THE 34TH ANNUAL INTERNATIONAL

SOLID FREEFORM FABRICATION SYMPOSIUM 2023

– AN ADDITIVE MANUFACTURING CONFERENCE –

August 14-16, 2023 | Hilton Austin
Austin, Texas, USA

FINAL PROGRAM

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

Sponsored by:

NSF

Office of Naval Research ONR Science & Technology

sffsymposium.org

SCHEDULE AT-A-GLANCE **Current as of 7/18/23 -** *Subject to change*

Date/Event	Time	Location
Sunday, August 13		
Registration	1:00 - 6:30 p.m.	Grand Ballroom Foyer
Welcome Reception	5:30 - 6:30 p.m.	Salon G
Monday, August 14		
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. - 12:00 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*
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, August 15		
Registration	7:00 a.m. - 5:00 p.m.	Grand Ballroom Foyer
Technical Sessions	8:00 a.m. - 12:05 p.m.	*See Technical Program*
Break	9:55 a.m. - 10:25 a.m.	Grand Ballroom Foyer
Blacks in Additive Manufacturing (BiAM) Networking Forum	11:00 a.m. - 12:00 p.m.	602
Poster Installation	12:00 p.m. - 3:00 p.m.	Salon JK
SFF 2023 Conference Lunch served	12:30 p.m. -1:40 p.m.	Grand Ballroom Foyer
AM Research - Reflection, Best Practices, and Future Directions Panel	12:30 p.m. - 1:40 p.m.	Salon H
Additional Lunch Seating	12:30 p.m. - 1:40 p.m.	Salon G & F
Technical Sessions	1:40 p.m. - 4:00 p.m.	*See Technical Program*
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)
Poster Dismantle	5:30 p.m. - 6:00 p.m.	Salon JK
Wednesday, August 16		
Registration	7:00 a.m. - 5:00 p.m.	Grand Ballroom Foyer
Luggage Storage	7:00 a.m. - 5:00 p.m.	Room 602
Technical Sessions	8:00 a.m. - 11:50 a.m.	*See Technical Program*
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 2023)

Individuals who cancel their registrations and do not receive a refund are entitled to access the PDF ebook conference proceedings

The daily registration rate includes the following:

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

Registration Hours

The registration desk will be located in the Salon H Foyer of the Hilton Austin during the following hours:

- Sunday, August 13: 1:00 p.m. to 6:30 p.m.
- Monday, August 14: 7:00 a.m. to 5:00 p.m.
- Tuesday, August 15: 7:00 a.m. to 5:00 p.m.
- Wednesday, August 16: 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 14-106 for locations.

Luggage Storage

Luggage storage will be available at no cost to attendees on Wednesday, August 16, from 7:00 a.m. to 5:00 p.m. in 602. 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, August 13 • 5:30-6:30 p.m.
Salon G
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.

Awards Banquet

Monday August 14 • Salon HJK
6:00 p.m. Reception
6:30 p.m. Welcome Remarks
6:40 p.m. Dinner & Wine Service
7:45 p.m. The FAME Awards

- International Outstanding Young Researcher in Freeform and Additive Manufacturing Award: Nicholas Meisel, Penn State University
- International Freeform and Additive Manufacturing Excellence Award: Anthony “Tony” Rollett, Carnegie Mellon University

9:00 p.m. Event Concludes

Conference Lunch

Tuesday August 15, 12:30 to 1:40 p.m.
Salon G & F
An informal networking lunch will be provided near the meeting rooms in Salon G & F at the Hilton Austin at the lunch break on Tuesday. The cost is included in the conference registration fee.

AM Research – Reflection, Best Practices and Future Directions Lunch Panel

Tuesday August 15, 12:30 to 1:40 p.m. • Salon H
The panel will take place during the lunch break on Tuesday. The cost is included in the conference registration fee. See Page 12-13 for additional details on speakers.

Blacks in Additive Manufacturing (BiAM) Networking Forum

Tuesday, August 15, 11:00 a.m. – 12 noon • 602
Join the Blacks In Additive Manufacturing (BiAM) Networking Forum at the International Solid Freeform Fabrication Symposium on August 15 from 11 a.m. to 12 noon in the Hilton Austin Room 602. Hosted by Dr. Chukwuzubelu Ufodike, Assistant Professor at Texas A&M University and founder of BiAM, the forum offers insightful discussions, networking opportunities, and the chance to explore career advancements and research collaborations. This event provides a valuable platform for diverse professionals, faculty, and students in Additive Manufacturing (AM).

A BIG THANK YOU TO:

- The **National Science Foundation** for providing meeting support for students
- The **Office of Naval Research** for providing meeting support
- **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 lunch panel.
- **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	
Joe Beaman,Chair, UT-Austin	David Leigh, Shinebranch
Desi Kovar, UT-Austin	Carolyn Seepersad, UT-Austin
Michael Cullinan, UT-Austin	Mehran Tehrani, University of California, San Diego
Zhenghui Sha, UT-Austin	Dave Bourell, emeritus-UT Austin

Intl SFF Symposium Advisory Committee	
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Chad Duty, University of Tennessee	Toshiki Niino, University of Tokyo
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Carl Hauser, TWI Technology Centre	Ryan Wicker, University of Texas at El Paso
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

DINING OPTIONS

RESTAURANT	ADDRESS	PHONE	WEBSITE	CUISINE
III Forks D $$$	111 Lavaca St.	512-474-1776	3forks.com	Steakhouse
1886 Bakery & Cafe, Driskill Hotel B L $$	604 Brazos St.	512-439-1234	1886cafeandbakery.com	Bakery
Anthem L D $$	91 Rainey St. #120	512-731-1411	eatdrinkanthem.com	Latin & Asian
Arlo Grey, The LINE D $$	111 E. Cesar Chavez St.	512-478-2991	thelinehotel.com/arlogrey	American
ATX Cocina D $$	110 San Antonio St. #170	512-263-2322	atxcocina.com	Mexican
Austin Taco Project, Hilton B L $$	500 E. Fourth St.	512-682-2739	austintacoproject.com	New Texan
The Backspace D $$	507 San Jacinto Blvd.	512-474-9899	thebackspace-austin.com	Italian
Banger's Sausage House & Beer Garden B L D $$ ♫	79 Rainey St.	512-386-1656	bangersaustin.com	American
Bar Chi D LN $$	206 Colorado St.	512-382-5557	barchisushi.com	Sushi
Bob's Steak and Chop D $$$	301 Lavaca St.	512-222-2627	bobs-steakandchop.com	Steakhouse
Burger Bar, JW Marriott L D $	110 E. Second St.	512-608-4822	burgerbaraustin.com	Burgers
Cabana Bar, Hotel ZaZa L D $$	400 Lavaca St.	888-880-3244	hotelzaza.com/austin	American
Cafe Blue L D $$	340 E. Second St.	512-428-5796	cafebluetx.com	Seafood
Cannon and Belle, Hilton D $$	500 E. Fourth St.	512-493-4900	cannonandbelle.com	American
The Capital Grille L D $$$	117 W. Fourth St.	512-322-2005	thecapitalgrille.com	Steakhouse
Caroline, Aloft B L D $$ ♫	621 Congress Ave. #101	512-982-6766	carolinerestaurant.com	American
Casino El Camino L D $	517 E 6th St.	512-469-9330	casinoelcamino.com	American
CAVA L D $$	515 Congress Ave.	512-256-8002	cava.com	Mediterranean
Cedar Door L D LN $$ ♫	201 Brazos St. Bldg. A	512-473-3712	cedardooraustin.com	American
Chick-fil-a B L D $	600 Congress Ave. Ste C150	512-482-8030	chick-fil-a.com	Southern
Ciclo, Four Seasons B L D LN $$	98 San Jacinto Blvd.	512-685-8300	cicloatx.com	Steakhouse
Comedor D LN $$$	501 Colorado St	512-499-0977	comedortx.com	Mexican
Cooper's Old Time Pit Bar-B-Que L D LN $$	217 Congress Ave.	512-474-4227	coopersbbqaustin.com	Barbeque
Corinne, Marriott Downtown B L D LN $$$	304 E Cesar Chavez St. #100	737-787-7018	corinneatx.com	American
Corner, JW Marriott B L D $$$	110 E. Second St.	512-608-4488	cornerrestaurantaustin.com	New Texan
CRÚ - A Wine Bar L D $$	238 W. Second St. #13	512-472-9463	cruwinebar.com	New American
Dean's Italian Steakhouse, JW Marriott D $$$	110 E Second St.	512-608-4490	opitalianaustin.com	Italian
Eddie V's Steakhouse D LN $$$ ♫	301 E Fifth St.	512-472-1860	eddiev.com	Seafood/Steak
Electric Shuffle L D $	91 Red River St.	512-894-8779	electricshuffleusa.com	Bar
Emmer & Rye D $$	51 Rainey St. #110	512-366-5530	emmerandrye.com	New American
Eureka! L D LN $$	200 E. Sixth St.	512-735-1144	eurekarestaurantgroup.com	American
Fareground	111 Congress Ave.	512-465-2107	fairgroundaustin.com	Assorted
Fleming's Prime Steakhouse L D $$$	320 E. Second St.	512-457-1500	flemingssteakhouse.com	Steakhouse
Flower Child L D $	500 W. Second St.	512-777-4132	iamaflowerchild.com	American
Forthright B L $$	35 Brazos St.	512-387-3370	forthright.cafe	American
Foxy's Proper Pub L D LN $$	201 Brazos St.	512-501-6713	foxysproperpub.com	Pub
Garrison, Fairmont Hotel D LN $$$	101 Red River St.	512-600-2000	garrisongrill.com	Assorted
Geraldine's, Hotel Van Zandt B L D LN $$	605 Davis St.	512-476-4755	geraldinesaustin.com	New American
Goldie's, Austin Proper D LN $$	600 W. 2nd St.	512-628-1500	properhotel.com	Bar
Group Therapy, Hotel ZaZa B L D LN $$$	400 Lavaca St.	512-542-9292	hotelzaza.com/austin	American
Gus's Fried Chicken L D $	117 San Jacinto Blvd.	512-474-4877	gusfriedchicken.com	Chicken
Iron Cactus L D LN $$	606 Trinity St.	512-472-9240	ironcactus.com	Mexican
Iron Works L D $$	100 Red River St.	512-478-4855	ironworksbbq.com	Barbeque
J. Prime Steakhouse D $$$$	301 Brazos St. #150	737-309-3301	jprimesteakhouse.com	Steakhouse
Jimmy John's L D $	515 Congress Ste 1200	512-457-4900	jimmyjohns.com	Sandwiches
Jo's Coffee B L D $ ♫	242 W. Second St.	512-469-9003	joscoffee.com	Coffee House
La Condesa L D $$$	400 W. Second St.	512-499-0300	lacondesa.com	Mexican
Lamberts BBQ B L D LN $$ ♫	401 W Second St.	512-494-1500	lambertsaustin.com	Barbeque

KEY B = Breakfast L = Lunch D = Dinner LN = Late Night $ = $5-14 $$ = $15-25 $$$ = $26+ ♫ = Live Music

RESTAURANT	ADDRESS	PHONE	WEBSITE	CUISINE
La Café Crepe B L $	200 San Jacinto Blvd.	512-480-0084	cafecrepeofaustin.com	French
La Piscina, Austin Proper B L D LN $$$	600 W 2nd St.	512-628-1415	properhotel.com	Tex-Mex
Loaf + Vine, Marriott Downtown $	304 E Cesar Chavez	512-457-1111	marriott.com/hotels/hotel-information	Coffee
Local Foods B L D $	454 W 2nd St.	512-614-1212	localfoodstexas.com	American
Maiko Sushi Lounge L D $	311 W 6th St.	737-236-9888	maikoaustin.com	Sushi
Mai Thai L D $$	207 San Jacinto Blvd. #201	512-482-8244	maithaiaustin.com	Asian
Mason's Famous Lobster Rolls L D $$	200 Congress Ave.	512-428-4006	masonslobster.com	Seafood
Michelada's L D $$	504 Trinity St.	737-320-0300	micheladasaustin.com	Mexican
Moonshine L D $$	303 Red River St.	512-236-9599	moonshinegrill.com	American
Newk's L D $	408 Congress Ave.	512-647-2420	newks.com	American
North Italia L D $$	500 W Second St. #120	512-777-5062	northitalianrestaurant.com	Italian
Numero 28 L D $$	452 W Second St.	512-494-5510	numero28austin.com	Italian
One Taco B L D $	402 Brazos St.	512-527-3002	onetaco.com	Tex Mex
P. Terry's B L D $	515 Congress Ave.	512-473-8722	pterrys.com	Burgers
P.F. Chang's China Bistro L D $$	201 San Jacinto Blvd.	512-457-8300	pfchangs.com	Asian
The Peacock Mediterranean Grill, Austin Proper	600 W 2nd St.	512-628-1410	properhotel.com	Mediterranean
Péché D LN $$	208 W Fourth St.	512-494-4011	pecheaustin.com	French
Pelon's Tex Mex L D $$	802 Red River St.	512-243-7874	pelonstexmex.com	Mexican
Perfect Strangers, Hotel ZaZa B L $$	400 Lavaca St.	737-484-5675	hotelzaza.com/austin	Coffee
Perry's Steakhouse & Grille L D $$$	114 W Seventh St.	512-474-6300	perryssteakhouse.com	Seafood
Punch Bowl Social L D $$	522 Congress Ave.	512-549-8937	punchbowlsocial.com	American
Rainey Street Food Truck Lot L D LN $$	82 Rainey St.	-	-	Assorted
RA Sushi L D $$	117 W Fourth St. #300	512-726-2130	rasushi.com	Asian
Red Ash D $$$	303 Colorado St. #200	512-379-2906	redashgrill.com	Italian
Revolucion Juice and Coffee B L D $	207 San Jacinto Blvd. STE 200	512-738-3112	revolucionsa.com	Cafe
Revue B D LN $$	101 Red River St.	512-524-4813	revueatx.com	Italian & Asian
Roaring Fork, Royal Sonesta Hotel – SFA D $$$	701 Congress Ave.	512-583-0000	roaringfork.com	Southwestern
Rules & Regs, Fairmont Austin B L D LN $$	101 Red River St.	512-717-4844	fairmont.com/austin	Latin American
Ruth's Chris Steak House D $$$	107 W Sixth St.	512-477-7884	ruthschris.com	Steakhouse
Smash ATX L D $	213 W 5th St.	737-263-0555	smashatx.com	Bar
Stella San Jac, The Westin B L D $$	310 E Fifth St.	512-792-5648	stellasanjac.com	New Texan
Stubb's BBQ L D LN $$ ♫	801 Red River St.	737-465-1218	stubbsaustin.com	Barbeque
Sushi Junai Omakase L D $$$	315 Congress Ave.	512-401-3822	sunconsulting.us	Sushi
Sweetgreen L D $$	200 W 2nd St.	512-798-4500	sweetgreen.com	Various
Swift's Attic D LN $$	315 Congress Ave.	512-482-8842	swiftsattic.com	American
Tacodeli B L $	301 Congress Ave.	512-601-6631	tacodeli.com	Mexican
Taverna Ristorante B L D $$	258 W Second St.	512-477-1001	tavernabylombardi.com	Italian
Torchy's Taco B L D LN $	110 San Antonio St. #120	512-792-5909	torchystacos.com	Mexican
Trace, W Hotel B L D LN $$$	200 Lavaca St.	512-542-3660	traceaustin.com	American
Truluck's D $$$	400 Colorado St.	512-482-9000	trulucks.com	Seafood & Steak
Velvet Taco L D $	522 Congress Ave. #100	512-298-5223	velvettaco.com	Mexican
Veracruz All Natural, LINE hotel B L D LN $$$	111 E Cesar Chavez St.	512-665-2713	veracruzallnatural.com	Mexican
Verbena, Canopy Hilton B L D LN $$	612 W 6th St.	512-991-3019	verbenaatx.com	Various
Vince Young Steakhouse D $$$	301 San Jacinto Blvd.	512-457-8325	vinceyoungsteakhouse.com	Steakhouse
Wax Murtle, Thompson Hotel L D LN $$$	506 San Jacinto Blvd.	737-257-3026	waxmyrtles.com	Mediterranean
The Well B L D $$	440 W 2nd St.	737-742-1129	eatwellatx.com	New American
Wu Chow L D $$	500 W Fifth St. #168	512-476-2469	wuchowaustin.com	Asian
Zanzibar, Marriott Downtown L D LN $$	304 E Cesar Chavez	737-787-6969	zanzibaratx.com	Island

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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.

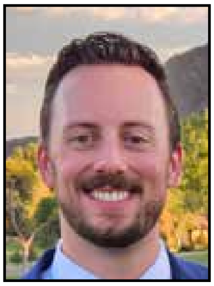
STUDENT REGISTRATION FEE WAIVER RECIPIENTS

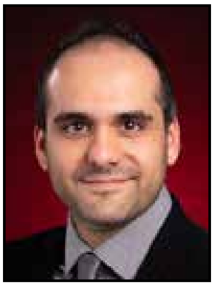
The following undergraduate and graduate students applied for and received conference registration fee waivers. Waivers are funded by a conference participant support grant from the National Science Foundation. Congratulations to all award winners.

SFF Symposium Student Registration Fee Waiver Award Winners	
Aaron Liao, The University of Texas at Austin	Kareem Tawil, Rochester Institute of Technology
Adrian Nez, Navajo Technical University	Kazi Safowan Shahed, Penn State University
Ahmet Alptug Tanrikulu, University of Texas at Arlington	Kishore Mysore Nagaraja, The University of Texas at Dallas
Alex De La Cruz, University of Texas at El Paso	Kourtney Porsch, Johns Hopkins University
Amiri Thorpe, Florida A&M University	Logan Hutton, Penn State University
Anannya Doris, The University of Texas at El Paso	Maharshi Arindom Sharma, Texas A&M University, College Station
A-Sun Truth, University of the District of Columbia	Malachi Landis, Northwestern University
Austen Thien, Georgia Institute of Technology	Martha Baldwin, Carnegie Mellon University
Basil J. Paudel, University of Pittsburgh	Matthew A. Roach, University of Tennessee, Knoxville
Benjamin D. Bevans, Virginia Tech	Matthew Ebert, Texas A&M University
Bharath Bhushan Ravichander, The University of Texas at Dallas	Michael Geuy, Penn State University
Bing Ren, University of Florida	MohammadBagher Mahtabi, Purdue University Northwest
Brett Emery, University of Washington	Mohanish Andurkar, Kansas State University
Cameron Noe, Arizona State University	Nathan Wassermann, Carnegie Mellon University
Carson Vath, Penn State University	Neshat Sayah, Baylor University
Casey Wong Tran, New Mexixo State University	Nicholas Capps, University of Notre Dame
Charles Wade, University of Colorado Boulder	Nicholas Lamprinakos, Carnegie Mellon University
Christie Hasbrouk, Penn State University	Olivia Fulkerson, Oklahoma State University
Christina Nissen, University of Texas at Austin	Oluwasola K. Arigbabowo, Texas State University, San Marcos
Christine Cummings, Penn State University	Orkhan Huseynov, Tennessee Technological University
Christophwer O'Brien, The University of Tennessee, Knoxville	Parimal Patel, The University of Texas at Arlington
Chuan He, University of Michigan, Ann Arbor	Rachel Tullis, Wright State University
Colin Ancalmo, Carnegie Mellon University	Rencheng Wu, University of Arkansas at Fayetteville
David Khanan, The University of Texas at Austin	Ricardo Arechiga De La Rosa, University of Houston – Clear Lake
Dawood Al Nabhani, University of Michigan- Dearborn	Ronnie Frank Pires Stone, University of Texas at Austin
Eric Weflen, Iowa State University	Sandeep Khadka, Clarkson University
Farzana Tasnim, University of Texas at Austin	Saroj Subedi, North Carolina State University
Fatemeh Elhambakhsh, Arizona State University	Satyanarayana Konala, North Carolina State University
Gabriel Lipkowitz, Stanford University	Seongun Yang, Oregon State University
Guadalupe Quirarte, Carnegie Mellon University	Shu Wang, Brigham Young University
Haolin Zhang, University of Pittsburgh	Sri Vaishnavi Thummalapalli, Arizona State University
Henry Haffner, Missouri University of Science and Technology	Stacy Ross, The Georgia Institute of Technology
Jacklyn Griffis, Penn State University	Subodh Subedi, University of Wisconsin-Madison
Janet Wong, Georgia Institute of Technology	Sumit Paul, University of Louisville
Janghan Park, The University of Texas at Austin	Tasrif Ul Anwar, Utah State University
Jazmin Ley, University of Nebraska – Lincoln	Timothy Shi Jie Yap, The University of Texas at Austin
Jennings Ye, University of California, Berkeley	Tunay Turk, Missouri University of Science and Technology
Jeremy Cleeman, Rutgers University	Usman Tariq, Missouri University of Science & Technology
Joselin Corral, The University of Texas at El Paso	Venkatavaradan Sunderarajan, Georgia Institute of Technology
Joseph Fisher, Penn State University	Wesley Combs, Rice University
Joshua Tarantino, University of New Mexico	Yousra Bensouda, University of Pittsburgh
Kaiyue Deng, University of Delaware	

Monday Morning Plenary

Hilton 6th floor • Salon HJK
The conference will begin with a Monday morning Plenary session beginning at 8:00 a.m. on the 14th. Please see details below on this year's speakers.



Plenary Speakers

Pictured left to right
- **Gershon Elber**, Technion
- **Michael Heiden**, Sandia National Laboratories
- **Jack L. Beuth**, Carnegie Mellon University
- **Ben Fotovvati**, Seurat Technologies
- **Joy Gockel**, Colorado School of Mines
- **Khershed Cooper**, National Science Foundation


FAME Award Speakers

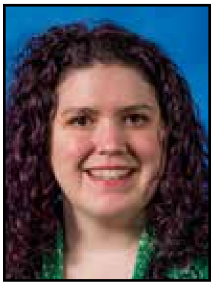
Pictured left to right
- **Nicholas Meisel**, Penn State University
- **Anthony "Tony" Rollett**, Carnegie Mellon University

AM Research – Reflection, Best Practices and Future Directions Lunch Panel

Tuesday August 15, 12:30 to 1:40 p.m. • Salon H
This special panel comprising of experienced AM researchers from federal agencies, industry, laboratories, and academia will focus on: (1) a short overview of their AM journey, (2) best practices in AM research for current graduate students, and early-career AM researchers, (3) future directions in AM research for senior researchers.

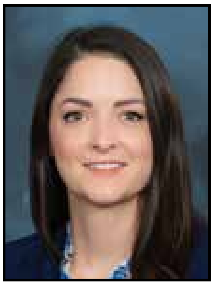
Panelists

Kershed Cooper
National Science Foundation
Dr. Khershed P. Cooper is a Program Director for Advanced Manufacturing in the CMMI Division of the ENG Directorate at the NSF. He directs basic research activities in all areas of advanced manufacturing, and associated Manufacturing USA Institutes and NSF-DFG collaborations. He is a disciplinary program officer for the ERC program, and a co-program officer for cross-cutting programs such as CAS, BRITE, NNCI and AccelNet. Recently, he also served on detail to the Office of International Science and Engineering (OISE), where he developed collaborations with funding agencies in partner countries. Dr. Cooper is an NSF representative for NSTC's NSET Sub-committee, which frames the NNI Strategic Plan and for NextFlex and REMADE Manufacturing USA Institutes. Prior to joining NSF, Dr. Cooper was Program Officer for Manufacturing Science at ONR and, concurrently, a Senior Research Metallurgist at NRL. Dr. Cooper received his MS and PhD from the University of Wisconsin–Madison. He has presented over 200 invited and over 70 contributed talks at national and international conferences and workshops. He has nearly 150 publications. He has sponsored and participated in international studies in various emerging areas of advanced manufacturing. He is a Fellow of SME and ASM International and a recipient of ASM International's Burgess Memorial Award.



Andelle Kudzal
Office of Naval Research
Dr. Andelle Kudzal is a materials engineer with 10 years of additive manufacturing research experience. Andelle is currently a research and development lead at the Naval Surface Warfare Center Carderock focusing on a transitioning additive manufacturing technology to the Navy. Andelle previously worked at the Army Research Laboratory as the powder bed fusion research lead focusing on material development and process property relations. Her current research interests include non-destructive inspection of additive parts, in-situ monitoring of additive manufacturing for process and part validation, and developing navy relevant alloy systems for naval applications.

Alaa Elwany
Department of Energy
Alaa Elwany is a Fellow at the Advanced Materials and Manufacturing Technologies Office (AMTTO), U.S. Department of Energy. He is currently on detail from Texas A&M University where he is an Associate Professor at the Department of Industrial and Systems Engineering and holder of the Kincaid Professorship. He has also previously served as Assistant Director for Technology at the National Institute of Standards and Technology Office of Advanced Manufacturing (NIST OAM), and Research Scientist at General Motors R&D. His research focuses on modeling, analysis, and control of advanced manufacturing processes and systems, with emphasis on metal additive manufacturing processes, process monitoring, and uncertainty quantification. He has received scholarly recognitions from leading agencies and professional societies including NSF CAREER, SME Outstanding Young Manufacturing Engineer, SME Manufacturing Vision Award, ASME Chao & Trigger Young Manufacturing Engineer, and IBM Faculty Award. Dr. Elwany acquired a PhD in Industrial and Systems Engineering from Georgia Institute of Technology in 2009.



Amy Elliott
Oak Ridge National Laboratory
Dr. Amy Elliott is group leader for the Robotics and Intelligent Systems (RIS) Group at ORNL's Manufacturing Demonstration Facility (MDF). At the MDF, the RIS group leads R&D in advanced controls, monitoring, software, hardware, and integration for large-scale metal Additive Manufacturing (AM) technologies, including the novel MedUSA platform. Dr. Elliott is also lead principle investigator for binder jet AM technology and has over numerous publications and 15 patents in the area. In her role she consults with industry partners across the US on potential uses for AM.

Denis Cormier
Rochester Institute of Technology
Denis Cormier is the Earl W. Brinkman Professor at Rochester Institute of Technology (RIT) where he also directs the New York State AMPrint Center for Advanced Technology. He was a professor at NC State University from 1994-2009 prior to joining RIT in 2009. He founded NC State's Rapid Prototyping Lab in 1995 where he focused on the design of engineered lattice structures and the development of aerospace materials using Arcam's EBM process. At RIT, he has largely focused on developing the molten metal droplet jetting AM process with Vader Systems and Xerox. He has been the PI on over $22M in industry and government funding during his career that has resulted in over 100 publications and 10 issued or pending patents. He has also advised 68 graduate students to date.

TECHNICAL PROGRAM GRID - OVERVIEW

Location	Room	Monday AM 8:00 a.m. to 12:05 p.m.	Monday PM 1:30 p.m. to 5:20 p.m.	Tuesday AM 8:15 a.m. to 12:05 p.m.	Tuesday PM 1:40 p.m. to 4:20 p.m.	Wednesday AM 8:00 a.m. to 11:50 a.m.	Wednesday PM 1:10 p.m. to 5:00 p.m.
Fourth Floor	400/402					Process Develoepment: Photopolymerization and Other Processes	Process Development: Powder Bed Fusion Process
	408					Process Development: Direct Ink Writing and Jetting	Applications: Biomedical
	404		Process Development: Hybrid and Convergent Processes- Robotics and Hybrid Polymer-metal Processes	Process Development: Powder Bed Fusion Process Innovations	Data Analytics: Large Scale AM, Deposition Methods, Metals		
	410		Process Development: Directed Energy Deposition and Cold Spray	Process Development: Powder Bed Fusion Monitoring and Imaging I -------------------------- Materials: Metals-Mechanical Properties II	Process Development: Powder Bed Fusion Monitoring and Imaging II	Process Development: Powder Bed Fusion Monitoring and Imaging III	Applications: Techniques for End Use Parts
	412		Process Development: Material Extrusion I	Process Development: Material Extrusion II	Applications: Process Techniques for Part Production	Data Analytics: Laser Powder Bed Fusion	Wire-fed DED: Gas and Thermal Management and Analysis
	415 AB		Modeling: Machine Learning, Data Driven, Digital Twins	Data Analytics: Application to General Additive Manufacturing	Data Driven Modeling and Process Control	Materials: Metals-Novel AM Methods I	Materials: Metals-Novel AM Methods II
	416 AB		Modeling: Uncertainty and Thermomechanical	Modeling: Deposition of Particles and Fibers	Materials: Polymers Powder Bed Fusion	Applications: Topology Optimization	Materials: Metals-Graded Compositions -------------------- Particulate and Dispersoid Reinforced Metals
	417 AB		Materials: Polymer AM Processes	Binder Jet AM: Material and Experiments	Materials: Polymers Material Extrusion	Applications: Finishing Techniques and Partameters	
	Salon A		Modeling: CAD, Scan Patterns, Contouring, Slicing I	Modeling: CAD, Scan Patterns, Contouring, Slicing II	Wire-fed DED: Aerospace and Others	Wire-fed DED: Materials and Experiments	
	Salon B		Applications: Lattices and Cellular I	Applications: Lattices and Cellular II	Applications: Lattices and Cellular III	Applications: Lattices and Cellular IV	
Sixth Floor	602		Binder Jet AM-systems, Modeling, and Simulation	Wire-fed DED: Machine Learning and AI Application	Materials: Metals-Characterization of AM Processes and Materials		
	615 AB		Wire-fed DED: Geometric and Path Optimization	Applications: Residual Stress	Process Modeling	Materials: Metals-Creep and Fatigue	
	616 AB		Materials: Ceramics, Glasses	Fiber Composites	Materials: Metals-Processing Strategies I	Materials: Metals-Processing Strategies II	
	Salon F		Materials: Metals-Mechanical Properties I	Polymers: Functional Materials	Education (2:40PM)		
	Salon G		Composites	Thermal Modelling	Economics of AM (2:40PM)		
	Salon HJK	Plenary Session (Salon HJK)			Poster Session (Salon JK)		

Session Name	Plenary Session
Room	Salon HJK
Chair	Joseph J. Beaman, University of Texas at Austin
8:00 AM	Introductory Comments
8:15 AM	Design, Analysis, Optimization, and Fabrication of Porous/Heterogeneous Microstructures via Spline-based Volumetric Representations: Gershon Elber, Technion
8:40 AM	Implementing In-situ Process Monitoring in Additive Manufacturing to Accelerate Qualification: Michael Heiden, Sandia National Laboratories
9:05 AM	Machine Learning Applied to Process Monitoring for Laser Hot Wire Additive Directed Energy Deposition : Jack Beuth, Carnegie Mellon University
9:30 AM	Experimental and Computational Study of Area Printing Additive Manufacturing : Ben Fotovvati, Seurat Technologies
9:55 AM	Gas Flow and Delivered Laser Power Effects on Mechanical Properties : Joy Gockel, Colorado School of Mines
10:20 AM	NSF Advanced Manufacturing Program and Funding Opportunities: Khershed Cooper, National Science Foundation
10:45 AM	Break
11:15 AM	You Must Unlearn What You Have Learned: Establishing a DfAM Mindset in the Face of Centuries of Traditional Manufacturing: Nicholas Meisel, Pennsylvania State University
11:40 AM	Co-design of 3D Printing, Parts and Microstructure in High-temperature and High-pressure Heat Exchangers: Anthony Rollett, Carnegie Mellon University

TECHNICAL PROGRAM GRID - MONDAY PM

Session Name	Process Development: Hybrid and Convergent Processes- Robotics and Hybrid Polymer-metal Processes	Process Development: Directed Energy Deposition and Cold Spray	Process Development: Material Extrusion I	Modeling: Machine Learning, Data Driven, Digital Twins	Modeling: Uncertainty and Thermomechanical	Materials: Polymer AM Processes	Modeling: CAD, Scan Patterns, Contouring, Slicing I
Room	404	410	412	415 AB	416 AB	417 AB	Salon A
Chair	Zhenghui Sha, University of Texas at Austin	Frank Liou, Missouri University of Science and Technology	TBD	David Rosen, Agency for Science, Technology and Research	Guha Manogharan, Pennsylvania State University	Jackson S. Bryant, Virginia Tech	Nicholas A. Meisel, Penn State University
1:30 PM	Time-optimal Path Planning for Heterogeneous Robots in Swarm Manufacturing: Ronnie Frank Pires Stone, The University of Texas at Austin	Electroslag Strip Cladding for Additive Manufacturing: Adam Stevens, Oak Ridge National Laboratory	Testing Protocol Development for Fracture Toughness of Parts Built with Big Area Additive Manufacturing: Juan Pablo Garcia Chavira, The University of Texas at El Paso	Validation of Simulation Based Predictions of Recoater Interference in Laser Powder Bed Fusion : Chao Li, Autodesk Inc.	Uncertainty Quantification in Laser Powder Bed Fusion from Mesoscale to Part Scale: Daniel Moser, Sandia National Laboratories	Investigation of Crack Formation Process during Low Temperature Laser Sintering of PEEK by Observing Melt and Solidification Behavior: Takashi Kigure, Tokyo Metropolitan Industrial Tech Rsch Inst	Single Path Generation for Closed Contours via Graph Theory and Topological Hierarchy: Michael Borish, Oak Ridge National Laboratory
1:50 PM	High-precision Camera-based Auto-calibration System for Cooperative 3D Printing: Charith Nanayakkara Ratnayake, University of Arkansas	Process Strategy and Geometrical Distortion of Heat-treated 17-4PH Stainless Steel Produced by Interleaved Machining and Blown-powder DED: Lauren Heinrich, Oak Ridge National Laboratory	Strengthening FFF Parts via Annealing with Structured Dual Material Filaments and Dissolvable High-temperature Shells: Ryan Dunn, US Army Research Laboratory	High Fidelity Model of Directed Energy Deposition: Laser-Powder-Melt Pool Interaction and Effect of Laser Beam Profile on Solidification Microstructure: Saad Khairallah, Lawrence Livermore National Laboratory	Evaluating Residual Heat-driven Melt Pool Variation through GPU-based Thermal Process Simulation: David Anderson, University of Pittsburgh	Investigation of the Processability of Polyether Block Amide in High Speed Sintering: Marco Wimmer, Universität Bayreuth	Path Planning for Non-Planar Robotic Additive Manufacturing : Nicholas Meisel, Pennsylvania State University
2:10 PM	Physical Validation of Job Placement Optimization in Cooperative 3D Printing: Cole Mensch, The University of Texas at Austin	Structural Integrity Assessment of Cold Spray Repaired High-strength Aluminium Alloy 7075 Specimens: Ali Bakir, Conventry University	Static Mixing Nozzles for Long and Short Fiber Additive Extrusion Processes: Tyler Smith, Oak Ridge National Laboratory	Thermal Monitoring and Cure Process Modelling of Dual-wavelength VPP Printing: Heyang Zhang, University of Pittsburgh	Modeling Morphological Development of Ti-6Al-4V for Cyclic Thermal Histories in Laser Powder-bed Fusion: Evan Adcock, Carnegie Mellon University	Photothermal Bleaching of Nickel Dithiolene for Bright Multi-colored 3D Printed Parts : Paul Olubummo, HP Labs	Novel Concepts to Integrate Dense and Sparse Infill Regions in Material Extrusion AM Parts: Logan Hutton, Pennsylvania State University
2:30 PM	Exploring a Supervisory Control System Using ROS2 and IoT Sensors: Matthew Roach, University of Tennessee, Knoxville	Side on Plasma Emission Spectroscopy of TiAl6V4 During Laser Scanning: Ethan Sprague, Lawrence Livermore	Self-heating Tooling on BAAM using Co-extruded Heating Wires: Jesse Heineman, Oak Ridge National Lab	Layer-wise Prediction of Microstructural Evolution in Laser Powder Bed Fusion Additive Manufacturing using Physics-based Machine Learning: Alexander Riensche, Virginia Tech	Residual Stress Estimation in a Complex Additively Manufactured Component with an Internal State Variable Material Model : David Failla, Mississippi State University	Powder Bed Fusion of Polypropylene-ethylene Co-polymers: Jackson Bryant, Virginia Tech	Modeling and Correcting Illumination Inhomogeneity over Multiple DLP Illumination Intensities for Better Fabrication Accuracy : Saroj Subedi, North Carolina State University, Mechanical and Aerospace Engineering (MAE)
2:50 PM	Lost-PLA Casting Process Development Using Material Extrusion with Low-density PLA: Mohammad Alshaikh Ali, Tennessee Tech University	Role of In-situ Monitoring Technique for Digital Twin Development using Direct Energy Deposition: Melt Pool Dynamics and Thermal Distribution: Sung-Heng Wu, Missouri University of Science & Technology	Real-time Image-based Quality Control for Bio-additive Manufacturing through Layer-by-layer Analysis: Casey Tran, New Mexico State University	Toward Post-superficial Temperature Monitoring During Additive Manufacturing through Data-driven Inpainting: Jiangce Chen, Carnegie Mellon University	Multi-load Support Optimization for Minimizing Part Deformation in LPBF: Subodh Subedi, University of Wisconsin Madison	Powder Bed Fusion of Ultra-high Molecular Weight Polyethylene via Novel Scan Strategy and Post-process: Jackson Bryant, Virginia Tech	Voxel-free Radon Transform for Improving Surface Quality in Computed Axial Lithography: Jennings Ye, University of California, Berkeley
3:10 PM	BREAK	BREAK	BREAK	BREAK	BREAK	BREAK	BREAK
3:40 PM	In-situ Electrical Resistance Measurements for Soldering Studies in Hybrid AM: Joselin Corral, University of Texas at El Paso	Influence of Substrate Temperature on the Formation of Individual Weld Paths during Laser Cladding (LMD) when Processing 316L.: Stefan Gnaase, Universität Paderborn / Lehrstuhl für Leichtbau im Automobil	Printing Parameter Optimization of Extruded Metal Paste by Response Surface Technique: Marshall Norris, Tennessee Tech University	Modeling and Simulation of Vat Photopolymerization Additive Manufacturing: A Review : Yousra Bensouda, University of Pittsburgh	Process Modeling of Multi-material Laser Powder Bed Fusion: Jacklyn C. Griffis, Pennsylvania State University	Stimuli Driven Morphing of Printed Liquid Crystal Elastomers : Caitlyn Krikorian, Lawrence Livermore National Laboratory	Level Set Grids for Hybrid Manufacturing: Liam White, Oak Ridge National Laboratory
4:00 PM	Hybrid Metalized Polymer Core (HMPC), Initial Concept and Design of Lightweight Additively Manufactured Hardware: Shaun Whetten, Sandia National Labs	Impact of Powder Deposition Parameters on Powder Catchment Efficiency in Laser Directed Energy Deposition: Colin Ancalmo, Carnegie Mellon University	Parametric Analyses of Impact of Deposition Pressure on Multi-axis Free-form Fabrication.: Aditya Thakur, Institute of Space System (IRAS)	Multi-scale Modeling of Thermal/reisidual Stress in Additive Manufacturing Across Grain- , track- and Part-scales: Wentao Yan, National University of Singapore	Generation and Simulation of Layer Wait Time to Prevent Overheating: Zack Francis, Ansys	Structural Stability During Thermal Post-curing of Direct Ink Write Thermoset Composites: Stian Romberg, National Institute of Standards and Technology	Computer Modelling of Residual Stress Development During Selective Laser Melting of 17-4 PH Stainless Steel and Experimental Validation via Contour Method: Yusuf Polat, Yunus Emre
4:20 PM	Hybrid Metalized Polymer Core (HMPC) Initial Results of Prototype Mass Optimized Pulsed Power Hardware: Charles Rose, Sandia National Labs	Experimental Study of Cryogenic Directed Energy Deposition Conducted at -20°C: Wei Li, University of Texas at Dallas	Non-linear Dynamic Modelling of Cartesian-frame FFF 3-D Printer Gantry for Predictive Control: Maharshi Arindom Sharma, Texas A&M University, College Station	Powder Bed Fusion Surrogate Models via Convolutional Neural Networks: David Rosen, Agency for Science, Technology and Research	Towards Large-scale Grain Growth Modeling in Powder Bed Fusion: Michael Paleos, University of Pittsburgh	Ultrasonic Non-destructive Characterization of Anisotropic Additively Manufactured Polymers: Akash Nivarthi, University of Texas at Austin	Developing an Application Programming Interface for Hypocycloid-based Inner and Outer Gears of Progressive Cavity Pumps in Advanced Extrusion Applications: Yusuf Furkan Ugurluoglu, Newcastle Unviersity
4:40 PM	Development of Multimaterial Additive Manufacturing Systems for the Embedded Electronics : Carson Vath, SHAPE Lab	Embedded Fiber Optic Sensing in DED Using High-temperature Adhesives: Elias Snider, Missouri University of Science and Technology		Predicting Temperature Field for Metal Additive Manufacturing using PINN: Bohan Peng, Imperial College London		Magnetic Characterization of 3D Printed High-performance Polyamide Magnetic Composite: Oluwasola Arigbabowo, Texas State University, San Marcos	
5:00 PM	State-of-the-art Cyber-enabled Physical and Digital Systems Deployed in Distributed Digital Factory Using Additive and Subtractive Manufacturing Systems: Open, Scalable, and Secure Framework: Frank Liou, Missouri University of Science and Technology						

Applications: Lattices and Cellular I	Binder Jet AM-systems, Modeling, and Simulation	Wire-fed DED: Geometric and Path Optimization	Materials: Ceramics, Glasses	Materials: Metals-Mechanical Properties I	Composites	Session Name
Salon B	602	615 AB	616 AB	Salon F	Salon G	Room
Denis Cormier, Rochester Institute of Technology	Nathan Crane, Brigham Young University; Chris Williams, Virginia Tech	TBD	Desiderio Kovar, University of Texas at Austin	Joseph J. Beaman, University of Texas at Austin	Xinyi Xiao, Miami University	Chair
Directional Dependence of Heat Treated IN718 Gyroid TPMS Lattices Fabricated by Selective Laser Melting : Bharath Bhushan Ravichander, University of Texas at Dallas	A Data-driven Reverse Shape Compensation Method to Reduce Large Deformation in Binder Jet Parts: Basil Paudel, University of Pittsburgh	A Spherical Test Artifact to Evaluate Three-dimensional Form Accuracy for Wire Arc Additive Manufacturing: Sakufu Ko, Institute of Technology, Shimizu Corporation	Effect of Binder Content on Ceramic Paste for Additively Manufactured Parts via Ceramic On-demand Extrusion: Abid Hasan Rafi, Missouri University of Science and Technology	Effect of Heat Treatment on the Microstructure and Mechanical Properties of Monel K500 Alloy Fabricated via L-PBF and LP-DED : Nabeel Ahmad, Auburn University	3D Metal Nanoparticle-polymer Composites: Strategies for Integrating Metal Nanoparticles with Two-photon Polymerization Process: Jisun Im, Centre for Additive Manufacturing/University of Nottingham	1:30 PM
LPBF Process Optimisation for Thin-walled Pure Copper Lattice Structures.: Michel Smet, KU Leuven	Does Finer Powder Get Deposited First in Powder Bed? – A Comparative Study using Simulation and Experimental Techniques: Kazi Shahed, The SHAPE Lab	Hybrid Metal Manufacturing of Large Freeform Geometries: Bradley Jared, University Of Tennessee, Knoxville	Origami Robocasting of High-density Ceramic Structures with Slurry-based Inks: Kayla Blalack, University of Virginia	Effect of Post Thermal Processing Conditions on Physical and Mechanical Properties of LPBF Processed Inconel 718: Swathi Vunnam, AddUp Inc	Cyber-informed Additively Manufactured Functionally Graded Materials and Structures: Xinyi Xiao, Miami University	1:50 PM
Additive Manufacturing of Hybrid Sandwich Sheets by Laser Powder Bed Fusion of Metals: Sebastian Platt, University Duisburg-Essen	Feasibility of Non-destructive Measurement of Powder Bed Density and Thermal Properties Using Flash Thermography: Shu Wang, Brigham Young University	In-situ Geometric Characterization via Embedded 3D Scanning and Implicit Modeling: Tadeusz Kosmal, Virginia Tech DREAMS Lab	The Impact of the Printed Part Size on the Shrinkage and Density in Binder Jetting Additive Manufacturing of Ceramics Powder: Chris Smith, Sam Houston State University	A Comparison of Microstructure and Mechanical Properties of Inconel 718 Manufactured via L-PBF, LP-DED and WAAM: Nabeel Ahmad, Auburn University	Engineering Hydrophobic Stainless Steel Nanocomposites : Troy Ansell, Naval Postgraduate School	2:10 PM
Fabrication of Supportless Lattice Structures Using Burst Mode Drop-on-Demand Liquid Metal Jetting: Paarth Mehta, Rochester Institute of Technology	Insights from High-speed Synchrotron X-ray Imaging of Binder-powder Interaction in Binder Jet Printing: Nathan Crane, Brigham Young University	Multi-bead and Multilayer Printing Geometric Defect Identification Using Single Bead Trained Models: Nowrin Akter Surovi, Singapore University of Technology and Design	Detecting the Onset of Flash Event in Selective Laser Flash Sintering : Joey Zamora, University of Texas at Austin	Exploring the Microstructure and Mechanical Properties of Additively Manufactured Haynes 282: A Comparative Analysis between L-PBF and LP-DED Technologies: Nabeel Ahmad, Auburn University	Knowledge Base Development for Additively Manufactured High-Iron/Low-PLA Polymer Composites : Joji Jeevan Kumar Dasari, Tennessee Technological University	2:30 PM
Towards Experimental Process Parameter Development for Ti-6Al-4V TPMS Lattice Structures with Application to Small Scale Dental Implants using Micrographs: Anne Jahn, Laser Zentrum Hannover e.V.	Numerical Investigation of the Spreading and Dynamic Flow Behavior of Poorly Sorted Sand Particles during Binder Jet Additive Manufacturing : Ibrahim Al Qabani, Kansas State University	The WAAM Number: A Dimensionless Number for Predicting Wire Arc Additive Manufacturing Bead Geometry: Bemnet Molla, Virginia Polytechnic Institute and State University	Open Loop Control of Selective Laser Flash Sintering of Ceramics: David Khanan, University of Texas Austin	Mechanical Performance of LPBF Manufactured Haynes 282: Nicholas Lamprinakos, Carnegie Mellon University	Additive Manufacturing of Polymer Composite Tooling: Kazi Md Masum Billah, University of Houston Clear Lake	2:50 PM
BREAK	BREAK	BREAK	BREAK	BREAK	BREAK	3:10 PM
Bio-inspired Cellular Structures using Co-extruded Continuous Carbon Fibre: Piyapat Jameekornkul, Imperial College London	Providing Anti-counterfeiting Security in Binder Jetting through Tailored Porosity Signatures: Christopher Williams, Virginia Tech	Dynamic Start Point Modification in Closed Contour Toolpaths for A Multi-robot Wire-fed Ded System: Riley Wallace, Oak Ridge National Laboratory	An Ultrasonic Technique to Determine the Onset of Localized Sintering in Additive Manufactured Ceramics: Christina Nissen, University of Texas at Austin	Effect of Heat Treatments on the Tensile Properties of Additively Manufactured 15-5 PH Stainless Steel: Rukesh Gusain, Auburn University	Assessing the Impact of the Powder Production Method on Ceramic-filled Polyamide 613 Composites Made by Laser Sintering: Ivo Kletetzka, Paderborn University (DMRC)	3:40 PM
Development of Artificially Tuned Microstructure using Interpenetrating Lattices Fabricated by Laser Powder Bed Fusion : Bharath Bhushan Ravichander, University of texas at dallas	Robotic Automation for Depowdering in Binder Jet Additive Manufacturing : Sarita Sepulveda, NC A&T State University	Optimal Planning and Control for Microhardness Demonstrated in Thin-walled Steel Parts Made via Wire Arc Additive Manufacturing: Mikhail Khrenov, Carnegie Mellon University	Volumetric Additive Manufacturing of Glass: Dominique Porcincula, Lawrence Livermore National Laboratory	Johnson-Cook Failure Model for Additively Manufactured 304L Stainless Steel Parts : Henry Haffner, Missouri University of Science and Technology	Additive Manufacturing of Shape-conforming Battery Components from Lunar and Martian Soil: Alexis Maurel, University of Texas at El Paso	4:00 PM
Additively Manufactured Molds for Large Gyroid Structures Cast from Concrete: Joseph Bartolai, Pennsylvania State University	X-ray Computed Tomographic Study of Density Gradients within Binder Jet Printed H-13 Components: Dustin Gilmer, UT-Oak Ridge Innovation Institute	Exploring the Effects of Oscillatory Deposition Paths on Wire Arc Additive Manufacturing (WAAM) of Al5Mg: Bemnet Molla, Virginia Polytechnic Institute and State University	Manufacturability of Custom Shape-conforming Battery Components using VPP: Bharat Yelamanchi, Youngstown State University	Process Sensitivity and Mechanical Properties of Blended AF-9628 Steel and Iron Powders Consolidated via Laser-directed Energy Deposition: Jonathan Kelley, Missouri University of Science and Technology	Advancing Sodium-ion Battery Technology for Both Terrestrial and Extraterrestrial Applications through 3D Printed Electrolytes: Ana Martinez, The University of Texas at El Paso	4:20 PM
		GKN Aerospace Deposition of a Laser Wire DED 2.5m Titanium Aerostructure Demonstrator: Leon Hill, GKN Aerospace	Control of Track Morphology in Digital Glass Forming: Nicholas Capps, University of Notre Dame	The Variation of Mechanical Properties of M300 Maraging Steel Manufactured with Varying Process Parameters in Laser Powder Bed Fusion: Haley Petersen, Center of Advanced Vehicular Systems		4:40 PM
		Resource Efficiency of the Robot-based Hybrid Additive Manufacturing Chain: Cornelia Tepper, PTW TU Darmstadt				5:00 PM

