoplastic polymers. These traits can manifest as relative increases in the performance properties of chemical resistance, stiffness, and strength particularly at elevated temperature. Although these performance properties are desired from additively manufactured parts, there are few engineering grade thermosetting polymers commercially available for any AM fabrication method. This presentation describes some of the challenges when processing and formulating thermosetting polymeric powder feedstocks for the laser powder bed fusion (L-PBF) mode of AM. In addition to this framework, the presentation includes a comparison of three different thermosetting polymers made via L-PBF and isothermal oven curing (i.e., cured per supplier direction). The differences in resultant performance properties and polymer network are characterized. Hypotheses of structure-process-structure-property relationships are also presented.

2:20 PM
Coalescence Behavior of Polyamide 12 as Function of Molecular Weight and Influence on Mechanical Performance: *Simon Cholewa*[1]; Andreas Jaksch[1]; Dietmar Drummer[1]; [1]Institute of Polymer Technology

The favored material for powder bed fusion of polymers (PBF-LB/P) is polyamide-12. Its molecular weight increases from post-condensation at elevated temperatures in the building chamber; consequently, having different properties when reused. An important aspect of PBF directly affected hereby is the coalescence behavior, as it significantly determines the surface quality, porosity, and thus the componenent's mechanical properties. However, detailed studies on coalescence are limited to virgin powders with low viscosity; therefore, coalescence behavior of polyamide-12 with different molecular weights is investigated using hot stage microscopy. Additionally, the zero shear viscosity is determined using the Carreu model, allowing comparison of experimental results to sintering models. Furthermore, the mechanical properties and surface qualities are analyzed, and components with adequate values are made with three-cycle reprocessed powder. Since surface defects do not exist uniformly across all components, the orange peel effect is not attributed solely to the increased viscosity of the reused powder.

2:40 PM
Optimization of Penetration Depth and Powder Layer Thickness for Proper Interlayer Adhesion in Polymer Laser Sintering: *Yuki Yamauchi*[1]; Toshiki Niino[2]; Takashi Kigure[1]; [1]Tokyo Metro Ind Tech Research Inst; [2]Institute of Industrial Science, the University of Tokyo

In laser sintering, melt pool depth relative to powder layer thickness is the main factor that determines interlayer adhesion strength. Melt pool depth is closely related to supplied energy amount and depth to which it reaches. Previous studies have shown that use of a near-infrared laser and an additive agent that absorbs its light allows for wide control of penetration depth. Present research focuses on the optimization of powder layer thickness and penetration depth to obtain proper interlayer adhesion. Supplied energy for each layer thickness was optimized to maximize built part density. To evaluate adhesion strength, ultimate tensile strength in the stacking direction of part built under the optimized supplied energy was measured. The dependence of adhesion strength on layer thickness normalized by penetration depth is discussed.

3:00 PM
Shelf Life of Polyamide 12 (PA2200) Laser Sintering Powder: *Ivo Kletetzka*[1]; Helge Klippstein[1]; Hans-Joachim Schmid[1]; [1]Paderborn University (DMRC)

It is a very well-known fact in the laser sintering community that polyamide powders age during processing. Therefore, the recycling rate of used powder is typically limited to around 50 % and it has to be mixed with new, virgin powder, before the next build job can be started. The aging of the polymer powder between its production and processing, in contrast, has hardly been investigated so far and has received little attention. In order to investigate the effects of storage time, thermal and rheological tests were carried out on two batches of PA2200 powder, which had been stored for 5 and 6.5 years respectively. Compared to freshly produced powders, aging effects were clearly visible. Furthermore, test specimens were built from the stored powder batches and the part properties were compared with those of reference powder.

3:20 PM
Process Optimisation of PA11 in Fiber-laser Powder-bed Fusion through Loading of an Optical Absorber: *Christian Budden*[1]; Aakil Lalwani[2]; Kenneth Meinert[1]; Anders Daugaard[3]; David Pedersen[1]; [1]DTU Civil and Mechanical Engineering; [2]LEGO Systems A/s ; [3]Danish Polymer Centre, Department of Chemical and Biochemical Engineering

Industrial laser processing is rapidly shifting towards fiber lasers with wavelengths between 780nm and 2200nm. This can be largely contributed to the excellent beam properties and, ease of operation. However, for Additive Manufacturing of polymers, CO2 lasers at wavelengths of 10,6um are predominantly used. Due to CO2 lasers providing unmatched energy absorption by the C-H bonds of Polyamide (PA). To remedy this, the current study investigates using a high-power fiber laser (1080nm) for consolidating PA11 mixed with a black optical absorber. Several compositions are produced by mixing commercially available white and black powder. Aiming at finding the optimum optical absorber loading and the corresponding process parameters, allowing the highest possible component fidelity, while achieving the lightest hue of grey possible to allow for later colouring. The experiment is conducted on an in house developed Open Architecture Laser Powder-Bed Fusion system. The parts are examined through, surface roughness, and mechanical characterisation.

3:40 PM
Powder Bed Fusion of Polypropylene Produced via Thermally Induced Phase Separation: *Jackson Bryant*[1]; Akan George[1]; Mark Dadmun[1]; Michael Bortner[1]; Christopher Williams[1]; [1]N/A

Currently, in laser-based polymer powder bed fusion (LP-PBF) there has been little investigation into the determination of an optimal molecular weight (MW) and MW distribution for the polymers used in this process. In this work, the research team investigated processing polypropylene (PP) of various molecular weights (MW) via LP-PBF to understand how melt viscosity influenced densification during processing. PP powders with number average MWs of 12, 250, and 340 kDa were prepared for LP-PBF via thermally induced phase separation (TIPS). It was hypothesized that lower melt viscosities would lead to faster densification during printing. Hot stage microscopy showed faster densification as MW decreased. Tensile tests and DMA showed decreasing MW led to a decrease in the necessary energy input to reach maximum density in the sample. This work provides a preliminary investigation into understanding how MW influences densification of PP printed via LP-PBF.

Modeling - Design and Analysis for AM

Tuesday PM — Room: 412
July 26, 2022 — Location: Hilton Austin Hotel

1:40 PM
Advances in the Modeling of Additive Manufacturing Process Simulation: *Nipun Wijesinghe*[1]; Ajit Achuthan[1]; [1]Clarkson University

Determining optimal process parameters that mitigate residual stress formation and part distortion can be achieved by using finite element analysis (FEA) based models to simulate additive manufacturing (AM) processes of metal parts and predict the residual stress and strain distributions accurately. However, existing FEA techniques are either accurate only at a very high computational cost, as in the case of process-based models, or if fast then inaccurate, as is the case for inherent strain-based models. To address these issues, we developed a new FEA framework where discretized geometries are introduced at regular intervals allowing for more flexible mesh coarsening. Additionally, we developed a hybrid approach where spatial and temporal resolution of the field solutions over different regions of the part are selectively controlled depending on the expected stress gradients. Together, these approaches resulted in substantial enhancement in computational efficiency without compromising solution accuracy.

2:00 PM
Hybrid Curve Fitting for Accurate Object Construction: *Charles Wade*[1]; Michael Borish[1]; [1]Oak Ridge National Laboratory

Existing slicing software for additive manufacturing typically requires a triangulated mesh as its input. Triangulated meshes are approximate representations of exact CAD models. Despite the loss in dimensional accuracy, triangulated meshes are used because they are computationally easier to cross-section and offset than the exact geometry in CAD format. When a triangulated object is prepared, the resulting machine instructions include only linear motion commands. Numerous modern motion controllers can move in arc and spline motions; however, the absence of slicing software that supports curvature prevents these commands from being leveraged. To address this limitation, this paper presents a method for the hybrid reconstruction of arcs and splines as a post processing step to traditional slicing. This method can print smooth curved surfaces resulting in better dimensional accuracy and more even extrusion. Additionally, the use of curved segments can greatly reduce the number of motion commands required to construct an object.

2:20 PM
Application of Field-driven CAD System for Design for Additive Manufacturing: *Sang-in Park*[1]; Jaeseung Ahn[1]; [1]Incheon National University

Design for additive manufacturing (DfAM) approach is a design methodology to utilize benefits from adopting additive manufacturing technologies. In this approach, all design information related to geometries, materials, and manufacturing processes need to be efficiently integrated. However, existing computer-aided design (CAD) systems cannot support DfAM activities efficiently because all information should be represented only by geometric information. The goal of this paper is to propose a field-driven CAD system to support DfAM activities. To achieve the goal, we implement shape modeling technics based on implicit representation, and we propose a method for creating and utilizing shape-material-process function fields for DfAM activities. To validate the effectiveness of the proposed CAD system, three DfAM activities including local shape modification, cellular structure generation and AM process optimization are performed, and results show the proposed CAD system efficiently supports DfAM activities.

2:40 PM
Boosting Artificial Intelligence in Design Processes by the Use of Additive Manufacturing: *Manuel Ott*[1]; Rainer Koch[1]; Niclas Meihöfener[1]; [1]Paderborn University

Additive manufacturing offers the option of converting digital prototypes into real structures as quickly as possible by the special property of tool-free manufacturing. However, this process can only be used at optimum speed if bottlenecks can be effectively avoided. One of these constraints is the design process. Although modern CAD systems allow a significant increase in many areas, this always requires a person with specific skills (e.g. engineer). In the field of AM in particular, more and more powerful software solutions have recently been published which accelerate the Design for Additive Manufacturing, including most CAD-tasks. In many areas, therefore, attempts are already made to automate relevant design steps as much as possible, more and more using neural networks and artificial intelligence. This paper presents how and why such techniques can be used to generate three-dimensional structures quickly and efficiently in cases of deep generative design tasks.

3:00 PM
The Effect of a Gas Stagnation Region on Nanoparticle Impact Velocity during Micro-Cold Spray: *Stephen Bierschenk*[1]; Michael Becker[1]; Desiderio Kovar[1]; [1]The University of Texas at Austin

Micro-cold spray is a direct-write process to deposit nanostructured films of metals and ceramics by accelerating solid nanoparticles in a gas stream from ~1 atm through a nozzle and impacting them at high velocity onto a substrate in vacuum. Particles only deposit within a material-specific impact velocity range because substrate erosion occurs when impact velocities are too high and elastic rebound occurs when impact velocities are too low. Determining this velocity range requires that the particle impact velocity be known. Calculation of the particle velocity is complicated by the stagnation region in the gas flow that forms above the substrate, directly beneath the nozzle, that slows the nanoparticles as they travel towards the surface. We present a study of the effect this region has on nanoparticle impact velocities for a range of carrier gasses, flow rates, nanoparticle diameters, and nanoparticle densities using computational fluid dynamics and particle velocity simulations.

3:20 PM
ORNL Large-scale Metal Slicer: A Custom Software that Meets the Challenges brought by Growing Complexity of Parts in Wire Arc Additive Manufacturing: *Canhai Lai*[1]; Andrzej Nycz[1]; Luke Meyer[1]; Alex Walters[1]; Chris Masuo[1]; Derek Vaughan[1]; William Carter[1]; Joshua Vaughan[1]; [1]ORNL

ORNL Slicer is a slicing engine and graphical user interface (GUI) developed for large scale additive manufacturing at Oak Ridge National Laboratory. A distinct version of it is being developed for the wire-arc robotic- based technology. The software imports .STL files and slices them into layers to generate robotic toolpaths in GCode. As the additive manufacturing technology advances and adapts to the geometrical complexity and customized design, many features have been added in the Slicer to address the complexities so that the 3D printing is optimized in characterizing geometric features with minimum mechanical and thermal stress. To help the final toolpaths to achieve the best printing quality, many post-slicing editing features have been added as necessary supplements to allow one to modify features locally. This presentation will bring a few examples of wire-arc parts to illustrate the features in either the engine or the front end that meet those challenges.

3:40 PM
Z-Chunking for Cooperative 3D Printing of Large and Tall Objects: *Daniel Weber*[1]; Wenchao Zhou[2]; Zhenghui Sha[1]; [1]Walker Department of Mechanical Engineering, The University of Texas at Austin; [2]Department of Mechanical Engineering, University of Arkansas

Cooperative 3D Printing (C3DP) is an emerging technology designed to address size and printing speed limitations of conventional gantry-based 3D printers. To print large-scale objects, C3DP divides a job into chunks to be printed by a swarm of robots. Previously, we developed a Chunker algorithm to partition jobs into printable parts in the XY direction, which theoretically enables printing of objects of unlimited size in XY dimensions. However, print size is limited in the Z direction due to physical constraints of the system. In this paper, we introduce the first working strategy and rules for Z-Chunking such as where and how to place chunk boundaries and alignment geometries. Additional challenges of interfacing with XY chunking and facilitating reassembly of the job are also considered. We conduct two case studies on objects of varying geometric complexity (e.g., simple solids vs. hollow structures) in which the object is chunked, printed, and assembled.

Physical Modeling - Unique Processes

Tuesday PM	Room: Salon A
July 26, 2022	Location: Hilton Austin Hotel

1:40 PM
A Pore-elimination Approach for Manufacturing Pore-free Feedstock Powders: *Ali Nabaa*[1]; Jiandong Yuan[1]; Minglei Qu[1]; Qilin Guo[1]; Luis I. Escano[1]; Lianyi Chen[1]; [1]UW-Madison

Pores formed during the atomization process of feedstock powders can be transferred to the melt region in the laser powder bed fusion (LPBF) additive manufacturing process. Those powder-inherited pores can bear complex interactions such as coalescence contributing to the deterioration of part property and quality uncertainty. Here, we report a pore-elimination approach for manufacturing pore-free feedstock powders. The approach involves applying uniformly incident heating pulses in intervals of a few microseconds on falling liquid droplets, inducing large thermal gradients, and prompting thermocapillary forces to drive pores out of the liquid droplet. The effectiveness of this approach was demonstrated in titanium alloy, aluminum alloy and stainless steel.

2:00 PM
Relationship between Flow-controlled Fiber Orientation and Spring-in Deformation in Extrusion Deposition Additive Manufacturing: *Akshay Jacob Thomas*[1]; Eduardo Barocio[1]; Vasudha Kapre[1]; Pasita Pibulchinda[1]; Felix Nguyen[2]; R. Byron Pipes[1]; [1]Purdue University; [2]Lockheed Martin Corporation

Extrusion deposition additive manufacturing (EDAM) with fiber-filled polymers has enabled the printing of structures in the scale of multiple meters owing to enhanced stiffness and lower coefficient of thermal expansion primarily in the printing direction. Developing manufacturing process simulations for EDAM requires extensive material characterization including mechanical and thermomechanical property characterization. Varying the process conditions alters the fiber orientation state of the composite thereby resulting in different mechanical and thermomechanical behavior. This increases the amount of characterization required to enable the digital twin framework. Therefore, we present a framework to infer the fiber orientation properties by conducting limited tensile tests at the composite coupon level. Using the inferred orientation state, we predict the unmeasured mechanical and thermomechanical properties and bypass the need for their experimental characterization. We present the application of this framework to predict the spring-in deformation of a geometry of interest printed using different process conditions.

2:20 PM
Understand Powder Deposition Behaviors of a Novel Electrostatic Powder Spreading Technique using Molecular Dynamics Simulation: *Ziheng Wu*[1]; Michael Troksa[1]; Gabe Guss[1]; Joshua DeOtte[1]; Brian Giera[1]; Eric Elton[1]; [1]Lawrence Livermore National Laboratory

Powder bed fusion is gaining more industrial presence across many sectors due to its increasing productivity. Most of the current process improvements focus on beam optimization while limited attention has been paid to modifying the spreading technique. Many industries show interest in multi-material printing as their applications can leverage the beneficial properties from several materials. However, almost all the existing spreading techniques are mechanical based which prevents the deposition of different feedstocks selectively. We are developing a contact free electrostatic powder spreader which can perform multi-material powder patterning and in-situ mixing. This study focuses on the development of a powder dynamics simulation which has been validated against deposition rate experiments using the electrostatic spreader. The model is used to study the different powder responses at various spreader geometries, electric fields, and materials. The results provide us important insights and guidelines for spreader prototyping.*Prepared by LLNL under Contract DE-AC52-07NA27344.

2:40 PM
Carbon Fiber Suspension Dynamics Analysis via Coupled CFD - DEM Simulations for Additive Manufacturing Polymer Melt Flows: *Jason Pierce*[1]; Douglas Smith[1]; [1]Baylor University

Bead microstructures formed though large-scale polymer extrusion/deposition additive manufacturing of short fiber polymer composites are defined by the distribution and orientation of fibers during processing. This research models carbon fiber motion within nozzles through coupled computational fluid dynamics (CFD) and discrete element modeling (DEM) simulations. Our approach models fibers as bonded discrete spheres, which allows for tracking of individual flexible and breakable fibers. DEM simulation parameters are calibrated to produce Jeffery's orbit for single fibers in simple shear flow. The DEM extrusion simulation includes fibers that interact with each other and the nozzle geometry while being driven by CFD-generated velocity fields. Our results are compared with Computational Tomography (CT) images of bead microstructures produced on our large area additive manufacturing printer and orientation tensor results computed from established theory. The results are expected to provide valuable insight for future work on part strength, layer path optimization, and nozzle design.

3:00 PM
Robotic Path Planning for the Automated Design of Compositionally Graded Alloys: *Marshall Allen*[1]; Jonathan Frutschy[1]; Raymundo Arroyave[1]; Richard Malak[1]; [1]Texas A&M University

Compositionally graded alloys are a special class of functionally graded materials that utilize spatial variations in alloy composition to satisfy competing property requirements. As the demands placed upon high-performance alloys increase, single material components will become less relevant, as material properties are often competing with one another. Instead, multi-material components, such as compositionally graded alloys, can more effectively meet competing requirements by placing satisfactory materials where they are needed. One significant barrier to the implementation of compositionally graded alloys is the formation of deleterious phases in gradient compositions, seen throughout experimental literature. In light of this challenge, the authors previously applied robotic path planning with CALculation of PHAse Diagram (CALPHAD) data to successfully design gradient alloy compositions that avoid deleterious phases. In this work, the authors present an open-source tool based on their methodology. With this computational tool, researchers can automatically design compositionally graded alloys free of deleterious phases.

3:20 PM
Modelling Fiber Orientation during Additive Manufacturing Compression Molding Processes: *Berin Seta*[1]; Md. Tusher Mollah[1]; Vipin Kumar[2]; Deepak Kumar Pokkalla[2]; Seokpum Kim[2]; Ahmed Arabi Hassen[2]; Jon Spangenberg[1]; [1]Technical University of Denmark; [2]Oak Ridge National Laboratory

The production of high-performance thermoplastic composites reinforced with short carbon fibers can be achieved by a novel "additive manufacturing-compression molding" technique. An advantage of such combination is two-fold: controlled fiber orientation in additive manufacturing and less void content by compression molding. In this study, a computational fluid dynamics model has been developed to predict the behavior of printed layers during fiber-reinforced thermoplastic extrusion and subsequent compression molding. The fiber orientation was modelled with the Advani-Tucker hybrid closure model. The interaction between the fibers is included using rotary diffusion coefficient which becomes significant in concentrated regimes. Finally, the second order orientation tensor is coupled with the momentum equation as an anisotropic part of the stress term. The effect of processing parameters on the behavior of printed layers was investigated to determine the favorable printing scenarios. The developed numerical model enables design of high-performance composites with tunable mechanical properties.

3:40 PM
Validation of Simulation Based Predictions of Recoater Interference in Laser Powder Bed Fusion: Michael Gouge[1]; *Chao Li*[1]; Jeff Irwin[1]; [1]Autodesk Inc.

Recoater interference is one of the most common and most expensive laser powder bed fusion (LPBF) failure modes. It is critical to investigate the mechanisms and the cause of recoater interference. Furthermore, accurate simulation-based predictions of recoater interference prior to manufacturing could help improve the printability, part quality, and economical feasibility. In this work, twenty-two overhang structures with various overhang angles, lengths, and build orientations were built to trigger recoater impacts. In situ imaging was used to identify the abnormality of powder surface. Nine of the parts penetrated the powder evidenced by recoater scraping, while three of parts caused recoater jams. The results show that the overhang angle and length were the most important indicators for recoater interference. Netfabb Local Simulation was used to create a digital twin of the experiment and was shown to accurately predict when parts were likely to cause recoater scraping and jams.

Special Session: Binder Jet AM III - Part Densification and Strengthening

Tuesday PM
July 26, 2022

Room: Salon B
Location: Hilton Austin Hotel

1:40 PM
Binder Jetting of Aluminum 6061 and Ti64: Highlights in Reactive Metal Sintering and Distortion Control using LiveSinter: *Patrick Dougherty*[1]; Tim Daugherty[1]; Debbie Wilhelmy[1]; Haden Calegan[1]; [1]ExOne

Binder jet additive manufacturing (AM) has a number of unique advantages compared to other AM including isotropic microstructure, wider range of materials, cheaper/faster throughputs. However, its reliance on successful debinding and traditional sintering technology prohibited sintering of high value materials like Titanium and Aluminum. The challenge with these materials arises from their stable oxide layer and natural affinity to soak up contaminants during processing. ExOne has developed proprietary processes for these materials capable of >98% density using careful design of powder feedstock, print/cure parameters, furnace type/setup, and sintering/debinding cycle. Despite reproduceable materials properties, reliable part geometries represents an ongoing challenge. In this work, furnace optimization will be coupled with design optimization using Desktop Metal's predictive software Live Sinter(TM), in order to combat the sensitivity of printing real part geometries in these high-value materials. Lastly, a state of the art in material properties and dimensional capability will be summarized.

2:00 PM
Increasing Part Strength and Density in Binder Jetting with Lattice Infill Patterning: *Amanda Wei*[1]; Kazi Raman[1]; Christopher Williams[1]; [1]Virginia Tech

Traditionally, binder jetting homogeneously deposits binder throughout the entire part cross-section to provide green part strength. However, recent research suggests that the deposited binder inhibits densification and final part density can be significantly improved by reducing the volume of binder in the green part. Thus, to balance the tradeoff between green part strength and final part properties, a binder patterning strategy comprised of a contour shell with various internal lattice or TPMS infill patterns is explored for 316L stainless steel. The results suggest that, while a solid binder infill provides the greatest green part strength, it results in a reduction of sintered part properties relative to the shell and infill patterns. In particular, an octet infill was found to have 14% of the green part strength of a traditional solid infill, but a 9% higher relative density and 36% higher flexural strength once in the sintered state.

2:20 PM
Comparison of Nanopowder and Granulated Powder in Compaction-assisted Binder Jetting: *MD Shakil Arman*[1]; Guanxiong Miao[1]; Zhijian Pei[1]; Chao Ma[1]; [1]Texas A&M University

In this study, nanopowder and granulated powder were compared in compaction-assisted binder jetting. From raw alumina nanopowder, granulated powder was prepared through spray freeze drying. Green samples were prepared from each powder with a lab-built machine which replicated the compaction-assisted binder jetting process. Then the samples were sintered in a furnace. Green density, sintered density, and sintered microstructure were analyzed using geometric method, Archimedes method, and scanning electron microscopy, respectively. The results shown that the granulated powder yielded samples with higher green density, higher sintered density, and fewer pores in sintered microstructure under the same compaction conditions. So, granulation can be an effective way to improve density in compaction-assisted binder jetting.

2:40 PM
A Data-driven Reverse Shape Compensation Method to Reduce Large Deformation in Binder Jet Parts: *Basil Paudel*[1]; Albert To[1]; [1]University of Pittsburgh

Binder jet parts undergo significant deformation during the sintering, a process that facilitates densification. This sintering distortion may result in parts with unacceptable geometric accuracy. The current work proposes an approach to compensate input geometry based on mechanistic simulations using a data-driven method. A multi-step neural network approach is proposed for the first time to learn the deformation pattern in binder jetted parts and offset for the sintering deformation. Initial geometries with several reverse scaling factors are simulated using a physics-based constitutive model to generate a training database. Once the training dataset is obtained, a reduced-order modeling technique is applied to extract the training dataset's features effectively. The model is trained and utilized to predict the compensated part. Finally, the proposed approach's efficacy is validated both numerically and experimentally by comparing the deformed sintered shape against the target.

3:00 PM
Reactive Binder Jet Additive Manufacturing for Microstructural Control of Ceramic Components: *Daniel Oropeza*[1]; Ricardo Roberts[2]; John Hart[3]; [1]NASA JPL; [2]Tecnologico de Monterrey; [3]MIT

Polymer binders are most commonly used in binder jet additive manufacturing (BJAM) to provide temporary strength to the printed component, enabling part removal and handling. However, it is challenging to manage distortion and shrinkage during sintering for polymer-bound parts. To address this issue, a process for the synthesis and rapid screening of custom binder inks involving exploration of binder ink rheology, thermal decomposition, and evaluation of green strength is presented. The ink development process is applied to synthesize custom polymer and reactive metal salt binder inks, showcasing the capability to control jetting behavior through rheological modifications. Using a custom-built BJAM testbed, reactive binders (which create solid interparticle bridges upon decomposition and provide additional benefit beyond temporary green strength) are implemented in BJAM. Direct deposition of a reactive binder sintering aid results in microstructural control and sustained part strength of ceramic BJAM parts.

3:20 PM
From Porous to Solid and Back: Densification of Binder Jet 3D Printed Materials: *Markus Chmielus*[1]; Aaron Acierno[1]; Pierangeli Rodriguez de Vecchis[1]; Eric Rhodes[1]; Teddi Sedlar[1]; Erica Erickson[1]; [1]University of Pittsburgh

Binder-jet 3D printing as a non-beam based additive manufacturing technique exhibits very high porosity in the green, as-printed state. Using post-print heat treatments, structures with densities from 40% to over 99% can be produced that have very different microstructures and properties and, therefore, very different applications. While fully dense structures are favorable for most mechanically focused applications, structures with predictable and tailorable porosity may be useful in filtration, heat transfer and functional materials applications. In this talk, we will discuss different approaches to achieving near full density of binder jetted metallic structures and compare their properties to bulk materials. Furthermore, we will discuss partially densified binder jetted materials and properties related to their intended function in air filtration and as functional magnetic materials.

3:40 PM
Support-free Sintering of 3D Printed Binder Jet Copper Parts and Stainless Steel Parts: *John Samuel Dilip Jangam*[1]; Thomas Anthony[1]; Ben Pon[1]; Jake Piderman[1]; Jim McKinnell[2]; Lihua Zhao[1]; [1]HP Labs; [2]HP Inc.

Binder jet additive manufacturing involves selectively applying a binder layer-by-layer to produce green parts, and subsequently followed by a high temperature sintering treatment. During sintering, the green parts inherently prone to undesired part deformation/sag in unsupported regions. Traditional methods use 3D printed supports or machined ceramic setters to avoid the part deformation/sag during sintering. In this work, we introduce shape-retaining-stimulus coating that will mitigate/eliminate the need of additional supports during sintering. Green parts made in copper and stainless steel in simply supported configuration with different thickness were evaluated for part deformation/sag. Our experimental results demonstrate with selective application of the shape-retainng-stimulus coating on the binder jet printed copper and stainless steel parts with a span upto 50 mm, and 25 mm, respectively, can be sintered without auxillary supports. Our shape-retaining-stimulus coating not only produces expectional results but also the ease of its removal makes it an attractive candidate.

4:00 PM
Binder Jetting of 316L Process Simulation Tools Evaluation: *Kevin Caballero*[1]; Victor Medrano Balderas[1]; Edel Arrieta[1]; Hector Sandoval[2]; Ryan Wicker[1]; Francisco Medina[1]; [1]W.M. Keck Center for 3D Innovation; [2]Lockheed Martin Corporation

Binder Jetting has become one of the most popular Additive Manufacturing technologies, nevertheless this technology has a steep learning curve due to the shrinking during the sintering process. It is difficult to predict which dimensions will be most affected because the shrinking is not uniform over the part. New Binder Jetting simulation tools are being developed and tested to evaluate the simulation software. A dimensional test artifact geometry was built and inspected to compare it with the predicted build simulations results. The purpose is to demonstrate the efficiency of the Binder Jetting Software in predicting material behavior during the Additive Manufacturing process. After the inspection, an evaluation of the effects of different sintering process parameters will start to be analyzed. We also consider the printing parameters of the machine, for example, the layer thickness, the binder saturation, among others.

Special Session: Wire-Fed DED III - Systems and Processes

Tuesday PM
July 26, 2022

Room: 410
Location: Hilton Austin Hotel

1:40 PM

Advanced Robotic Gantry Directed Energy Deposition (DED) System for Large Format Structures with Multi-Process Capabilities: *James McNeil*[1]; Michael Carney[1]; Nick Kaputska[1]; Dennis Harwig[1]; [1]EWI

Large Scale Additive Manufacturing of Metals (LSAMM) has gained traction in the ship-building industry for manufacturing propellers and other high mix, low volume parts. As a part of a National Shipbuilding Research Program (NSRP) project, an advanced robotic gantry DED AM system was developed and integrated that contained two different power sources for WAAM, PushCorp 5hp Spindle for subtractive processes, and a variety of sensors for monitoring and scanning during builds. Initial work on this project centered around depositing a high-skew propeller blade out of stainless steel. A digital twin was developed in PowerMill where offline robot toolpath planning was completed for the builds on this system. A Single Sided Integrated Build Platform (SS-IBP) Scaled Quality Build (SQB) was built on the system to inform deposited material properties. Future works are moving to "lights-out" capabilities for this system by integrating thermal management, automated torch maintenance, and hybrid manufacturing capabilities.

2:00 PM

Creating Large-scale Metal Parts with Multi-arm High Deposition Wire-arc System: *Andrzej Nycz*[1]; Chris Masuo[1]; Luke Meyer[1]; Alex Walters[1]; Derek Vaughan[1]; William Carter[1]; Riley Wallace[1]; peter Wang[1]; Mark Noakes[1]; Joshua Vaughan[1]; [1]Oak Ridge National Laboratory

Wire-arc additive technology is gaining popularity due its low cost and well understood welding-based methodology. A lot of effort is focused on increasing already relatively high deposition rate. ORNL developed a new type of multi-arm multi-head technology system called Medusa. By using many coordinated print heads, the deposition rate can be increased without investment in new types on deposition torches. In addition, system reliability and quality of the prints can be increased. In this work the lessons learned on several different large builds will be presented as well as future directions for the technology.

2:20 PM

High Deposition Rate Wire Arc Additive Manufacturing: William Carter[1]; Chris Masuo[1]; Andrzej Nycz[1]; Derek Vaughan[1]; Luke Meyer[1]; Alex Walters[1]; Mark Noakes[1]; *Riley Wallace*[1]; Joshua Vaughan[1]; Jonathan Paul[2]; Jason Flamm[2]; [1]Oak Ridge National Laboratory; [2]The Lincoln Electric Company

Typical deposition rates for wire-arc additive manufacturing process range from five to fifteen pounds of material per hour. While this is fine for smaller parts, an increase in deposition rate would significantly cut down on the build time increasing throughput and making parts in excess of several hundred pounds more viable. Additionally, it could potentially result in more desirable interpass temperatures due to an increased heat input and decreased layer time. Experiments have shown successful wire-arc additive manufacturing is possible at rates exceeding thirty pounds per hour, more than double typical rates. Two methods for high-deposition rate wire-arc additive manufacturing will be presented along with a system under development capable of using multiple robots simultaneously to achieve rates in excess of one hundred pounds per hour.

2:40 PM

Feasibility Study of Large-sized Aluminum Facades by Using Wire Arc Additive Manufacturing: *Yuka Yamagata*[1]; Takayuki Sagawa[1]; Masashi Nitawaki[1]; Takeyuki Abe[2]; [1]Shimizu Corporation; [2]Saitama University

Over the past few years, there has been growing interest in the fabrication of construction components by using wire arc additive manufacturing (WAAM). We focused on the finishing materials as a potential application for WAAM and began to consider fabricating aluminum building facades. However, there are several issues, such as fabrication size of 4-5m, aesthetics, and structural performance. Therefore, a trial fabrication and a non-destructive static loading test were conducted. In the study, an aluminum chair was used as a model because it contains the engineering basis of the building facades. In the trial fabrication, a method of leveling the build surface for each of the multiple layers was found to be effective for large-sized fabrication. Bead blasting was also effective in removing oxides from aluminum surfaces and adjusting the appearance. In the loading test, both displacement and strain measurements agreed well with the FEM analytical values. The results showed that WAAM has the possibility of fabricating large-sized aluminum building facades with the structural performance expected in the FEM analysis.

3:00 PM

Large-scale Hybrid Manufacturing of Freeform Metal Components: *Bradley Jared*[1]; Aaron Cornelius[1]; Eduardo Miramontes[1]; Tiffany Quigley[1]; Joshua Penney[1]; Joshua Kincaid[1]; Ross Zameroski[1]; Gregory Corson[1]; Leah Jacobs[1]; Timothy No[1]; Tony Schmitz[1]; William Hamel[1]; [1]University of Tennessee, Knoxville

The timely fabrication of large, complex metallic structures is a persistent challenge for America's industrial base. On-going work is addressing these challenges through the development of a large-scale hybrid metal manufacturing system which combines multi-material metal inert gas deposition, structured light-scanning metrology, part handling and five-axis machining. Existing challenges in the hybrid manufacturing of complex, multi-material part topographies will be discussed in the context of on-going research efforts. Deposition challenges include the monitoring and control of melt pools and layer deposits to improve the accuracy of printed preform geometries and to eliminate the presence of deposition defects. Metrology research is focused on generating accurate, but efficient, path plans for automated fringe projection scanning of part geometries. Finally, challenges with part residual stress and distortion will be discussed since they couple across deposition and machining and represent a fundamental barrier to final part accuracy and performance.

3:20 PM

Process Development and Thermomechanical Modeling of Laser Hot Wire Additive Manufacturing Process: *Elizabeth Chang-Davidson*[1]; Brandon Abranovic[1]; Jack Beuth[1]; [1]Carnegie Mellon University

Laser hot wire additive manufacturing (LHWAM) is a relatively unexplored process within the space of DED metal additive manufacturing that provides unique benefits relative to other DED processes, in terms of better deposited bead quality than many non-laser-based processes and higher deposition rates than other laser-based processes. In this work, process development was completed on a LHWAM machine manufactured by Lincoln Electric, starting with process mapping of common flaw types through the multidimensional process space, as well as a flaw type unique to this process. Subsequently, optimization of deposition strategies was accomplished through thermal modeling for thin wall parts as well as axisymmetric parts. Thermomechanical modeling was carried out to support the printing of large-scale test parts, which are especially susceptible to undesirable deformation. At the culmination of the project, several complex large-scale geometries were successfully printed.

3:40 PM

Mitigating Thermal Distortion in Wire Arc Additive Manufacturing thru Integrating Topology Optimization and Modified Inherent Strain Modeling: *Wen Dong*[1]; Carter Gassler[1]; Xavier Jimenez[1]; Albert To[1]; [1]University of Pittsburgh

The heat accumulation during the wire arc additive manufacturing (WAAM) process may result in significant residual stress and distortion in the as-built part. Although the subsequent heat treatment can relieve the residual stress, most of the distortion remains, harming product quality and making post- processing like machining and cutting more difficult. In the present work, a fixture attached to the substrate bottom is designed to reduce distortion in the as-built part. The design is achieved by using topology optimization to reduce weight and distortion by incorporating the modified inherent strain (MIS) method into the optimization. The MIS method is employed to implement the load in each iteration of the optimization in order to simulate the deposition process. The effect of heat accumulation is included by assigning temperature-dependent inherent strains to each layer. The topology optimized design is further modified to satisfy various manufacturability criteria.

4:00 PM
Process Response of Martensitic 250 Stainless Steel Alloy + Wire Arc Additive Manufacturing with Cold Metal Transfer: *Ryan Stokes*[1]; Haley Doude[1]; Linkan Bian[1]; Matthew Priddy[1]; [1]Center for Advanced Vehicular Systems

The process response of m250 stainless steel alloy is reported on and the relationship of torch travel speed and heat input on the final bead geometry, depth of penetration, and density of the single weld tracks is established. Bead geometry and depth of penetration are critical to achieving proper layer thickness and hatch overlap to achieve maximum density in multi-layer build ups. This work also identifies ideal operating parameters that deliver the lowest heat input, while maintaining optimal bead geometry. The energy input is obtained via weld monitoring and correlated via an IR camera aimed at the depositions and thermocouples placed on the substrate. Once ideal processing parameters are obtained, multi-layer thin walls are constructed to evaluate density and oxide inclusions within the tracks. Using the established relationship between energy input and heat input, target specific interpass temperatures and times that create controlled martensitic transformation of the buildups.