TECHNICAL PROGRAM GRID - TUESDAY AM

Session Name	Process Development: Powder Bed Fusion Process Innovations	Process Development: Powder Bed Fusion Monitoring and Imaging I	Process Development: Material Extrusion II	Data Analytics: Application to General Additive Manufacturing	Modeling: Deposition of Particles and Fibers	Binder Jet AM: Material and Experiments	Modeling: CAD, Scan Patterns, Contouring, Slicing II
Room	404	410	412	415 AB	416 AB	417 AB	Salon A
Chair	Venkatavaradan Sunderarajan, Georgia Institute of Technology	David Hoelzle, Ohio State University	David Espalin, Univ of Texas El Paso	Nicholas A. Meisel, Pennsylvania State University	TBD	Patryk Pawel Radyjowski, Advanced Cooling Technologies, Inc.	Gabriel Lipkowitz, Stanford University
8:15 AM	Layer-wise Control Charts in Laser Powder Bed Fusion Metal Additive Manufacturing: Venkatavaradan Sunderarajan, Georgia Institute of Technology	Convergence Studies of Ensemble Kalman Filter Accuracy at Estimating Powder Bed Fusion Temperatures as a Function of Measurement Resolution: Nathaniel Wood, Ohio State University	Mechanically Bonding and Thermally Releasing Print Surface for Big Area Additive Manufacturing: Eric Weflen, Iowa State University	Nowcasting Melt Pool Dynamics using Transformer on In-situ Monitoring Images: Shu Wan, Arizona State University	Part-scale Thermal Model for Parameter Optimization in a Microscale Selective Laser Sintering System: Joshua Grose, The University of Texas at Austin	Additive Manufacturing of Si-SiC Cermets by Binder Jetting with Si infiltration – Process and Material Properties: Patryk Rady=jowski, Advanced Cooling Technologies, Inc.	Demonstrating Paraflow: Interactive Fluid Dynamics Simulation with Real-time Visualization for Augmented Resin 3D Printing: Gabriel Lipkowitz, Stanford University
8:35 AM	SmartScan Extension: Enhancing Temperature Uniformity in 3D Laser Powder Bed Fusion Additive Manufacturing for Reduced Part Defects and Distortions: Chuan He, University of Michigan	Experimental Validations of an Ensemble Kalman Filter Method for Powder Bed Fusion Temperature Estimation.: Nathaniel Wood, Ohio State University	Inexpensive Mechanistic-Knowledge-Agnostic Machine Learning in Additive Manufacturing: Jeremy Cleeman, Rutgers University	Dreaming of Data: Examining Data Augmentation for Machine Learning in Additive Manufacturing: Martha Baldwin, Carnegie Mellon University	On the Effect of Recoater Damage on Spreading Behavior: Caroline Massey, Georgia Institute of Technology	An Effective Method for Predicting the Mechanical Properties of Parts with Site-specific Microstructure : Sun Li, Nanyang Technological University	Methodical Approach to Reducing Design Time by using Neural Networks in Early Stages of Concept Development: Manuel Ott, Paderborn University
8:55 AM	Toward Voxel Level Control for Laser Powder Bed Fusion Additive Manufacturing Process: Ho Yeung, National Institute of Standards and Technology	An Ensemble Kalman Filter Method for Laser Powder Bed Fusion Temperature Estimation, Augmented with Adaptive Meshing and Joint Estimation of the Absorptivity: Nathaniel Wood, Ohio State University	In-situ Process Monitoring System for Large Format Thermoplastic Additive Manufacturing: Adam Stevens, Oak Ridge National Laboratory	A Framework for Physics-guided Machine Learning to Extract and Transfer Process-structure-property Knowledge in Additive Manufacturing: Hyunwoong Ko, Arizona State University	Modeling Carbon Fiber Suspension Dynamics for Additive Manufacturing Polymer Melt Flows: Jason Pierce, Baylor University	An Experimentally-tuned Finite Element Model for Predicting Sintering Deformation in Binder-jet Additive Manufacturing: Roman Boychuk, University of Waterloo Multi-Scale Additive Manufacturing Lab	OpenVCAD: An Open Source Volumetric Multi-material Geometry Compiler: Charles Wade, University of Colorado Boulder
9:15 AM	Enabling Multi-material LPBF Printing via Electrostatic Powder Spreading of Patterned Powder Beds: Eric Elton, Lawrence Livermore National Laboratory	AI-driven In Situ Detection of Keyhole Pore Generation in Laser Powder Bed Fusion: Zhongshu Ren, University of Virginia	Distributed Optical Fiber Testing for Additive Manufacturing: Brian Hlifka, University of Notre Dame	Additive Manufacturing (AM) Lattice Segmentation and Analysis Enabled through Deep Learning: Michael Juhasz, Lawrence Livermore National Laboratory	Understand Powder Deposition Behaviors of a Novel Electrostatic Powder Spreading Technique Using Particle Dynamics Simulation: Ziheng Wu, Lawrence Livermore National Laboratory	Binding and Alloying Properties of a Solid-free Organic Binder in Binder Jetting Additive Manufacturing of Steel: Wei Xin Tan, Nanyang Technological University	Catalog of Triply Periodic Minimal Surfaces, Equation-based Lattice Structures, and Their Homogenized Property Data: Joseph Fisher, Pennsylvania State University
9:35 AM	In-situ Reinforcement Processing for Laser Powder Bed Fused Ti64 Parts: Aditya Krishna Ganesh Ram, University of Texas at Arlington	In-situ Monitoring of Laser Powder Bed Fusion for Production Environments: Jesse Adamczyk, Sandia National Laboratories	An Extrusion-based 3D Printing Method for Direct Deposition of Photopolymers : Rencheng Wu, University of Arkansas	Machine-Learning-Driven Digital Twin Construction for Additive Manufacturing: A Review: Fatemeh Elhambakhsh, Arizona State University	Predicting the Printable Parameter Space for Laser Directed Energy Deposition Using a Calibrated Model: Peter Morcos, Texas A&M University	Elucidating Size and Location Effects on Green Density of Binder Jet Additive Manufactured Parts: Basil Paudel, University of Pittsburgh	Application of Implicit CAD System to Support Subtract-additive Hybrid Manufacturing: Sang-in Park, Incheon National University
9:55 AM	Break	Materials: Metals-Mechanical Properties II	Break	Break	Break	Break	Break
10:25 AM	Method to Balance Thermals for Multi-functional 3D MJF Printing: Aja Hartman, HP Labs	A Comparison of the Mechanical Behavior of AlSi7Mg Alloy Produced Through Additive Manufacturing and Subjected to Different Heat Treatment and Aging Conditions: Kevin Caballero, W.M. Keck Center for 3D Innovation	Beyond Throughput-resolution-flexibility Tradeoffs with Mutliplexed Fused Fabrication: Jeremy Cleeman, Rutgers University	PRISM: Process Parameter Optimization for Selective Manufacturing: Anthony Garland, Sandia National Laboratories	Investigating the Effect of Generalized Newtonian Fluid on the Micro-void Development within Large Scale Polymer Composite Deposition Beads: Aigbe Awenlimobor, Baylor University	Equalization of Metal Powder for Binder Jet Printing: Michelle Niu, HP Inc	Adaptively Sampled Distance Functions: A Unifying Digital Twin Representation for Additive Manufacturing: Tadek Kosmal, Virginia Tech
10:45 AM	Parametric Study of Processing of Ti6Al4V with Multiple 450 nm Diode Lasers: Halil Caglar, University of Sheffield	Experimental Investigations of Inhomogeneous Component Properties in Laser-based Additive Manufacturing of AlSi10Mg: Steffen Czink, Karlsruhe Institute of Technology	Calibration Method for Combined Structured Light and Additive Manufacturing Systems: William Keller, Purdue University	Towards a FAIR Knowledge Management System for Additive Manufacturing: Shengyen Li, National Institute of Standards and Tecnhology	Multi-physics Modeling of Low-temperature Directed Energy Deposition of Stainless Steel 316L: Kishore Mysore Nagaraja, The University of Texas at Dallas	Fiber-reinforcement of Binder-jetted Casting Molds for Multiple Usage: Jan Angenoorth, Fraunhofer IGCV	Depiction of Support Structures in Technical Drawings: Thorsten Koers, Paderborn University
11:05 AM	Use of a Vibrating Build Platform during Powder-bed Fusion of Metals Using a Laser Beam: Nick Hantke, Ruhr University Bochum, Chair of Hybrid Additive Manufacturing	Microstructure and Tensile Properties of Aluminum Alloy 4008 (A356) Processed via Liquid Metal Jetting: Kellen Traxel, Lawrence Livermore National Laboratory	In-situ and In-line Monitoring for Robocasting using Ceramic Slurries: Jason McCleary, University of Texas at El Paso	Usage of Unconventional Data Sources for Market Intelligence (MI) in the Field of Additive Manufacturing (AM) - Expert Networks, Technology Territories and Trends: Stephan Ziegler, RWTH Aachen University - Digital Additive Production DAP	Real Time Quantification of Shear-induced Molecular Ordering in Direct Write Printing of Bottlebrush Based Polymer Networks: Daniel Rau, University of Virginia	Microstructures, Mechanical and Thermal Property Evaluation of Binder Jet Printed High Conductivity Copper Parts.: John Samuel Dilip Jangam, HP Inc	Additive Manufacturing and the Moving NDT Target: Bill Hayes, Waygate Technologies
11:25 AM	Thin Wall Manufacturing in Laser Powder Bed Fusion for Heat Exchanger Applications: James Whincup, AMRC NW	Comparison of Layerwise Preheating and Post Heating Laser Scan on the Microstructure and Mechanical Properties of L-PBF Ti6Al4V: Ahmet Tanrikulu, University of Texas at Arlington		Virtual Inspection of Advanced Manufacturing via Digital Twins: Brian Giera, Lawrence Livermore National Laboratory	Optimization of Computational Time for Digital Twin in Directed Energy Deposition for Residual Stresses: Usman Tariq, Missouri University of Science and technology	Slurry-based Binder Jetting of Ceramic Casting Cores: Patricia Erhard, Fraunhofer IGCV	Development of a Novel Software Tool for Toolpath-centric Design of Small Aircraft Wings: Justin Valenti, Pennsylvania State University
11:45 PM	Open Architecture Control Software for Laser Powder Bed Fusion Machines: Justin Patridge, Lawrence Livermore National Laboratory	Microtensile and Weibull Analyses of Additively Manufactured Ti–6Al–4V with Process Parameter Induced Defects: Kourtney Porsch, JHU APL			Experimental and Finite Element Comparison of 3-axis and 5-axis Wire Arc Directed Energy Deposition: Matthew Register, Mississippi State University		Transmitting G-Code with Geometry Commands for Extrusion Additive Manufacturing: Alex Roschli, Oak Ridge National Laboratory
12:05 PM					Adapting a Conventional Design for Additive Manufacturing Workflow to Account for Continuous Carbon Fiber Reinforced Parts: Nicholas Meisel, Pennsylvania State University		

Applications: Lattices and Cellular II	Wire-fed DED: Machine Learning and AI Application	Applications: Residual Stress	Fiber Composites	Polymers: Functional Materials	Thermal Modelling	Session Name
Salon B	602	615 AB	616 AB	Salon F	Salon G	Room
Jack L Beuth, Carnegie Mellon University	Benjamin D. Bevans, Virginia Tech	Ming C. Leu, Missouri University of Science and Technology	Roneisha Tearre Haney, Air Force Research Laboratory	Allison K. Murray, Marquette University	Bradley Jared, The University of Tennessee, Knoxville	Chair
Experimental and Numerical Investigations on Dynamic Mechanical Properties of TPMS Structures: Deepak Kumar Pokkalla, Oak Ridge National Laboratory	Monitoring of Process Stability in Laser Wire Directed Energy Deposition using Machine Vision: Benjamin Bevans, Virginia Tech	Distortion and Residual Stress Mitigation of Large Parts for Wire-arc Additive Manufacturing: Wen Dong, University of Pittsburgh	3D Printing of Continuous Stainless Steel Fiber Reinforced Polymer Composites: Alison Clarke, University College Dublin	A Comparison of Mechanical Properties from Natural and Process Induced Interfaces in Filament Extrusion Additive Manufacturing of Polymer Blends: Camden Chatham, Savannah River National Lab	A Comparative Computational Analysis of Heat Transfer in Material Extrusion Process: Orkhan Huseynov, Tennessee Technological University	8:15 AM
Behavior of Additively Manufactured Plate-lattice Structures in Quasi-static, Dynamic, and Ballistic Testing: Joseph Berthel, Carnegie Mellon University	Real-time Monitoring of Directed Energy Deposition Additive Manufacturing Process Using Multiple Sensors and Machine Learning: Shuchi Khurana, Addiguru	Effect Of Inter-layer Dwell Time on Residual Stresses in Directed Energy Deposition: Ranjit Joy, Missouri University of Science and Technology	3D Printing of High-performance Carbon Fiber Composites via Modified Drop-on-demand Method: Xiangyang Dong, Missouri University of Science and Technology	A Novel 4D Printing Approach for Freeform Electronics: Xinyi Xiao, Miami University	Analytical Modeling of Cooling Rates in PBF-LB/M of Bulk Metallic Glasses: Hanna Schonrath, Universität Duisburg-Essen	8:35 AM
Out-of-plane Mechanical Properties of Additively Manufactured Fractal Reinforced Structures: Mario Martinez Magallanes, Tecnológico de Monterrey	Thermal Imaging for Wire Arc Additive Manufacturing Using an Off-the-shelf Color Camera: Gala Solis, Carnegie Mellon Univeristy	Quantification of Residual Stress in Directed Energy Deposition Additive Manufacturing via Bridge Method: joshua taggart-scarff, DEVCOM Army Research Laboratory	Core-shell-structured High Strength Composite with 3D Aligned Carbon Fiber via Embedded 3D Printing: Qiyi Chen, University of California, Berkeley	Additive Manufacturing of High Entropy Shape Memory Polymer Blends: Katia Lizbeth Delgado, Ramos, UTEP	A Robust Local Preheat Temperature Dependent Stochastic Finite Element Heat Source Model for Inconel 718 Laser Powder Bed Fusion : Seth Strayer, University Of Pittsburgh	8:55 AM
Experimental Characterization of the Mechanical Properties of 3D Printed Bézier-based Lattice Beams: Alberto Álvarez-Trejo, Tecnologico de Monterrey, Querétaro	Toolpath Planning Approach for Parts with Multiple Revolving Features for Wire Arc Additive Manufacturing.: Wilson Lim, Singapore University of Technology and Design	Residual Stress Analysis of Laser Powder Blown Inconel 718 Across Different Overhang Angles and Laser Outputs: Alejandro Hernandez, W.M. Keck Center for 3D Innovation	Direct Ink Writing of Frontally Polymerized Polymer Matrix Reinforced with Continuous Carbon Fiber Tows: Nadim Hmeidat, University of Illinois Urbana-Champaign	Additive Manufacturing of Modular Soft Stretchable Elastomers for Adaptive Dissipative Structures: Daniel Rau, University of Virginia	Enabling Part-scale Melt Pool Prediction in Laser Powder Bed Fusion via a Global-local Thermal Process Simulation Model : Shawn Hinnebusch, University Of Pittsburgh	9:15 AM
Strength Enhancement of Cellular Structures Through Selective Reinforcement of Elements Based on Analytical Modeling: Naresh Koju, University of Louisville	Towards a Generic Deposition Model in Wire-arc Directed Energy Deposition: A Deep Learning-based Wetted Area Prediction Model: Magnus Glasder, ETH Zurich | IWF / AMLZ	A Data Driven-based Geometric Compensation Method for Laser Powder Bed Fusion: Wen Dong, University of Pittsburgh	Effect of the Print Bed Temperature on Void Distribution and Fiber Orientation within the Microstructure of Short Carbon Fiber Reinforced/ ABS Manufactured via Large Area Additive Manufacturing: Neshat Sayah, Baylor University	Additive Manufacturing of NiTinol Wire Embedded Thermoplastic Polyurethane Actuator: Kazi Md Masum Billah, University of Houston Clear Lake	Component Geometry Feature-based Heat Source Model for Temperature History Fast Prediction in the Directed Energy Deposition Process: Lei Yan, Nanjing University of Aeronautics and Astronautics	9:35 AM
Break	Uncovering Fundamental Process Deficiencies in Wire-laser Directed Energy Deposition using In-situ High Speed Imaging: Jakob Hamilton, Rochester Institute of Technology	Break	Break	Break	Break	9:55 AM
3D Printing of Passive Microfluidic Flow Mixers using Triply Period Minimal Surface Microlattice Structures:Mazher Mohammed, Loughborough University		In-situ Residual Stress Evaluation in Laser Powder Bed Fusion by Infrared Thermography: Tao Liu, Missouri University of Science and Technology	Machine Learning-Assisted Prediction of Fatigue Behaviour in Fiber-Reinforced Composites Manufactured via Material Extrusion: Orkhan Huseynov, Tennessee Technological University (TTU)	Additive Manufacturing of Self-healing Polymers as a Pathway for Environmental Stability: David Roberson, University Of Texas At El Paso	A Preliminary Understanding of Process-property Effects on the Thermal Response via High-throughput Finite Element Models of Wire Arc Direct Energy Deposition : Jeffery Betts, Mississippi State University	10:25 AM
Tailoring Anisotropic Material Properties of Hierarchical Lattice Structures through Strut Diameter and Orientation Variations: Implications for 3D-printed Ti6Al4V Lattices: Ata Babazadeh Naseri, Rice University		Resonant Ultrasound Spectroscopy Modeling of Hybrid Metal Additive Manufacturing Samples with Residual Stresses: Jazmin Ley, University of Nebraska - Lincoln (UNL)	Process and Material Optimisations for Integration of Chopped Glass Fibres in Laser Sintered Polymer Parts: Hellen De Coninck, KU Leuven	Charge Programmed Additive Manufacturing of High-performance Antennas: Zhen Wang, UC Berkeley	CIFEM: Elucidating the Role of Local Preheat Temperature on Multi-track Melt Pool Morphology Variation for Inconel 718 Laser Powder Bed Fusion: Seth Strayer, University Of Pittsburgh	10:45 AM
Building Equation-based Lattice Structures using Large Minimum Feature Size AM Processes: Joseph Bartolai, Pennsylvania State University		The Effect of LaserSscan Strategy on Residual Stress of Titanium Alloys Using Laser Foil Printing Additive Manufacturing Processes: Ting-Chun Huang, National Cheng Kung University	Additive Manufacturing of Continuously Reinforced Thermally Curable Thermoset Composite: Kelvin Fu, University of Delaware	Manufacturing of Foam Dampening Structures for Machining Applications: Tyler Smith, ORNL	Thermomechanical Modeling and Fabrication of Tungsten Carbide-nickel Geometries Through Laser Powder Bed Fusion: Alexander Gourley, Carnegie Mellon University	11:05 AM
Quasistatic Energy Absorption in Aperiodic Cellular Materials: Dhruv Bhate, Arizona State University				Additive Manufacturing of Functionally Graded Materials by High Speed Sintering: Jan Kemnitzer, Fraunhofer Institute for Manufacturing Engineering and Automation IPA		11:25 AM
						11:45 PM
						12:05 PM

TECHNICAL PROGRAM GRID - TUESDAY PM

Session Name	Data Analytics: Large Scale AM, Deposition Methods, Metals	Process Development: Powder Bed Fusion Monitoring and Imaging II	Applications: Process Techniques for Part Production	Data Driven Modeling and Process Control	Materials: Polymers Powder Bed Fusion	Materials: Polymers Material Extrusion	Wire-fed DED: Aerospace and Others
Room	404	410	412	415 AB	416 AB	417 AB	Salon A
Chair	Eric MacDonald, University of Texas at El Paso	Toshiki Niino, University of Tokyo	Christie Hasbrouck, Pennsylvania State University	Chinedum E. Okwudire, University of Michigan	Camden A. Chatham, Savannah River National Lab	TBD	Wei Li, University of Texas at Dallas
1:40 PM	Automated Layer Identification in Large Area Additive Manufacturing (LAAM): A Comparison of Image Thresholding and Edge Detection Techniques: Aissata Wadidie, Advanced Stuctures and composites center	Analysis of Process Stability in PBF-LB/M: Melt Pool Monitoring vs. Thermal Highspeed Imaging using Novel Gas Mixtures: Tobias Deckers, University Duisburg-Essen Linde Technology GmbH	Characterizing Thermomechanical Performance of Large-format Printed Composite Polymer Structures: Tyler Corum, University of Tennessee	A Data-driven Surrogate Model for Time-dependent Scanwise Thermal Simulations of Centimeter Scale Laser Powder Bed Fusion Parts : Berkay Bostan, University of Pittsburgh	Analysis of Flow Additives in Laser-based Powder Bed Fusion of Polymers: Implications for Flow Behavior, Processing, Temperature Profile, and Part Characteristics: Simon Cholewa, Institute of Polymer Technology	Benchmarking the Tensile Properties of Polylactic Acid (PLA) Recycled through Fused Granule Fabrication Additive Manufacturing: Dawood AL Nabhani, University of Michigan - Dearborn	Exploratory Study of In-space Wire Arc Additive Manufacturing on the Mars: Wei Li, University of Texas at Dallas
2:00 PM	Coaxial Color Channel Focus Evaluation to Estimate Standoff Height in Directed Energy Deposition: Callan Herberger, The University of Texas at El Paso	Application of In-situ Process Monitoring to Optimise Laser Parameters during the L-PBF Printing of Ti-6Al-4V Parts with Overhang Structures: John Power, UCD	Evaluating the Design and Compressive Strength of AM Risers for Green Sand Metalcasting: C. Hasbrouck, The Pennsylvania State University	A Machine Learning Approach to Part Scale Microstructure Predictions in LPBF: Mason Jones, University of California Davis	Determination of Input Laser Energy for Melting Powder Layers with Various Thicknesses in High-speed PBF-LB/P using Near-infrared Laser and Absorbent: Yuki Yamauchi, Tokyo Metro Ind Tech Research Inst	Determination and Compensation of the Shrinkage Behavior of Cylindrical Elements in the FDM Process: Thorsten Koers, Paderborn University	Qualification of Low-criticality AM Components in an Expeditionary Environment: Jacob Aljundi, Naval Surface Warfare Center Carderock Division
2:20 PM	Automated Fiber Length Measurement for 3D Printed Polymer Composites, Including Identification and Measurement of Non-trivially Placed Fibers: Chris O'Brien, University of Tennessee - Knoxville	Coaxial Photodiode Signal Trends and Predictions: Power, Speed, Spot Size, Material and Time: Gabe Guss, Lawrence Livermore National Laboratory	A Novel Metric for Geometric Accuracy Quantification using Point Clouds in Additive Manufacutring: Chuan He, University of Michigan	A Physics-guided Data-driven Model for Enhanced Temperature Prediction and Control of LPBF Additive Manufacturing: Cheng-Hao Chou, University of Michigan	Effect of Temperature on the Cohesiveness of Polymeric Powders: Implications on Spreadability: Aurelien Neveu, GranuTools	Development and Analysis of Direct-write Photopolymer, Multi-material Manufacturing Process: Allison Murray, Marquette University	Towards Functionally Graded Materials Using Wire-arc Technology: Andrzej Nycz, Oak Ridge National Laboratory
2:40 PM	Variational Autoencoders for Comprehensive Feature Identification in Fatigue Analysis : William Frieden Templeton, Carnegie Mellon University	Enabling Advances in Laser Powder Bed Fusion with In Situ Monitoring: Steven Storck, Johns Hopkins Applied Physics Laboratory	An Adaptive Meshing Framework using Octree Data Structure for Voxel Based Meshes: Pradeep Chalavadi, Ansys Inc.	A Scientific Artificial Intelligence (Sci-AI)-based Concurrent Multiscale Simulation Framework for Accurate Temperature Prediction of Large-scale Metal Additive Manufacturing: Lin Cheng, Worcester Polytechnic institute	Enhancing the Thermal Stability of Polyamide 6 in Powder Bed Fusion via Primary and Secondary Antioxidant Incorporation: Andreas Jaksch, University of Erlangen–Nuremberg	Estimating Effective Stiffness of FFF Components based on Layer-by-Layer Raster Orientation obtained from Ultrasonic Waveform Analysis: Atik Amin, 100 Research Pkway	NASA Technology Development for In-space Manufacturing Application: Christopher Roberts, NASA
3:00 PM	In-situ Monitoring of Wire Arc Additive Manufacturing for Machine Learning Based Prediction of Shape Irregularites and Mechanical Defects: Eduardo Miramontes, University of Tennessee	High-precision Measurement of Melt Pool Properties during Laser-based Powder Bed Fusion of Metals by High-speed Imaging: Arno Elspass, University Duisburg-Essen	In-situ Defect Detection for Laser Powder Bed Fusion with Active Laser Thermography: Philipp Peter Breese, Bundesanstalt für Materialforschung und -prüfung (BAM)	System Identification of Fused Filament Fabrication Additive Manufacturing Extrusion and Spreading Dynamics: Christopher Pannier, University of Michigan Dearborn	Fundamentals of Polymer Crystallization in Laser Powder Bed Fusion for New Material Screening: Camden Chatham, Savannah River National Lab	Experimental Characterization of Enhanced Fused Filament Fabricated Tall Thin-walled Structures Using Polylactic Acid (PLA): Parimal Patel, The University of Texas at Arlington	Robotic Wire-fed Additive Manufacturing for Forging Dies.: Bishal Silwal, Georgia Southern University
3:20 PM	End-to-end AI Models for Error Detection and Correction in Extrusion AM.: Douglas Brion, Matta	High-speed Observations and Quantification of Spatter Counts and Trajectories in Laser Powder Bed Fusion : Jack Beuth, Carnegie Mellon University	Hybrid Manufacturing: How Interleaving Processes Enables Local Control of Material Performance: Thomas Feldhausen, Oak Ridge National Laboratory		Halogen-free Flame-retardant Powder Materials for Laser Sintering: Evaluation and Process Stability Analysis: Fabian Neitzel, University Paderborn (DMRC)	Effects of Fiber Alignment on the Thermomechnical Properties of Large-format Printed Composite Polymer Structures: Tyler Corum, University of Tennessee	The Effect of Thermal Conditions on Process Defects in Electron Beam Directed Energy Deposition: Ronald Aman, EWI
3:40 PM	Bayesian Data-augmentation of Thermal Models for Design of Nb-Ta-W Alloys: Brent Vela, Texas A&M University	High Speed Video Imaging of overhang surfaces in Beam Shaped Laser Powder Bed Fusion of 316L stainless steel: Lars Vanmunster, KU Leuven	Digital Model Generation Strategy for Printing Miniaturized Replica of Historical Cast Iron Objects: Detlev Borstell, Koblenz University of Applied Sciences			Fatigue Life Prediction of Functionally Graded TPU and PLA Components Produced by Material Extrusion: Orkhan Huseynov, Tennessee Tech University	
4:00 PM			Mechanical Properties of Polymer-bonded Magnets Fabricated using Magnetic Field Assisted Additive Manufacturing (MFAAM): Mandesh Khadka, Texas State University			Fused Filament Fabrication of Polymer Blends with In Situ Layerwise Chemical Modifications: Donald W Benza, Savannah River National Lab	

Applications: Lattices and Cellular III	Materials: Metals-Characterization of AM Processes and Materials	Process Modeling	Materials: Metals-Processing Strategies I	Education	Economics of AM	Session Name
Salon B	602	615 AB	616 AB	Salon F	Salon G	Room
Vinayak Krishnamurthy, Texas A&M University	Halsey Ostergaard, University of Sydney	TBD	Chris Ledford, Oak Ridge National Laboratory	Doug Sassaman, University of Texas at Austin	Paul Hooper, Imperial College London	Chair
Unweaving the Macrostructure of the Venus Flower Basket: From Bio-morphism to Biological Insight: Yash Mistry, Arizona State University	In- and Ex-situ Neutron Characterization of Metal Additive Processes and Microstructures: Halsey Ostergaard, The University of Sydney	A General Model of Hot Isostatic Pressing for Additively Manufactured Metal Component Performance Improvement: Lei Yan, Nanjing University of Aeronautics and Astronautics	The Development of a Directed Energy Deposition (DED) Printability Framework for Improving Part Density and Performance in High Strength Martensitic Steels: Ibrahim Karaman, Texas A&M University			1:40 PM
Machine Learning Assisted Mechanical Metamaterial Design for Additive Manufacturing: Jier Wang, Imperial College London	X-Ray Computed Tomography: A Game-Changer for Quality Control in Additive Manufacturing: Curtis Frederick, Carl Zeiss Microscopy	Laser Beam Shape Optimization: Exploring Alternative Profiles to Gaussian-shaped Laser Beams to Achieve a More Stable Melt Pool: Vijaya Holla, Technical University Munich	AM Process Development of NASA HR1 Alloy using Laser Powder Direct Energy Deposition (LP-DED).: Javier Lares, W.M. Keck Center			2:00 PM
Generative Design of 2D Cellular Structures through Stochastic Modification of 2-Honeycombs: Matthew Ebert, Texas A&M University	In situ Layer-wise Optical Imaging for Defect Detection during Laser Powder Bed Fusion: Sanam Gorgannejad, Lawrence Livermore National Laboratory	An Evaluation of a Programmatic Method for the Generation of Finite Element Event Series for Additive Manufacturing Against Machine Print Paths: Chuyen Nguyen, Mississippi State University	Laser Powder Bed Fusion Process Feedback Control Based on In-situ Powder Layer Thickness : Jorge Neira, National Institute of Standards and Technology			2:20 PM
Design of Three-dimensional Complex Truss Metamaterials with Graph Neural Networks: Marco Maurizi, University of California Berkeley	Challenges and Opportunities in Acoustic Emission Monitoring for Quality Control of Directed Energy Deposition Additive Manufacturing: Ehsan Dehghan Niri, Arizona State University	Characterization of Simulated Coaxial Melt Pool Monitoring Signal Variations Due to Melt Pool Morphology.: Conor Porter, Northwestern University	Towards High-throughput Assessment of Printability in Refractory Alloys Systems for Laser-powder Bed Fusion: Peter Morcos, Texas A&M University	A Case Study of Cognitive Workload and Design Knowledge Gaps in Hybrid Manufacturing Teams: Kenton Fillingim, Oak Ridge National Laboratory	Anticounterfeiting Signatures for Additively Manufactured Parts via Electromechanical Impedance Measurements: Nathan Raeker-Jordan, Virginia Tech	2:40 PM
Design of Spatially Varying Orientation Lattice Structures using Triply Periodic Minimal Surfaces: Chongyi Wei, Baylor University	Absorptivity Behavior of High Reflectivity Aluminum and Copper Alloys During Laser Powder Bed Fusion: Sagar Patel, University of Waterloo	Energy Flow (Bond Graph) Dynamic Modelling of Cartesian-frame FFF 3-D Printer Gantry: Maharshi Arindom Sharma, Texas A&M University, College Station	Effects of Preheating and Multi-laser Melting of Refractory Alloys in Laser Powder Bed Fusion: Frank Brinkley, Oak Ridge National Laboratory	Design For(e!) Additive Manufacturing: In Search of a Comprehensive Design Challenge Suitable Across AM Education: Nicholas Meisel, Pennsylvania State University	Streaming in Additive Manufacturing: Analyzing the Impact on the Powder Bed Fusion of Metals Process Chain: Moritz Kolter, RWTH Aachen University - Digital Additive Production DAP	3:00 PM
Improving the Mechanical Response of the IWP Exo-skeletal Lattice Through Shape Optimization: Joseph Fisher, Pennsylvania State University	Machinability of Additively Made Alloys: A Case Study of Ti64 and A205 Alloys: Otto Randolph, Texas A&M University		The Use of Laser Preheating for Microstructural Customization of Ti6Al4V Processed Using Diode Point Melting System: Alkim Aydin, University of Sheffield	Multi-material Design in Metal Additive Manufacturing: Dennis Lehnert, Paderborn University	Designing for Circular Economies: Creating Impact from Local Plastic Waste using Off-grid Containerized 3D Printers & Practice Based Learning: Doug Sassaman, University of Texas Austin	3:20 PM
Hybrid Geometric/ Functional Autoencoders for Multi-lattice Transitions: Martha Baldwin, Carnegie Mellon University	Additively Manufactured Lunar Rover Wheel Case Study: Brian Gibson, Oak Ridge National Laboratory		Effect of Build Height on Microstructure and Mechanical Behavior of Ti-6Al-4V Fabricated via Laser Powder Bed Fusion (LPBF): MohammadBagher Mahtabi, Purdue University Northwest	Development of a Testbench for Additive Manufacturing Data Integration, Management, and Analytics: Chen Wei Yang, Engineering Lab, National Institute of Standards and Technology (NIST)	How Good is Good Enough? The Economics of In-process Monitoring in AM: Paul Hooper, Imperial College London	3:40 PM
Tailoring Mechanical Behaviors through Programmable Lattice Structures: Xinyi Xiao, Miami University			Influence of Silane-doped Argon Processing Atmosphere on Powder Recycling and Part Properties in LPBF of Ti-6Al-4V: Nicole Emminghaus, Laser Zentrum Hannover e. V.	Development of 3D Printable Part Library for Easy to Manufacture Components for Educational and Competetive Robotics : Rajeev Dwivedi, STEM and Robotics Academy	Development of High Filled Bio-based Composites for Sustainable, Low-cost AM Feedstock: Katie Copenhaver, Oak Ridge National Laboratory	4:00 PM

TECHNICAL PROGRAM GRID - WEDNESDAY AM

Session Name	Process Develoepment: Photopolymerization and Other Processes	Process Development: Direct Ink Writing and Jetting	Process Development: Powder Bed Fusion Monitoring and Imaging III	Data Analytics: Laser Powder Bed Fusion	Materials: Metals-Novel AM Methods I	Applications: Topology Optimization	Applications: Finishing Techniques and Partameters
Room	400/402	408	410	412	415 AB	416 AB	417 AB
Chair	Michael Cullinan, University of Texas at Austin	Richard Hague, University of Nottingham	David Deisenroth, National Institute of Standards and Technology	Paul Hooper, Imperial College	Aaron Liao, University of Texas at Austin	Mehran Tehrani, University of California, San Diego	TBD
8:00 AM	Probing Temperature and Degree-of-conversion States via Tomographic Fluorescence Imaging: Sui Man Luk, University of California, Berkeley	Understanding Electrospray of MoS2 for Scalable Additive Manufacturing : Bo Shen, University of Arkansas	Infrared Camera (IR) Feature Extraction for Defect Detection in Laser Powder Bed Fusion : Shawn Hinnebusch, University Of Pittsburgh	Self-repair of Defects: The Achilles Heel for In-process Detection of Small Pores?: Paul Hooper, Imperial College London	Formation of Easy-to-Remove Support Structures in Metal LPBF with En-situ Powder Bed Doping.: Nathan Crane, Brigham Young University	Topology Optimization of Continuous Fiber-reinforced Composites Considering Manufacturing Constraints: Janet Wong, Georgia Institute of Technology	Effect of Printing Parameters on the Internal Geometry of Products Manufactured by Fused Filament Fabrication (FFF): Benjamin Moreno-Nunez, Tec de Monterrey
8:20 AM	Process Modeling for Fluid Interface Supported Printing : Siva Appana, Georgia Institute of Technology	Thin Strand Printing of Silicone Ink with Direct Ink Write Process: Siddharthan Selvasekar, Lawrence Livermore National Laboratory	Laser Induced Breakdown Spectroscopy for In-situ Monitoring of Laser Powder Bed Fusion Processing: Justin Krantz, University of Notre Dame	Unveiling Melt Pool Defect Signatures with Interpretable Machine Learning: Sebastian Larsen, Imperial College London	Reduced Silver Consumption using Particle-free Reactive Silver Inks for Low-temperature Solar Cell Metallization: Steven DiGregorio, Colorado School of Mines	Off the Grid: Re-defining Design Resolution in Inkjet 3D-printing for Sub-droplet Position Control and Facile Geometry Improvement: Oliver Nelson-Dummett, University of Nottingham	Assessing the Impact of Melt Pool Variability on Fatigue Life in Laser Powder Bed Fusion: Justin Miner, Carnegie Mellon University
8:40 AM	In-situ Interferometric Monitoring of Dual-wavelength Vat Photopolymerization: Yue Zhang, University of Pittsburgh	Simulation Based Optimization for High Frequency Piezo-actuated Molten Metal Droplet Jetting : Kareem Tawil, Rochester Institute of Technology	Layer-wise In-process Monitoring-and-Feedback System Based on Surface Characteristics Evaluated by Machine-Learning-Generated Criteria: Toshi-Taka Ikeshoji, Kinki University K.U.RING	Real-time Melt Pool Characterization in Laser Powder Bed Fusion Using Acoustic and Photodiode Monitoring: Haolin Liu, Carnegie Mellon University	Solid-state Production of Uniform Metal Powders for Additive Manufacturing by Ultrasonic Vibration Machining: Malachi Landis, Northwestern University	Designing for Cleanability: A Topology Optimization Approach for Electron Beam Melted Parts: Alptug Öztaskin, Addpark Advanced Engineering	Comparison of Surface Texture from Various Surface Morphology Techniques for Evaluating As-built Ti6Al4V Laser Powder Bed Fusion: Alex De La Cruz, University of Texas El Paso
9:00 AM	Design and Integration of a Multi-modal Machine Safety Architecture for a Novel AM-CM System: Paritosh Mhatre, Oak Ridge National Laboratory	Liquid Metal Jetting of Aluminum Parts with Salt Support Structures: Benedikt Kirchebner, Technical University of Munich	Multi-laser Diode Area Melting of Ti6Al4V: A Novel Alternative Approach to Traditional Laser Powder Bed Fusion: Mohammed Alsaddah, The University of Sheffield	Process Parameter Optimization Using Photodiode Intensity in Laser Powder Bed Fusion: Amit Verma, LLNL	Surface Roughness of Machined 316L Stainless Steel Fabricated by FDM/ FFF 3D Printing Technology: Eduardo Rodriguez, Sam Houston State University	Design Optimization, Multi-axis Additive Manufacturing, and Mechanical Evaluation of Continuous-fiber Composite Structures: Joseph Kubalak, Virginia Tech	Fatigue Endurance Investigation of Post-processed Surfaces of L-PBF Ti-6Al-4V under Flexural Stress.: Cristian Banuelos, W.M. Keck Center for 3D Innovation
9:20 AM	A Solid Free Form Fabrication Equipment to Manufacture Axisymmetric Parts with improved surface quality : Rajeev Dwivedi, STEM and Robotics Academy	Further Developments of a Novel Low Cost Material Jetting platform for 3D Printing.: Craig Sturgess, Added Scientific Ltd	Multimodal Process Monitoring to Predict Outcomes during Laser Powder Bed Fusion: Nicholas Calta, Lawrence Livermore National Laboratory	Monitoring of Single-track Quality in Laser Powder Bed Fusion using In-situ Thermionic Sensing: Benjamin Bevans, Virginia Tech	Amorphous Magnetic Alloys Printed from Carbonyl Based Metal-organic Decomposition Inks: Owen Hildreth, Colorado School Of Mines	Design for Internal Lattice Structures with Application in Additive Manufacturing: Bingbing Li, California State University Northridge	Investigating the Effects of Chemical Smoothing on Mechanical Properties and Surface Roughness of Additive Manufactured Polymer Parts : Paul Oehlmann, BMW Group
9:40 AM	Wire + Arc Additive Manufacturing of Cryogenic Liquid Hydrogen Storage Tank Demonstrator: James Whincup, AMRC, Univ. of Sheffield	Break	Break	Break	Break	Break	Break
10:10 AM		Exploring Additively Manufactured Heterostructures of Functional Materials: Focus on Interfaces: Geoffrey Rivers, University of Nottingham	Optical Metrology for Laser-matter Interaction in LPBF: Challenges and Opportunities : David Deisenroth, National Institute of Standards and Technology	Mining Complex Feedstock-Geometry-Process-Quality Relationships for Powder Bed Fusion Thin Features using Graphical Model: Naresh Koju, University of Louisville	Binder Evaporation During Powder Sheet Additive Manufacturing: Joerg Volpp, Lulea University of Technology	Continuous Fiber Reinforced Composites: Design for Additive Manufacturing: Mehran Tehrani, University of California, San Diego	Improving Fatigue Performance of PBF Metals using Self-terminating Etching Processes: Owen Hildreth, Colorado School of Mines
10:30 AM		Effects of Double-pulse Waveform on Piezoelectric Inkjet Printing Speed: Chao Sui, University of Arkansas	The Detection of Defects Caused by Reduced or Interrupted Shield Gas Flow in Laser Powder Bed Fusion: James Bell, Imperial College London	Distilling Thermal Signatures from Reduced Order Physics Models for Electron Beam Powder Bed Fusion Processing: Patxi Fernandez-Zelai, Oak Ridge National Laboratory	Embedding of Luminescent Pigments within 316L Stainless Steel Matrix by Laser Powder Bed Fusion for Optical Functionalities: Christina Baslari, CEA Paris Saclay	Battery Electrode Topology Optimisation: Chikwesiri Imediegwu, Imperial College London	Investigating the Effects of Thermal Post-processing Parameters on Interfacial Delamination of Bimetallic 3D Printed Parts: Erik Inman, Oklahoma State School of Industrial Engineering and Management
10:50 AM		Development of Dual-head MetalJet System for Drop-on-demand Multi-metal Deposition: Xiangyun Gao, University of Nottingham	Time-resolved Optical Spectroscopy in Metal Powder Bed Fusion: Matthias Beuting, University of Wisconsin-Madison	Detecting Failures in Laser Powder Bed Fusion Additive Manufacturing of Complex Lattice Structures using Multi-sensor Data and Machine Learning: Benjamin Bevans, Virginia Tech	Embedding Temperature Sensors with the Use of Laser-Foil-Printing Additive Manufacturing: Tunay Turk, Missouri University of Science and Technology	A Case Study on Lightweight Design of a Robot Leg: Integrating Topology Optimization and Lattice Configuration: Shujie Tan, Nanjing University of Aeronautics and Astronautics	Mechanical Surface Treatment of Polymer Parts Produced by FFF: Stefan Dietrich, KIT
11:10 AM		Investigation of Multi Liquid Metal Jetting with Copper Materials: Maximilian Ploetz, Technical University of Munich	Using In-situ Two-color Thermal Imaging to Validate Multi-physics CFD Melt Pool Models for LPBF: Alexander Myers, Carnegie Mellon University	Data-driven Local Porosity Prediction in Laser Powder Bed Fusion via In-situ Monitoring: Berkay Bostan, University of Pittsburgh	Novel Welding Strategies in the High Deposition Rate Laser-assisted Double Wire Welding Process with Non-transferred Arc: Kai Biester, Laser Zentrum Hannover e.V.	Constrained Topology Optimization using Mechanical Homogenization: Ehsan Haghighat, Carbon Inc.	Optimizing the Surface Texture and Chemistry of Laser Powder Bed Fusion (LPBF) Haynes 282 for Increased Solar Absorptance: Junwon Seo, Carnegie Mellon University
11:30 AM		Comparison of High-resolution Aerosol Jet Printing of Silver Inductors on Rotary and Linear Stages: Max Tafoya, SNL New Mexico - Albuquerque	Two-color Thermal Imaging of WC-Ni Cermet Melt Pools in Laser Powder Bed Fusion : Guadalupe Quirarte, Carnegie Mellon University	3D Geometry Reconstruction of Overhang Part: A Machine Learning Approach Using In-situ Monitoring Data: Zhuo Yang, Georgetown University	A Novel Coating Method Used to Enable Multilayer Structures with Microscale Selective Laser Sintering: Aaron Liao, The University of Texas at Austin		Complex Laser Beam Shaping for Improved Process Control in Metal Additive Manufacturing: Thej Tumkur, Lawrence Livermore National Lab

Wire-fed DED: Materials and Experiments	Applications: Lattices and Cellular IV	Materials: Metals-Creep and Fatigue	Materials: Metals-Processing Strategies II	Session Name
Salon A	Salon B	615 AB	616 AB	Room
Carolyn Seepersad, University of Texas at Austin	Richard H. Crawford, University of Texas	Joy Gockel, Colorado School of Mines	TBD	Chair
Challenges in Wire-Arc Additive Manufacture of Nickel Aluminum Bronze: Bradley Jared, University Of Tennessee, Knoxville	Deformation Pattern of Cellular Mechanical Interface in a Bi-material Structure Fabricated by Material Extrusion Additive Manufacturing: Sumit Paul, University of Louisville	Evolution of Creep Damage of 316L Produced by Laser Powder Bed Fusion: Alexander Ulbricht, Bundesanstalt fuer Materialforschung und -pruefung	Effect of Decarburization on Tailoring the Mechanical Properties of Additively Manufactured High-strength Martensitic Steels: Stephanie Pestka, Texas A&M University	8:00 AM
Failure Mechanisms in Grading Inconel 625-GRCop 42 via Hybrid Wire-powder Directed Energy Deposition: Somayeh Pasebani, Oregon State University	Compressive and energy absorption behavior of heat treated functionally graded 316L Triply periodic minimal surfaces fabricated by selective laser melting: Bharath Bhushan Ravichander, University of texas at dallas	Effects of Surface Roughness, Process Parameters, and Heat Treatments on the Fatigue Properties of Laser Powder Bed Fusion of 316L Stainless Steel: Jorge Ramirez Lujan, Colorado School Of Mines	Effectiveness of Ex-situ Heat Treatment of L-PBF AM 17-4PH Stainless Steel Specimens Intentionally Exposed to Different As-built Thermal Histories: C. Hasbrouck, The Pennsylvania State University	8:20 AM
Framework Development for Optimization of DED Parameters using Nickel-Aluminum Bronze Feedstock and Arc Wire Directed Energy Deposition: Jack Canaday, Naval Surface Warfare Center Carderock Division	A Review on the Joining Mechanisms of Multiple Materials using Additive Manufacturing: Sumit Paul, University of Louisville	Effect of Heat Treatment on High-cycle Fatigue of Additively Manufactured 17% Chromium 4% Nickel Precipitation Hardened Stainless Steel: Julianna Posey, University of Maryland, Baltimore County	Effect of Process Parameters on Microstructure and Properties for the Application of 316L Additively Manufactured Medical Device Components: Fabienne Riester, KARL STORZ SE & Co. KG	8:40 AM
Process-integrated Alloy Adjustment in Laser Deposition Welding with Two Wires: Laura Budde, Laser Zentrum Hannover e.V.	3D Printed Intelligently Graded Functional Stiffness Foam for Sturdier Multi Stiffness Materials: Brett Emery, University of Washington	Fatigue Strength Prediction of Additively Manufactured 17-4 PH Stainless Steel Specimens with Various Geometries : Jade Welsh, University of North Florida	The Influence of Heat Treatments on the Microstructure and Tensile Properties of Additively Manufactured Inconel 939: Rukesh Gusain, Auburn University	9:00 AM
Process Development for the Wire Arc Additive Manufacturing of AlSi10Mg: Moritz Baldauf, BMW Group		A Vibration Fatigue Life Prediction Model for Additively Manufactured Metal Components: Lei Yan, Nanjing University of Aeronautics and Astronautics	Exploring IN718 Alloy Production with Bidirectional Raster and Stochastic Spot Melting Techniques using an Open-source Electron Beam Melting System: Shadman Tahsin Nabil, WM Keck Center for 3D Innovation	9:20 AM
Break		Break	Break	9:40 AM
Process Stability and Monitoring for WAAM-CMT of Aluminum Alloys : Austen Thien, Georgia Institute of Technology		Metal Additive Manufacturing of Rollers for Railroad Bearings: Rolling Contact Fatigue Performance : Joseph Turner, University Of Nebraska-Lincoln	Effects of Build Orientation and Heat Treatment on the Porosity Distribution and Morphology within Inconel 625 Fabricated via Laser Powder Bed Fusion: Mohanish Andurkar, Kansas State University	10:10 AM
Simulation of Anisotropic Mechanical Behavior of Additively Manufactured Ti-6Al-4V Wall Structures using VPSC: Rajib Halder, Carnegie Mellon University		Uniaxial Fatigue Behavior and Life Prediction of Additively Manufactured Inconel 718 with Different Grain Morphology: Nabeel Ahmad, Auburn University	Microstructural and Microhardness Variations of Laser Powder Bed Fusion (L-PBF) Additively Manufactured Inconel 718 Due to Machine Variability and Thickness for Aerospace Applications: Anannya Doris, W.M. Keck Center for 3D Innovation at the University of Texas at El Paso	10:30 AM
Solidification Behavior, Texture Evolution, and Mechanical Behavior of Large Scale Fusion Additively Manufactured Steels: Interplay Between Chemistry and Unique Processing Conditions: Saket Thapliyal, Oak Ridge National Laboratory		Corner Effects on Fatigue for As-printed Surfaces in Alloy 718: Rachel Tullis, Wright State Universtiy	Numerical and Experimental Investigations on Manufacturability of Al-Si-10Mg Thin Wall Structures Made by LB-PBF: Mahyar Khorasani, RMIT	10:50 AM
Wire Arc Additive Manufacturing in Steel Foundries: Eric Weflen, Iowa State University		The Effect of Near-surface Pores on Fatigue Life of Ti-6Al-4V Components: Christine Cummings, Pennsylvania State University	Controlling Chemical Composition Changes in Laser Powder Bed Fusion of AlSi10Mg: Bochuan Liu, University of Warwick	11:10 AM
Additive Manufacturing of ODS Steels using Powder Feedstock Atomized with Elemental Yttrium: Seongun Yang, Oregon State University		Comparing the Effects of Different Chemical Treatments on Surface Texture and Fatigue Behavior of U-notched Additive Manufactured AlSi10Mg: Nabeel Ahmad, Auburn University	Compositional Variation Effect on the Microstructure and Nanomechanical Properties of Additively Manufactured AlCuFeNiTi High Entropy Alloy: Sandeep Khadka, Clarkson University	11:30 AM

Session Name	Process Development: Powder Bed Fusion Process	Applications: Biomedical	Applications: Techniques for End Use Parts	Wire-fed DED: Gas and Thermal Management and Analysis	Materials: Metals-Novel AM Methods II	Materials: Metals-Graded Compositions
Room	400/402	408	410	412	415 AB	416 AB
Chair	Lianyi Chen, University of Wisconsin-Madison	Fay R. Claybrook, Loughborough University	Timothy B. Phillips, University of Texas Austin	TBD	Yaguo Wang, University of Texas at Austin	Anthony Stair, Carnegie Mellon University
1:10 PM	Revealing and Controlling Process Instabilities for Defect Lean Metal Additive Manufacturing: Lianyi Chen, University of Wisconsin-Madison	Additive Manufacturing of Person Specific Diabetic Foot Insoles with Tuneable Cushioning Properties using TPMS Lattice Structures: Fay Claybrook, Loughborough University	Guided Manual Design for Additive Manufacturing of Topologically Optimized Legacy Tooling Parts: Nicholas Meisel, Pennsylvania State University	A Small Volume, Local Shielding Gas Chamber with Low Gas Consumption for Laser Wire Additive Manufacturing of Bigger Titanium Parts: Alexander Barroi, Laser Zentrum Hannover e.V.	A Hybrid Aerosol Jet Printing and Electrochemical Deposition Process for Manufacturing Multi-layer Inductors and Transformers: Lok-kun Tsui, University of New Mexico	Compositionally Graded Transition from Tungsten to Ferritic-martensitic Steels via Directed Energy Deposition: Ibrahim Karaman, Texas A&M University
1:30 PM	Acoustic Mechanisms of Laser Powder Bed Fusion through an Analogous Whistle Model: Yuchen Sun, Lawrence Livermore National Laboratory	Assembly-free Hybrid Printing of Microfluidic Devices for Biosensing: Yipu Du, University of Notre Dame	Hybrid Electromagnetics: Printed RF Sensitive Structures, Circuits, and Sensors Integrated with Non-traditional Electromagnetic Substrates: Christopher Molinari, University of Massachusetts Lowell	Comparison of Process Control Methods for Wire-arc Directed Energy Deposition of Low Carbon Steels with In-situ Temperature Measurement : Ahamed Ameen, Coventry University	Double-pulse Femtosecond Laser Sintering of Metal Nanoparticles on Flexible Substrate: Janghan Park, The University of Texas at Austin	Directed Energy Deposition of Stainless Steel 304L to Inconel 625 Gradients: Print Strategies and Defects: Anthony Stair, Carnegie Mellon University
1:50 PM	Surface Roughness Formation and Measurement for Metals Built with Laser Powder Bed Fusion: Edwin Glaubitz, Colorado School of Mines	Evaluation of the Performance of 3D Printed Cutting Guides for Canine Caudal Maxillectomy: Satyanarayana Konala, North Carolina State University	3D Printing of Complex Wire Geometries for Tailored Resistance Response: Timothy B. Phillips, University of Texas Austin	Efficient Thermomechanical Simulation for WAAM using Automated GPU-based Modeling : Xavier Jimenez, University of Pittsburgh	Effect of Surface State and Material on Surface Quality Enhancement by Dual Laser Powder Bed Fusion: Daniel Ordnung, KU Leuven	Microstructural Investigations on SS316L-Cu Graded Deposition Prepared using Wire Arc Additive Manufacturing.: Bunty Tomar, Indian Institute of Technology Jammu
2:10 PM	Quality Prediction of AM Processes Using Volumetric CNNs with Spatialized Representations of Structure-borne Sound Sensor Data: Jork Groenewold, wbk Institute of Production Science, Karlsruhe Institute of Technology (KIT)	Fabrication of Thick Vascularized Tissues using Sacrificial Ink-assisted Embedded 3D Bioprinting: Bing Ren, University of Florida	Additive Compliant Mechanisms for Deployable Space Structures: Savannah Sunez, NASA Jet Propulsion Laboratory	Inter-pass Temperature Impact in Wire-Arc Additive Manufacturing: Steven Williams, University of Tennessee	Fabrication of Crack-free Aluminum Alloy 6061 Parts using Laser Foil Printing Additive Manufacturing Process: Yu-Xiang Wang, National Cheng Kung University	Particulate and Dispersoid Reinforced Metals Session Chair Jared Allison, University of Texas Austin
2:30 PM	Pushing Boundaries: Machine Learning Applied to Selective Laser Melting: Mary Daffron, Johns Hopkins University Applied Physics Lab	Improving Food 3D Printing Through Texture Modification of Designed Food Inks: Paul Egan, Texas Tech University	Process and Design Strategies for Fluid Wicking in Additively Manufactured Inconel 718 for Monolithic Heat Pipes: Cameron Noe, Arizona State University	Localized Shielding Gas Lens and Inert Enclosure Effects on Titanium GMAW for Wire-Arc Additive Manufacturing: Harold Walters, Oak Ridge National Laboratory	Identification of Nanoparticles Dispersion Mechanism in 316L Matrix Additively Manufactured By hybrid Process of Ink Jetting and Laser Powder Bed Fusion : Somayeh Pasebani, Oregon State University	Oxide Dispersion Strengthened (ODS) SS316L Prepared by Laser Powder Bed Fusion: Analysis of Microstructure and Hardness Properties: Changyu Ma, California State University Northridge
2:50 PM	Break	Break	Break	Break	Break	
3:20 PM	Localized Porosity Prediction in Laser Powder Bed Fusion via Deep Learning of Multi-modal Melt Pool Signatures: Haolin Zhang, University of Pittsburgh	Materials Screening Methodology for Additive Manufacturing in Bioreactor Technology: Johann Schorzmann, University of Bayreuth	Additively Manufactured Inconel718-Methanol Heat Pipe: Fabrication and Low Temperature Thermal Testing: Adnen Mezghani, The Pennsylvania State University	Prediction of Inter-pass Temperature for Large-scale Double Sided Component Fabricated Electron Beam Wire Additive Manufacturing: Yousub Lee, Oak Ridge National Laboratory	Liquid Metal Jet-on-Demand Printing of Al-6061: Eric Elton, Lawrence Livermore National Laboratory	Effect of Solidification Conditions on the Evolution of Dispersoids in a Ni-20Cr + 1 wt% Y_2O_3 ODS Alloy Fabricated with Laser Powder Bed Fusion: Nathan Wassermann, Carnegie Mellon University
3:40 PM	Investigation of the Influence of Process Parameters to Increase Productivity in the LPBF Process for the Material Inconel 718: Christian Bödger, Paderborn University	A Study of Additively Manufactured Ti-6Al-4V ELI Surface Roughness Coupons with Differing Processing Parameters: Lucas Becker, AddUp Inc.	Mechanical and Dimensional Characterization of Polymer Powder Bed Fusion Parts for Non-assembly Mechanisms: Paul Egan, Texas Tech University	Process Parameters and Interpass Temperature Effects on WAAM Inconel 718: Xavier Jimenez, University of Pittsburgh	Advancing the Process Window for Reliable Metal Droplet-on-demand Manufacturing: Nicholas Watkins, Lawrence Livermore National Laboratory	Influence of TiC-Nanoparticles on the Material Properties of AlSi10Mg Manufactured by Laser Powder Bed Fusion: Victor Lubkowitz, wbk Institute of Production Science, Karlsruhe Institute of Technology (KIT)
4:00 PM	High Frequency Ultrasonic Detection of Security Markers in Additive Manufacturing Components: Mihaela Vlasea, University of Waterloo		Using Solid Freefrom Fabrication to Develop and Test Unique Texture on Mecanum Wheel Rollers and the Ground for Improved Robot Position Accuracy: Rajeev Dwivedi, STEM and Robotics Academy	Shielding Gas Flow Analysis for Wire-Arc Additive Manufacturing using Schlieren Imaging: William Carter, Oak Ridge National Laboratory	Diode Area Melting – A Multi-laser Alternative to Traditional Laser Powder Bed Fusion: Anqi Liang, University of Southampton	Process Structure Relationships of Carbide Containing Molybdenum Alloys Produced via Electron Beam Powder Bed Fusion: Christopher Ledford, Oak Ridge National Laboratory
4:20 PM			Rapid Foam Foundry: The Future of Foam Foundry: Gopal Gote, IITB		Nanoparticle-modification of NiCu-based Alloy 400 for Laser Powder Bed Fusion: Jan-Philipp Roth, Osnabrück University of Applied Sciences	
4:40 PM			Material Jetting of Suspension System Components: Jeffrey Lipton, University of Washington			

Poster Sessions		
Room: Salon JK		
Comparative Success of EBM and SLM for Fabrication of Lattice Structures in Metal Orthopaedic Implants: Onur Demirak, Ankara University	Investigation of Electrical Properties in TPU/CNT Conductive Composites: Hansol Kim, Chungbuk National University	Data Pipelines for Direct Ink Write Digital Twins: Alex Caviness, LLNL
Modifying Glass Surface Morphology via Temperature-controlled Laser Melting: Andre Bos, Los Alamos National Laboratory	Dissimilar Vacuum Brazing of Additive Manufactured 17-4PH Stainless Steel to Conventional 304 and 17-4 Stainless Steel by BNi-2 Brazing Filler Material: Tansu Göynük, ROKETSAN A.S., Middle East Technical University	PEEK Parameter Optimization for Fused Deposition Modeling : Quang Ha, Sandia National Laboratory
Mechanical and Corrosion Response of Minor and Trace Elements in CoCrMo Alloy Powders on Additively Manufactured Dental Crowns and Bridges : Ece Tutsak, TraBtech	3D Bio Printed Biodegradable Composite Material for Pediatric Craniomaxillofacial Implants: Ipek Dös, TraBtech	Influence of In-process Layer-wise Surface Property on the Mechanical Properties of Laser Powder Bed Fusion Products: Haolin Zhang, University of Pittsburgh
Photoinhibition Aided Vat Photopolymerization (PinVPP) Additive Manufacturing : Yue Zhang, University of Pittsburgh	Design of Lightweight 3D Printed Structures for the 7th Annual 3D Printed Aircraft Competition: Robert Taylor, University of Texas Arlington	Development of Joint Manufacturing and In-line Metrology System for the Patterning of 3D Holographic Structures in Roll-to-roll Processes: Barbara Groh, University of Texas at Austin
Wide-field Low-coherence Interferometry for Keyhole Depth Measurements in Laser Powder Bed Fusion: Matthias Beuting, University of Wisconsin-Madison	Fabrication of Solid-state Electrolytes Using 3D Printing for Lithium Metal Batteries: John Obielodan, University of Wisconsin-Platteville	A Pilot Study on Temperature Monitoring and Morphology of the Meltpool in EB-PBF of Copper using Numerical and Analytical Models: Elmira Sharabian, UTEP University
Fabrication of 3-Dimensional Flexible Tactile Sensor using Pressure Sensitive Material: Chae Young Park, Chungbuk National University	Development of Soft Gripper Pneumatic Control System Based on Deep Reinforcement Learning: Seongyeon Kim, Chungbuk National University	Fabrication of Superhydrophobic Surfaces using Waste PET: Tae Gyun Kim, Chungbuk National University
Development of Flexible Circuits using Epoxy-based Flexible Electrical Conductors: Jongho Jeon, Chungbuk National University	Characterization of Thermoset Feedstocks for Laser Powder Bed Fusion : Malik A. Blackman, Georgia Institute of Technology	Robot-aided Selective Embedding of Spatially Steered Continuous Fibers in Polymer Composite Parts Made using Vat Photopolymerization: G. K. Ananthasuresh, Indian Institute of Science, Bangalore
Increasing Precision Towards NiTi Lattice Structure using PBF-EB : Zeyu Lin, KTH	FE Predictions of Residual Stresses in L-PBF Generated Ti-6Al-4V NIST Bridges : Caitlin Luke, Mississippi State University Department of Mechanical Engineering	Enhancement of Profile Data for Repetitive Process Control Measurements in DED Additive Manufacturing: Kyle Saake, Missouri University of Science and Technology
Accelerating Design and Additive Manufacturing of Polymer Matrix Composites : Olivia Fulkerson, Oklahoma State University	Building Blocks for Understanding Triply Periodic Surfaces: A Visual and Tactile Learning Aid: Joseph Fisher, Pennsylvania State University	Experimental Evaluation of Hierarchical Functionally Graded Lattices Using Digital Image Correlation and Micro-CT: Junyang Ye, Rice University
Metal Additive Manufacturing of A36 Steel to Improve Techno-economic Performance of Marine Renewable Energy Technology: Hyein Choi, Sandia National Labs	Spreading and Packing of Ceramic Powder Using a Displacement-controlled Roller in SLFS: Kaya Bayazitoglu, The University of Texas at Austin	Computer Vision for Powder Mass Flow Rate Measurement in Blown Powder Directed Energy Deposition : Erik LaNeave, The University of Texas at El Paso
3D Printing of Gel Polymer Electrolytes via Vat Photopolymerization for Lithium-ion Batteries: Eva Schiaffino Bustamante, The University of Texas at El Paso	Electrochemical Stability of 3D Printed Separators and Gaskets for Shape-conformable Lithium-ion Batteries : Christian Fernandez, The University of Texas at El Paso	Structural Analysis and Design of Mantis Shrimp-inspired Composites for Enhanced Impact Resistance: Ailin Chen, University of California Berkeley
Enabling Part-scale Melt Pool Prediction in Laser Powder Bed Fusion via a Global-local Thermal Process Simulation Model : Shawn Hinnebusch, University Of Pittsburgh	Towards Large-scale Grain Growth Modeling in Powder Bed Fusion: Michael Paleos, University of Pittsburgh	Elucidating the Role of Local Preheat Temperature on Multi-track Melt Pool Morphology Variation for Inconel 718 Laser Powder Bed Fusion via CIFEM: Seth Strayer, University Of Pittsburgh
A Local Preheat Temperature Dependent Stochastic Finite Element Heat Source Model for Inconel 718 Laser Powder Bed Fusion : Seth Strayer, University Of Pittsburgh	A Data Driven-based Geometric Compensation Method for Laser Powder Bed Fusion: Wen Dong, University of Pittsburgh	Distortion and Residual Stress Mitigation of Large Parts for Wire-arc Additive Manufacturing: Wen Dong, University of Pittsburgh
Efficient Thermomechanical Simulation for WAAM using Automated GPU-based Modeling : Xavier Jimenez, University of Pittsburgh	A Data-driven Distortion Compensation Method and the Necessity to Consider Spatial Effects in Binder Jet Parts: Basil Paudel, University of Pittsburgh	Data-driven Local Porosity Prediction in Laser Powder Bed Fusion via In-situ Monitoring: Berkay Bostan, University of Pittsburgh
Data Management for Additive Manufacturing Process Monitoring: Matthew Roach, University of Tennessee, Knoxville	Additively Manufactured LiCoO2-based Photocurable Resin as Positive Electrode for Lithium-ion Batteries: Ana Aranzola, University of Texas at El Paso	Monitoring of Single-track Quality in Laser Powder Bed Fusion using In-situ Thermionic Sensing: Benjamin Bevans, Virginia Tech
Monitoring of Process Stability in Laser Wire Directed Energy Deposition using Machine Vision: Benjamin Bevans, Virginia Tech	Mechanical Test Plan of Niobium Alloy C103 for Laser Powder - Direct Energy Deposition : Hugo Garcia, University of Texas at El Paso	Layer-wise Prediction of Microstructure Evolution in Laser Powder Bed Fusion Additive Manufacturing using Physics-based Machine Learning: Alexander Riensche, Virginia Tech
Exploring Capillary Suspension Technique to Develop 3D Printable Oxide Based Lithium Electrolytes for All Solid-state Batteries by Direct Ink Writing: Siri Vaishnavi Thummalapalli, Arizona State University	Characterization and Validation Experiments for a Binder Jet 3D Printing Modeling Framework: Wesley Combs, Rice University	Laser Synthesized Molybdenum Trioxide (MoO3) Nanoparticles for Energy Storage Applications: Amiri Thorpe, Florida A&M University

Plenary Session

Monday AM | Room: Salon HJK
August 14, 2023 | Location: Hilton Austin

Session Chair: Joe Beaman, University of Texas at Austin

8:00 AM Introductory Comments

8:15 AM Plenary
Design, Analysis, Optimization, and Fabrication of Porous/Heterogeneous Microstructures via Spline-based Volumetric Representations: *Gershon Elber*[1]; [1]Technion

Boundary representations (B-reps) can no longer satisfy the needs of modern (additive) manufacturing (AM) technologies. AM requires the representation and manipulation of interior fields and materials. Further, while the need for a tight coupling between design and analysis has been recognized as crucial almost since geometric modelling (GM) has been conceived, contemporary GM systems only offer loose links between the two. For more than half a century, the (trimmed NURBs) surface representation has been the B-rep of choice for the GM industry. Fundamentally, B-rep GM has evolved little during this period. Herein, we present a, B-spline based, volumetric representation (V-rep) that successfully confronts existing and anticipated design, analysis, and manufacturing foreseen challenges. Among others, full support of AM of porous heterogeneous artifacts.Examples and applications of V-rep GM, that span design, analysis and optimization, and AM, of (heterogeneous) lattice- and micro-structures, including compliant microstructure mechanisms, will be demonstrated.

8:40 AM Plenary
Implementing In-situ Process Monitoring in Additive Manufacturing to Accelerate Qualification: *Michael Heiden*[1]; Jesse Adamczyk[1]; Dan Bolintineanu[1]; Anthony Garland[1]; Ana Love[1]; Hyein Choi[1]; David Moore[1]; Catherine Appleby[1]; David Saiz[1]; [1]Sandia National Laboratories

Studies across industry have demonstrated in-situ monitoring's ability to track build events during metal additive manufacturing (AM) processes. However, process monitoring hasn't yet been implemented in production environments due to the slow, resource-intensive nature associated with acquiring/analyzing large datasets with multiple complex outputs. The goal is to equip AM production machines with deployable sensor hardware, along with a simple user interface and software that provides a manageable amount of data for designer decision-making. This presentation describes a multi-year effort to develop a resource-effective in-situ instrumentation toolset for AM production environments that incorporates machine learning to ultimately form a common data processing framework. The study aims to assist AM process development, ensure process consistency, and contribute to part acceptance for metal AM production. Furthermore, this work investigates how in-situ process monitoring contributes to an AM part's digital thread.SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

9:05 AM Plenary
Machine Learning Applied to Process Monitoring for Laser Hot Wire Additive Directed Energy Deposition: Brandon Abranovic[1]; Elizabeth Chang-Davidson[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 deposition, 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 real-time 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.

9:30 AM Plenary
Experimental and Computational Study of Area Printing Additive Manufacturing: *Ben Fotovvati*[1]; Subin Shrestha[1]; Nicholas Ferreri[1]; Ning Duanmu[1]; [1]Seurat Technologies

The low manufacturing speed of laser-powder bed fusion (LPBF) additive manufacturing has hindered its adoption in conventional manufacturing methods. Large-area pulsed laser powder bed fusion (LAPBF), also known as "Area Printing", has addressed this limitation by replacing the point laser with a large-area pulsed laser. Each pulse melts a region of the powder bed on the order of square millimeters, which enables shorter manufacturing time and lower final production costs in addition to higher quality parts due to the lack of spatter compared to conventional LPBF methods. In this study, process parameters are optimized to achieve near full-density parts, and a computational model is developed to understand the multi-physics governing the process. It is observed that the shallow depth and large aspect ratio of the melt pool lead to a unidirectional solidification front extending along the build direction where grains grow epitaxially, and highly directional microstructures are created.

9:55 AM Plenary
Gas Flow and Delivered Laser Power Effects on Mechanical Properties: *Joy Gockel*[1]; Edwin Glaubitz[1]; Clay Perbix[1]; Sage Frontella[1]; Allan Huntington[2]; Ryan Fishel[2]; Jeff Shaffer[2]; [1]Colorado School of Mines; [2]3D Systems

Reducing process variability to achieve predictable and repeatable part performance is necessary to accomplish successful machine qualification of AM technology. Machine processing variables (e.g.- gas flow) and laser window contamination by process byproducts lead to within-build and build-to-build anomalies that are currently unexplained and hinder the translation of processing knowledge from one build, or one machine, to another. This work investigates a measured grid of gas flow and laser power and relates to material structure and mechanical properties. Investigated structure and properties include microstructural characteristics, surface features (protrusions vs notches), forms of porosity (interlayer, spatter, sub contour, etc.), tensile strength and fatigue life. The outcome of this work will identify additional process metrology needs, monitoring requirements, and processing pedigree documentation that must be included in AM qualification standards.

10:20 AM Plenary
NSF Advanced Manufacturing Program and Funding Opportunities: *Khershed Cooper*[1]; [1]National Science Foundation

NSF's Advanced Manufacturing (AM) program supports transformative advances in materials engineering, processing, and manufacturing and fosters multidisciplinary research that applies innovative manufacturing approaches to accelerate new product development, customize products, increase production efficiency and reduce production cost. The AM program encourages industry partnerships through collaborations with the Manufacturing USA Institutes and international partnerships through collaborations with DFG and funding agencies of other countries. The AM portfolio includes the entire manufacturing enterprise including additive manufacturing, all scales (nano to infrastructure), all materials systems and most applications. The AM program participates in several cross-cutting activities such as Future Manufacturing (FM), Critical Aspects of Sustainability (CAS), Engineering Research Centers (ERCs) and others, and supports education and outreach activities through solicitations such as BRITE and supplements such as INTERN. These programs address national priorities such as AI/ML, semiconductors, quantum, sustainability, climate change, clean energy, biomanufacturing, and workforce development. This presentation describes program goals, basic research activities and accomplishments of the AM and related programs.

10:45 AM Break

11:15 AM Plenary

You Must Unlearn What You Have Learned: Establishing a DfAM Mindset in the Face of Centuries of Traditional Manufacturing: *Nicholas Meisel*[1]; [1]Pennsylvania State University

With the rise of additive manufacturing, we as designers need to dig deeper into our designs, with the aim of getting straight to the heart of functionality, without limiting ourselves to previous notions of what something is "supposed" to look like. In this talk, the speaker will discuss his lab's ongoing research into establishing an evidence-based design for additive manufacturing mindset in human designers as derived from years of research. This will include discussion of the types of designs that engineers are likely to generate early-on in their design process, as well as how these designs align with the principles of traditional manufacturing or additive manufacturing. Practical strategies for changing designers' thinking about manufacturing will also be demonstrated, with findings reported from the use of virtual reality, problem-based learning activities, and online design evaluation tools. At the end of this presentation, attendees will be able to better understand not only the challenges facing engineers when it comes to unlearning their previous notions of manufacturability, but also how to address these challenges head-on to encourage the generation of additive manufacturing-appropriate designs earlier in the design process.

11:40 AM Plenary

Co-design of 3D Printing, Parts and Microstructure in High-temperature and High-pressure Heat Exchangers: *Anthony Rollett*[1]; [1]Carnegie Mellon University

Abstract available in addendum

Process Development: Hybrid and Convergent Processes- Robotics and Hybrid Polymer-metal Processes

Monday PM — Room: 404
August 14, 2023 — Location: Hilton Austin

Session Chair: Zhenghui Sha, University of Texas at Austin

1:30 PM

Time-optimal Path Planning for Heterogeneous Robots in Swarm Manufacturing: *Ronnie Stone*[1]; Junmin Wang[1]; Zhenghui Sha[1]; [1]University of Texas at Austin

Autonomous mobile robots (AMRs) are gaining popularity in advanced manufacturing. Continuous advances in robotics path planning and the need for increased automation in manufacturing processes have caused a rising demand for integrating AMRs into modern factories. The success of this integration is critical to swarm manufacturing (SM), a new paradigm that employs multiple heterogeneous AMRs to perform a wide range of manufacturing tasks. However, path planning in SM poses unique challenges that must be addressed. Much of the literature on path planning operates under two major assumptions: the environment is static, and the robot's shape is approximated as a center of mass. These assumptions do not hold in SM, where the environment is dynamic, and the robot's orientation could impact the manufacturing task. In this paper, we propose a new methodology to find time-optimal paths in dynamic environments while explicitly considering the shape of AMRs and the obstacles surrounding them.

1:50 PM

High-precision Camera-based Auto-calibration System for Cooperative 3D Printing: *Charith Nanayakkara Ratnayake*[1]; Wenchao Zhou[1]; Zhenghui Sha[2]; Ali Ugur[3]; [1]University of Arkansas; [2]University of Texas at Austin; [3]Yildiz Technical University

Cooperative 3D printing (C3DP) is an emerging technology that addresses the scalability in size and printing speed in conventional 3D printers by employing multiple 3D printers working together. Accurate positioning and aligning between printers are critical for the success and quality of C3DP. In this study, we have developed a camera-based auto-calibration system for C3DP, which enables more precise and efficient printer calibration. The auto-calibration system utilizes computer vision with a camera that reads ArUco markers placed at known positions on the print bed. With the camera readings, the system accurately calibrates the kinematic parameters of the printers, ensuring the agreement between different printers on the markers' positions thereby spatially aligning them for C3DP. Our results show that this method significantly improves the calibration accuracy, achieving precision beyond 100 microns. In conclusion, the system provides confident printer alignment in C3DP, enhancing the overall efficiency and reliability of the C3DP process.

2:10 PM

Physical Validation of Job Placement Optimization in Cooperative 3D Printing: *Cole Mensch*[1]; Wenchao Zhou[2]; Zhenghui Sha[1]; [1]University of Texas at Austin; [2]University of Arkansas

Cooperative 3D printing (C3DP) is an emerging technology designed to overcome the limitations of traditional 3D printing, including speed and scalability. C3DP achieves this by partitioning prints into smaller jobs, e.g., chunks or line segments at each layer, and assigning them to a team of mobile 3D printers that work cooperatively in parallel. Our prior work established a framework for optimizing job placement by connecting geometric partitioning algorithms with path planning and scheduling algorithms. However, this framework was not physically validated. In this paper, we present the first physical validation of the job placement algorithm by chunking and printing two objects using the proposed algorithm. The objects used in the test cases vary in size and complexity, from a small and simple object to a large object with intricate geometry. We demonstrate that our optimized placement algorithm provides results comparable to the physical C3DP system, providing a significant step forward in the practical implementation of C3DP technology.

2:30 PM

Exploring a Supervisory Control System Using ROS2 and IoT Sensors: *Matthew Roach*[1]; Josh Penny[1]; Bradley Jared[1]; [1]University of Tennessee, Knoxville

Whether collecting data from process monitoring sensors or controlling a system of multiple actuators and electrical systems, a powerful supervisory control system must be developed for additive manufacturing (AM) systems. The Robot Operating System version 2 (ROS2) is a set of software libraries that can be used to control robotics systems and has tools for sensor value publishing. This research project is exploring the use of computational nodes connected to process monitoring sensors and robotic or electrical systems to allow for a more in-depth knowledge of the system health and process as well as open the possibilities of process control. These nodes can be connected and controlled by the ROS2 architecture. Work will be discussed exploring the reliability and speed of common AM processes and sensors such as robot controllers and thermal monitoring.

2:50 PM

Lost-PLA Casting Process Development Using Material Extrusion with Low-density PLA: *Mohammad Alshaikh Ali*[1]; Orkhan Huseynov[1]; Ismail Fidan[1]; Fred Vondra[1]; [1]Tennessee Tech University

The goal of this research is to develop a baseline procedure for lost-PLA casting process of aluminum. Traditional Manufacturing techniques and Smart Manufacturing techniques have their advantages and disadvantages. Integrating the traditional and modern aspects of manufacturing enhances the capabilities of manufacturing. Low-weight PLA is used in a Material Extrusion (MEX) machine to fabricate sacrificial patterns for an aluminum lost-casting process. Different process parameters are tested for both the MEX and casting processes. The MEX process parameters tested are: infill pattern, shell count, top/bottom layers, and print orientation. The MEX process parameter investigation allows to draw conclusions to establish a standard for which parameters are ideal for the casting process. The casting process parameters considered are: aluminum temperature, ceramic coating, and sprue size. The preliminary studies show that this casting process is successful in producing dimensionally accurate aluminum parts by a direct-pour casting process using the suggested MEX process parameters.

3:10 PM Break

3:40 PM

In-situ Electrical Resistance Measurements for Soldering Studies in Hybrid AM: Alexander Pustinger[1]; *Joselin Corral*[1]; Arianna Villegas[1]; David Espalin[2]; [1]University of Texas at El Paso; [2]University of Texas at El Paso - W.M. Keck Center for 3D Innovation

The convergence of additive manufacturing (AM) along with multiple applicable technologies has been shown to augment the functionality of printed parts such that mechanical, electrical, and electromagnetic functions can, for example, reside within the same part. This work used an electrical connector commonly used in satellites to demonstrate a hybrid AM approach by embedding the connector, ultrasonically embedding wires, and laser soldering. The connector was a six-pin Easy-on FFC/FPC connector with a fine pitch and leads of 200-micron width. Resistance measurements were carried out during laser soldering, application of insulation material, and encapsulation with thermoplastic extruded at high temperatures (> 300ºC). The measurements were made to observe the impact of 1) a laser power profile and 2) thermal input from the extrusion nozzle and heated build environment for diagnostics of low yield or performance. Additionally, temperature history data was collected to coincide with resistance measurements.

4:00 PM

Hybrid Metalized Polymer Core (HMPC), Initial Concept and Design of Lightweight Additively Manufactured Hardware: *Shaun Whetten*[1]; Charles Rose[1]; Michael Kracum[1]; Jacob Mahaffey[1]; David Saiz[1]; Joseph Padilla[1]; Levi Van Bastian[1]; John Cochrane[1]; Raymond Puckett[1]; Brian Hutsel[1]; [1]Sandia National Labs

Sandia National Laboratories (SNL) builds and maintains some of the world's most complex testbeds which are reliant on advanced hardware. Given one of the main thrusts at SNL is stockpile stewardship, production of these testbeds is both paramount and incredibly difficult. Traditionally hardware has been designed and manufactured with the classical reductive processes yielding undesirably large amounts of waste material. Further, some hardware cannot be classically machined, and hardware overall is becoming increasingly complex. Given this, we present initial concept design and results of our additively manufactured (AM) Hybrid Metalized Polymer Core (HMPC) concept hardware. Our hybrid design approach is rooted in AM and well suited for mass optimized (lightweight) applications and dramatically increases geometric possibilities. Current research includes directly replacing mission critical hardware for pulsed power applications. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525

4:20 PM

Hybrid Metalized Polymer Core (HMPC) Initial Results of Prototype Mass Optimized Pulsed Power Hardware: *Charles Rose*[1]; Shaun Whetten[1]; Michael Kracum[1]; Jacob Mahaffey[1]; David Saiz[1]; Joseph Padilla[1]; Levi Van Bastian[1]; John Cochrane[1]; Raymond Puckett[1]; Brian Hutsel[1]; [1]Sandia National Labs

Stockpile stewardship, being one of the main thrusts of Sandia National Laboratories(SNL), requires the worlds most advanced test beds which rely on accurate and predictive models of high energy and density environments. Generation of these extreme environments is incredibly difficult and traditional reductive manufacturing limitations must be overcome. Given this, we present initial results of our additively manufactured Hybrid Metalized Polymer Core (HMPC) mass optimized concept hardware fired on the Mykonos accelerator at SNL. Initial results show no obvious power flow differences given an apples-to-apples comparison of like kind shot conditions and hardware topology propagating > 400 kV at > 600 kA while maintaining a ~ 3X mass reduction. Further work is necessary, but we report HMPC power flow hardware works as intended and is believed to be a viable candidate for next generation pulsed power (NGPP). SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525

4:40 PM

Development of Multimaterial Additive Manufacturing Systems for the Embedded Electronics: *Carson Vath*[1]; Kazi Md Masum Billah[2]; Guhaprasanna Manogharan[1]; [1]SHAPE Lab; [2]University of Houston

Hybrid manufacturing for integrating different material systems/structures within additively manufactured structures is of growing interest to the AM community. Current wire deposition system in thermoplastic substrates uses thermal energy to embed the wire which in general leads to surface damage and loss the part integrity. This research develops a wire embedding tool that is designed to embed wire in a photocurable thermoset. Thermoset is relatively stable and does not require heat for implanting wire. This method will have relatively more rapid production rate as the extrusion process can be conducted without any interruptions.

5:00 PM

State-of-the-art Cyber-enabled Physical and Digital Systems Deployed in Distributed Digital Factory Using Additive and Subtractive Manufacturing Systems: Open, Scalable, and Secure Framework: Ranjit Roy[1]; Sung-Heng Wu[1]; Usman Tariq[1]; Sriram Praneeth Isanaka[1]; Asad Malik[1]; Muhammad Arif Mahmood[1]; *Frank Liou*[1]; [1]Missouri University of Science and Technology

A distributed digital factory (DDF) integrates physical and digital systems, leveraging additive manufacturing (AM) and subtractive manufacturing (SM), to enable the dispersed production of components. Existing work focuses on digital twins, AM and SM systems and some security aspects. Nevertheless, a holistic view of integrating devices with dynamic provisions to invoke digital twins has limited supporting research. This paper will detail cyber-physical and digital systems deployed in DDFs. The components of cyber systems, including AM & SM equipment, sensors, communication protocols, and monitoring software, are covered. Challenges associated with the design and deployment of DDFs, such as security, scalability, and interoperability, are detailed. The assessment emphasizes an open framework for DDF development, allowing system integration from vendors & participants across diverse locations and capabilities. The article also examines the significance of a scalable and secure framework for the implementation of DDFs, which ensures the dependability and availability of on-demand manufacturing.

Process Development: Directed Energy Deposition and Cold Spray

Monday PM
August 14, 2023

Room: 410
Location: Hilton Austin

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

1:30 PM

Electroslag Strip Cladding for Additive Manufacturing: *Adam Stevens*[1]; Paritosh Mhatre[1]; Christopher Masuo[1]; William Carter[1]; Jesse Heineman[1]; Rangasayee Kannan[1]; Andrzej Nycz[1]; Nikolaos Tsiamis[1]; Sudarsanam Babu[1]; Brian Post[1]; [1]Oak Ridge National Laboratory

Electroslag strip cladding is used industrially to apply corrosion-resistant inner surfaces to process vessels in the chemical industry and elsewhere. Cladding deposition rate and coverage area are subject to continuous industry development to improve the process economics, and therefore the process is uniquely suited to high-throughput additive manufacturing of large metal structures. We report preliminary experiments utilizing an electroslag strip cladding system for high-throughput metal additive manufacturing, including measured build rates, process conditions, and metallurgical characterization of multi-layer prints.

1:50 PM
Process Strategy and Geometrical Distortion of Heat-treated 17-4PH Stainless Steel Produced by Interleaved Machining and Blown-powder DED: *Lauren Heinrich*[1]; Kenton Fillingim[1]; Rangasayee Kannan[1]; Peeyush Nandwana[1]; Thomas Feldhausen[1]; [1]Oak Ridge National Laboratory

Hybrid manufacturing systems incorporate subtractive and additive manufacturing within one build volume enabling interleaving between the two processes. However, the interleaving of these two processes has been found to create geometric misalignment between the interleaved steps due to the complex thermal cycling of the hybrid process. To investigate this phenomena, four differing interleaving strategies were applied to a 17-4PH stainless steel planar wall. Different rough and finish machining scheduling strategies were used to determine the best interleaving strategy for optimal geometric accuracy. Of the four walls, the wall that was machined at a distance away from the recently deposited material was found to have the highest dimensional accuracy. To simulate real-world applications, subsequent heat treatments were applied to three of the walls to better understand the effect that heat treatment after final machining has on geometrical accuracy. This result will better enable the accurate manufacture of interleaved hybrid manufactured components.

2:10 PM
Structural Integrity Assessment of Cold Spray Repaired High-strength Aluminium Alloy 7075 Specimens: *Ali Bakir*[1]; Xiang Zhang[2]; Matthew Dore[3]; Kashif Khan[2]; Phil McNutt[4]; [1]Coventry University/NSIRC, TWI Ltd.; [2]Coventry University; [3]Conventry University/TWI Ltd.; [4]TWI Ltd.

Cold spray (CS) has seen an emerging role in repair applications, especially for temperature- and oxidation-sensitive materials. Despite its advantages, the structural integrity of CS repaired materials remains a concern due to the porosity, poor inter-particle bonding, and lack of data and standards. In this study, the mechanical performance of CS repaired samples under static and cyclic loading is being investigated. Different powder heat-treatment conditions and repair geometries are used to improve the deposition performance and structural integrity. Under tensile loading, the CS repair failed and started delaminating at around 1% elongation, whereas the specimens continued carrying tensile loading up to 7% elongation before the complete fracture, which is 50% less than the wrought material performance. Conversely, the high cycle fatigue life of the repaired samples is similar to the wrought ones, exceeding 10 million cycles at 200MPa. The common observation for all repaired samples was the fatigue crack initiated at the substrate-CS interface and propagated towards the substrate.

2:30 PM
Side on Plasma Emission Spectroscopy of TiAl6V4 During Laser Scanning: *Ethan Sprague*[1]; Nicholas Calta[1]; Erik Busby[1]; [1]Lawerence Livermore

Significant focus has been placed on in-situ diagnostics for powder-based additive manufacturing, like Powder Bed Fusion (PBF) and Directed Energy Deposition (DED), using tools such as layer imaging and pyrometry over the last decade. Plasma Emission Spectroscopy is a technique which uses the spectra of the plasma plume which forms directly above the laser-metal interaction zone to study the sample below. A series of high-speed, side-on, and height-resolved spectra are taken for laser scanned TiAl6V4 plate, such that the spectra can be resolved in time and at 7 different heights above the melt pool. This data can be used to calculate the plasma temperature at different heights above the melt pool and study the stability of the plasma itself. Results show plasma temperatures generally decline with increased distance from build plate, and a high sensitivity to atmospheric quality of both plasma intensity and temperature. Prepared by LLNL under Contract DE-AC52-07NA27344.

2:50 PM
Role of In-situ Monitoring Technique for Digital Twin Development using Direct Energy Deposition: Melt Pool Dynamics and Thermal Distribution: *Sung-Heng Wu*[1]; Usman Tariq[1]; Ranjit Joy[1]; Muhammad Arif Mahmood[2]; Frank Liou[1]; [1]Missouri University of Science & Technology; [2]Intelligent Systems Center

Direct energy deposition (DED) is a promising additive manufacturing technique that enables the fabrication of complex structures with excellent mechanical properties. However, the quality of the final product depends on several parameters, including melt pool dynamics and thermal distribution. For process monitoring and continuous improvement of digital twins, in-situ monitoring allows real-time tracking of these parameters, providing valuable data for process optimization. However, existing monitoring methods are limited in their accuracy due to emissivity issues. To address this challenge, a visual spectrum camera has been tested for real-time process monitoring via a dual-wavelength technique. Based on the analyses, the area and thermal distribution inside the melt pool can be estimated accurately. The data from the camera can be integrated into a digital twin's continuous improvement, providing efficiency and reducing manufacturing costs.

3:10 PM Break

3:40 PM
Influence of Substrate Temperature on the Formation of Individual Weld Paths during Laser Cladding (LMD) when Processing 316L.: *Stefan Gnaase*[1]; Christian Bödger[1]; Dennis Lehnert[1]; Thomas Tröster[1]; Robin Rohling[1]; [1]Universität Paderborn / Lehrstuhl für Leichtbau im Automobil

Additive manufacturing by means of laser metal deposition (LMD) of metals holds high application potential due to the simple process scaling with regard to the production of large and complex three-dimensional structures. One of the central process variables to be considered is the component heat. The thermal energy supplied by a laser during the manufacturing process leads to different temperatures on the surface to be welded. This can lead to deviating welding results with otherwise constant process parameters. The investigations aimed at in this work shall contribute to the understanding of the influence of the substrate/part heat on the LMD process result and bring solutions for the correction of possible deviations of the welding result. For this purpose, individual weld tracks with different process parameters on substrates with controlled temperature levels will be produced and analyzed to formulate a model for the prediction of the weld result.

4:00 PM
Impact of Powder Deposition Parameters on Powder Catchment Efficiency in Laser Directed Energy Deposition: *Colin Ancalmo*[1]; Sneha Narra[1]; [1]Carnegie Mellon University

Blown powder laser directed energy deposition (L-DED) is subject to low end-to-end material efficiencies resulting from the yield of gas atomized powder below 150μm and in-process powder catchment efficiencies (usually < 50%). These inefficiencies become important as feedstock procurement represents about 20% of the cost and 30% of the energy consumed for typical parts. Higher catchment efficiencies require smaller powder spot diameters for a fixed melt pool, and powder spot diameter is influenced by powder mass flow rate, nozzle carrier gas flow rate, and nozzle standoff distance. However, the relationship between these powder deposition parameters and catchment efficiency is not known. This work uses low-cost imaging and computer vision-based feature extraction to capture powder spot diameter for AISI 420 powder under different powder deposition parameters. The results from deposition experiments will determine whether powder deposition parameters can be optimized for increased powder catchment efficiency.

4:20 PM
Experimental Study of Cryogenic Directed Energy Deposition Conducted at -20°C: *Wei Li*[1]; Kishore Nagaraja[1]; Benquan Li[1]; [1]University of Texas at Dallas

Ambient temperature has a great influence on directed energy deposition (DED), such as temperature gradient, cooling rate, and grain evolution. Currently, the DED is only performed under laboratory conditions (20°C to 25°C). So far, the DED has not been explored specifically under low temperature or cryogenic conditions. This experimental study fills this gap. In this work, the ambient temperature of DED (including substrate) was chilled to -20°C. The authors printed three thin-wall samples with stainless steel 316L powder at this cold condition. As comparative test, another sample with same geometry and material was printed with same DED parameters at room temperature (20°C). The results show some interesting findings. The sample height and molten pool size (-20°C) are larger than the sample printed at 20°C. Additionally, the hardness values of samples printed at -20°C are greater than those printed at room temperature. The tensile tests showed the -20°C samples had better mechanical properties.

4:40 PM

Embedded Fiber Optic Sensing in DED Using High-temperature Adhesives: *Elias Snider*[1]; Douglas Bristow[1]; Cesar Dominguez[2]; [1]Missouri University of Science and Technology; [2]Los Alamos National Laboratory

Fiber optics are useful as strain and temperature sensors in a variety of applications involving high-value parts. Embedding fiber optic sensors into end-use parts can allow for real-time strain and temperature monitoring of these parts in extreme conditions. Direct energy deposition processes have distinct advantages for producing parts in high-value embedded sensing applications, however, ensuring survival of the optical fiber during embedment is challenging. A method of fiber embedment using high-temperature ceramic adhesives is presented as a flexible method of embedding fiber optic sensors into end-use parts such as to preserve fiber transmission and sensor integrity. Example specimens are presented and functionality of sensing capabilities is demonstrated.