Student Panel Discussion

Tuesday PM	Room: Salon F-G
July 26, 2022	Location: Hilton Austin Hotel

12:10 PM Introductory Comments

12:15 PM Panel Discussion

1:00 PM Concluding Comments

Applications - Aerospace

Wednesday AM	Room: 416 AB
July 27, 2022	Location: Hilton Austin Hotel

8:00 AM
On-Orbit Fabrication of Spacecraft Structures by Direct Solar Photopolymerization: *William Yerazunis*[1]; Avishai Weiss[1]; [1]Mitsubishi Electric Research Laboratories

One of the paradoxes of spacecraft design is that spacecraft are destined to operate in orbit where maneuvering thruster firings produce stresses below 0.01 G, but the spacecraft must be strong enough (and heavy enough) to survive the roughly 50 G's of vibration in a rocket launch. In this paper, we develop and test an alternative: the post-launch freeform 3D printing of a major communications satellite structural element in UV cured resin, using solar UV to trigger polymerization. This involves consideration of the chemistry of a UV liquid resin that not only has a very low (below our chamber limit of 0.2 kPa) vapor pressure post-degassing, but also is not dependent on oxygen presence to activate the thermal inhibitors that prevent premature polymerization. In tests, we successfully freeform 3D print a small (60 mm) parabolic dish at chamber limit pressure using simulated solar UV flooding the chamber.

8:20 AM
Lightweight Additively Manufactured Bell Crank: Carlos Rodriguez[1]; Sol Barraza[1]; Julio Diaz[1]; Edel Arrieta[1]; Francisco Medina[1]; Adam Hicks[2]; Ryan Wicker[1]; *Alejandro Hernandez*[1]; [1]W.M. Keck Center; [2]Air Force Research Lab

As the longevity of the service life of Air Force Legacy aircrafts increases, companies that had once manufactured their components and spares are not able to do so anymore. To mitigate this issue, Additive Manufacturing (AM) presents as a feasible alternative to manufacture and improve these components in terms of cost, weight and performance. The project prioritizes the innovating of a bell crank, a vital aircraft component by printing the components through Fused Deposition Modeling (FDM) and using ABS as the printing material. The components were then modified using Fusion 360's Generative design to reduce weight and improve strength and tested using an adapted Instron 5900 Series. Testing showcases that a horizontal build orientation and the Bk_fpx design were most optimal respective to its strength-weight ratio (29.7) and cost ($160). Continued work is recommended to be done through Selective Laser Melting (SLM) using Aluminum.

8:40 AM
Experimental Study of Wing Structure Geometry to Mitigate Process-Induced Deformation: *Justin Valenti*[1]; Joseph Bartolai[1]; Michael Yukish[1]; [1]Pennsylvania State University

Small unmanned aerial vehicles that are fabricated with material extrusion additive manufacturing are often single-perimeter structures with sparse internal structure. The large distance between internal supports creates an ``unsupported wall distance'', which leaves the wall prone to deformation during fabrication. This work explores and quantifies the relationship between the deformation of the wing perimeters and two geometric parameters: (1) unsupported wall distance and (2) local surface curvature. An experimental study was designed to investigate this relationship. Wing sections of varying surface curvature and unsupported wall distance were built. The surfaces of the wing sections were then digitized into point clouds with a coordinate measuring machine, and the point cloud data were compared to the toolpaths used to print each wing section. The deformation data were then analyzed to quantify the relationship between deformation and the experimental parameters.

9:00 AM
Autonomous Manufacturing of Aerial Vehicles via Robotic Additive Manufacturing and Embedding: Tadeusz Kosmal[1]; Kieran Beaumont[1]; Eric Link[1]; Dalton Phillips[1]; Conner Pulling[1]; Heather Wotton[1]; Camille Kudrna[1]; *Joseph Kubalak*[1]; Christopher Williams[1]; [1]Virginia Tech

Production of unmanned aerial systems (UAS) is broadly restricted to centralized manufacturing of a limited set of general-purpose designs. For deployed applications or missions with rapidly changing parameters, a more flexible manufacturing platform is required. Robotic Aerial Vehicle Fabricator (RAV-Fab) is a robotic workcell that leverages additive manufacturing (AM) and pick and place (PnP) operations to fabricate mission-specific UAS. In one automated process, i) UAS chassis are printed and ii) electronics packages are embedded and connected such that the UAS can fly out of the workcell with no human intervention. The use of AM and a modular set of electronics packages enables a wide variety of drone designs to be printed while minimizing impact on the supporting supply chain. This allows users to customize UAS designs for performance metrics (e.g., flight time, maneuverability, equipment, payload) in response to changing mission conditions in a deployed (e.g., rescue or extraterrestrial) environment.

9:20 AM
Additive Manufacturing of Compliant Mechanisms for Deployable Space Structures: *Christine Gebara*[1]; Sarah Ludeman[1]; Savannah Sunez[1]; Paul Lytal[1]; [1]NASA Jet Propulsion Laboratory

Over the past decade, additive manufacturing (AM) has matured and been infused into numerous spaceflight missions. Simultaneously, deployable structures have become more common on spacecraft. These structures seek to maximize packing efficiency using complex systems that challenge traditional manufacturing methods. An example is the spring mechanisms developed for the NISAR satellite antenna. The mechanism required high torque and was severely volume constrained. This resulted in the use of high aspect ratio rectangular cross-section torsion springs. These springs represented the state of the art for manufacturing. Significant testing, development, and rework was needed for the traditional springs to meet requirements.These issues can now be avoided using AM. By printing torsion springs, novel geometries are possible, thus increasing performance while decreasing complexity. The springs can be printed with the surrounding structure, minimizing part count. This work will demonstrate that AM hardware can provide novel capability for resource limited missions.

9:40 AM Break

10:10 AM

Additive Manufacturing Development of an Aerospike Breadboard Engine: Lukas Stepien[1]; Samira Gruber[1]; Alex Selbmann[1]; Martin Probst[2]; Tim Dorau[2]; Sebastian Soller[3]; Simon Hyde[4]; Elena Lopez[1]; Christian Bach[2]; *Frank Brueckner*[1]; Christoph Leyens[1]; [1]Fraunhofer IWS Dresden; [2]Technische Universität Dresden; [3]Ariane Group GmbH; [4]ESTEC (TEC-MPC)

Here we present the additive manufacturing process route and post processing of an 6 kN aerospike breadboard engine for kerosene and hydrogen peroxide propellants. The initial design was adapted for the additive manufacturing process and matured over several development stages. The recent design is a two part build-up, with a separated spike from the body to allow optimal powder removal. The aerospike is made of the nickel-base super alloy INCONEL® 718, manufactured by laser powder bed fusion. Addi-tionally a thermal barrier coating made of Yttrium stabilized Zirconium oxide was applied by thermal spraying. An extensive material characterization campaign was conducted, including tensile tests at 700 °C and 900 °C, accompanied with a quality management along the process chain by nondestructive test-ing. Post processing includes heat treatment, milling of interfaces and welding of the spike to the shroud.

10:30 AM

3D Metal Printing of Pure Copper Antenna using Ultrafast Pulse Laser: *Chiyen Kim*[1]; In Hwan Lee[2]; Hochan Kim[3]; [1]Korea Polytechnics; [2]Chungbuk National University; [3]Andong National University

The additive manufacturing technology of wireless power transfer (WPT) antenna has been explored to apply the mobility feature of 3D printed devices. In the case of an antenna, the material's electrical properties have a significant impact on the antenna's performance, particularly in this study's wireless energy transmission efficiency. This work challenged a new technique to overcome the poor laser absorption ratio and high thermal conductivity of copper material by using an impulse laser instead of a normal CW laser to construct an additively manufactured pure copper antenna with high electrical attributes. Using a 20-Watt femtosecond impulse laser, this paper demonstrated a 1mm depth pure copper spiral antenna.

10:50 AM

Hybrid Laser Powder Bed Fusion Additive Manufacturing: Application to Microwave Radio Frequency Quarter Wave Cavity Resonators: *Alexander Riensche*; Paul Carriere[1]; Ziyad Sm[2]; And Menendez[2]; Pedro Frigola[1]; Sergey Kutsaev[1]; Aurora Araujo[1]; Nanda Matavalam[1]; Prahalada Rao[2]; [1]Radiabeam Technologies; [2]University of Nebraska-Lincoln

Radio frequency (RF) components are intricate, high-value components. Conventional manufacturing of RF components imposes two bottlenecks: cumbersome assembly of multiple parts that are produced with different processes, and lack of flexibility to rapidly customize design for targeting specific RF bandwidths. Laser powder bed fusion (LPBF) is an attractive solution to make RF components given its ability to accommodate design complexity and dimensional accuracy. However, a main impediment in LPBF is its poor surface finish. In this work, we apply a hybrid-LPBF approach for making aluminum alloy RF resonators. The key idea is to use in-situ layer-wise machining to enable high quality surface finish on hard-to-access surfaces which are difficult, if not impossible, to machine or polish post-LPBF. Hybrid-LPBF is shown to improve resonator RF performance (Q-factor) by enhancing both dimensional accuracy and surface finish.

Applications: Lattices and Cellular - Lattice Structure Design

Wednesday AM	Room: 417 AB
July 27, 2022	Location: Hilton Austin Hotel

8:00 AM

Application of Systems Engineering to Lattice Structure Design: A Framework for Requirements Flow Down: *Joseph Fisher*[1]; Timothy Simpson[1]; Simon Miller[1]; [1]The Pennsylvania State University

In the field of additive manufacturing, highly ordered cellular structures with repeating patterns in space, known as lattice structures or simply "lattices", have been shown to significantly improve the performance per unit mass of engineered components compared to traditionally machined designs. The characteristics of these lattices are dependent on many design decisions, leading to challenges in determining how to best utilize them. This issue is further complicated when the density, size, and topology of the lattice can spatially vary in the design domain. Many methods have been proposed to optimally distribute material within a lattice structure; however, these methods exist in a bubble, independent of broader engineering design criteria and processes. In this paper, we introduce a framework based on systems engineering to guide the design of lattice structures using the component requirements as inputs and outputting a verified and validated design based on those requirements. The framework translates component requirements down to the lattice structure and provides a means to verify and validate that the final design meets those requirements. We provide a walk-through of the framework by designing a lattice structure for an oil and gas component. We also discuss ongoing and future research to extend, verify, and validate the framework itself.

8:20 AM

Carbon Design Engine: Powerful Lattice Design Software for Precisely Tuned, High-Performance Products: *Ruiqi Chen*[1]; [1]Carbon, Inc.

Multi-zonal lattices can vary in density and topology throughout a single part to deliver uniquely tuned characteristics in different zones, allowing designers to specify characteristics required for their products at every millimeter. In this presentation, we dive into the technology behind how multi-zonal lattices are generated using Design Engine, Carbon's lattice design and analysis tool. First, we present a technique for generating infinite combinations of hybrid strut lattice cell types from a small set of primary cell types. The family of cell types can be expressed using a common low-order parameterization. Next, we demonstrate the construction of multi-zonal lattices from arbitrary combinations of user-specified cell types using a self-consistent interpolation method. This method guarantees the creation of struts that seamlessly join together while spatially transitioning between different cell types. Finally, we present experiments and simulations to showcase the spatially varying densities, large deformation mechanics, and potential applications of multi-zonal lattices.

8:40 AM

A Data-driven Approach for Multi-Topology Lattice Transitions: *Martha Baldwin*[1]; Nicholas Meisel[2]; Christopher McComb[1]; [1]Carnegie Mellon University; [2]The Pennsylvania State University

Additive manufacturing is advantageous for producing lightweight components while maintaining function and form. This ability has been bolstered by the introduction of unit lattice cells and the gradation of those cells. In cases where the loading varies throughout a part, it may be necessary to use multiple lattice cell types, also known as multi-topology lattice structures. In such structures, abrupt transitions between lattice types may cause stress concentrations, making the boundary a primary failure point; thus, transition regions should be created between each lattice cell type. However, smooth transition regions are currently difficult to intuit and design, especially between lattices of drastically different geometries. This work demonstrates and assesses a method for using variational autoencoders to automate the creation of transitional lattice cells. Such a data-driven approach has the potential to achieve complex unit cell transitions over varying transition lengths, promoting innovative solutions.

9:00 AM

Machine Learning-assisted Additive Manufactured Sandwich Structure Design: Jier Wang[1]; *Ajit Panesar*[1]; [1] Imperial College London

Lattice structure, an important structural design feature in Additive Manufacturing (AM), is commonly used for lightweighting and multiple functions such as thermal dissipation, vibration damping and energy absorption. In this work, a Machine Learning (ML)-based inverse generator, capable of identifying optimal 3D lattice unit cells with desirable mechanical properties, is trained using the dataset computed using homogenisation method. The proposed inverse generator can be applied to multi-scale structural design where grading of lattice is needed. As an example, designs from the proposed methods are generated for lattice core sandwich structures. Within the core design domain, the spatially-varied lattice parameters are identified through the inverse generator. The benchmark example considered proves that the proposed method is capable of generating structures that are high performing (e.g. stiffness, energy absorption and impact resistance) at minimal computational cost.

9:20 AM

Load Alignment Ratio – A Novel Lattice Evaluation and Optimization Metric: *Joseph Bartolai*[1]; Simon Miller[1]; Joseph Fisher[1]; Michael Yukish[1]; [1]Pennsylvania State University

Comparisons between lattice structures often requires experimental data, finite element analyses, or solution of closed-form bending equations. Designers are often required to make decisions only informed by limited and disparate experimental data or analyses available in published literature. Equivalent evaluation of strut-based and equation-based lattice structures is particularly difficult. This work introduces the Load Alignment Ratio (LAR), a lattice structure metric that compares the local alignment of material within a lattice structure to an externally applied load. This scalar metric allows fast "apples-to-apples" comparison of lattice structures appropriate for a particular application. LAR scores of select strut-based and equation-based lattices are compared to their associated mechanical properties. Application of the LAR demonstrates the optimization of a lattice structure for a single loading condition. Performance improvements in lattices with LAR-informed adjustments are evaluated and compared using mechanical testing.

9:40 AM Break

10:10 AM

Utilizing Lattice Infill Structures to Optimize Weight with Structural Integrity Investigation for Commonly Used 3D Printing Technologies: *Mohammad Alshaikh Ali*[1]; Ismail Fidan[1]; Indranil Bhattacharya[1]; Khalid Tantawi[2]; Michael Allen[1]; [1]Tennessee Tech University; [2]University of Tennessee Chattanooga

Additive Manufacturing (AM) is utilized in various applications and fields. This research study investigates the use of lattice infill structures to reduce weight in two commonly used AM methods; Stereolithography (SLA) and Fused Filament Fabrication (FFF). Structural integrity of lattice infilled parts is investigated. Before utilizing lattice infill structures, different process parameters are also investigated to gain a knowledge base for these patterns' effect on the weight and power consumption (PC). Cubes are used as test specimens to perform the knowledge base study for the process parameters. Optimum printing parameters are used to compare to lattice infill structures and validate results of the initial study. The test specimens for this study are chosen to be of different background and complexity. Experimental data indicates a reduction in weight with no increase in PC for SLA and an increase in PC for FFF. Lattice infilled structures respond well to structural integrity testing.

10:30 AM

Enhancing Aircraft Acoustic Liner Performance with Lattices and Cellular Structures: *Andrew Swanson*[1]; Michael Geuy[1]; Timothy Simpson[1]; Jay Martin[2]; [1]Pennsylvania State University; [2]Pennsylvania State University Applied Research Laboratory

Lattices and cellular structures give designers many unique capabilities and have been leveraged for numerous engineering applications. One emerging use of these structures is in aircraft acoustics. To meet acoustic emission requirements, modern aircraft have increasingly adopted acoustic liners to reduce the sound emitted by their turbofan engines. Most current acoustic liners take the form of micro-perforated panel (MPP) absorbers. Although MPPs do a good job absorbing high-frequency sound, they do not perform as well at low frequencies. As future aircraft engines become more compact and utilize high-bypass ratios, acoustic liners that can attenuate low-frequency noise are needed. Developing a traditional MPP with adequate broadband absorption that also meets size and weight requirements would be challenging, expensive, and time-consuming. Therefore, a new integrated development approach for aircraft acoustic liners is needed to address this barrier. A rapid acoustic liner development workflow leveraging additive manufacturing of complex geometries will be presented.

10:50 AM

Using Mean Curvature of Implicitly Defined Minimal Surface Approximations to Generate New Unit Cells for Lattice Design: *Joseph Fisher*[1]; Simon Miller[1]; Joseph Bartolai[1]; Michael Yukish[1]; [1]The Pennsylvania State University

Triply Periodic Minimal Surfaces (TPMS) are smoothly varying surfaces that exhibit zero mean curvature at all points on the surface. TPMS can be modeled with high accuracy using discrete differential geometry techniques. However, generating a useful number of unit cells with this approach would be computationally expensive, and variable lattices would be impossible. Level sets of Fourier series approximations are often used instead. While these approximations have continuous geometry, they no longer retain zero mean curvature like the exact TPMS. In this paper, we calculate the mean curvature of the commonly used approximations of the gyroid and D-surface TPMS. Using isosurfaces of the mean curvature from these approximates, we define, similar but unique surface topologies. The development of these surfaces expands the list of lattices available to designers, broadening the lattice design space. Application to other approximations and further study of the application of these new surfaces is discussed.

11:10 AM

Exploration and Evaluation of Offset Equation-Based Lattices: *Joseph Bartolai*[1]; Thomas Jones[1]; Simon Miller[1]; Joseph Fisher[1]; Michael Yukish[1]; [1]Pennsylvania State University

Advances in Additive Manufacturing and Computer Aided Design have made equation-based lattice structures readily accessible for design inclusion. These equation-based lattices are typically closed-form approximations of Triply Periodic Minimal Surfaces. Lattice geometry is defined by a single level set (the isosurface of constant value within the domain) with equal offsets to change lattice volume fraction. This work introduces the concept of using independent level set values for a single equation to define multiple distinct lattice structures, each with unique inherent mechanical properties. Additionally, by changing the level set value through the equation's domain, one lattice can smoothly transform into another. This allows for smooth changes in mechanical properties within a lattice structure while maintaining a constant volume fraction. Mechanical property between the distinct lattices, as well as within the variable structures, are demonstrated using quasi-static compression.

11:30 AM

An Experimental Study of Cellular Mechanical Interface in a Bi-material Structure Fabricated by Material Extrusion Additive Manufacturing: *Sumit Paul*[1]; Li Yang[1]; [1]University of Louisville

This work is a continuation of the preliminary project with the investigation of the characteristics of the cellular structure-based mechanical interlocking interface designs for bi-material structures fabricated by material extrusion additive manufacturing (AM). Three different cellular designs, including auxetic, body centered cubic (BCC), and octahedral, were investigated for the topology design effects on the interface performance. In addition, the effects of build orientation and interface polarity were also studied. The results clearly suggested that the cellular-based mechanical interlocking interface exhibit significantly enhanced ductility and energy absorption that can be desirable to many applications, and that the interface characteristics are influenced by both the topology design of the cellular structures and the intrinsic properties of the processed materials.

11:50 AM
Design Strategies for Stochastic Strut-based Lattices: *Jan-Hendrik Groth*[1]; Mirco Magnini[1]; Christopher Tuck[1]; Adam Clare[1]; [1]University of Nottingham

Lattices produced by AM continue to attract attention. The design tools which are available for these are somewhat limited and require expertise in their operation. A typical design strategy is to make use of the same unit cell which is patterned ad infinitum. This is at odds with similar structures observed in nature which have a degree of stochasticity. Here a novel way to design lattices more 'naturally' is presented. First, the same levels of stochasticity are applied to all parameters (Isotropic Randomness). Second, different levels of stochasticity are applied to each parameter (Anisotropic Randomness). Third, the stochastic level for each parameter is graded from regular to a given level of stochasticity (Graded Randomness). Fourth, a layer within the regular structure is randomised. Finally, stochasticity is applied to the surface to create a stochastic roughness pattern. This talk will explore our progress in developing this technique towards engineering application.

Design for AM Workshop

Wednesday AM — Room: 410
July 27, 2022 — Location: Hilton Austin Hotel

8:00 AM About the Session:
Additive manufacturing (AM) benefits from a range of design tools (e.g., topology optimization, lattice structure generation) during the later stages of design intended to improve part quality. However, how can we as engineers change our thinking generate with more ideal design candidates for AM earlier in the design process? In this special, hands-on workshop session, attendees will explore different tools for considering design for additive manufacturing (DfAM) in early-stage design. Special emphasis will be placed on the role of DfAM in concept generation. Through this workshop, participants will also be challenged to confront their own subconscious consideration of manufacturability throughout the design process. Participants from both academia and industry are encouraged to attend. There is no additional cost for to attend this workshop.

Materials: Composites - Polymer-Based Composites

Wednesday AM — Room: 615 AB
July 27, 2022 — Location: Hilton Austin Hotel

8:00 AM
Additive Manufacturing of Fiber-Reinforced Polymer Composites: A Technical Review and Status of Design Methodologies: *Abdulmajeed Altassan*[1]; Janet Wong[1]; David Rosen[1]; [1]Georgia Institute of Technology

Additive manufacturing (AM) of fiber-reinforced composites is gaining traction as an important manufacturing technology to produce complex, highly customized structures. AM processes enable the fabrication of complex 3D structures with control over fiber position and orientation, offering tremendous design freedom. Although the use of AM to fabricate fiber-reinforced composites is promising, various design difficulties remain. These includes consideration of structural performance subject to manufacturing constraints on fiber placement, orientation, bend radius, and other relevant limitations. Design engineers will have to consider these limitations to be able to reap the full benefits of AM to fabricate fiber-reinforced polymer composites. This talk aims to provide a survey on the advances in multi-scale topology optimization, fiber orientation parameterization, micromechanics of fiber-matrix interactions and process planning specific for the AM of complex fiber reinforced composites. The status of recent research is summarized, and future directions outlined.

8:20 AM
Reactive Extrusion Additive Manufacturing of a Highly Loaded Carbon Fiber Reinforced Epoxy: *Pratik Koirala*[1]; Jacob Aber[1]; Cole Mensch[1]; Robert Pavlovic[1]; Michael Fogg[1]; Carolyn Seepersad[1]; Mehran Tehrani[1]; [1]University of Texas at Austin

This talk focuses on in-nozzle mixing of a carbon fiber-filled resin with its hardener to fabricate composite parts using reactive extrusion additive manufacturing (REAM). In REAM, a thermoset resin is mixed with its hardener inside the nozzle and deposited and cured in situ via chemical cross-linking without external heat. Carbon fibers added to resins enhance their mechanical and thermal properties but are known to make them significantly more viscous. Therefore, incorporating active mixing is essential to uniformly mix and extrude the resin filled with relatively high volume fractions of carbon fibers. In this study, resins with 20-30 wt.% milled carbon fibers are processed in a REAM system coupled with an active mixing nozzle. Mechanical and thermal properties of printed parts are examined and correlated with their degree of curing and fiber orientation distribution in printed parts.

8:40 AM
Towards Non-Planar Woven Carbon Fiber Composite Surfaces: *Nidhi Munaganuru*[1]; Ajinkya Patil[1]; David Trauernicht[1]; Denis Cormier[1]; [1]Rochester Institute of Technology

Continuously reinforced carbon fiber composites fabricated using traditional methods typically employ woven sheets with a degree of mechanical interlocking between the fibers. Although a small number of continuous fiber AM machines have been introduced in the past decade, slicers for these machines do not produce toolpaths that exhibit interlocking of fibers as seen in traditional composites. However, some research groups have recently demonstrated novel continuous fiber fused filament fabrication (FFF) pathing strategies that produce planar woven structures. In this paper, previous work on planar woven fiber toolpath generation is extended to consider non-planar surfaces. Preliminary proof of concept prints using a 5-Axis Maker fused filament fabrication machine are presented along with plans for future work.

9:00 AM
Investigating the Directed Energy Deposition Additive Manufacturing of Thermoplastic Composites: *Nathaniel Heathman*[1]; Pratik Koirala[1]; Timothy Yap[1]; Mehran Tehrani[1]; [1]The University of Texas at Austin

Automated fiber placement (AFP) is a leading manufacturing method for aerospace composites. AFP is an additive manufacturing (AM) technique that involves laying down unidirectional carbon fiber reinforced polymer tapes with a gantry or robotic system. AFP also uses a specialized end effector that includes a heating source and compaction roller. While AFP manufacturing of thermosetting composites has been commonplace in the industry for years, recent developments have led to the emergence of AFP of thermoplastic composites utilizing in-situ consolidation via high-power laser heating; directed energy deposition AM. In this study, several test coupons were printed using a laser-assisted AFP manufacturing cell. Effects of processing parameters on part quality and inter-laminar bonding strength are correlated with the microstructure and crystallinity in different samples. Sensory data collected during AFP along with numerical simulations are also utilized to reveal bonding and defect formation mechanisms in AFP parts.

9:20 AM
Robotic Additive Manufacturing of Thermoplastic Composite Assistive Technology: *Nadia Hannon*[1]; Walter Stark[1]; Nathan Heathman[1]; Nicholas Fey[1]; Mehran Tehrani[1]; [1]University of Texas at Austin

In the United States, about 2 million people suffer from limb loss, with at least half of those being lower limb transtibial amputations. For these patients, there are a wide range of prosthetic feet available on the market, such as solid ankle cushion heel (SACH) feet, microprocessor feet, and carbon fiber-reinforced polymer (CFRP) feet. All these solutions are either very expensive or difficult to manufacture. Automated fiber placement (AFP), an additive manufacturing (AM) process, enables single-step, rapid manufacturing of prosthetics compared with other conventional techniques. This presentation shows how AM tooling (molds) and AFP of thermoplastic composites can lead to high-quality and low-cost composite prosthetics.

9:40 AM Break

10:10 AM

Effect of Z-Pin Geometric Parameters on Mechanical Properties of Z-Pinned Additively Manufacturing Composites: Aslan Nasirov[1]; *Deepak Kumar Pokkalla*[1]; Seokpum Kim[1]; Tyler Smith[1]; Halil Tekinalp[1]; Soydan Ozcan[1]; Chad Duty[2]; Vlastimil Kunc[1]; [1]Oak Ridge National Laboratory; [2]University of Tennessee

Additive manufacturing of fiber-reinforced composites using a conventional 3D printing approach results in significant mechanical anisotropy and limited tensile strength in the build direction due to layer-wise deposition. A novel "z-pinning" technique allowing material to be continuously deposited across multiple layers within the part was proposed recently to achieve mechanical isotropy. Preliminary experimental investigations demonstrating "z-pinning" approach revealed that the mechanical properties are highly dependent on the geometrical parameters of z-pins such as size and spacing. In this study, a finite element-based model was developed to predict the mechanical response of printed composites with z-pins and validated with experimental results. The developed numerical model accounts for orientation of fibers, bead-to-bead adhesion, pin-to- pin adhesion, and pin-to-bead mechanical interlocking. The effect of z-pin geometric parameters on modulus, tensile strength, and toughness was investigated to develop design guidelines for additive manufacturing of composites with enhanced mechanical properties in the build direction.

10:30 AM

Fatigue Analysis of Short Carbon Fiber Reinforced Composite Components Manufactured using Fiber-Reinforced Additive Manufacturing: *Mithila Rajeshirke*[1]; Ismail Fidan[1]; Ankit Gupta[1]; Kari Mäntyjärvi[2]; [1]Tennessee Tech University; [2]University of Oulu

Fiber-reinforced additive manufacturing (FRAM) has become quite popular in several industries. The technology offers an opportunity to improve the existing mechanical performance of the part. This research study has presented the successful methodology to fabricate the FRAM-based composite parts with improved fatigue properties. Most engineering applications are subjected to cycling loading which makes the fatigue study an important analysis. The scope of this paper is to present the fatigue properties of short carbon fiber (13.78% by weight)-reinforced Polyethylene Terephthalate Glycol (SCFs/PETG). The fatigue behavior was analyzed by varying the 3D printing process parameters i.e., infill orientation (00, 450, and 900), and infill layer heights (0.2 and 0.3 mm). The tests are carried out on 1600N as a maximum load of fatigue cycle with a 0.1 stress ratio, for the specimens with 900 and 450 orientations with 0.2- and 0.3-mm layer heights. For 00 orientation, both 0.2- and 0.3-mm layer heights specimens are applied to 2600N as maximum load, keeping the stress ratio the same as 0.1. Analysis of Variance (ANOVA) is used to statistically analyze the testing data to understand the influence of input variables on fatigue properties.

10:50 AM

Carbon Nanotube-induced Crystallinity in PEEK Nanocomposite Filaments for Additive Manufacturing: *Amir Asadi*[1]; Mia Carrola[1]; Hilmar Koerner[2]; [1]Texas A&M University; [2]Air Force Research Laboratory

Nanocomposite filaments have helped to bridge the gaps that FDM processes currently have, allowing tailoring the material properties to the desired application through proper selection of a nanofillers. Much of the focus in nanocomposites in AM has been on improving strength or optimizing processing parameters, while the effects that AM process and feedstocks have on each other has not been investigated in depth. This work explains the connection between the behavior of PEEK-carbon nanotubes (CNTs) nanocomposite filaments and the AM process. A series of PEEK-CNT nanocomposite filaments were fabricated and used for evaluating crystallization behavior. PEEK-CNT printed parts exhibited increased crystallinity induced by CNT's, despite the rapid cooling rate from melting temperature (400 °C), as well as improved tensile strength. With a better understanding of the relationship between PEEK-CNT nanocomposite filaments and AM, the material and process can be simultaneously improved to create custom and highly functioning parts.

11:10 AM

A Preliminary Study of Composite-Based Additive Manufacturing (CBAM) Material Properties: *Mathew Marinelli*[1]; Evan Cole[1]; Denis Cormier[1]; [1]Rochester Institute of Technology

Composite-Based Additive Manufacturing (CBAM) is a new high speed sheet lamination AM process in which thermoplastic or thermoset matrix powder is selectively deposited onto non-woven carbon fiber sheets. The individual sheets are stacked and placed in a heated platen press which thermally fuses the powder particles in/around the fibers. Sand blasting is used to remove unbound fibers around the part. As this is a new composite AM process, there are essentially no published studies in the literature. For this study, non-woven carbon fiber sheets were used with either PA-12 or PEEK as the polymer matrix. Coupons fabricated at numerous build orientations were tested in tension and flexure to determine orientation-specific properties. X-ray CT scans were used to assess porosity of fabricated parts in relation to powder loading and thermal processing conditions. Micrographs of fracture surfaces were studied to gain insight into failure behavior of the material.

Materials: Metals - Aluminum

Wednesday AM July 27, 2022 — Room: 616 AB — Location: Hilton Austin Hotel

8:00 AM

Droplet on Demand Printing of Al-6061 and Pure Aluminum: *Eric Elton*[1]; Kellen Traxel[1]; Viktor Sukhotskiy[1]; Andrew Pascall[1]; Jason Jeffries[1]; [1]Lawrence Livermore National Laboratory

Metal droplet on demand printing is a developing 3D printing technique where droplets of liquid metal are formed by pushing the metal through a nozzle. The droplets are then collected to create a 3D printed part. This technique does not require large amounts of powder and, as such, is particularly advantageous for reactive materials. Thus far, droplet on demand printing has largely been limited to pure metals and castable alloys. Here we demonstrate droplet printing of Al-6061, a wrought aluminum alloy, and compare it to droplet printed pure aluminum. We show that the final microstructure of the part is dependent on the droplet cooling rate (as determined by the build plate temperature and liquid metal superheat) and that the microstructure varies with part height. We also show that post-print heat treatment of the part can homogenize the microstructure. Prepared by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS-833934

8:20 AM

Liquid Metal Droplet Jetting of 4008 Aluminum Alloy: *Usama Rifat*[1]; Paarth Mehta[1]; Denis Cormier[1]; [1]Rochester Institute of Technology

This paper studies properties of 4008 aluminum alloy components that have been fabricated via the liquid metal droplet jetting (LMJ) process. Alloy 4008 is the wire form of the Al-Si-Mg-Ti A356 aluminum casting alloy. A Xerox ElemX machine using 4008 aluminum wire was used to fabricate all samples in this study. In order to assess the effect of layer orientation and droplet raster direction on mechanical properties, standard ASTM E-8 tensile bars were fabricated at multiple orientations within the build envelop. The default recommended values for parameters such as layer thickness, jetting frequency, and drop spacing were used. The printed coupons were heat treated to a T6 temper and then finish machined. Prior to tensile testing, the porosity of coupons in each orientation was assessed using a Pinnacle X-ray CT scanner. Results of tensile testing, porosity analysis, fractography, and microstructural analysis will be presented.

8:40 AM
Process-controlled Grading of the Young's Modulus of AlSi10Mg Components Using L-PBF: *Johannes Geis*[1]; Jannik Reichwein[1]; Eckhard Kirchner[1]; Holger Merschroth[2]; Matthias Weigold[2]; [1]Technical University Darmstadt - Product Development and Machine Elements; [2]Technical University Darmstadt - Institute for Production Management, Technology and Machine Tools

Laser Powder Bed Fusion (L-PBF) increases freedom in the design of components and is therefore well suited for the manufacturing of complex geometries tailored to their function. In addition, it is possible to influence the microstructural characteristics of the components by varying the process parameters during the L-PBF process. This allows shifting the load from areas with high stresses to less heavily loaded areas in order to exploit the full potential of the material. For this purpose, the process window in which the Young‘s modulus of the material AlSi10Mg can be varied was investigated. Subsequently, test geometries were analyzed by finite element method with respect to their critical component areas and a design for grading the Young‘s modulus to distribute stress more uniformly was developed. These specimens were then manufactured and compared with the simulation results as well as with components manufactured using homogeneous parameters.

9:00 AM
Investigate the height dependency of the micro-/defect-structure and mechanical properties of additively manufactured AlF357 aluminum alloy: *Md Faysal Khan*[1]; P.D. Nezhadfar[1]; Paul R. Gradl[2]; Donald Godfrey[3]; Jacky Diemann[4]; Shuai Shao[1]; Nima Shamsaei[1]; [1]Auburn University; [2]NASA Marshall Space Flight Center; [3]SLM Solutions NA, Inc.; [4]SLM Solutions Group AG

When the laser powder bed fusion (L-PBF) additive manufacturing method is used to build components with increased heights, there is an increased probability of additional defects. This study investigated the effect of build height on the micro-/defect-structures, and, consequently, the mechanical properties of L-PBF AlF357, a member of the Al-Si-Mg alloy family. In this study, vertically fabricated cylinders of 316 mm tall and 15 mm diameter are fabricated and cut into specimens at different heights. Although not much differences in the microstructure (grain size and morphology) are observed, the defect size and population slightly vary with the height. Nonetheless, the tensile properties of the L-PBF AlF357 are found to be independent of height. This is ascribed to the identical microstructure and marginal difference in the defect size and distribution along the heights.

9:20 AM
Characterization Techniques for Quantifying Effect of Interlayer Surface Peening on AlSi10Mg: *Guru Charan Reddy Madireddy*[1]; Luz Sotelo[2]; Rangasayee Kannan[1]; Joseph Turner[2]; Thomas Feldhausen[1]; Michael Sealy[3]; [1]Oak Ridge National Lab; [2]University of Nebraska-Lincoln; [3]Purdue University

With the development of new hybrid additive manufacturing (hybrid AM) technologies that enable complex and interconnected pseudo-composite properties, new material characterization methods need to be developed. This work explores the effect of interlayer laser peening during powder bed fusion of AlSi10Mg coupons, using a semi-destructive method by hole drilling for residual stress measurement, a nondestructive ultrasound method via surface wave measurements, and traditional material characterization such as microstructure (SEM and EBSD) and microhardness. These methods were used to quantify the effect of hybrid AM process on parts and evaluate the capability and sensitivity of measuring methods for glocal integrity in parts. Results show the residual stresses were reduced by 100 MPa when compared as printed and are in correlation with the ultrasound wave speed and scattering amplitude. Refined grains were observed in hybrid parts while increasing the hardness throughout the sample when compared to as printed coupon.