Process Development: Material Extrusion I

Monday PM — Room: 412
August 14, 2023 — Location: Hilton Austin

Session Chair: To Be Announced

1:30 PM

Testing Protocol Development for Fracture Toughness of Parts Built with Big Area Additive Manufacturing: *Juan Pablo Garcia Chavira*[1]; Luis Camacho[1]; David Espalin[2]; [1]University of Texas at El Paso; [2]University of Texas at El Paso - W.M. Keck Center for 3D Innovation

Mechanical testing of additively manufactured parts has largely relied on existing standards developed for traditional manufacturing. While this approach leverages the investment made on current standards development, it inaccurately assumes that mechanical response of AM parts is identical to that of parts manufactured through traditional processes. When considering thermoplastic, material extrusion AM, differences in response can be attributed to an AM part's inherent inhomogeneity caused by porosity, interlayer zones, and surface texture. Additionally, interlayer bonding of parts printed with large-scale AM is difficult to adequately assess as much testing is done such that stress is distributed across many layer interfaces; therefore, the lack of AM-specific standard to assess interlayer bonding is a significant research gap. To quantify interlayer bonding via fracture toughness, double cantilever beam (DCB) testing has been used for some AM materials, and DCB has been generally used for a variety of materials including metal, wood, and laminates. Mode I DCB testing was performed on thermoplastic matrix composites printed with Big Area Additive Manufacturing (BAAM). Of particular interest was the crack shape and deflection speed during testing. Results discuss the differences when using two crack types and three deflection speeds.

1:50 PM

Strengthening FFF Parts via Annealing with Structured Dual Material Filaments and Dissolvable High-temperature Shells: *Ryan Dunn*[1]; Eric Wetzel[1]; [1]US Army Research Laboratory

Thermal annealing is an established method for strengthening polymer interfaces, including the weak interlaminar bonds produced by fused filament fabrication (FFF). However, highly effective annealing takes place at temperatures where the polymer will deform. By printing models with an added shell composed of a dissolvable high-temperature polymer, annealing can be achieved without deformation. Because the shell is dissolvable none of the model's geometry is replaced with temperature resistant polymer allowing the resulting part to fully benefit from annealing. Annealing can also take place during the dual-material print, or in a printer's heated build chamber post-print, reducing the time and equipment requirements for this process. Applications are discussed, as well as numerical improvements in mechanical properties such as fracture toughness and impact strength.

2:10 PM

Static Mixing Nozzles for Long and Short Fiber Additive Extrusion Processes: *Tyler Smith*[1]; Katie Copenhaver[1]; Chase Joslin[1]; John Lindahl[1]; Chris Hershey[1]; Meghan Lamm[1]; James Brackett[1]; Vipin Kumar[1]; Ahmed Hassen[1]; Vlastimil Kunc[1]; [1]Oak Ridge National Laboratory

Additive Manufacturing is conventionally used to create structures through extruding plastic or metal layer by layer. In the case of polymer processes, fibers are typically added to increase stiffness and reduce warping during building. The of the fiber exiting the nozzle can impact the overall mechanical properties of the structure. Using Long Fiber Pellets can increase the starting length of the pellets to help increase the average fiber length coming out from the extruder. However, extruded long fiber materials tend to have low fiber alignment and high porosity leading to poor mechanical properties. By using a blend of materials and a static mixing nozzle, consolidated beads can be created to produce more stable and solid structures while added a fixed amount of long fiber into the extruded bead to increase mechanical performance.

2:30 PM

Self-heating Tooling on BAAM using Co-extruded Heating Wires: *Jesse Heineman*[1]; [1]Oak Ridge National Laboratory

Oak Ridge National Laboratory (ORNL) has developed a wire co-extrusion module that enables wires to be embedded inside the selected polymer beads during fused deposition modeling (FDM) manufacturing. The FDM machine used for this research is the Big Area Additive Manufacturing (BAAM) machine from Cincinnati Incorporated, which has a build volume of 7' x 20' x 6' high. The composite tooling industry relies heavily on applied heat to improve the curing rate and final mechanical properties of composite parts. However, as the size of the tools get larger, the cost and practicality of autoclave tooling becomes prohibitively expensive. This method of manufacturing aims to reduce the cost and delivery time of large-scale self-heated tooling. This paper will include details about the custom hardware and software developed by ORNL for this process, as well as the results from initial heating trials of a demonstration tool.

2:50 PM

Real-time Image-based Quality Control for Bio-additive Manufacturing through Layer-by-layer Analysis: *Casey Tran*[1]; Camila Ceballos-Santa[2]; Chaitanya Mahajan[1]; Sri Ramesh[3]; Iris Rivero[2]; Satyajayant Misra[1]; [1]New Mexico State University; [2]Rochestor Institute of Technology; [3]Rochester Institute of Technology

Achieving precise geometric quality control in bio-additive manufacturing is crucial for fabricating functional tissue constructs with high fidelity. However, this can be challenging, especially when dealing with hydrogels that are difficult to 3D scan accurately. To detect any inaccuracies in the printed construct, we developed a real-time monitoring framework for extrusion-based printing processes that generates layer-by-layer nominal images of the tool path and computes the MSE/SSIM similarity score of the actual printed construct for geometrical variations. The proposed monitoring system represents a significant step towards ensuring quality control and process efficiency in bio-additive manufacturing, with implications for tissue engineering and regenerative medicine. Future research will focus on optimizing the system design and improving the accuracy of monitoring algorithms, especially in accounting for layer thickness and hydrogel material rheology, and a feedback system to correct the next layer or cancel the print given detected anomalies.

3:10 PM Break

3:40 PM
Printing Parameter Optimization of Extruded Metal Paste by Response Surface Technique: *Marshall Norris*[1]; Ismail Fidan[1]; [1]Tennessee Tech University

This research will be focused on optimizing printing parameters using the response surface (RS) methodology. If the printing parameters are not optimized, the resulting prints will contain an unacceptable surface finish or porosity, or incomplete print as the lower portion of the print must withstand the weight of each consecutive layer. Layer height and percent infill will be adjusted for the study while volumetric flowrate and print head speed will be held constant. RS is a statistical based process that uses multiple data points of a curve and regression to determine local maxima or minima. For this study, RS will be used to identify the inflection point where density is maximized. A local starting point for the parameters begins with the material rheological characterization and geometric modeling or brute force method. Once the parameters are close, the RS approach will be used to refine printing parameters.

4:00 PM
Parametric Analyses of Impact of Deposition Pressure on Multi-axis Free-form Fabrication.: *Aditya Thakur*[1]; Jan Eine[1]; Niklas kyriazis[1]; [1]Institute of Space System (IRAS)

Additive manufacturing is being explored as one of the promising in-space manufacturing techniques. The presence of µgravity enables fabrication of support-free spare structures with ease. Sparse structures (e.g. trusses) are attractive for space applications as they can be tailored for specific load paths. Previous studies have identified positive correlation between the deposition pressure and inter-layer adhesion in 3Dprinting. However, excessive deposition pressures negatively influence the in-orbit printing accuracy. Therefore, a parametric investigation was conducted to determine optimal deposition pressure to fabricate mechanically sound trusses in orbit. Support-free arches with varying nodal deposition pressures were 3Dprinted using multi-axis robotic arms with integrated force sensors. Mechanical testing of these arches concluded that the strength improvement plateaus. It registers no significant increase in joint strength after a certain deposition pressure, characterized by the properties of the extrude. Integration of a force-feedback facilitates printing of complex, multi-layered, support-free trusses in a free-floating space environment.

4:20 PM
Non-linear Dynamic Modelling of Cartesian-frame FFF 3-D Printer Gantry for Predictive Control: *Maharshi Arindom Sharma*[1]; Albert Patterson[1]; [1]Texas A&M University

This paper addresses the dynamic modelling of an FFF 3-D printer gantry (2-D) to reduce manufacturing defects from extruder carriage error. Physical examples of vibration errors are presented with observations about the machine-related causes of these errors. A six-dimensional non-linear dynamic model of the printer gantry was derived using Newton-Euler method. The Lagrangian dynamic model was derived to get additional insight on energy transfer aspects and model validation. A state-space model of the full system was developed for positioning and control. A detailed case-study of an example printer was completed in Matlab-Simulink to demonstrate the system model with comparisons from the analytical model and some physical characterization on a printer. Finally, a few examples of passive control designs were illustrated for predictive control. It was concluded that dynamics-based predictive control is a promising, realistic, and practical approach to controlling the dynamic error and dimensional error commonly seen with FFF machines.

Modeling: Machine Learning, Data Driven, Digital Twins

Monday PM — Room: 415 AB
August 14, 2023 — Location: Hilton Austin

Session Chair: Dave Rosen, Agency for Science, Technology and Research

1:30 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.

1:50 PM
High Fidelity Model of Directed Energy Deposition: Laser-Powder-Melt Pool Interaction and Effect of Laser Beam Profile on Solidification Microstructure: *Saad Khairallah*[1]; Eric Chin[1]; Michael Juhasz[1]; Aurelien Perron[1]; Scott Mccall[1]; Joseph Mckeown[1]; [1]Lawrence Livermore National Laboratory

A multiphysics model was developed to reproduce the laser directed energy deposition process to a high-fidelity. This includes resolving the laser-powder-melt pool interactions (powder impingement and incorporation into melt pool, hydrodynamics flow condition and laser absorption inefficiencies) as well as the resulting solidification microstructure. This micrometer scale digital twin captured the details of a grain refinement mechanism caused by high powder flow rate. Furthermore, it was used to explore how laser beam shaping could impact the microstructure. Using a ring laser beam profile instead of the standard Gaussian laser profile, the model predicted a decrease in the thermal gradient which in turn can increase propensity for more desirable equiaxed grains. This work was performed under the auspices of the U.S. Department of Energy (DOE), by Lawrence Livermore National Laboratory (LLNL) under Contract No. DE-AC52-07NA27344. Funding: Laboratory directed research and development project 22-SI-007. IM release LLNL-JRNL-844475.

2:10 PM
Thermal Monitoring and Cure Process Modelling of Dual-wavelength VPP Printing: *Heyang Zhang*[1]; Yue Zhang[1]; Xiayun Zhao[1]; [1]University of Pittsburgh

Dual-wavelength vat photopolymerization (VPP) is an emerging multi-material additive manufacturing (AM) technology in which liquid photopolymers are selectively cured by two individually controlled light beams that have disparate wavelengths. In this work, ultraviolet and visible light beams are delivered through digital light processing (DLP) using digital micromirror devices. A model multi-material system that comprises epoxy and acrylate curing components is used. As the heat generated differs between epoxy and acrylic curing reactions, a thermal model with binary heat sources is created using in-situ thermal monitoring, ex-situ photo differential scanning calorimetry, and inverse heat conduction (IHCP) optimization methods to estimate the exothermic rate, time-resolved thermal profile, and degree of curing during the dual-wavelength VPP. This work will develop a framework of integrating in-situ thermal monitoring, physics simulation, and data-driven modeling to identify and quantify different reactions occurring during multi-wavelength multi-material VPP processes.

2:30 PM
Layer-wise Prediction of Microstructural Evolution in Laser Powder Bed Fusion Additive Manufacturing using Physics-based Machine Learning: *Alexander Riensche*[1]; Ajay Krishnan[2]; Benjamin Bevans[1]; Grant King[3]; Kevin Cole[3]; Prahalada Rao[1]; [1]Virginia Tech; [2]Edison Welding Institute; [3]University of Nebraska-Lincoln

In this work we developed a framework to predict microstructure formation in the laser powder bed fusion (LPBF) of Inconel 718 parts. The microstructure is predicted as a function of sub-surface cooling rate estimated from a rapid part-level computational thermal model within elementary machine learning models. In this work, the microstructure evolved is quantified layer-by-layer in terms of three aspects: meltpool depth, grain size (primary dendritic arm spacing), and microhardness. The approach predicts the microstructure evolved with statistical fidelity exceeding 85% (R2). This is substantial improvement over existing microstructure prediction which are only able to predict the microstructure of a small region (~1 mm3) and not of the entire part.

2:50 PM
Toward Post-superficial Temperature Monitoring During Additive Manufacturing through Data-driven Inpainting: *Jiangce Chen*[1]; Mikhail Khrenov[1]; Jiayi Jin[2]; Sneha Narra[1]; Chris McComb[1]; [1]Carnegie Mellon University; [2]Tsinghua University

Understanding the temperature history of a built part during additive manufacturing (AM) is critical for studying the relationship between process parameters and product quality as temperature plays determinant role in melt pool dimensions, defect formation, and microstructure evolution. Unfortunately, the current thermal sensors used to monitor the AM process cannot provide a complete temperature distribution, which restricts the ability to study this relationship. In this paper, we propose a data-driven inpainting machine learning (ML) model that restores the temperature of the entire built part from incomplete temperature data captured by thermal sensors. We generate a dataset of temperature histories for parts with various geometries using a finite element model calibrated using experimental data. Our experiments demonstrate that the inpainting ML model accurately predicts both simulation and experimental data. This ML model has the potential to establish digital twins for AM-built parts, enabling efficient process optimization.

3:10 PM Break

3:40 PM
Modeling and Simulation of Vat Photopolymerization Additive Manufacturing: A Review: *Yousra Bensouda*[1]; Heyang Zhang[1]; Yue Zhang[1]; Xiayun Zhao[1]; [1]University of Pittsburgh

Vat photopolymerization (VPP) additive manufacturing (AM) has gained a lot of popularity across many industries, with various applications in biomedical engineering and electronics. This work aims to present a comprehensive review of existing work on model and simulation of conventional VPP processes and identify the critical gaps to improve the model prediction accuracy. Further, we propose a framework of developing comprehensive VPP processes via combining multiscale multi-physics modeling and simulation with machine learning to achieve surrogate modeling of VPP for compute efficiency and thus real-time process control. Moreover, we discuss the unique challenges in modeling and simulation of some emerging VPP processes such as two-wavelength VPP and possible physics-based data-driven methods by extending the methods that are aimed for improving traditional single-wavelength VPP. Keywords: Photopolymerization, additive manufacturing, modeling and simulation, multimaterial, multiphysics, machine learning

4:00 PM
Multi-scale Modeling of Thermal/reisidual Stress in Additive Manufacturing Across Grain- , track- and Part-scales: *Wentao Yan*[1]; [1]National University of Singapore

To obtain comprehensive understanding and accurate prediction of thermal/residual stress, we have developed multi-scale models. In the grain-scale model using the crystal plasticity finite element method, the grain structure evolutions are implemented from phase field simulation to resolve the interactions of different grains. With the temperature profiles from meso-scale thermal-fluid flow model, both the thermal deformation during heating and redistribution of the plastic deformation during cooling are simulated. In the track-scale model, besides the temperature profiles, the realistic geometry including rough surfaces and internal voids is implemented from the meso-scale thermal-fluid flow model, to reproduce the thermal stress concentrations and explain the cracking phenomenon. The part-scale model incorporates the track-scale thermal stress results to ensure acceptable computation burden and good accuracy. Moreover, to reduce the computational cost, we develop a physically-informed data-driven prognostic model of temperature, with a training database of only ~40 high-fidelity simulation cases under different manufacturing parameters.

4:20 PM
Powder Bed Fusion Surrogate Models via Convolutional Neural Networks: *David Rosen*[1]; John Ong[2]; U-Xuan Tan[2]; Qing Tan[2]; Umesh Kizhakkinan[2]; Huy Do[2]; Clive Ford[1]; [1]Agency for Science, Technology and Research; [2]Singapore University of Technology and Design

To support the design of structural metal parts for demanding applications, accurate predictions of part properties are needed, which high fidelity simulations can provide. However, metal powder bed fusion (PBF) simulations are far too computationally demanding, due to their very complex physical phenomena, for use in design optimization that can require dozens or hundreds of iterations. Rather, we are developing surrogate models of PBF process simulation results based on 3D convolutional neural network (CNN) technology. These CNN surrogate models compute part properties at high resolution in much less than one second. In this presentation, we summarize PBF process simulations and detail the CNN surrogate models developed for residual stress, deformation, and mechanical property distribution predictions of part designs. Examples of metal part fabrication results are compared with simulation and surrogate model predictions. Application of the surrogate models in part design optimization is illustrated.

4:40 PM
Predicting Temperature Field for Metal Additive Manufacturing using PINN: *Bohan Peng*[1]; Ajit Panesar[1]; [1]Imperial College London

Performing thermomechanical simulation for selective laser melting is a non-trivial and critical task for printability simulation. In addition to the numerical methods, attempts of using a physics-informed neural network (PINN) have shown promise in predicting the temperature fields. In this work, a PINN is constructed with the physics of only homogeneous heat transfer but augmented with data points from a heterogeneous condition with phase change occurring (i.e. from metal power to solid metal). It demonstrates the capability of adopting a PINN (even based on a simple and imperfect physical model) to account for real and more complex phenomena, paving the way for more complex and faster printability simulation for SLM as supplemented by PINN.

Modeling: Uncertainty and Thermomechanical

Monday PM
August 14, 2023

Room: 416 AB
Location: Hilton Austin

Session Chair: Guha Manogharan, Pennsylvania State University

1:30 PM
Uncertainty Quantification in Laser Powder Bed Fusion from Mesoscale to Part Scale: *Daniel Moser*[1]; Nicole Aragon[1]; Helen Cleaves[1]; Michael Heiden[1]; Jeffrey Horner[1]; Kyle Johnson[1]; Mario Martinez[1]; Aashique Rezwan[1]; Theron Rodgers[1]; David Saiz[1]; Michael Stender[1]; [1]Sandia National Laboratories

Laser powder bed fusion (LPBF) is an inherently multiscale process with detailed physics at the powder particle scale impacting part scale behavior. Quantifying uncertainties in LPBF process models is an important step in building model credibility so results can be used to support decision-making, particularly for qualification. However, applying uncertainty quantification to the multiscale physics models needed to simulate the LPBF process is challenging as bridging length scales introduces model form uncertainty that is difficult to represent. The work investigates techniques for quantifying uncertainties between powder scale and part scale LPBF models in order to make credible predictions with uncertainty of the outcomes of the LPBF process, particularly part distortion and microstructural features. Predictions are compared with experimental results to assess the performance of the developed techniques.This work was supported by the LDRD program at SNL, managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

1:50 PM
Evaluating Residual Heat-driven Melt Pool Variation through GPU-based Thermal Process Simulation: *David Anderson*[1]; Haolin Zhang[1]; Shawn Hinnebusch[1]; Xiayun Zhao[1]; Albert To[1]; [1]University of Pittsburgh

Despite well-studied process parameters, melt pool variation due to residual heat accumulation has remained a potential source of porosity and spattering defects. However, at the part-scale, traditional finite element methods require extremely fine meshes relative to the part scale to accurately resolve melt pool dimensions, resulting in long processing times and high memory requirements. To resolve this, a matrix-free finite element model has been developed, implementing adaptive remeshing and GPU-based parallelization to improve processing times. The model has been calibrated against optical microscopy data to improve the implementation of a Goldak heat source model, and compared against in-situ monitoring data to validate simulated results. This model enables investigation into melt pool variations at the part scale due to residual heating effects from previous layers, part geometry, and hatching patterns, to better understand and predict transitions from conduction to keyhole regimes.

2:10 PM
Modeling Morphological Development of Ti-6Al-4V for Cyclic Thermal Histories in Laser Powder-bed Fusion: *Evan Adcock*[1]; Anthony Rollett[1]; [1]Carnegie Mellon University

Laser powder-bed fusion (LPBF) introduces rapid temperature changes and cyclic thermal histories impacted by printing parameters and part geometry. This research aim is to develop a model that can efficiently compute predicted morphological outcomes of Ti-6Al-4V from LPBF temperature histories. Baseline microstructure results have been analyzed in an "inverted pyramid" part that was developed to generate variability in thermal history throughout the build. The geometry induced elevated preheat temperatures in subsequent layers which result in different cooling rates and thermal cycling. More data for validation will be gathered in future builds from process monitoring with a controlled stage preheat. Simultaneously a thermal simulation has been performed to provide thermal history input to the microstructure model. Comparison of the thermal histories with observed α morphology suggests the model can be simplified to predict microstructure based on the cooling rate after the last peak above the temperature of α dissolution.

2:30 PM
Residual Stress Estimation in a Complex Additively Manufactured Component with an Internal State Variable Material Model: *David Failla*[1]; Matthew Dantin[2]; Chuyen Nguyen[1]; Matthew Priddy[1]; [1]Mississippi State University; [2]Naval Surface Warfare Center

Internal state variable models are well suited to predict the effects of an evolving microstructure as a result of the additive manufacturing (AM) process in components with complex features. As AM becomes more utilized, accurate methods for predicting residual strains grow in need. To this end, the evolving microstructural model of inelasticity (EMMI) is adapted to modeling these residual strains due to its ability to capture the evolution of rate- and temperature-dependent hardening and softening as a result of the rapid thermal cycling present in AM processes. The current effort contrasts the efficacy of using EMMI with an elastic-perfectly plastic material model to predict the residual strains for an IN718 component produced via laser powder bed fusion. Both constitutive models are used within a thermo-mechanical finite element framework and are validated by published neutron diffraction measurements to demonstrate the need for high-fidelity models to predict residual strains in complex components.

2:50 PM
Multi-load Support Optimization for Minimizing Part Deformation in LPBF: *Subodh Subedi*[1]; Dan Thoma[1]; Krishnan Suresh[1]; [1]University of Wisconsin Madison

Support structures act as primary conduits for heat flow in laser powder bed fusion (LPBF). Truss-type supports have proven to be a good choice for LPBF because of no metal powder entrapment and ease of removal. In a typical build process, these supports experience time-varying thermal and structural loads. We propose a multi-load strategy for optimizing truss-type support structures for minimizing part deformation. Equivalent static loads (ESLs) are computed using the inherent strains induced at each layer of deposition. These ESLs are applied as multi-loads to optimize the cross-section area by minimizing the compliance of the truss-type supports. The results demonstrate a reduction in part and support deformation when the optimized supports are used instead of un-optimized ones.

3:10 PM Break

3:40 PM
Process Modeling of Multi-material Laser Powder Bed Fusion: *Jacklyn Griffis*[1]; Kazi Shahed[1]; Chinedum Okwudire[2]; Guha Manogharan[1]; [1]Pennsylvania State University; [2]University of Michigan

Thermomechanical simulation of the laser powder bed fusion process has been a valuable tool to help researchers and practitioners across the AM production cycle. For instance: Design for AM (DfAM), material development, process mapping, prediction, and support generations, among others. In this study, multi-material laser powder bed fusion (MM-LPBF), specifically of 904LSS and CuSn10 are examined through process simulation and non-destructive techniques to determine the impact of component orientation on defect mitigation. It is determined that material orientation along the build direction is a large contributor in as-build defects. Introductory MM-LPBF simulation is established to better understand the capabilities of current LPBF simulation tools in accurately predicting and mitigating the new challenges of MM-LPBF simulation.

4:00 PM
Generation and Simulation of Layer Wait Time to Prevent Overheating: *Zack Francis*[1]; [1]Ansys

Control over thermal conditions during additive manufacturing is key to producing reliable parts consistently. Overheating during the build process leads to keyholing and increased variability and uncertainty in downstream outcomes involving part quality. One of the simplest methods to gain control over the thermal conditions through a part is to implement additional wait time between layers to allow the part to cool to a consistent temperature. This can be accomplished through "ghost parts" or other means of manipulating the scan time. Simulation can be a powerful tool by enabling users to determine the appropriate cooling time to reach a target temperature as well as simulate the effects of such a wait time to ensure that parts are reaching acceptable temperatures for the process parameters. This work will demonstrate how simulation can be used to simulate thermal conditions during a build as well as generate solutions to prevent overheating.

4:20 PM
Towards Large-scale Grain Growth Modeling in Powder Bed Fusion: *Michael Paleos*[1]; Albert To[1]; [1]University of Pittsburgh

Grain growth models in the context of additive manufacturing are dealing with both the inherent complexity of the process and the computational expense of thermal process simulations. Cellular automata models have been successful in approximating the true physics of melt pool solidification, but they are typically confined to relatively small spatial domains. Building on recent advances in powder bed fusion process and microstructure modeling, we propose an integration framework based on several computational schemes that can lead to accurate simulations on unprecedented scales. For that purpose, we leverage and properly combine both the recently developed matrix-free FEM-based PAMSIM process simulator and the open-source ExaCA software. Our work centers around efficiently capturing information about several thermal signatures that would then guide grain growth in a decoupled manner. This framework would enable the computational study of microstructure (and property) heterogeneity and of the effect of unconventional scanning strategies.

Materials: Polymer AM Processes

Monday PM — Room: 417 AB
August 14, 2023 — Location: Hilton Austin

Session Chair: Jackson Bryant, Virginia Tech

1:30 PM
Investigation of Crack Formation Process during Low Temperature Laser Sintering of PEEK by Observing Melt and Solidification Behavior: *Takashi Kigure*[1]; Yuki Yamauchi[1]; Toshiki Niino[2]; [1]Tokyo Metropolitan Industrial Tech Rsch Inst; [2]Institute of Industrial Science, University of Tokyo

In a previous study, PEEK was successfully laser sintered at a mild powder bed preheating temperature below the recrystallization point with in-process part warpage suppressed by fixing the parts to a rigid base plate instead of using "process window," but serious surface finish degradation and large crack formation were observed. In this study, a video camera observation of the melting and solidification processes is performed to investigates formation process of such rough surfaces and cracks, with the aim of improving the part quality out of "low-temperature process," which does not preheat the powder bed above recrystallization temperature. The results reveals that volume changes during melting and solidification play an important role in the generation of rough surfaces and the cracks.

1:50 PM
Investigation of the Processability of Polyether Block Amide in High Speed Sintering: *Marco Wimmer*[1]; Jan Kemnitzer[2]; Johann Schorzmann[1]; Frank Döpper[1]; David Förster[1]; [1]Universität Bayreuth; [2]Fraunhofer IPA

The High Speed Sintering (HSS) process ranks among the Powder Bed Fusion processes of polymers (PBF-P) of Additive Manufacturing (AM). Its scalability, constant layer time and high quality of complex parts compared to other AM processes are some of the characteristics of the HSS showing its potential for series production for small to medium series. Most of the conducted investigations for the PBF-P processes were conducted using commercially available materials Polyamide 12 (PA12), Polyamide 6 (PA6), Thermoplastic polyurethane (TPU), Polypropylene (PP) and Polybutylene terephthalate (PBT). This work reports from the processing of Polyether block amide (PEBA) in HSS. As a block-copolymer on amide basis, PEBA shows higher performance compared to other block-copolymers like TPU: The high elastic properties, low density and high service temperature make PEBA an ideal material for the use in the athletic footwear and outdoor industry. Until now, no research was conducted using PEBA powder in HSS.

2:10 PM
Photothermal Bleaching of Nickel Dithiolene for Bright Multi-colored 3D Printed Parts : *Paul Olubummo*[1]; Aja Hartman[1]; [1]HP Labs

HP's Multi Jet Fusion is a powder bed fusion 3D printing technology that utilizes a carbon-based radiation absorber 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. However, there are many applications that require variable color, including prosthetics, medical models, and indicators, among others. To create white, bright colored, and translucent 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 turns colorless after harvesting irradiation energy during the MJF 3D printing process and provide a bright colored part when working with other color agents.

2:30 PM
Powder Bed Fusion of Polypropylene-ethylene Co-polymers: *Jackson Bryant*[1]; Michelle Pomatto[1]; Robert Moore[1]; Michael Bortner[1]; Christopher Williams[1]; [1]Virginia Tech

Polypropylene has proven challenging to process in powder bed fusion (PBF) technologies. This work uses flash DSC to demonstrate how the crystallization kinetics in polypropylene-ethylene copolymers slow down with increasing ethylene content. Slower crystallization kinetics enable more time for the coalescence of polymer particles such that the mechanical properties frequently expected from polypropylenes – impact resistance, flexibility – improve. However, the addition of the ethylene copolymer results in a much smaller processing window due to widening of the melting endotherm. A series of PP-PE copolymers with 1 – 5 wt% ethylene content were compared to a PP homopolymer samples. It was possible to process all samples and the higher ethylene content samples resulted in higher extensions at break. However, the broader melt endotherm narrowed the usable bed temperature for copolymer samples, which frequently resulted in problems during powder recoating at higher z-heights and much longer layer times.

2:50 PM
Powder Bed Fusion of Ultra-high Molecular Weight Polyethylene via Novel Scan Strategy and Post-process: *Jackson Bryant*[1]; Michael Bortner[1]; Christopher Williams[1]; [1]Virginia Tech

Ultra-high molecular weight polyethylene (UHMWPE) is a polymer known for its especially high wear properties. Currently, there is no successful method for printing UHMWPE components with mechanical properties sufficient for end-use applications. When irradiated by the laser during powder bed fusion (PBF), UHMWPE undergoes melt explosion, which makes the powder expand and causes recoating failure. Furthermore, the melt viscosity of UHMWPE prevents the powder particles from coalescing and densifying. In this work we employ a novel scan strategy with large hatch spacing to minimize layer growth in the z-direction and enables multilayer UHMWPE prints. Printed parts are then post-processed under pressure above melting temp to further coalesce the powder. Due to UHMWPE's high melt viscosity, part shape is retained durig postprocessing without distortion. This approach is validated on a 3000 kDA UHWMPE powder, and resulted in complex printed parts with ultimate tensile strength 2 > MPa.

3:10 PM Break

3:40 PM
Stimuli Driven Morphing of Printed Liquid Crystal Elastomers: *Caitlyn Krikorian*[1]; Michael Ford[1]; Dominique Porcincula[1]; Rodrigo Telles-Arriaga[2]; Yuchen Wang[3]; Bryan Moran[1]; Julie Mancini[1]; Elaine Lee[1]; Jennifer Lewis[2]; Shu Yang[3]; [1]Lawrence Livermore National Laboratory; [2]Harvard University; [3]University of Pennsylvania

Responsive feedstocks for additive manufacturing have opened a new regime of material design, where printed materials can morph into programmed architectures with exposure from a specific stimulus. Shape memory polymers have shown success in printability and in programmability with heating and mechanical force but is generally limited in a one-way shape morphing. Liquid crystal elastomers (LCEs) have more recently been developed for additive manufacturing where programming can be instated during the printing of complex shapes and shape morphing can occur reversibly and repeatably over many cycles of stimuli exposure. Here, we report custom LCE direct ink write feedstocks that can be programmed during printing and reprogrammed with localized light and reversibly locking stimuli to induce novel behaviors like locomotion and reversibly locking stiffness change.

4:00 PM
Structural Stability During Thermal Post-curing of Direct Ink Write Thermoset Composites: *Stian Romberg*[1]; Anthony Kotula[1]; [1]National Institute of Standards and Technology

Thermoset composites are excellent candidates for direct ink writing because they shear thin during extrusion but retain their shape once deposited via a yield stress. However, thermal post-curing is often required to solidify these materials, which can destabilize printed parts. To understand instability during post-curing, we utilize rheo-Raman spectroscopy to simultaneously measure rheological properties and extent of reaction (i.e., conversion) at different temperatures. Although elevated temperatures accelerate the curing process, they decrease the yield stress before crosslinking solidifies the material, explaining why collapse occurs during thermal post-curing. On the other hand, curing at lower temperatures reduces instability at the cost of processing speed. The simultaneous Raman-based conversion measurements are used to determine when temperature can be increased without risking structural collapse. The results enable the design of a curing schedule that avoids instability, but still quickly drives the reaction towards full conversion.

4:20 PM
Ultrasonic Non-destructive Characterization of Anisotropic Additively Manufactured Polymers: *Akash Nivarthi*[1]; Michael Haberman[1]; Christina Naify[1]; [1]Applied Research Laboratories, The University of Texas at Austin

Ultrasonic nondestructive testing can be used to infer the print settings of additively manufactured (AM) polymers to macroscopic elastic properties. We present a comparison of measurements of angle- and frequency-dependent ultrasonic transmission through AM plates in water tank to model predictions that consider infill properties. The experiment employs a point source ultrasonic source and a synthetic linear array to measure the transmission coefficient of fused deposition-modeled polylactic (PLA) acid plates over various frequencies and incident angles. Measurements are compared to predictions from a finite element (FE) model of the effective stiffness based on assumed infill geometry and PLA material properties paired with a reflection-transmission model for anisotropic elastic plates submerged in a fluid. Minimizing the difference between measured and modeled transmission coefficients by varying FE model inputs provides an improved understanding of the effects of the print settings on the as-built mechanical properties for 3D-printed materials.

4:40 PM
Magnetic Characterization of 3D Printed High-performance Polyamide Magnetic Composite: *Oluwasola Arigbabowo*[1]; Yash Tate[2]; Wilhelmus Geerts[1]; [1]Texas State University; [2]James Bowie High School

Polyamide 4.6 is classified as a high-temperature thermoplastic because of its service temperatures of up to 175°C, bringing them close to high-temperature plastics like PPS or PEEK. Due to its high-temperature capability and price/performance ratio, Polyamide 4.6 is considered viable in developing high-performance bonded magnets by serving as a binder/matrix to magnetic powders/fillers to form multifunctional magneto polymeric composites that offer superior properties to conventional materials. The thermal integrity of the polyamide 4.6 matrix would lock the orientation of the magnetic particles in place by limiting the sporadic motion that could arise due to heat which causes misalignment of the magnetic domains and a decrease in magnetism. Strontium ferrite magnetic powders were compounded with polyamide 4.6 using a co-rotating twin screw extruder. Thermal, mechanical, and magnetic characterization was performed on 3D printed samples using Simultaneous Differential Thermogravimetry, MTS Servo hydraulic test system, and Vibrating Sample Magnetometer, respectively.This work was supported in part by NSF through DMR- MRI Grant under awards 2216440 and in part by DOD instrumentation grant (78810-W911NF-21-1-0253).

Modeling: CAD, Scan Patterns, Contouring, Slicing I

Monday PM — Room: Salon A
August 14, 2023 — Location: Hilton Austin

Session Chair: Nicholas Meisel, Pennsylvania State University

1:30 PM
Single Path Generation for Closed Contours via Graph Theory and Topological Hierarchy: *Michael Borish*[1]; Alex Roschli[1]; Charles Wade[2]; Brian Post[1]; Liam White[1]; Cameron Adkins[1]; [1]Oak Ridge National Laboratory; [2]University of Colorado Boulder

Slicing converts a 3D object into a set of 2D polygons that are filled with multiple path types. These paths involve travels where the extruder of the machine must stop building, lift, travel to the next path, lower, and resume construction. Travels are considered wasted time as construction of the object is not occurring. Further, the start/stop point, called a seam, causes both reduced aesthetic and weaker material properties. To address these issues, an algorithmic approach was developed to compute a continuous single path from closed contours. The algorithm utilizes graph theory and a topological hierarchy to produce a single path for an individual layer. This approach can be combined with spiralization techniques to compute a single path for entire objects. The resulting objects can be constructed quicker and have improved material properties as verified via tensile testing.

1:50 PM
Path Planning for Non-Planar Robotic Additive Manufacturing: Michael Geuy[1]; Jay Martin[1]; Timothy Simpson[1]; *Nicholas Meisel*[1]; [1]Pennsylvania State University

As material extrusion additive manufacturing continues to mature, there is increasing need for an extrusion path planning (“slicing”) method that takes advantage of the capabilities of many-degree-of-freedom systems like those used in Robotic Material Extrusion (RoMEX). In this paper, key principles from planar, multi-planar, active-Z, and conical slicing techniques including variable layer thickness, nozzle angle control, and arbitrary layer shape have been integrated into a novel strategy. Specifically, 3D surfaces are used as the basis of non-planar layer generation without the need to decompose the object into regions. This surface is used as a layer parting line and is stacked along a single axis to produce non-planar layers that leverage the kinematics of a RoMEX system. This approach is capable of quickly producing parts with complex geometries, quality surface finish, and improved mechanical properties by leveraging layer shapes that are self-supporting with high interlayer bonding.

2:10 PM
Novel Concepts to Integrate Dense and Sparse Infill Regions in Material Extrusion AM Parts: *Logan Hutton*[1]; Joseph Bartolai[1]; [1]Pennsylvania State University

Modern toolpath generation softwares, or “slicers,” allow for multiple regions within a Material Extrusion Additive Manufacturing produced part to be assigned different processing parameters, including infill density. Contemporary slicers develop these different infill regions independently, leading to discontinuities in the toolpaths at the region’s boundaries. This work investigates the effect these discontinuities have on part strength, and tests a variety of novel approaches to connect infill regions in a continuous manner to improve part properties. Mechanical properties of parts built by toolpaths generated using Ultimaker Cura and Slic3r are compared to those of parts built using the novel build strategies presented in this work. The continuous and sequential novel build strategies presented in this work show statistically significant mechanical property increases.

2:30 PM
Modeling and Correcting Illumination Inhomogeneity over Multiple DLP Illumination Intensities for Better Fabrication Accuracy: *Saroj Subedi*[1]; Henry Oliver Ware[1]; [1]North Carolina State University

Within custom Digital Light Processing (DLP) systems, various small issues either in the optical assembly or with the DMD can lead to non-uniform illumination at the curing interface. This inhomogeneity leads to inaccurate dimensions of fabricated features over the full print area. To remedy this in our system, we have explored the relationship between LED output illumination, broke the illuminated area into a regional mesh, measured the light intensity and grayscale values over the mesh to obtain region-specific grayscale mask adjustments for illumination-leveling. This process involves producing grayscale mask by quantifiably balancing the light intensity values over build area and thus obtaining more uniform printed features. We compared the dimensional accuracy of features printed using full white pixel value images for 250µm features and those obtained using illumination-leveling grayscale processed images. Our results demonstrate the effectiveness of our method to obtain dimensionally accurate features, thanks to the achieved uniform illumination.

2:50 PM
Voxel-free Radon Transform for Improving Surface Quality in Computed Axial Lithography: *Jennings Ye*[1]; Yaxuan Sun[1]; Hayden Taylor[1]; [1]University of California, Berkeley

Computed axial lithography (CAL) is an additive manufacturing process that projects light patterns into a rotating volume of photosensitive resin to print the desired object through the superposition of light energy. Currently, these projection patterns are generated by voxelizing a target object from an STL or another 3D file format and applying the Radon transform followed by an iterative optimization process. This work proposes a voxel-free method to transform the target object into the projection space. Here, the Radon transform is performed directly on a non-voxelized target object by finding intersections between incident rays of light and triangles of the original STL surface mesh. Initial simulated results show a more consistent dose gradient at the edges of the printed object, indicating improved surface quality and smoothness. Additionally, simulations show a more uniform object interior using the proposed method.

3:10 PM Break

3:40 PM
Level Set Grids for Hybrid Manufacturing: *Liam White*[1]; Bryan Quaife[2]; Michael Borish[1]; Cameron Adkins[1]; Alex Roschli[1]; [1]Oak Ridge National Laboratory; [2]Florida State University

To ensure optimal part quality, accurate model representation is essential. Traditional additive manufacturing methods utilize STL meshes, which often lack precise curvature information. This information is critical for hybrid or post-manufacturing subtractive processes. When alternative mesh representations are unavailable, such as in object repair scenarios, curvature information must be derived from a triangulated mesh. To address this, an innovative approach employing sparse volumetric grids to voxelize a mesh's volume was developed. Utilizing this representation, calculating the gradient of the level set function within the grid yields accurate curvature information where none previously existed. Leveraging this information, surface pathing can adhere to the object's curvature enabling accurate pathing for hybrid and subtractive processes. Furthermore, a partial object representation is possible that facilitates synchronous additive and subtractive processes.

4:00 PM
Computer Modelling of Residual Stress Development During Selective Laser Melting of 17-4 PH Stainless Steel and Experimental Validation via Contour Method: *Yusuf Polat*[1]; [1]Yunus Emre

SLM is a promising manufacturing technique which has been developed significantly in recent years. Additive nature of the process enables manufacturing of complex geometries with minimum wastage. However, residual stress formation during building of SLM process has negative effects on mechanical properties and service life such as cracking or reducing fatigue life therefore strong understanding of residual stress is required in order to mitigate the detrimental effects. At this point numerical simulation techniques offer an applicable practice for the understanding, prediction and mitigation of residual stress problem. In this study, macro scale mechanical and thermomechanical simulations are practiced with Simufact Additive software for SLM processing. Experimental validations are practiced with contour method. Experimental and computational efforts yielded highly consistent results. The applicability of the Contour method in bulk SLM parts has been confirmed and the simufact additive software has been verified to give reliable results as a simulation tool.

4:20 PM
Developing an Application Programming Interface for Hypocycloid-based Inner and Outer Gears of Progressive Cavity Pumps in Advanced Extrusion Applications: *Yusuf Furkan Ugurluoglu*[1]; Piergiorgio Gentile[1]; Ana Ferreira-Duarte[1]; Javier Munguia[2]; [1]Newcastle Unviersity; [2]Warwick University

Additive manufacturing has transformed the field of bioprinting, enabling the creation of complex tissue structures with exceptional precision. Recently, there has been interest in using progressive cavity pumps (PCPs) as an advanced extrusion method in bioprinting applications. Some studies have shown that PCPs offer better accuracy than the traditional method of syringe-based extruders. However, PCPs were originally designed for the adhesive dispensing industry and need to be adapted for bioprinting applications. To address this issue, an application programming interface (API) was developed in this study to model the intricate components of the inner and outer gears of PCPs. A hypocycloid-based API was presented in this research with the adjustable parameters of the number of outer gear lobes, generator radius, tolerance, cusp diameter, number of gear turns and gear height. This API will be a valuable tool for supporting PCP research in academia and designing PCPs for specific bioprinting applications.

Applications: Lattices and Cellular I

Monday PM — Room: Salon B
August 14, 2023 — Location: Hilton Austin

Session Chair: Denis Cormier, Rochester Institute of Technology

1:30 PM
Directional Dependence of Heat Treated IN718 Gyroid TPMS Lattices Fabricated by Selective Laser Melting: *Bharath Bhushan Ravichander*[1]; Shweta Hanmant Jagdale[1]; Golden Kumar[1]; [1]University of Texas at Dallas

Inconel 718, a nickel-based superalloy that has impressive mechanical properties such as tensile and impact resistance, as well as resistance to corrosion at high temperatures. One commonly used cellular structure is the gyroid lattice, which is a type of triply periodic minimal surface that can be customized to create lightweight materials with adequate strength and low stiffness. Selective laser melting (SLM) process has made it possible to manufacture these complex structures, and the properties can be controlled by adjusting various process parameters such as scan strategy, laser power, and build direction. However, the impact of build orientation, heat treatment on the properties of the lattices has not been extensively studied. This work focused on fabricating gyroid lattice structures at different build orientations, and the deformation behavior, and specific energy absorption of the structures were studied through quasi-static compression tests after sandblasting and heat treatment.

1:50 PM
Towards the Limits in Copper Lattice Production via Fiber Laser Powder Bed Fusion: *Michel Smet*[1]; Louca Goossens[1]; Sam Buls[1]; Brecht Van Hooreweder[1]; [1]KUleuven

Laser Powder Bed Fusion of copper paves the way for innovation in thermal systems and heat transfer devices. Recent simulations have shown that by interchanging typical fin designs with more complex structures an overall improvement in pressure drop and weight can be obtained while offering the same thermal performance. Small-scale lattice structures are especially of interest for AM as they form a reliable, periodic infill. However, until now, their study has been mainly theoretical. To analyse these structures, an in-house built LPBF machine at KU Leuven has been successfully used to manufacture pure copper parts. Measurements showed a conductivity exceeding 100%IACS, which is the result of low contamination and low porosity in the as-built material. In this work, the parameter optimisation for thin-walled lattices is discussed in combination with an in-depth review of the thermal properties of the resulting structures.

2:10 PM

Additive Manufacturing of Hybrid Sandwich Sheets by Laser Powder Bed Fusion of Metals: *Sebastian Platt*[1]; Norman Schnell[1]; Gerd Witt[1]; Stefan Kleszczynski[1]; [1]Universität Duisburg-Essen

Within lightweight applications, powder bed fusion of metals using a laser beam (PBF-LB/M) allows the realization of filigree structures at minimal use of material. A traditional element of lightweight construction are sandwich sheets. These lightweight elements contain both geometrically simple (cover sheets) and geometrically complex (core structure) elements. Conventional Manufacturing of core structures is limited in terms of complexity. Additive Manufacturing of sheets has disadvantages in terms of economic efficiency. A combination of additive and conventional manufacturing processes is proposed to eliminate both disadvantages. Therefore, this publication presents a fabrication route to produce hybrid sandwich sheets. The hybrid sandwich sheets are manufactured using a rolled cover sheet (<1 mm) as base plate and additive manufactured core structures including an upper cover sheet. A developed mounting system for implementation in the PBF-LB/M process is presented and evaluated concerning manufacturing criteria such as process stability and dimensional accuracy of the built-up components.

2:30 PM

Fabrication of Supportless Lattice Structures Using Burst Mode Drop-on-Demand Liquid Metal Jetting: *Paarth Mehta*[1]; Usama Rifat[1]; Denis Cormier[1]; [1]Rochester Institute of Technology

The properties of topology optimized metallic additively manufactured (AM) lattice structures have been extensively studied to date. One challenge with using powder bed or vat AM processes, however, is that lattice structures that are enclosed by solid skin surfaces cannot be produced, as it would be impossible to remove trapped powder or liquid. This talk will present advances in support-free fabrication of engineered lattice structures using drop-on-demand liquid metal jetting (LMJ). This approach enables fabrication of completely enclosed lightweight lattice structures. A burst-mode jetting strategy is introduced in which multiple droplets are ejected at high frequency followed by a brief delay to allow the droplet cluster to partially solidify. By varying the drops/burst, frequency, stepover distance, and pause time, struts can be produced with a range of diameters and inclination angles without supports. Experimental results, including characterization of density, microstructure, and mechanical properties will be presented.

2:50 PM

Towards Experimental Process Parameter Development for Ti-6Al-4V TPMS Lattice Structures with Application to Small Scale Dental Implants using Micrographs: *Anne Jahn*[1]; Hui Li[1]; Nicole Emminghaus[1]; Tatjana Melnyk[1]; Jörg Hermsdorf[1]; Stefan Kaierle[1]; [1]Laser Zentrum Hannover e.V.

Ti-6Al-4V is a widely used alloy in implant engineering and lattice structures are applied to locally align the stiffness of the implant to the one of bone. Triply periodic minimal surface (TPMS) structures are popular due to their curved surface and good manufacturability. Tests with different TPMS structures showed a strong interaction between design factors and manufacturing parameters resulting in the need for individual parameter development. However, to the best of our knowledge, the most work in the current literature focusses on mechanical and biological examinations of TPMS structures manufactured with standard parameters. As process parameters influence the structural properties, the optimum values for further analysis may not have been investigated (e.g., their influence on microstructure and mechanical properties). In this work, a design of experiments approach is used to develop process parameters. As computer tomography scans are resource intensive for large scale parameter development, a sparser approach using micrographs for porosity analysis is introduced. Small structures with unit cell size as small as 1.0 mm are fabricated on an industrial machine. Our initial studies show that the design factor pore size is negligible in comparison to wall thickness when optimizing internal porosity.

3:10 PM Break

3:40 PM

Bio-inspired AM Structure using Co-extruded Continuous Carbon Fibre Reinforcement: *Piyapat Jameekornkul*[1]; Ajit Panesar[1]; [1]Imperial College London

The bio-inspired cellular structure has been recognised as an innovative approach in Additive Manufacturing (AM) for lightweight and energy absorption applications. In this study, the objective is to investigate the use of continuous carbon fibre AM (C-FRAM) co-extrusion technology to manufacture the lattice structures inspired by the helicoidal structure and Kersling folding mechanism. The corresponding mechanical properties of the bio-inspired reinforced honeycomb and squared-grid 2D structure will be reported under quasi-static compression test. The interlayer pitch angle of reinforced path will be varied from 0 to 90° which the adhesive area will be observed. The Kersling pattern is introduced to further the understanding of the continuity of reinforcement stacking. This work aims to demonstrate the applicability of C-FRAM to enhance the potential design for high-strength and light-weighting infills.

4:00 PM

Development of Artificially Tuned Microstructure using Interpenetrating Lattices Fabricated by Laser Powder Bed Fusion: Shweta Hanmant Jagdale[1]; *Bharath Bhushan Ravichander*[1]; Golden Kumar[1]; [1]University of Texas at Dallas

The continuous demand of better performance of product has led designers to design parts innovatively. Laser powder bed fusion (LPBF), a well-adapted additive manufacturing processes which fabricates near net shaped fully dense complex metal parts with accuracy. Quality of the printed parts depends on the laser process parameters such as, laser power, hatch distance, scan speed, scan strategy and layer thickness. Mechanical properties have strong dependence on the laser process parameters and direction of the build. LPBF part exhibits anisotropic microstructure and mechanical properties. In this work, LPBF is used to fabricate interpenetrating lattices with enhanced mechanical and functional properties than the non-reinforced metallic alloys by using innovative interpenetrating TPMS lattices. Interpenetrating lattices are fabricated with LPBF process by selecting two different sets of laser process parameters which shows different microstructural and mechanical properties. Relative density analysis, micrographic analysis and Vickers microhardness analysis is carried out in the printed composites.

4:20 PM

Additively Manufactured Molds for Large Gyroid Structures Cast from Concrete: *Joseph Bartolai*[1]; Simon Miller[1]; Michael Yukish[1]; [1]Pennsylvania State University

This work presents the design of additively manufactured molds use to cast large gyroid patterns from concrete. Key contributions are the method of segmentation of the continuous gyroid structure into castable subsections that tile the space in 3D via "rods" with hexagonal symmetry, and the design of the separable multi-section molds that accommodate the gyroid's complex geometry. These mold sections are additively manufactured using Thermoplastic Polyurethane (TPU) so that when combined they form all of the complex features of the gyroid shape. Upwards of 60 segments make up the more complex molds, with the TPU's flexibility critical to mold release. The TPU has proven surprisingly robust, with over 60 casts from the same sections. The paper presents the design history for the molds, the current final design, and recommendations for expanding to other Equation-Based Lattice shapes.

Binder Jet AM: Systems, Modeling, and Simulation

Monday PM
August 14, 2023

Room: 602
Location: Hilton Austin

Session Chairs: Nathan Crane, Brigham Young University; Chris Williams, Virginia Tech

1:30 PM
A Data-driven Reverse Shape Compensation Method to Reduce Large Deformation in Binder Jet Parts: *Basil Paudel*[1]; Hao Deng[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 machine learning 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 dimension reduction 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.

1:50 PM
Does Finer Powder Get Deposited First in Powder Bed? – A Comparative Study using Simulation and Experimental Techniques: Willem Groeneveld-Meijer[1]; *Kazi Shahed*[1]; Matthew Lear[1]; Jeremy Schreiber[1]; Chinedum Okwudire[2]; Guhaprasanna Manogharan[1]; [1]Pennsylvania State University; [2]University of Michigan

Characteristics of an additively manufactured part through powder bed processes (e.g., binder jetting, powder bed fusion) are well influenced by the attributes of the powder and powder spreading process. Previous studies compared the printed part from unimodal powder and bimodal powder and showed that bimodal powder improves part density. But the distribution of the bimodal powders and their effect on the powder bed and subsequently on printed part has not been fully understood. In this study, unimodal and bimodal powder were used to experimentally study the powder particle distribution and the powder bed surface contour in the powder bed generated from the spreading process.

2:10 PM
Feasibility of Non-destructive Measurement of Powder Bed Density and Thermal Properties Using Flash Thermography: *Shu Wang*[1]; Nathan Crane[1]; [1]Brigham Young University

In powder bed additive manufacturing, consistent powder bed density is critical to ensure high-quality, repeatable results. Additionally, the thermal properties of the powder bed may be important to the process results. A non-contact method that measures the density of the powder bed without direct contact can ensure that the density of the powder remains high during the manufacturing process and improve the print quality of the final product. However, there is a lack of effective methods for in-situ monitoring of these key parameters. This paper considers the use of flash thermography (FT) for this purpose. In FT, a flash of light rapidly heats a sample surface and the resulting temperature response measured by an IR camera. This paper will report on the application of this technique to rolled powder beds in binder jetting and discuss the criteria under which the thermal conductivity, thermal diffusivity, and packing density can be found.

2:30 PM
Insights from High-speed Synchrotron X-ray Imaging of Binder-powder Interaction in Binder Jet Printing: Jacob Lawrence[1]; Colton Inkley[1]; Christina Thorley[1]; Kamel Fezzaa[2]; Samuel Clark[2]; *Nathan Crane*[1]; [1]Brigham Young University; [2]Argonne National Laboratory

Binder Jetting (BJ) is an additive manufacturing process that enables production of complex, high-resolution parts. Understanding binder-powder interaction during the printing process is essential to optimizing the printing process, selecting appropriate process parameters, and improving final part quality. This work presents findings from high-speed imaging of the BJ process using synchrotron X-rays. During testing, five key print process parameters were adjusted including: powder material, droplet spacing, line number, powder bed packing fraction, and powder bed moisture levels. High-speed X-ray footage acquired during printing captures powder ejection above the powder bed surface and powder disturbance below the powder bed surface due to droplet impact. Interaction behavior extracted from the X-ray footage was used to help identify significant print process parameters that impact the observed binder-powder interactions and help develop understanding of the underlying physical mechanisms of binder-powder interaction during the BJ printing process.

2:50 PM
Numerical Investigation of the Spreading and Dynamic Flow Behavior of Poorly Sorted Sand Particles during Binder Jet Additive Manufacturing: *Ibrahim Al Qabani*[1]; Karin Goldberg[1]; Julio Silva[2]; Genevieve Baudoin[1]; Raphael Quirino[2]; Scott Thompson[1]; Drew Snelling[2]; [1]Kansas State University; [2]Georgia Southern University

During binder jet additive manufacturing, the consistency and homogeneity of the employed powder plays a crucial role in the final density and dimensional accuracy of the green part. In this study, Discrete Element Method (DEM) simulations were performed to investigate the influence of roller spreading input parameters (roller speed, traverse speed, geometry, etc.) on the dynamic flow of powder during layer spreading. Via DEM, we examine how different material properties, such as powder morphology, size distribution, surface morphology, and composition, affect the homogeneity and porosity of the spread layer, yielding accurate predictions for the green part's density and dimensional accuracy. Today, most research focuses on simulating the dispersion of high-quality, evenly sized, clean foundry sand. This study focuses on the flow behavior of locally-sourced, raw earth sand during the spreading process to support remote additive manufacturing.

3:10 PM Break

3:40 PM
Providing Anti-counterfeiting Security in Binder Jetting through Tailored Porosity Signatures: Kazi Rahman[1]; *Christopher Williams*[1]; [1]Virginia Tech

The democratization of digital product design, reverse engineering, and distributed fabrication enabled by additive manufacturing (AM) has made it highly vulnerable to counterfeiting. While some anti-counterfeiting measures have been proposed for a number of AM processes, none have been presented for metal binder jetting (BJT). In this work, the authors propose a novel method of anti-counterfeiting security for printed BJT parts wherein tailored regions of porosity are created within a part through selective patterning of binder. Upon sintering, the selectively applied binder forms stochastic regions of porosity within the part volume, which can be identified through non-destructive evaluation. Using this strategy, porous regions can be selectively generated and used as a unique part identifier. Cross-sectional microscopy and x-ray computed tomography verify successful creation of the embedded porous tag, and elucidate the technique's achievable feature resolution within the volume of a printed copper specimen.

4:00 PM
Robotic Automation for Depowdering in Binder Jet Additive Manufacturing: *Sarita Sepulveda*[1]; Sun Yi[1]; Amy Elliott[2]; [1]North Carolina A&T State University; [2]Oak Ridge National Laboratory

Binder Jet is an additive manufacturing technology (BJAM) that uses powdered materials, such as powdered ceramics and metals, and a binder agent. After a part is printed and cured, it becomes a green part, which would go through a process of depowdering, sintering or infiltration, before a product is finished. Currently, manual depowdering of BJAM parts is cost intensive and prohibits the technology's wide-spread use in industry. Automation of binder jet depowdering consists of controlling a robot to grip and lift a part. In this study, we present an automation of binder jet depowdering with a robotic gripper of a novel design. Findings in literatures will be discussed about gouging limit, which would enable the robotic gripper to find the part without inflicting damage. These new findings from the experimental and theoretical findings will be done to understand the force constraints to aid in the automation process for BJAM.

4:20 PM
X-ray Computed Tomographic Study of Density Gradients within Binder Jet Printed H-13 Components: *Dustin Gilmer*[1]; Peeyush Nandwana[2]; Curtis Frederick[3]; [1]UT-Oak Ridge Innovation Institute; [2]Oak Ridge National Laboratory; [3]Carl Zeiss Industrial Metrology

Binder Jet Additive Manufacturing (BJAM) is a versatile powder bed technique that uses a binder deposited using ink jetting to form complex components. BJAM is well suited for manufacturing at scale due to its high production rates and high resolution. It has been reported that binder-particle interactions during the deposition process result in powder particles being ejected from the powder bed. However, the impact of these ejected particles on the bulk part is not well understood. We use X-Ray computed tomography to study this in H13 steel parts as printed in the green state, as well as how it subsequently impacts the debinding and sintering behavior of the material. This information will be critical for understanding the evolution of defects in sintered components and their role on material properties as well as provide insights towards sintering kinetics of H13.

Wire-fed DED: Geometric and Path Optimization

Monday PM — Room: 615 AB
August 14, 2023 — Location: Hilton Austin

Session Chair: To Be Announced

1:30 PM
A Spherical Test Artifact to Evaluate Three-dimensional Form Accuracy for Wire Arc Additive Manufacturing: *Sakufu Ko*[1]; Takayuki Sagawa[1]; Yuka Yamagata[1]; Shigeru Aoki[1]; Takeyuki Abe[2]; [1]Institute of Technology, Shimizu Corporation; [2]Saitama University

Additive manufacturing, including the wire arc additive manufacturing (WAAM), is gradually gaining attraction and providing benefits in the aerospace and construction industries. In both industries, large-scale manufacturing capability and quality consistency of manufactured 3D parts are crucial. As part of quality evaluation, test artifacts for the geometric capability assessment are specified in ISO/ASTM52902-2019(E). On the other hand, the test artifact for curved wall is left undefined. This paper proposes a sphere shape wall as a representative of three-dimensional shapes that are supportless and feature large overhangs, for testing the geometric capability. A universally applicable mechanical configuration and deposition strategy for depositing large scale curved walls, is proposed. A quality evaluation process for the sphere deposition was also described and experimentally demonstrated.Keywords: Wire arc additive manufacturing (WAAM), Test artifact, Inspection method, Sphere.

1:50 PM
Hybrid Metal Manufacturing of Large Freeform Geometries: *Bradley Jared*[1]; Ross Zameroski[1]; Joshua Penney[1]; Aaron Cornelius[1]; Tiffany Quigley[1]; Devon Goodspeed[1]; Eduardo Miramontes[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 as schedules for large parts, i.e one to two feet cube and larger, are routinely defined in months and years; introducing unacceptable risk and cost for most products. On-going work is addressing these challenges using a large-scale hybrid metal manufacturing system which combines multi-material metal inert gas (MIG) deposition, robotic fringe projection scanning metrology, part handling and five-axis machining. The integration, capabilities, challenges and operation of the hybrid process flow will be demonstrated through the processing of multiple structures. Geometric control of final part shape is a research focus as work is addressing multiple elements associated with part distortion due to internal stresses, complex geometry path planning, real-time process monitoring and control, and finish machining.

2:10 PM
In-situ Geometric Characterization via Embedded 3D Scanning and Implicit Modeling: *Tadeusz Kosmal*[1]; Samuel Pratt[1]; Christopher Williams[1]; [1]Virginia Tech DREAMS Lab

Additive Manufacturing's (AM) layer-wise construction is susceptible to intrinsic process variation and fabrication errors. In-situ monitoring techniques have been proposed to detect errors, but limit inspection to a localized deposition or final part state, failing to capture how formed layers change throughout processing. Embedded 3D scanning can address these limitations, yet conducting layer-wise evaluation of high-resolution scans presents significant data management and optical challenges for compatibility with a production environment. We present a novel methodology to rapidly capture and characterize error using a digitally integrated Structured Light Scanning (SLS) system and Signed Distance Function (SDF) approach. Using this approach, in-situ deviation of printed structures can be analyzed within seconds over relatively large areas (250 cm2) at a high spatial resolution (0.3mm). The proposed method is process agnostic and is validated in a layer-by-layer analysis of hybrid Wire-Arc AM processing.

2:30 PM
Multi-bead and Multilayer Printing Geometric Defect Identification Using Single Bead Trained Models: *Nowrin Akter Surovi*[1]; Gim Song Soh[1]; [1]SUTD

In Wire Arc Additive Manufacturing (WAAM), a geometric defect is a defect that creates voids in the final printed part due to incomplete fusion between two non-uniform overlapping bead segments. Such a defect poses the onset of a severe problem during multi-bead prints. In our earlier work, a methodology has been developed to construct machine learning (ML)-based models to identify geometrically defective bead segments using acoustic signals. In this paper, we investigate the performance of these single-bead segments trained defect detection model scalability for identifying voids during multi-bead prints. A comparative study of the performance of a variety of ML models is explored based on Inconel 718 material block printing. The results show that the single bead segments-based defect identification model can identify defective and non-defective segments in multi-bead printing effectively.

2:50 PM
The WAAM Number: A Dimensionless Number for Predicting Wire Arc Additive Manufacturing Bead Geometry: *Bemnet Molla*[1]; Christopher Williams[1]; [1]Virginia Polytechnic Institute and State University

Wire Arc Additive Manufacturing (WAAM) has many process parameters with complex interactions in the formed melt pool that affect its ability to obtain consistent depositions. This work introduces a novel dimensionless number, the WAAM Number, that characterizes bead geometry by encapsulating multiple process parameters, including ac voltage, arc current, mass flow rate, travel speed, and intrinsic material properties into a single independent variable. This WAAM number presents a generalizable representation for predicting bead geometry, width, and height, and can be applied across multiple materials, welding modes, and WAAM systems. The utility of the WAAM number for characterizing and predicting bead geometry is validated through analysis of single-track depositions of Al5Mg and mild steel using two short circuit welding modes on two separate WAAM machines.

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Dynamic Start Point Modification in Closed Contour Toolpaths for A Multi-robot Wire-fed Ded System: Christopher Masuo[1]; Andrzej Nycz[1]; Peter Wang[1]; Joshua Vaughan[1]; Alex Walters[1]; William Carter[1]; Luke Meyer[1]; *Riley Wallace*[1]; Jonathan Paul[2]; Jason Flamm[2]; [1]Oak Ridge National Laboratory; [2]Lincoln Electric

A multi-robot wire-fed directed energy deposition (DED) system can exceed the production rate seen in a standard single wire-fed DED robot. Multiple robots can deposit material simultaneously and collaborate with each other to effectively produce a large-scaled additive part. This, however, introduces the challenge of proper toolpath assignment for each robot to ensure that the robots would not interfere with each other. Pre-processed toolpaths, dynamic toolpath assignment, and region-of-interest (ROI) can eliminate this challenge. However, this can still result in long idle times for most robots solely based on their toolpath start points. In this work, a dynamic start point modification algorithm was developed to improve the utilization of the robots. A case-study was conducted to compare production efficiencies with and without using this algorithm.

4:00 PM
Optimal Planning and Control for Microhardness Demonstrated in Thin-walled Steel Parts Made via Wire Arc Additive Manufacturing: *Mikhail Khrenov*[1]; P. Chris Pistorius[1]; Sneha Narra[1]; [1]Carnegie Mellon University

High power inputs and changing geometries induce highly transient and dynamic thermal histories over parts produced by Wire Arc Additive Manufacturing (WAAM). This, in turn, results in uncontrolled in-situ heat treatments and varying properties, such as differences in hardness, across the final part. This work proposes and demonstrates the application of optimal planning techniques, utilized to great effect in fields such as aerospace engineering and robotics, to control these outcomes. The dynamics of temperature and hardness evolution are modeled using physics-based techniques informed by in-situ data. These are used to solve a joint trajectory optimization problem for desired outcomes. State estimation and feedback control is employed to track the resultant solutions during fabrication. Control of hardness by the combined system is experimentally verified. This work has the potential to advance the use of WAAM for mission-critical parts, while also laying the foundation for similar developments in large-scale additive manufacturing broadly.

4:20 PM
Exploring the Effects of Oscillatory Deposition Paths on Wire Arc Additive Manufacturing (WAAM) of Al5Mg: *Bemnet Molla*[1]; Christopher Williams[1]; [1]Virginia Polytechnic Institute and State University

Wire Arc Additive Manufacturing (WAAM) is a relatively low-cost, high throughput additive manufacturing technology that uses arc welding to deposit metal beads in a layer-wise fashion to produce large-scale, complex parts. WAAM toolpathing strategies commonly feature overlapping linear deposition paths, which result in a high number of thermal cycles and internal porosity defects that can reduce final part performance. Traditional arc welding for joining utilizes oscillatory paths to increase productivity and improve mechanical performance of the weld. The use of oscillatory paths in WAAM is underreported in literature; no prior work has explored how oscillatory path geometries effect part quality. This work analyzes the effects of a variety of single-track and multi-layer oscillatory path geometries on the bead geometry, energy input, mechanical performance, and grain structure of Al5Mg produced by WAAM.

5:00 PM
Resource Efficiency of the Robot-based Hybrid Additive Manufacturing Chain: *Cornelia Tepper*[1]; Jonathan Utsch[1]; Jonas Zarges[1]; Matthias Weigold[1]; [1]PTW TU Darmstadt

Combining additive and subtractive metal processes to a hybrid additive manufacturing chain not only enables the production of parts with application-oriented design but also leads to increased resource efficiency especially when combined in an industrial robotic cell. Compared to parts manufactured through subtractive processes from full material the hybrid additive manufacturing chain is considered to be resource efficient due to reduced material consumption. However, the energy consumption of the hybrid additive processes is considered higher because of the use of laser for the additive process. It is assumed that the decreased material consumption outweighs the higher energy consumption regarding the resource efficiency but until now it is not investigated. Therefore, in this paper the resource consumption of the robot-based hybrid additive manufacturing chain including the wire based direct energy deposition process and the milling process is analysed through measurements during experiments and compared to subtractive processes using the carbon footprint.

4:40 PM
GKN Aerospace Deposition of a Laser Wire DED 2.5m Titanium Aerostructure Demonstrator: *Leon Hill*[1]; Jeremy Tylenda[1]; [1]GKN Aerospace

GKN Aerospace in collaboration with Northrop Grumman deposited a large scale titanium aerostructure representative of a primary air vehicle structure. The titanium laser wire directed energy deposition (DED) preform measures approximately 8 feet (2.5 meters) and is the largest additively manufactured aerostructure produced by GKN Aerospace to date. The demonstration article utilized novel toolpathing techniques to manage thermal history and distortion concurrently. In addition, the deposition was completed first-time-right using GKN's proprietary adaptive closed loop control systems to maintain build quality throughout the deposition. This milestone demonstrates cutting-edge manufacturing technology to build large primary aerostructures for future air vehicles. This presentation will shares the whole story of adaptive closed loop control, toolpath, and thermal history management to deposit a preform of this monumental scale. Link to public press release:https://www.gknaerospace.com/en/newsroom/news-releases/2022/gkn-aerospace---northrop-grumman-collaboration-achieves-additive-manufacturing-milestone/

Materials: Ceramics, Glasses

Monday PM
August 14, 2023

Room: 616 AB
Location: Hilton Austin

Session Chair: Desi Kovar, University of Texas at Austin

1:30 PM
Effect of Binder Content on Ceramic Paste for Additively Manufactured Parts via Ceramic On-demand Extrusion: *Abid Hasan Rafi*[1]; Marharyta Lakusta[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 an extrusion-based process to produce highly dense sintered ceramic components from aqueous pastes with low binder content. This study examines the effects of the binder amount addition and dispersion on paste printability and residual porosity of sintered parts. An aqueous paste made of ZrB_2/SiC (70/30 by volume) powder with ~45 vol% solid loadings and methylcellulose binder is used. When the binder is directly added as a powder to the paste, a notable reduction in the relative density of post-processed samples is observed when the binder amount increases. This work also reports the effects of alternative homogenization procedures, including using filtered dissolved binder solutions on sintered density and pore size distributions. This study is significant for extrusion-based ceramic additive manufacturing, particularly fabricating parts with microscale features such as microchannels in compact heat exchangers, where the frequency of large pores (relative to feature sizes) must be controlled.

1:50 PM

Origami Robocasting of High-density Ceramic Structures with Slurry-based Inks: *Kayla Blalack*[1]; Lilly Balderson[1]; Tao Sun[1]; [1]University of Virginia

Robocasting of ceramics offers a simple process, yet has limitations in geometrical freedom due to the need for external supports. Previous research explored the potential of origami robocasting, which involves printing a flexible green body that can be reshaped. However, the ink formulations used before mainly rely on preceramic polymers with good elasticity, which are often limited to silicon-based ceramics and may result in large shrinkage and/or low density in the final part. In our work, a slurry-based ink with flexible polymeric binders and a wide range of material options is used for robocasting origami-folded parts. Our results show that sintered alumina produced with this ink exhibited high density and moderate shrinkage while retaining manipulated shapes without any adverse deformation. The use of this ink for ceramic origami opens up many possibilities for creating advanced geometries in various applications, including aerospace components, biomedical scaffolds, and precise catalyst supports.

2:10 PM

The Impact of the Printed Part Size on the Shrinkage and Density in Binder Jetting Additive Manufacturing of Ceramics Powder: Suleiman Obeidat[1]; *Chris Smith*[1]; Junkun Ma[1]; [1]Sam Houston State University

Ceramics particles are used to investigate the effect of the part size on the shrinkage percentage, the apparent, and the relative density of the printed part in the Binder Jetting 3D printing process. Four different shapes including cylinders, rectangular blocks, cones, and spheres of different sizes are printed at 100 %, 75%, and 50 % core saturation limits at 0 and 10 second delay using a binder jetting 3D printer. After the fabrication process, the parts are de-powdered and dried, the binder is cured at 35°C for 6- 8 hours then the parts are sintered. The shrinkage percentage, the apparent, and the relative density of the printed parts are calculated after the sintering process for each geometry at two different sizes. We use ceramics powder of 50% crystalline silica (quartz), 25% kaolinite, and 25% of potassium feldspar. The binder consists of 8% Diethylene glycol, 2% Surfactant, and 90 % water.

2:30 PM

Detecting the Onset of Flash Event in Selective Laser Flash Sintering: *Joey Zamora*[1]; Joseph Beaman[1]; Desiderio Kovar[1]; [1]University of Texas at Austin

Selective laser flash sintering (SLFS) is proposed as a method for directly additively manufacturing ceramics without the need for a polymeric binder. Understanding the onset of the flash event is essential in SLFS because it is necessary to interrupt the flash before thermal runaway occurs. Successful development of a non-contact method for detecting the onset of SLFS is needed to allow a repeatable additive manufacturing process. A high-speed camera is considered in this research for its ultra-high frame rate and ability to measure temperatures from light emission from the sample surface. Experiments are conducted using alternating electric fields in the SLFS system to determine the sensitivity of this technique for detecting the onset of SLFS.

2:50 PM

Open Loop Control of Selective Laser Flash Sintering of Ceramics: *David Khanan*[1]; Desiderio Kovar[1]; Joseph Beaman[1]; [1]University of Texas at Austin

A goal for selective laser flash sintering (SLFS) is the production of ceramic parts with complex shapes and without the addition of a polymer binder to the powder. During the SLFS process, an electric field is passed through the build surface while a laser scans at high speeds to heat the powder. The combination of the large electric field and localized heating from the laser activates carriers in the scanned region and this produces current flow. The resulting Joule heating produces further heating of the powder that bonds the particles at the contact points. A variety of tests were conducted with a DC electric field that was actively controlled to determine conditions that produce localized flash sintering. The current across the sample was measured in situ and variable electric fields and laser parameters were tested. Experiments were also conducted with an AC electric field.

3:10 PM Break

3:40 PM

An Ultrasonic Technique to Determine the Onset of Localized Sintering in Additive Manufactured Ceramics: *Christina Nissen*[1]; Arturo Hernandez[1]; Joseph Beaman[1]; Desiderio Kovar[1]; [1]University of Texas at Austin

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. Excellent correlations were found on these monolithic samples between the Young's moduli determined using the ultrasonic method and established resonance method. We then test the methodology on model samples that have local regions of high density that are embedded in regions of lower density. These tests show that the laser ultrasonic technique can detect local partially sintered and sintered regions within regions of unsintered packed powder beds.

4:00 PM

Volumetric Additive Manufacturing of Glass: *Dominique Porcincula*[1]; Rebecca Walton[1]; Martin De Beer[1]; Johanna Schwartz[1]; Luke Myers[1]; Alyssa Troksa[1]; Drew Melchert[1]; Rebecca Dylla-Spears[1]; Maxim Shusteff[1]; [1]Lawrence Livermore National Laboratory

Volumetric Additive Manufacturing (VAM) is a novel photopolymer additive manufacturing technique that allows for the all-in-one fabrication of parts without the need for support material, in geometries not available in other AM techniques, and with smooth surfaces, which minimize the need for post-processing procedures, such as polishing. While previous work has successfully demonstrated fabrication of glass micro-optics using the VAM technique, limitations in resin formulation have prevented fabrication of parts with cross-sections larger than a few square millimeters. Here, we report on our progress in formulating a glass photopolymer resin that allows for fabrication of parts with cross-sections in the realm of square centimeters, in addition to our work in creating various glass resins with varying refractive indices.This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 within the LDRD 22-ERD-012. LLNL-ABS-847039.

4:20 PM

Manufacturability of Custom Shape-conforming Battery Components using VPP: *Bharat Yelamanchi*[1]; Sina Bakhtar Chavari[1]; Alexis Maurel[2]; Ana Martinez[2]; Cameroun Sherrard[3]; Eric MacDonald[2]; Pedro Cortes[1]; [1]Youngstown State University; [2]University of Texas at El Paso; [3]Marshall NASA

The rise of miniature electronics has spurred the need to develop custom power sources, especially batteries with microscale and aesthetic diversity. Tape casting, the conventional manufacturing method falls short as it can handle only large sizes and restricted form factors. This proves to be a serious constraint in the design of the end components that house such batteries especially when considering applications ranging from the handheld smart devices to NASA's human missions in space. This need is very efficiently catered for by the Vat photopolymerization (VPP). In this presentation, the manufacturability of metal collectors and electrodes using different materials and designs, their electrochemical performance and mechanical stability will be discussed. The challenges in process development and optimization of such electrodes and collectors including their metal-ceramic interface will also be discussed.

4:40 PM
Control of Track Morphology in Digital Glass Forming: Edward Kinzel[1]; *Nicholas Capps*[1]; Jonathan Goldstein[2]; Robert Landers[1]; [1]University of Notre Dame; [2]Air Force Research Laboratory

Digital Glass Forming involves locally heating a glass filament using a laser while it is continuously fed relative to the workpiece. This enables precise control of the viscosity of the molten region. The viscous melt pool is deformed by forces from the filament and workpiece. This paper investigates the relationships between the input parameters, laser power, feed rate, and scan speed, with the resulting track morphology. Tracks are used to build larger, more complex structures. By underfeeding the filament relative to the table scan speed, the glass is locally drawn to produce tracks with significantly smaller cross-sectional areas than the feedstock material. This technique allows for the production of arbitrary geometries and surface features using a smaller equivalent diameter than the input feedstock. The paper explores the available process zone for this underfed deposition mode as well as the limitations of this method.

Materials: Metals-Mechanical Properties I

Monday PM — Room: Salon F
August 14, 2023 — Location: Hilton Austin

Session Chair: Joe Beaman, University of Texas at Austin

1:30 PM
Effect of Heat Treatment on the Microstructure and Mechanical Properties of Monel K500 Alloy Fabricated via L-PBF and LP-DED: Indrajit Nandi[1]; Seyed Ghiaasiaan[1]; *Nabeel Ahmad*[1]; Paul R. Gradl[2]; Shuai Shao[1]; Nima Shamsaei[1]; [1]Auburn University; [2]NASA

This study examines and compares the effects of different heat treatments on microstructure and mechanical properties of additively manufactured (AM) Monel K500 alloy fabricated using laser powder bed fusion (L-PBF) and laser direct energy deposition (LP-DED) technologies. The as-fabricated AM Monel K500 specimens displayed dendritic microstructure and elemental micro-segregation, due to high cooling rates induced during AM fabrication process, which differs significantly from its wrought counterparts. Applicability of standard heat treatments (HT) proposed in literature for wrought material was validated for the AM Monel K500 alloy using multi-step HT such as hot isostatic pressing, solution annealing, and different aging processes. The mechanical properties of test specimens were evaluated using uniaxial tensile and fatigue testing at room temperature. Microstructural evolution of the test specimens during HT was analyzed using scanning electron microscope. The mechanical properties of the L-PBF and LP-DED test specimens were discussed and compared in various heat treatment conditions.

1:50 PM
Effect of Post Thermal Processing Conditions on Physical and Mechanical Properties of LPBF Processed Inconel 718: *Swathi Vunnam*[1]; [1]AddUp Inc

Laser powder bed fusion (LPBF) processed material performance strongly depends on the post thermal processing conditions. This study investigates the material properties of Inconel 718 processed through a roller recoating process with fine powder having a median particle size D50 <11 µm in different post-thermal conditions. Three sets of specimens were printed using identical printing conditions and tested in as-built, stress-relieved, and solution-aged post thermal conditions. Average material density ≥ 99.95% and surface roughness Ra < 4 µm was achieved across the build platform in as-built condition. Homogenization coupled with double aging achieved superior mechanical properties with a significant increase in hardness and tensile strength. This study demonstrates that the combination of the roller spreading mechanism with fine powder can be utilized to produce high-quality parts by employing the appropriate post thermal processing.

2:10 PM
A Comparison of Microstructure and Mechanical Performance of Inconel 718 Manufactured via L-PBF, LP-DED, and WAAM Technologies: *Nabeel Ahmad*[1]; Alireza Bidar[1]; Reza Ghiaasiaan[1]; Paul Gradl[2]; Shuai Shao[1]; Nima Shamsaei[1]; [1]Auburn University; [2]National Aeronautics and Space Administration

The microstructure and mechanical properties of additively manufactured (AM) alloys can be significantly affected by variations in cooling rates, resulting from different process conditions across different additive manufacturing (AM) platforms. Therefore, it is crucial to understand the effect of manufacturing process on the microstructure and mechanical properties of AM Inconel 718. This study examines three AM processes: laser powder bed fusion, laser powder directed energy deposition, and wire arc additive manufacturing. Results show that fully heat treated laser powder bed fused (L-PBF) and wire arc additively manufactured (WAAM) Inconel 718 specimens exhibit higher strength compared to laser powder directed energy deposited (LP-DED) ones due to finer grain structure in L-PBF and retained dendritic microstructure in WAAM. The ductility in LP-DED Inconel 718 was slightly higher compared to WAAM and L-PBF due to relatively small carbide size, which causes stress concentration in a small material volume, leading to delayed fracture.

2:30 PM
Microstructure and Mechanical Properties of Additively Manufactured Haynes 282: A Comparative Analysis between L-PBF and LP-DED Technologies: *Nabeel Ahmad*[1]; Reza Ghiaasiaan[1]; Paul Gradl[2]; Shuai Shao[1]; Nima Shamsaei[1]; [1]Auburn University; [2]National Aeronautics and Space Administration

This study compares the microstructure and tensile properties of Haynes 282 fabricated using laser powder bed fusion and laser powder directed energy deposition. Both sets underwent stress-relieving, followed by hot isostatic pressing, and the standard double aging heat treatment. Tensile testing was conducted at room temperature on specimens fabricated with both technologies to evaluate and compare their tensile behaviors. Results show that the ultimate tensile and yield strengths of laser powder bed fused specimens were 18% and 57% higher, respectively than those of laser powder directed energy deposited ones, whereas the elongation to failure was similar in both. The difference in strengths is attributed to the differences in the size of γ' precipitates and grains, i.e., those in the LP-DED specimens being larger, whereas similar elongation to failure is attributed to the carbide debonding dominating the fracture mechanism in both batches.

2:50 PM
Mechanical Performance of LPBF Manufactured Haynes 282: *Nicholas Lamprinakos*[1]; Junwon Seo[1]; Anthony Rollett[1]; [1]Carnegie Mellon University

Haynes 282 is a nickel-based superalloy which excels in high temperature structural applications. While it has traditionally been used as a wrought product, its relatively high weldability makes it a good candidate for laser powder bed fusion (LPBF). But parts produced via LBPF often have significantly different microstructures, and thereby properties, compared to wrought parts. Furthermore, as a precipitation strengthened alloy, Haynes 282 generally requires heat treatment, which needs to be optimized for the printed material. In this study, Haynes 282 samples were printed with different printing parameters and orientations and were subject to varying post-printing heat treatments. The microstructures of the samples were observed before and after heat treatment to characterize grain structure, crystallographic texture, and precipitate structure. Hardness, tensile, and creep testing was performed to evaluate the effect of the processing conditions on the mechanical properties and to compare the properties to literature values for wrought Haynes 282.

3:10 PM Break

3:40 PM
Effect of Heat Treatments on the Tensile Properties of Additively Manufactured 15-5 PH Stainless Steel: *Rukesh Gusain*[1]; Paul Gradl[2]; Shuai Shao[1]; Nima Shamsaei[1]; [1]Auburn University; [2]NASA Marshall Space Flight Center

This study investigates the effect of post-manufacture heat treatments on the mechanical properties of 15-5 PH stainless steel (SS) fabricated by laser powder-directed energy deposition (LP-DED). Two different heat treatment procedures (CA-H900 and CA-H1150) were performed, and their influence on the microstructure was examined using the scanning electron microscope. Tensile tests were performed to evaluate the mechanical properties at cryogenic and room temperatures. The elongation at failure was significantly higher for specimens treated with CA-H1150 than those with CA-H900 at both testing temperatures. In contrast, the ultimate tensile and yield strengths of CA-H900 specimens were higher than CA-H1150 specimens. The fractography examinations reveal that the specimens treated with CA-H900 exhibited brittle behavior at cryogenic temperature.

4:00 PM
Johnson-Cook Failure Model for Additively Manufactured 304L Stainless Steel Parts: *Henry Haffner*[1]; Manoj Kumar Reddy Rangapuram[1]; Siva Sai Krishna Dasari[1]; Sriram Praneeth Isanaka[1]; K. Chandrashekhara[1]; Mario F. Buchely[1]; Joseph W. Newkirk[1]; [1]Missouri University of Science and Technology

Laser powder bed fusion (LPBF) process 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 damage initiation in the parts manufactured by LPBF process using 304L stainless steel powder, which is widely used in numerous applications. The tensile specimens were manufactured using 304LSS powder through LPBF. Tensile specimens with varying notches were tested to calibrate the parameters of the constitutive Johnson-Cook failure model. To obtain the strength parameters, the tensile tests were performed at different temperatures and strain-rates. The material model developed was used in numerical simulation of the tensile tests and compared with the experimental results.

4:20 PM
Process Sensitivity and Mechanical Properties of Blended AF-9628 Steel and Iron Powders Consolidated via Laser-directed Energy Deposition: *Jonathan Kelley*[1]; [1]Missouri University of Science and Technology

To ensure consistent quality of additively manufactured steel parts, it is advantageous to identify alloys which can routinely meet performance criteria while being robust to process changes. Toward this end, multiple steel compositions produced by blending AF-9628 steel with pure iron powders were deposited via laser-directed energy deposition (L-DED) and analyzed for process sensitivity and mechanical properties. Studied mixtures ranged from 100% to 10% AF-9628 by mass. Considering thermal features relevant to L-DED, JMatPro simulation software was used to roughly predict material properties, phase fractions, and sensitivity to cooling rate variations and tempering conditions. Test samples were deposited using a variety of parameter sets, and the sensitivity of as-built hardness to processing conditions was evaluated for each composition. Further investigation of tensile property sensitivity was conducted on a smaller set of select compositions, and results were compared to those of unmixed AF-9628.

4:40 PM
The Variation of Mechanical Properties of M300 Maraging Steel Manufactured with Varying Process Parameters in Laser Powder Bed Fusion: *Haley Petersen*[1]; Bradley Sampson[1]; David Failla[1]; Matthew Priddy[1]; Zackery McCleland[2]; [1]Mississippi State University; [2]US Army Engineer Research and Development Center

Laser powder bed fusion (L-PBF) is a type of additive manufacturing (AM) that uses layers of powdered metal and a laser to manufacture a part in a layer-by-layer fashion. L-PBF has the ability to use a variety of process parameters for production of fully dense parts with satisfactory mechanical properties. Maraging 300 steel (M300) is a material of interest due to its combined tensile strength and high strength-to-weight ratio. This study aims to determine optimal process parameters of M300 manufactured using L-PBF by comparing the parameters effects on the resulting mechanical properties. Specifically, the primary process parameters (e.g., laser power and scan speed) were varied based on literature review and the as-built properties (e.g., tensile strength, and hardness) and conditions (e.g., surface roughness and porosity) were explored through statistical means for determining an acceptable parameter range.

Composites

Monday PM — Room: Salon G
August 14, 2023 — Location: Hilton Austin

Session Chair: Xinyi Xiao, Miami University

1:30 PM
3D Metal Nanoparticle-polymer Composites: Strategies for Integrating Metal Nanoparticles with Two-photon Polymerization Process: *Jisun Im*[1]; Yaan Liu[2]; Qin Hu[3]; Gustavo Trindade[4]; Christopher Parmenter[1]; Michael Fay[1]; Yinfeng He[3]; Derek Irvine[3]; Christopher Tuck[3]; Ricky Wildman[3]; Richard Hague[3]; Lyudmila Turyanska[3]; [1]University of Nottingham; [2]University of Exeter; [3]Centre for Additive Manufacturing/University of Nottingham; [4]National Physical Laboratory

Integration of metal nanoparticles (MeNPs) into three-dimensional (3D) micro/nanoscale structures without disturbing the quality and resolution of two photon polymerization (2PP) processes has attracted considerable attention in various applications including nanophotonics, micro-electrochemical systems, microelectronics, and tissue engineering and drug delivery. Here we report three complementary strategies for integration of MeNPs with 2PP process: in-situ formation of MeNPs through a single-step photoreduction process, integration of pre-formed MeNPs into 2PP resin, and site-selective MeNPs decoration of 3D 2PP structures. We demonstrate successful fabrication of high-fidelity structures with incorporated MeNPs and provide detailed morphological and compositional analysis including advanced time-of-flight secondary ion mass spectrometry (Tof-SIMS) mapping results. These complementary strategies open up a broad range of prospective applications from metamaterials and nano/micro-photonics to optoelectronics and biomedicine.

1:50 PM
Cyber-informed Additively Manufactured Functionally Graded Materials and Structures: *Xinyi Xiao*[1]; [1]Miami University

Functionally Graded Materials and Structures (FGMS) are a class of materials with spatial variation in either form of volume or composition, contributing to corresponding property response changes in line with the volumetric/composition gradient. The multi-functional property of a component is tailed through the heterogeneous material allocation at a micro-mesoscale to meet an intended performance requirement. One of the main advantages that micro-mesoscale graded materials/structures gains can contribute to the smooth transition within the overall component property. The move towards graded material and structure design has been "brewing" for some time. By strategically controlling the composition and volumetric density of heterogeneous material deposition in a complex 3D distribution, AM provides huge design opportunities to push manufacturing towards FGMS development. This project aims to develop a novel holistic framework for comprehensively characterizing Functionally Graded Materials and Structures from design to property through intelligently searching and informing from a model-process-performance database.

2:10 PM

Engineering Hydrophobic Stainless Steel Nanocomposites: *Troy Ansell*[1]; Michael O'Donnell[1]; Justin Budan[1]; John McGuire[2]; Prajna Jalagam[3]; [1]Naval Postgraduate School; [2]Johns Hopkins University; [3]Brown University

316L stainless steel powder was milled with either carbon nanotubes (CNT) or graphene nanoplatelets (GNP) via high energy ball milling. The composite powders were then printed in simple square pieces or with a pillared surface geometry by selective laser melting. Contact angle measurements with the printed surface of both CNT and GNP composite square pieces revealed increasingly hydrophobic behavior. Low nanoparticle loading exhibited hydrophilic behavior but when CNTs exceeded 3 vol% and GNPs exceeded 2 vol%, contact angles of greater than 90 deg, i.e., hydrophobicity, was measured. When a water droplets were deposited on pillared samples, a wicking effect was observed where the surface would support a water droplet for up to tens of minutes before dropping to the substrate. Trends indicate that further increasing CNT concentration, adjusting laser energy density, and changing model specifications could lead to greater hydrophobic effects.

2:30 PM

Developing Additively Manufactured Iron Powder-filled PLA Composites: *Joji Jeevan Kumar Dasari*[1]; Orkhan Huseynov[1]; Ismail Fidan[1]; Mustafa Rajabali[1]; [1]Tennessee Technological University

The Low-Cost Metal Material Extrusion (LCMMEX) process has gained attention in recent years to produce metallic parts with complex designs. High Iron concentration composite materials have been extensively researched to improve their properties and functionality for advanced manufacturing applications. This study aims to develop knowledge blocks for producing Composite parts with high iron percentages and analyze their mechanical, magnetic, and thermal properties and their sintering behavior based on print parameters. A rectangular sample is manufactured using the Material Extrusion (MEX) process by varying layer height, infill density, and print speed. The results show that sintering significantly affects the change in surface roughness, weight, and dimensional accuracy of the printed parts. Furthermore, an increase in the infill percentage leads to a significant increase in magnetic flux. This research provides insights into the influence of print parameters and sintering on the properties of High-Iron filled composite parts, ideal for high-density applications.

2:50 PM

Additive Manufacturing of Polymer Composite Tooling: *Kazi Md Masum Billah*[1]; Mario Barron Gonzalez[1]; Ricardo Arechiga De La Rosa[1]; Youssef K Hamidi[1]; [1]University of Houston Clear Lake

Polymer composite materials are made by combining multiple materials to achieve improved properties including mechanical, electrical, and thermal compared to the constituents or parent materials. In the polymer-based composite manufacturing process chain, tooling is an integral component. Exploration of design freedom is paramount to add agility and complex shape composite manufacturing tools. This research uniquely proposed the methodology of composite tooling. We designed complex and nonplanner-shaped composite molds to fabricate fiber-reinforced composite parts. Material extrusion 3D printing technology was used to fabricate molds. The most commonly used thermoplastic ABS was used in a desktop-scale 3D printer to fabricate a variety of molds. After fabrication of the molds, surface finishing and resign infiltration was performed to make sure sealed tooling part manufacturing. The 3D printed mold was then used in composite layup applications when fiber-reinforced composites were manufactured.

3:10 PM Break

3:40 PM

Assessing the Impact of the Powder Production Method on Ceramic-filled Polyamide 613 Composites Made by Laser Sintering: *Ivo Kletetzka*[1]; Fabian Neitzel[1]; Hans-Joachim Schmid[1]; [1]Paderborn University (DMRC)

Polymer composites represent the industry standard in injection molding for the production of plastic components with increased requirements in terms of heat resistance and stiffness. In the field of laser sintering (LS), these materials are less common so far. In order to extend the available material variety for the LS process, ceramic-filled Polyamide 613 powders are produced and processed within the scope of this work. Here, the resulting properties from two different powder production methods are compared. One filled powder is produced by dry blending and the other powder with the same filler and filling ratio is produced by encapsulating the filler particles inside the polymer particles within the dissolution precipitation process. It was found, that encapsulating the filler particles can provide certain benefits for the processability, for example an improved powder flowability or better filler dispersion. However, encapsulating the filler also alters the thermal properties of the precipitated powder.

4:00 PM

Additive Manufacturing of Shape-conforming Battery Components from Lunar and Martian Soil: *Alexis Maurel*[1]; Ana C. Martinez[1]; Sina Bakhtar Chavari[2]; Bharat Yelamanchi[2]; Cameroun Sherrard[3]; Pedro Cortes[2]; Eric MacDonald[1]; [1]University of Texas at El Paso; [2]Youngstown State University; [3]NASA MSFC

Vat photopolymerization (VPP) 3D printing enables the manufacturing of customized and shape-conformable energy storage devices that can be used in various applications, including portable power devices, rovers, and drones, ultimately supporting NASA's human missions in space, on the Moon, and Mars. Sodium-ion batteries (SIBs) have emerged as a promising alternative to traditional lithium-ion batteries because the Lunar and Martian regolith contain more abundant SIB materials and precursors, making them a viable option for in-situ resource utilization. In this presentation, the development and VPP printing of TiO_2-based and hard carbon-based composite photocurable resins will be discussed. The impact of 3D printed negative electrode design and thermal post-processing on the final SIB electrochemical performance and mechanical integrity of the printed items will also be addressed.

4:20 PM

Advancing Sodium-ion Battery Technology for Both Terrestrial and Extraterrestrial Applications through 3D Printed Electrolytes: *Ana Martinez*[1]; Alexis Maurel[1]; Eva Schiaffino Bustamante[1]; Ana Aranzola[1]; Cameroun Sherrard[1]; Eric MacDonald[1]; [1]University of Texas at El Paso

With the growing demand for sustainable batteries that bear higher energy density than conventional lithium-ion batteries on Earth and on the space, sodium-ion batteries have emerged as the primary alternative due to the lower toxicity, wider sodium availability, and higher theoretical capacity. In this context, this project explores the 3D printing and testing of the electrolyte-separator component of a conventional sodium-ion battery, here referred to as gel or solid polymer electrolyte due to the use of a photocurable acrylate as polymer matrix. This work will show the optimization of printing parameters and utilization of various battery testing methods to validate the functioning of 3D printed electrolytes in real sodium-ion batteries. This research enhances the current knowledge regarding three-dimensional shape-conformable battery manufacturing, and complements our team's efforts to 3D print full batteries in the near future.

Process Development: Powder Bed Fusion Process Innovations

Tuesday AM Room: 404
August 15, 2023 Location: Hilton Austin

Session Chair: Venkatavaradan Sunderarajan, Georgia Institute of Technology

8:15 AM
Layer-wise Control Charts in Laser Powder Bed Fusion Metal Additive Manufacturing: *Venkatavaradan Sunderarajan*[1]; Suman Das[1]; [1]Georgia Institute of Technology

Implementing robust statistical process control will address many challenges that prevent widespread industrial adoption of Laser Powder Bed Fusion (LPBF) Metal Additive Manufacturing. Presently, vast amounts of heterogeneous data from multiple in-situ monitoring sensors capture process information in real-time across length and time scales. This work demonstrates an effective method to parse and analyze this data, extract valuable information, and apply multivariate statistics to develop control charts for monitoring the LPBF process. This will enable a direct approach to layer-wise monitoring of the build, to track and quantify process variations across builds on the same machine and also compare performance across machines. Post-build part characterization helps establish correlations between the part properties and process state measured in-situ. Appropriate process control measures and critical limits can then be implemented for each process variable (or any combination), commensurate with the tolerance in part property allowables depending on the end-use application.