9:40 AM Break

10:10 AM
Comparison of Multiple Heat Treatments by Observing Mechanical Properties and Microstructure of LPBF Fabricated Aluminum F357: *Julio Diaz*[1]; Victor Medrano[1]; Kevin Caballero[1]; Edel Arrieta[1]; Mark Benedict[2]; Ryan Wicker[1]; Francisco Medina[1]; [1]W.M. Keck Center for 3D Innovation; [2]Air Force Research Lab

In this paper, Aluminum F357 (AlSi7Mg), a material which is widely used in the automotive, aerospace, and additive manufacturing industries, will be analyzed after performing several heat treatments to enhance the properties of the material. However, there is currently no standard for the usage and heat treating of F357 alloy; for that reason, ASTM F3318 standard will be followed for heat treating it. Having a comprehensive study on the performance of 3D-printed F357 benefits the automotive, military and aerospace industries due to the numerous casted components already in service and many becoming legacy components. This work presents mechanical and microstructural properties of F357 specimens fabricated with SLM technology and subjected to heat treatments. As-build, stress-relief, T6, hot isostatic pressing (HIP), and HIP+T6 heat treatments conditions were applied to tensile specimens and tested. Furthermore, with the interest of the alloy performance in-service conditions, the specimens were subjected to artificial thermal aging.

10:30 AM
Effect of Thermal Aging in the Fatigue Life of Hot Isostatic Pressed AlSi10Mg Alloy fabricated from Laser Powder Bed Fusion: *Shadman Tahsin Nabil*[1]; Edel Arrieta[1]; Ryan B Wicker[1]; Mark Benedict[2]; Francisco Medina[1]; [1]W.M. Keck Center for 3D Innovation at The University of Texas at El Paso; [2]Air Force Research Laboratory

AlSi10Mg is a widely used material in the aerospace industry. Extended exposure to elevated temperatures can have a detrimental effect on it. In this work, multiple AlSi10Mg horizontal bars and vertical rods were fabricated using an L-PBF system. Following ASTM F3318-18, the material blanks were HIPed (Hot Isostatic Pressed). Emulating service temperatures, these blanks were aged at 177°C for 10, 100, and 1000h. Fatigue test specimens were machined down from the aged blanks. The machined specimens were subjected to force controlled fatigue test as per ASTM E466-15 with two stress levels: one within the elastic range (62MPa) of the material and another close to UTS (124MPa). The results indicated that even aging for 10h can dramatically reduce the fatigue life of the alloy. The work concludes with discussion on the reduction of fatigue life and visible progressive change in the ductility of the alloy with respect to the aging time.

10:50 AM
Effect of thermal post-processing on microstructure and tensile behavior of additively manufactured aluminum alloys (AlSi10Mg and Scalmalloy) via L-PBF: A comparative study: *Md Faysal Khan*[1]; Shaharyar Baig[1]; Seyed R. Ghiaasiaan[1]; Paul R. Gradl[2]; Shuai Shao[1]; Nima Shamsaei[1]; [1]Auburn University; [2]NASA Marshall Space Flight Center

Additive manufactured aluminum (Al) alloys have recently received growing interest from different industrial sectors. This study aims to compare the microstructure and tensile properties of two laser powder bed fused (L-PBF) Al alloys, i.e., AlSi10Mg and Scalmalloy, in both heat-treated and non-heat-treated conditions. In this study, the microstructure is examined using scanning electron microscope (SEM), and quasi-static mechanical properties are generated using tensile tests. For AlSi10Mg, Si-networks are observed to break down, and Mg2Si precipitates form during hot isostatic pressing (HIP) followed by T6 heat treatment. For Scalmalloy, the density of nano-sized intergranular Al3(ScxZr1-x) precipitates increases after only HIP. Furthermore, it is observed that the addition of HIP process improves the tensile strength compared to their conventionally heat-treated AM (for AlSi10Mg T6 and for Scalmalloy stress relief) as well as wrought counterparts.

11:10 AM

Study of Different Aging Conditions for Analysis of Microstructure and Mechanical Properties of F357 Alloy Fabricatd in LPBF printer: *Victor Medrano*[1]; Julio Diaz[1]; Edel Arrieta[1]; Kevin Caballero[1]; Francisco Medina[1]; Ryan Wicker[1]; Mark Benedict[2]; [1]W.M. Keck Center; [2]Air Force Research Laboratory

Aluminum F357 is a widely used material for casting in aerospace and additive manufacturing industry. Heat treatments are commonly applied to some aluminum alloys to modify its properties. With a further study on the aging and performance of the F357 with 3D printing technology, several industries benefit of this, military, automotive and aerospace are some examples, because the numerous components casted in service. This work presents mechanical properties of F357 specimens fabricated with EOS technology and subjected to heat treatments. Heat treatments conditions were applied to tensile specimens and tested. Furthermore, the specimens were subjected to artificial thermal aging for 100 h and 1000 h at two different temperatures (285 ºF and 350 ºF), and their mechanical properties were also determined. Finally, remarks on the comparison between the heat treatments and the effect of thermal aging on the microstructures and mechanical properties of the specimens will be presented.

11:30 AM

The Effect of Heat Treatment on Microstructural and Mechanical Performance of a Laser Powder Bed-fused Al-Cu-Mg-Ag-Ti-B Alloy: As-built Versus T7 Heat Treated: *Maryam Avateffazeli*[1]; Md Faysal Khan[2]; Nima Shamsaei[2]; Meysam Haghshenas[1]; [1]University of Toledo; [2]Auburn University

This research aims at assessing the effect of heat treatment on microstructure/mechanical properties a novel laser-powder bed fused (L-PBF) Al-Cu-Mg-Ag-Ti-B alloy, i.e., A205. To this end, two batches of L-PBF samples were post heat-treated to (i) stress-relieving, and (ii) T7 stabilizing over-aging. Upon fabrication and post-heat treatments, advanced microstructural characterizations (employing electron backscattered diffraction and transmission electron microscopy), quasi-static tensile, and fatigue tests were conducted to assess the effect of the mentioned heat treatments on microstructure, mechanical properties of the materials, and the fatigue performance of the materials. We also studied the controlling mechanisms of deformation and the contribution of defects and T7-produced precipitates on tensile and fatigue properties. These findings present useful information for the selection of appropriate heat treatment conditions to facilitate control of the strength, microstructure, and fatigue performance in the L-PBF A205 material, which is of great significance for their high-demanding applications in the aerospace sector.

Materials: Polymers - Material Extrusion

Wednesday AM — Room: 415 AB
July 27, 2022 — Location: Hilton Austin Hotel

8:00 AM

Recycling PET Bottles in a Fused Granule Fabrication Additive Manufacturing System: *Darren Scruggs*[1]; Jason Weaver[1]; [1]Brigham Young University

Polyethylene Terephthalate (PET), a commonly used thermoplastic in plastic bottles, can be recycled for use in other applications. There are currently methods of recycling PET bottles for use in Fused Deposition Modeling (FDM) 3D printing, but these methods produce a filament that is often outside of the ideal specifications required for the tolerances of most FDM printers. Comparatively, the process of Fused Granular Fabrication (FGF) 3D printing requires looser tolerances compared to those of FDM printing. As a result, recycling PET bottles into printable pellets for use in an FGF printer would result in a more reliable, resilient printing of recycled PET bottles. The goal of this paper is to explore the ability to recycle and pelletize PET bottles for use in FGF 3D printing and compare the mechanical properties of the recycled PET bottle pellets to virgin PET pellets.

8:20 AM

Induction Initiated Curing of Additively Manufactured Thermoset Composites: Jitendra Tate[1]; Jitendra Tate[1]; Ben Dudek[1]; Ian Sporn[1]; Hribhu Chowdhury[1]; *Jasim Uddin*[1]; [1]Texas State University

Current work in printing thermoset composite parts is limited. One of the confounding factors in the AM of thermoset composites involves in situ curing of the composite resin system. This research proposes the creation of an additive manufacturing process for thermoset composites based upon induction initiated thermoset curing. The use of induction-based curing will allow the production of parts without the normal constraint of either oven or autoclave curing. The ability to cure parts during printing will further reduce the workflow and energy requirements of composite manufacturing. A rapid curing resin system will be reinforced using milled fiber reinforcement and doped with a ferromagnetic susceptor to induce homogenous heating and curing of the resin in situ. The resulting composite will be evaluated for mechanical performance versus oven cure samples. Scanning electron microscopy in tandem with energy dispersive x-ray spectroscopy will be used to validate homogenous particle dispersion.

8:40 AM

Ultrasonic Characterization of Sound Speeds in 3D-printed Polymers: *Akash Nivarthi*[1]; Michael Haberman[1]; Christina Naify[1]; [1]Applied Research Laboratories, The University of Texas at Austin

Ultrasonic testing can be used to nondestructively measure longitudinal and shear sound speeds to characterize additively manufactured materials. Fused deposition modeling (FDM), a popular additive method, extrudes heated filament layer-by-layer onto a print bed to produce 3D models. Despite widespread use of FDM to produce complex geometries, the acoustical properties of the as-built materials are under-characterized. Previous efforts have measured longitudinal sound speed for various FDM-built materials with a single sample thickness. This work reports longitudinal and shear wave measurements on polylactic acid (PLA) samples of varying thickness using pulse-echo and through-transmission methods. Moduli are determined from group and phase speed estimation using the measured time-of-flight. Measurements on a range of sample thicknesses improves statistical significance of the effective modulus estimates when compared to previous work. Further, samples were printed in two orientations to examine anisotropy in the effective stiffness.

9:00 AM

Improved Interfacial Bonding of Multimaterial-fused Filament Fabrication Parts: *Kazi Md Masum Billah*[1]; Mario Barron Gonzalez[1]; Youssef K. Hamidi[1]; [1]University of Houston - Clear Lake

Interfacial bond strength in fused filament fabrication part highly impacts the inherent anisotropy. Depending on the orientation of the printing, the interfacial bonding can be significantly low compared to the direction of extrusion. In multiple materials fabrication, often time the welding at the materials interface is not complete, thus yielding poor interfacial bonding. Several methods were explored in the past including thermal annealing, preheating, infrared heating, localized heating, and many more. This research explores a resistance heating method to improve the bonding of multiple materials. Acrylic Styrene Acrylonitrile (ASA) and Polyethylene terephthalate glycol (PETG) materials were printed using a dual extrusion 3D printer. Resistance heating wire was inserted at the interface of these two materials to create a composite structure. Ongoing research efforts showed that the bonding strength of PETG and ASA is relatively low, however, resistance heating with embedded wires increased the polymer chain mobility and yielded improved bond strength.

9:20 AM
Layerwise Modification of Material Chemistry via UV and Reactive Gas Exposure during Fused Filament Fabrication Additive Manufacturing: *Camden Chatham*[1]; Donald Benza[1]; Aaron Washington[1]; Adrian Mistreanu[1]; Jonathon Baker[1]; [1]Savannah River National Lab

Additive manufacturing (AM) technologies are distinguished from traditional molding processes by their layer-by-layer fabrication paradigm. This paradigm enables design flexibility and agility, but also often affects significantly different final part performance properties compared to traditional bulk manufacturing methods. If properly understood, the layer-by-layer process can be leveraged toward novel materials and fabrication methods impossible to achieve through traditional bulk manufacturing. In this presentation, we describe two methods of leveraging the layer-by-layer process to influence final part performance properties of Fused Filament Fabrication AM. Polylactic acid is exposed to UV light and reactive gas in operando to alter the chemical structure and mechanical properties of printed parts. Both light and gaseous reactants have effective depths of penetration. As layer size decreases, the effective depth of penetration represents a larger proportion of total part volume resulting in an increased effectiveness for altering final part properties, especially compared to traditional bulk manufacturing methods.

9:40 AM Break

10:10 AM
FFF Printing of Semi-crystalline PET: Exploring the Effects of Layer Specific Area and Build Rate on Crystallinity and Mechanical Properties: *Yifeng Lin*[1]; Christopher Williams[1]; [1]Virginia Tech

The majority of FFF feedstock has been limited to amorphous polymers due to the shrinkage or poor adhesion during printing of semi-crystalline polymers. In comparison to amorphous polymers, the process/structure/property relationship for semi-crystalline polymers in FFF is not well established. As FFF printing process induces a variable thermal history, the resultant part's crystallinity can vary significantly, which prevents FFF from producing semi-crystalline parts that offer constant and ideal performance. In this work, a widespread semi-crystalline polymer (Poly(ethylene terephthalate, PET) is processed via FFF, to explore process/structure/property relationships. The authors investigate two influencing factors of thermal history: the specific area (SA), which affects the convective cooling efficiency, and build rate (BR), which affects the interlayer cooling time. It is shown that at higher BR, together with a smaller SA, leads to an extended time under higher temperature, thus resulting in a higher crystallinity together with an increased Young's modulus around 20%.

10:30 AM
Size Effects on Elastic Moduli of Polymers 3D Printed by Fused Deposition Modeling: *Gabriel Olaivar*[1]; Charul Chadha[2]; Albert Patterson[3]; Iwona Jasiuk[4]; [1]Undergraduate Student Department of Systems Engineering & Design University of Illinois at Urbana-Champaign ; [2] PhD-Candidate Department of Mechanical Engineering University of Illinois at Urbana-Champaign; [3]Faculty of Manufacturing and Mechanical Engineering Technology, Department of Engineering Technology and Industrial Distribution, Texas A&M University.; [4]Department of mechanical science and engineering, the University of Illinois at Urbana-Champaign

This study investigates the size effect on the compressive elastic modulus of polycarbonate (PC) and thermoplastic polyurethane (TPU) materials. Cubic samples from both materials were printed in different size and layer height using fused deposition modelling. A full factorial design of experiments was used to study the relationship between material, size of cube, layer height and compressive elastic modulus. The cubic samples were first analyzed with micro-computed tomography to determine the volume fraction of voids and the geometry of the deposited material. The samples were then tested under quasi-static compression with the deflections recorded using digital image correlation. The results indicate that the compressive elastic modulus of the materials varies with the size of the printed samples. This size dependence should be considered while designing components manufactured using FDM. Further, the variation in elastic modulus can be attributed to the variation in volume fraction and the geometry of deposited material.

10:50 AM
Moisture Absorption of 3D Printing Nylon Filament in Humid Environment: *Haijun Gong*[1]; Michael Runzi[1]; Zezheng Wang[1]; Lianjun Wu[1]; [1]Georgia Southern University

Nylon is a commonly used thermoplastic material featured for its high resistance to heat, chemical, and impact. Nylon filaments that facilitate complex part manufacturing through the extrusion-based 3D printing process are widely used by industry and can be easily acquired from various vendors or suppliers. However, as a hygroscopic material, nylon directly absorbs moisture from the surrounding air at a fast rate. This study concentrates on evaluating the moisture absorption of nylon filament in a humid environment. Experiments are conducted to correlate the moisture content of nylon filament with its dwelling time in a humidity chamber. Test artifacts are printed to demonstrate the influence of moisture on nylon part quality. Mechanical testing is also carried out for analyzing the material property degradation due to increased moisture content. Suggestions on nylon filament usage and storage are discussed.

11:10 AM
High Fidelity Additive Manufacturing of PMDA-ODA Polyimide via Supramolecular Salts: *John Will*[1]; Clay Arrington[2]; Cody Weyhrich[3]; Timothy Long[3]; Christopher Williams[1]; [1]Virginia Tech; [2]Virginia Tech / Arizona State University; [3]Arizona State University

All-aromatic polyimides offer strong abrasion resistance, dielectric properties, and chemical resistance across a broad temperature range, making them invaluable materials in the aerospace and electronics industry. Additive manufacturing provides an opportunity to advance from 2D polyimide films to more complex parts with intricate geometries that can withstand temperatures exceeding 500°C. Previous efforts to print all-aromatic polyimide precursor photopolymer resins had high viscosity, low solids loading, and were arduous to synthesize. In this work, a supramolecular salt approach replaces high molecular weight polyamic acid precursors with small molecule precursors that associate via salt interactions until post-print polymerization, greatly reducing resin viscosity with facile synthesis. Successful printing of a new polyimide precursor resin with 50wt% solids loading, low viscosity (<1Pas), and 26% linear isotropic shrinkage is demonstrated. Resulting properties are shown to be equivalent to traditional 2D film polyimides. In addition, the resultant all-aromatic polyimides are converted to graphitic carbon via pyrolysis.

Modeling - Process Planning and Scanning Strategies

Wednesday AM Room: 412
July 27, 2022 Location: Hilton Austin Hotel

8:00 AM
Toolpath Planning for Multiple Build Points using K-Means Clustering: *Breanne Crockett*[1]; Michael Borish[1]; [1]Oak Ridge National Laboratory

Traditional 3D printers deposit material at one build point at a time, often resulting in long print times. To reduce print time, 3D printers could increase throughput with parallel construction at multiple build points. The primary challenge in path planning for parallel construction is dividing an object between the build points. The object should be divided such that the workload is balanced, and the individual build areas are discrete. This work proposes a variation of k-means clustering for object division. The algorithm considers coordinate position and geometric area as an indicator of workload. This method is demonstrated on several test models to compare workload across the number of build points.

8:20 AM
Intelligent Scan Sequence Generation for Reduced Hot Spots, Residual Stress and Distortion in Multi-laser PBF: Chuan He[1]; *Chinedum Okwudire*[1]; [1]University of Michigan

Multi-laser powder bed fusion (PBF) machines are gaining attention for improving the productivity and quality of metallic parts produced by additive manufacturing (AM). Recent research by the authors has presented SmartScan, an intelligent scan sequence generation approach that is model-based and optimization-driven. Compared to existing methods, SmartScan has demonstrated up to 41% improvement in thermal uniformity and 47% reduction part deformation in experiments on a single-laser PBF system. This work extends SmartScan to multi-laser PBF systems. A major challenge addressed is the combinatorial nature of optimizing scan sequence for multi-laser systems. A master-slave approximation is proposed to simplify the optimization. Simulation results on a two-laser PBF system demonstrate that the proposed master-slave approximation is 6.3 times faster in computation than the exact solution, at the expense of only 2.6% in optimality. Experiments are planned for the final manuscript submission and oral presentation.

8:40 AM
Automated Path Planning for Wire Feeding in Large Format Polymer Additive Manufacturing: *Michael Borish*[1]; Alex Roschli[1]; [1]Oak Ridge National Laboratory

Large format polymer-based additive manufacturing has allowed the cost-effective construction of numerous classifications of objects. One such object classification is molds. Large molds typically require heating via heating elements or large ovens making them cost prohibitive in some cases. To address this issue, researchers at Oak Ridge National Laboratory developed the capability to embed heating wire via a feeding mechanism. This wire feeder was paired with the extrusion nozzle to embed wire in the polymer beads during construction. To support this capability, a unique pathing solution was required. This pathing solution was developed as part of ORNL Slicer 2 and is detailed in this paper. Successful examples of polymer construction with embedded wire are also presented.

9:00 AM
Hybrid AM Toolpath Planning via Signed Distance Functions: *Sam Pratt*[1]; Christopher Williams[1]; [1]Virginia Tech

One key advantage of hybrid AM systems is their ability to remove and repair defective portions of the build in situ. However, due to their reliance on machining-focused path planning software systems, true in situ part repair is often impractical even with extensive operator intervention, due to the complexity of current path planning approaches. To address these limitations, the presented work uses signed distance functions (SDFs), a mathematical representation of geometry, as they are computationally efficient, highly parallelizable, and mathematically robust. The presented SDF-based path planning approach allows rapid generation and evaluation of paths, and could enable future work focused in real-time in-situ comparison of as-built material against the as-designed geometry. A detailed overview of the GPU-accelerated SDF toolpath planning kernel is shown, along with a demonstration and comparison of components built with the SDF and traditional path planning approaches via hybrid wire-arc AM.

9:20 AM
Discontinuity-free Additive Manufacturing Strategy for Axisymmetric Components: *Thomas Feldhausen*[1]; Rangasayee Kannan[1]; Kyle Saleeby[1]; James Haley[1]; Rebecca Kurfess[1]; Kenton Fillingim[1]; David Bourdages[2]; Peeyush Nandwana[1]; [1]Oak Ridge National Laboratory; [2]Open Mind Technologies AG

It's known that computer aided manufacturing (CAM) techniques for additive manufacturing (AM) influence material properties of the resulting component. However, CAM strategies used today have existed for decades without improvement. This research investigates the use of a novel toolpath strategy to generate discontinuity-free, axisymmetric components by AM. This strategy, termed additive turning, leverages CAM technology for turning strategies, where the component rotates around a stationary cutting tool. The additive turning strategy allows for entire components to be manufactured in one continuous deposition. This results in reduced cycle-time, improved material usage efficiency, decreased time to steady state temperature, and lower manufacturing costs compared to conventional AM strategies. Furthermore, additive turning can produce over 99% dense components, lesser variation and anisotropy in hardness, and low variation in elongation. The research highlights that specific CAM strategies can be deployed for AM to improve process efficiency, or to enable localized control over part performance.

9:40 AM Break

10:10 AM
Maxel Framework for Representing and Process Planning of Functionally Graded Materials: *Rajeev Dwivedi*[1]; [1]STEM and Robotics Academy

Functionally Graded Materials are characterized by variation in material composition or density per the required functionality. Inherent ability of various Solidfree Form Fabrication techniques to access bulk volume of part makes it a amenable to fabricating range of functionally graded materials. However, most of the Solid Free Form fabrication follow 2-1/2 additive process. In SFF manufacturing methods the tool path for each layer follows a Zig-zag or similar profile that necessarily is not most optimal path for material delivery. This may led to process inefficiencies. This paper presents a framework based on the maxel representation of materials to enable more efficient and accurate manufacturing of FGMs.

10:30 AM
Cad-To-Scan Planning For Hybrid Manufacturing: *Tiffany Quigley*[1]; Bradley Jared[1]; Joshua Penney[1]; Aaron Cornelius[1]; William Hamel[1]; [1]University of Tennessee

The University of Tennessee, Knoxville has developed a hybrid manufacturing work cell incorporating wire-arc additive manufacturing, fringe projection scanning and 5-axis machining. Integrating metrology into the hybrid manufacturing work cell allows for informed control of where the printed part requires machining or supplementary material via additional deposition. This presentation will explore path planning for efficient imaging. The acquired scans are then polygonized and compared to the desired geometry which is utilized in defining machining areas with excess material or underbuilt areas for additional material deposition via a gas metal arc welder (GMAW).

10:50 AM
Expanding Laser Powder Bed Fusion Processing Space Using Alternative Scan Strategies: *Elizabeth Chang-Davidson*[1]; Nicholas Jones[1]; Jack Beuth[1]; [1]Carnegie Mellon University

Laser powder bed fusion is a commonly used technology within the space of metal additive manufacturing, but most machines are highly limited in the sizes of melt pools they can produce. Since melt pool size is directly tied to microstructural properties, expanding the range of possible melt pools produced is a desirable goal. By leveraging an alternative scan strategy, a systematic technique was developed to produce melt pools much larger than the typical melt pool size. This technique was mapped through process space using semi-analytical modeling, and the modeling was then calibrated using experimental data. Using the calibrated models, test parts were printed using parameters designed to produce large melt pools.

11:10 AM
Conformal Additive Manufacturing on A Curved Substrate Using Isothermal Surface Slicing: *Yujie Shan*[1]; Yiyang Shui[1]; Renda Yang[1]; Huachao Mao[1]; [1]Purdue University

Most conventional additive manufacturing (AM) processes create an object on a horizontal substrate in a planar layer-based manner, which leads to roughed surface and weakened material strength. In the present work, conformal 3D printing algorithms based on the isothermal surface were developed and used for printing arbitrary 3D structures on freeform substrates to address these issues. The designed 3D structure can be virtually placed on the freeform substrates, and the heat spreads out through this new part. The isothermal surfaces of this created temperature field can naturally generate curved layers to offset the top surface of this freeform substrate model, and it returns tool paths for the conventional FFF 3D printing process as output. A hybrid methodology that combines conventional planar 3D printing with conformal printing, was presented. Several test cases were sliced and printed on the freeform surface to validate the developed process.

Physical Modeling - Novel Approaches

Wednesday AM Room: Salon B
July 27, 2022 Location: Hilton Austin Hotel

8:00 AM
A Finite Element Modelling of Densification and Distortion Behaviour of Laser Powder Bed Fusion Processed Inconel 718 Product: *Mohit Yadav*[1]; Samrat rao[1]; Anand kumar[1]; Abhishek Shrivastava[1]; [1]IIT JAMMU

The present work focuses on the densification and distortion behaviour of Inconel 718 parts fabricated using the laser powder bed fusion (LPBF) technique. A three-dimensional (3D) Finite Element Modeling of LPBF was developed using ANSYS software to predict the unsteady temperature distribution, solid ratio, microstructure, and distortion. The melt pool characteristics in size and the porosity in LPBF processed Inconel 718 were investigated at the 3D component level. The melt pool characteristics developed with both single-track and multi-track were evaluated. It was found that melt pool characteristic is critical for densification behaviour. The results show densification behaviour depending on the melt pool size and reference width. This result is explained based on the solid ratio. LPBF processed Inconel 718 samples were achieved when the solid ratio = 1. Further, these results help gain insight into the temperature distribution for a comprehensive understanding of the distortion in the 3D-built part.

8:20 AM
Optimal Truss-Type Supports for Minimal Part Deformation in LPBF: *Subodh Subedi*[1]; Dan Thoma[1]; Krishnan Suresh[1]; [1]University of Wisconsin-Madison

Adequate thermal dissipation through support structures is crucial for part printability in laser powder bed fusion (LPBF). Truss-type supports have been proposed for better thermal management in LPBF. Further truss structures are easy to analyze, optimize and post-process. In this paper, we consider coupled thermo-elastic LBPF simulation, where a part and corresponding truss-type support are progressively coupled during the build process. Transient thermal FEA is performed as each layer is built to obtain temperature profiles. Thermal equivalent static loads (ESL) are obtained from the transient results, which are accumulated to compute aggregate equivalent static load (AESL). Elastic deformation of coupled systems involving part and truss-type supports, is also computed after each layer-wise built. Finally, cross-sectional areas of truss-type supports are optimized using AESL to minimize elastic deformation. Optimized supports show significant reduction in part deformation compared to un-optimized supports. Numerical results are presented to demonstrate the merits of proposed method.

8:40 AM
Modified Inherent Strain Method: *Albert To*[1]; [1]University of Pittsburgh

The modified inherent strain (MIS) method is developed for the fast prediction of residual distortion and stress for metal parts produced by beam-based additive manufacturing (AM) processes. A model is proposed to extract the inherent strains from scanwise process simulation, and the extracted inherent strains are applied to a layerwise quasi-static finite element analysis model to simulate residual stress and deformation accurately and efficiently. The MIS model is shown to be much more accurate than the original IS model that is based on plastic strain alone. Recent advancements of the MIS method include a two-temperature numerical implementation and an accurate layer lumping technique that makes the method even more accurate and faster. Some applications of the MIS method will be presented including optimization of support structure, build orientation, and scanning pattern.

9:00 AM
Machine Learning-Assisted Prediction of Thermophysical Properties of Nickel-Base Alloys over a Temperature Range: Sudeepta Mondal[1]; Asok Ray[1]; *Nandana Menon*[1]; Amrita Basak[1]; [1]Pennsylvania State University

First-principal calculation of thermophysical properties of complex alloys as functions of composition and temperature is computationally expensive. The presence of multiple elements in complex alloys often results in numerical instabilities while such calculations. Furthermore, complex multi-component alloys often exhibit a range of melting temperatures (e.g., solidus and liquidus temperatures), as opposed to a single melting point. To circumvent these challenges, this paper proposes an alternative approach that implements a Gaussian Process (GP) framework to predict thermophysical properties (e.g., bulk density, solidus/liquidus temperatures) of a nickel-base metallic alloy system, nickel-chromium-aluminum (Ni-Cr-Al), over a temperature range. The results show that the proposed GP-based framework is conducive to predicting thermophysical properties with a significantly lower computational overhead and, thus, can be implemented as a surrogate in the digital twin development of additive manufacturing processes.

9:20 AM
Designing Calibration-Free Physics-Based Printability Maps for Additively Manufactured Cantor Alloys: *Sofia Sheikh*[1]; Brent Vela[1]; Peter Morcos[1]; Pejman Honarmandi[1]; Raymundo Arroyave[1]; Alaa Elwany[1]; Ibrahim Karaman[1]; [1]Texas A&M University

To design for printability in additive manufacturing, the material, and processing spacing need to be analyzed as well as visualized. However, designing for printability can be a costly process due to the involvement of experiments. Therefore, we propose a framework using the Cantor system that calculates the material properties using a CALPHAD model and a reduced-order model. Using the material properties, the melt pool geometry is calculated using one of the three thermal models - the analytical Eagar-Tsai model, the scaled Eagar-Tsai model, and the neural network Eagar-Tsai model – during the AM processing. Further, the printability map for an arbitrary alloy in the material system is constructed using defined criteria for lack of fusion, balling, and keyholing. In the end, the material system's susceptibility to balling and hot cracking is assessed to construct printability maps for compositions that are least susceptible to balling and hot cracking.

9:40 AM Break

10:10 AM
Revealing Texture-induced Abnormal Tensile Deformation Behavior in Additively Manufactured Haynes 282 using Crystal Plasticity Simulations: *Indrajit Nandi*[1]; Nabeel Ahmad[1]; Nima Shamsaei[1]; Shuai Shao[1]; [1]Auburn University

A ductile fracture typically features a dimpled surface appearance and cup-and-cone morphology because of micro void coalescence. Tensile fracture surfaces of additively manufactured Haynes 282, a nickel-base superalloy, in this work exhibit elliptical shape – an aberration to classic failure mode. Both microstructural characterization and fractography are performed using scanning electron microscopy (SEM) on the tensile deformed surface to assess the fracture behavior. To gain better mechanistic insights into the governing factors of this elliptical shape fracture, crystal plasticity finite element analysis (CPFEA) simulations are performed using the experimentally calibrated material parameters. Uniaxial tensile loading simulations are carried out on a polycrystalline aggregate of columnar grains structure. The initial texture are varied to the CPFEA simulation to emulate the experimental microstructure. The mechanical response and shape of the fracture surface obtained from the simulations are compared with the experimental tensile geometry to illustrate the texture depended deformation inhomogeneity.

10:30 AM
Computational Fluid Dynamics Data-driven Heat Source Model for Finite Element Process Simulation in Laser Powder Bed Fusion Additive Manufacturing: *Seth Strayer*[1]; Florian Dugast[1]; Albert To[1]; [1]University Of Pittsburgh

Thermal field prediction of the laser powder bed fusion (L-PBF) process via the finite element (FE) method can help optimize the process while avoiding the cost of experimental techniques. However, FE models require the abstraction of critical physics into an analytical heat source model, which is not accurate for simulating moderate to high energy melting regimes. This work attempts to mitigate these issues via a data-driven heat source model. In this approach, the thermal fields from a higher-fidelity computational fluid dynamics (CFD) simulation obtained via deep learning are imposed onto the FE solution and entirely replace any analytical heat source model. The resulting thermal fields and melt pool sizes are within 10% error regarding the CFD simulation and experiment, respectively, while the computational expense is significantly reduced compared to the CFD simulations. Hence, this model provides a path for improving the accuracy and potential of thermal FE modeling for L-PBF.

10:50 AM
An Efficient Surrogate-based Model Optimisation to Predict the Morphology of Inkjet-printed Dielectric Tracks: *Juan Francisco Reyes Luna*[1]; Sean Chang[2]; Christopher Tuck[1]; Ian Ashcroft[1]; [1]University of Nottingham; [2]Texas Instruments

Current trends in manufacturing electronics feature digital inkjet printing as a key technology to enable the production of microscale functional devices. However, significant printed morphology quality challenges are present in current applications. Several studies predict the morphology of printed features using computationally expensive simulations, but little attention has been paid to reduced order models. Here we propose a framework to predict the inkjet-printed track morphology created by the sequential deposition of microdroplets on non-porous substrates. Assuming physical properties of a dielectric ink, a set of response surface equations built from lattice Boltzmann simulation predict the track morphology as a function of drop spacing and contact angle hysteresis with an error percentage less than 10%. Furthermore, the model captures fluid transient effects and builds morphology in seconds, enabling efficient optimisation of printing parameters. The simplicity of the proposed technique paves the way for better quality devices in the printed electronics industry.

11:10 AM
A Multiphysics Modeling Approach to Assess the Powder Bed Characteristics of High Strength Steel in Selective Laser Melting: *Manoj Kumar Reddy Rangapuram*[1]; Mianqing Yang[1]; Saheed Babalola[1]; Joseph Newkirk[1]; Laura Nicole Bartlett[1]; Frank Liou[1]; K. Chandrashekhara[1]; [1]Missouri University of Science and Technology

Selective laser melting (SLM) is a type of additive manufacturing technique which uses a powder bed to form complex metal parts in a layer-by-layer process. The density of the powder bed in SLM affects the mechanical properties of the produced part. Good powder packing results in a higher powder bed density which in turn influences the quality of the produced part. In this work, a computational fluid dynamics (CFD) model was developed for the SLM process using Flow 3D software to study the effect of powder bed density on the melt pool characteristics of high strength steel. Discrete element method (DEM) was used to generate powder beds with realistic powder properties. The powder beds were irradiated with a moving laser heat source to study the melt pool characteristics. These models were validated with experimental results.

11:30 AM
A Multiphysics Computational Framework for Interfacial Fluid - Particle Interaction in Binder Jet 3D Printing: *Joshua Wagner*[1]; C. Fred Higgs III[1]; [1]Rice University

The underlying physics of powder bed additive manufacturing (AM) methods, namely binder jet 3D printing (BJ3DP) and powder bed fusion (PBF), include interfacial fluid flow, particle dynamics, and the simultaneous interaction of the two. Recently, numerical simulation has been employed to investigate the melt pool dynamics and binder migration in PBF and BJ3DP, respectively. However, the coupling of particle motion with these interfacial flows is notoriously difficult to model and thus has largely been ignored. We present a novel framework capable of simulating the fully-coupled fluid-particle interaction in BJ3DP. The volume-of-fluid method with adaptive mesh refinement is used to capture high-resolution interfacial dynamics with increased computational efficiency. The discrete element method is adopted to model particle motion, and the fluid-particle coupling is realized through an immersed boundary approach. A heterogeneous CPU-GPU parallelization strategy is employed for increased performance.

Process Development - Large-scale Processing

Wednesday AM	Room: 400-402
July 27, 2022	Location: Hilton Austin Hotel

8:00 AM
A Review of Extrudate Shaping for Large-Scale Additive Manufacturing: *Phillip Chesser*[1]; Alex Roschli[1]; Randall Lind[1]; Celeste Atkins[1]; Jesse Heineman[1]; Brian Post[1]; [1]Oak Ridge National Lab

In recent years numerous extrusion-based large-scale additive manufacturing systems have been developed. With all extrusion-based systems the extruded bead of material has imperfections, anomalies and deviations from the ideal. With conventional small-scale systems, the size of these errors is small enough to be neglected in many cases. However, with large-scale systems which extrude large beads of material, these anomalies can be significant. Hence, various researchers have used different methods of post-shaping the bead of material after it exits the extruder through the use of various devices such as reciprocating platens, rollers, shapers and even irregularly shaped nozzles. A review of these methods is presented herein with emphasis being placed upon technologies developed at the Manufacturing Demonstration Facility (MDF) at Oak Ridge National Laboratory (ORNL).

8:20 AM
Large-volume, High-viscosity Masked Stereolithography: *Nicholas Rodriguez*[1]; Hongtao Song[1]; James Oakdale[2]; Eric Duoss[2]; Carolyn Seepersad[1]; Richard Crawford[1]; [1]The University of Texas at Austin; [2]Lawrence Livermore National Laboratory

This work details the design and fabrication of a large-volume stereolithography printer that is capable of printing structures over one foot per dimension out of high-viscosity, paste-like elastomeric resins as well as low-reactivity resins that need orders of magnitude greater exposures of light to cure than traditional SLA resins. We present a detailed overview of the printer design and capabilities including a novel method of recoating high-viscosity resins for SLA and a roll-to-roll film tensioning technique to greatly reduce the separation force experienced by the printed structure between each layer. We also describe the scaling up of a recently reported novel light-patterning technique that can pattern high-intensity UV light over areas exceeding one foot per dimension with 8K resolution.

8:40 AM
Post-processing Volumetric Additive Manufacturing Components: *Daniel Meile*[1]; Carl Kruse[1]; Roozbeh Salajeghe[1]; Jon Spangenberg[1]; [1]Technical University of Denmark

Volumetric additive manufacturing, a new 3D printing technology, has shown great potential to revolutionize the manufacturing industry. Within the field of volumetric additive manufacturing, research has predominantly been focused on improving the projection algorithm and optical system and expanding the technique's applicability to different materials and little attention has been paid to the post-processing stage. As the printed geometry in this method is not fully cured by the end of the projection time, it is highly prone to damage in the post-process phase. In this study, a comparison has been made between the effects of different post-processing protocols and techniques on the dimensional accuracy of the final products. The results highlight that it is a non-trivial task to sustain high geometrical precision during post-processing of components produced by volumetric additive manufacturing.