8:35 AM
SmartScan Extension: Enhancing Temperature Uniformity in 3D Laser Powder Bed Fusion Additive Manufacturing for Reduced Part Defects and Distortions: *Chuan He*[1]; Nevzat Bugdayci[1]; Chinedum Okwudire[1]; [1]University of Michigan

Laser powder bed fusion (LPBF) additive manufacturing often faces part defects due to non-uniform temperature distribution during fabrication. To address this, the authors previously introduced SmartScan, an intelligent method utilizing modeling and optimization to generate scan sequences enhancing temperature uniformity. However, its application was limited to single layers. This work extends SmartScan to three-dimensional parts by modifying the thermal model and optimization objective. Through simulations and experimental fabrication of AISI 316L stainless steel parts, the study demonstrates that the proposed SmartScan approach substantially improves temperature uniformity, diminishes part distortion, and alleviates residual stress when compared to conventional heuristic sequences.

8:55 AM
Toward Voxel Level Control for Laser Powder Bed Fusion Additive Manufacturing Process: *Ho Yeung*[1]; Jorge Neira[1]; [1]National Institute of Standards and Technology

In the Laser Powder Bed Fusion (LPBF) additive manufacturing (AM) process, a high-speed scanning laser beam is employed to construct components by melting and fusing metal powder together. While AM is generally characterized as a layer-by-layer technique, LPBF actually builds parts on a voxel-by-voxel basis (utilizing a point laser heating source). As a result, managing the LPBF process at the voxel level – that is, focusing on individual 3D printing elements or volume pixels – will be highly beneficial. In this study, we will explore the laser control requirements necessary for achieving voxel-level precision in the LPBF process and demonstrate these concepts through experiments.

9:15 AM
Enabling Multi-material LPBF Printing via Electrostatic Powder Spreading of Patterned Powder Beds: *Eric Elton*[1]; Michael Troksa[1]; Ziheng Wu[1]; Gabe Guss[1]; [1]Lawrence Livermore National Laboratory

Laser powder bed fusion processes typically 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 use electrostatic powder spreading (ESPS) to deposit multiple metal powders on a single layer and build multi-material LPBF parts. ESPS uses the electric field between a powder reservoir and an electrode to move powder from the reservoir to the powder bed. By using an array of electrodes, powder can be selectively deposited in regions of the build area. We show that the applied voltage can be varied to affect the gradient between two materials, potentially leading to increased bonding between the materials. This suggests that ESPS can be used for multi-material LPBF parts with arbitrary 3-dimensional gradients.

9:35 AM
In-situ Reinforcement Processing for Laser Powder Bed Fused Ti64 Parts: *Aditya Krishna Ganesh Ram*[1]; Ahmet Tanrikulu[1]; Oscar Valdez Loya[1]; Paul Davidson[1]; Amirhesam Amerinatanzi[1]; [1]University of Texas at Arlington

The objective of this study was to investigate how the microstructure and mechanical properties of Ti-6Al-4V samples, fabricated using laser powder bed fusion (L-PBF), change when a predefined local double melting strategy is employed within each layer of the manufacturing process. The analysis primarily focused on evaluating microstructural aspects, defects, and grain size, along with the mechanical properties, specifically the Vickers hardness at various positions within the samples. The findings indicated that the integration of the predefined locally double melting scan in each layer had a significant influence on the microstructure, resulting in variations in grain size across different locations, as well as hardness values with variations of up to 10% across different areas. Moreover, these discoveries underscore the potential of employing the predefined locally double melting strategy in each layer to create fabricated components with distinctive behaviors, like composites, which could find applications in the aerospace industry.

9:55 AM Break

10:25 AM
Method to Balance Thermals for Multi-functional 3D MJF Printing: *Aja Hartman*[1]; Lihua Zhao[1]; [1]HP Labs

HP's Multi Jet Fusion (MJF) is a powder-based additive manufacturing technology that selectively melts polymer powder, in a layer-by-layer fashion to create 3D parts. There are several different voxel properties that can be modulated using MJF including multi-color, ductility, conductivity, among others. Creating mechanically uniform multi-material parts with varying voxel properties throughout is challenging due to the liquid creating a competing cooling and active absorbing components that effect the temperature of printed parts differently. Here, we balance fusibility by utilizing a thermal imaging and an agent loading sweep thermal profile characterization print for each individual agent. We then digitally control the agent loading based on this data set and dynamic thermal imaging to produce a uniform temperature profile. This ensures even fusing throughout multi-agent printed parts, shown by uniform weight measurements of multi-color cubes from average weight 1.4±0.2 g to 1.5±0.1 g.

10:45 AM
Parametric Study of Processing of Ti6Al4V with Multiple 450 nm Diode Lasers: *Halil Caglar*[1]; Anqi Liang[1]; Kamran Mumtaz[1]; [1]University of Sheffield

Diode Area Melting (DAM) presents an alternative approach to traditional Laser Powder Bed Fusion (LPBF) approaches, integrating multiple individually addressable low-power fibre-coupled diode lasers into a laser head, these traverse across a powder bed to melt powdered feedstock. DAM research to date has focused on using low-power 808nm lasers to process Ti6Al4V (Ti64) powder. This work focuses on using multiple short wavelength 450nm 3W lasers to process Ti64 feedstock. It was found that when processing Ti64, absorption was 11% higher using 450nm lasers when compared to using 808 nm lasers and 14% higher than 1064nm lasers. This work demonstrated the potential to use shorter wavelength lasers in DAM/LPBF for improved melting efficiency and also it aimed to examine the impact of 450nm diode lasers on Ti64 and generate a parameter map for this material.

11:05 AM
Use of a Vibrating Build Platform during Powder-bed Fusion of Metals Using a Laser Beam: *Nick Hantke*[1]; Tobias Grimm[1]; Jan Sehrt[1]; [1]Ruhr University Bochum

Powder-bed fusion of metals using a laser beam (PBF-LB/M) is an additive manufacturing technique with rising interest in industry and academia. One major topic of current research is to optimize the performance of parts manufactured by PBF-LB/M. The use of vibrations during the solidification of metals to improve their mechanical properties is well-known for metal casting and directed energy deposition. In this work, a vibrating build platform was used during the PBF-LB/M process to influence the microstructure of parts. Analyses show grain refinement when a vibrating build platform is used, which leads to an increase in sample hardness by up to 12.3 % for the same process parameters. Especially for process parameters that produce parts with lower relative densities, vibrations have an influence on part density. With an increase in part density, this effect gets less pronounced.

11:25 AM
Thin Wall Manufacturing in Laser Powder Bed Fusion for Heat Exchanger Applications: Evren Yasa[1]; Finlay Parson[1]; Anthony Molyneux[1]; *James Whincup*[1]; Ozgur Poyraz[1]; James Hughes[1]; [1]Advanced Manufacturing Research Center, University of Sheffield

Laser Powder Bed Fusion (LPBF) has the highest technological maturity and industrial applicability among other metallic Additive Manufacturing (AM) processes due to its advantages such as enabling very complex geometries, a fine feature resolution and a good surface quality. Those benefits make LPBF very suitable especially for heat exchanger applications with intricate features, which are otherwise impossible or very costly to manufacture. To enable complex heat exchanger geometries by LPBF, thin wall manufacturing in various orientations is necessary with a good surface integrity which necessitates process parameters optimized in a different manner than bulk part manufacturing. This study aims at understanding the impact of various process parameters such as scan speed (1050-1950 mm/s) and laser power (280-480 W) as well as scan strategies like contour scanning and blocked path strategy on thin wall characteristics. These characteristics are demonstrated on S-curved walls addressing wall thickness and surface integrity.

11:45 AM
Open Architecture Control Software for Laser Powder Bed Fusion Machines: *Justin Patridge*[1]; Gabe Guss[1]; Saad Khairallah[1]; Amit Kumar[1]; Steven Hoover[1]; Ibo Matthews[1]; [1]Lawrence Livermore National Laboratory

The modification of commercial machines and creation of custom systems furthers the development of the laser powder bed fusion additive manufacturing process. Adding sensors, changing scanning hardware, or changing how commands are processed and passed to the scanner can be crucial in designing an effective experiment. Commercial machine control software are usually inflexible and machine manufactures are reluctant to make modifications. Our software provides a way for communicating with existing scanner APIs and interfacing with the existing PLCs and other hardware on systems. Furthermore, the software provides a flexible GUI that is setup for a variety of powder bed machine layouts. We will outline our standardized architecture that limits the amount of machine specific code necessary to control a system.Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy, National Nuclear Security Administration under Contract DE-AC52-07NA27344.

Materials: Metals-Mechanical Properties II

Tuesday AM — Room: 410
August 15, 2023 — Location: Hilton Austin

Session Chair: To Be Announced

10:25 AM
A Comparison of the Mechanical Behavior of AlSi7Mg Alloy Produced Through Additive Manufacturing and Subjected to Different Heat Treatment and Aging Conditions: Victor Medrano[1]; *Kevin Caballero*[1]; Edel Arrieta[1]; Jorge Merino[1]; Bryan Ruvalcaba[1]; Brandon Ramirez[1]; Jacky Diemann[2]; Lawrence Murr[1]; Ryan Wicker[1]; Donald Godfrey[3]; Mark Benedict[4]; Francisco Medina[1]; [1]W.M. Keck Center for 3D Innovation; [2]SLM Solutions Group AG; [3]SLM Solutions NA; [4]Air Force Research Laboratory

Aluminum F357 (AlSi7Mg) is a versatile material used in aerospace and defense industries, which undergoes heat treatment for enhancing its mechanical properties. This study fabricated Aluminum F357 specimens using two different laser powder bed fusion systems and subjected them to five different heat treatments, followed by aging at two different temperatures for varying durations. The aged specimens were machined to create tensile specimens that were tested for mechanical properties. The study found that the specimens fabricated in the Z build direction had higher yield strengths than those subjected to HIP and unaged specimens. HIPed components when aged at 177°C for 1000 hours showed lower yield strengths. These results were consistent regardless of the fabrication system used, indicating the compatibility of the LPBF system fabrication. The study provides valuable information for the aerospace and defense industries to optimize their processes and produce high-quality components.

10:45 AM
Experimental Investigations of Inhomogeneous Component Properties in Laser-based Additive Manufacturing of AlSi10Mg: *Steffen Czink*[1]; Volker Schulze[1]; Stefan Dietrich[1]; [1]Karlsruhe Institute of Technology

In the laser-based additive manufacturing (PBF-LB) process of AlSi10Mg components, the layer-by-layer deposition leads to microscopic and macroscopic thermal effects (shrinkage, residual stresses, overheating) depending the component geometry. This results in a strong dependence of the microstructure and therefore of the process-induced material properties on the shape of the manufactured component. To analyze this behavior, components with different geometric aspects, such as various construction angles, were built in the PBF-LB process. In order to perform a spatially-resolved characterization and evaluation of the mechanical behavior of the component, small-scale tensile specimen in the sub-millimeter range were manufactured from representative areas of the components. With the obtained results, design approaches based on local material data can be improved significantly.

11:05 AM
Microstructure and Tensile Properties of Aluminum Alloy 4008 (A356) Processed via Liquid Metal Jetting: *Kellen Traxel*[1]; Nicholas Watkins[1]; Alex Wilson-Heid[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 as high as 400Hz. While opening a large application space due to a wide array of acceptable feedstock forms, questions about part quality and processability of different materials limit industrial use. Being a non-fusion based AM technique, processing parameters such as buildplate temperature can likely influence part densification, microstructure, and tensile properties, but these relationships 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 buildplate temperatures and layer-wise rastering angles to understand their influence on densification, microstructure, and tensile properties. 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-847002.

11:25 AM

Comparison of Layerwise Preheating and Post Heating Laser Scan on the Microstructure and Mechanical Properties of L-PBF Ti6Al4V: *Ahmet Tanrikulu*[1]; Aditya Krishna Ganesh Ram[2]; Behzad Farhang[2]; Amirhesam Amerinatanzi[2]; [1]University of Texas at Arlington / Turkish Aerospace Industries; [2]University of Texas at Arlington

This study aimed to investigate the evolution of the microstructure and mechanical properties of as-fabricated laser powder bed fusion (L-PBF) Ti-6Al-4V samples by introducing layerwise pre-heating or post-heating laser scans. Multiple laser scans, varying in power and scanning speed, were examined before the melting laser scan (pre-heating) or after it (post-heating). The analysis focused on microstructural features such as porosity, lattice structure, phases, and grain size, as well as the tensile response of the material. The results revealed the additional layerwise scans had a significant impact on reducing porosity by up to 98% when the additional scan was applied prior to the melting scan. Post-heating laser scan enhanced the material's plastic deformation by up to 9%. Furthermore, these findings highlight the potential of layerwise heating strategies to improve the overall quality and performance of L-PBF Ti-6Al-4V components, thus paving the way for enhanced applications in various industries such as aerospace.

11:45 AM

Microtensile Analysis of Additively Manufactured Ti–6Al–4V with Process Parameter Induced Defects: *Kourtney Porsch*[1]; [1]Johns Hopkins University Applied Physics Laboratory

Additively manufactured Ti–6Al–4V samples, with intentionally induced defects generated by varying the process parameters, were analyzed using microtensile testing techniques. Samples with defects exhibited statistically-significant larger microtensile than macrotensile ultimate strengths. Weibull microtensile moduli are smaller than macrotensile moduli indicating greater variability. Comparing the microtensile results to macrotensile properties reveals how changing these process parameters affects the range of mechanical behaviors potentially present in additively manufactured parts due to the varying microstructures in the material.

Process Development: Powder Bed Fusion Monitoring and Imaging I

Tuesday AM | Room: 410
August 15, 2023 | Location: Hilton Austin

Session Chair: David Hoelzle, Ohio State University

8:15 AM

Convergence Studies of Ensemble Kalman Filter Accuracy at Estimating Powder Bed Fusion Temperatures as a Function of Measurement Resolution: *Nathaniel Wood*[1]; Edwin Schwalbach[2]; Sean Donegan[2]; Andrew Gillman[2]; David Hoelzle[1]; [1]Ohio State University; [2]Air Force Research Laboratory

Achieving in-situ quality control of the Laser Powder Bed Fusion (PBF) process is an ongoing challenge, and resolving process features near the melt pool is an area of active research. High-resolution infrared (IR) cameras can image these features directly, but the data is impractical to process in-situ, and using less detailed measurements typically requires large quantities of training data. An algorithm called the Ensemble Kalman Filter (EnKF) avoids the tradeoff between accurate feature identification and measurement resolution by self-tuning the correlation between features and measurement values. Here, our feature is the PBF temperature field, and our measurement is a combination of two IR cameras. We perform two tests of EnKF accuracy as measurement resolution, and the data processing burden, decreases: First, decreasing the source IR camera resolution, where performance asymptotes after the resolution exceeds a threshold. Second, the resolution of the combined measurement decreases, where no asymptote is present.

8:35 AM

Experimental Validations of an Ensemble Kalman Filter Method for Powder Bed Fusion Temperature Estimation: *Nathaniel Wood*[1]; Edwin Schwalbach[2]; Sean Donegan[2]; Andrew Gillman[2]; David Hoelzle[1]; [1]Ohio State University; [2]Air Force Research Laboratory

Standard methods for estimating Laser Powder Bed Fusion (PBF) process variables rely on costly and time-consuming training data. The Ensemble Kalman Filter (EnKF) avoids this burden by using in-situ measurements to apply self-tuned corrections to physics-based model predictions of the process. Here, the process variable is the PBF temperature field, and the model is a Finite Element Method (FEM) description of heat conduction. In this work, we describe implementing the EnKF with this model and two PBF measurement architectures. Using data from previous experiments, we demonstrate EnKF effectiveness under three subsets of PBF process physics, which tests how it well it corrects increasing modeling error: solely heat conduction, melting a metal surface, and fusing layers of powder. The EnKF accurately estimates heat affected zone temperatures in every test, which is critical for PBF quality control, but incorrect estimates at isolated FEM nodes become more frequent as modeling error increases.

8:55 AM

An Ensemble Kalman Filter Method for Laser Powder Bed Fusion Temperature Estimation, Augmented with Adaptive Meshing and Joint Estimation of the Absorptivity: *Nathaniel Wood*[1]; Edwin Schwalbach[2]; Sean Donegan[2]; Andrew Gillman[2]; David Hoelzle[1]; [1]Ohio State University; [2]Air Force Research Laboratory

Methods for in-situ process monitoring of Laser Powder Bed Fusion (PBF) typically use large quantities of training data, since accurate predictive models are too computationally expensive. The Ensemble Kalman Filter (EnKF) overcomes this limitation by using the available measurements to apply self-tuned corrections to naïve model predictions. Here, we estimate the PBF temperature field, and the naïve model is Finite Element Method (FEM) heat conduction. The laser absorptivity is a modeling hyperparameter. We test three implementations of the EnKF using data from previous experiments: Implementation 1 uses a time-varying FEM mesh that is only dense nearby the laser (adaptive meshing), with fixed absorptivity. Implementation 2 uses a time-invariant mesh while jointly estimating temperature and absorptivity. Finally, Implementation 3 combines joint estimation and adaptive meshing. Implementations 1 and 2 show good accuracy in the heat affected zone, which enables accurate identification of several defect types, but performance suffers in Implementation 3.

9:15 AM

AI-driven In Situ Detection of Keyhole Pore Generation in Laser Powder Bed Fusion: *Zhongshu Ren*[1]; Tao Sun[1]; [1]University of Virginia

Laser powder bed fusion (LPBF) process is a metal 3D printing technology, where the laser selectively melts powder and fuses it with the underneath substrate based on computer design. Certain defects such as porosity hinders the widespread adoption of LPBF into applications, which have strict quality requirements. One type of porosity defects occurs under some conditions of high laser power and slow scan speed, known as keyhole porosity. We developed an artificial intelligence (AI)-driven approach to detect the pore generation in situ with near-perfect prediction. We used the synchrotron high-speed x-ray imaging as ground truth and acquired simultaneous thermal imaging of the sample surface as training data. We also performed multiphysics simulation to reveal the physical meaning of the features used in the training process. This approach shows a practical way of detecting porosity defects and potential of improving the build parts quality.

9:35 AM
In-situ Monitoring of Laser Powder Bed Fusion for Production Environments: *Jesse Adamczyk*[1]; David Saiz[1]; Dan Bolintineanu[1]; Anthony Garland[1]; Ana Love[1]; Hyein Choi[1]; David Moore[1]; Catherine Appleby[1]; Michael Heiden[1]; [1]Sandia National Laboratories

Additive manufacturing (AM) has shown major growth across the energy, aerospace, and automotive sectors. However, there is a critical need for identification of process-induced defects and porosity. Such determinations typically require expensive and time-consuming techniques that are not amenable to production environments. In-situ monitoring can reduce the need for post-build inspection by leveraging correlated multi-modal data streams to identify off-nominal build events and potential defects. Acoustic signals during builds can be correlated to laser energy density, along with the part surface finish and density. Commanded laser positions linked with layer-wise optical images of the actual laser position enables external validation of correct machine behavior. Additionally, relative heat inputs and spatter behavior can be determined by long-wave infrared imaging. Ultimately, this work highlights how in-situ monitoring can benefit AM production by automatically tracking process deviations and anomalies.

9:55 AM Break

Process Development: Material Extrusion II

Tuesday AM — Room: 412
August 15, 2023 — Location: Hilton Austin

Session Chair: David Espalin, Univ of Texas El Paso

8:15 AM
Mechanically Bonding and Thermally Releasing Print Surface for Big Area Additive Manufacturing: *Eric Weflen*[1]; Frank Peters[1]; Matthew Frank[1]; [1]Iowa State University

Part retention and removal is a challenge for Big Area Additive Manufacturing (BAAM) systems, increasing production costs and impacting part quality. A part should remain locked to the print surface during processing, then be released for removal when processing is completed. However, a method for releasing the large, multi-meter parts from the print surface on BAAM systems is not existent. This work presents a print surface with a mechanically bonding interfacial structure that locks the part to the print surface during processing and then thermal releases the part for removal. Design and process parameters were evaluated, and a model was developed as a design guide for industry implementation. A demonstration casting pattern was produced in a hybrid manufacturing machining center by iterating between polymer pellet-fed material extrusion and surface machining. The viable applications of BAAM can be expanded by improving the process and reducing costs.

8:35 AM
Inexpensive Mechanistic-Knowledge-Agnostic Machine Learning in Additive Manufacturing: *Jeremy Cleeman*[1]; Rajiv Malhotra[1]; [1]Rutgers University

Machine Learning (ML) enables deployable modeling of parametric effects in additive manufacturing. Multi-Fidelity Learning (MFL) reduces the cost of training such a ML model by initially training it on a large amount of low-fidelity (LF) modeling data and then fine-tuning it based on a small high-fidelity (HF) experimental dataset. But current approaches for generating the LF data incur high model development cost (≈ decades) due to the need for deep mechanistic understanding of the process. We address this issue by pushing the boundary of the functional similarity necessary between the LF and HF data. This capability is demonstrated for two problems in Fused Filament Fabrication, i.e., predicting the printed road's size and modeling the compression induced by an emerging in-situ rolling technique. We envision that our approach will enable accelerated and inexpensive understanding and adoption of new aspects or performance metrics in additive manufacturing despite limited mechanistic knowledge.

8:55 AM
In-situ Process Monitoring System for Large Format Thermoplastic Additive Manufacturing: James Haley[1]; *Adam Stevens*[1]; Phillip Chesser[1]; James Tobin[1]; Celeste Atkins[1]; Alex Roschli[1]; Brian Post[1]; [1]Oak Ridge National Laboratory

An in-situ process monitoring system was developed to track geometric and thermal data during large-format thermoplastic additive manufacturing (LFAM). The monitoring system is designed to repeatably mount near the nozzle and consists of dual stereoscopic depth cameras and eight thermal cameras. The data streams are gathered and combined utilizing a Robot Operating System (ROS) framework to synthesize top-down bead width and temperature information unobstructed by the nozzle and used for print validation. We present the hardware and software design for this system, as well as performance validation.

9:15 AM
Distributed Optical Fiber Testing for Additive Manufacturing: *Brian Hlifka*[1]; Edward Kinzel[1]; [1]University of Notre Dame

This paper explores the use of optical fiber for in-situ inspection of additive manufacturing. Single-mode SMF-28 optical fiber can be placed on the build plate to monitor the printing process or embedded in the part itself. Distributed measurements using optical backscattering reflectometry (OBR) resolve the strain along the optical fiber as well as the temperature. OBR-enabled sensing is demonstrated for the fused filament fabrication (FFF) process. The small diameter (0.25 mm) of SMF-28 lends itself to embedding in FFF prints this enables laying the fiber into the part which provides continued sensing for the parts in use. Knowledge of the process and the fiber arrangement allows heating from the deposition head to be distinguished from stress-driven strain. Calibration of the fiber arrangement is discussed as well as a comparison with process modeling.

9:35 AM
An Extrusion-based 3D Printing Method for Direct Deposition of Photopolymers: *Rencheng Wu*[1]; Chao Sui[1]; Zachary Hyden[2]; Wan Shou[1]; Zhenghui Sha[1]; Wenchao Zhou[1]; [1]University of Arkansas; [2]AMBOTS

Photopolymer 3D printing methods, such as stereolithography (SLA), digital light processing (DLP), and inkjet 3D printing, suffer from various limitations, such as the need of a resin tank and postprocessing, or high equipment cost. This paper introduces a novel extrusion-based method for direct deposition photopolymer printing (DDPP) that resembles fused deposition modeling (FDM), one of the most widely used 3D printing methods. The proposed DDPP method uses a gear pump to continuously extrude photopolymer resin and instantly cure the photopolymer while printing. Specifically, we have addressed the challenges associated with the system reliability issues, such as dripping, spreading, and shrinkage, via a systematic design of curing mechanism, synchronizing control, and slicing under various resin material scenarios. The performance of the developed DDPP system is experimentally evaluated, which shows promise as an easy and low-cost alternative for printing photopolymers.

9:55 AM Break

10:25 AM
Beyond Throughput-resolution-flexibility Tradeoffs with Mutliplexed Fused Fabrication: *Jeremy Cleeman*[1]; Rajiv Malhotra[1]; [1]Rutgers University

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.

10:45 AM

Calibration Method for Combined Structured Light and Additive Manufacturing Systems: *William Keller*[1]; Jack Girard[1]; Song Zhang[1]; [1]Purdue University

The combination of 3D imaging and additive manufacturing systems has given rise to novel in-situ monitoring and error correction techniques allowing for increased efficiency and reduced operational costs. A novel method of the coordinate system calibration for a fused filament fabrication printer and digital fringe projection (DFP) scanner was developed. A single layer rhombus outline is printed with known G-code coordinate corners. The shape is scanned and a series of image processing and DFP techniques yields the corner locations in scanner coordinates. The number of scanner and G-code data points are increased using linear interpolation between the corners to improve accuracy. The transformation matrix is calculated. With this, scanned data can easily be compared to the ideal print geometry leading to improved monitoring and correction. Preliminary results indicate the calibration method has acceptable accuracy. When used in underfill correction techniques this method has proved to be effective and reliable.

11:05 AM

In-situ and In-line Monitoring for Robocasting using Ceramic Slurries: *Jason McCleary*[1]; David Espalin[1]; [1]University of Texas at El Paso

Robocasting has multiple steps from ceramic slurry preparation to sintering that can impact the end part quality. In-situ monitoring and process controls can aid in minimizing differences in the quality of printed parts. The study and impact of different parameters during the printing process and a parameter database will improve the quality between green bodies and sintered parts. This paper discusses implementation of a CMOS camera, dynamic pressure sensor, and 2D laser scanner into a custom-built robocasting printer for in process monitoring. Single line beads and single layer samples were printed and analyzed by measuring the dimensions and pressure changes during printing. Results show that the printer with sensors detected the location of defects and changes in printed samples.

Data Analytics: Application to General Additive Manufacturing

Tuesday AM — Room: 415 AB
August 15, 2023 — Location: Hilton Austin

Session Chair: Nicholas Meisel, Pennsylvania State University

8:15 AM

Nowcasting Melt Pool Dynamics using Transformer on In-situ Monitoring Images: *Shu Wan*[1]; Hyunwoong Ko[1]; [1]Arizona State University

Accurate understanding and prediction of melt-pool dynamics are crucial for Additive Manufacturing (AM) processes, as they significantly impact final products' quality and mechanical properties. In this paper, we propose a novel method, Melt-pool Generative Pre-trained Transformer (MeltpoolGPT), for predicting the next melt pools using a GPT-based architecture specifically designed for video frame predictions. Our approach captures spatio-temporal dependencies between melt pools and learns the underlying physical dynamics governing laser-powder-bed-fusion processes. We evaluate MeltpoolGPT on melt-pool image data acquired from the AM Metrology Testbed at the National Institute of Standards and Technology, and design a series of experiments to assess the accuracy and stability of its predictions. Our experiments indicate that MeltpoolGPT achieves high accuracy in predicting the next melt-pool images, outperforming other state-of-the-art methods. This work presents a first step in predicting future melt pools, a largely unexplored area with immense potential to benefit real-time monitoring and control in AM significantly.

8:35 AM

Dreaming of Data: Examining Data Augmentation for Machine Learning in Additive Manufacturing: Glen Williams[1]; *Martha Baldwin*[2]; Timothy Simpson[1]; Nicholas Meisel[1]; Christopher McComb[2]; [1]Pennsylvania State University; [2]Carnegie Mellon University

The data generated during additive manufacturing (AM) practice can be used to train machine learning (ML) tools to reduce defects, optimize mechanical properties, or increase efficiency. In addition to the size of the repository, emerging research shows that other characteristics of the data also impact suitability for AM-ML application. What should be done in cases for which the data in too small, too homogeneous, or otherwise insufficient? Data augmentation techniques present a solution, offering automated methods for increasing the quality of data. However, many of these techniques were developed for machine vision tasks, and hence their suitability for AM data has not been verified. In this study, several data augmentation techniques are applied to synthetic design repositories to characterize if and to what degree they enhance their performance as ML training sets. We discuss the comparative advantage of these data augmentation techniques across several canonical AM-ML tasks.

8:55 AM

A Framework for Physics-guided Machine Learning to Extract and Transfer Process-structure-property Knowledge in Additive Manufacturing: *Hyunwoong Ko*[1]; Shu Wan[1]; Fatemeh Elhambakhsh[1]; [1]Arizona State University

Emerging research in Additive Manufacturing (AM) seeks to pursue Machine Learning (ML) that can improve the understanding of Process-structure-property (PSP) causality. To address the challenge, we provide a novel framework for physics-guided ML to extract and transfer PSP knowledge. The framework first uses an approach guided by physics knowledge graphs to generate the requirements for predictive PSP analytics. Then, the framework uses physics-informed ML to construct new PSP knowledge. The study enables ML to systematically couple physics knowledge with the versatility of cyber-physical AM data in PSP analytics. This study also provides a foundational basis for AM to synergically merge newfound knowledge about PSP from data with a priori physics knowledge. The framework continuously updates coupled PSP linkages to improve the understanding of dynamic AM processes. The continuous PSP learning accumulates structured newfound PSP knowledge in iterations for future ML and proactive control decisions.

9:15 AM

Additive Manufacturing (AM) Lattice Segmentation and Analysis Enabled through Deep Learning: *Michael Juhasz*[1]; Gabe Guss[1]; J. B. Forien[1]; Nick Calta[1]; [1]Lawrence Livermore National Laboratory

Ex-situ computed tomography (CT) analysis of Additive Manufacturing (AM) produced parts is commonplace as a means of Non-Destructive Evaluation (NDE) quality assurance. Most CT examinations focus on porosity, both from keyholing or entrained gas. With the recent acceleration in image processing enabled through Deep Learning/Machine Learning (ML/DL), this presentation suggests expanding CT analysis of AM parts to extend beyond porosity analysis to encompass the study of other requirement-driven, critical geometries. This was applied to AM produced lattices which underwent CT and were subsequently segmented into component pieces. These segmented components were then registered to in-situ diagnostic signals for comparison where dependence and correlation was assessed, and it is those results which will be presented. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

9:35 AM
Machine-Learning-Driven Digital Twin Construction for Additive Manufacturing: A Review: *Fatemeh Elhambakhsh*[1]; Hyunwoong Ko[1]; [1]Arizona State University

Machine Learning (ML) on high-value data, both from cyber and physical systems, has significant potential for constructing a novel Digital Twin (DT) of Additive Manufacturing (AM). However, the use of ML has been largely hindered in the AM DT construction due to the limited understanding of the potential. To address the limitation, in this study, we thoroughly identify ML's capability and newfound opportunities driven by ML in the DT construction for AM. This study reviews AM DTs' key features and emerging applications, and state-of-the-art ML methods for the DT construction. This study also discusses open issues and outlooks on the future directions of the ML-driven DT construction for AM. This study helps maximize ML on cyber-physical AM data in automatically constructing spatiotemporally scalable DTs that improve the understanding of physical phenomena and control decisions in AM.

9:55 AM Break

10:25 AM
PRISM: Process Parameter Optimization for Selective Manufacturing: *Anthony Garland*[1]; Dale Cillessen[1]; Kaitlynn Conway[1]; Johnson Kyle[1]; Brad Boyce[1]; Jay Carroll[1]; [1]Sandia National Laboratories

The process of selecting optimal process parameters for additive manufacturing (AM) of a new material can be a challenging task, particularly for materials with limited information in the literature. This study describes an iterative approach that uses machine learning algorithms to predict printability and the target material property when given a set of process parameters. These ML algorithms when combined with optimal design of experiments, enable the selection of optimal process parameters for additive manufacturing (AM) of new materials. The results demonstrate the effectiveness of our approach. This study provides a framework for future research in the selection of optimal process parameters for manufacturing processes and highlights the potential of machine learning in optimizing materials design and manufacturing processes.

10:45 AM
Towards a FAIR Knowledge Management System for Additive Manufacturing: *Shengyen Li*[1]; Yan Lu[1]; Paul Witherell[1]; [1]National Institute of Standards and Tecnhology

Additive manufacturing builds near-net-shape parts using high volume data for designing, operating, and certifying processes and products. To cost-effectively mature AM technology, a FAIR (Findable, Accessible, Interoperable, and Reusable) infrastructure is developed that enables integrations among machines, analytics, and computer tools. This infrastructure includes data models, which is developed following ASTM standards defining key terminologies in a structure for archiving AM related data. A selected dataset, including AM building files, in-situ sensing data, and measuring results, are used to validate the data models. This infrastructure also provides API tools to manage raw data and metadata for statistical analyses to identify the variability of the processes and assess the data quality. The results from this analytical process assist the following sensitivity analyses for the design of experiments and predictive model developments. This presentation will share a case study of identifying the metrology and analytics gaps and opportunities using this informatics-based framework.

11:05 AM
Usage of Unconventional Data Sources for Market Intelligence (MI) in the Field of Additive Manufacturing (AM) - Expert Networks, Technology Territories and Trends: *Stephan Ziegler*[1]; [1]RWTH Aachen University - Digital Additive Production DAP

The geographic expansion of the markets for AM increasingly confronts companies with greater competitiveness due to the globalization. In addition, market participants are facing rapid changes in the business environment - due to new information and communication technologies. Companies only have a chance to hold their market position if they quickly adopt market changes. Therefore, the decision-making process needs to be accelerated by on-demand information provision. MI offers one possibility to meet these requirements, but typically based on external unstructured data for market and competitive evaluation, which makes it cost and time consuming.A specific investigation of such data sources related to MI for systematic use within the AM markets is being carried out. For this purpose, different data sources (e.g. LinkedIn) will be identified, analysed with focus on information synthesis using text mining and their suitability for the evaluation of expert networks, technology territories and trends be presented.

11:25 AM
Virtual Inspection of Advanced Manufacturing via Digital Twins: *Brian Giera*[1]; Brian Weston[1]; Ziad Ammar[1]; Seth Watts[1]; Haichao Miao[1]; [1]Lawrence Livermore National Laboratory

A digital twin (DT) is an amalgam of physics-based and/or data driven models that describe a physical system. In additive manufacturing (AM), inputs/outputs of digital and physical twins are identical. Like many, LLNL's approach requires refining DTs with data to better capture behavior of its physical twin via advanced analytical techniques. As such, a DT's evolving parameter set can inform of machine health and aging behavior, providing actionable insights on lifetime performance. A suite of DTs that capture all fabrication and inspection platforms of a given AM process can accelerate production for qualifying parts at scale with minimized and quantified defects. This talk will walk through examples of how we are leveraging data from integrated pairs of real and digital twins of inspection and fabrication platforms to become more flexible and agile. This work was performed under the auspices of the U.S. DOE by LLNL under Contract DE-AC52-07NA27344, LLNL-ABS-820420.

Modeling: Deposition of Particles and Fibers

Tuesday AM
August 15, 2023

Room: 416 AB
Location: Hilton Austin

Session Chair: to be announced

8:15 AM
Part-scale Thermal Model for Parameter Optimization in a Microscale Selective Laser Sintering System: *Joshua Grose*[1]; Farzana Tasnim[1]; Michael Cullinan[1]; [1]University of Texas at Austin

The Microscale Selective Laser Sintering (μ-SLS) system can produce feature sizes on the order of a single micrometer, far smaller than existing additive technologies. Despite this advantage, there are challenges in producing reliable small-scale parts due to unwanted heat transfer in the nanoparticle particle bed. To address this issue, a multiscale Finite Element thermal model has been developed to predict the temperature changes that occur during sintering within the particle bed. Nanoscale particle models are used to quantify material property changes experience by particle groups that undergo laser sintering. This work processes the property relationships developed by the particle models and integrates a comprehensive property function into the part-scale model to capture the nuanced thermal evolution that occurs during sintering. The multiscale model predicts the extent of heat spread during sintering to optimize input laser parameters, reduce unwanted heat spread, and improve the minimum feature resolution of printable parts.

8:35 AM
On the Effect of Recoater Damage on Spreading Behavior: *Caroline Massey*[1]; Christopher Saldaña[1]; [1]Georgia Institute of Technology

Laser powder bed fusion (LPBF) additive manufacturing allows for the opportunity to customize parts, manufacture low lot size items, and revolutionize supply chain logistics. One key challenge to the adaptation of LPBF technology is that the process needs to be optimized to achieve consistency between builds and lots. Recoater spreading can affect the topology of the powder bed, which could lead to variability in porosity and surface roughness if the recoater blade is damaged. The present study will investigate the effect of damage to the recoater on the powder bed using the discrete element method (DEM). Intentional notches will be introduced to the recoater to simulate damage. Interactions between the damaged recoater and the topology and spread quality of the powder bed will be investigated.

8:55 AM
Modeling Carbon Fiber Suspension Dynamics for Additive Manufacturing Polymer Melt Flows: *Jason Pierce*[1]; Douglas Smith[1]; [1]Baylor University

The addition of short carbon fibers to the feedstock of large-scale polymer extrusion/deposition additive manufacturing results in significant increases in mechanical properties dependent on the fibers' distribution and orientation in the beads. In order to analyze those factors, a coupled computational fluid dynamics (CFD) and discrete element modeling (DEM) simulation system is utilized to model the behavior of fibers in nozzle geometries after calibrations in simple shear flows. The DEM model uses bonded discrete particles to make up flexible and breakable fibers that interact with each other in alignment with established literature as well as with the variable flow and geometries present in nozzles. Results enable determination of proper Coefficient of Interaction values as well as provide enhanced insight into the evolution of fiber orientation during deposition over existing models through individual fiber tracking over time and space on multiple parameters of interest such as orientation, flexure, and contact forces.

9:15 AM
Understand Powder Deposition Behaviors of a Novel Electrostatic Powder Spreading Technique Using Particle Dynamics Simulation: *Ziheng Wu*[1]; Michael Troksa[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 of several materials. However, almost all the existing spreading methods are mechanical based which prevents the deposition of different feedstocks selectively. We are developing a contact free electrostatic powder spreader that can perform multi-material powder patterning and in-situ mixing. This study focuses on developing custom modules in Ansys Rocky to perform powder dynamics simulations which have been validated against the deposition rate experiments using the electrostatic spreader. The simulations are used to study the different powder responses at various spreader geometries, electric fields, and materials. The results provide us with essential insights and guidelines for spreader prototyping.

9:35 AM
Predicting the Printable Parameter Space for Laser Directed Energy Deposition Using a Calibrated Model: *Peter Morcos*[1]; Matthew Vaughan[1]; Jiahui Ye[1]; Alaa Elwany[1]; Ibrahim Karaman[1]; Raymundo Arroyave[1]; [1]Texas A&M University

Laser Directed Energy Deposition (DED) is an additive manufacturing technique used to produce large and complex metal parts through the deposition of metal powder. However, the complexity of the process due to the presence of multiple processing parameters makes it very challenging to fabricate high-density parts without extensive experimental work. Therefore, the urge of having a reliable and efficient tool for predicting the printable space of parameters is crucial. In this work, a computationally inexpensive model is used to predict the clad geometry using the primary parameters in DED, including laser power, scanning speed, and mass flow rate. Singe tack experiments were printed and characterized. The measured clad dimensions were used to calibrate the model before generating 3D process maps.

9:55 AM Break

10:25 AM
Investigating the Effect of Generalized Newtonian Fluid on the 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

Continuous research on the formation and development of micro-voids within the bead microstructure of polymer composite during extrusion/deposition process is currently ongoing, considering the adverse effect these features have on part quality. A computational method is employed to investigate potential volatile-induced micro-void nucleation mechanism by simulating the evolution of a single rigid ellipsoidal fiber in purely viscous polymer extrusion/deposition flow through a BAAM nozzle. While previous studies on potential micro-void nucleation mechanisms have assumed a Newtonian fluid property definition for the polymer melt flow, the current study assesses the impact of a generalized Newtonian fluid (GNF) model on the fiber's response. Preliminary findings based on Jeffery's flow assumption reveal a decrease in the fiber's orientation kinetics due to the shear-thinning fluid behavior with an accompanying reduction in the pressure distribution around the fiber's surface for a power-law fluid with low flow behavior index which increases the likelihood for micro-void nucleation.

10:45 AM
Multi-physics Modeling of Low-temperature Directed Energy Deposition of Stainless Steel 316L: *Kishore Mysore Nagaraja*[1]; Dong Qian[1]; Wei Li[1]; [1]The University of Texas

The Directed energy deposition (DED) process is greatly influenced by the ambient temperature at on-site repair. In Northern hemisphere locations, DED is particularly influenced by sub-freezing temperatures. However, its influence on the process is not yet studied. This critical gap is fulfilled in this research through a multi-physics computational fluid dynamics (CFD) modeling of the low-temperature DED of the SS316L powders. The model is validated with test cases: -3°C for sub-freezing and 20°C for room temperature cases using a cryogenic DED platform. The modeling involves powder spray, local melting, rapid cooling, solidification, evaporation, and fluid-gas interactions. The results show, at sub-freezing, the molten pool is ~63% bigger with the maximum temperature reduced by ~9.5%. The deposition saw an increase in width by ~8.6% and height by ~26% than the room temperature case. Overall, the versatile modeling-experimental platform helps study cryogenic DED cases for in-space additive manufacturing.

11:05 AM
Real Time Quantification of Shear-induced Molecular Ordering in Direct Write Printing of Bottlebrush Based Polymer Networks: *Daniel Rau*[1]; Baiqiang Huang[1]; Liheng Cai[1]; [1]University of Virginia

Bottlebrush polymer networks provide a new class of inks with extreme softness for Direct Ink Write. However, it remains a challenge to understand the effects of the extrusion process on the molecular ordering of bottlebrush polymers, which have a long linear backbone densely grafted by many relatively short linear side chains. Here, we leverage a customized extrusion system and use small and wide-angle x-ray scattering to quantify the molecular ordering of linear-bottlebrush-linear triblock copolymers in-situ. We discover that higher shear rates promote the alignment of the self-assembled microstructures resulting in much larger characteristic length scales. Moreover, the ordering profile across the nozzle diameter is highly correlated to the flow profile of the viscoelastic triblock copolymer inks. Our results provide insights into the previously unexplored processing-microstructure-mechanical property relationships of bottlebrush-based polymer networks and may provide a new avenue for printing single material structures with functionally graded mechanical properties.

11:25 AM
Optimization of Computational Time for Digital Twin in Directed Energy Deposition for Residual Stresses: *Usman Tariq*[1]; Ranjit Joy[1]; Sung-Heng Wu[1]; Muhammad Arif Mahmood[2]; Frank Liou[1]; [1]Missouri Univeristy of Science and Technology; [2]Intelligent Systems Center

Metal Additive Manufacturing has grown rapidly and proven to be a cost-effective way to produce high-quality products. As metal additive manufacturing involves large thermal gradients which incorporate residual stresses and distortion at the end part hence having knowledge of these properties is essential for quality control. Finite Element Analysis (FEA) is one of the methods to predict for residual stresses to improve part quality and strength at the cost of high computational power. The aim of this study is to decrease computational time by incorporating thermo-mechanical model for Directed Energy Deposition (DED) process using Ti-6V-4Al which would predict thermal history and consequent residual stresses. Different methods of FEA models are included which use simple assumptions and gives a comparison between computational cost and numerical accuracy which can help move towards the realization of digital twin.

11:45 AM

Experimental and Finite Element Comparison of 3-axis and 5-axis Wire Arc Directed Energy Deposition: *Matthew Register*[1]; Ryan Stokes[1]; J Betts[1]; Liv Russell[1]; Matthew Priddy[1]; [1]Mississippi State University

Wire arc directed energy deposition (WA-DED) is a metal additive manufacturing (AM) process that utilizes an electric arc heat source to melt wire in a layer-by-layer fashion. Unlike traditional AM, the WA-DED process has six axes of rotation, allowing geometrically complex parts to be built without the need of support structures. However, it is not well understood how the thermal history may change as an effect of multi-axis toolpaths, thus also affecting the resultant mechanical properties. This work examines the variation in temperature history, residual stress, and distortion between 3- and 5-axis toolpaths for the same geometry using an experimental and computational approach. Using finite element (FE) thermo-mechanical modeling, the nodal temperature history was compared with thermocouples on the substrate and infrared camera data near the melt pool to validate the FE thermal response. Deflection experimental measurements were collected with a laser profilometer for FE mechanical model validation.

12:05 PM

Adapting a Conventional Design for Additive Manufacturing Workflow to Account for Continuous Carbon Fiber Reinforced Parts: Gavin Adams[1]; *Nicholas Meisel*[1]; [1]Pennsylvania State University

The use of continuous carbon fiber (CCF) reinforcement has the potential to revolutionize the material extrusion field of additive manufacturing. For example, the Markforged X7 system utilizes CCF reinforcement with the aim to produce parts with mechanical results rivaling those of aluminum. However, due to certain constraints with the deposition of CCF in material extrusion, traditional design for additive manufacturing (DfAM) techniques must be reevaluated. This paper explores the application of DfAM principles in CCF and include the development of a new DfAM workflow for this technology. The research is demonstrated through a case study, which highlights the importance of considering fiber orientation in the design stage to achieve ideal mechanical results relative to the loads associated with the part. Overall, this paper provides an initial, potentially valuable workflow for designing and manufacturing CCF parts using AM and highlights the importance of DfAM principles in achieving desirable mechanical results.

Binder Jet AM: Material and Experiments

Tuesday AM   Room: 417 AB
August 15, 2023   Location: Hilton Austin

Session Chair: Patryk Radyjowski, Advanced Cooling Technologies, Inc.

8:15 AM

Additive Manufacturing of Si-SiC Cermets by Binder Jetting with Si infiltration – Process and Material Properties: *Patryk Radyjowski*[1]; Saikamal Srinivas[1]; Chien-Hua Chen[1]; Benjamin Groth[2]; Luke Phalen[2]; [1]Advanced Cooling Technologies, Inc.; [2]ExOne

Siliconized Silicon Carbide (Si-SiC) is a promising material for high-temperature and high-wear applications. Additive Manufacturing (AM) of Si-SiC reduces lead times and opens the design space for complex geometries. The AM-generated SiC preform is densified using deformation-free pressure-less silicon metal infiltration. The binder jetting with high-ash binders is a high throughput, low heat AM method used for preform manufacturing. Subsequently, the binder is pyrolyzed and infiltrated by liquid silicon inside the vacuum furnace to achieve final properties. The manufacturing process is discussed, together with the investigation of minimal feature resolution capabilities. Furthermore, the mechanical strength of Si-SiC parts is studied in accordance with ASTM C1161 and including the statistical Weibull approach. Finally, a large-scale, high-temperature application of the described process is presented in manufacturing a 10in diameter by 10in tall Swiss-roll style combustor targeted at flare incineration.

8:35 AM

An Effective Method for Predicting the Mechanical Properties of Parts with Site-specific Microstructure: *Sun Li*[1]; Po-Ju Chiang[1]; Jonathan Jeevan Singham[2]; Wei Xin Tan[1]; John Samuel Dilip Jangam[3]; Chang Quan Lai[4]; [1]HP-NTU Digital Manufacturing Corporate Lab, School of Mechanical and Aerospace Engineering, Nanyang Technological University; [2]School of Material Science Engineering, Nanyang Technological University; [3]HP Labs; [4]School of Mechanical and Aerospace Engineering, Nanyang Technological University

Site-specific microstructures in metallic materials offer the potential to develop functional components with tailored properties. However, accurately predicting the mechanical properties of such materials is challenging. In this work, microstructure-based finite element simulation results reveal that, for materials containing randomly distributed identical phases, the mechanical properties are predominantly determined by phase proportion. Based on this finding, a method is proposed to predict the mechanical properties of site-specific material by developing a mathematical model that can predict the properties under varying phase proportions and then incorporating them as material data of the partitioned regions in a finite element model to predict its overall mechanical properties. The proposed method is verified by the experimental tensile test results of the site-specific pearlitic-ferritic steel fabricated using HP's metal binder jet additive manufacturing technology. This method provides an effective way to predict mechanical properties and can facilitate the design of 3D printing site-specific alloy parts.

8:55 AM

An Experimentally-tuned Finite Element Model for Predicting Sintering Deformation in Binder-jet Additive Manufacturing: *Roman Boychuk*[1]; Mihaela Vlasea[1]; Kamyar Ghavam[2]; [1]University of Waterloo Multi-Scale Additive Manufacturing Lab; [2]University of Waterloo

Parts produced through binder jetting undergo shrinkage and distortion driven by densification and by the external forces of gravity and friction acting on the part in a softened state. This work presents an FEM-compatible deformation predictor based on the Skorohod Olevsky Viscous Sintering (SOVS) model to represent the solid-phase sintering process and predict the final shape of a complex sintered part. A sintering distortion artifact was designed, and sintered inside an optical dilatometer, where the part contour over time is recorded and used to train the sintering model through a regression algorithm. The model is then validated against variations of the training artifact, and other challenging overhang geometries under optical dilatometry, and yields a maximum contour deviation ranging from 3-7% after an initial round of optimization. This model presents a novel approach to predicting sintering shape deformation which uses experimental data with minimal material property knowledge.

9:15 AM

Binding and Alloying Properties of a Solid-free Organic Binder in Binder Jetting Additive Manufacturing of Steel: *Wei Xin Tan*[1]; Po-Ju Chiang[1]; Chang Quan Lai[2]; Adrian Ong[1]; John Samuel Dilip Jangam[3]; Ming Jen Tan[1]; Raju V. Ramanujan[2]; Li Ping Tan[2]; [1]HP-NTU Digital Manufacturing Corporate Lab; [2]Nanyang Technological University; [3]HP Labs

In-situ alloying in steel can be achieved in binder jetting additive manufacturing technology by altering the composition of the liquid binder used. Carbon is often left as residue after high temperature sintering in organic binder. The diffusion of the carbon will result in the change of microstructure of the sintered steel part, often leading to enhancement in mechanical properties. Nanoparticles or suspensions are usually added to binder to achieve doping properties, but this can cause non-uniform particles dispersion and print nozzle clogging. Hence, we developed a solid-free binder with doping properties using an organic compound to act as binder and dopant simultaneously. In this study, the binding and doping properties were evaluated, and improvements in mechanical properties were observed in both the green and sintered parts. Finally, we also demonstrated the potential to fabricate site-specific alloy through the control of the carbon concentration using the newly developed binder.

9:35 AM
Elucidating Size and Location Effects on Green Density of Binder Jet Additive Manufactured Parts: *Basil Paudel*[1]; Albert To[1]; [1]University of Pittsburgh

Despite large distortions inherent in Binder Jet Additive Manufacturing (BJAM), the geometric accuracy after compensation using continuum-based phenomenological models has been improved to 2-3% of the part dimension. Such prediction models, however, require the bulk green density of the part as an input parameter. The green density has been reported to depend on printing parameters including location within the build and may not be readily known. In the present work, we investigate this three-dimensional spatial effect on the bulk green density. The study is repeated for four directionally scaled samples to elucidate the role of geometric size as well. Results indicate that larger parts achieve higher bulk green density despite being in similar location within the build. At least a 5% variation in density is also obtained within a given 'component-layer' which can be attributed to the powder spreading and compaction process. A green density prediction model is proposed.

9:55 AM Break

10:25 AM
Equalization of Metal Powder for Binder Jet Printing: *Michelle Niu*[1]; Krzysztof Nauka[1]; [1]HP Inc

Metal powders used in additive manufacturing often face the issue of variable powder surface characteristics, causing inconsistent part quality. As such, a "homogenization" treatment for metal powder surfaces may be advantageous for relevant fabrication processes. By using high-powered xenon flash lamp to rapidly heat powder samples, the surface energy of the powder can be brought to the same value regardless of the powder source and past usage. Pulse-heating the powder can cause the atomic structure of particle surfaces to undergo rearrangement, and adsorbed moieties can be removed. Effects of this treatment on metal powders have been investigated and evaluated by measuring the absorption time of water droplets on treated and untreated thin powder layers.

10:45 AM
Fiber-Reinforcement of Binder-Jetted Casting Molds for Multiple Usage: *Jan Angenoorth*[1]; Dominik Rumschöttel[1]; Florian Ettemeyer[1]; Bernhard Leitner[1]; Violetta Schumm[1]; Ismail Ünsal[1]; Daniel Günther[1]; [1]Fraunhofer IGCV

Widely used sand casting with lost molds is an efficient and cost-effective way of producing geometrically complex components. As the demand for sand has tripled over the last two decades, finding new solutions for thermostable binder systems and ensuring the efficient use of resources is essential. To address this issue, the REINFORCED SAND project is exploring glass fiber-reinforced sand molds and temperature-stable inorganic binders within the binder-jetting process. The aim is to improve the mechanical properties of the 3D-printed casting molds to make multiple uses of these possible, reducing resource consumption and increasing profitability. For this purpose, various material systems and manufacturing parameters were examined. It has been demonstrated that fiber-reinforced sand molds can be used for multiple castings, and fibers can be principally processed in the binder jetting process. These efforts aim to make sand casting production more environmentally friendly and sustainable. The REINFORCED SAND project is a step towards achieving these goals.

11:05 AM
Microstructures, Mechanical and Thermal Property Evaluation of Binder Jet Printed High Conductivity Copper Parts.: *John Samuel Dilip Jangam*[1]; Thomas Anthony[1]; Jake Piderman[1]; Michelle Niu[1]; Elizabeth Galati[1]; Lihua Zhao[1]; [1]HP Labs

Binder jet additive manufacturing technology involves binding metal powder particles together to produce a green part. In this work, HC Cu copper powder from Sandvik Osprey was used to 3D print green parts using proprietary organic and inorganic binders. Green parts possessed good green strength, typically around 4 to 8 MPa, after curing at 90°C or 120°C. Green parts were subjected to debind and sintering treatment to improve density and properties. Debound parts and parts sintered at different temperatures were subjected to microstructural examination to determine the effects of the binder on sintering. Fully sintered parts were subjected to HIP to achieve high density (~98%). Mechanical and thermal properties were evaluated in as-sintered and HIP conditions. Binder jet printed copper parts after HIP showed yield strength up to 80MPa, ultimate tensile strength 210MPa, elongation 55%, and thermal conductivity, typically 365W/m-K.

11:25 AM
Slurry-based Binder Jetting of Ceramic Casting Cores: *Patricia Erhard*[1]; Wolfram Volk[1]; Daniel Günther[1]; [1]Fraunhofer IGCV

The production of complex sand cores to represent internal contours in castings is typically achieved by powder-based binder jetting. However, a trade-off between the load-bearing capacity during casting and the subsequent removability from the cast part leads to design limitations. Slurry-based binder jetting allows the processing of fine powders and the economical production of sinterable ceramic cores. Its performance, potential, and challenges are presented in the context of the foundry process chain. As drying affects material properties and process efficiency, detailed investigations are carried out to control the properties via drying. Average roughness depths of 1.2 µm and flexural strengths of 25 MPa were achieved using aqueous quartz slurry and appropriate process parameters. By incorporating predetermined breaking lines into the internal geometry of hollow casting core structures, the stress generated during the solidification of the cast metal induces decoring. A promising process chain is outlined for producing efficient, close-contour coolings in high-performance castings and digital code tags for part tracking in foundries.

Modeling: CAD, Scan Patterns, Contouring, Slicing II

Tuesday AM — Room: Salon A
August 15, 2023 — Location: Hilton Austin

Session Chair: Gabriel Lipkowitz, Stanford University

8:15 AM
Demonstrating Paraflow: Interactive Fluid Dynamics Simulation with Real-time Visualization for Augmented Resin 3D Printing: *Gabriel Lipkowitz*[1]; Eric Shaqfeh[1]; Joseph DeSimone[1]; [1]Stanford University

Continuous liquid interface production (CLIP), a form of vat photopolymerization (VP), affords designers unprecedented geometric complexity in their products; however, currently CLIP requires cumbersome support structures that are materially wasteful, human labor-intensive, time-consuming to remove, and damaging to part surface finish. Recent physical demonstrations suggest injection through conduits embedded within the part itself can offset suction forces during CLIP. Here we demonstrate that in addition to increasing printing speeds, such injection can alleviate the need for supports. To demonstrate such improvements, we develop a novel fluid dynamics-guided computational inverse design tool, Paraflow. Paraflow takes as input a user's arbitrary 3D model for printing, formulates the design problem as a path planning optimization problem, and computationally designs a corresponding fluidic injection network that distributes one, or potentially multiple, materials during printing. We experimentally show such networks enable printing of farther unsupported overhang geometries than can current state-of-the-art CLIP methods.

8:35 AM
Methodical Approach to Reducing Design Time by using Neural Networks in Early Stages of Concept Development: *Manuel Ott*[1]; Iryna Mozgova[1]; Niclas Meihöfener[1]; [1]Paderborn University

Modern companies often face various challenges in concept development of products or systems. Design engineers prepare initial concepts and incorporate them into 3D models. These are then simulated by computational engineers. If requirements are not met, this necessitates an iterative process that runs between the design and computation departments until a concept that is valid for both sides is created. Design methods such as topology optimization are often used here. The upcoming result is then attempted to be adapted to certain manufacturing processes. These iteration loops can sometimes take a very long time, since the model construction and structural optimization generate large computational efforts. The present work shows on an example a methodical approach to solving this problem, including a description of methods and techniques, as well as possible problems in a detailed analysis concerning training data for neural networks and their abstraction capabilities.

8:55 AM

OpenVCAD: An Open Source Volumetric Multi-material Geometry Compiler: *Charles Wade*[1]; Graham Williams[1]; Robert MacCurdy[1]; [1]University of Colorado Boulder

Additive manufacturing has made significant advancements in multi-material fabrication techniques that allow for site-specific control of material deposition. With these advancements, design tools have fallen behind machine capabilities in accommodating volumetric information. Traditionally design and slicing workflows have expressed multi-material objects as several single-material bodies. The intense interest in compliant mechanisms and meta-materials demands a new design workflow that can support architecting material distribution throughout an object. To address these needs, we present OpenVCAD, an open-source volumetric design compiler with multi-material capabilities. OpenVCAD provides a scriptable suite of geometric and material design methods that enable efficient representation of complex objects with hundreds of materials. Through functional grading and convolutional blending, OpenVCAD allows for material distributions to be parameterized on spatial locations to yield complex multi-material distributions that would be impossible to describe using alternative workflows. We will demonstrate applications of OpenVCAD with additively manufactured meta-materials, compliant mechanisms, and 3D-electronics.

9:15 AM

Catalog of Triply Periodic Minimal Surfaces, Equation-based Lattice Structures, and Their Homogenized Property Data: *Joseph Fisher*[1]; Simon Miller[1]; Joseph Bartolai[1]; Michael Yukish[1]; Timothy Simpson[1]; [1]Pennsylvania State University

We have compiled a catalog of equation-based lattice structures that are derived from Triply Periodic Minimal Surfaces (TPMS) for which a low-order Fourier series fit is known. The Fourier series fit allows the TPMS to be modeled and manufactured. For each equation-based lattice the catalog includes images, homogenized elastic property data, an equation for implicit modeling, and CAD models. The information can help in selection and implementation of equation-based lattice structures for engineering applications. Using lattice structures in a design allows engineers to tailor the properties and response of a component independent of material and overall geometry. We discuss the methods used to generate and process the lattice property data, and provide examples of its use.

9:35 AM

Application of Implicit CAD System to Support Subtract-additive Hybrid Manufacturing: Jaeseung Ahn[1]; *Sang-in Park*[1]; [1]Incheon National University

Subtract-additive hybrid manufacturing systems have been developed to improve manufacturing time and cost for customized parts. However, CAD tools are limited to support design activities, such as modifying an original design for the hybrid manufacturing and detecting internal defects. In this research, we proposed an implicit CAD system and show applications to support design for additive manufacturing activities for subtract-additive manufacturing system. We considered two activities, model modification and defect detection. In the proposed CAD system, two function-fields are defined and utilized, which are signed distance and material function fields. The result shows the proposed algorithm effectively modified a CAD model to self-supported model, which can be fabricated with support structures. The proposed approach also estimates a distribution of defects as varying process parameters.

9:55 AM Break

10:25 AM

Adaptively Sampled Distance Functions: A Unifying Digital Twin Representation for Additive Manufacturing: Sam Pratt[1]; *Tadek Kosmal*[2]; Christopher Williams[2]; [1]NSWCCD/Virginia Tech; [2]Virginia Tech

Digital twin models for advanced manufacturing are constrained by the fundamental geometric representations that are currently used. Instead of a singular representation, mesh, voxel, and parametric surface representations all require multiple conversions along the digital design, manufacturing, and inspection processes. These conversions inherently introduce error and are time-consuming, complicate comparison of in-situ sensor data to the as-designed model, and result in a complex, fragmented process chain.We introduce a novel holistic digital twin representation based on a voxelized, GPU-accelerated, adaptively sampled distance function (ASDF). The framework enables rapid comparison of in-situ sensor data to as-designed models, provides a baseline representation of as-designed geometry for control systems, serves as a foundation for path planning tools, allows rapid comparison of sensor data to as-designed models, and as such, could enable real-time, online path planning during the manufacturing process.

10:45 AM

Depiction of Support Structures in Technical Drawings: Stefan Lammers[1]; *Thorsten Koers*[1]; Tobias Lieneke[2]; Detmar Zimmer[1]; Balazs Magyar[1]; [1]Paderborn University; [2]Paderborn University / Direct Manufacturing Research Center

To ensure uniform documentation of support structure information, a concept is presented that enables a standardized depiction of support structures in technical drawings based on DIN ISO 128-50. The drawing entry should contain all production-relevant support structure information and is intended to ensure a simple, clearly and safe exchange of information between business units or different companies. Therefore, the state of the art of support structures is determined first. Secondly, requirements for a useful depiction of support structures are presented. At the end a procedure to depict the support structures in technical drawings with respect to existing standards of drawing entries is defined. Different support structure types can be documented by using a specification field. The specification field gives a detailed description of the support structure type, the geometry and the connection to the part and the building platform. Also, uncommon support structure types like lattice structures can be implemented.

11:05 AM

Additive Manufacturing and the Moving NDT Target: Cole Vaughan[1]; *Bill Hayes*[1]; [1]Waygate Technologies

For engineers and manufacturers, additive manufacturing holds an unprecedented promise. It is an engineering marvel that enables the creation of highly complex, technically intricate and customizable three-dimensional parts, while wreaking havoc on the world of NDT and the inspectors needing to validate it. An overview of typical additive defect and indications types will be presented, along with possible solutions and tools for visualizing and inspecting them. We will also highlight the many challenges that still lie ahead for the CT inspection of additive parts to meet the demanding criteria of design engineers and drawing requirements, as well as the substantiation of our NDT methods to meet these.

11:25 AM

G-Wing: A Novel Software Tool for Toolpath-Centric Design of Wings for Material Extrusion: *Justin Valenti*[1]; Joseph Batolai[1]; Michael Yukish[1]; [1]Pennsylvania State University

A novel software tool for the rapid design of a small aircraft wing to be fabricated with material extrusion is presented. The tool, named GWing, uses rapid design algorithms based on lifting line theory to determine the outer-mold line of the wing based on desired aerodynamic behavior. The resulting wing shape and flight-load distribution are given to a structural design algorithm to determine the internal structure of the wing based on both expected flight loads and manufacturing constraints. Finally, manufacturing instructions in the form of gcode are created directly from the wing shape and internal structure. This process removes explicit geometric modeling and slicing from the critical design path and directly converts airfoil coordinates to perimeter gcode points, minimizing the introduction of geometric error. This process has been used to design and fabricate multiple small aircraft wings that have successfully flown.

11:45 AM

Transmitting G-Code with Geometry Commands for Extrusion Additive Manufacturing: *Alex Roschli*[1]; Michael Borish[1]; Liam White[1]; Cameron Adkins[1]; Celeste Atkins[1]; Abigail Barnes[1]; Brian Post[1]; Zac DiVencenzo[2]; Charlie Dwyer[2]; Gaven Rudiak[2]; Brian Zellers[2]; [1]Oak Ridge National Laboratory; [2]Juggerbot3D

G-code refers to text-based commands used to instruct a 3D printer how to construct an object. G-code is generated to represent each toolpath during the slicing process. Each toolpath is represented as a list of points that define the trajectory of the path to be printed. Additional commands are included to define the motion velocity and extrusion rate, called the feeds and speeds. These toolpaths and commands must be generated specific to the machine, material, and calibration settings that will be used during the print. This paper outlines a new approach for the slicing and g-code creation process that eliminates the need for outputting feeds and speeds in the slicing process. Instead, the slicer outputs g-code that defines the desired bead geometry as printed. The 3D printer can then read this geometry data and calculate the necessary feeds and speeds based on internal calibration data to successfully print the object.

Applications: Lattices and Cellular II

Tuesday AM — Room: Salon B
August 15, 2023 — Location: Hilton Austin

Session Chair: Jack Beuth, Carnegie Mellon University

8:15 AM

Experimental and Numerical Investigations on Dynamic Mechanical Properties of TPMS Structures: *Deepak Kumar Pokkalla*[1]; Jier Wang[2]; Brandon Turner White[3]; Ryan Spencer[3]; Ajit Panesar[2]; Seokpum Kim[1]; Uday Vaidya[3]; [1]Oak Ridge National Laboratory; [2]Imperial College London; [3]University of Tennessee

Triply Periodic Minimal Surface (TPMS) lattice structures have been of increasing interest due to their light weighting, enhanced mechanical properties, and energy absorption characteristics for automotive and biomedical applications. With the advent of additive manufacturing and geometric modeling software, TPMS lattices with complex geometries can be realized. In this work, several TPMS lattice structures were fabricated using fused filament fabrication (FFF) and characterized through a combination of experimental and numerical investigations. Although lightweight TPMS lattices are beneficial for their impact absorption capability, most of the existing works are limited to quasi-static compression and dynamic impact tests are rarely performed. The current study investigates the stress-strain and energy absorption characteristics of TPMS lattices through drop tower testing and numerical modeling. Finite element modeling for TPMS lattices is carried out with experimental validation. The mechanical properties, deformation, and failure mechanisms of TPMS lattices under dynamic impact are summarized for potential future applications.

8:35 AM

Behavior of Additively Manufactured Plate-lattice Structures in Quasi-static, Dynamic, and Ballistic Testing: *Joseph Berthel*[1]; Yayati Jadhav[1]; Chunshan Hu[1]; Rahul Panat[1]; Jack Beuth[1]; [1]Carnegie Mellon University

The manufacturing of complex lattice structures is made possible through additive manufacturing. Among the different possible lattice topologies, plate lattices have attracted attention for ballistic impact applications because of their potential for high energy absorption at low relative weights. Here, we manufacture and study different plate lattice topologies in three different mechanical tests: quasi-static compression, Split Hopkinson Pressure Bar dynamic compression, and ballistic impact. Plate lattice samples were manufactured using laser powder bed fusion, where plate lattice topology and volume fraction were varied. Stress-strain behaviors were extracted from compression testing and specific energy absorptions were calculated. Specific energy absorptions and ballistic penetration resistances were compared to determine the effect of plate lattice topology and volume fraction. Finite element simulations of the mechanical tests were also performed and compared to experimental test results.

8:55 AM

Out-of-plane Mechanical Properties of Additively Manufactured Fractal Reinforced Structures: *Mario Martinez Magallanes*[1]; Enrique Cuan-Urquizo[1]; Erick Ramírez-Cedillo[1]; Armando Roman-Flores[1]; [1]Tecnológico de Monterrey

Architected materials are an emergent kind of materials that gain their physical properties from their rationally designed micro-structures. They are normally conformed by regular unit-cells repetition, but other variations, such as hierarchal, aperiodic, and graded arrangements have also been explored as well. Here we propose an approach consisting of using fractal geometry to control the mechanical response of the metamaterials. We designed a set of 11 different arrangements based on the self-filling Hilbert fractal, the set consisted of 3 different iteration orders at 3 different matching relative densities, and two other graded arrangements. The samples were fabricated using a Micro-LCD 3D-printer and tested under out-of-plane loads. The test was performed using a texturometer with a spherical probe impregnated with red paint to characterize the conformability of the samples. Force and displacement were recorded to compare the mechanical response of the samples against the fractal parameters and obtain the structure-property relation.

9:15 AM

Experimental Characterization of the Mechanical Properties of 3D Printed Bézier-based Lattice Beams: *Alberto Álvarez-Trejo*[1]; Enrique Cuan-Urquizo[1]; Armando Roman-Flores[1]; [1]Tecnologico de Monterrey

Architected materials are widely used in additive manufacturing to reduce weight. The controlled arrangement of material allows to tailor their mechanical properties by tuning their geometrical parameters. A parametrization based on cubic Bézier curves is employed here to generate lattice-beams by changing the position of a free control point. Two topologies with the same volume fraction and base curve for the lattice constituent elements at different positions are studied and compared. Lattice beams are manufactured via Fused Filament Fabrication of polylactic acid. The effective stiffness and yield stress of these lattice-beams is analyzed experimentally using three-point bending tests. Adjusting the control point location leads to tailoring the effective mechanical properties of the lattice-beams. This methodology leads to the synthesis of architected topologies with customized mechanical properties.

9:35 AM

Strength Enhancement of Cellular Structures Through Selective Reinforcement of Elements Based on Analytical Modeling: *Naresh Koju*[1]; Li Yang[1]; [1]University of Louisville

This work investigate the strength enhancement of cellular structures via individual element thickness optimization based on the analytical model for critical elements. In order to focus on the investigation of the enhancement method, a rather simplified perfectly elastic material property was assumed, and an analytical model was utilized to identify the critical element of a number of cellular structure designs. Stepwise element thickness enhancement was utilized to investigate the effectiveness of overall strength enhancement. The results indicate that the strength of cellular structures can be improved by selectively reinforcing critical elements. In addition, the enhanced cellular structures also exhibit altered fracture failure characteristics that could potentially be exploited for more application objectives.

9:55 AM Break

10:25 AM
3D Printing of Passive Microfluidic Flow Mixers using Triply Period Minimal Surface Microlattice Structures: *Mazher Mohammed*[1]; [1]Loughborough University

Microfluidics are miniaturised devices useful for precision fluid handling phases when conducting a range of chemical reactions or biological processes. Such devices operate at micrometre length scales, where laminar flow dominates and so interactions are limited to diffusion between the flowing liquid interfaces unless flow is made turbulent to induce mixing. Passive mixers are desirable for this task as they comprise geometrical features which can be incorporated during the fabrication of such devices. Designs largely remain planar due to traditional microfluidic manufacturing being conducted with 2.5D fabrication processes. Additive Manufacturing now allows for passive mixers to now be realised in true 3D but have seen limited investigation. This study explores the efficacy of several miniaturised Triply Period Minimal Surface micro-lattice structures, formed within microfluidic channels as turbulence inducing structures for increased mixing. We explore several lattice designs and report on their efficacy for mixing reactions conducted during continuous flow conditions.

10:45 AM
Tailoring Anisotropic Material Properties of Hierarchical Lattice Structures through Strut Diameter and Orientation Variations: Implications for 3D-printed Ti6Al4V Lattices: *Ata Babazadeh Naseri*[1]; Jason Ye[1]; Benjamin Fregly[1]; C. Fred Higgs[1]; [1]Rice University

Functional grading of strut diameters and orientations within hierarchical lattice structures (HLSs) offers the potential to achieve complex mechanical properties, including material anisotropy. However, the extent to which the desired anisotropy can be materialized in 3D-printed HLSs remains unclear. Here, we report on the experimental characterization of anisotropic mechanical properties in 3D-printed HLSs manufactured using Ti6Al4V alloy. Four anisotropic HLS designs were created by varying strut diameters or orientations on an 8-by-8-by-8 array, and 21 samples were fabricated and tested in two principal directions. Digital image correlation was used to record the deformations. We found that strut orientations were slightly more effective than strut diameters in generating stiffness anisotropy. However, statistical significance could not be established for the stiffness due to variations within samples of the same design. In contrast, the effective yield strength exhibited significant anisotropy. Our findings provide guidance for tailoring the material properties of 3D-printed HLSs.

11:05 AM
Building Equation-based Lattice Structures using Large Minimum Feature Size AM Processes: *Joseph Bartolai*[1]; Joseph Fisher[1]; Simon Miller[1]; [1]Pennsylvania State University

This work discusses the challenges of 3D printing equation-based lattice structures where the ratio of wall thickness to AM process minimum feature size is quite small. Lattice structures are typically constructed with unit cell sizes where the AM minimum feature size is much smaller than that of the lattice's structural thickness. This is not always possible for certain AM processes (e.g., DED, WAAM) at unit cell sizes and volume fractions where a lattice would be most beneficial. Results of this study include: a design space within which fabrication of a lattice structure is possible with a large minimum feature size AM process; modifications necessary to ensure a lattice structure is producible; and simulated changes to unit cell mechanical properties based on these geometric modifications. Work presented explores the Gyriod and D-surface equation-based lattices using Material Extrusion AM (MEX) and discusses the lessons learned and extension for Directed Energy Deposition.

11:25 AM
Quasistatic Energy Absorption in Aperiodic Cellular Materials: Irving Ramirez-Chavez[1]; Mandar Shinde[1]; *Dhruv Bhate*[1]; [1]Arizona State University

Cellular materials have been used for decades for their energy absorbing properties. These have typically been either honeycombs or open cell foams, the former representing a periodic distribution of cells, the latter a stochastic one. Recently however, several studies have demonstrated the potential for additively manufactured cellular materials as energy absorbers, but the majority of them have been focused on periodic cellular designs. In this work, we present a classification of aperiodic cellular materials, followed by a discussion of studies that examined the influence of aperiodicity on the energy absorption properties, for three types of modifiers: hybridization, perturbation, and gradation. These experimental and numerical studies were conducted on honeycombs and surface-based cellular structures under quasistatic compression. Our findings suggest that aperiodicity does occasionally benefit energy absorption behavior, but that these benefits depend on how the underlying cellular topology and the aperiodicity influence the failure patterns that develop during compression.

Wire-fed DED: Machine Learning and AI Application

Tuesday AM — Room: 602
August 15, 2023 — Location: Hilton Austin

Session Chair: Benjamin Bevans, Virginia Tech

8:15 AM
Monitoring of Process Stability in Laser Wire Directed Energy Deposition using Machine Vision: Anis Asad[1]; *Benjamin Bevans*[1]; Jakob Hamilton[2]; Iris Rivero[2]; Prahalada Rao[1]; [1]Virginia Tech; [2]Rochester Institute of Technology

The goal of this work is to mitigate flaw formation in parts made using the laser wire directed energy deposition (LW-DED) additive manufacturing process. As a step towards this goal, the objective of this work is to use real-time data from a meltpool imaging sensor to detect process instabilities. This is an important area of research, as LW-DED process tends to incessantly drift due to poorly understood thermophysical phenomena and stochastic effects. To realize the foregoing objective, we developed a machine learning model that acquires real-time imaging data, and automatically classifies the process state into one of four possible regimes: stable, dripping, stubbing, and incomplete melting. Through single track experiments conducted over 128 conditions, we show that the approach is capable of accurately classifying the process state with a statistical fidelity approaching 90% (F-score).

8:35 AM
Real-time Monitoring of Directed Energy Deposition Additive Manufacturing Process Using Multiple Sensors and Machine Learning: *Shuchi Khurana*[1]; Petros Apostolou[1]; Bradley Jared[2]; Josh Norton[2]; Steven Williams[2]; Eduardo Miramontes[2]; Charles Babbitt[1]; [1]Addiguru; [2]The University of Tennessee, Knoxville

Additive manufacturing of components via Directed Energy Deposition (DED) is a complex process involving melt pool dynamics, high cooling rates, power fluctuation, changes in feedstock flow, gas flow, etc. contributing to process instability and failed parts. It has been recognized that in-situ monitoring can be used to measure and control the bead shape, hence build geometry, helping save significant time and money by reducing part failures. Addiguru in collaboration with the University of Tennessee, Knoxville demonstrated the feasibility to fuse data from Short Wave Infrared (SWIR) and Long Wave Infrared (LWIR) cameras for measurement and control of bead shape.A dependency on bead size and inter-layer temperature (ILT) was observed. An experiment showed that the bead size or shape can be controlled in real-time to reduce issues that cause process instability and part failure.

8:55 AM

Thermal Imaging for Wire Arc Additive Manufacturing Using an Off-the-shelf Color Camera: *Gala Solis*[1]; Alex Myers[1]; Guadalupe Quirarte[1]; Mikhail Khrenov[1]; Sneha Narra[1]; Jonathan Malen[1]; [1]Carnegie Mellon Univeristy

Process modeling and process monitoring are key to the adoption of additive manufacturing. For this purpose, imaging methods have attempted to measure weld pool temperature fields in wire-arc additive manufacturing (WAAM). A major challenge in estimating temperatures from monochromatic or infrared cameras is the need-to-know spectral emissivity. A novel two-color method is used to reduce sensitivity to the spectral emissivity by taking the signal ratio from two channels of an RGB color camera and correlating with the temperature predicted by Planck's law, given the spectral sensitivity of the camera. Images are captured with varying exposure times and apertures to generate a full thermal field, along with a set of bandpass filters to reduce interference from plasma arc emission. These in-situ measurements can be used for model validation/calibration and flagging weld pool anomalies, thus furthering process parameter development, optimization, and monitoring.

9:15 AM

Toolpath Planning Approach for Parts with Multiple Revolving Features for Wire Arc Additive Manufacturing.: *Wei Sheng Lim*[1]; Gim Song Soh[1]; [1]Singapore University of Technology and Design

In wire arc additive manufacturing, existing toolpath planner for complex 3D shapes such as propellers and turbines, with multiple revolving features radiating tend to utilize a cylindrical slicing approach. Such slicing approach are highly customized, complex, and not readily available for printing such 3D shapes. In addition, such complicated motion planning requires coordination between the print head and substrate motion to be synchronized well which can be difficult to achieve. In this paper, we propose an alternative strategy using planar slicing and adaptive width contour-based toolpath planner. To achieve this, a two-step approach is proposed with the substrate and radiating elements treated as separate features. The substrate is printed with part of the revolving feature, providing a flat surface for the second step to print from. The approach is applied for a propeller over 0.7m in diameter where a 3D scan is done to compare with the part model.

9:35 AM

Towards a Generic Deposition Model in Wire-arc Directed Energy Deposition: A Deep Learning-based Wetted Area Prediction Model: *Magnus Glasder*[1]; Maicol Fabbri[2]; [1]ETH Zurich | IWF / AMLZ; [2]ETH Zurich | IWF / AMLZ / inspire AG

Wire-arc directed energy deposition poses significant challenges in accurately predicting the geometry of weld beads, particularly regarding the overlap and stacking of multiple beads. This is due to the complex interaction between electric arc and previously deposited layers. Existing methods are inadequate in capturing this relationship for arbitrary layer geometries. A novel approach is proposed, which separates the prediction task into wetted area and shape prediction. The wetted area is predicted using a deep learning model, while shape prediction is achieved through an energy minimization technique, which places no assumptions on bead geometry. The wetted area prediction is treated as a computer vision task. 3D surface scans of the workpiece, welding parameters, and torch positions are encoded into images. A pre-trained vision network is fine-tuned on these images to predict the wetted area. The presentation emphasizes the machine learning aspect of the approach and delves into data management and pre-processing.

9:55 AM

Uncovering Fundamental Process Deficiencies in Wire-laser Directed Energy Deposition using In-situ High Speed Imaging: *Jakob Hamilton*[1]; Anis Assad[2]; Benjamin Bevans[2]; A. Cardinali[1]; Prahalada Rao[2]; Denis Cormier[1]; Iris Rivero[1]; [1]Rochester Institute of Technology; [2]Virginia Tech

Wire-based directed energy deposition (DED) offers key advantages over their powder counterparts but retains several major hurdles in becoming a push-button additive manufacturing technology. While powder DED provides high resolution, localized metallic deposition capabilities, it has yet to widely penetrate industrial manufacturing environments for several reasons. Powder safety, reactivity with oxygen, and low recyclability provide onerous economic and environmental barriers. Compared to atomized powder, wire requires considerably fewer safety precautions and resources during feedstock production and use. When implemented in laser DED, wire circumvents these limitations and shows promise for high-resolution, high-throughput manufacturing. This work outlines state-of-the-art limitations for wire-laser DED. Process deficiencies are captured using high-speed in-situ optical imaging and classified into several categories: incomplete melting, balling, stubbing, and stable deposition. Auxiliary deficiencies including substrate material and shielding gas coverage are also explained along with remediation strategies. Future strategies are suggested for transitioning nascent wire-laser DED into mainstream manufacturing.

Applications: Residual Stress

Tuesday AM | Room: 615 AB
August 15, 2023 | Location: Hilton Austin

Session Chair: Ming Leu, Missouri University of Science and Technology

8:15 AM

Distortion and Residual Stress Mitigation of Large Parts for Wire-arc Additive Manufacturing: *Wen Dong*[1]; Xavier Jimenez[1]; Carter Gassler[1]; Albert To[1]; [1]University of Pittsburgh

Wire arc additive manufacturing (WAAM) has drawn increasing attention due to its ability to print large metal parts. However, thermal gradients during the process can result in significant residual stress and distortion, negatively affecting product quality and making post-processing more difficult. In the present work, we have implemented several strategies when printing a part ~900 mm long to mitigate these issues. Firstly, a fixture designed based on topology optimization is attached to the baseplate to reduce distortion. However, cracks were observed in the baseplate near the deposit ends after the first trial. Then, we carefully examined and modified the deposit and baseplate shapes to further reduce the residual stress. The second trial successfully printed a part that met the required specifications. Due to its high accuracy and low cost, the modified inherent strain (MIS) method is employed to predict the distortion and residual stress for fixture design and shape modification.

8:35 AM

Effect Of Inter-layer Dwell Time on Residual Stresses in Directed Energy Deposition: *Ranjit Joy*[1]; Sung-Heng Wu[1]; Usman Tariq[1]; Muhammad Arif Mahmood[1]; Frank Liou[1]; [1]Missouri University of Science and Technology

Metal Additive Manufacturing is being rapidly adopted by various industries to manufacture customized products and parts having complex designs. However, high thermal gradients between the parts and substrate often results in residual stresses in the final deposit, adding hindrance to the adoption of metal AM for critical applications. Parameter optimization often helps in residual stress mitigation. The current research aims to study the effect of inter-layer dwell time on residual stresses in directed energy deposition. Three levels of Inter-layer dwell time at high and low levels of volume energy density were deposited. Residual stresses of each sample were analyzed to identify the influence of variation of inter layer dwell time

8:55 AM
Quantification of Residual Stress in Directed Energy Deposition Additive Manufacturing via Bridge Method: *Joshua Taggart-Scarff*[1]; Stephen Cluff[2]; Clara Mock[2]; Brandon McWilliams[2]; [1]Survice Engineering Company; [2]DEVCOM Army Research Laboratory

Residual stress buildup in additively manufactured parts can result in cracks, part delamination, and other warpage in the final part. Current methods of evaluating residual stress in directed energy deposition (DED) additively manufactured parts are either non-quantitative or are complex, expensive, and time consuming. Quantification of residual stress in additively manufactured parts is key to validating models that accurately predict the effects of processing parameters on mechanical properties and part geometry. Bridge structures were built via DED using three different hatch-fill strategies. After completion of the build, a section of the bridge feet was removed creating a cantilever beam section. The deflection of the cantilever beam section was measured using a coordinate measuring machine and compared to the predictions of a fast part-scale residual stress model. The method developed can lead to more efficient predictions of residual stress formation for DED additively manufactured parts.

9:15 AM
Residual Stress Analysis of Laser Powder Blown Inconel 718 Across Different Overhang Angles and Laser Outputs: *Alejandro Hernandez*[1]; Kurtis Watanbe[1]; Dajalma Garcia[1]; Kevin Wheeler[2]; Francisco Medina[1]; Ryan Wicker[1]; [1]W.M. Keck Center for 3D Innovation; [2]National Aeronautics and Space Administration

Directed Energy Deposition (DED) is an increasingly utilized additive manufacturing (AM) method to reproduce tough and utilitarian components for fields such as Aerospace. These components, however, are subject to a unique thermal process that impacts their mechanical properties. Such properties include the residual stress concentration and its direction, deformation, and microstructural composition of a component. Since the thermal fluctuations derive from the printing process itself, it is possible that the mechanical properties are impacted by other DED printing parameters. By using an Inconel 718 powder feedstock in Laser Powder blown Directed Energy Deposition (LPF-DED), a series of coupons with four different overhang angles of 0-, 20-, 30-, and 35° printed with different laser power outputs (1070W and 2000W) to observe these properties. These coupons will be analyzed using both non-destructive and destructive methods to record how these parameters mechanically affect the prints.

9:35 AM
A Data Driven-based Geometric Compensation Method for Laser Powder Bed Fusion: *Wen Dong*[1]; Basil Paudel[1]; Albert To[1]; [1]University of Pittsburgh

The residual stress and deformation induced during the laser powder bed fusion (L-PBF) process can degrade the performance and quality of the products and increase the difficulty of post-processing like machining and cutting. The present work develops a data driven-based geometric compensation method to reduce the part distortion in L-PBF processes. The method includes four steps: (1) collect distortion data based on both numerical simulations and experimental measurement; (2) implement principal component analysis to reduce the data size and extract features that account for 99.99% of the total energy; (3) train the Gaussian process model for each feature to establish relationships between the initial and as-built shape of a part; (4) apply the trained model to generate the compensated geometry so that the as-built shape is the desired one. The experimental validation shows that the proposed approach is able to effectively improve the geometric accuracy of the as-built part.

9:55 AM Break

10:25 AM
In-situ Residual Stress Evaluation in Laser Powder Bed Fusion by Infrared Thermography: *Tao Liu*[1]; Edward Kinzel[2]; Ming Leu[1]; [1]Missouri University of Science and Technology; [2]University of Notre Dame

Residual stresses, caused by non-uniform heating, in the parts produced by laser powder bed fusion (LPBF) can lead to geometric errors as well as mechanical defects such as cracks. This paper presents the potential for predicting residual stresses in-process using data obtained from in-situ infrared thermography. The measured surface temperature is used to rapidly predict the part's interior temperature field using a Green's function approach. The stress field is then predicted from the temperature field and the residual stresses are estimated from an elastic-plastic analysis. The predicted residual stress is compared to experiments LPBF printed cantilevers by measuring the deflection after the parts are removed from the build plate. This method can be used to select process parameters that minimize residual stress, as well as detecting and correcting defects as they occur.

10:45 AM
Resonant Ultrasound Spectroscopy Modeling of Hybrid Metal Additive Manufacturing Samples with Residual Stresses: *Jazmin Ley*[1]; Cristian Pantea[2]; John Greenhall[2]; Joseph Turner[1]; [1]University of Nebraska - Lincoln (UNL); [2]Los Alamos National Laboratory

Hybrid additive manufacturing (AM) involves secondary processes or energy sources to alter specified locations within the build. Each hybrid step can refine the grain size, increase dislocation density, or modify residual stresses. Typically, the changes in mechanical properties are not confined within a single layer but have a compounding effect on preceding layers. Control of properties within a build can enhance component performance but unique challenges remain for nondestructive validation of such samples. Traditional ultrasonic methods on hybrid-AM components have successfully mapped material variations with sufficient spatial resolution. However, the use of resonance ultrasound spectroscopy (RUS) for hybrid-AM is less developed. In this presentation, finite element models are used to examine the sensitivity of RUS measurements in terms of frequency shifts and mode shapes with respect to specific layers of residual stress. The RUS model provides new insights for experimental results from hybrid-AM samples of stainless steel with milled layers.

11:05 AM
The Effect of LaserSscan Strategy on Residual Stress of Titanium Alloys Using Laser Foil Printing Additive Manufacturing Processes: Ting-Chun Huang[1]; *Chia-Hung Hung*[1]; [1]National Cheng Kung University

In this study, we investigated the effect of two different scan strategies, line pattern scanning (LPS) and spot pattern scanning (SPS) strategies, on the residual stress for the fabrication of Ti-6Al-4V parts by using the laser-foil-printing (LFP) process. The residual stress of LFP-fabricated parts was measured through X-ray diffraction (XRD). The XRD and simulated results indicate the residual stress of part made by SPS can be significantly reduced by 55% compared part made by LPS because LPS scanning length is clearly larger than SPS scanning length. No accumulation of residual stress occurs when using SPS in LFP. Besides, SEM images and XRD patterns show the cross section of LPS is dominated by α' phase while the cross section of SPS is consisted of α phase and β phase. Thus, the residual stress of Ti-6Al-4V parts can be reduced effectively in LFP by using a SPS strategy.

Fiber Composites

Tuesday AM August 15, 2023 | Room: 616 AB | Location: Hilton Austin

Session Chairs: Roneisha Haney, Air Force Research Laboratory; Xiangyang Dong, Missouri Univ of Science and Technology

8:15 AM

3D Printing of Continuous Stainless Steel Fiber Reinforced Polymer Composites: *Alison Clarke*[1]; [1]University College Dublin

This study investigates for the first time, the incorporation of stainless steel fibers (SSF), as a reinforcement for 3D printed polymer parts. The steel fibre bundle contains 90 fibers each of 14 µm diameter. Polylactic acid (PLA) is co-extruded with the SSF to fabricate PLA-SSF filaments, with a diameter of approximately 0.5 mm. A fused filament fabrication technique was used to print composites, with a fibre volume fraction of up to 30%. Good polymer ingress around the individual steel fibers was demonstrated and part porosity levels down to 2%, were achieved (based on CT scans). Particular attention was given to achieving a homogeneous distribution of the steel fibers within the printed PLA-SSF composites. The composites' exhibited a six-fold increase in interlaminar shear strength (ILSS), compared with PLA only parts. The values obtained of up to 28.5 MPa are significantly higher than the approx. 13 MPa obtained for glass fibre composites.

8:35 AM

3D Printing of High-performance Carbon Fiber Composites via Modified Drop-on-demand Method: John Pappas[1]; *Xiangyang Dong*[1]; [1]Missouri University of Science and Technology

This study presents a novel method to fabricate high-strength, continuous-fiber composites through a hybrid drop-on-demand and stereolithography technique. Photopolymer resin was selectively applied onto strategically placed carbon fiber. Control of the composite fiber volume fraction was achieved through compression of the resin-infused carbon-fiber layer using a custom glass plate. Laser-assisted curing resulted in high-resolution semi-cured continuous fiber composites. A thermal post-curing procedure was utilized to achieve the final properties of the printed composites. The effect of electrophoretically deposited nanoporous carbon-nanotube coatings was also investigated to evaluate resin impregnation efficiency due to capillary forces, and hence mechanical properties by three-point bending test on printed test specimens. The microstructure of the resulting composites was also characterized. This study demonstrated the feasibility of fabricating high-performance carbon fiber composites using drop-on-demand printing techniques, while providing potential for customization of mechanical properties through control of fiber placement.

8:55 AM

Core-shell-structured High Strength Composite with 3D Aligned Carbon Fiber via Embedded 3D Printing: *Qiyi Chen*[1]; [1]University of California, Berkeley

The orientation of carbon fibers, induced by shear forces during extrusion, has been demonstrated to significantly enhance mechanical properties, albeit primarily in a two-dimensional (2D) x-y plane. In this study, we present a novel approach for achieving fiber alignment in a three-dimensional (3D) context, with an emphasis on the Z-direction, by utilizing embedded 3D printing techniques. This process involves the extrusion and suspension of composite inks within a viscoelastic gel medium. The embedded printing technique enables the creation of complex architectures that exhibit well-known high-strength characteristics, such as the octet lattice structure. Furthermore, by tailoring specific formulations of elastic-gel resin and stiff-ink resin, we generate an elastic core-stiff shell structure featuring covalent adhesion, which concurrently exhibits remarkable strength and toughness properties.

9:15 AM

Direct Ink Writing of Frontally Polymerized Polymer Matrix Reinforced with Continuous Carbon Fiber Tows: *Nadim Hmeidat*[1]; Michael Zakoworotny[1]; Philippe Geubelle[1]; Sameh Tawfick[1]; Nancy Sottos[1]; [1]University of Illinois Urbana-Champaign

The development of next-generation high-performance polymer composites for advanced manufacturing demands rapid, versatile, and energy-efficient manufacturing strategies. This work presents a novel approach for the fabrication of frontally-polymerized continuous carbon fiber-reinforced thermoset tows. The proposed process combines the advantages of direct ink writing, pultrusion and frontal-polymerization to enable tow extrusion and consolidation, in-situ curing, and rapid manufacturing of free-standing composite members with reduced processing time, energy, and cost. In this process, a pre-impregnated fiber tow is extruded and then pulled through heated rollers to compact the tow, cure the resin, and form the composite. We investigate the effects of compaction, extrusion rate, and roller temperature on the cure kinetics, front location, fiber volume fraction, and thermo-mechanical properties of the resulting composites. A homogenized thermo-chemical model is developed to capture the effect of process parameters on heat transfer in the tow and curing of the resin, and is compared with experiments.

9:35 AM

Effect of the Print Bed Temperature on Void Distribution and Fiber Orientation within the Microstructure of Short Carbon Fiber Reinforced/ABS Manufactured via Large Area Additive Manufacturing: *Neshat Sayah*[1]; Douglas Smith[1]; [1]Baylor University

Short carbon fiber-reinforced polymer composite structures produced using Large Area Additive Manufacturing (LAAM) have garnered significant attention due to the design flexibility, energy savings, and materials selection associated with this process. However, the physical and mechanical properties of the additively manufactured composite parts often fall below expectations due to void formation between printed beads and within the microstructure of individual beads. This study aims to investigate the effect of bed temperature on the microstructure within the beads of two bead layer Short Carbon Fiber reinforced Acrylonitrile Butadiene Styrene (SCF/ABS) manufactured via the LAAM system. This study employs high-resolution 3D micro-computed tomography (µCT) to evaluate the void shape, and distribution within the microstructure of composite parts printed at various bed temperatures. The results of this study demonstrate substantial variation in the void volume fraction among four bead sets deposited at different print bed temperatures. Moreover, within each part, a noticeable discrepancy in void volume fraction is observed between the top and bottom bead of the two-bead test samples. Preliminary results indicate that increasing the bed temperature from 25°C to 75°C reduces void volume fraction within the microstructure of the composite parts. However, an opposite trend emerges when the bed temperature is further increased to 100°C, increasing void volume fraction, which needs further investigation to understand. This study also evaluated the void shapes through the calculation of their sphericity. The preliminary results reveal that as the bed temperature is increased from 25°C to 75°C, the voids exhibit higher sphericity within the printed parts as the amount of interconnected voids decrease.

9:55 AM Break

10:25 AM

Machine Learning-Assisted Prediction of Fatigue Behaviour in Fiber-Reinforced Composites Manufactured via Material Extrusion: Mithila Rajeshirke[1]; Suhas Alkunte[1]; *Orkhan Huseynov*[1]; Ismail Fidan[1]; [1]Tennessee Tech University

The recent advancements in material extrusion (MEX) have expanded the potential use of polymeric and composite structures in a wide range of structural and load-bearing applications. However, cyclic loads can induce fatigue, resulting in the development of structural damage and potentially leading to catastrophic failure at lower stress levels compared to normal mechanical loading. Therefore, it is crucial to thoroughly investigate and understand the fatigue behavior of composite parts manufactured using MEX. Predicting the fatigue life of polymeric composite components poses a significant challenge due to the complex nature of the materials involved. In this research, the aim is to utilize machine learning techniques to predict the fatigue life of fiber-reinforced composites produced through the MEX process. Machine learning (ML) focuses on developing models that can learn from data, recognize underlying patterns within the data, and use those patterns to make accurate predictions or decisions.