9:00 AM
Robot-guided Electrophotographic Powder Application System for Powder Bed Fusion of Metals by means of Laser Beam: Julia Förster[1]; *Maximilian Binder*[1]; Georg Schlick[1]; Christian Seidel[1]; Johannes Schilp[1]; [1]Fraunhofer IGCV

Powder application remains amongst the core challenges in Powder bed based additive manufacturing. Current state of the art does hardly allow processing of powders with low flowability or the processing of multiple materials (multi-material) within one layer. In this paper, a powder application process based on electrophotography is presented to increase the flexibility of additive manufacturing processes using powder bed fusion of metals (PBF-LB/M) as specific reference. A novel conceptual design of an automated 6-axis robot-controlled prototype for electrophotographic powder application in a machine environment is presented. Experiments demonstrate single- and multi-layer powder depositions for the PBF-LB/M typical powder CW106C (CuCrZr1). A first qualitative comparison of the powder application process in the ambient media in atmospheric conditions and in an argon inert gas atmosphere is performed. With the automated powder application, the general inclusion in the PBF-LB/M cycle for multi-layer deposition and melting can be demonstrated.

9:20 AM
Evaluating the Mechanical Properties within the Transition Region of Multi-Material Large-Format Extrusion Additive Manufacturing: *James Brackett*[1]; Alex Defilippis[1]; Tyler Smith[2]; Ahmed Hassen[2]; Vlastimil Kunc[2]; Chad Duty[1]; [1]Univ of Tennessee Knoxville; [2]Oak Ridge National Laboratory

Recent developments in Large-Format Additive Manufacturing (LFAM) have enabled in-situ material changes and production of Multi-Material (MM) structures. The Big Area Additive Manufacturing (BAAM) system utilizes a dual-hopper configuration to feed different materials into a screw-based extruder which results in a blended material transition rather than a discrete material boundary, avoiding associated delamination issues. While this system enables site-specific material deposition at a large scale, the mechanical performance within the transition region needs to be evaluated to determine the impact on end-part performance. Additionally, the transition region can exhibit incomplete mixing, which could further influence mechanical performance. This study investigates the change in mechanical properties throughout the transition region using dynamic mechanical analysis and tensile testing of printed samples. Optical microscopy of the internal microstructure of the printed beads was also utilized to determine the influence of material blending within the transition on mechanical performance.

9:40 AM Break

10:10 AM
Integration of Plasma-Arc Directed Energy Deposition (PA-DED) System to Drive Higher Fidelity Large Scale Additive Manufacturing of Metals (LSAMM): *James McNeil*[1]; Michael Carney[1]; Nick Kaputska[1]; Dennis Harwig[1]; [1]EWI

Wire Arc Additive Manufacturing (WAAM) systems typically use Metal Inert Gas (MIG) welding as the transfer mode to build parts. While MIG processes have advantages in simplifying joint kinematics by allowing rotation around the robot wrist axis, a higher fidelity process where Wire Feed Speed (WFS) can be decoupled from the metal transfer method is desired for certain applications. Plasma Arc Welding (PAW) has been used for applications where high quality of deposition must be maintained in parts such as turbine or propellers. A new dual arm robotic system with PA-DED capabilities has been developed, as well as the matching digital twin used for offline robot path planning and simulation. The PA-DED path planning is vital as maintaining directionality of the plasma head for wire feed for process stability. Future work on the system include creating omni-directional capabilities for the PA system to simplify path-planning.

10:30 AM
Detecting Layerwise Build Defects Using Low-Cost Imaging and Machine Learning: Bradley Jared[1]; *Devon Goodspeed*[1]; Dylan Lewis[1]; Ethan Rummel[1]; Shuchi Khurana[1]; [1]University of Tennessee, Knoxville

Process monitoring is a timely and necessary topic in metal laser-powder bed fusion as interest continues to cost effectively improve part confidence and simultaneously reduce inspection and qualification cycle times. The identification of build defects will be demonstrated using low-cost optical hardware retro-fitted onto a Farsoon FS271M powder bed system. The existing system captures static powder bed images during each layering step. It then utilizes customized machine learning algorithms to detect powder bed anomalies, re-coater streaking and hopping, and part swelling. After discussing the equipment and approach, its efficacy will be exhibited in 316L stainless steel using varying build artifacts intended to introduce build errors or to yield acceptable parts. The utility of the existing hardware and software in detailing excessive part deformations and internal porosity will also be explored.

10:50 AM
Volumetric Sintering of Polymers via Radio Frequency Additive Manufacturing: *Hongtao Song*[1]; Ali Sohaib[2]; Jared Allison[1]; Joseph Beaman[1]; Richard Hague[2]; Chris Tuck[2]; Carolyn Seepersad[1]; [1]University of Texas at Austin; [2]University of Nottingham

Radio Frequency Additive Manufacturing (RFAM) utilizes Radio Frequency (RF) radiation to heat and sinter an entire part simultaneously in a polymer powder bed. By selectively depositing electrically conductive dopants into an insulating polymer powder bed, it is possible to sinter a part rapidly and volumetrically with RF heating. In this work, the feasibility of RF heating is demonstrated by volumetrically sintering parts that are either cast from hand-mixed graphite-Nylon 12 powder mixtures or doped by a commercial binder jetting printer. The result showed that adding graphite powder to the Nylon 12 powder bed can generate sufficient heat to sinter a part fully, but heating uniformity is a challenge related to the dopant density and the geometry of the part. Parts with uniform dopant density exhibit distorted geometry after sintering; fine-tuning the dopant density across the powder bed improves heating uniformity and enhances the geometric accuracy of the sintered parts.

11:10 AM
Use of a Static Mixing Nozzle to Homogenize Material in Large-Format Extrusion Additive Manufacturing: *James Brackett*[1]; Tyler Smith[2]; Elijah Charles[1]; Ahmed Hassen[2]; Vlastimil Kunc[2]; Chad Duty[1]; [1]Univ of Tennessee Knoxville; [2]Oak Ridge National Laboratory

Large Format Additive Manufacturing (LFAM) provides numerous benefits over traditional, smaller Additive Manufacturing (AM) methods, including production speeds, feedstock compatibility, and lower costs. Recent advancements have enabled Multi-Material (MM) systems that provide the ability for site-specific placement of materials within complex geometries, providing additional pathways for single-stream AM. While MM LFAM typically requires a stop-start process or the in-situ blending of materials, extrusion screw-based systems such as the Big Area Additive Manufacturing (BAAM) are uniquely compatible with in-situ material changes due to the use of pelletized feedstock. This results in a transition region that typically exhibits a regional, heterogeneous microstructure. This study investigates mixing behavior within the transition region using carbon fiber-filled Acrylonitrile Butadiene-Styrene (ABS) and unfilled ABS printed with an innovative static mixing nozzle design. Through optical microscopy of cross-sections taken from the transition region, it was demonstrated that the mixing nozzle increased microstructural homogenization compared to standard nozzles.

11:30 AM
Swarm Manufacturing of a Robotic Vehicle: *Rencheng Wu*[1]; Nahid Tushar[1]; Zhenghui Sha[2]; Wan Shou[1]; Wenchao Zhou[1]; [1]University of Arkansas; [2]University of Texas, Austin

Although increasingly automated and flexible, modern factories are mostly designed for specific products, which often rely on other special-purpose factory for components. This leads to high dependencies between factories, making it challenging to secure a supply chain against disruptions (e.g., COVID). Swarm manufacturing employs an army of manufacturing robots to work together to manufacture a wide variety of products autonomously for general-purpose factories, which can potentially create a distributed manufacturing infrastructure which ensures a more resilient supply chain. In this paper, we demonstrate the swarm manufacturing of a simple robotic car and present a set of principles for swarm manufacturing of complex electromechanical products. Specifically, we first designed a simple robotic car for swarm manufacturing. A series of manufacturing tasks are generated and carried out by two types of robots - 3D printing robot and assembly robot. The results demonstrate a proof-of-concept of swarm manufacturing of complex products.

Process Development - Novel Methods and Processes II

Wednesday AM | Room: 408
July 27, 2022 | Location: Hilton Austin Hotel

8:00 AM
High-Resolution Reactive Extrusion Additive Manufacturing: *Robert Pavlovic*[1]; Jacob Aber[1]; Michael Fogg[1]; Carolyn Seepersad[1]; Mehran Tehrani[1]; [1]The University of Texas at Austin

Reactive extrusion additive manufacturing (REAM) is a new additive manufacturing method in which a low viscosity thermoset resin is mixed with its curing agent and immediately deposited and cured in situ on the build plate. This method reduces the energy requirements of additive manufacturing by eliminating the need for external heating elements and improving part strength by allowing for crosslinking between layers or individual rasters. Flowrate-dependent passive mixers typically accomplish mixing in REAM, making low volume high-resolution prints particularly difficult. This talk will present active mixing as a modification to REAM, where an external power source mixes the resin and curing agent prior to deposition, removing the flowrate dependency for printing. The primary result of this modification is an improvement to maximum print resolution. This talk will also highlight the effects of processing parameters on part resolution, quality, and thermo-mechanical properties.

8:20 AM
Impact of Zirconia Slurry Doping on 316L Stainless Steel prepared by Laser Powder Bed Fusion for biological/high corrosion applications: *McKay Sperry*[1]; Jakob Bates[1]; Taylor Davis[1]; Tracy Nelson[1]; Nathan Crane[1]; [1]Brigham Young University

Laser Powder Bed Fusion (LPBF) is a versatile additive manufacturing (AM) technique. Steel is an important material for AM because its many forms can take on a wide variety of properties. This paper presents the process development and results of depositing small quantities of Zirconium Dioxide (zirconia) nanoparticles in a stainless steel (316L) powder bed en-situ prior to fusion in the LPBF process. The process may be adapted to selectively dope a powder bed to form parts with different properties in different areas. Analysis of line tracks and multi-layer parts shows that the added zirconia is not uniformly dispersed, but the majority agglomerates in porous regions within the fused part. The deposition of zirconia limits the anisotropic crystal growth that is characteristic in many metal AM processes. A similar procedure applied with dopant materials that are soluble in the melt pool is recommended modify the properties of finished steel parts.

8:40 AM
Copper Tape Manipulation for Additive Manufacturing: *Nahid Tushar*[1]; Rencheng Wu[1]; Muhammad Ghufran[1]; Wenchao Zhou[1]; Wan Shou[1]; [1]University of Arkansas

Additive manufacturing (AM) has made significant strides in the past decades in printing different forms of materials ranging from the nanoscale to the macroscale. However, little research is available regarding the 3D printing of tape materials with unique geometry between filaments and sheets, such as copper tapes. Being able to print copper tape will greatly expand 3D printing capabilities for electronics, such as circuits, sensors, and actuators. In this work, we present a printhead design for 3D printing of tape materials, specifically, the copper tape is used as a proof of concept. Further, we demonstrate the printing of a LED circuit and a pressure sensor array. Such an end-effector can be easily integrated with existing printers or industrial robots. We believe this printing approach could unlock the potential of tape materials in AM, which can be extended to other materials, such as polyimide tape and carbon fiber prepreg tape.

9:00 AM
Continuous Sculpting as a Novel Method to Reduce the Staircase Effect in Solidfreeform Fabrication Processes that are Dependent on Phase Transformation: *Rajeev Dwivedi*[1]; Indira Dwivedi[1]; Bharat Dwivedi[1]; [1]STEM and Robotics Academy

Inherent to 2-1/2 axis deposition in Solid Freeform Fabrication is Staircase effect. The surface geometry of parts produced using Solid Freeform Fabrication, therefore is not smooth. Continuous sculpting is a novel method that combines additive manufacturing to surface modification by relative motion of a forming tool. Molten material is added to substrate. The forming tool can tilt along different axe is connected to the end effector. The forming tool is oriented along a desired angle and then applies force on the molten material to give it desired shape on the fly. This paper introduces the novel method and few simple case studies.

9:20 AM
High-power Microwave Irradiation for Localized Curing of Opaque Polymer Composites: *Saptarshi Mukherjee*[1]; Johanna Schwartz[1]; Emer Baluyot[1]; Joseph Tringe[1]; Maxim Shusteff[1]; [1]Lawrence Livermore National Laboratory

The recent development of light-based volumetric additive manufacturing (VAM) technology has enabled rapid 3-D printing of optically transparent resins. However, there is growing interest in employing other materials that extend the design space of VAM. Here we leverage focused microwave radiation to expand VAM to a broader family of resins, including those which are opaque. We use an X-band microwave applicator array coupled to a beam-steering algorithm to focus microwave energy into resins. We performed numerical simulations to demonstrate microwave energy localization, that are supported with experimental results on resins loaded with different opaque additives. This work culminated in two prototype AM systems, based on VAM and direct-ink-writing, capable of making large opaque structures.This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory (LLNL) under Contract DE-AC52-07NA27344, supported by LLNL-LDRD Program under Project No. 22-FS-030. This is LLNL Contribution Number LLNL-ABS-834044.

9:40 AM Break

10:10 AM
Experimental Study for Improved Productivity of Laser-Foil-Printing Additive Manufacturing: *Tunay Turk*[1]; Ming Leu[1]; [1]Missouri University of Science and Technology

Laser Foil Printing (LFP) is a metal additive manufacturing process recently developed at the Missouri University of Science and Technology. This process uses metal foil as feedstock, substantially increasing the cooling rate during solidification of melt pool vs. the use of metal powder as feedstock in other metal additive manufacturing processes. The LFP process steps consist of spot welding, pattern welding, cutting, and surface polishing for each layer, which involve using two lasers – a continuous-wave fiber laser and a pulsed UV laser – for the various process steps. This study examines each process step in order to increase the LFP productivity. The investigation is performed experimentally, from which the spot-welding jump speed, dwelling duration, weld pattern, line welding speed, and wait time between weld lines are determined for minimizing the LFP process time, resulting in substantial increase in part fabrication productivity.

10:30 AM
Optimizing Build Plate Adhesion of Polymers in Fused Granule Fabrication Processes: *Alexander Schroeder*[1]; Jason Weaver[1]; [1]Brigham Young University

Perhaps the most crucial element of fused granule fabrication (FGF) is material adhesion; in order to achieve a successful product, the material being printed must adhere to the build plate. For optimal products, the material should only adhere to the build plate until the print is complete, then be easily removable. This paper examines the effects of different build plates, environments, and bonding agents on material adhesion during the FGF process in a CNC mill machine. The force to remove polycarbonate (PC) and polypropylene (PP) from build plates was tested with various bonding agents. Except in one case, the adhesive force after the samples cooled was too low to measure; further research is required with a more precise tool to collect more quantitative data.

10:50 AM

Use of a Fluid Interface to Reduce Support Structures in Top-down Stereolithography: *Jenny Wang*[1]; Amit Jariwala[1]; David Rosen[1]; [1]Georgia Institute of Technology

Stereolithography (SLA) is a vat photopolymerization additive manufacturing process which utilizes ultraviolet (UV) light energy to cure resin layer-by-layer to build parts. The fabrication of overhanging geometry in SLA typically requires sacrificial support structures. Printing supports increases fabrication time and material usage, and their removal prolongs the post-processing and has a detrimental effect on the surface quality of the final part. This study investigates a top-down mask projection SLA system in which a fluid of similar density to the cured resin is used to support the part during fabrication. The buoyant force of the displaced fluid counteracts the gravitational force the part experiences, thus reducing the need for support structures in overhangs. The overall system design is presented and the feasibility of using various components and materials is verified. Additionally, a predictive model of part deformation resulting from internal stresses, buoyant and gravitational forces, and dynamic reactionary forces is proposed.

11:10 AM

Infrastructure Scale Additive Manufacturing: Contemporary Concepts and Challenges in Concrete 3D Printing: *Brian Post*[1]; Joshua Vaughan[1]; Phillip Chesser[1]; Celeste Atkins[1]; [1]Oak Ridge National Laboratory

The construction industry has survived the last three industrial revolutions relatively untouched by advancements in automation, robotics, computing, and cyber-physical systems. These on-site fabrication practices are heavily reliant on manual labor and result in enormous material waste. Many researchers and private sector startups are aiming to change this paradigm by leveraging additive manufacturing for low-cost and on-site construction using materials like concrete and mortars. In this presentation Dr. Brian Post, group leader for the Manufacturing Systems Design Group at Oak Ridge National Laboratory (ORNL), will discuss contemporary concepts and challenges in concrete 3d printing. Concentrating on the development of a novel scalable cable robot SkyBAAM, multi agent coordination (drone printing), material considerations, and general applications, the audience will leave with a better understanding of the critical barriers to the success of this technology and how lessons learned by the larger AM industry can enable the next revolution in construction.

11:30 AM

Thermal-Imaging Feedback Control of Glass Additive Manufacturing Deposition Products: *Aidan Brooks*[1]; Douglas Bristow[1]; [1]Dept. of Mechanical and Aerospace Engineering at Missouri S&T

Additive manufacturing of glass has the potential to revolutionize optical component production, but traditional methods of 3D fabrication, such as laser powder bed fusion (LPBF), create too much porosity for printed glass to be optically transparent. Direct energy deposition (DED) methods utilizing fully-dense glass feedstock can produce optically transparent parts, but material and process variations can result in variations in quality. Further, quality is significantly dependent on path and geometry. Here, we report the use of a thermal camera to provide in-situ feedback of material thermal state during deposition. Several methods are considered for generating a scalar measure of the thermal state, including area above a threshold, integrated temperature, and width of the softened region. Laser power is adjusted through feedback to maintain constant print behavior, evaluated in both rastered (in-layer) and layer-to-layer paths. This presentation will report on the performance results of the regulated process.

Special Session: Data Analytics III - Sensing and Analytics

Wednesday AM
July 27, 2022

Room: Salon A
Location: Hilton Austin Hotel

8:00 AM

Holistic Development of the Electron Beam Melting Process for Ni-base Superalloys: Feedstock, Process Optimization, Data Analytics, to Component Evaluation: *Michael Kirka*[1]; Vincent Paquit[1]; Yousub Lee[1]; William Hallsey[1]; Daniel Ryan[2]; Paul Brackman[3]; [1]Oak Ridge National Laboratory; [2]Solar Turbines Inc. ; [3]Carl Zeiss Industrial Metrology

Recently, a program was concluded which developed the processing science to enable the fabrication of prototype rotating airfoils for hot-fire evaluation in an industrial gas turbine engine using the crack prone Ni-base superalloy Inconel 738LC produced with the electron beam melting (EBM) process. However, confirming the conformity and homogeneity of serial builds presented additional challenges. To be discussed is the process optimization pathway necessary to fabricate the airfoils from Inconel 738LC through the EBM process to scale across multiple machine platforms. Further, protocols developed leveraging data analytics for co-registering available data streams in the EBM process on a voxel basis to enable the screening and identification of defect bearing airfoils, and build-to-build and machine-to-machine variability will be discussed. Ultimately, this holistic effort led to a hot-fire demonstration and evaluation of an AM prototype airfoil set under full power generating loads in a land-based gas turbine engine.

8:20 AM

Monitoring and Flaw Detection during Wire-based Directed Energy Deposition using In-situ Acoustic Sensing and Wavelet Graph Signal Analysis: *Benjamin Bevans*[1]; André Ramalho[2]; Ziyad Smoqi[1]; Aniruddha Gaikwad[1]; Telmo Santos[2]; Prahalada Rao[1]; J.P. Oliveira[2]; [1]University of Nebraska-Lincoln; [2]UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, Universidade NOVA de Lisboa

The goal of this work is to detect flaw formation in the wire-based directed energy deposition (W-DED) process using in-situ sensor data. The W-DED studied in this work uses an electric arc to melt the wire; known as wire arc additive manufacturing (WAAM). The adoption of WAAM in industry is limited in industry due to the lack of process consistency. The process is susceptible to stochastic and environmental disturbances that cause arc instabilities, leading to the formation of porosity and suboptimal geometric integrity. Accordingly, the objective of this work is to detect flaw formation in WAAM using data acquired from an acoustic sensor installed near the electric arc. We develop an approach that extracts a single graph feature (Fiedler number) from the acoustic sensor data, which is subsequently tracked in a control chart. Using this approach, flaw formations are detected with a false alarm rate less-than 2%.

8:40 AM

In-Process Quality Monitoring of Biological Additive Manufacturing Using Machine Learning: *Sam Gerdes*[1]; [1]University of Nebraska-Lincoln

An emerging platform for tissue engineering, extrusion-based (bio)printing, allows for the rapid fabrication of scaffolds with clinically relevant dimensions but suffers from limited resolution and print defect occurrence. Print defects risk the functionality of printed tissue engineering scaffolds, making it vital to negate defect occurrence. As such, the goal of this work is the defect-free biological additive manufacturing of tissue constructs (Bio-AM). In the context of this goal, the in-process detection of flaw formation is the critical first step toward the clinical scaling of Bio-AM processes. The objective of this work was to detect flaw formation in Bio-AM of bone tissue constructs as they develop using data from in-situ infrared thermocouple sensors. The data was analyzed using several machine learning approaches to ascertain critical quality metrics: print regime, strand width, strand height, and strand fusion severity. Defects were classified and predicted using this approach with statistical accuracy nearing 90%.

9:00 AM
Towards Online Monitoring and Data-driven Control: A Study of Segmentation Algorithms for Laser Powder Bed Fusion Processes: *Alexander Nettekoven*[1]; Scott Fish; Joseph Beaman[1]; Ufuk Topcu[1]; [1]University of Texas Austin

An increasing number of laser powder bed fusion machines use off-axis infrared cameras to improve online monitoring and data-driven control capabilities. However, there is still a severe lack of algorithmic solutions to properly process the infrared images from these cameras, which has led to several key limitations: a lack of online monitoring capabilities for the laser tracks, insufficient pre-processing of the infrared images for data-driven methods, and large memory requirements for storing the infrared images. To address these limitations, we study over 30 segmentation algorithms that segment each infrared image into a foreground and background. By evaluating each algorithm based on its segmentation accuracy, computational speed, and spatter detection characteristics, we identify promising algorithmic solutions. The identified algorithms can be readily applied to the laser powder bed fusion machines to address each of the above limitations and thus, significantly improve process control.

9:20 AM
In- and Ex-situ Optical Signal Correlation in LPBF: *Michael Juhasz*[1]; Gabe Guss[1]; Jean-Baptiste Forien[1]; Nicolas Calta[1]; [1]Lawrence Livermore National Laboratory

In-situ monitoring during LPBF has garnered serious attention recently with some form of monitoring appearing on all commercially available machines at present. In this presentation a workflow will be described and implemented which leverages in-situ optical signals (namely pyrometry and photodiode) with ex-situ x-ray computed tomography (XCT). This workflow characterizes not only internal defects but also geometric conformance. This work will address common occurrences within the field relating to data management, exploratory analysis, processing, and relevant metrics. Finally, the workflow is implemented for quality assessment on lattice structures produced with LPBF with good results. Prepared by LLNL under Contract DE-AC52-07NA27344.

9:40 AM Break

10:10 AM
Multi-Phenomena Data Fusion for Enhanced Process Monitoring in Laser Powder Bed Fusion (LPBF): Aniruddha Gaikwad[1]; Harry DeWinton[2]; Ben Bevans[1]; Ziyad Smoqi[1]; Paul Hooper[2]; *Prahalad Rao*[1]; [1]University of Nebraska; [2]Imperial College London

In this work, to improve flaw detection performance in LPBF, we adopted a data fusion approach that captures multiple process phenomena. Cylindrical specimens were produced with different laser spot sizes, emulating laser defocusing due to thermal lensing. During the build, the melt pool state was monitored with two coaxial high-speed video cameras and a temperature field imaging system. Physically intuitive low-level melt pool signatures, such as melt pool temperature, shape and size, and spatter intensity were extracted from this high-dimensional, image-based sensor data. These process signatures were used as input features in relatively simple machine learning models, such as a support vector machine, which were trained to detect laser defocusing, and predict porosity type and severity. The data fusion approach significantly reduced the overall false positive rate from ~ 0.1 to ~0.001 without sacrificing the true positive rate (~ 0.90). These results were at par with deep machine learning approach.

10:30 AM
In-process Multi-physical Melt Pool Characteristics Sensing and Data Correlation in Laser Powder Bed Fusion: *Rongxuan Wang*[1]; David Garcia[1]; Chaoran Dou[1]; Bo Shen[1]; Xiaohan Ma[1]; Rakesh Kamath[2]; Hahn Choo[2]; Kamel Fezzaa[3]; Zhenyu Kong[1]; [1]Virginia Tech; [2]University of Tennessee Knoxville; [3]X-ray Science Division, Advanced Photon Source, Argonne National Laboratory

Laser powder bed fusion has many advantages, but it still suffers from defects such as delamination and porosities due to the lack of understanding and control of melt pool dynamics. This work integrates three advanced sensing technologies: synchrotron X-ray imaging, high-speed IR camera, and high-spatial-resolution IR camera to characterize the melt pool dynamics, vapor plume, and thermal evolution. Numerous experiments were performed at the Advanced Photon Source in Argonne national lab to test Ti-64 and 410 stainless steel samples with various processing conditions. Pre-processing methods are developed for X-ray and IR imaging. Information such as boundary velocities, melt pool dimensions, thermal gradient, and cooling rates can be extracted based on the pre-processed data. The correlation study discovers a strong relationship between the thermal and X-ray data, enabling the possibility of using relatively cheap IR cameras to predict expense information that needs to be captured using synchrotron imaging.

10:50 AM
Logistic regression classification to predict regional anomalies in nominally printed volume of separate test pieces: *Andrew Lang*[1]; James Castle[1]; Douglas Bristow[2]; Robert Landers[3]; Venkata Sriram Siddhardh Nadendla[2]; [1]The Boeing Company; [2]Missouri University of Science and Technology; [3]University of Notre Dame

Supervised machine learning techniques have struggled to accurately predict voxel-wise occurrence of anomalies in metal powder bed parts printed with optimal processing parameters. This work discusses a method to visualize machine learning model predictions in 3D to interrogate patterns in the predictions. A simple logistic regression classifier, with cross validation and an optimized classification threshold, is trained using synthetic in situ features, a machine parameter, and post-process output labels. The logistic regression classifier developed is shown to outperform deep learning and boosted classifiers on the datasets used. Voxel-wise prediction performance is very low, but 3D representation of model predictions shows the developed model can predict anomalies in the correct region of the printed part. The practical use of the developed method is demonstrated by predicting the occurrence of anomalies in nominally printed volume using a model that had been trained on a dataset printed with induced defects.

11:10 AM
Prediction of Microstructure in LPBF using Part-level Thermal Simulations, In-process Sensor Data, and Machine Learning: *Grant King*[1]; [1]University of Nebraska–Lincoln

The microstructure of parts manufactured using laser powder bed fusion (LPBF) are highly dependent on the thermal history (cooling rate) of the part during material deposition. Currently characterization of the microstructure must be completed post-processing. In this research a combination of part-level thermal simulations and in-process sensor data (infrared thermal camera and meltpool imaging pyrometer) are used as inputs to machine learning models trained to predict the microstructure of a part (primary dendritic arm spacing). The approach is demonstrated in the context of twenty-one Inconel 718 parts of various shapes built under differing laser power and velocity settings.

Applications - Hybrid Manufacturing and Composites

Wednesday PM	Room: 416 AB
July 27, 2022	Location: Hilton Austin Hotel

1:10 PM
Inserting Components into Geometries Contructed onto Non-standard Substrates for Electronics Packaging: *Robert Plant*[1]; [1]Nottingham University

AM processes must be optimised to meet standard requirements for industrial applications. Here, we investigate inserting components into geometries constructed onto non-standard substrates using stereolithography (SLA), for the purpose of electronics packaging. Compared to conventional processes, SLA permits greater flexibility to arrange components in three dimensions. This enables an increased feature density, optimised packages for contorted or confined spaces, and permits rapid production for bespoke applications. Additionally, the SLA process-material effects and substrate interactions can result in distortion and compromise the ability to deliver products to the required standard. Specific phenomena of interest to this application, are build accuracy and the quality of adhesion. The latter has been substantially enhanced by a technique involving plasma treatment and the application of a monolayer. The influence of process parameters are analysed and the impact of distorting effects quantified.

1:30 PM
Rapid Three-dimensional Printing of Architected Piezoelectric Structures Using Micro-CLIP: *Siying Liu*[1]; Wenbo Wang[1]; Luyang Liu[1]; Xiangfan Chen[1]; [1]Arizona State University

Piezoelectric composites are thriving in the field of self-sustainable wearable electronics owning to their intrinsic capability of converting mechanical energy to electrical energy and vice versa. Three-dimensional (3D) printing is being extensively adopted in manufacturing 3D piezoelectric structures that deliver anisotropic and directional responses, yet most 3D printing techniques face the speed-accuracy trade-off and either limit themselves to macroscale devices or require prolonged fabrication time. On the contrary, micro continuous liquid interface production (μCLIP) has shown its efficacy in high-speed, high-quality productions of 3D structures.Here, we report rapid, high-resolution 3D printing of piezoelectric composite structures via μCLIP. We formulated functionalized resins utilizing piezoelectric nanoparticles (PiezoNPs) like barium titanate (BTO) with concentrations up to 30 wt% to print 3D structures that deliver piezoelectric performance comparable to other vat-polymerization-based works at unprecedented speeds of up to ~ 60 μm/s. Proof-of-concept demonstrations further validate their capability in flexible and wearable sensing applications.

1:50 PM
Additive Manufacturing of LiNi1/3Mn1/3Co1/3O2 Battery Electrode Material via Vat Photopolymerization Precursor Approach: *Ana Martinez*[1]; Alexis Maurel[1]; Ana Aranzola[1]; Sreeprasad Sreenivasan T[1]; Eric MacDonald[1]; [1]UTEP

This work will show the development of three-dimensional complex battery electrode structures of high-energy density LiNi1/3Mn1/3Co1/3O2 ceramic material by means of a vat photopolymerization process combined with a precursor approach. This approach involves the solubilization of metal precursor salts into a UV-photopolymerizable resin and the in-situ synthesis of the battery material upon thermal post-processing of the printed item. The particular innovation relies on the introduction of soluble salts into the resin, instead of solid particles, which reduces detrimental light scattering and increased viscosity. Formulation of the composite resin and 3D printing of complex structures, followed by an optimization of the thermal post-processing will be thoroughly described. Moreover, this work will address the need for a compromise between the electrochemical performance and mechanical one in order to obtain fully functional additively manufactured battery electrodes. Finally, it will discuss the gaps that limit the multi-material 3D printing of batteries via the vat photopolymerization process.

2:10 PM
Design and Fabrication of Cost-Effective, Light-Weight Bipolar Plate for PEM Fuel Cells using FDM Process: Dinesh Kumar Madheswaran[1]; Arunkumar Jayakumar[1]; *Rajkumar Velu*[2]; [1]SRM-Institute of Science and Technology; [2]Indian Institute of Technology Jammu

The fuel cell technologies have substantial potential to empower the global energy transition. Among various fuel cells, Polymer Electrolyte Membrane Fuel Cells (PEMFCs) are the predominant due to their unique properties. The critical components of PEMFC are the Membrane Electrode Assembly, Gas Diffusion Layer and bipolar plates (BPPs). The BPPs have significant functional attributes such as carrying electric current cell-to-cell, separating each stack cell, providing a reactant gas flow field, and mechanical support. Graphite and metal are conventionally used materials, expensive, and time-consuming based on conventional manufacturing. Polymer composites gained attention for BPPs because of their lightweight, strength and anti-corrosive. The BPP will be manufactured using the Fused Deposition Modelling (FDM) technique at an appropriate proportion of the conductive polymer material. Ironically, polymer composite is less conductive. Carbon/conductive filler is used to enhance the conductivity will be investigated. The fabricated plates undergo characterisation studies and mechanical and electrical conductivity testing.

2:30 PM
Additive Manufacturing of Mixed Potential Sensors for Natural Gas Emissions Monitoring: *Lok-kun Tsui*[1]; Sleight Halley[1]; Kannan Ramaiyan[1]; Kamil Agi[2]; Fernando Garzon[1]; [1]University of New Mexico; [2]SensorComm Technologies Inc.

Methane leaks from natural gas infrastructure represent a significant challenge in combating climate change. There is a need to develop low-cost, robust, and field deployable sensor systems to monitor the nation's natural gas infrastructure for leaks. These requirements are met by the use of mixed potential electrochemical sensors (MPES). MPES are solid-state electrochemical devices where differences in catalytic activity between the electrodes produce a sensor response to an analyte gas. Additive manufacturing methods enable the prototyping of materials and geometries for these devices at low cost and with rapid iteration times. Syringe extrusion was used to deposit zirconia substrates, metal and metal oxide electrodes, and porous solid-state electrolytes. Sensor responses to simulants of methane emissions from natural gas, bovines, and wetlands were collected. Finally, integration of the printed sensors with portable readout and transmission hardware was demonstrated.This project was supported by US Department of Energy award DE-FE0031864.

2:50 PM Break

3:20 PM
Reactive Extrusion Additive Manufacturing (REAM) of Functionally Graded Field-Responsive Thermoset Composites: Oliver Uitz[1]; Ademola Oridate[1]; Rui Leng[2]; Tan Pan[2]; *Carolyn Seepersad*[1]; Zoubeida Ounaies[2]; Mary Frecker[2]; [1]University of Texas at Austin; [2]Penn State

Reactive extrusion is an AM process in which a motion-controlled nozzle mixes and immediately deposits a multi-part thermoset resin to create layered parts that cure rapidly in the ambient environment. By mixing filled and neat resins on demand, it is possible to functionally grade both the structure and the resulting properties of the parts. This research investigates a two-part shape memory polymer in which a low viscosity resin is combined with a crosslinker to yield a thermoset polymer part with structural integrity. Magneto-active iron oxide particles are added to the epoxy resin to create a filled resin that is mixed on demand with neat epoxy resin and crosslinker; control over the mixing and deposition results in a customized distribution of iron oxide content spatially within a part. These composites are shape programmed, and the effect of the functional grading on the magneto-active properties of the shape memory polymer are demonstrated.

3:40 PM
Concrete Additive Manufacturing and Its Use in Energy Storage: *Celeste Atkins*[1]; Brian Post[1]; Joshua Vaughan[1]; Alex Roschli[1]; Amiee Jackson[1]; Phillip Chesser[1]; Peter Wang[1]; Jesse Heineman[1]; [1]Oak Ridge National Laboratory

Heating and cooling buildings is a major source of energy consumption. Ways to store energy in low demand times and use it in peak demand times are needed, especially as renewable energy use become more prevalent. Concrete additive manufacturing (AM) could provide another avenue for thermal storage in buildings. In partnership with the Federal Energy Management Program (FEMP), Oak Ridge National Laboratory (ORNL) has conducted a field validation of thermal energy storage with an active insulation system called the Empower Wall. Concrete AM formwork enabled the use of these technologies. The wall uses electricity in low demand times such as at night when cooling loads are lower to cool the printed concrete formwork and central concrete mass to be used to cool the room at a later time. The Empower Wall was able to reduce energy cost and peak loads on the HVAC system.

4:00 PM
Comparing Additive Approaches: Manufacturing a Wind Turbine Structural Component: *Celeste Atkins*[1]; Brian Post[1]; Alex Roschli[1]; Amiee Jackson[1]; Phillip Chesser[1]; Abigail Barnes[1]; Andrzej Nycz[1]; Luke Meyer[1]; [1]Oak Ridge National Laboratory

As the popularity of large-scale additive manufacturing grows, the question of whether to 3D print a component or manufacture it through traditional means is become more prevalent. This work set out to determine if a component should be 3d printed for one application in particular. A skeleton node (SN) in a wind turbine nacelle is usually made by welding several flat plates together. Three alternative methods were investigated for manufacturing a SN: direct AM of a composite component, AM of a sand-casting mold, and direct AM of a metallic component. These methods included the use of topology optimization to inform the new designs. Then the full-scale components were tested to see how they would perform when loaded. The performance and potential drawbacks of the AM components will be discussed in this work.

4:20 PM
Hybrid Additive and Subtractive Manufacturing of Self-Heating Tooling: *Eric Weflen*[1]; Frank Peters[1]; Matthew Frank[1]; [1]Iowa State University

Pre-heating is a common requirement for production tooling in applications such as compression and injection molding. While the carbon fiber reinforcements commonly used in large-area additive manufacturing improve the thermal conductivity of polymers, they are still far below that of aluminum and steel tooling. This study presents a method for direct, local heating of composite tooling through electrical resistance heating without the need for additional heating elements. A current is induced on the surface of the composite tooling, resulting in resistance heating of the substrate. High conductivity material is locally embedded to achieve local control over the heating characteristics. Demonstration tooling is produced using hybrid additive and subtractive manufacturing using an AMBIT XTRUDE in a HAAS machining center and evaluated with thermal imaging across several different voltage settings. Self-heating tooling expands the potential tooling applications of additive manufacturing by overcoming the challenges of low thermal conductivity materials.

4:40 PM
Clamping Concept for 6-side Hybrid Manufacturing: *Stefan Mischliwski*[1]; Matthias Weigold[1]; [1]PTW - TU Darmstadt

For most technical applications, the surface quality and tolerances that result directly from additive processes are not suitable. Hybrid manufacturing as a combination of additive and subtractive manufacturing process steps can help solving this issue. In this work, a conceptional adjustable cast clamping pro-cess is introduced for a combination of Laser-based Powder-Bed-Fusion (LPBF) and milling. For component clamping during the milling process, the components are cast in place with a low-melting metal alloy, creating form-fit and force-fit connection. To prove the applicability, a rough estimation of oc-curring milling forces was conducted. In a subsequent series of tests, validation of clamping force was carried out using complex part geometries. A prototype fixture designed for this cast clamping process has been developed and tested. This fixture allows complex non-restricted 6-side machining of parts without moving it relative to the fixture or the need of any additional manual rework on part surfaces.

Applications: Lattices and Cellular - Heterogeneous Lattice Structures

Wednesday PM	Room: 417 AB
July 27, 2022	Location: Hilton Austin Hotel

1:10 PM
Evaluation of Functionally Graded Lattice Properties of Laser Powder Bed Fused Stainless Steel 316l: *Bharath Bhushan Ravichander*[1]; Shweta Hanmant Jagdale[1]; Sumanth Theeda[1]; Golden Kumar[1]; [1]University of texas at dallas

The development of metal Additive Manufacturing (AM) techniques, in particular the laser powder bed fusion (LPBF) process, has led to an increase in the innovative design and fabrication of lightweight and complex porous metal structures. Despite the limitations of LPBF process which prevent the porous structures from being geometrically accurate, it eliminates the difficulties presented by conventional manufacturing techniques in the fabrication of highly complex structures. The properties of as-built porous structures depend on the unit cell design and porosity level. These lightweight metal structures have applications in medical and aerospace fields. The relationships between the lattice geometry and performance must be determined to successfully implement the functional lattice designs. In this study, functionally graded lattice structures are fabricated from steel using SLM technique and the effect of different porosity types on the manufacturability, density and mechanical properties are investigated.

1:30 PM
Electrodeposition of Metals onto 3D-Printed Lattices: *Auston Clemens*[1]; Anna Ivanoskaya[1]; Jack Davis[1]; Chris Orme[1]; Rohan Akolkar[2]; Nikola Dudukovic[1]; [1]Lawrence Livermore National Laboratory; [2]Case Western Reserve University

The ability to uniformly deposit metallic coatings onto geometrically complex substrates plays a significant role in developing specialized applications from coating detailed RF components to depositing catalytic coatings onto ordered foams electrodes for electrochemical flow reactors. However, there presently lacks guidelines for electrodeposition in porous media due to the problem's multi-scale complexity. We present a framework for deconvoluting this process through continuum-level modeling and experimental validation of electrodeposited copper onto additively manufactured conductive lattice structures. By implementing kinetics, nucleation, and coupling electric field and hydrodynamic effects, we can predict the metallic deposit quality and thickness profile using 3D numerical simulations. We further devise scaling laws with the aim of facilitating control over deposition uniformities on different lattice architectures and dimensions under fluid flow. This work is 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 20-ERD-056. LLNL-ABS-834015.

1:50 PM
Fused Filament Fabrication of a Multi-material Metamaterial for Tailored Compliance: *Callie Zawaski*[1]; Seda Oturak[1]; Melinda McKeehan[1]; Wesley Reinhart[1]; [1]Penn State

Tailored compliance is valuable to provide comfort and prevent unnecessary pain or strain on individuals in pain or recovering from injury by tailoring seats, footwear, braces, or prosthetics with variable compliance to accommodate for the pain or injury. Multi-material additive manufacturing enables the ability to manufacture meta-materials with tailored material properties, such as compliance. This study focuses on tailoring compression response by patterning an elastic matrix with stiff reinforcement material in quasi-2-D laminate patterns and 3-D spherical patterns. The composites are simulated using finite element analysis with hyperelastic constitutive models. Patterned parts were printed using Fused Filament Fabrication (FFF) of two different grades of TPU to verify and fit the computational model. These results will be used to design for variable compliance within a structure.

2:10 PM
Experimental and Numerical Analysis of Lattice Structures with Different Heterogeneities: *Guoying Dong*[1]; Yuchen Ding[1]; Ladpha Teawdeswan[1]; Chaoqian Luo[1]; Kai Yu[1]; [1]University of Colorado Denver

Lattice structures with optimized material distributions can achieve unique mechanical properties such as high stiffness-to-weight ratio. However, the numerical analysis of the mechanical properties of heterogeneous lattice structures is challenging. In this research, three numerical approaches, including the beam element model, tetrahedral element model, and two-stage homogenization model, were used to predict the stiffness of lattice structures with different heterogeneities. Compression tests were conducted to evaluate the accuracy of the simulation results of each numerical approach. It was found that the accuracy of the numerical model varies with the increasing of heterogeneities. The beam element model significantly underestimated the stiffness. The tetrahedral element model is the most accurate, but the computational cost is extremely higher than others. The results also indicated that, although the homogenization-based numerical model can substantially reduce the computational cost, the accuracy can be compromised due to the heterogeneity of lattice structures.

2:30 PM
A Limited-scale Experimental Investigation of the Unit Cell Topology Effects of Interpenetrating Compound Cellular Structure Designs: Matthew Roe[1]; *Li Yang*[1]; [1]University of Louisville

The interpenetrating cellular structure is a novel recent design concept that has been subjected to some preliminary research efforts in recent years. As there still exist relatively limited understanding of such design concept, the current work aimed to provide additional insights via experimental-based study. Several baseline cellular unit cell structures that follow multiple cellular unit cell topology design rules were included in the study, in order to investigate whether there exist significant design relationships between the cellular topology pairing and the resulting performance of the interpenetrating structures. In general, the interpenetrating designs did not result in synergetic performance reinforcement with elastic modulus, ultimate strength or energy absorption, except for specific cases. In most cases, the local strut interaction between the two component cellular structures appear to exert negative effects on the properties of the interpenetrating structures. The results tentatively suggest the need of additional research with such concept.

2:50 PM Break

3:20 PM
Cellular Fluidics: Tuning Multiphase Interfaces in 3D Using Architected Porous Media: *Nikola Dudukovic*[1]; [1]Lawrence Livermore National Laboratory

Many processes in both nature and industry occur at the microscale and involve complex multiphase interfaces. Most microporous media, both natural and man-made, is stochastic and difficult to predict or control reliably. On the other hand, conventional microfluidic devices are often limited to enclosed channels and planar geometries, hindering their usefulness in multiphase processes. We present a novel platform based on capillary fluid flow in ordered 3D lattices [1]. Using deterministic cell and lattice design, combined with additive manufacturing methods that provide access to length scales < 100 um, we can fabricate complex structures with tuned porosity and functionalities. This approach enables selective placement and direction of fluid flow into predetermined continuous paths through the structure, as well as optimizing for the occurrence of gas-liquid, liquid-liquid, or gas-liquid-solid interfaces. 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-778327.

3:40 PM
Optimized Dissolvable Support Design for 316L Stainless Steel Produced by Laser Powder Bed Fusion: *Shawn Hinnebusch*[1]; David Anderson[1]; Kevin Glunt[1]; Robert Hoffman[2]; Owen Hildreth[2]; Albert To[1]; [1]University of Pittsburgh; [2]Colorado School of Mines

Creating parts by laser powder bed fusion (L-PBF) process is challenging as support material is usually required for complex parts. As L-PBF can only use one material, creating a dissolvable support structure has many challenges. To have a dissolvable support, a low-density structure is usually required, but this type of structure typically has cracking and high distortion due to the presence of high residual stress. This work proposes a lattice structure design that can ensure printability while maintaining fluid flow across all the support to allow the structure to fully dissolvable. Using a hybrid lattice structure, the overall mass is minimized while still meeting the criteria for residual stress. Also, employing a self-terminating solution, the part retains the material while the support structure can be fully dissolved.

Materials: Ceramics and Glasses

Wednesday PM	Room: 400-402
July 27, 2022	Location: Hilton Austin Hotel

1:10 PM
Laser Additive Manufacturing of Thermoelectric Bismuth Telluride (Bi2Te3), Earth-Abundant Copper Sulfide (Cu2S) and Silver Selenide (Ag2Se): Cagri Oztan[1]; Eric Barnes[2]; *Eric Fodran*[2]; Saniya LeBlanc[1]; [1]The George Washington University; [2]Northrop Grumman

Thermoelectric energy conversion materials are used for waste heat recovery and thermal management. Traditional thermoelectric manufacturing methods are complex, limited to planar shapes, require use of expensive equipment and result in a substantial loss of material. Additive manufacturing has effectively been used to address these limitations lately. In this research, process-structure-property relationships of three different laser additive manufactured thermoelectric compounds, bismuth telluride (the standard reference material) along with earth abundant copper sulfide and silver selenide were studied. The impacts of various laser processing parameters such as scan speed, laser power, number of scans and scan pattern on microstructural features and thermoelectric properties are reported in this work.

1:30 PM
Additive Manufacturing of Zirconium Carbide by Ceramic On-Demand Extrusion: *Clare Sabata*[1]; Austin Martin[1]; Gregory Hilmas[1]; Jeremy Watts[1]; Ming Leu[1]; Tieshu Huang[2]; [1]Missouri University of Science and Technology; [2]NNSA's Kansas City National Security Campus

Zirconium carbide (ZrC) is an ultra-high temperature ceramic that is of interest for applications in extreme environments due to its high melting point (>3000°C), high hardness (~25 GPa) and low density (6.73 g/cm3). Ceramic On-Demand Extrusion (CODE) is a direct-ink writing additive manufacturing process that can create large and complex geometries. In this work, the feasibility of the additive manufacturing (AM) of ZrC via CODE was investigated. A highly loaded paste formulation was created using commercial ZrC powder. Paste rheology was optimized by altering the concentrations of ZrC, dispersant, and binder. ZrC specimens of various geometries were processed using CODE and then pressurelessly sintered to near full density. The CODE printing parameters, final print results, and sintering studies will be discussed. Archimedes' density, scanning electron microscopy, thermal property testing, and mechanical property testing were performed to characterize the material data for the printed ZrC parts and will also be discussed.

1:50 PM

Laser Powder Bed Fusion Additive Manufacturing of Zirconium Carbide: *Alexander Wilson-Heid*[1]; R. Joey Griffiths[1]; Aiden Martin[1]; Kiel Holliday[1]; Jason Jeffries[1]; [1]Lawrence Livermore National Laboratory

Laser powder bed fusion (LPBF) additive manufacturing (AM) can realize the extreme temperatures required for melting and solidification of ultra-high temperature ceramics, including zirconium carbide (ZrC). ZrC has a melting temperature above 3000 °C and a high hardness, making ZrC suitable for a broad range of high temperature environments. In this study, build process parameter combinations of laser power, scan speed, and beam size were selected based on single track melt pool characteristics, including dimensional uniformity. A custom LPBF machine was then used to determine hatch spacing and layer height parameters that resulted in fabricated cylinder samples with density >70% based on optical measurements. Generating complex structures using AM for high temperature applications while still maintaining chemical stability expands the application of ZrC particularly in next generation nuclear reactor designs. This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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Ceramic On-Demand Extrusion of ZrB_2-SiC Microchannels for Ultra High-Temperature Compact Heat Exchanger: *Abid Hasan Rafi*[1]; Marharyta Lakusta[1]; Vincenzo Anthony[1]; Grace Basler[1]; Sophie Grier[1]; Lauren Moeller[1]; David Lipke[1]; Jeremy Lee Watts[1]; Greg Hilmas[1]; Ming C. Leu[1]; [1]Missouri University of Science and Technology

Ceramic On-Demand Extrusion (CODE) is a paste extrusion based additive manufacturing process that has been developed for fabrication of dense ceramic components. This paper presents a study of using the CODE process to build microchannels with ZrB_2-SiC aqueous paste for the fabrication of an ultra-high-temperature compact heat exchanger (UHTCHE). The aqueous paste is developed from a mixture of ZrB_2-SiC (70/30) powders to possess properties suitable for the extrusion process. The performance and properties of the microchannels are tested for use in the UHTCHE, which features a large heat transfer area to volume ratio and has potential applications in aero-engines, microturbines, etc., as well as high efficiency power generation systems.

2:30 PM

Printed Photonics Using Single Mode Optical Fiber: Nicholas Capps[1]; Robert Landers[1]; *Edward Kinzel*[1]; [1]Univ. of Notre Dame

Single mode optical fiber is widely used for communications and sensing. This study investigates using it as a feedstock for digital glass forming with applications ranging from printed photonics to light weight low coefficient of thermal expansion structures. The fiber is fed into the intersection of a CO2 laser and workpiece. The laser heats the fiber allowing the molten region to be fomed by reaction forces from the workpiece and filament. The core cladding structure of the fiber which permits waveguiding. The transmission of the waveguide is highly dependent on the morphology and significant precision is required. This includes gradual transitions to minimize reflections to/from to optical fiber. This approach can be used to print 3D freestanding wave guiding structures in addition to well fused 2D patterns on the substrate. The morphology of the printed fiber is characterized along with the waveguiding properties.

2:50 PM Break

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Direct-Writing SiC with Micro-Cold Spray: Effect of Particle Impact Velocity on Film Morphology: *Derek Davies*[1]; Michael Gammage[2]; Michael Becker[1]; John Keto[1]; Desiderio Kovar[1]; [1]University of Texas at Austin; [2]CCDC DEVCOM Army Research Laboratory

Micro-cold spray produces thick films by accelerating aerosolized submicron to micon-scale particles through a nozzle from near atmospheric pressure (200-760 Torr) to medium vacuum (0.5-3 Torr). By impacting these accelerated particles on a substrate that is translated orthogonal to the aerosol jet, patterned films are deposited. As compared to cold spray, which is capable of depositing metallic or metal-matrix composite films, micro-cold spray has demonstrated the unique capability of depositing high quality ceramic films at room temperature. Deposition of SiC powder with average particle size of 500 nm is performed using a custom MCS machine equipped with a long converging-diverging nozzle. Impact velocity of the particles is varied by changing carrier gas type and upstream and downstream pressures. The resulting films are characterized by SEM imaging, EDS analysis, nano-wear testing, and adhesion testing.

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Direct Write of Zinc Oxide Films by Micro Cold Spray: *Scott Burlison*[1]; Michael Becker[2]; Desiderio Kovar[3]; [1]Department of Mechanical Engineering and Center for Additive Manufacturing and Design Innovation at The University of Texas at Austin; [2]Center for Additive Manufacturing and Design Innovation, Materials Science and Engineering Program, and Department of Electrical and Computer Engineering at The University of Texas at Austin; [3]Department of Mechanical Engineering, Center for Additive Manufacturing and Design Innovation, and Materials Science and Engineering Program at The University of Texas at Austin

The micro cold spray (MCS) process utilizes high velocity impact of solid sub-micron ceramic particles for direct writing of patterned, high quality, thick films at room temperature. Compared to cold spray, which is primarily used for metals and composites, MCS allows for lower operating pressures, smaller particles, finer feature sizes, and the deposition of ceramics. Zinc oxide (ZnO) powder with a size distribution of 10 - 30 nm was deposited using a custom MCS machine equipped with a long converging-diverging nozzle, with impact velocity being altered by means of carrier gas type and the upstream (~1 atm) and downstream (~few torr) gas pressures. Produced films were characterized by SEM imaging and EDS analysis.

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Single Particle Impacts in Micro Cold Spray: *Aidan Moyers*[1]; Michael Becker[1]; Desiderio Kovar[1]; [1]The University of Texas at Austin

Micro-cold spray (MCS) is a direct-write process that can produce patterned thick ceramic films (1-100 μm) onto a wide variety of substrates through repeated high velocity impacts of sub-micron particles. Thick films of yttria (Y2O3) have applications as protective barriers against highly aggressive environments, such as plasma etching chambers or mold coatings for reactive metal castings, yet are difficult to manufacture through other techniques. However, the deformation mechanisms active within individual particle impacts are poorly understood, and as a result, the processing window of MCS is difficult to predict. This study seeks to experimentally analyze individual particle impacts over a wide range of particle sizes, using electron microscopy coupled with aerodynamic modeling to predict impact velocity based on input process variables. Trends in these behaviors were analyzed and used to understand which processing conditions produce high quality films.

4:20 PM

Lightweight, Electrically Conductive, and Thermally Insulating porous ceramics through Stereolithography 3D Printing: *Zipeng Guo*[1]; Chi Zhou[1]; Shengqiang Ren[1]; Jason Armstrong[1]; [1]University at Buffalo, State University of New York

Ceramics have strong ionic and covalent bonds to firmly pack the atoms, ensuring outstanding structural integrity. However, most ceramics are considered electric insulators because the intrinsic dense structure does not allow free electrons to move, resisting the electric current flows. We report an additive manufacturing strategy that uses mesoporous silica and graphene to fabricate electrically conductive ceramic architectures via stereolithography printing. Graphene percolates into the porous silica to establish a uniform conductive graphitic network embedded in the silica-silicon carbide scaffold. Correspondingly, it shows high electrical conductivity measured up to 1,000S/m and maintains stability under high temperatures above 600C. Benefit from the ultra-porous silica feedstock, the 3D-printed conductive ceramic demonstrates outstanding lightweight and thermal insulation properties. Furthermore, the mechanical performance can be effectively reinforced by densifying the microstructures via spark plasma sintering treatment. The proposed AM strategy widens the potential of ceramics as structural materials, offering promising pathways toward high-temperature applications.

4:40 PM
Study on Development of DLP Printed Metal - Ceramic Structures: *Bharat Yelamanchi*[1]; Eric MacDonald[2]; Pedro Cortes[1]; [1]Youngstown state university; [2]The University of Texas at El Paso

Multi Material 3D printing is gaining traction in various industries where there is a need for enhanced electrochemical and electro mechanical properties. Such multi material components provide a good balance of the properties as opposed to the individual constituents. Many additive manufacturing (AM) techniques are employed in an effort to cater such needs for multi material printing, some more successful than the other. In this study, a Digital light processing (DLP) AM technique was employed to successfully manufacture multilayered metal-ceramic structures. Different materials such as alumina and copper were selected to investigate the interfacial interaction. The printability of the materials to produce the multi material parts was studied and a process parameter optimization was conducted to optimize the compatibility of the materials and to maximize the automation of the printing process. Sintering behavior of the multimaterial components at the interface was also studied in this research program.

Materials: Metals - Ferrous Metals including 17-4PH

Wednesday PM Room: 615 AB
July 27, 2022 Location: Hilton Austin Hotel

1:10 PM
Effect of Powder Characteristics on Fatigue Performance of Additively Manufactured 17-4 PH Stainless Steel: *Arun Poudel*[1]; Arash Soltani-Tehrani[1]; Shuai Shao[1]; Nima Shamsaei[1]; [1]Auburn University

The characteristics of powder feedstock used during laser powder bed fusion (L-PBF) can influence the mechanical performance of the fabricated parts. The rheological properties and the internal porosity of the powder particles can affect the defect content and thus, impact the fatigue performance. Two batches of 17-4 precipitation hardening stainless steel powders supplied by two different vendors are used to fabricate the L-PBF specimens and investigate the effect of powder characteristics on porosity and fatigue behavior. It is observed that the powder batch with wider particle size distribution, higher compressibility, and internal porosity results in a higher defect content in the fabricated specimens. In addition, higher cohesion between the powder particles also contributed to the higher defect content due to the formation of agglomerates leading to a poor packing state. Higher defect content in the machined specimens can result in an inferior fatigue lives with more scatter.

1:30 PM
Defect-sensitive Fatigue Modeling for L-PBF Parts in Very High Cycle Regime: Jade Welsh[1]; Pooriya Nezhadfar[2]; *Indrajit Nandi*[2]; Jutima Simsiriwong[1]; Shuai Shao[2]; Nima Shamsaei[2]; [1]University of North Florida; [2]Auburn University

Murakami's approach has been shown to work well in high cycle fatigue regime to related the fatigue strength to the critical defect size and location in additively manufactured (AM) metallic materials. However, the applicability of this model has not yet been fully examined for AM materials in the very high cycle fatigue (VHCF) regime. Therefore, this study investigates the possibility of relating the volumetric defect features to the fatigue strength of 17-4 precipitation hardened (PH) stainless steel (SS) manufactured via laser-powder bed fusion (L-PBF) additive manufacturing technology. The 17-4 PH SS specimens are manufactured using an EOS M290 L-PBF system, heat treated, machined and polished, and tested in VHCF regime using an ultrasonic fatigue testing system. Careful fractography has been also performed on all fractured specimens to determine the volumetric defects responsible for the crack initiation.

1:50 PM
Embedding Information in Additively Manufactured Metals via Magnetic Property Grading for Traceability and Counterfeiting Prevention: *Deniz Ebeperi*[1]; Daniel Salas Mula[1]; Ibrahim Karaman[1]; Raymundo Arroyave[1]; Richard Malak[2]; [1]Texas A&M University Department of Materials Science and Engineering; [2]Texas A&M University, Department of Mechanical Engineering

Counterfeiting is a significant problem in global product market which has social and economic consequences, such as fiscal losses, failure of investments and unemployment. According to International Commission of Commerce in 2022, the total value of counterfeit products will reach $2.3 trillion, and their negative impact on global economy will be $4.2 trillion while putting 5.4 million employments at stake. We have recently developed a cost-effective countermeasure for counterfeiting, by embedding information as hidden magnetic barcodes via direct energy deposition of stainless steels with different magnetic properties. The local magnetic flux was measured in fabricated parts to obtain a magnetic flux intensity map, clearly revealing the embedded magnetic barcode. A comparison between microstructure of different stainless steels and magnetic flux intensities revealed the effects of process parameters on magnetic response. Optimization of processing parameters were discussed in the light of the challenges associated with incorporating this technique in practice.

2:10 PM
A Process Optimization Framework for Direct Energy Deposition: Densification, Microstructure, and Mechanical Properties of an Iron-chromium Alloy: *Austin Whitt*[1]; Raiyan Seede[1]; Jiahui Ye[2]; Michael Elverud[1]; Matthew Vaughan[1]; Alaa Elwany[2]; Raymundo Arroyave[1]; Ibrahim Karaman[1]; [1]Department of Materials Science and Engineering, Texas A&M University; [2]Department of Industrial and Systems Engineering, Texas A&M University

Achieving high-density parts and targeted build heights using direct energy deposition (DED) can be challenging due to the large number of highly sensitive process variables. This work proposes a robust parameter optimization framework to generate process maps for primary parameters in DED. Single-track experiments are utilized to map the laser power – scan speed – mass flow rate parameter space, and a combination of geometric criteria for hatch spacing and layer height are proposed to determine parameter sets that achieve both targeted build heights and mitigate porosity formation. Specimens with >99% density, excellent dimensional accuracy, and consistent mechanical properties were successfully fabricated over a wide range of process parameters for an Fe-9wt.%Cr (Fe9Cr) alloy, a surrogate for radiation damage-resistant reduced activation ferritic/martensitic (RAFM) steels. This framework will allow for accelerated parameter optimization for novel alloy systems, as well as open the possibility for local microstructure control while mitigating defect formation.

2:30 PM
Visualization of Melt Pool Stability for Wire- and Powder-based Directed Energy Deposition Repair of Gray Cast Iron: *Jakob Hamilton*[1]; Iris Rivero[1]; [1]Rochester Institute of Technology

Gray cast iron is favorable in agricultural and automotive castings for its high strength and wear resistance but offers difficulty during remanufacturing. Key challenges include restoring strength while avoiding brittle phases and porosity. While wire-based directed energy deposition (DED) repair studies are limited, powder-based DED has shown promise under specific thermal conditions. Determining these conditions is challenging due to the localized and transient nature of the process. Herein, in-situ high speed imaging is employed for quantifying melt pool stability for optimal thermal conditions in wire- and powder-based DED repair of gray cast iron. The rate of gas generation and escapement from the melt pool is driven by laser power and traverse speed. Stable deposition conditions, i.e. minimal melt pool geometric deviation, are identified for both media types, and the resultant strength is quantified. The insights provided by in-situ imaging promote superior parameter selection and is extendable to other difficult-to-repair materials.

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Directed Energy Deposition Processing-Performance Relationship of AF9628: *Mianqing Yang*[1]; Mohammad Parvez[1]; Todd Sparks[2]; Saheed Babolola[1]; Joseph Newkrik[1]; Frank Liou[1]; K Chandrashekhara[1]; [1]Missouri University of Science and Technology; [2]Product Innovation and Engineering, LLC, St. James, MO 65559

AF9628 low alloy steel is a type of novel steel known for its low cost, high hardness, and outstanding tensile performance. However, the processing methods of AF9628 have been less studied in the additive manufacturing field. As the balance of hardness and tensile results is closely related to the cooling process during manufacturing the process window and its relationship to resultant tensile properties were explored. By using the DED method, specimens of this steel were successfully fabricated, and tensile test results were obtained. The AF9628 steel can be manufactured for tailored properties with the DED process by controlling the cooling method. This work was funded by ARL - GVSC under cooperative agreement W911NF-20-2-0251.

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Alternative Stainless Tool Steels for Additive Manufacturing: *Emilie Valente*[1]; Venkata Karthrik Nadimpalli[1]; Thomas Dahmen[1]; Marcel Somers[1]; Thomas Christiansen[1]; David Pedersen[1]; [1]Technical University of Denmark

The additive manufacturing of tool steels have been limited to either low carbon maraging steels, or extreme pre-heating temperatures for materials such as H13 or D2, to avoid crack formation. This study investigates the use of austenite stabilizing elements, to avoid the phase transformations that have so far been limiting the processability of tool steels. The study will show L-PBF of a broad range of chemical compositions, identifying an area with high processability without pre-heating, due to austenitic solidification. A selected composition is chosen for further investigations, show-casing that a hardness of 60 HRC can be achieved after heat treatment.

4:00 PM

Effect of Surface Preparation on LPBF 17-4PH Mechanical Properties: *Joseph Bartolai*[1]; Natalie Nukaya[2]; [1]Pennsylvania State University; [2]Idaho National Laboratory

Typically, when mechanical properties are reported for a combination of a feedstock material and a Laser Powder Bed Fusion (LPBF) additive machine, they are derived from experiments performed on test specimen machined out of blanks produced by the LPBF machine. The as-machined surface condition of these test specimens does not match the as-built surface condition of most end-use parts produced by LPBF, leading to mechanical property discrepancies. This work finds a statistically significant difference between the two surface conditions when comparing quasi-static tension and impact testing results. This discovered result is found consistently among samples built using the same 17-4PH stainless steel feedstock and H900 heat treatment process across two different manufacturer's LPBF machines and process parameters. The findings suggest that designers use mechanical properties of the appropriate surface condition (as-built or as-machined) to optimize material usage and mechanical properties from LPBF produced parts.

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Comparison of Tensile Properties and Microstructure of Laser-Powder Bed Fusion 17-4PH Stainless Steel: *Katherine Fowler*; Evan Handler; Aidan Cowhig; Caroline Vail; [1]

Additive manufacturing (AM) processes such as Laser-Powder Bed Fusion (L-PBF) have gained interest due to their ability to manufacture parts with complex geometries. However, the properties of material manufactured by L-PBF can vary widely between different manufacturing parameters, systems, and manufacturing sites. This results in the need for extensive qualification processes for L-PBF systems, which must be repeated with each system and whenever any change is made in the essential manufacturing parameters. To improve the qualification process, Naval Surface Warfare Center, Carderock Division (NSWCCD) has led a round-robin study to examine the repeatability of L-PBF material manufactured on different AM systems across different warfare centers. This study examined the material properties, including microstructure and tensile properties, of 17-4PH stainless steel printed on six different L-PBF systems by three different manufacturers. Correlations between the tensile properties and microstructure were examined across builds manufactured at different warfare centers with different AM systems.

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Phase Transformation Dynamics-guided Alloy Design for Additive Manufacturing: *Qilin Guo*[1]; Minglei Qu[1]; Chihpin Chuang[2]; Lianghua Xiong[3]; Ali Nabaa[1]; Zachary Young[1]; Yang Ren[2]; Peter Kenesei[2]; Fan Zhang[4]; Lianyi Chen[1]; [1]University Of Wisconsin Madison; [2]Argonne National Laboratory; [3]Missouri University of Science and Technology; [4]National Institute of Standards and Technology

Fusion-based additive manufacturing technologies enable the fabrication of geometrically and compositionally complex parts unachievable by conventional manufacturing methods. However, the non-uniform and far-from-equilibrium heating/cooling conditions pose a significant challenge to consistently obtaining desirable phases in the as-printed parts. Here we report a martensite stainless steel design guided by phase transformation dynamics revealed by in-situ high-speed high-energy X-ray diffraction. This designed stainless steel consistently forms desired fully-martensitic structure across a wide range of cooling rates (10^2–10^7 □/s), which enables direct printing of parts with fully-martensitic structure. The as-printed material exhibits a yield strength of 1157 ± 23 MPa, comparable to its wrought counterpart after precipitation-hardening heat-treatment. The as-printed property is attributed to the fully-martensitic structure and the fine precipitates formed during the intrinsic heat treatment in additive manufacturing. The phase transformation dynamics guided alloy design strategy demonstrated here opens the path for developing reliable, high-performance alloys specific for additive manufacturing.

Materials: Metals - Titanium

Wednesday PM	Room: 616 AB
July 27, 2022	Location: Hilton Austin Hotel

1:10 PM

Effect of Defects on the Mechanical Properties of Laser Powder Bed-fused Ti-6Al-4V: *Muztahid Muhammad*[1]; Shuai Shao[1]; Nima Shamsaei[1]; [1]Auburn University

Process-induced volumetric defects are inherent to additively manufactured parts. This study investigates the effect of volumetric defects on the tensile properties of the laser powder bed fusion (L-PBF) Ti-6Al-4V specimens fabricated with large variations in process parameters (a total of six sets of process parameters). Cylindrical bars of L-PBF Ti-6Al-4V specimens are stress-relieved before removal from plates and machined to tensile specimens. The defect distribution of specimens resulting from each set of process parameters is analyzed using a high-resolution X-ray Computed Tomography machine. Quasi-static tensile tests are performed at room temperature. A scanning electron microscope is used to conduct fractography. Tensile results are correlated with defect statistics and identified features on fracture surfaces.

1:30 PM

Development of Composite-like Parts using SLM: *Aditya Krishna Ganesh Ram*[1]; Oscar Valdez Loya[1]; Sandesh Amgai[1]; Ahmet Tanrikulu[1]; Paul Davidson[1]; Amirhesam Amerinatanzi[1]; [1]The University of Texas at Arlington

Additive manufacturing (AM) has allowed fabrication of intricate structures with ease compared to conventional methods. Although traditional composite structures use two or more materials, in this study Selective Laser Melting (SLM) was used to realize a composite like structure out of a single material stock. Ti64 powder was used to fabricate specimens with print patterns representing [0/90]xs and [+45/-45]xs composite configurations. Patterns were realized by varying the print parameters and cooling rates. Resulting variation in the microstructure was confirmed with hardness testing and SEM images of the sample across the printed patterns. Tensile tests combined with DIC analysis showed print patterns do influence mechanical and fracture response. On this basis, it is possible to create an additively manufactured part that shows a response like that of a composite, therefore allowing for the fabrication of parts with tailored material properties while using a single material feedstock.

1:50 PM
Key Process Variable Drifts and their Impact on Defect Structure and Tensile Behavior of L-PBF Ti-6Al-4V: Mohammad Salman Yasin[1]; Arash Soltani-Tehrani[1]; *Arun Poudel*[1]; Shuai Shao[1]; Nima Shamsaei[1]; [1]Auburn University

The process parameters used in laser powder bed fusion (L-PBF) influence the defect formation in fabricated parts. However, key process variables (KPVs) such as laser power and hatch distance may drift within their tolerances during fabrication. These variations can result in different defect contents in parts and consequently, may lead to build-to-build inconsistency. Therefore, this study aims to investigate the effects of KPV drifts on the porosity and tensile behavior of L-PBF Ti-6Al-4V. To simulate potential drifts in the parameters of EOS M290 L-PBF machine, laser power and hatch distance are altered by ± 4% and ± 2.4%, respectively, according to the manufacturer's input. Porosity analysis and hardness tests are conducted on witness coupons, while tensile tests are performed on machined specimens.

2:10 PM
Effect of Powder Reuse on Microstructural and Fatigue Properties of Ti-6Al-4V Fabricated via Directed Energy Deposition: *Mohammad Bagher Mahtabi*[1]; Aref Yadollahi[1]; Ryan Stokes[2]; Courtney Morgan[2]; Joseph Young[2]; Haley Doude[2]; Linkan Bian[2]; [1]University of South Alabama; [2]Mississippi State University

In metal Additive Manufacturing (AM) processes, due to the high cost of metal powder, it is common to reuse the collected unused powder from the build envelope for future builds. Powder reuse may adversely affect the powder characteristics, including powder followability, size distribution, chemical composition, etc., and consequently, the resultant microstructural features and mechanical properties. Thus, this study aims to investigate the effect of powder reuse on the microstructural features and various mechanical properties of Ti-6Al-4V specimens fabricated using a directed laser deposition (DLD) process. Characteristics of reused powder, such as the size distribution and chemical composition, were evaluated and compared with the virgin powder. Microstructural features and characteristics of the process-induced defects were examined using scanning electron microscopy and x-ray computed tomography, respectively. Monotonic tensile and fatigue properties of the specimens fabricated using the reused powder were compared to their control counterparts, i.e. fabricated using the virgin powder.

2:30 PM
Hot Isostatic Pressing to Increase Isotropic Behavior of Wire DED Ti6Al4V: LaRico Treadwell; Jonathan Pegues[1]; *Shaun Whetten*[1]; Tyler Chilson[1]; [1]Sandia National Labs

Hot Isostatic Pressing (HIP) can be a useful tool to increase the density of metal Additively Manufactured (AM) parts. This post-process route can have significant impacts on the microstructure and material properties such as strength, ductility, and fatigue resistance. Many metal AM materials, especially those fabricated using wire based directed energy deposition (W-DED) process, have a high degree of anisotropic behavior resulting from the columnar prior microstructure. Titanium based alloys can be highly sensitive to these massive grains as the prior boundaries are primary nucleation sites for grains promoting the formation of continuous across the length of the boundaries. This talk discusses preliminary efforts to utilize HIP as a means to reduce variability in mechanical properties and its effects on the anisotropic behavior of W-DED Ti-6Al-4V products.SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525

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Heat Treatment Effects on Mechanical Properties of Electron Beam Additive Manufactured Ti-6Al-4V: *Jonathan Pegues*[1]; Shaun Whetten[1]; Andrew Kustas[1]; Tyler Chilson[1]; [1]Sandia National Labs

Electron beam additive manufacturing (EBAM) is an attractive additive manufacturing (AM) process for large structural components. The rapid solidification and layer-by-layer process associated with DED results in non-ideal microstructures, such as large grains with strong crystallographic textures, resulting in severe anisotropy and low ductility. Despite these challenges, DED has been identified as a potential solution for the manufacturing of near net shape Ti-6Al-4V preforms. In this work, we explore several heat treatment processes, including HIP, and their effects on microstructure and tensile properties. A high throughput tensile testing procedure was utilized to generate statistically relevant data sets related to each specific heat treatment and sample orientation. Results are discussed in the context of microstructural evolution and the resulting fracture behavior for each condition as compared to conventionally processed and wire arc additive manufactured Ti-6Al-4V. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525

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Characterization of the Fatigue Strength of Additively Manufactured Ti-6Al-4V Specimens with Residual Stress and Recoater Blade Interference Flaws: *Joshua Mochache*[1]; Robert Taylor[2]; Amir Ameri[2]; Jeremy Wilson[3]; [1]Bell Flight Textron Inc.; [2]University of Texas Arlington; [3]AADFW Inc.

A study was undertaken to characterize the reduction in fatigue strength of additively manufactured (AM) Ti-6Al-4V specimens built using the University of Texas at Arlington's EOS m290 Laser Powder Bed Fusion (L-PBF) machine with residual stresses and Recoater Blade Interference Flaws (RBIF). The specimens were built per ASTM-E466 and had cylindrical test sections slightly over quarter-inch diameter with as-built surface finishes and no post process heat treatment for residual stress relief. Fatigue strength comparisons based on fatigue test results were presented by S-N and Soderberg plots juxtaposing similarly-built specimens with residual stresses and RBIF against those without RBIF with additional comparisons from other results of similar L-PBF Ti-6Al-4V specimens with heat treatment stress relief and with as-built surface finish versus polished surface finishes. Notional Knock-Down-Factors (KDFs) resulting from the RBIF only comparisons as well as the combination of RBIF and residual stresses to baseline polished and stress-relieved specimens are presented with the aim of providing enhancements in the understanding of worst-case KDFs especially for application in aerospace deterministic structural fatigue and damage tolerance evaluation.

4:00 PM
Effects of Process Interruption during Laser Powder Bed Fusion on the Microstructural and Mechanical Properties of Fabricated Parts: *Mohammad Bagher Mahtabi*[1]; Ryan Stokes[2]; Aref Yadollahi[1]; Joseph Young[2]; Haley Doude[2]; Linkan Bian[2]; [1]University of South Alabama; [2]Mississippi State University

Despite appropriate planning, various incidents can stop the additive manufacturing (AM) process of metals and cause build interruption, such as power outage, lack of powder feedstock, and/or shielding gas to mention a few. Due to the layer-by-layer nature of fabrication, an interruption to the AM process can be resumed from the location where the stoppage occurred. However, build interruption may adversely affect the mechanical performance of the fabricated parts, by causing localized failure near the interruption plane. This study aims to explore the influence of process interruption during the laser powder bed fusion (LPBF) process on the microstructural and various mechanical properties of Ti-6Al-4V and Al-Si-10Mg specimens. Effects of heat treatment and surface finish on tensile properties of the interrupted specimens were investigated and compared to their control counterparts, fabricated without an interruption. Results showed tensile failures near the interruption location for some interrupted specimens in the as-built surface condition.

Materials: Polymers - Novel Materials and Processes

Wednesday PM July 27, 2022 | Room: 415 AB | Location: Hilton Austin Hotel

1:10 PM
Reliable PEDOT:PSS Inks using Bio-renewable Green Co-solvents for Inkjet 3D-printed Electronics: *Geoffrey Rivers*[1]; Jonathan Austin[1]; Yinfeng He[1]; Adam Thompson[2]; Nathan Roberts[2]; Peng Zhao[1]; Christopher Tuck[1]; Richard Hague[1]; Ricky Wildman[1]; Lyudmila Turyanska[1]; [1]Centre for Additive Manufacturing; [2]Manufacturing Metrology Team

Inkjet-based 3D printing (IJ3DP) of the conductive polymer poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) can enable manufacturing of the next generation of electronics, having been successfully used previously in devices such as solar cells and sensors. However, to achieve precise printing of PEDOT:PSS inks over large areas, challenges with jetting reliability must be addressed. We report on the development of new PEDOT:PSS ink formulations, utilising three bio-renewable co-solvents: dihydrolevoglucosenone ('cyrene'), glycerol carbonate, and n-butanol. These formulations improved jetting reliability, which enabled large-area printing of electronic patterns (140 capacitive electrodes over a 62.5 cm2 area) presenting an as-printed conductivity of 218 S/cm, as well as enabling improved layer flatness (Sa = 16 nm) via adapted printing strategies. The formulation also had enhanced stability in different environments (elevated temperature, UV exposure, air exposure), presenting realistic prospects for its application in printed heterostructures with other inkjet deposited functional materials such as graphene and metal nanoparticles.

1:30 PM
Aerosol Jet Printing of Carbon Nanotubes for Electronic Interconnects: *Lok-kun Tsui*[1]; Yongkun Sui[2]; Rachel Martin[2]; Martha Gross[2]; Michael Siegal[2]; David Wheeler[2]; Elizabeth Paisley[2]; Judith Lavin[2]; [1]University of New Mexico; [2]Sandia National Laboratories

Aerosol jet printing (AJP) enables the printing of a wide range of electronic materials at 10-100 µm resolution. An investigation into the deposition of carbon nanotubes (CNTs) by AJP as a novel material for use in electronic interconnects has been conducted. CNTs are attractive for interconnects due to their long mean free path and large current carrying capacity.[1] AJP process conditions for single walled CNTs in water-based inks were optimized to generate linewidths of 100 µm. Here, we will present our findings and characterization of CNT microstructure, alignment and chemical structure by SEM, transmission microscopy and Raman spectroscopy. A comparison of the electrical resistance of the printed CNT lines before and after annealing will also be shown. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525. SAND2022-3933A[1] Naeemi, A. and Meindl, J. D. Ann. Rev. Mater. Res., 2009. 39:255-75

1:50 PM
Opacity Modulation in Additive Manufacturing: *Aja Hartman*[1]; Mary Baker[1]; Ingeborg Tastl[1]; Krzysztof Nauka[1]; [1]HP Labs

HP's powder-based technology, Multi Jet Fusion (MJF), uses a fusing agent to selectively melt polymer powder in a layer-by-layer fashion to create 3D parts. There are many applications that require variable opacity including signage, medical models, and backlit buttons and indicators on computers, vehicles, and instruments. The industry also needs to replicate different materials that have varying optical properties throughout their thickness, such as skin or marble, and to enable techniques such as covert marking on parts. Although completely opaque parts are achievable by doping the base powder material with an opacifying material, this opacifying method makes the whole part opaque instead of allowing variability at a voxel level. By modulating both opacifying agent loading and the geometric design of the opaque part region in our MJF platform, we have achieved variable optical properties within parts, modulating total transmitted light from 10% to 1%.

2:10 PM
Effects of UV Overcuring in Multi-Material Jetting Additive Manufacturing: *Lindsey Bezek*[1]; Christopher Williams[1]; [1]Virginia Tech

Photopolymer material jetting (MJ) presents designers the opportunity to tune material properties on a voxel-by-voxel basis to fabricate high-resolution, multi-material parts; however, it is mainly constrained to prototyping use. Indiscriminate dosing of ultraviolet (UV) irradiation in MJ systems could cause variations in parts' mechanical properties depending on part design and build layout. This study quantifies how UV irradiation affects mechanical properties. Leveraging physical MJ system measurements, a process model is presented that predicts accumulated exposure in batch-printed parts of dissimilar build heights for different materials and surface finishings. Experimental testing enables correlation of parts' total exposure to mechanical properties. Adjacently printing parts 50 mm taller than a VeroWhitePlus part of interest causes a 29,500% increase in surface exposure, corresponding to a 12.6% increase in tensile strength. Connecting accumulated exposure to mechanical performance enables improved strategies for build layout and process modification to ensure consistency of UV dosage and mechanical performance.

2:30 PM
Investigation of Mechanical Properties of Structures fabricated by Continuous Volumetric Photopolymerization based 3D Printing: *Yizhen Zhu*[1]; Shengyinghao Chen[1]; Xiangjia Li[1]; [1]Arizona State University

Material is stacked in a layered manner to build objects with complex three-dimensional (3D)geometry shapes using most additive manufacturing processes. However, the way of material is deposited to create parts has a significant impact on the mechanical performance of printed 3D structures. In specific, 3D printed materials show anisotropic mechanical properties, which are determined by printing orientations. To overcome this bottleneck, a novel structural beam-based ultra-fast volumetric 3D printing, inspired by the plant growth in nature, was thereby developed. Such a process features constructing desired geometry continuously by direct manipulation of the optical field in 3D space, where the photopolymerization occurs consistently in all directions. The mechanical properties of printed parts were fully investigated and further modulated by adjusting printing parameters. The proposed technology enables the construction of 3D structures with isotropic mechanical properties and opens intriguing perspectives for mass production using advanced printing technology.

2:50 PM Break

3:20 PM
Aging Behavior of UV Curable PDMS Developed for Large-scale, High Viscosity Stereolithography: *Hongtao Song*[1]; Nicholas Rodriguez[1]; James Oakdale[2]; Eric Duoss[2]; Richard Crawford[1]; Carolyn Seepersad[1]; [1]University of Texas at Austin; [2]LLNL

Polydimethylsiloxane (PDMS) elastomers have been used widely in academic and industrial applications. With a specially designed, photosensitive platinum-based catalyst, it is possible to fabricate PDMS parts with stereolithography by UV activated hydrosilylation. For long term applications, it is important to understand the aging behavior of the PDMS fabricated through UV hydrosylilation and how it compares with PDMS cured through normal hydrosylilation. In this paper, UV and thermal aging research is conducted on the UV curable PDMS. The results show that PDMS continues to crosslink throughout the aging experiment with an accompanying increase in stiffness and decrease in elongation. The tensile strength decreases slightly after aging. FTIR spectroscopy shows that no new chemical bonds or functional groups are generated through the aging process, meaning that no thermal degradation or polymer chain scissoring is occuring in the polymer matrix. Overall, this PDMS formulation shows excellent aging properties.

3:40 PM
Material Modelling of the Photopolymers for Additive Manufacturing Processes: *Kubra Sekmen*[1]; Thomas Rehbein[2]; Michael Johlitz[2]; Alexander Lion[2]; Andrei Constantinescu[1]; [1]Laboratoire de Mécanique des Solides (LMS), CNRS, Ecole Polytechnique; [2]Department of Aerospace Engineering, Institute of Mechanics, Bundeswehr University Munich

This contribution presents experimental investigations and material modelling of the UV curing polymers to predict the influence of process parameters on the thermal and mechanical properties. Firstly, photo-DSC measurements are performed to investigate the crosslinking reaction and to model the degree of cure as a function of the light intensity and temperature. The change of the viscoelastic properties is measured with UV rheometry and dynamic mechanical analysis (DMA). Time-temperature and time-cure superposition principles are applied to the experimental results. In addition, chemical shrinkage behaviour is captured as a function of the degree of cure by the high-precision balance setup. Model equations are provided to describe the material behaviour as a result of our experimental findings.

4:00 PM
Study of Proximity Effect in Projection-based Micro Stereolithography Process: *Aditya Chivate*[1]; Zipeng Guo[1]; Chi Zhou[1]; [1]University at Buffalo

Micro Projection-based stereolithography is a powerful technique that has the potential to disrupt microfabrication. However, a significant challenge that plagues µPSL is the local change in thresholds depending on the pitch between adjacent features, and having features in close spatial proximity generates undesired artifacts. This is termed as "proximity effect," which strongly limits the attainable fabrication resolution. This can be linked to pixel-pixel light interactions and is found to affect the process in spatial as well as temporal domains. Despite tormenting researchers for a long, not much has been done to study these effects in DLP printing. Models developed for laser-based systems can be used to explain the proximity effect in µPSL. However, they still rely on hindsight observations, fail to consider the effects of large area projection, and fail to explain how the local change in thresholds affects the part size. This research uses in-situ observation systems to study the spatial and temporal proximity effects in single-shot PSL microfabrication. We briefly illustrate the role of oxygen in the proximity effect and lay the foundations to better understand the proximity effect in periodic structures with micronic inter-feature distances.

4:20 PM
Powder Bed Fusion of Polymers with Ultraviolet Light Emitting Diode Energy Sources: *Krzysztof Nauka*[1]; Michelle Niu[1]; Emre Discekici[1]; Aja Hartman[1]; Paul Olubummo[1]; [1]HP Inc

Powder bed 3D printing of polymers frequently uses broadband near-infrared (NIR) emitters and selectively printed fusing agents with absorption spectrum matching the emission of selected IR energy source. However, due to few available NIR absorbers that can be formulated into printable agent, printed 3D parts often have unwanted color limiting their applications. Shifting the emitter spectrum to a narrow, near-ultraviolet band (NUV LEDs; wavelength > 350 nm) provides more printable absorber candidates while minimizing the potential UV-induced damage of polymer. Choice of the printable absorber span from inorganic metal oxides (TiO_2, ZnO, etc.) to organic absorbers that may include commercial UV absorbing ingredients used in paints, vitamins, food derivatives, cosmetic and pharmaceutical components. Some of the absorbers, being colorless or white, enable printing parts with the original polymer powder color or white base for desired coloring of the printed objects.

Physical Modeling - Analysis and Experiments

Wednesday PM Room: 412
July 27, 2022 Location: Hilton Austin Hotel

1:10 PM
A Dislocation Mechanism Based Constitutive Model for Hierarchical Anisotropic Materials: *Chamara Herath*[1]; Ajit Achuthan[1]; [1]Clarkson University

The development of a hierarchical microstructure informed crystal plasticity based constitutive model that accounts for the geometric and mechanistic effects of the features of different length scales such as grains and subgranular solidification cells is presented. The developed model relies on three major strengthening mechanisms: the boundary strengthening, the geometrically necessary dislocation strengthening, and the back stress effect. The size and shape effect of individual grains are accounted by considering the grains as ellipsoids and cells as tubular structures with circular cross sections. The anisotropic effect of cellular structure is also introduced. Homogenization schemes are developed to simplify the implementation of the constitutive model on a finite element analysis (FEA) network. The model is validated experimentally by testing 316L coupon specimens manufactured by laser engineered net shaping (LENS). Predicted stress-strain behaviors agreed very well with those obtained experimentally, both in the loading and building directions.

1:30 PM
Characterization of Microscopic Deformation of Materials Using Deep Learning Methods: *Kavindu Wijesinghe*[1]; Janith Wanni[1]; Natasha Banerjee[1]; Sean Banerjee[1]; Ajit Achuthan[1]; [1]Clarkson University

A microstructure-informed design approach is expected to revolutionize the design of metals and alloy components for aerospace applications. In this approach, a designer utilizes the influence of individual microstructural features on microscopic deformation to yield desirable macroscopic properties. To realize this paradigm shift in practice, advanced experimental capabilities that enable detailed characterization of microscopic deformation of material test specimens are critical. In this study, we propose a data analysis framework based on instance segmentation and tracking of microstructural features using deep learning methods. The method consists of a Mask R-CNN model combined with a regional segmentation algorithm for the instance segmentation of features, an intersection over union (IoU) based multi-object tracking (MOT) algorithm to track segmented instances as they deform, and kinematics models to extract the material characteristics from the geometrical characteristics of the deforming instances. The method is successfully validated experimentally using an additively manufactured 316L stainless steel.

1:50 PM
A Preliminary Study of Microstructural Evolution Modeling for Liquid Metal Droplet Jetting: *Khushbu Zope*[1]; Prahalada Rao[2]; Reza Yavari[2]; Denis Cormier[1]; [1]Rochester Institute of Technology; [2]University of Nebraska-Lincoln

Liquid metal droplet jetting (LMJ) is an emerging metal AM process in which droplets are jetted on demand onto a moving substrate to build up 3D structures. The microstructure and mechanical properties of deposited material are driven by the impact, spreading, cooling and solidification of individual droplets. Parameters such as droplet jetting frequency, drop spacing, and part geometry significantly influence the material's thermal history and hence microstructure. Conventional finite element methods are impractical for modeling LMJ microstructural evolution at the part scale. This study uses a computationally efficient graph theory approach to model spatiotemporal thermal history as a function of printing conditions. The macroscale heat flow calculations are coupled with the cellular automata (CA) method to model grain nucleation and growth within the mushy zone window between the solidus and liquidus temperatures. Predicted microstructures will be compared with actual 4008 aluminum microstructures obtained using a Xerox ElemX machine.

2:10 PM
CalPhaD Method Contribution to Optimize Heat Treatments on a Ti-6Al-4V Additive Manufactured Alloy: *Christophe Voltz*[1]; François Buy[1]; Benoît Bourton[1]; William Mottay[1]; [1]CEA

Additive manufacturing (AM) process is accompanied by a wide range of specific metallurgical microstructures due to high cooling rates and thermal gradients. Thermal post treatments are applied to obtain the desired mechanical properties.In the case of Ti-6Al-4V titanium alloy, we apply the CalPhaD method to understand the effect of a subsequent heat treatment on the microstructure. This alloy is composed of two phases: hcp a-phase and bcc ß-phase contributes to the stability of the alloy. The morphology and composition of these two phases depend both on the composition in minor alloying elements and cooling rate. The study focusses how elements as iron or nitrogen affect transus temperature. The developed approach uses solutions to the one-dimensional, diffusion controlled moving boundary problem to predict metastable phase composition and the size of metallurgical features that occur upon cooling. The simulation results are compared with experimental data stemming from thermal treatments.

2:30 PM
Digitally Twinned Additive Manufacturing: Real-time Detection of Flaws in Laser Powder Bed Fusion by Combining Thermal Simulations with In-Situ Meltpool Sensor Data: Alex Riensche[1]; Reza Yavari[1]; Emine Tekerek[2]; Lars Jacquemetton[3]; Harold (Scott) Halliday[4]; Ziyad Smoqi[1]; Vignesh Perumal[2]; Antonios Kontsos[2]; Kevin Cole[1]; *Prahalad Rao*[1]; [1]University of Nebraska; [2]Drexel University; [3]Sigma Labs, Inc.; [4]Navajo Technical University

The goal of this research is the real-time detection of incipient flaw formation in metal parts made using the laser powder bed fusion (LPBF) additive manufacturing process. Another emerging concern in LPBF, and additive manufacturing in general, is related to cyber security – malicious actors may tamper with the process or plant flaws inside a part to compromise its performance. The objective of this work is to develop and apply a physics and data integrated strategy to detect incipient flaw formation in LPBF parts. The approach is based on combining (twinning) real-time in-situ meltpool temperature measurements with a computationally efficient graph theory-based thermal simulation model predicts the thermal history. The temperature distribution predictions provided by the computational thermal model are updated with real-time meltpool temperature measurements. This digital twin approach is applied to detect flaw formation in stainless steel (316L) impeller-shaped parts made using a commercial LPBF system.

2:50 PM Break

3:20 PM
Incorporating Physical Property Measurements in DEM for Modeling AM Powders: Joshua Wagner[1]; Wesley Combs[1]; *C. Fred Higgs III*[1]; [1]Rice University

The discrete element method (DEM) is a popular numerical modeling approach for simulating particle dynamics in additive manufacturing (AM) processes that involve powder feedstocks. Constitutive material properties are required to adequately model realistic particle interactions. Certain parameters, such as the density and elastic modulus of the bulk material, are either straightforward to measure or well-established in the literature. Other parameters, specifically those underlying energy dissipation and particle cohesion, require involved experimental calibration due to their sensitivity to particle morphology, environment, powder processing methods, and various other factors. In this work, we present experimental calibration approaches for important DEM parameters in AM applications. Particle contact friction and cohesion is effectively tuned via powder rheometery and angle of repose experiments, respectively. The coefficient of restitution for stainless steel, titanium, and nickle alloy powder systems is measured using microscopic, high-speed imaging.

3:40 PM
Calibration of the Johnson-Cook Material Model for Additively Manufactured 304LSS Parts: Modeling and Experiments: Manoj Kumar Reddy Rangapuram[1]; *Siva Sai Krishna Dasari*[1]; Sriram Praneeth Isanaka[1]; Mario F. Buchely[1]; Joseph Newkirk[1]; K. Chandrashekhara[1]; [1]Missouri University of Science and Technology

Selective laser melting (SLM) is a type of additive manufacturing technique which uses a powder bed to form complex metal parts in a layer-by-layer process. This study aims to understand the material flow of parts manufactured by SLM process using 304L stainless steel powder, which is widely used in numerous applications. The tensile specimens were manufactured using 304LSS powder through SLM process. Quasi-static high temperature tensile tests were carried out to calibrate the parameters of the constitutive Johnson-Cook strength model. To conduct the tensile tests, different temperatures (25 oC, 150 oC and 250 oC) and strain rates (0.1 s-1, 0.01 s-1 and 0.001 s-1) were used. The material model developed was used in numerical simulation of the tensile tests and compared with the experimental results.

4:00 PM
Numerical and Experimental Characterization of the Dynamic Properties of As-built 316L Components Produced via Laser Powder Bed Fusion: *David Failla*[1]; Matthew Priddy[1]; [1]Mississippi State University

One of the more prominent additive manufacturing (AM) technologies being adopted is laser powder bed fusion (L-PBF) for its capacity to accurately create complex geometries such as porous scaffolds because of its high dimensional resolution. For this reason, the adoption of L-PBF components for dynamic loading situations is of increasing interest for defense systems and low-orbit spacecrafts for potentially improved impact resistance, rapid deployment, and light-weighting. Furthermore, as the residual stresses and defects induced by the cyclic heating and cooling of AM technologies become more defined, the leveraging and manipulation of the resultant mechanical properties of L-PBF components has increased. This work aims to demonstrate the efficacy of using as-built 316L components fabricated via L-PBF for dynamic events by coupling high fidelity simulations of the printing process with sequential explicit tensile simulations. The predicted characterizations will be validated by using high-rate tensile tests from Split-Hopkinson pressure bar experimental data.

4:20 PM
Anticipating Build Risk of Complex Geometries Using Commercial Additive Manufacturing Simulation Tools: *Adam Gershen*[1]; Matthew Dantin[1]; Charles Fisher[1]; [1]Naval Surface Warfare Center, Carderock Division

Additive manufacturing (AM) is enabling a revolution in digital design capabilities. Optimized geometries can retain certain specified properties while reducing unnecessary weight. These optimization practices often form organic-looking shapes that could not be fabricated through any conventional means, though the new design comes with a corresponding increased risk of AM build failure. Process simulation is one way to anticipate these risks; and select commercially available software tools now detect distortion and recoater blade crashes in laser powder bed fusion (LPBF) processes. A recent study has focused on understanding the capabilities and limitations of these AM simulation tools. The example design is a conformally shaped pressure vessel put through various evolutions of internal design changes, including wall-thinning and optimized internal struts. This presentation outlines observations from both the simulations as well as validating physical builds of this pressure vessel as the design evolved.

Physical Modeling - Part-Scale Modeling

Wednesday PM Room: Salon B
July 27, 2022 Location: Hilton Austin Hotel

1:10 PM
Towards Tractable, Fully Time-resolved Simulations of Engineering Scale Parts Built using the Laser Powder Bed Fusion Process: *Daniel Moser*[1]; Kyle Johnson[1]; Michael Heiden[1]; Theron Rodgers[1]; Scott Jensen[1]; Michael Stender[1]; David Saiz[1]; Mario Martinez[1]; Helen Cleaves[1]; [1]Sandia National Laboratories

Simulation can help address the repeatability issues with laser additive manufacturing. Theoretically, simulation can be used to predict process-property relationships for properties such as microstructure and mechanical behavior. Practically, simulating builds of most geometries remains intractable due to the enormous number of time steps needed to resolve the laser action. There are strategies to overcome this, like heat source agglomeration and time-averaging, but these can hinder predictive capability. This work explores time integration techniques beyond traditional time stepping. These include analytical solutions, domain decomposition, and parallel-in-time methods. Assessments are made of computational cost, wall-time performance, and scalability to realistic geometries. Predictive capability is explored through estimation of model form uncertainties, consideration of the need for and effectiveness of calibration, and comparison to experimental data.This work was supported by the Laboratory Directed Research and Development program at SNL. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525

1:30 PM
Thermal Modeling of Wire Arc Additive Manufacturing using Spectral Graph Theory: *Nicholas Piercy*[1]; [1]University Of Nebraska Lincoln

The wire arc additive manufacturing (WAAM) process is a fast, cost-effective, and easy to implement solution for near net shape part production. In WAAM, an electric arc is used to deposit a wire feedstock to create parts, layer by layer. Before, during, and after the layer deposition, knowing the transient temperature distribution, also known as the thermal history, supports our understanding of the as-printed material characteristics. In the current work, we develop an approach to model the thermal history of a part utilizing spectral graph theory which reduces the computational cost when compared with commercial finite element analysis (FEA) software. The predicted thermal history is compared with experimental data collected during the WAAM deposition of thin walls.

1:50 PM
Fundamental physics effects of background gas species and pressure on vapor plume structure and spatter entrainment in laser melting: *Saad Khairallah*[1]; Michael Stokes[2]; Alexey Volkov[2]; Sasha Rubenchik[1]; [1]Lawrence Livermore National Laboratory; [2]U. Alabama

First-principles modeling, based on the direct simulation Monte Carlo (DSMC) method, is applied to quantitatively explain the physics of stainless-steel (SS316L) vapor plumes and jets and powder particle entrainment under conditions relevant to laser welding and laser powder bed fusion additive manufacturing. The simulations are performed for different background gas species (argon, helium, and neon) at background gas pressures from 0.1 to 5 bar and molten pool temperatures from 3250 K to 4000 K. This study emphasizes that the ambient gas species and the pressure in the build chamber should be treated as process parameters that are as important as controlling laser power and scan speed when trying to prevent 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. Based on LLNL document review and release number LLNL-JRNL-829362.

2:10 PM
Investigation on Corner Precision at Different Corner Angles in Material Extrusion Additive Manufacturing: An Experimental and Computational Fluid Dynamics Analysis: *Md. Tusher Mollah*[1]; Amirpasha Moetazedian[2]; Andy Gleadall[2]; Jiongyi Yan[2]; Wayne Alphonso[1]; Raphaël Comminal[1]; Berin Šeta[1]; Tony Lock[3]; Jon Spangenberg[1]; [1]Technical University of Denmark; [2]Loughborough University; [3]Duet3D Ltd

This paper investigates the influence of different corner angles on microscale geometry in material extrusion additive manufacturing. Polylactic acid (PLA) was 3D-printed with corner angles of 15°, 30°, 45°, 60°, 75°, 90°, and 135° using Bowden and Direct-drive extruders. A computational fluid dynamics (CFD) model was developed to simulate the polymer flow through the extrusion nozzle of both extruders. The simulated corner geometries were compared with experiments to assess simulation accuracy. This included the primary and secondary mitre cross-sectional width through the corner point of the 3D-printed strands. This enabled a new understanding about the prediction accuracy of the CFD model as well as the state of material at the corners, and the deviation of experimental and simulated corners from the analytical one. Moreover, the amount of over- and under-extrusion around the corner was estimated for experimental and simulated studies compared with the analytical corner, which provided fundamental knowledge on corner precision for angular print paths.

2:30 PM
Rapid Qualification of Wire Feed Direct Energy Deposition Process Builds using ICME Approach: *Amit Verma*[1]; Andrew (Drew) Huck[1]; Rajib Halder[1]; Anthony Rollett[1]; [1]Carnegie Mellon University

To leverage the potential benefits of AM, the role of geometry in the qualification of parts needs to be minimized such that any arbitrary geometry can be printed with confidence. This translates to mapping the build as it is deposited, i.e., qualification of a small volume rather than of the entire build at the end of the deposition process and reducing the post-process characterization as much as possible. Currently, a suite of ICME (Integrated Computational Materials Engineering) tools in conjunction with in-situ process monitoring supported by artificial intelligence (AI) / machine learning (ML) methods provide a range of opportunities. This talk focuses on the Wire feed Direct Energy Deposition AM process, applied to Ti-6Al-4V, for which we employed a host of modelling and simulation tools, along with in-situ process monitoring, to accelerate the qualification process.

2:50 PM Break

3:20 PM
Effect of Scanning Strategies on Defects Generated by Lack of Fusion during Laser Power Bed Fusion: A Part-Scale Finite Element Simulation Study: Alaa Olleak[1]; *Albert To*[1]; Sneha Narra[1]; [1]University of Pittsburgh

The quality and reliability of additively manufactured parts by Laser Power Bed Fusion (LPBF) are significantly affected by Lack of Fusion (LOF) porosity, caused by insufficient overlap of melt pools. For LPBF parts, LOF porosity is location dependent and affected by both the process parameters and scanning strategy. The widely used few-tracks experimental or numerical approaches to investigate LOF cannot capture the effects of the residual heat and geometrical features. In addition, the experimental investigations of porosity generated during the LPBF process for part-scale are expensive and time consuming. However, leveraging high performance GPUs, adaptive remeshing, and matrix-free Finite Element Modeling (FEM), LOF porosity for part-scale can be predicted. The work proposes the use of this highly efficient framework to investigate the effects of process parameters and scanning strategy on the melt pool size variability due to the geometrical features and residual heat, and thus the location dependent LOF porosity.

3:40 PM
Enabling Part-Scale Scanwise Process Simulation of Laser Powder Bed Fusion by Combining Matrix-free Finite Element Modeling, Adaptive Remeshing, and GPU Computing: Alaa Olleak[1]; *Albert To*[1]; [1]University of Pittsburgh

This work proposes to combine matrix-free finite element modeling (FEM), adaptive remeshing, and graphical processing unit (GPU) computing to enable scanwise process simulation of the Laser Powder Bed Fusion (L-PBF) process with temperature-dependent thermophysical properties at the part scale. Compared to the conventional FEM using the global stiffness approach and a uniform mesh running on 10 CPU cores, L-PBF process simulation based on the proposed methodology running on a GPU card with 5,120 Compute Unified Device Architecture (CUDA) cores enables a speedup of over 10,000x. This significant speedup facilitates detailed thermal history and melt pool geometry predictions at high resolution for centimeter-scale parts within days of computation time. Several parts consisting of various geometric features are simulated to reveal the effects of scan strategy and local geometry on melt pool size variation.

4:00 PM
Investigating the Influence of Thermal and Mechanical Properties of Resin on the Sedimentation Rate of Components Produced by Volumetric Additive Manufacturing: *Roozbeh Salajeghe*[1]; Carl Kruse[1]; Daniel Meile[1]; Deepak Marla[2]; Jon Spangenberg[1]; [1]Technical University of Denmark; [2]India Institute of Technology Bombay

Converse to conventional additive manufacturing methods that apply layer-by-layer techniques, volumetric additive manufacturing produces the whole geometry simultaneously. While it is faster, creates features with better surface quality, and requires no overhang support structures, all of which push the limits of additive manufacturing, it is still premature and suffers from some effects such as component sedimentation. The sinking of the structure, in turn, adversely affects its geometric fidelity and resolution. The sedimentation rate of the printed body during its formation is highly dependent on the resin type, its viscosity, and its curing behavior. Herein, we propose a CFD model that takes into account the synergistic effect of reaction-based heating, curing behavior, and resin properties to predict the sedimentation rate of the printed geometry. The model results are in qualitatively good agreement with the experiments and can be used to quantify material behaviors that are beneficial when applying volumetric additive manufacturing.

4:20 PM
Transient Nature of the Raster Scan Areas in the Laser Powder Bed Fusion Process: *Santosh Rauniyar*[1]; Kevin Chou[1]; [1]University of Louisville

In the laser powder bed fusion process, the energy density affects the change in the melt pool geometry and the hatch spacing determines the extent of the overlap between the subsequent tracks. The raster scans are built with single tracks in alternating scan direction. For a continuous solidified single track, there are three distinct melt geometries at the start, the middle and at the end. In the first few hundreds of microns there is a bump and the last several hundred microns have a shallow depression corresponding to the transient regime. In this study, raster scan areas of multiple scan lengths is analyzed through thermo-fluid simulation. The quasi-steady state in the middle region showed the least variation in terms of the surface height. The transition into the quasi-steady is dependent on the power and the scan speed and it may not reach the quasi-steady state for shorter scan length.

4:40 PM
Layerwise Thermal Process Simulation for Laser Powder Bed Fusion: Calibration and Validation with Infrared Camera: *Shawn Hinnebusch*[1]; Alaa Olleak[1]; Christopher Barrett[2]; Seth Strayer[1]; Florian Dugast[1]; Albert To[1]; [1]University of Pittsburgh; [2]Open Additive, LLC

Current part-scale thermal process simulation models for laser powder bed fusion (L-PBF) are calibrated using thermocouple data and do not capture the correct temperature distribution. Most layerwise simulations apply a constant heat flux for the duration of the layer or apply the melting temperature to the layer for a set time. These methods are tuned with the absorptivity and heat convection coefficients for a set geometry to match experimental data. With the help of thermocouples and an infrared (IR) camera, the simulations can be accurately calibrated for various geometries by tuning the model parameters throughout the build process. This proposed workflow uses a voxel mesh and matrix-free formulation to take full advantage of GPU-based computing allowing for rapid and accurate calibration of L-PBF process simulation models.

Process Development - AM Control

Wednesday PM — July 27, 2022
Room: 410 — Location: Hilton Austin Hotel

1:10 PM
Electrostatic Powder Spreading (ESPS) as a Method to Build Multi-Material Powder Bed Fusion Parts: *Eric Elton*[1]; Ziheng Wu[1]; Michael Troksa[1]; Gabe Guss[1]; [1]Lawrence Livermore National Laboratory

Laser powder bed fusion processes rely on mechanically spreading each powder layer with a spreader bar, limiting the ability to deposit multiple materials on one layer. While methods to deposit more than one powder per layer exist, they are complicated and time consuming. Here we demonstrate electrostatic powder spreading (ESPS) as a new method to deposit metal powders for LPBF and enable multi-material LPBF builds. ESPS uses the electric field between a powder reservoir and a counter electrode to move powder from the reservoir to the bed with no contact to the powder bed. We demonstrate control over deposition rate and layer thickness and show parts built using ESPS. Finally, we demonstrate that ESPS can deposit powder layers with more than one material when an array of electrodes is used, pointing to a method to build metal parts with arbitrary 3D material gradients. Prepared by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS-833932

1:30 PM
A Comparison Of Additive Layer Deposition And Open Molding of PETG by Fused Pellet Fabrication in A Hybrid Manufacturing System.: *Alex Gibson*[1]; Jason Weaver[1]; [1]Brigham Young University

Additive manufacturing (AM) continues to offer new possibilities in both production and economics. The industry has quickly adopted it to rapidly produce parts that would be difficult or cost preventative otherwise. Recent innovation have expanded it's capabilities, however there are still significant limitations. Most AM processes are restricted by materials available, in producing large parts, or by not achieving material deposition speeds to make certain products feasible. In addition, tight tolerances for features and surfaces cannot be produced without substantial post processing. Hybrid Manufacturing (HM) offers expanded capabilities as additive and subtractive process are used within the same space and in conjunction. Fabrication of multi-material parts is also possible where HM can be employed to create joining interfaces without adhesive or fasteners. This, in combination with Large Area Additive Manufacturing (LAAM), enables parts that leverage the strengths of new and traditional methods at scales and speeds previously unavailable.

1:50 PM
Investigating the Relationship Between In-Process Quality Metrics and Mechanical Response in the L-PBF Process: *Bradley Sampson*[1]; Courtney Morgan-Barnes[1]; Ryan Stokes[1]; Haley Doude[1]; Matthew Priddy[1]; [1]Center for Advanced Vehicular Systems

Laser powder bed fusion (L-PBF) additive manufacturing is a process that utilizes a high-power laser to build near net shape parts in a layer-by-layer fashion using metal powder as the feedstock material. Traditionally, the analysis of L-PBF produced parts has relied solely on post-build characterization to understand the relationship between the printing process and the final mechanical properties. Recent developments of in-process quality assurance systems, such as Sigma Lab's PrintRite3D, can measure in-process thermal signatures and melt pool disturbances in real-time. This research aims to examine the relationship between process parameters (e.g., scan strategy, scanning speed, and layer thickness) and in-process quality metrics (IPQMs) captured by the PrintRite3D system on a Renishaw AM400. The mechanical response of multiple part geometries (NIST residual stress bridges, single-arched bridges) and build materials (Ti-6Al-4V) includes residual stress deflection, hardness, and porosity; the results are compared with the IPQMs.

2:10 PM

Influence of Micro-scale Zig-zag Interlock on the Adhesion Strength of Multi-material Interface Printed by Material Extrusion Additive Manufacturing: *Fangkai Xue*[1]; Guillaume Robin[2]; Hakim BOUDAOUD[3]; Fabio Sanchez[1]; El Daya[4]; [1]Equipe de Recherche sur les Processus Innovatifs (ERPI), Université de lorraine; [2]LEM3, CNRS, Arts et Métiers ParisTech, Université de lorraine; [3] Equipe de Recherche sur les Processus Innovatifs (ERPI), Université de lorraine ; [4] LEM3, CNRS, Arts et Métiers ParisTech, Université de lorraine

Achieving adequate adhesion strength at multi-material interfaces is always a challenge in material extrusion additive manufacturing (MEAM), especially when the materials have very different chemical affinities. This study investigated the adhesion mechanism of multi-material interfaces in MEAM from a micro-geometric perspective. The horizontally printed interface was found to have a smooth surface, while the vertically printed interface had a micro-zigzag interlocking geometry. The formation of this micro-zigzag interlock is due to the switching of extruders during printing, which mechanically reinforces the interface adhesion strength. Using butt-joint tensile tests and microscope observation, it was found that the geometry of this zigzag interlock is significantly influenced by the layer thickness, nozzle temperature and extruder offset. By optimizing these three parameters, the interface adhesion strength between dissimilar materials was doubled without significantly increasing the printing time or fabrication complexity.

2:30 PM

Laser Line Profile Scanning for Powder Bed Measurement: *Jaime Berez*[1]; Christopher Saldaña[1]; [1]Georgia Institute of Technology

The metal additive manufacturing (AM) method of laser powder bed fusion (LPBF) relies upon the formation of uniform, densely packed, and defect free spread powder layers. The direct measurement of spread powder layer quality is challenging owing to the fine size of the powder bed features and limited selection of instruments which can assess the powder bed in-situ. This work assesses the fitness of a laser line profiling instrument in the measurement of an LPBF system powder bed. The ability of the instrument to detect macroscopic powder bed defects is shown. Additionally, results which assess the minimum resolvable feature size are presented, which suggest the instrument can capture microscopic powder bed defects. Measures of bed quality which may relate to end-component quality are examined.

2:50 PM Break

3:20 PM

Melt Pool Feature Extraction, Spatial Registration and Layer-to-Layer Control in Powder Bed Fusion: Bumsoo Park[1]; *Xin Wang*[2]; Sandipan Mishra[1]; Douglas Bristow[2]; Robert Landers[3]; [1]Rensselaer Polytechnic Institute; [2]Missouri University of Science & Tech; [3]University of Notre Dame

Laser Powder Bed Fusion (LPBF) is a well-known additive manufacturing technique that uses a high-power laser to fuse loose metal powder into a solid part. A major issue restricting this technology from wider industrial applications is the lack of part quality assurance. In this paper, a high-speed (2kHz) co-axial near-infrared optical camera setup is implemented for process monitoring and control. The acquisition locations for individual images are estimated based on specified scan paths and scan velocities to create a spatial registration technique. Melt pool thermal features are linked to specific locations instead of time instants, motivating a spatial control strategy to achieve thermal feature uniformity. Based on the spatial mapping of the thermal features, experimental studies are conducted where a spatial layer-to-layer iterative learning controller is implemented to achieve spatial uniformity of the thermal features. The experimental results present a convergence of the thermal features to a uniform level.

3:40 PM

A Hierarchical V-Network Framework for Part Qualification in Metal Additive Manufacturing: *Byeong-Min Roh*[1]; Hui Yang[1]; Timothy Simpson[1]; Paul Witherell[2]; Albert Jones[2]; [1]Pennsylvania State University; [2]National Institute of Standards and Technology (NIST)

Advances in metal additive manufacturing (AM) technology enable greater design freedom. The design freedom and flexibility offered by a metal AM system, however, dramatically increase process uncertainties that may also raise part-quality variability. Much research has been conducted on sensing-based part qualification in AM systems by closely monitoring the fabrication process. We propose a hierarchical V-model framework of quality assurance with corresponding in-situ and ex-situ part qualification, offering innovations in modeling, test generation, and validation, and compositional verification methods in cyber-physical systems (CPS). The hierarchical V-network framework proposed here supports and guides in-situ and ex-situ quality measurements, providing a systematic structure and focusing on interrelationships between key observations that influence part quality in metal AM processing. Each networked interrelationship helps quantify the quality uncertainty associated with a metal AM process through relevant sensing data collected and by supporting decision-making regarding process anomalies in the metal AM cyber-physical infrastructure.

4:00 PM

Characterization of Defects within AM Fabricated Metal Components: *Admas Kedebe*[1]; Richard Anarfi[1]; Benjamin Kwapong[1]; Kenneth Fletcher[1]; Todd Sparks[2]; Aaron Flood[2]; [1]University of Massachusetts Boston; [2]Product Innovation and Engineering LLC

Characterization of defects within the volume of metal components produced via additive manufacturing (AM) processes is a critical component in both developing the process and qualifying it for end uses. X-ray tomography techniques offer a method for inspecting volumes of material rather than the 2d slices of conventional microscopy that may miss important data due to sampling frequency issues. For metal AM processes, both the spatial distribution and morphology of internal defects are meaningful. A common approach to AM volumetric data analysis is to use deep 2D convolutional neural networks (CNN). However, dealing with the individual slices independently in 2D CNNs discards the depth information which results in poor classification performance. In this paper, we propose to build a 3D CNN to predict defects in fabricated additive manufacturing metal components. Results from experiments with simulated models and from a DED process show that our model successfully classifies defects.

4:20 PM

Design of an In-situ Microscope for Selective Laser Sintering: *Doug Sassaman*[1]; Matthew Ide[2]; Desiderio Kovar[1]; Joseph Beaman[1]; [1]University of Texas Austin; [2]ExxonMobil Research and Engineering Company

The phenomena responsible particle fusion during selective laser sintering (SLS) have been modeled, but attempts at experimental validation have been limited to unrealistic conditions compared to those used in commercial SLS processes. We have designed, implemented, and tested an instrument that is capable of performing in situ microscopy to image particle-scale dynamics of the SLS process at realistic scan speeds, temperatures, and gas environments. The instrument uses a combination of purchased and manufactured components to capture video at length scales of ~1 µm and timescales of ~1 ms. Spatial and temporal calibration is performed so that the laser position can be mapped onto the recorded video. Results show that laser melting of polymer is accompanied by particle rearrangement that occurs over an extended time (~10 ms) after the laser scans a particular location. The findings highlight the importance of performing in situ microscopy under realistic conditions for SLS.

Process Development - Novel Methods and Processes III

Wednesday PM July 27, 2022 | Room: 408 Location: Hilton Austin Hotel

1:10 PM
Reducing Porosity of Extruded Fiber Reinforced Thermoplastics with a Vacuum-Assisted Pellet Hopper: *Frye Mattingly*[1]; Vipin Kumar[2]; Chad Duty[1]; Wim Bras[2]; Vlastimil Kunc[2]; [1]University of Tennessee Knoxville; [2]Oak Ridge National Laboratory

Fiber-reinforced thermoplastics have higher theoretical stiffness and strength than neat thermoplastics. However, when they are 3D-printed using a pellet fed extruder they often exhibit a high degree of internal porosity which can negatively impact their functional properties. A measurable portion of this internal porosity is likely caused by the mechanical entrapment of air between pellets as they are fed into the single screw extruder of a large format AM system, such as the Big Area Additive Manufacturing (BAAM) system. This study attempts to reduce internal porosity by applying a vacuum to the feed hopper of a smaller-scale single screw extrusion system while depositing either carbon or glass fiber reinforced acrylonitrile butadiene styrene (CF-ABS, GF-ABS). Archimedes density analysis showed a significant improvement in the final density of the material after a vacuum was applied to the feed hopper.

1:30 PM
Active Control of Selective Laser Flash Sintering of Ceramics: *David Khanan*[1]; Desiderio Kovar[1]; Joseph Beaman[1]; [1]UT Austin

Selective Laser Flash Sintering (SLFS) is a new additive manufacturing process that can enable a direct process for producing ceramic parts without the need for a polymer binder. In the SLFS process, an electric field is passed through the part while scanning a laser over the surface of the part. The electric field allows the laser to locally heat and bind the ceramic powder particles together at high scan speeds and relatively low temperatures by forming necks between the particles. Since SLFS is prone to temperature runaway that can result in cracking and/or melting, we are investigating the implementation of a closed loop optimal controller that can control temperature so that runaway can be avoided. This is implemented by monitoring the current flowing through the sample in situ and adjusting the electric field applied to the sample in real time so that the temperature remains below the specified temperature.

1:50 PM
An Ultrasonic Technique to Determine the Onset of Select Laser Flash Sintering: *Christina Nissen*[1]; Arturo Hernandez-Barreto[2]; Michael Haberman[3]; Joseph Beaman[1]; Desiderio Kovar[4]; [1]Walker Department of Mechanical Engineering, Center for Additive Manufacturing and Design Innovation; [2]Department of Physics; [3]Walker Department of Mechanical Engineering; [4]Walker Department of Mechanical Engineering, Center for Additive Manufacturing and Design Innovation, Materials Science and Engineering Program

Detecting the onset of sintering non-destructively is challenging because visible changes to the powder particle morphology may be too subtle to observe directly. One material property that is highly sensitive to even small changes in particle morphology is the Young's modulus. Here we investigate the use of an ultrasonic laser system to measure the local Young's modulus from the surface acoustic wave speed. Time-of-flight measurements are made on control samples that were partially sintered at different temperatures. These samples provide known reference values that relate the relative densities to the Young's modulus. We then test the methodology on model samples that have local regions of high density that are embedded in regions of lower density to demonstrate the utility of this technique for detecting the onset of selective laser flash sintering. We expect that this technique may also be applicable to other powder-based additive manufacturing processes.

2:10 PM
A Study on the Effect of Heating on the Ceramic Suspension for Maximizing the Solid Loading in the Vat Polymerization Process: *Seungjae Han*[1]; Hae-Jin Choi[1]; Hyewon Jeong[1]; Sungtae Wi[1]; [1]Chung-Ang university

Handling highly viscous materials for high solid loading is the typical problem to solve in the vat polymerization process of ceramic materials. In this study, we added a heat source in the pre-process (mixing) system, the layer coating system and, material feeding system to efficiently handle high solid loading ceramic suspension. We also used the dual heating system of conduction and convection to maintain a constant temperature of the material to reduce quality degradation such as shrinkage of the green part. We observed the viscosity of suspensions decreases as we increase the processing temperature. Green parts were efficiently printed with 60.7 Vol% of solid loading using a dechlorane plus powder. We measured mechanical properties, rheological properties, microscopic analysis and, curing performance of the green parts for this report. AcknowledgementThis work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. NRF-2022R1A2C2003580).

2:30 PM
Multiplexed 3D Printing of Thermoplastics: *Jeremy Cleeman*[1]; Alex Bogut[1]; Brijesh Mangrolia[1]; Rajiv Malhotra[1]; [1]Rutgers

Low build time in Material Extrusion Additive Manufacturing (MatEx) is key to economically scalable printing of both large and small parts. A common approach used to overcome this issue today is to print larger roads at the cost of reduced geometric resolution and greater waste. The alternative approach of parallelization is limited by issues with geometric complexity, high cost, and machine design. We develop a new paradigm for parallelized MatEx of thermoplastics called Multiplexed Fused Filament Fabrication (MF3). MF3 simultaneously prints the same part or multiple parts with multiple FFF extruders without controlling each extruder's motion, based on a continuous filament retraction and advancement strategy. MF3 can print non-periodic 3D structures, larger or smaller parts, unitary or distinct parts or a mixture of both, on the same machine, at a high throughput-resolution combination, without the limits of existing parallelization techniques.

2:50 PM Break

3:20 PM
Effects of Varied Support Structure Strategies on the Melt Pool Temperature and Mechanical Properties of SS316L in Laser Powder Bed Fusion: *William Young*[1]; Haley Doude[1]; Matthew Priddy[1]; [1]Mississippi State Univ

Support structures are often used in Laser Powder Bed Fusion (LPBF) additive manufacturing (AM) to anchor small parts to the substrate or for supporting delicate features or overhangs. These structures make post-build removal easier than removing parts built directly onto the substrate. However, since the substrate acts as a heat sink, these support structures can affect the thermal buildup during the deposition process. To relate mechanical properties to the change in thermal response, the shape, cross-sectional area, height, and packing density of supports on LPBF SS316L specimens were varied, while the melt pool temperature was monitored with a SigmaLabs PrintRite 3D system. The hardness and microstructure of the specimens were then compared to the change in melt pool temperature due to the varied support structure parameters. By isolating these relationships, material properties could be selected by manipulating the support structure parameters during the design and setup phase of LPBF.

3:40 PM

Decoupling Control of Processing Conditions for Hybrid Manufacturing Systems with ROS: *Kyle Saleeby*[1]; Thomas Feldhausen[1]; Kenton Fillingim[1]; Joshua Vaughan[1]; [1]Oak Ridge National Lab

Standard operation of hybrid manufacturing systems, where multiple processing conditions are interchangeably used within the same build volume, has traditionally leveraged existing Computer Numeric Control (CNC) platforms for integrated motion and material processing control. Commercially available metal additive systems via directed-energy deposition (DED) are often retrofitted on the motion platform of existing 5-axis CNC machining systems. These systems inherently rely on static, pre-compiled G-code for all operations. However, the introduction of additional processing conditions within standard subtractive platforms necessitates an improved control architecture. This work investigates a decoupled processing architecture through the open-source Robot Operating System (ROS), where control of motion planning and material processing conditions are distributed in separate control nodes for dynamic operational capabilities. A synchronization architecture is proposed such that operations are coordinated, yet independent. The results of this work enable dynamic modification of hybrid processing conditions at multiple timescales, enabling data-driven hybrid manufacturing control.

4:00 PM

Convolutional Autoencoder for Image Denoising AM Process Monitoring: *Jaison Mneyergi*[1]; Richard Anarfi[1]; Benjamin Kwapong[1]; Kenneth Fletcher[1]; Todd Sparks[2]; Aaron Flood[2]; [1]University of Massachusetts Boston; [2]Product Innovation and Engineering LLC

To properly monitor the directed energy deposition (DED) additive manufacturing process, real time pictures/videos are sometimes transmitted to the human experts or engineered algorithms to determine whether the process is achieving its desired goal as at that point. Image noise from in-camera and in-process sources can obscure some features and make it difficult to ascertain whether the manufacturing process is proceeding as expected at that time. In this paper, we propose to use a computer vision approach to train a denoising convolutional autoencoder that learns to recreate clean images from noisy ones. It does this by learning the important features from the images and using those features to reconstruct the images. We conduct experiments with simulated images from a powder-based DED process. The results from our experiments show that our model successfully removes varying forms of noise from the images.

4:20 PM

Closed Loop Control Utilizing in Situ Pattern Printing and Reading for Quality Level Determination in Additive Manufacturing: *Aja Hartman*[1]; Lihua Zhao[1]; [1]HP Labs

HP's Multi Jet Fusion (MJF) is a powder-based technology that selectively melts polymer powder, using a fusing agent, in a layer-by-layer fashion to create 3D parts. One of challenges for wide adoption of additive manufacturing is the assurance of the print process and part consistency through a cost-effective and non-destructive fashion. Here, we showcase a method to print two-dimensional patterns at desired locations throughout the part. The readability of the pattern can provide either the signals to take action during the print process or information on part quality during and after printing, thus non-destructive part quality measurements can be achieved. This method can also be used for covert part marking to provide design intellectual property security.

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As-built Mechanical Property Estimation and Control of Laser Powder Bed Fusion SS-316L Parts: *Xinyi Xiao*[1]; Hanbin Xiao[2]; [1]Miami University; [2]Wuhan University of Technology

Laser Powder Bed Fusion (LPBF) provides a rapid fusion and solidification of the metal powders to form 3D models, enlarging the design and manufacturability compared with the traditional subtractive machining process. However, there are still challenges in repeatability and reproducibility of the LPBF-ed AM parts that hinder the on-demand product needs. This is particularly difficult for an LPBF-ed AM part needs to be qualified through destructive measurements, such as tensile test, fatigue, and hardness. The as-built mechanical properties are highly correlated to the process parameters. In this study, LPBF-ed 316L tensile testing samples are analyzed for investigating the correlation between input process parameters and the tensile strength measures. This study establishes the quantitative comprehensive process-quality modeling with a proposed novel multi-dimensional machine learning framework, as-built tensile strength can be maintained as desired or enhanced through adjusting the process parameters.

Process Development - Process Monitoring

Wednesday PM	Room: Salon A
July 27, 2022	Location: Hilton Austin Hotel

1:10 PM

Evaluation of Solidification in PBF-LB Using a High Speed Camera: *Holger Merschroth*[1]; Jana Harbig[1]; Matthias Weigold[1]; Johannes Geis[2]; Eckhard Kirchner[2]; [1]Institute of Production Management, Technology and Machine Tools, TU Darmstadt; [2]Technical University Darmstadt - Product Development and Machine Elements

Powder bed fusion using a laser beam (PBF-LB) enables geometrical design freedom to build parts for optimized functionality. Furthermore, PBF-LB enables microstructural design freedom. By controlling the solidification behaviour microstructural adaptions can be made to obtain the full potential of the material. As the solidification rates and the thermal gradient depend on the local part geometry, new data-driven approaches, e.g. machine learning (ML), seem to be suitable for local microstructural adaptions. In this work an evaluation concept to analyse the thermal melt pool characteristics based on a high-speed camera is developed. The melt pool intensity is used to derive the thermal gradient and combined with an image rate of 41,000 fps the solidification rate is derived. The developed approach provides data for ML-based process adaptions but also serves for quality assurance tasks.

1:30 PM

In-Situ Infrared Thermographic Measurement of Powder Properties in Laser Powder Bed Fusion: *Tao Liu*[1]; Edward Kinzel[2]; Ming Leu[1]; [1]Missouri University of Science and Technology; [2]University of Notre Dame

The laser powder bed fusion (LPBF) process is strongly influenced by the characteristics of the powder layer, including its thickness and thermal transport properties. This paper presents an investigation of in-situ characterization of the powder layer using active infrared thermography. The printing laser beam is diffused and illuminates onto the powder bed's top surface in various frequencies. A long-wavelength thermal camera monitors the surface temperature history. Insight is provided by a one-dimensional thermal model of the process, which shows the frequency dependence of the surface temperature amplitude and phase on the powder layer thickness and thermal properties. An experiment demonstrates the validity of this model and shows its potential for measuring local powder properties in-situ.

1:50 PM

In-situ Microwave Tomography for Temperature Monitoring during Powder Bed Fusion of Polymers: *Francesco Sillani*[1]; Samuel Poretti[2]; Tommaso Pagani[2]; Fatlind Hajdaj[2]; Andrea Randazzo[3]; Manfred Schmid[4]; Konrad Wegener[5]; [1]inspire AG/ETH Zurich; [2]SUPSI; [3]University of Genoa; [4]Inspire AG; [5]ETH Zurich

In polymer powder bed fusion, hundreds of parts can be produced in a few hours, but strict quality requirements may lead to costly post-built quality assurance analyses, which can result in high rejection rates. Temperature monitoring throughout the process is essential to quantify the crystallization behavior of the polymer parts, but the direct reading of the temperature is hindered by the powder. In this work, an innovative temperature monitoring technology based on microwave tomography is used to assess the part cooldown history in an industry-grade EOS P110 machine. Thus, relative and absolute readings of the temperature field can be carried out even for parts surrounded by powder, and this will allow the development of a new generation of smart powder bed fusion of polymers machines that can better sense and control the entire process, including the cooldown phase, which is often neglected but has the highest impact on final performances.

2:10 PM
In Situ High-speed X-ray Imaging of the Alloying Process via Laser-based Directed Energy Deposition with Dissimilar Powders: *Hui Wang*[1]; Benjamin Gould[2]; Marwan Haddad[1]; Michael Moorehead[3]; Adrien Couet[3]; Sarah Wolff[1]; [1]Texas A&M University; [2]The Chemours Company; [3]University of Wisconsin, Madison

Laser-based directed energy deposition (DED) additive manufacturing (AM) of the alloying process was performed using dissimilar powders of Mo, Nb, Ti, and V. The alloying processes were directly observed by in situ high-speed X-ray imaging. The traveling trajectories and velocities of four different types of powders were studied to reveal the particle delivery performance. The melting modes, residence times, and the size changes of these four-element powders were obtained during the in situ alloying processes. The melt-pool dynamics were studied through the analysis of the resulting melt-flow velocities. The melt flow will benefit the uniform element distributions in the fabricated alloy. The porosity was mainly induced by unmelted particles and entrapped gas in such a process. This study will narrow the gaps between the applied research and the fundamental understanding of the impact of different elemental powders on melt-pool properties and defect production in the alloying formation via DED AM.

2:30 PM
Key Wavelength Selection for Optical Emission Spectroscopy Metrology of Direct Metal Laser Sintering: *Kun-Chieh Chien*[1]; Jared Allison[1]; Briana Cuero[1]; Tim Phillips[1]; Dragan Djurdjanovic[1]; Carolyn Seepersad[1]; Chih-Hao Chang[1]; [1]University of Texas at Austin

Direct Metal Laser Sintering (DMLS) is an additive manufacturing (AM) technique to create arbitrary three-dimensional parts layer-by-layer. In-situ optical emission spectroscopy (OES) has been demonstrated in recent work as a viable method to study the AM process. However, the methodology to select the key wavelengths to monitor is not well established and typically based on the peak characteristic emission. Therefore, we present a key wavelength selection method via principal component analysis (PCA) for different powers in DMLS. To validate the results, we compare the performance of linear regression models built by the identified 520 nm wavelength in previous references and key wavelengths selected via PCA. The results show that the root-mean-square error is decreased by 5.8 % and the resolving power increased by 20.4 %. In the future, this technique will be incorporated with other sensors, such as an IR camera, to achieve the in-situ AM process monitoring and control.

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3:20 PM
Laser-material Interactions in LPBF, Visualised through Simultaneous X-ray and Schlieren High-speed Imaging: *Ioannis Bitharas*[1]; Tao Sun[2]; Anthony Rollett[3]; Andrew Moore[1]; [1]Heriot-Watt University; [2]University of Virginia; [3]Carnegie Mellon University

We present results from visualisation studies of atmospheric fluid dynamics during LPBF. The interactions between the laser, metallic vapour, particles, and gas cross-flow are analysed both experimentally and through multiphysics modelling. Simultaneous synchrotron x-ray and schlieren imaging experiments give insight into the joint behaviour of the melt pool, laser plume, and powder particles. The interconnected dynamics of the vapour and liquid phases are explored under varying energy input. Fundamental laser-powder interactions, as well as the effect that the powder layer has on melt pool and plume dynamics are investigated. Image processing and analysis aid in relating our observations to process stability. Our results show that even monitoring the laser plume alone can yield valuable information about the state of the melt pool and processing regime.

3:40 PM
Powder Movement and Spattering during Green Laser Powder Bed Fusion of Copper: *Joerg Volpp*[1]; Himani Naesstroem[1]; Frank Brueckner[2]; [1]Luleå University of Technology; [2]Fraunhofer Institute for Material and Beam Technology

Additive Manufacturing is a promising technology for processing complex parts and structures. Highly desired is the processing of copper due to e.g. its high thermal and electrical conductivity. However, copper is known to be difficult to process due to the tendency to produce spatters and pores because of its low viscosity and high heat conductivity. Therefore, this work aims to explain some fundamental effects that happen during powder bed fusion of copper using a green cw laser. High-speed video analysis showed the occurrence of large agglomerations in front of the processing zone, which can move and burst when interacting with the laser beam. It was concluded that copper powder movement is governed by an agglomeration of particles due to the high heat conduction of copper, while their movement is likely to be initiated by the accelerated gases.

4:00 PM
Process Monitoring for Pore Detection using in situ X-ray Imaging and Pyrometry Signal: *Sanam Gorgannejad*[1]; Aiden Martin[1]; Jenny Wang[1]; Jean-Baptiste Forien[1]; Maria Strantza[1]; Peiyu Quan[2]; Sen Liu[2]; Vivek Thampy[2]; Christopher Tassone[2]; Nicholas Calta[1]; [1]Lawrence Livermore National Laboratory; [2]SLAC National Accelerator Laboratory

Systematic fault detection and control over the laser powder bed fusion (LPBF) technique has been a long-lasting objective to achieve high-quality parts and process repeatability. In situ process monitoring approaches have gained popularity for real-time quality assurance purposes. However, the correlation between specific defect formation events and process monitoring signatures remains elusive. In this study, we employed high-speed in-situ X-ray radiography to probe subsurface dynamics during LPBF of Ti-6Al-4V alloy while simultaneously collecting thermal emission data. An automated feature extraction workflow and object tracking algorithm were developed to quantify the X-ray images, determine the pore formation times, and trace their trajectories within the melt pool. By processing the thermal emission signals, the process signatures were identified, and the probability of pore formation associated with various signatures was computed.Prepared by LLNL under Contract DE-AC52-07NA27344.

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Process Monitoring of Laser Powder Bed Fusion Additive Manufacturing using Thermionic Emission Detection: *Aiden Martin*[1]; Philip Depond[1]; John Fuller[1]; Saad Khairallah[1]; Justin Angus[1]; Gabe Guss[1]; Manyalibo Matthews[1]; [1]Lawrence Livermore National Laboratory

In situ monitoring is required to improve the understanding and increase the reliability of additive manufacturing (AM) methods such as laser powder bed fusion. Here we discuss a methodology based on the thermally induced emission of electrons - thermionic emission - from the metal surface during laser heating. Experimental studies show that thermionic emission signatures are correlated to laser heating conditions that give rise to pore formation and regions where surface defects are pronounced. Thermionic sensor signals collected during processing monitoring of small scale part builds will be presented and compared to conventional photodiode based sensors. The information presented here is a critical step in furthering our understanding and validation of laser-based metal AM and demonstrates that the collected thermionic signals can be incorporated into conventional data collection methodologies. This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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Towards Inline Material Microstructure Imaging using Spatially Resolved Acoustic Spectroscopy (SRAS): *Wenqi Li*[1]; Rikesh Patel[1]; Rafael Fuentes-Dominguez[1]; Paul Dryburgh[1]; Richard Smith[1]; Matt Clark[1]; [1]University of Nottingham

Monitoring of material characteristics is the next step need towards the realisation of truly autonomous manufacturing. For additive manufacturing the issue of structural defects has been minimised through intense research into process control and traditional testing regimes, however the ability to measure the microstructure is currently limited to offline and destructive measurement methods. In this paper, we present our work towards integrating the laser ultrasound characterisation technique spatially resolved acoustic spectroscopy (SRAS) in-situ with the manufacturing process. SRAS is an established lab-based tool that is capable of imaging material microstructure, however there are significant challenges in bringing this technique to workshop environments, including operating on rough surfaces, high-speed acquisition and image resolution. We present our work to date on concepts on integration into an additive manufacturing (AM) environment, microstructural images made on as-deposited samples made using a variety of AM techniques, and solutions to instrumentation to operate on rough surfaces.

Poster Session

Tuesday PM Room: Salon JK
July 26, 2022 Location: Hilton Austin Hotel

A Low Cost, Flexible Sensor Architecture for Process Monitoring in Metal Casting with 3D Printed Sand Molds: *Janely Villela*[1]; Juan Villela[1]; Alan Aleman Perez[1]; Eric MacDonald[1]; [1]University of Texas at El Paso

Metal casting is a 3000-year form of manufacturing that is relied upon in industries for medium to large metal parts. Binder jetting (3D printing) of sand has been employed for almost two decades to digitize the casting industry and allow for the fabrication of disposable molds created directly from a computer aid design file. As the binder systems can be interrupted at predefined layers, components like sensors systems (Internet of Things) can be introduced within the mold and can wirelessly transmit data from an armada of sensors to provide unprecedented process monitoring to improve casting quality and yield.

A Data-driven Reverse Shape Compensation Method to Reduce Large Deformation in Binder Jet Parts: *Basil Paudel*[1]; Albert To[1]; [1]University of Pittsburgh

Binder jet parts undergo significant deformation during the sintering, a process that facilitates densification. This sintering distortion may result in parts with unacceptable geometric accuracy. The current work proposes an approach to compensate input geometry based on mechanistic simulations using a data-driven method. A multi-step neural network approach is proposed for the first time to learn the deformation pattern in binder jetted parts and offset for the sintering deformation. Initial geometries with several reverse scaling factors are simulated using a physics-based constitutive model to generate a training database. Once the training dataset is obtained, a reduced-order modeling technique is applied to extract the training dataset's features effectively. The model is trained and utilized to predict the compensated part. Finally, the proposed approach's efficacy is validated both numerically and experimentally by comparing the deformed sintered shape against the target.

Biopolymer Composites with Dairy Protein for Use in Additive Manufacturing: *Maia Delwiche*[1]; John Obielodan[1]; [1]University of Wisconsin-Platteville

As the popularity and versatility of additive manufacturing grows, so does interest in developing new materials, including biopolymers. Casein is a protein found in dairy and historically has been used in food applications, but its use as a biopolymer for engineering structures is not common. This study pioneers the investigation into the value of casein in biopolymer composite materials for additive manufacturing. To observe changes to material properties, a base polymer was combined with various weight-percentages of casein. Mechanical testing specimens were produced using both Fused Filament Fabrication and Stereolithography. Test results show increases in the stiffness of the materials with casein compositions over the neat matrix materials. The composite materials had varying reductions in ductility and marginal decreases in tensile strengths. Preliminary results indicates viability and prompts further inquiry into casein-based composites for additive manufacturing.

Characterization and Validation Experiments for a Binder Jet 3D Printing Modeling Framework: *Wesley Combs*[1]; Joshua Wagner[1]; Fred Higgs[1]; [1]Rice University

Binder jet 3D printing (BJ3DP) is an additive manufacturing (AM) process that is based on the selective joining of powder particles by precision jetting of liquid binder droplets. Recently, we've developed a computational framework that resolves the coupled fluid-particle interaction that occurs between the binder and powder during the binding process. Supplementary experiments are required for this numerical model to (1) calibrate the powder material properties such that the behavior of the modeled particles represents the physical powder in question, and (2) to validate the overall simulation results with direct experimental comparisons. For the former, we present a methodology for calibrating the cohesion behavior of metal AM powder using angle of repose experiments. For the latter, we introduce a dedicated experimental apparatus that isolates the fundamental physics of binder-powder interactions in BJ3DP. This apparatus employs high-speed, microscopic imaging for real time observation of the binder deposition event.

Computational Fluid Dynamics Data-driven Heat Source Model for Finite Element Process Simulation in Laser Powder Bed Fusion Additive Manufacturing: *Seth Strayer*[1]; Florian Dugast[1]; Albert To[1]; [1]University Of Pittsburgh

Thermal field prediction of the laser powder bed fusion (L-PBF) process via the finite element (FE) method can help optimize the process while avoiding the cost of experimental techniques. However, FE models require the abstraction of critical physics into an analytical heat source model, which is not accurate for simulating moderate to high energy melting regimes. This work attempts to mitigate these issues via a data-driven heat source model. In this approach, the thermal fields from a higher-fidelity computational fluid dynamics (CFD) simulation obtained via deep learning are imposed onto the FE solution and entirely replace any analytical heat source model. The resulting thermal fields and melt pool sizes are within 10% error regarding the CFD simulation and experiment, respectively, while the computational expense is significantly reduced compared to the CFD simulations. Hence, this model provides a path for improving the accuracy and potential of thermal FE modeling for L-PBF.

Computational Modeling and Experimental Validation of Primitive Formation in Binder Jet 3D Printing: *Joshua Wagner*[1]; C. Fred Higgs III[1]; [1]Rice University

While significant advancements in binder jet 3D printing (BJ3DP) technology have been realized through experimental approaches, various physical limitations, such as exceedingly small length and time scales, often make direct empirical observations intractable. Consequently, there remains an incomplete understanding of the fluid and particle dynamics governing the agglomeration of powder during liquid binder deposition. This cluster of bound particles, known as a *primitive*, is the fundamental building element of the part and its characteristics have important implications on the quality of the final component. In this work, we present fully resolved simulations of primitive formation events modeled with a novel computational fluid dynamics (CFD) and discrete element method (DEM) framework. The volume-of-fluid (VOF) method is used to capture the dynamic binder-air interface and the resulting capillary forces responsible for primitive formation. The framework is deployed for parametric studies to determine optimal combinations of process parameters with various powder systems.

Construction of Laboratory-Scale Binder Jetting System for High-Speed Synchrotron X-Ray Imaging: *Jacob Lawrence*[1]; Hector Pena Vega[1]; Bryant Stegman[1]; Caleb Roberts[1]; Joseph Spencer[1]; Clinton James[1]; McKay Christensen[1]; Nathan Crane[1]; [1]Brigham Young University

Although commercial binder jetting (BJ) printers are available, they typically do not allow sufficient control over process parameters needed to study fundamental process characteristics. This work presents an overview of the design and construction of a custom BJ system used to observe fundamental phenomena in the BJ process. This system will help elucidate the mechanisms that introduce part defects and other challenges unique to the BJ process. The BJ system was designed for both laboratory-scale experiments with a 100 x 100 mm build box and high-speed synchrotron X-ray imaging with a 500 µm wide powder bed, requiring high-accuracy motion stages and a controller with precise timings. The printer includes functionality for depositing and rolling powder, printing multi-layer parts, and direct observation of the jetting nozzle. This BJ system has enabled experiments that provide insight into the printing process that will aid future efforts to mitigate challenges associated with BJ.

Data-driven Surrogate Model for Laser Powder Bed Fusion Part - Process Design: *Jannatul Bushra*[1]; Hannah Budinoff[1]; Md Habibor Rahman[1]; Mohammed Shafae[1]; [1]University of Arizona

The quality of parts produced using laser powder bed fusion (LPBF) is affected by numerous input variables such as process parameters and part geometry. Experimentation is frequently used to optimize part quality given a set of parameters and geometry. However, experimentation is time-consuming and expensive, especially early in the design process when part geometry and dimensions are iteratively updated. Physics-based simulations can predict part quality, but these simulations are computationally expensive. We present a data-driven surrogate model to approximate simulation output rapidly. We use calibrated part-scale finite-element LPBF process simulations to generate part distortion training data for a Gaussian process-based surrogate model. The surrogate model enables sensitivity analysis and visualization of relationships between inputs (i.e., volumetric energy density and part geometry) and the simulated output (i.e., maximum part distortion). We quantify time savings from the surrogate model, showing that this approach can speed process planning and the product development cycle.

Development of Standards Education Modules for Robotics and Additive Manufacturing: Yue Zhang[1]; *Haijun Gong*[1]; Lianjun Wu[1]; [1]Georgia Southern University

This project develops students' consensus on the value of standards and standardization through systematic training that includes lectures, labs, and industrial experience. To improve students' workforce career readiness, plant tours and webinars from industrial professionals are offered. Topics include robotics and additive manufacturing standards and standardization. The plant tours, lab projects, and webinars are recorded with videos and integrated in online learning modules for adoption and replication. The products of the project are presented to diverse populations of instructors by using social media, scholarly societies, and conferences. Workshops and e-conferences are organized to promote the adoption of the modules and provide training to build a similar curriculum at other educational programs.

Direct Writing of Thick, Patterned Films of Ag by Micro Cold Spray: *Aditya Goyal*[1]; Prabhjot Singh[2]; Thomas Hiromoto[3]; Desiderio Kovar[4]; [1]Center for Additive Manufacturing and Design Innovation, Department of Mechanical Engineering, The University of Texas at Austin; [2]Lockheed Martin Space; [3]Lockheed Martin Missiles and Fire Control; [4]Center for Additive Manufacturing and Design Innovation, Materials Science and Engineering Program, Department of Mechanical Engineering, The University of Texas at Austin

The micro-cold spray process is a direct-write process that allows thick films to be deposited at room temperature by impacting nano-sized particles at velocities exceeding 1000 m/s. This technique allows for additive manufacturing on heat-sensitive substrates such as printed circuit boards. This study explores the deposition of silver particles using the micro-cold spray process. The effects of nozzle diameter and nozzle to substrate distance on silver deposits is also studied. Both of these variables affect the particle impact velocity and the breadth of the deposit. Parameters that are of interest include the deposit line width, the film density, film adhesion, electrical conductivity, and the film microstructure.

Feedback Control Development for Glass Additive Manufacturing: *Andre Bos*[1]; Douglas Meredith[1]; John Bernardin[1]; Robert Landers[2]; Edward Kinzel[2]; Alexander Rose[1]; Zechariah Jibben[1]; [1]Los Alamos National Laboratory; [2]University on Norte Dame

Glass additive manufacturing (GLAMS) is an emerging technology with a wide range of applications in chemistry, biology, optical science and engineering. A custom laser-based glass 3D printer was developed and is being optimized to produce such hardware as chemical processing equipment, microfluidic systems, as well as optical elements (e.g, lenses and fiber optics). By utilizing a standard robotic gantry system, infrared radiation-based thermal sensors, and a CO2 laser to heat glass filament to its softening temperature, glass can be extruded into various complex shapes. If the laser overheats the deposited glass, undesired defects can form in the glass, deteriorating its optical and mechanical properties. To mitigate these undesired defects, a glass temperature feedback control system is being developed. A PI closed-loop feedback algorithm is fed temperature data from a pyrometer and outputs a variable duty cycle to change the power of the CO2 laser.

Feedforward Control of Laser Powder Bed Fusion Process: *Alexander Riensche*; Benjamin Bevans[1]; Ziyad Smoqi[1]; Reza Yavari[1]; Josie Gilligan[2]; Ajay Krishnan[3]; Kevin Cole[1]; Prahalada Rao[1]; [1]University of Nebraska-Lincoln; [2]Lincoln Public Schools; [3]Edison Welding Institue

In this work we mitigated flaw formation in laser powder bed fusion (LPBF) additive manufacturing by introducing feedforward process control. In LPBF the spatiotemporal temperature distribution in the part during processing, called thermal history, is the root cause of flaw formation such as distortion, poor geometric integrity, microstructure heterogeneity, and degraded surface finish. The key idea is to use physics-based thermal simulation to optimally adjust the processing parameters layer-by-layer before the part is printed. The effectiveness of this smart additive manufacturing approach is demonstrated in the context of several LPBF parts (Inconel 718) built on two separate build plates. The results demonstrate that controlled processing improves surface finish, geometric inaccuracy, and resolution of fine features.

In-situ Monitoring and Prediction of Porosity in Laser Powder Bed Fusion using Physics-informed Meltpool Signature and Machine Learning: *Ziyad Smoqi*[1]; Aniruddha Gaikwad[1]; Benjamin Bevans[1]; Md Humaun Kobir[1]; James Craig[1]; Alan Abul-Haj[1]; Alonso Peralta[1]; Prahalada Rao[1]; [1]University of Nebraska-Lincoln

The goal of this research is the in-situ monitoring and detection of porosity formation in LPBF using a two-wavelength imaging pyrometer (ThermaViz). To realize this goal, a large cuboid of ATI 718Plus Alloy part (10 mm × 10 mm × 137 mm) was built under different conditions of laser powers and scanning speeds. During the process, meltpool temperature and shape measurements were acquired using the two-wavelength imaging pyrometer. The porosity analysis of the part was performed offline using X-ray computed tomography (XCT). The porosity in different segments of the part was correlated with physically relevant meltpool signatures, such as meltpool length, temperature distribution, and ejecta (spatter) characteristics, using simple machine learning approaches. Both the severity of porosity and its type were predicted with an accuracy exceeding 95% (statistical F1-score).

Intelligent Scan Sequence Optimization for PBF Additive Manufacturing of Complex Geometries: *Chuan He*[1]; Keval Ramani[1]; Chinedum Okwudire[1]; [1]University of Michigan, Ann Arbor

Powder bed fusion (PBF) additive manufacturing attracts attention in various industries, but its potential is limited by the defects due to non-uniform temperature distribution. To address this problem, the authors have recently presented SmartScan, an intelligent approach that is model-based and optimization-driven for generating scan sequences. The experiments demonstrated that the approach could improve up to 41% in thermal uniformity and 47% in deformation reduction compared to the existing method. However, the current version of SmartScan has only been applied to laser scanning of simple geometric patterns with uniform-length features. This work extends SmartScan to complex geometries by reformulating the original method. Simulations involving laser marking of AISI 316L stainless steel plates demonstrate that, compared to heuristic sequences, the proposed SmartScan approach improves temperature uniformity by up to 7.24 times with high efficiency. The experiment was planned for the final poster, which contains deformation reduction results.

Interlayer Mechanical Properties of Thermoset Components Produced by Material Extrusion Additive Manufacturing: *Jonathan Pedersen-Bjergaard*[1]; Mathias Michael Christensen[1]; Marco Brander[1]; Berin Seta[1]; David Pedersen[1]; Jon Spangenberg[1]; [1]Technical University of Denmark

Material extrusion additive manufacturing (MEX-AM) with thermosets has recently received interest as its material properties are appropriate for many applications. However, it is still not fully understood how the layer-by-layer technique applied in MEX-AM affects the interlayer mechanical properties. In this study, a robot arm with accompanying dispensing system is used to 3D print a two-component polyurethane with different deposition strategies (i.e., varying holding intervals between layers) in order to investigate its effect on the interlayer-stiffness and –strength. The material is extruded through a 7 mm nozzle to fabricate 42 mm high walls with a width equal to a single strand. The degree of isotropy is measured through tensile testing of dogbone samples that are milled parallel and orthogonal to the print direction thereby quantifying the bulk- and interlayer-mechanical properties, respectively. The results illuminate the importance of choosing a printing strategy that limits the reduction in interlayer-stiffness and –strength.

Investigations for the Optimization of Metal Freeforming using the ARBURG freeformer: *Nikolai Krischke*[1]; Marco Friedmann[1]; Jürgen Fleischer[1]; [1]Karlsruhe Institute of Technology - wbk Institute of Production Science

The ARBURG freeformer represents an additive manufacturing system for the production of thermoplastic components using commercially available polymer granulate. This fabrication process offers the potential to use feedstocks known from the metal injection molding (MIM) sector to manufacture so-called green parts. These parts consist of 60 Vol.-% stainless steel powder and 40 Vol-% organic polymer binding system. By debinding and sintering these green parts, it is possible to economically produce full metal components with mechanical properties comparable to metal injection molding. In this publication, the process of producing stainless steel parts with ARBURG plastic freeforming will be presented. The mechanical properties and part density are optimized by varying manufacturing parameters and raw materials. Furthermore, concepts to optimize and increase the service life of the nozzle are shown and discussed. An increase of at least 250% could be achieved by plasma nitriding and coating components of the discharge system.

Layerwise Thermal Process Simulation for Laser Powder Bed Fusion: Calibration and Validation with Infrared Camera: *Shawn Hinnebusch*[1]; Alaa Olleak[1]; Christopher Barrett[2]; Seth Strayer[1]; Florian Dugast[1]; Albert To[1]; [1]University of Pittsburgh; [2]Open Additive, LLC

Current part-scale thermal process simulation models for laser powder bed fusion (L-PBF) are calibrated using thermocouple data and do not capture the correct temperature distribution. Most layerwise simulations apply a constant heat flux for the duration of the layer or apply the melting temperature to the layer for a set time. These methods are tuned with the absorptivity and heat convection coefficients for a set geometry to match experimental data. With the help of thermocouples and an infrared (IR) camera, the simulations can be accurately calibrated for various geometries by tuning the model parameters throughout the build process. This proposed workflow uses a voxel mesh and matrix-free formulation to take full advantage of GPU-based computing allowing for rapid and accurate calibration of L-PBF process simulation models.

Monitoring and Flaw Detection during Wire-based Directed Energy Deposition using In-situ Acoustic Sensing and Wavelet Graph Signal Analysis: *Benjamin Bevans*[1]; André Ramalho[2]; Ziyad Smoqi[1]; Aniruddha Gaikwad[1]; Telmo Santos[2]; Prahalada Rao[1]; J.P. Oliveira[2]; [1]University of Nebraska-Lincoln; [2]UNIDEMI

The goal of this work is to detect flaw formation in the wire-based directed energy deposition (W-DED) process using in-situ sensor data. The W-DED studied in this work uses an electric arc to melt the wire; known as wire arc additive manufacturing (WAAM). The adoption of WAAM in industry is limited in industry due to the lack of process consistency. The process is susceptible to stochastic and environmental disturbances that cause arc instabilities, leading to the formation of porosity and suboptimal geometric integrity. Accordingly, the objective of this work is to detect flaw formation in WAAM using data acquired from an acoustic sensor installed near the electric arc. We develop an approach that extracts a single graph feature (Fiedler number) from the acoustic sensor data, which is subsequently tracked in a control chart. Using this approach, flaw formations are detected with a false alarm rate less-than 2%.

Multi-Stage Additive Manufacturing Process for Multi-Scale Porous Structures: *Zipeng Guo*[1]; [1]University at Buffalo, State University of New York

As porous structures find more and more applications across various industries, a generic and cost-effective additive manufacturing technique for fabricating multi-scale (combined nano-, micro-, and macro-) porous structures is highly desirable. We propose the hypothesis that a multi-stage additive manufacturing process, including printable material preparation, 3D printing techniques, and post-processing, could offer a universal solution to build an agile AM process for porous structures. This presentation analyzes how each stage can be better correlated to fabricate multi-scale porous structures. Additionally, we explored experimental and CFD-based analytical tests to optimize the resolution of the developed multi-stage process. Such that not only can the end-part shape fidelity be improved but also achieve a well-ordered pore arrangement. With a high-fidelity three-dimensional (3D) printing process and the precise controllability of the porosity, we showed that the printed end-part exhibited remarkable multi-functionalities, including robust mechanical strength, thermal insulation, and energetic applications, etc.

Optimization of Vat Photopolymerization Parameters for $LiCoO_2$ Battery Electrode Manufacturing: *Ana Aranzola*[1]; Ana Martinez[1]; Alexis Maurel[1]; Eric MacDonald[1]; [1]University of Texas at El Paso

Additive manufacturing has the potential to revolutionize the fabrication of energy storage devices such as lithium-ion batteries (LIB) for portable and transportation applications. In this work, vat photopolymerization (VPP) 3D printing of a photosensitive resin, loaded with LiCoO2 positive electrode active material for a classical LIB, was performed using Direct Light Processing (DLP) and Stereolithography (SLA). To overcome the challenges related to the opacity, high viscosity, and light refraction—caused by the composite nature of the resin, an optimization of the printing parameters such as layer thickness, exposure time, heating of the resin, laser intensity, and brightness of UV light was achieved. Printed items were subjected to an additional thermal post-processing step with a view to reach the best compromise between electrochemical performances and mechanical integrity. The results obtained through this research will pave the way toward the development of 3D-printed batteries via VPP.

Prediction of Microstructure in LPBF using Part-level Thermal Simulations, In-process Sensor Data, and Machine Learning: *Grant King*[1]; [1]University of Nebraska–Lincoln

The microstructure of parts manufactured using laser powder bed fusion (LPBF) are highly dependent on the thermal history (cooling rate) of the part during material deposition. Currently characterization of the microstructure must be completed post-processing.In this research a combination of part-level thermal simulations and in-process sensor data (infrared thermal camera and meltpool imaging pyrometer) are used as inputs to machine learning models trained to predict the microstructure of a part (primary dendritic arm spacing). The approach is demonstrated in the context of twenty-one Inconel 718 parts of various shapes built under differing laser power and velocity settings.

Preventing Recoater Crash in Laser Powder Bed Fusion via Modified Inherent Strain Modeling: *Wen Dong*[1]; Albert To[1]; [1]University of Pittsburgh

When fabricating overhang structures with the laser powder bed fusion (L-PBF) process, the recoater blade is prone to stoppage during printing if the overhang tip significantly deforms, which is often referred to as the recoater crash. In the present work, the modified inherent strain (MIS) method, as a fast modeling approach, is implemented to predict the distortion of a part with overhangs during printing. Through experimental measurement and simulation results, we investigate the relationships between multiple geometrical parameters and the height of the part immediately before a recoater crash. After that, the critical criterion is found to predict the recoater crash. The proposed criterion can be applied in the design stage of a part to reduce the possibility of a recoater crash, thus saving cost and increasing manufacturing efficiency.

Processing Evaluation of Al-4008 (Al-Si-Mg) Alloy via Liquid Metal Jetting-based Additive Manufacturing: *Kellen Traxel*[1]; Nicholas Watkins[1]; Viktor Sukhotskiy[1]; Alex Wilson-Heid[1]; Eric Elton[1]; Andrew Pascall[1]; Jason Jeffries[1]; [1]Lawrence Livermore National Laboratory

Liquid metal jetting based-AM is an emerging process requiring only raw metal ingot to produce near-fully dense parts through jetting molten metal at frequencies in excess of 400Hz. While opening a large application space due to a wide array of acceptable feedstocks, questions about part quality and processability of different materials limit industrial use. Droplet impingement on the build substrate, coalescence between adjacent droplets and solidification, as well as the chosen processing parameters can generate variations in both surface and bulk part characteristics which are not well understood to date. To this end, we present results of printing studies where aluminum alloy Al4008 was jetted onto metallic substrates at various input processing parameters such as ejection frequency, spacing between droplets, hatch spacing, and the buildplate surface temperature. Our results help manufacturers and researchers working to develop non-powder based metal additive manufacturing methods. Prepared by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS-833717.

Reducing Part Distortion in Laser Powder Bed Fusion through Data-driven Topology Optimization: *Praveen Vulimiri*[1]; Florian Dugast[1]; Shane Riley[1]; Albert To[1]; [1]University of Pittsburgh

Laser powder bed fusion (LPBF) is a popular method to produce complex metal additive manufactured (AM) parts. However, during the process, the laser melting of the metal powder introduces thermal stresses which distort the part from the desired dimensions. If the stress is large, it could lead to cracking, recoater blade crash, or other build failures. A new data-driven model has been developed based on the modified inherent strain method to provide a near instantaneous approximation of the residual stress and strain in a part. The model is used in topology optimization to optimize the part for end use application and constrain the distortion during the build process simultaneously. A computational example of the method will be shown followed by a plan for experimental validation of the method.

Simulation of Curing Behavior with Temperature Dependent Kinetic Constants in Vat Photopolymerization: *Yue Zhang*[1]; Heyang Zhang[1]; Xiayun Zhao[1]; [1]University of Pittsburgh

Vat photopolymerization (VPP) prints 3D parts by crosslinking monomers with light activation. The degree of conversion (DoC) is a primary indicator of VPP performance since it is closely related to the resulting geometrical and mechanical properties. A common approach to obtain DoC is via simulation, which however has limited accuracy due to using simplified models that assume invariant reaction rate constants during VPP. In this work, we develop a method of modeling and simulating a digital light processing (DLP) based VPP process, which incorporates the potential effect of process temperature on kinetic constants, by coupling the chemical kinetics with heat and mass transfer. In-situ thermal monitoring is used to update the model and simulation parameters. Experiment is conducted to validate the developed model simulation approach by comparing the predicted DoC with a Fourier-transform infrared spectroscopy (FTIR) characterization result. The method can be used for DLP-VPP process planning, optimization and control.

Support Free Directed Energy Deposition: *William Dong*[1]; Minglei Qu[1]; Lianyi Chen[1]; [1]University of Wisconsin-Madison

Direct energy deposition (DED), as one of the metal AM technologies, is adaptable to large-scale applications, with versatile materials' uses. However, most DED technologies are using a top-down configuration (i.e., laser irradiates downwards) relying on gravity to hold the melt pool onto the substrate. This significantly restricts the application of DED technologies, by not being able to print horizontally in an unmovable part or in space where gravity will no longer pull the melted metal to the substrate. In this work, we build a DED system and show the possibility of printing horizontally without support using a metal material with a highly viscous liquid phase. This study demonstrates that viscosity can replace gravity to hold the melt pool in all directions, and presents possibilities of applications of DED systems where gravity will not exist or in unfavorable directions.

Thermal History Validation of Directed Energy Deposition Process: *Usman Tariq*[1]; Freddy Wu[1]; [1]Missouri University of S&T

Direct Energy Deposition (DED) incorporates high thermal gradients due to continuous heating and cooling during the deposition of new layers, which can cause serious distortion due to the formation of residual stresses in the final product which decreases the desired quality. One method to optimize the thermal gradient to reduce the residual stresses is to predict required values with the help of FEA and later validate with experimental results. We use the layer-by-layer technique to predict thermal and residual stress which can take much less computational time as compared to the track-by-track method. In the experiment, monitoring the distributed thermal data of substrate and the melting pool of each layer's deposition is significant. Monitoring each layer's thermal data to validate the FEA model is more convincible. In this study, we would do the numerical model of the DED process and design a comprehensive experiment to validate the DED model.

Investigation of Wear Behavior of Centrifugal Disc Finishing on Additively Manufactured Ti6Al4V Samples: *Foxian Fan*[1]; Sagar Jalui[1]; Nicholas Lajoie[1]; Guha Manogharan[1]; [1]Penn State University

As-built metal Additive Manufacturing (AM) parts require secondary processing in most applications to improve surface finish and mechanical strength. Mass finishing technologies use abrasive media to deburr bulk parts to improve surface finish. Fixtureless MF method such as Centrifugal Disc Finishing (CDF) is an effective and economical surface improvement method for additively manufactured metal parts. However, effects of different build orientations and AM processes on the wear behaviors between abrasive media and AM surfaces are still unclear. This study investigates the wear behavior of Laser Powder Bed Fusion (L-PBF) and Electron Beam Powder Bed Fusion (EB-PBF) fabricated Ti6Al4V parts by post processing with CDF. Both AM orientation-based surface finish and wear behavior are evaluated to gain new insights into the key mechanism of AM mass finishing. In addition, findings from this study could offer optimal build orientation and mass finishing for surface improvement.

X-ray Analysis of Magnetically Induced Additive Manufacturing: *Ronald Sellers*[1]; Christopher McCullough[1]; Eduardo Gonzalez[1]; Adam Light[1]; Sarah Wolff[1]; Hui Wang[1]; [1]Texas A&M University

Through advancements in technology over the last several years, additive manufacturing has become increasingly mainstream in the manufacturing industry. A method that was observed in this study for improving additive manufacturing processes is the incorporation of magnets into the manufacturing process. Laser powder bed fusion experiments were conducted in order to evaluate the effects of the introduction of magnets on parts printed. Stainless steel 316L was printed onto Ti64 substrates using both spot welding and line scanning techniques. It was observed that magnets had a varying effect on the melt pool and the keyhole depth through x-ray image analysis. Additionally, the various magnets altered the melt-flow dynamics of tungsten particles in the melt pools generated through line scanning. There is strong evidence that magnetic fields could be a viable solution to increasing additive manufacturing's precision, though future research is needed to visualize and quantify this effect on printed parts.

X-ray Tomography as a 3D Metrology Technique for AM Materials: *Bryan Hunter*[1]; Erica Jacobson[2]; Ian Cummings[3]; Adam Wachtor[2]; Brian Patterson[1]; [1]Materials Science and Technology Division, Los Alamos National Laboratory; [2]National Security Education Center, Los Alamos National Laboratory; [3]Space and Remote Sensing, Los Alamos National Laboratory

Although metal AM produces parts faster and easier, the printing process often produces defects (pores and surface roughness) that undermine the part's mechanical properties. We will use X-ray CT to assess print quality through void measurement (size and distribution) as well as gross dimensional accuracy and printed surface roughness. The STL file becomes the ground truth from which all 3D measures can be quantified. In comparison to line-of-sight surface measurement techniques, our developed method can interrogate inner and outer surfaces, which allows for a more encompassing measurement of surface roughness. From this, we can determine the optimal printing parameters to minimize defects within parts to optimize mechanical performance. We are investigating the minimum feature size that can be measured with X-ray CT as a comparison with the in situ quality control measurements, ultrasonic, thermal, acoustic and optical sensing measurements acquired during the printing process.

A Literature Review of the Application of M300 Maraging Steel for Laser Powder Bed Fusion: *Haley Petersen*[1]; Matthew Priddy[1]; [1]Department of Mechanical Engineering, Mississippi State University

Maraging 300 steel (M300) shares similar mechanical properties as other maraging steels and is used in a large scope of applications interested in the combined tensile strength and high strength-to-weight ratio. This form of steel is unique because of its hardening reaction that does not include carbon. M300 from laser powder bed fusion (L-PBF) additive manufacturing has a unique fine microstructure, which is a result of the layer-by-layer printing process and process parameters of L-PBF. Due to the nature of the L-PBF printing process, it is expected that the manufactured parts have residual stress and other defects. There are several post-processing procedures, such as heat treatments, that are performed on these parts to eliminate some of these defects. This research explores the process parameters that can improve the overall quality and mechanical properties of a print as well as the current status of M300 in L-PBF.

Developing a Roadmap to Manufacture Feedstocks for Selective Laser Sintering: *Peter Braegelmann*[1]; Rachel Collino[1]; Cade Willis[1]; Natasha Story[1]; Matthew Dirmyer[2]; Joseph Torres[1]; [1]Los Alamos National Laboratory; [2]C-CDE: Chemical Diagnostics and Engineering

An important goal for the National Nuclear Security Administration (NNSA) weapons complex is to improve the agility and responsiveness to field new stockpile designs. Manufacturing of polymeric components for nuclear weapons applications is often performed by outside vendors via injection molding and machining. Recent problems with this strategy include failures in visual (inclusions/discolorations) and dimensional inspections. Additive Manufacturing (AM) supports this goal by providing the ability to rapidly produce small lots of prototype components early in the production process, with the hope of opportunities for insertion of actual components in the future. In order to realize this goal, we seek to optimize custom powder feedstocks for SLS. This work focuses on developing a roadmap to process non- commercial materials into printable feedstocks. Kansas City National Security Campus (KCNSC) has the ability to scale up which can potentially give the complex full control of feedstocks, mitigating any supply chain risks. Efforts have focused on ensuring LANL has necessary benchtop processing equipment to be able to transfer to KCNSC.Additionally, developing industry partners is critical to advance AM technology. Specifically, Advance Laser Materials (ALM) is currently developing thermoplastic feedstocks for the SLS process. Working with industry allows the complex to have input on formulations. Specifically, having input on any additives or flow agents gives us more flexibility to ensure materials meet specified requirements. This will ultimately define an overarching framework for printing non-commercial thermoplastic materials in an agile and responsive manner.

GPU-accelerated WAAM Process Simulation using an Improved Modeling Workflow: *Xavier Jimenez*[1]; Alaa Olleak[1]; Albert To[1]; [1]University of Pittsburgh

Several studies have been published on using computational methods to simulate wire arc additive manufacturing (WAAM). Most of those studies focus on a specific geometry with a hard-coded model that is difficult to implement on a new geometry. This paper focuses on an improved workflow that combines slicing and simulation to create a WAAM part with a digital twin. The model is solved using a GPU-accelerated process simulator and the parts are printed on a Gefertec Arc605 system. The model calibration process and challenges associated with it are also discussed. The improved workflow helps to accelerate the manufacturing process of new parts using WAAM, through thermal history prediction at the part scale level.

Localized Curing of Thermoset Composites via Microwave Irradiation: *Johanna Schwartz*[1]; Saptarshi Mukherjee[1]; Emer Baluyot[1]; Joe Tringe[1]; Maxim Shusteff[1]; [1]Lawrence Livermore National Laboratory

Microwave irradiation enables thermal curing of composite thermoset materials not possible in light-based additive manufacturing approaches. Herein we show our group's progress in controlling localized curing in transparent and opaque composite thermoset materials via directed microwave irradiation. This exploratory study focused on controlling cure spot size in relation to power, thermal heat profile, and time in a wide range of materials. Numerical simulations studying microwave energy localization are conducted to determine key parameters for experiments. The experimental system comprising a microwave applicator coupled to an RF amplifier will be discussed. Additives include glass, ceramic, and conductive nanoparticles, as well as fiber reinforcement. This work culminated in a prototype additive manufacturing system, capable of making large opaque structures.

Finite Element Modeling of Material Deposition for 5-axis Additive Manufacturing: *Liv Russell*[1]; Matthew Register[1]; David Failla[1]; Matthew Priddy[1]; [1]Mississippi State University

Traditional additive manufacturing (AM), though it has revolutionized prototyping and small batch manufacturing, is geometrically limited to parts without overhangs or inclusion of supports at the sacrifice of surface quality. Wire-arc additive manufacturing (WAAM) and other 5-axis AM remove these limitations by rotating both the workpiece and the heat source, allowing for more complex geometries. However, rotating the heat source introduces new thermal variability as old material is reheated in varying directions rather than just downwards into the bed. The affects of these temperature cycles are not well known. This work focuses on finite element (FE) simulations of 5-axis material deposition processes for geometries with varying overhangs sliced multi-directionally. The relationship between cooling and heat source directions relative to deposited material will be explored, as well as the current limitations of FE simulations of 5-axis AM.

Wire-arc Fabrication of Topology Optimized Aviation Components: Nic Tomanelli[1]; Ben Nguyen[1]; Daniel Chrivasuta[1]; Matthew Martin[1]; Nathanael High[1]; Christopher Williams[1]; *Sam Pratt*[1]; [1]Virginia Tech

Hybrid wire arc am (hWAAM) processing provides an opportunity for onsite maintenance and repair of damaged aviation components that would otherwise be costly to reproduce and/or deliver. The aim of this project is to explore the suitability of hWAAM for this application via a case study aimed to redesign an aerospace component for processing via hWAAM in Al5556. A screening study verified design and material constraints. These findings and the part loading conditions were used to topologically optimize (TO) the component, resulting in reduced mass, cost, and production time compared to the original casting. The output of the TO solver was then used as the basis for the final design, incorporating DfAM rules required for our specific process. The part was then printed, machined where necessary, and load tested to validate its performance compared to the OEM component, resulting in 20% lower mass and substantial cost and time savings.

Immersed Electrohydrodynamic Direct Writing: Fabrication of Nanofiber-reinforced Composites with Spatially Controlled Distribution: Yunzhi Xu[1]; Ange-Therese Akono[1]; *Ping Guo*[1]; [1]Northwestern University

Nanofiber-reinforced composites have provided tremendous opportunities in advanced engineering material design. However, the control over the spatial distribution of nanofibers is the primary challenge in manufacturing nanocomposites. Our research focuses on developing an innovative fabrication approach for nanofiber-reinforced composites with spatially resolved fiber distribution based on a modified electrospinning process. We explore the viability of directly generating nanofibers inside a viscous liquid matrix to yield nanofiber-reinforced composites with controlled distribution and deposition of nanofibers. Our process, inspired by 3D bioprinting, makes use of a high electrostatic force to draw nano-scale fibers inside the liquid bath matrix and allows the freestanding of the electrospun nanofibers with the support of the liquid bath. This novel approach enables dynamic control of the fiber morphology and the fiber 3D spatial distribution inside the composites and further leads to a scalable manufacturing approach of multifunctional nanofiber-reinforced composites and potential advances in micro-scale 3D printing.

Evaluation of Direct Ink-write Additive Manufacturing: *Sidney Scott*[1]; Joseph Torres[1]; Matthew Dirmyer[1]; Adam Pacheco[1]; Jim Tata[1]; Rachel Collino[1]; [1]Los Alamos National Laboratory

Direct Ink-Writing is an extrusion-based additive manufacturing technique in which viscoelastic inks such as resins, gels, or pastes are deposited onto a translation stage in a pre-defined sequence. Commonly, these materials consist of two or more components that are mixed during the printing process and cured upon deposition1. Careful selection of the curing method, material components, and process parameters allow for fabrication of a wide range of materials with functionalized additives and fillers. Multiple methods of in-situ curing have been developed to address one of the primary challenges of Direct Ink Writing: optimizing the mechanical properties of the material post-extrusion2. Significant investment into the development of this technology for the nuclear enterprise has been made by the NNSA thus far; with mirrored capabilities being implemented at LANL, LLNL, and KCNSC with the intention of increasing the production yields of current weapons components and evaluating the efficacy of new materials for legacy and future systems. Our work presented here aims to provide an overview of the Aerotech 5-axis Direct Ink-Write printer; highlighting its benefits, challenges, and potential as a manufacturing capability at Los Alamos National Laboratory.

Melt Pool Size Control in LENS Direct Metal Deposition: Brandon Botchway[1]; Elias Snider[2]; *Douglas Bristow*[3]; [1]Department of Mechanical Engineering, University of District of the Columbia; [2]Department of Mechanical and Aerospace Engineering, Missouri University of Science and Technology; [3]TMS

Metal additive manufacturing processes that utilize direct energy deposition (DED) can be more efficient than their selective laser melting (SLM) counterparts, especially for smaller parts that would not utilize the full size of the powder bed in SLM. Blown powder processes (a subset of DED) utilize a stream of powder directed into the focus of a laser to deposit material in precise locations to build a part. The process dynamics in this process, however, are not always well-behaved and can result in very rough surface finishes or even failed prints due to amplified propagating variations in material deposition along the path. Melt pool size control via laser power is explored here as a method of reducing variation and improving the quality of deposition in the blown powder process. The experimental setup, image processing methods, and results for various single-bead builds are presented.

Origami Expandable Printing using Fused Granular Fabrication and Fabric Substrates: *Victoria Stone*[1]; Jason Weaver[1]; [1]Brigham Young University

Bed size is a major limiting factor in the 3d printing community. The maximum size of a printed part is generally slightly smaller than the printer's build plate. This paper describes research to print parts with multiple materials that are able to unfold once removed from the build plate. This capability greatly increases the possible part size for a given print envelope and aids in the compactability and transportation of large objects. Using fused granular fabrication (FGF), successful tests have been achieved with a variety of fabrics and plastics. Several promising combinations are demonstrated using an example design.

Digital Twin Research and Development for an Additive Manufacturing Cell: Francisco Parra[1]; Freddy Wu[2]; Usman Tariq[2]; *Frank Liou*[2]; [1]Department of Computer Science, University of Texas at El Paso; [2]Department of Mechanical and Aerospace Engineering, Missouri University of Science and Technology

This project is to research and develop a digital twin for an additive manufacturing cell, and it is involved in hardware/software R&D to implement such a system. This research mainly discusses the technologies of image processing and data transmission in the digital twin. First, collecting thermal data during additive manufacturing through sensors and thermal model; Second, isolating the melt pool image and calculating its dimension; Third, transferring post-processing data to the cloud through versatile communication protocols. During these three steps, cyber security issues are also explored. Overall, this research explores the basic and significant technology in additive manufacturing to implement digital twin.

Development of a Hybrid Carbon Fiber Composites Additive Manufacturing Machine: Jesus Duran[1]; John Pappas[2]; Ming Leu[2]; *Xiangyang Dong*[3]; [1]Department of Aerospace and Mechanical Engineering, University of Texas at El Paso; [2]Department of Mechanical and Aerospace Engineering, Missouri University of Science and Technology; [3]TMS

The rapidly increasing demand in lightweight high-strength materials makes it necessary to develop fiber reinforced polymer for automotive and aerospace applications. Our previous studies have developed hybrid additive manufacturing system and techniques for carbon fiber composites based on an API robotic machine. To transit the developed platform toward commercialization, it will be necessary to evaluate the stability of the additively manufactured large-scale parts. The project objective is to study the stability of the 3D printed large-scale parts toward mold and tooling applications over long period. One large-scale carbon fiber composite part will first be designed and tested. Specifically, a panel structure is designed and then printed with a continuous toolpath. A laser tracker will then be used to measure the geometry change of the 3D printed part. This will be the first study to perform stability analysis of carbon fiber composite parts prepared by large-scale additive manufacturing techniques.

Print Initiation and Termination in Glass Additive Manufacturing: Miguel Jaquez-Sagarnaga[1]; Aidan Brooks[2]; *Douglas Bristow*[3]; [1]Department of Mechanical and Aerospace Engineering, New Mexico State University; [2]Department of Mechanical and Aerospace Engineering, Missouri University of Science and Technology; [3]TMS

Glass-wire laser direct energy deposition is an additive manufacturing process that uses a laser to melt glass filaments or fiber optic into a glass structure. Unlike metal deposition processes, the large thermal working range for glasses enables unique capabilities in printing, including printing completely unsupported spans such as in spring and truss structures. Glass AM has been used to print functional structures including lenses, glass-to-metal seals, fiber optic devices, and microfluidic systems, as well artistic structures. One challenge in Glass AM is effective and repeatable control of bonding and geometry during initiation and termination of the wire print. This is particularly critical when occurring in the middle of a build, as can frequently occur for most glass wires that cannot be spooled. Wire feed and laser power process parameters and wire preparation strategies will be explored for repeatable initiation and termination of the print.

Four-Axis Coordinated Motion for Glass Additive Manufacturing: Natalie Althof[1]; Aidan Brooks[2]; *Douglas Bristow*[2]; [1]Department of Electrical Engineering, Missouri University of Science and Technology; [2]Department of Mechanical and Aerospace Engineering, Missouri University of Science and Technology

Glass-wire laser direct energy deposition is an additive manufacturing process that uses a laser to melt glass filaments or fiber optic into a glass structure. Unlike metal deposition processes, the large thermal working range for glasses enables unique capabilities in printing, including printing completely unsupported spans such as in spring and truss structures. Glass AM has been used to print functional structures including lenses, glass-to-metal seals, fiber optic devices, and microfluidic systems, as well artistic structures. Printing with glass generally requires control of the wire orientation as well as direction to achieve consistent bead geometry. However, coordination of the orientation with the linear motion can be challenging, particularly around corners. This poster presents a method of coordinating the rotational axis with linear axes during print to reduce geometric defects when the print changes direction. Interpolation algorithms and parameter optimization results will be presented.

Metal Additive Manufacturing for Advanced Materials by Laser Foil Printing: Fernando Sepulveda[1]; Hiep Pham[2]; Tunay Turk[2]; Ming Leu[2]; *Jonghyun Park*[3]; [1]Department of Computer Science, University of Texas at El Paso; [2]Department of Mechanical and Aerospace Engineering, Missouri University of Science and Technology; [3]TMS

Metal Glasses (MGs) have superior mechanical properties compared to crystalline metals due to a lack of crystalline defects, and are typically produced by rapid quenching and solidification of molten metals. However, parts made of metallic glasses have been limited to simple geometries (e.g., thin films) because the manufacturing of MG parts requires a very high cooling rate that conventional powder-based metal additive manufacturing technologies cannot meet. A new foil-based metal additive manufacturing technique called Laser Foil Printing (LFP) has the potential to overcome the challenge of rapid cooling because the thermal heat of the melt pool can be conducted away very efficiently through the bulk foil compared to powders, opening the possibility to print MGs with 3D structures and in commercially significant sizes. In this work, the LFP manufacturing approach is used to produce advanced MG materials and structures with extremely high mechanical properties (density, toughness, corrosion resistance, etc.) by developing a controllable active cooling system to rapidly cool the metal foil after each printing step. The research focuses on studying the heat generation and temperature profile of the LFP technique with and without an active cooling system. The impact on the melting and welding of the metal foils layers, material composition and structure, material property, and resulting part geometry have been investigated. The study aspires to refine LFP processes to create unique composite MG alloys with complex 3D structures.

Soybean-Derived Printed Graphene Structures via Aerosol Jet Printing Process: Simon Zuluaga[1]; Tazdik Patwary Plateau[2]; *Jonghyun Park*[3]; [1]Department of Mechanical and Materials Engineering, Florida International University; [2]Department of Mechanical and Aerospace Engineering, Missouri University of Science and Technology; [3]TMS

The continuing demand for graphene due to its unique properties and scientific applications has driven innovation in current production technologies to speed up production. However, the production yield of graphene is still very low, which makes graphene expensive. This work focuses on the low-cost, high yield and quality graphene (HYQG) synthesized from low-cost soybean via an electrochemical exfoliation. Current methods are limited to exfoliate in flake/bulk level of graphene precursor, which cannot exfoliate HYQG. Here, a newly designed electrode is used to exfoliate particle-level graphene that achieved a yield of 70% (HYQG). This work also addresses the challenge of 3D printing of HYQG via aerosol jet printing, where controlled printing of atomized graphene-particles can create a well-controlled structure of HYQG. A parametric study for both materials and process has been conducted to optimize HYQG structures.

Additive Manufacturing of Embedded Sensors with Laser Foil Printing Method: Miguel Escobar[1]; Tunay Turk[2]; Jonghyun Park[2]; *Ming Leu*[3]; [1]Department of Industrial, Manufacturing, and Systems Engineering, University of Texas at El Paso; [2]Department of Mechanical and Aerospace Engineering, Missouri University of Science and Technology; [3]TMS

Laser Foil Printing (LFP) is a laser-based Additive Manufacturing process being developed at the Missouri University of Science and Technology. This process uses metal foils as the feedstock, which is melted by directing a laser beam to selectively melt and solidify a portion of metal foil, followed by laser contour cutting into a desired geometry, layer by layer, to form a three-dimensional metal part according to a computer-aided design (CAD) model. This study investigates the feasibility of embedding commercially available “foil type” sensors during the process of LFP for fabricating 3D parts using 304L stainless steel as the part material. A main challenge with embedding foil-type sensors is their construction, normally being encased in a thin plastic film with maximum temperature ratings in the range of 500-700□ F. This study will investigate how the sensor can survive the heat transferred from the high-temperature molten metal resulted from melting of metal foils during the LFP part fabrication process.

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