10:45 AM

Process and Material Optimisations for Integration of Chopped Glass Fibres in Laser Sintered Polymer Parts: *Hellen De Coninck*[1]; Arnout Dejans[1]; Sebastian Meyers[1]; Sam Buls[1]; Yannis Kinds[1]; Jeroen Soete[1]; Peter Van Puyvelde[1]; Brecht Van Hooreweder[1]; [1]KU Leuven

Additively manufactured polymer composites gain popularity in a variety of industries such as aerospace, biomedical and automotive. Laser sintering (LS) is a well-known AM process that typically uses polyamide which can serve as matrix material. Hence, LS has potential to produce reinforced polymers that can meet demanding requirements. In previous research, issues with powder flowability and poor fibre dispersion led to limited increase of mechanical properties. To overcome this, a novel fibre deposition system was recently developed and optimised at KU Leuven to successfully produce fibre reinforced LS samples with random inter- and intralayer fibre orientations. A limited but promising influence of deposited glass fibres on produced LS parts was noted after mechanical testing. In this work, the influence of different (heat) treatments on glass fibres used during LS will be discussed as well as the resulting differences in the fibre/matrix behaviour as analysed by means of hot stage microscopy.

11:05 AM

Additive Manufacturing of Continuously Reinforced Thermally Curable Thermoset Composite: *Kelvin Fu*[1]; [1]University of Delaware

Additive manufacturing of lightweight and energy-efficient composite using continuous fibers to reinforce thermoset polymers is highly desirable. However, the material, architectural, and technical limitations make existing AM technologies unavailable for printing structural and functional thermoset/continuous carbon fiber composite. In our work, we overcome these difficulties and introduced a new AM technology by creating a controllable resin system and a dynamic curing window to enable fast solidification of composite to hold the shape, realizing a feasible 3D printing of thermoset/continuous carbon fiber composite with near net shape, complex geometry, and programmable performance. Our process enables us to print composite with overhanding structure in free space, without need for support material. This AM technology provides a new 3D printing concept and process knowledge beyond existing AM technologies to potentially enable high throughput processing and geometric complexity of printed composite, and could promisingly produce a transformative impact on the upgrade of additive manufacturing.

Polymers: Functional Materials

Tuesday AM	Room: Salon F
August 15, 2023	Location: Hilton Austin

Session Chair: Allison Murray, Marquette University

8:15 AM

A Comparison of Mechanical Properties from Natural and Process Induced Interfaces in Filament Extrusion Additive Manufacturing of Polymer Blends: *Camden Chatham*[1]; Donald Benza[1]; [1]Savannah River National Lab

Polymer blends are commonly tuned for specific applications to achieve desired properties otherwise inaccessible or prohibitively expensive to obtain via homopolymers. The interfacial characteristics of the polymer A-polymer B interface and resultant domain sizes govern key performance properties. Micro- and meso-scale morphology forms through the interplay of surface forces between the polymers and between each polymer and the surrounding atmosphere. Analogously, the layer-layer and road-road interfaces of material extrusion (MEX) additive manufacturing (AM) govern key performance properties of printed parts. This work explores the effect of layer height (i.e., number of interfaces) on the thermomechanical performance of polystyrene (PS)-polycarbonate (PC) blends. Filament is prepared from a 50/50 weight ratio of the two polymers and compared against dual-nozzle printing where every layer alternates between PS or PC homopolymer forming a part with an overall 50/50 polymer ratio. Typical indicators of polymer blend compatibility are also studied.

8:35 AM

A Novel 4D Printing Approach for Freeform Electronics: *Xinyi Xiao*[1]; [1]Miami University

The combination of additive manufacturing (AM) processes with enhanced technologies for electronics production enables the highly flexible manufacturing of personalized 3D electronic devices. The conductive paths and electronic components can be embedded on the surface of the 3D printed substrates, which can be tailored through the various material properties. AM fabricated planar electronics have been widely studied and used in various applications, such as wearable devices, medical implants, and sensors. However, research on the AM non-planar ones is still in its infancy. This research presents an approach that is able to program the freeform electronics topology through the 4D printing process, which overcomes the rigidity of the "fixed" substrate. The 4D printing provides the substrate with an additional shapeshifting dimension for producing customized complex components with improved performance characteristics. The programmed pre-morphed AM-ed structure is tested and validated under the stimulant condition by comparing it with the as-desired freeform shapes.

8:55 AM

Additive Manufacturing of High Entropy Shape Memory Polymer Blends: *Katia Delgado, Ramos*[1]; Luis Lares Carrillo[1]; David Roberson[1]; [1]University of Texas At El Paso

Shape memory polymers can be combined with additive manufacturing to enable what is referred to as "4D Printing." High entropy materials have garnered much attention in materials science due to the manifestation of unexpected results in terms of physical properties and phase composition. The work presented here explores the additive manufacturing of high entropy polymer blends with shape memory properties. We will present our strategy of incrementally increasing the constituents of multi-component polymer blends as a pathway towards the creation of high entropy blends. For this work we melt compounded blends of different types of linear polyesters such as thermoplastic urethane (TPU), polylactic acid (PLA), and polycaprolactone (PCL). The effect of the fused filament fabrication (FFF) process on the phase morphology and overall microstructure was determined by way of scanning transmission electron microscopy (STEM). A comparison of shape memory performance between binary and high entropy polymer blends is also presented.

9:15 AM
Additive Manufacturing of Modular Soft Stretchable Elastomers for Adaptive Dissipative Structures: *Daniel Rau*[1]; Myoeum Kim[1]; Liheng Cai[1]; [1]University of Virginia

Additive manufacturing of elastomers enables fabrication of many technologically important structures and devices. However, the basic materials are limited to a few thermoplastics and photocrosslinkable networks with a limited range of accessible stiffness and stretchability. Here, we develop a modular, soft, and stretchable acrylate-based elastomeric resin for stereolithography additive manufacturing. The resin can be photocrosslinked to form a network consisting of both covalent and reversible bonds. By controlling the ratio of covalent and reversible bonds, we create elastomers with a wide range of stiffness from nearly 20-300 kPa and tensile breaking strain from 75% to 1360%. We demonstrate printing this resin to produce high-resolution three-dimensional structures with extreme dissipative properties that can protect brain tissue mimicking soft gels from impact damage. Together with the low cost of raw chemicals and modular material design, our soft and stretchable elastomeric resins provide a new class of soft materials for additive manufacturing.

9:35 AM
Additive Manufacturing of NiTinol Wire Embedded Thermoplastic Polyurethane Actuator: *Kazi Md Masum Billah*[1]; Ricardo Arechiga De La Rosa[1]; Mario Barron Gonzalez[1]; [1]University of Houston Clear Lake

Thermoplastic Polyurethane (TPU) is best known for its elastic and flexible qualities. In this research, commercially available nickel-titanium alloy (Nitinol) shape memory alloy (SMA) wire is embedded within a 3D printed TPU substrate. 3D printing “Pause and Go” approach is being considered to insert the pause during the printing of the specimen and embeds the SMA wire. After embedding the wire, printing is continued to complete the fabrication of the specimen with embedded wire. Making multiple specimens, these thin strips of TPU with nitinol SMA embedded are assembled to mimic a clamp fixture in the shape of a claw machine. It is expected that, due to the external thermal and electrical excitement, SMA will regain the treated shape which ultimately demonstrates the actuation. This research explores the low-cost manufacturing of soft robotics elements which can be used in many real-life applications in medical, aerospace, and domestic appliances.

9:55 AM Break

10:25 AM
Additive Manufacturing of Self-healing Polymers as a Pathway for Environmental Stability: *David Roberson*[1]; [1]University of Texas At El Paso

The environmental impact of polymers has continually gained attention as it is becoming more and more apparent that recycling of polymers does not provide a solution to this problem as plastic refuse can be found in the form of numerous “plastic islands” in the oceans. Additionally, understanding of the impact of microplastics on human health has been brought to light. Here we present the use of self-healing polymers as a pathway towards the mitigation of polymeric waste. Past efforts in the development of sustainable polymer matrix composites as well as the upcycling of plastics from waste streams will be discussed. The benefits of the additive manufacturing (AM) of polymers with shape-memory and self-healing properties will also be presented in terms of the effect of AM-facilitated microstructural control on the resultant physical properties. The development of a metric for the self-healing of polymers will also be described.

10:45 AM
Charge Programmed Additive Manufacturing of High-performance Antennas: *Zhen Wang*[1]; Zhenpeng Xu[1]; Junbo Wang[2]; Ryan Hensleigh[2]; Yahya Rahmat-Samii[2]; Xiaoyu Zheng[1]; [1]UC Berkeley; [2]UCLA

Antennas are essential components of all radio equipment that radiate/transmit and receive energy as electromagnetic waves. Next-generation wireless communications demand lightweight, low-profile, and high-performance antennas that require co-evolution in both design and manufacturing of antennas. Here we report the design and printing of previously impossible ultra-lightweight antennas via charge programmed multi-material additive manufacturing. We achieve this via tailoring the charge programmability of photopolymer to enable selective metalization of 3D conductive materials. These antennas are comprised of a network of interpenetrating metal and dielectric phase-shifting 3D unit cell arrays, which enable 3D electronic topologies with significantly less material (over 90% weight reduction) compared to standard antenna designs. We demonstrate the design and printing of full antenna systems comprised of a feed source, a 19 GHz circular polarized transmitarray with 20 cm aperture. Our measurement results obtained with the spherical near-field measurement system reveal excellent agreement with the simulated radiation patterns.

11:05 AM
Manufacturing of Foam Dampening Structures for Machining Applications: *Tyler Smith*[1]; Mithulan Paramanathan[1]; Thomas Feldhausen[1]; Matt Sallas[1]; Chris Tyler[1]; Ahmed Hassen[1]; [1]ORNL

Additive Manufacturing utilizes the unique capability to create structures in a layer by layer process to create a final structure. In the case of polymer structures, materials can range from rigid to elastomeric. In addition, foaming agents can be used to turn these standard polymers into a lightweight foam version of its base polymer. Changing the parameters and amounts of foaming agent can create different densities , surface quality, and stiffness of the foam. In the case of TPU foams, these differences can lead to vastly different stiffness and dampening co-efficient to be created. Traditional machining of thin walled structures can be difficult and costly due to the low stiffness and dampening along the structures being machined leading to increased chatter and defects. TPU foams can be used to create custom parts to support machining surfaces increasing surface quality of the machined surface.

11:25 AM
Additive Manufacturing of Functionally Graded Materials by High Speed Sintering: *Jan Kemnitzer*[1]; Marco Wimmer[1]; Tobias Rosnitschek[2]; Frank Döpper[2]; [1]Fraunhofer Institute for Manufacturing Engineering and Automation IPA; [2]University of Bayreuth

Parts fabricated from a functionally graded material (FGM) show specifically adjusted gradual changes in properties and functions along single or multiple spatial directions due to changes of composition and/or microstructure. The additive manufacturing (AM) process of High Speed Sintering (HSS) has vast potential to manufacture such FGM parts. Within the HSS process, the selective energy input into the polymer powder occurs by a sinterlamp and a radiation absorbing material (RAM). The selective adjustment of the amount of RAM controls the energy input and allows thus to adjust the microstructure and therefore the mechanical properties of the parts. This contribution describes the manufacturing process of FGM parts in HSS and the realizable propertie changes in detail for the first time. This is done by parts made of thermoplastic polyurethane (TPU) with continuous and discontinuous mechanical property changes, which are produced under variations of the relevant process parameters.

Thermal Modelling

Tuesday AM — Room: Salon G
August 15, 2023 — Location: Hilton Austin

Session Chair: Bradley Jared, University of Tennessee, Knoxville

8:15 AM
Thermal Simulation of the Material Extrusion Process with Different Print Bed Boundary Conditions: *Orkhan Huseynov*[1]; Mohammad Al-Shaikh Ali[1]; Ismail Fidan[1]; [1]Tennessee Technological University

The temperature evolution in the material extrusion (MEX) process significantly affects the stability and bonding of 3D printed parts. Numerous studies have focused on developing models to capture the temperature history of the MEX process. However, there remains a need to explore the influence of different boundary conditions applied to the print bed. Additionally, the size of the bed relative to the 3D printed object has not been extensively investigated. This study aims to analyze the thermal behavior of the first layer in MEX by considering various boundary conditions and bed sizes. The obtained results will contribute to the development of faster yet reliable models for simulating the temperature variation in the MEX process.

8:35 AM

Analytical Modeling of Cooling Rates in PBF-LB/M of Bulk Metallic Glasses: *Hanna Schönrath*[1]; Jan Wegner[1]; Maximilian Frey[2]; Erika Barreto[3]; Arno Elspaß[1]; Norman Schnell[1]; Benjamin H. Erdmann[1]; Julian Neises[1]; Nils Ellendt[3]; Ralf Busch[2]; Stefan Kleszczynski[1]; [1]Universität Duisburg-Essen; [2]Saarland University; [3]Leibniz Institute for Materials Engineering

Additive manufacturing through laser powder bed fusion (PBF-LB/M) inheres great potential for the processing of bulk metallic glasses (BMGs). The size-independent high cooling rates during processing issue a breakthrough for amorphous fabrication of large and complex structural components. Albeit partial crystallization is frequently observed in additively manufactured BMGs, which limits the resulting mechanical properties. In this matter the complex thermal history during processing states a remaining uncertainty. Besides temperature measurements and numerical estimation, analytical models might be useful for a deeper understanding of the transient temperature evolution. In this work, an iterative solution to the analytical Rosenthal equation was developed and applied to ZrCuAlNb- and CuTiZrNi-BMGs to predict melt pool dimensions and cooling rates during PBF-LB/M. Therefore, temperature dependent thermal properties were determined via laser flash measurements. The effective absorptivity of the two materials was additionally measured and single line experiments were performed as a validation for the approach.

8:55 AM

A Robust Local Preheat Temperature Dependent Stochastic Finite Element Heat Source Model for Inconel 718 Laser Powder Bed Fusion: *Seth Strayer*[1]; Albert To[1]; [1]University of Pittsburgh

Thermal field prediction of laser powder bed fusion (L-PBF) via the finite element method can help optimize the process while avoiding the cost of experiments. However, these models abstract critical physics into an effective heat source model that does not readily capture the experimentally-measured melt pool size magnitude and variance, especially for multi-track cases. This work presents a novel local preheat temperature dependent stochastic heat source model to help address these issues. First, the heat source parameters are calibrated to the mean melt pool sizes for Inconel 718 L-PBF multi-track experiments. These parameters are predicted during the simulation to establish the role of a local preheat temperature metric. Second, random sampling techniques are employed to match the experimentally-measured variance within each track. Accordingly, the simulated melt pool sizes are within 10% error regarding experimental measurements up to five consecutive tracks while more closely matching the measured melt pool size variance.

9:15 AM

Enabling Part-scale Melt Pool Prediction in Laser Powder Bed Fusion via a Global-local Thermal Process Simulation Model: *Shawn Hinnebusch*[1]; William Templeton[2]; Alaa Olleak[1]; Praveen Vulimiri[1]; Florian Dugast[1]; Sneha Narra[2]; Albert To[1]; [1]University of Pittsburgh; [2]Carnegie Mellon University

Predicting accurate thermal history in laser powder bed fusion (LPBF) is a challenging problem. Layerwise simulations are geometry dependent for calibration and cannot capture the local heat accumulation due to the laser scanning process. Scanwise simulations are far more accurate but are restricted in size to just a few millimeters. An infrared (IR) camera is mounted on an LPBF system to calibrate and validate the interpass temperatures. Using a GPU-accelerated finite element based solver, the geometry-agnostic layerwise calibration was completed with less than 6% mean absolute percentage error. The layerwise simulation provides an accurate thermal boundary condition for the local scanwise simulations at a reduced computational cost. Melt pool width and depth can be predicted in any location before printing. Integrating high-speed layerwise simulations with scanwise simulations results in a low-cost yet accurate thermal history that identifies problematic regions before costly builds.

9:35 AM

Component Geometry Feature-based Heat Source Model for Temperature History Fast Prediction in the Directed Energy Deposition Process: *Lei Yan*[1]; Wei Gao[1]; Frank Liou[2]; [1]Nanjing University of Aeronautics and Astronautics; [2]MIssouri University of Science and Technology

Temperature prediction is critical in metal directed energy deposition (DED) for process parameters optimization, especially comes to components with large sizes and complex geometry features. To improve prediction efficiency with accuracy guaranteed, a component geometry feature-based heat source model is proposed and developed with ANSYS APDL. The heat source model is applied layer-wise and has energy intensity redistributed according to the geometry features of each slice. Predicted temperature history is validated with thermocouple data and shows a maximum 50K temperature difference. This model provides a promising tool for high-efficiency process window optimization.

9:55 AM Break

10:25 AM

A Preliminary Understanding of Process-property Effects on the Thermal Response via High-throughput Finite Element Models of Wire Arc Direct Energy Deposition: *Jeffery Betts*[1]; Matthew Register[1]; Matthew Priddy[1]; [1]Mississippi State University

Historically, process parameters for wire arc DED have been found in a heuristic manner for both experimental and computational efforts since process parameters are material- and geometry-dependent. However, finite element (FE) analysis can provide a low-cost, high-throughput method to simulate many process parameters. This worked utilized a sequentially coupled thermo-mechanical framework in Abaqus, using progressive element activation and the Goldak double-ellipsoidal heat source. A full-factorial design of experiments was constructed for the thermal analysis, varying the boundary conditions, material properties, time increment, mesh density and heat input. The results were post-processed to analyze the effects of each parameter on the maximum temperature and weld pool evolution at the start, middle, and end of the single-pass weld. An ANOVA test was conducted to examine relationships between process parameters (or combinations of parameters) and the nodal temperatures (at the start, middle, and end of the weld) as well as the melt-pool dimensions.

10:45 AM

CIFEM: Elucidating the Role of Local Preheat Temperature on Multi-track Melt Pool Morphology Variation for Inconel 718 Laser Powder Bed Fusion: *Seth Strayer*[1]; William Frieden Templeton[2]; Alaaeldin Olleak[1]; Florian Dugast[1]; Sneha Narra[2]; Albert To[1]; [1]University of Pittsburgh; [2]Carnegie Mellon University

Despite advancements in finite element (FE) thermal simulation techniques for laser powder bed fusion (L-PBF), these models employ an effective heat source model, which invokes a tedious calibration process and provides inaccurate thermal fields compared to high-fidelity computational fluid dynamics (CFD) simulations. Accordingly, the driving force behind melt pool size variation, especially in the multi-track case, has remained enigmatic up to this point. In this work, the authors extend CIFEM to multi-track scenarios for Inconel 718 L-PBF to help address these issues. CIFEM's data-driven heat source model is trained to predict the thermal fields from multi-track CFD simulations with different scan lengths to establish the role of a local preheat temperature metric. By imposing these fields on the desired FE solution domain, the simulated melt pool sizes are within 10% error regarding experimental measurements up to five consecutive tracks while providing substantially more accurate thermal fields to traditional FE models.

11:05 AM

Thermomechanical Modeling and Fabrication of Tungsten Carbide-nickel Geometries Through Laser Powder Bed Fusion: *Alexander Gourley*[1]; Edgar Mendoza Jimenez[1]; Reeja Jayan[1]; Jack Beuth[1]; [1]Carnegie Mellon University

The combination of hardness, abrasion resistance, and fracture toughness make cemented carbides desirable for machining and tooling, but these properties limit achievable geometries when fabricating parts through traditional techniques. Laser powder bed fusion (LPBF) provides a fabrication pathway through which cemented carbide parts can be achieved with greater geometric freedom. Our lab explored various process parameter combinations with a tungsten carbide - 17wt% Ni agglomerated powder, but recoater blade collisions limited achievable geometries to 15 mm tall cylinders. Leveraging a commercially available thermomechanical modeling software, Netfabb, the effects of interlayer timing, parameter combinations, and geometric features on recoater clearance guided designs for two prints evaluating printing larger and taller parts with more geometric features. All parts were printed to completion except for a long geometry that delaminated from the build plate. the measured density and hardness values in the taller parts were similar to the previous 15 mm tall cylinders.

Data Analytics: Large Scale AM, Deposition Methods, Metals

Tuesday PM Room: 404
August 15, 2023 Location: Hilton Austin

Session Chair: Eric MacDonald, University of Texas at El Paso

1:40 PM
Automated Layer Identification in Large Area Additive Manufacturing (LAAM): A Comparison of Image Thresholding and Edge Detection Techniques: *Aissata Wadidie*[1]; Gregory Studer[1]; Kris Villez[2]; [1]Advanced Stuctures and Composites Center; [2]Oak Ridge National Laboratory

Our study aims to develop an automated method for identifying layers on images of 3D-printed walls from a LAAM printer, as manual identification can be time-consuming. We applied three different image processing methods to identify edges between layers. Otsu thresholding was found to be the most accurate and required minimal manual intervention. From our study, we propose a new composite algorithm combining multiple methods for even greater accuracy. This research demonstrates the feasibility of using computer-based methods to automatically identify layers in 3D printing, reducing manual time and effort and improving the strength and quality of 3D-printed parts.

2:00 PM
Coaxial Color Channel Focus Evaluation to Estimate Standoff Height in Directed Energy Deposition: *Callan Herberger*[1]; Lauren Heinrich[2]; Erik LaNeave[1]; Brian Post[2]; Blane Fillingim[2]; Eric MacDonald[1]; Thomas Feldhausen[2]; James Haley[2]; [1]The University of Texas at El Paso; [2]Oak Ridge National Laboratory

Directed Energy Deposition is an additive manufacturing process that is being rapidly adopted by industry and is well suited for the fabrication of complex components in a variety of metal alloys. Inexpensive and minimally intrusive methods to find the best standoff are needed to supply real time control to maintain optimal standoff distance. The present work explores the quantification of the focus of the three-color channels of a coaxial camera to determine the standoff height. An experiment was performed in which a 254 mm wall is built and the standoff height, initially 5.0 mm below the optimal position, was then intentionally increased by 1.0 mm to a final position 7.0 mm above optimal. Computer vision is shown to monitor the focus in each color band and estimate standoff distance. A response can be calculated in under 40 ms using simple hardware and can work in most laser-based DED systems.

2:20 PM
Automated Fiber Length Measurement for 3D Printed Polymer Composites, Including Identification and Measurement of Non-trivially Placed Fibers: *Chris O'Brien*[1]; Chad Duty[1]; [1]University of Tennessee - Knoxville

The mechanical stiffness and strength of a composite material is significantly influenced by the fiber length. Processing parameters for large-scale printing systems (e.g., extrusion screw speed) can directly impact the resulting fiber length distribution. There are limited standardized methods for reproducible and generalizable quantification of fiber length. Current measurement techniques are often expensive, laborious, and error prone due to dependence upon human involvement. Deep learning offers the potential to automate the laborious tasks such as segmentation, identification, and measurement of imaged fibers. The aim of the presented work is a first step in establishing a deep learning-based fiber measurement pipeline that may be generalized across various fiber imaging set-ups. This presentation focuses on the description of the measurement of both stand-alone fibers as well fibers those that are imaged in non-trivial placements (e.g., overlapping). The end goal is an open-source method for reliable, automated quantification of residual fiber length.

2:40 PM
Variational Autoencoders for Comprehensive Feature Identification in Fatigue Analysis: *William Frieden Templeton*[1]; Tharun Kondareddy[1]; Justin Miner[1]; Sneha Narra[1]; [1]Carnegie Mellon University

Fatigue life is a key performance metric for metal AM parts, making it an active research area generating vast datasets of micrographs from fatigue test specimens. Using these image-based datasets, this study pursues data analytics to find correlations between fatigue life and porosity defects. To do so, the information in the images must be quantified for statistical analysis, thereby introducing a source of information loss. This work aims to preserve information by applying variational autoencoders (VAEs) to the image dataset. By encoding the micrographs to a low-dimensional latent space, valuable information in the dataset is captured and similar features are clustered. Encodings that correlate with poor fatigue life are identified using random forest models, and examples of the features they link to are generated. The results will demonstrate the potential application of VAEs to quantify micrographs and discern useful correlations between defects and fatigue life.

3:00 PM
In-situ Monitoring of Wire Arc Additive Manufacturing for Machine Learning Based Prediction of Shape Irregularites and Mechanical Defects: *Eduardo Miramontes*[1]; Joshua Penney[1]; Bennett Fowler[1]; Ethan Rummel[1]; Sean Caufield[1]; Anahita Khojandi[1]; Bradley Jared[1]; [1]University of Tennessee

Wire Arc Additive Manufacturing (WAAM) has made great strides in recent years however, there remain numerous challenges still hindering adoption by industry. Defects in the parts degrade their mechanical performance. Inconsistency in the geometry of the weld beads or undesirable anomalies such as waviness, or humps can lead to loss of geometric accuracy and in extreme cases, they can propagate to subsequent layers, causing build failure. Developing a controls framework for defect mitigation requires a model that maps undesirable outcomes to information about the process obtained in real time. The development of a multi-sensor framework for real time data acquisition and several approaches for arriving at defect prediction model, employing well known machine learning methodologies including Random Forests, and Neural Networks are explored. The models are trained first on data obtained on a single build layer, and subsequently on a multi-layer wall. Their merits and drawbacks are discussed.

3:20 PM
End-to-end AI Models for Error Detection and Correction in Extrusion AM: *Douglas Brion*[1]; Sebastian Pattinson[2]; [1]Matta; [2]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 operators can detect errors but cannot provide continuous monitoring or real-time correction. This has led to significant 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 discuss the application of recent advances in large AI models and deep learning to tackle these problems. End-to-end models show great promise for detecting errors autonomously and powering feedback systems that can correct process parameters in real time, opening the door to improved part quality and uptake in end-use applications.

3:40 PM
Bayesian Data-augmentation of Thermal Models for Design of Nb-Ta-W Alloys: *Brent Vela*[1]; Cafer Acemi[1]; Peter Morcos[1]; Alaa Elwany[1]; Ibrahim Karaman[1]; Raymundo Arróyave[1]; [1]Texas A&M University

Refractory alloys are difficult to process via conventional means due to their high strength and brittle nature. Additive manufacturing (AM) is an emerging solution which can bypass these processing difficulties, enabling the fabrication of refractory alloys into complex shapes with reduced material usage. Despite this, there is limited experimental data on the printability of refractory alloys. Both AM simulation and experimentation are prohibitively expensive and are thus not appropriate for high-throughput alloy design. In this work we propose printable alloys can be designed within the Nb-Ta-W chemistry-process space using a combination low-fidelity (Eagar-Tsai model), high-fidelity (Thermo-Calc Additive Manufacturing Module) thermal models, and limited single-track experiments. Specifically, using the Eagar-Tsai model as our prior belief of printability within this chemistry-process space, we leverage Bayesian-updating and networks of Gaussian Process Regressors to 1) fuse information from both thermal models and 2) to correct this fused-model with experimental data.

Process Development: Powder Bed Fusion Monitoring and Imaging II

Tuesday PM — Room: 410
August 15, 2023 — Location: Hilton Austin

Session Chair: Toshiki Niino, University of Tokyo

1:40 PM
Comparative Analysis of Process Stability in PBF-LB/M: (Thermal) Highspeed Imaging vs. Melt Pool Monitoring using Novel Gas Mixtures: *Tobias Deckers*[1]; Pierre Forêt[1]; Franz Wolf[1]; Stefan Kleszczynski[2]; Gerd Witt[2]; [1]Linde GmbH; [2]University Duisburg-Essen

The powder bed fusion of metals using a laser beam (PBF-LB/M) is increasingly gaining popularity in the industry. However, to compete with established manufacturing processes, ensuring a consistent quality of parts processed by PBF-LB/M is crucial. In-situ process monitoring systems, such as coaxial melt pool monitoring (MPM), can contribute to this goal by minimizing post-process quality control. To identify the relevant phenomena to be monitored, firstly, two monitoring systems, a commercially available MPM system and a thermal high-speed camera, were compared. Secondly, the suitability of the MPM system for in-situ quality control was tested by employing novel gas mixtures to the process. The mixtures include argon with hydrogen, helium, and carbon dioxide. The first results showed the capabilities of the MPM system to monitor relevant process anomalies. Also, the addition of helium and hydrogen to the process gas resulted in an improvement in the melt pool stability compared to argon.

2:00 PM
Application of In-situ Process Monitoring to Optimise Laser Parameters during the L-PBF Printing of Ti-6Al-4V Parts with Overhang Structures: *John Power*[1]; Owen Humphreys[1]; Mark Hartnett[2]; Darragh Egan[1]; Denis Dowling[1]; [1]I-Form; [2]Irish Manufacturing Research

The development of laser powder bed fusion (L-PBF) has allowed for increased flexibility and complexity of designs over other manufacturing methods. Overhang structures are a common challenge in L-PBF, as they can lead to print defects, e.g. porosity, due to the decreased thermal conductivity of the powder below the print layer, which causes overheating in the overhang meltpool. In-situ process monitoring, which involves real-time monitoring of the printing process, has been shown to be effective in detecting and correcting overhang defects. By controlling the laser energy during the printing of L-PBF overhang structures, the level of porosity and roughness can be significantly reduced (an 88% reduction in Ra roughness was achieved), while the microstructure can be optimised. This result was achieved by monitoring the meltpool temperature (based on photodiode IR measurements). Informed by these measurements, the laser treatment energy is closely controlled to prevent overheating the overhang print layer's meltpool.

2:20 PM
Coaxial Photodiode Signal Trends and Predictions: Power, Speed, Spot Size, Material and Time: *Gabe Guss*[1]; Aiden Martin[1]; Nick Calta[1]; [1]Lawrence Livermore National Laboratory

The coaxial photodiode signal collected during laser powder bed fusion printing on our GE M2 series 4+ machine, has become important for multiple projects related to building feed forward models, predicting defects and optimizing parameters. To help justify our heavy use of this sensor data, more than a thousand single tracks were generated on titanium, stainless steel and aluminum, while varying power, speed and spot size. The experiment was then repeated after a year of time. We will report the trends in sensor data observed across these parameters, like increasing signal with laser power, decreasing signal with scan speed, and an unexpected, peaked signal with spot size, and the variation from the two, time separated experiments. Prepared by LLNL under Contract DE-AC52-07NA27344

2:40 PM
Enabling Advances in Laser Powder Bed Fusion with In Situ Monitoring: *Steven Storck*[1]; vince pagan[1]; Brendan Croom[1]; Mary Daffron[1]; Ari Lax[1]; Robert Mueller[1]; Mark Foster[2]; Colin Goodman[2]; [1]Johns Hopkins Applied Physics Laboratory; [2]Johns Hopkins University

The potential of additive manufacturing to disrupt production of components from aerospace to medical devices has been demonstrated over the last 2 decades. The application of these innovative technologies has, however, been limited by the ability to qualify critical hardware which often exceeds 60% of the final part cost. In addition to process quality, novel ways to apply in situ monitoring for alloy development will be discussed aiding in the accelerated implementation of classical or novel alloys currently unattainable with the technology. The JHU/APL team has developed two novel on-axis sensors capable of measuring at between 500,000 and 11,000,000 Hz in hyperspectral ranges enabling direct measurement of real time temperature and spectral information. This technology paired with advanced calibration enables decoupling of wavelength and thermally dependent emissivity. The sensor paired with a FPGA enables real-time control of the laser parameters at high rates unlocking prescribed processing temperature set point.

3:00 PM
High-precision Measurement of Melt Pool Properties during Laser-based Powder Bed Fusion of Metals by High-speed Imaging: *Arno Elspass*[1]; Jan Wegner[1]; Hanna Schönrath[1]; Niklas Horstjann[1]; Stefan Kleszczynski[1]; [1]University Duisburg-Essen

Laser-based powder bed fusion of metals is used to produce complex and high performance components for different industrial applications. Due to the high complexity of the underlying physical mechanisms during the process, its control is still challenging. To avoid process-specific defects, which affect mechanical properties, a huge amount of specific knowhow is crucial. Especially for regulated industries, such as medical or aerospace, this is a limiting factor for the widespread use of this technology. In this work high speed imaging in combination with a high magnification optic, resulting in a resolution of 1.44 µm/pixel is used to gain a deeper insight in the property-determining mechanism and boundary conditions during the process. Thereby, the intensity distribution of the melt pool is measured and analyzed with an imaging script to determine width, length and cooling rate by means of intensity. The potential of this data for predicting resulting material properties is demonstrated.

3:20 PM

High-speed Observations and Quantification of Spatter Counts and Trajectories in Laser Powder Bed Fusion: Christian Gobert[1]; *Jack Beuth*[1]; [1]Carnegie Mellon University

In laser powder bed fusion additive (L-PBF) manufacturing, key process variables such as laser power, scan speed and hatch distance are varied and the respective impact on porosity content for coupon specimens is observed and reported in process maps. The resulting process maps help end-users identify key process regimes such as keyholing, fully dense, and lack of fusion in parameter space. One potential cause of porosity in L-PBF is spatter, which encompasses ejected material from laser-material interaction. In this work, spatter generation quantified through high-speed video observations of the printing process is correlated to the porosity content in cross-sectioned coupons across process space. Trained machine learning models are used to identify and track spatter in high-speed observations of the printing process. Spatter generation related to key process variables and materials is studied in the aim of identifying optimal process settings to minimize spatter emissions.

3:40 PM

High Speed Video Imaging of overhang surfaces in Beam Shaped Laser Powder Bed Fusion of 316L stainless steel: *Lars Vanmunster*[1]; Arnout Dejans[1]; Brecht Van Hooreweder[1]; Bey Vrancken[1]; [1]KU Leuven

One of the novel strategies under investigation increase the build rate of laser powder bed fusion (LPBF) additive manufacturing is shaping the beam intensity profile to something other than a Gaussian distribution. Ring-like spot shapes are thought to allow for faster scan speeds and increased hatch spacing compared to defocused Gaussian beams. In this talk we will present our work on LPBF of 316L stainless steel with a variable beam profile laser switching between single mode and ring-like multimode spot shapes, implemented in a system allowing for in-layer beam switching. A high speed camera with fixed reference frame and a top down view is used to compare the difference in evaporation, denudation and spatter behavior between the different beam shapes for single tracks and full layers. The results improve our understanding of the potential to increase productivity with different beam shapes, and in-layer switching thereof.

Applications: Process Techniques for Part Production

Tuesday PM — Room: 412
August 15, 2023 — Location: Hilton Austin

Session Chair: Christie Hasbrouck, The Pennsylvania State University

1:40 PM

Characterizing Thermomechanical Performance of Large-format Printed Composite Polymer Structures: *Tyler Corum*[1]; Johnna O'Connell[1]; Maximilian Heres[2]; Jeff Foote[2]; Ahmed Hassen[3]; Chad Duty[1]; [1]University of Tennessee; [2]Loci Robotics, Inc.; [3]Oak Ridge National Laboratory

Large-format additive manufacturing (LFAM) is a manufacturing technique where a high volume of material is extruded in a layer-by-layer fashion to form structures that typically measure several meters in scale. Loci Robotics, Inc.'s LOCI-One system is an LFAM-type system that features a high throughput extruder mounted on a 6-axis robot arm. This research used the LOCI-One system to print single bead walls of 20% by weight carbon fiber reinforced acrylonitrile butadiene styrene (CF-ABS) at various print speed control, layer times, and bead widths. Thermomechanical performance of the CF-ABS walls was measured to quantify effects of print parameters on the z-strength, modulus, and coefficient of thermal expansion (CTE). Mechanical properties were measured using flexural testing. The CTE of the LFAM printed walls was measured using a large-scale digital image correlation system to characterize the distortion of the fiber reinforced composite material in the x- (print direction) and z- (between layers) directions.

2:00 PM

Evaluating the Compressive Strength of AM Risers for Green Sand Metalcasting: *C. Hasbrouck*[1]; Samantha Melnik[1]; [1]The Pennsylvania State University

While many metalcasting foundries have experimented with using additive manufacturing (AM) for patternmaking, the compressive strength of the tapered AM risers for green sand metalcasting has not yet been explored. This study investigates the effects of infill pattern type, infill density, and shell thickness on the compressive strength of a standard 3-inch diameter by 5-inch tall by 3-degree taper cylindrical riser manufactured with PLA using a material extrusion process. The findings for these AM risers include plots and mathematical models of compressive strengths at three different scales of the standard geometry (full, three-quarters, and half), predicted build times and masses using other common infill patterns, potential failure mechanisms during use of AM and conventionally manufactured riser patterns, and considerations on design for both additive manufacturing and green sand metalcasting. It is concluded that AM risers can be incorporated into and perform well as part of conventional green sand metalcasting patterns.

2:20 PM

A Novel Metric for Geometric Accuracy Quantification using Point Clouds in Additive Manufacutring: *Chuan He*[1]; Sushmit Chowdhury[2]; Robert Bedard[2]; Chinedum Okwudire[1]; [1]University of Michigan; [2]Ford Motor Company

Additive manufacturing (AM) possesses a significant advantage over traditional manufacturing methods due to the complexity of parts it can produce. Nevertheless, this complexity introduces challenges in quantifying geometric errors, which significantly affect AM process quality. An automated print quality inspection framework is indispensable for differentiating the performance of various AM processes and machines, particularly in high-value applications. This study presents an approach employing the Iterative Closest Point (ICP) algorithm for registration, establishing a one-to-one correspondence between point clouds based on geometric features. A novel metric, the Similarity Score, is proposed to represent the quality of printed parts. Validated on printed parts, the Similarity Score accurately characterizes print quality with high computational efficiency. Despite the limitations of current commercial software packages and research, this approach holds potential for advancing AM error reduction and compensation strategies.

2:40 PM

An Adaptive Meshing Framework using Octree Data Structure for Voxel Based Meshes: *Pradeep Chalavadi*[1]; [1]Ansys Inc.

We present an adaptive meshing framework for voxel-based meshes, designed for use in various process simulations for additive manufacturing, such as thermal, distortion, grain growth, etc. The framework uses an octree data structure to represent the meshes, and a coarsening/refinement algorithm to generate coarser and finer meshes. The algorithm preserves a 2:1 ratio of coarse to fine meshes to maintain desired accuracy. Efficient tree traversal is used for fast nodal/Gaussian solution mapping. In many cases, selective element coarsening enables the reduction of the number of nodes to be solved by the iterative matrix solver. To maintain accuracy at boundary, the algorithm can be configured to maintain a certain level of fine mesh at boundary. When part and support mesh touch, they are automatically flagged to be not combined to be coarsened at any stage. Overall, the algorithm enables reduction of solution nodes while maintaining desired accuracy at areas of interest.

3:00 PM
In-situ Defect Detection for Laser Powder Bed Fusion with Active Laser Thermography: *Philipp Peter Breese*[1]; Tina Becker[1]; Simon Oster[1]; Christian Metz[2]; Simon J. Altenburg[1]; [1]Bundesanstalt für Materialforschung und -prüfung (BAM); [2]THETASCAN GmbH

Defects are still common in metal components built with Additive Manufacturing (AM). Process monitoring methods for laser powder bed fusion (PBF-LB/M) are used in industry, but relationships between monitoring data and defect formation are not fully understood yet. Additionally, defects and deformations may develop with a time delay to the laser energy input. Thus, currently, the component quality is only determinable after the finished process. Here, active laser thermography, a non-destructive testing method, is adapted to PBF-LB/M, using the defocused process laser as heat source. The testing can be performed layer by layer throughout the manufacturing process. The results of the defect detection using infrared cameras are presented for a custom research PBF-LB/M machine.Our work enables a shift from post-process testing of components towards in-situ testing during the AM process. The actual component quality is evaluated in the process chamber and defects can be detected between layers.

3:20 PM
Hybrid Manufacturing: How Interleaving Processes Enables Local Control of Material Performance: *Thomas Feldhausen*[1]; Brian Post[1]; Kenton Fillingim[1]; Lauren Heinrich[1]; Peeyush Nandwana[1]; Rangasayee Kannan[1]; Yousub Lee[1]; [1]Oak Ridge National Laboratory

The convergence of multiple manufacturing techniques and processing domains has enabled new uses of existing manufacturing equipment in novel workflows. For example, integration of additive and subtractive techniques by means of hybrid manufacturing has enabled manufacturers to reduce labor and material costs by mitigating disjointed processing. While these systems are more capable than single-purpose systems, the science of interleaving multiple operations is complex. A lack of fundamental understanding of factors like residual stress, microstructure evolution, and geometric distortion in these complex processes remains the primary barrier to success. However, recent work has shown that hybrid manufacturing has the potential to enable localized control of material performance characteristics. This presentation details how research into the fundamental understanding of hybrid processes is being translated to real-world applications. By covering specific developments like the world's largest metal-wire laser-directed energy deposition hybrid system and novel programming strategies, the audience will gain an appreciation of the challenges and future opportunities for hybrid additive manufacturing systems.

3:40 PM
Digital Model Generation Strategy for Printing Miniaturized Replica of Historical Cast Iron Objects: *Detlev Borstell*[1]; Barbara Friedhofen[2]; Dominik Kunz[1]; [1]Koblenz University of Applied Sciences; [2]Cast Iron Museum

The Cast Iron Museum at Sayn (Germany) hosts a wide range of historic cast iron objects ranging from highly detailed fly-size figures to oversize eagles and church bells. Replicating the historical cast iron, i.e. free formed objects, as miniaturized 3D prints for a new exhibition requires scanning to create the digital model. High quality of the digital model is a fundamental prerequisite for the production of the miniaturized 3D print. Size, color and surface quality of the object determine the selection of scanner and scanning method. The influence of software selection and settings during data preparation from digital photos to point cloud, mesh and finally solid is highlighted. Printing process selection is the final step in achieving the required print quality. A scanning and model generation strategy is developed using several exemplary objects from the Sayn Museum. The final print quality resulting from the selected scanning process is evaluated.

4:00 PM
Mechanical Properties of Polymer-bonded Magnets Fabricated using Magnetic Field Assisted Additive Manufacturing (MFAAM): *Mandesh Khadka*[1]; Wilhemus Geerts[1]; Jitendra Tate[1]; [1]Texas State University

Magnetic Field Assisted Additive Manufacturing (MFAAM) is an additive manufacturing process that employs an external magnetic field in an extrusion-based additive manufacturing technology to fabricate polymeric magnetic structures. The traditional method of magnet fabrication, such as sintering, cannot produce magnets of complex structures. However, MFAAM can print polymer-bonded magnets with complex shapes. MFAAM can produce polymer-bonded magnets, the mechanical and magnetic properties of such magnets remain a great field to explore. In this research using MFAAM, the magnetic field was implemented during the printing of composites comprising Polyamide 12 as matrix and strontium ferrite magnetic particles as filler, at different orientations. The tensile and flexural properties are compared with neat Polyamide 12, composites printed in the magnetic field and without the magnetic field. Finally, by developing polymer-bonded magnets using MFAAM, this project achieved structures with mechanical properties like or even higher than the matrix material. This work was supported in part by NSF through DMR- MRI Grant under awards 2216440 and in part by DOD instrumentation grant (78810-W911NF-21-1-0253).

Data Driven Modeling and Process Control

Tuesday PM — Room: 415 AB
August 15, 2023 — Location: Hilton Austin

Session Chair: Chinedum Okwudire, University of Michigan

1:40 PM
A Data-driven Surrogate Model for Time-dependent Scanwise Thermal Simulations of Centimeter Scale Laser Powder Bed Fusion Parts: *Berkay Bostan*[1]; Shawn Hinnebusch[1]; David Anderson[1]; Albert To[1]; [1]University of Pittsburgh

The intricate thermal conditions that arise throughout the laser powder bed fusion (LPBF) process depend on the local geometry and have significant impact on the part quality in terms of defect formation, microstructure, and residual distortion. However, due to the large length scale difference between the laser beam (μm) and part (cm), scanwise simulations are intractable for part-scale models due to the immense computational expense. In this study, a surrogate model which represents time-dependent, part-scale scanwise thermal simulations is proposed. The developed architecture consists of a sequence of convolutional neural networks (CNNs), and long short-term memory (LSTM) units. The input vector consists of interpass temperatures of a 3D LPBF part and time-dependent point heat source locations. A 100x speedup is achieved by the proposed model, thus enabling defect formation and microstructure simulations of centimeters scale parts.

2:00 PM
A Machine Learning Approach to Part Scale Microstructure Predictions in LPBF: *Mason Jones*[1]; Brian Weston[2]; Theron Rodgers[3]; Daniel Moser[3]; Jean-Pierre Delplanque[1]; [1]University of California Davis; [2]Lawrence Livermore National Laboratory; [3]Sandia National Laboratories

Laser powder bed fusion additive manufacturing uses microscale processes to create macroscale parts with complex microstructures. This makes part-scale modeling and simulation of microstructures challenging and expensive. A newly developed machine learning based surrogate microstructure model for this process has been shown to significantly accelerate predictions of microstructure statistics while maintaining accuracy. This work uses ensemble modeling in conjunction with this surrogate model to identify and explore viable routes for scaling this surrogate model to part scale predictions for the purposes of process parameter optimization. This will include analysis and refinement of the surrogate model as well as statistical analyses to identify shortcuts to part scale modeling.

2:20 PM
A Physics-guided Data-driven Model for Enhanced Temperature Prediction and Control of LPBF Additive Manufacturing: *Cheng-Hao Chou*[1]; Chinedum Okwudire[1]; [1]University of Michigan

A hybrid (i.e., physics-guided data-driven) model is proposed for temperature prediction and control of laser powder bed fusion (LPBF) additive manufacturing. Parts produced by the LPBF process are subject to deformation or other defects due to the thermal behavior during the manufacturing process, which can be resolved by model-based control techniques. However, existing temperature prediction models are either inaccurate or computationally costly, and hence are not suitable for closed-loop control. To overcome these deficiencies, the authors propose a linear hybrid model, which cascades a physics-based finite difference method (FDM) model with a linear data-driven model that aims to correct the temperature prediction of the FDM model by learning the unmodeled dynamics. By simulation, the proposed hybrid model is shown to achieve significant improvement in the temperature prediction accuracy compared to the baseline model (i.e., the physics-based FDM model).

2:40 PM
A Scientific Artificial Intelligence (Sci-AI)-based Concurrent Multiscale Simulation Framework for Accurate Temperature Prediction of Large-scale Metal Additive Manufacturing: *Lin Cheng*[1]; [1]Worcester Polytechnic institute

The broad applications of metal AM are hindered by the variability of mechanical performances due to time- and space-dependent thermal history. Although simulation models of multiple scales have been developed, either of them is able to provide accurate thermal history of large-scale production. This work aims to develop a concurrent multiscale framework capable of capturing the detailed melt pool dynamics in part-scale analysis. A Sci-AI model is to incorporate the in-situ data into the melt pool dynamics simulation for more accurate and efficient analysis. The computational cost of the Sci-AI model is at the microseconds level, allowing real-time coupling with part-scale analysis. This makes it possible to accomplish more accurate thermal history with detailed thermal fluid information for the part-scale fabrication and lays the foundation for concurrent multiscale modeling of metal AM process. Several numerical examples will be conducted to illustrate the performance of the proposed framework.

3:00 PM
System Identification of Fused Filament Fabrication Additive Manufacturing Extrusion and Spreading Dynamics: Osama Habbal[1]; Ali Kassab[1]; George Ayoub[1]; Pravansu Mohanty[1]; *Christopher Pannier*[1]; [1]University of Michigan Dearborn

In fused filament fabrication additive manufacturing, polymer extrusion and spreading dynamics affect build quality in both surface finish and mechanical properties. However, the nonlinear extrusion and spreading dynamics are ignored by slicers. To advance the aim of slicing using accurate nonlinear dynamic models, this work presents a system and procedure for automated measurement of dynamic bead extrusion. The system uses a belt printer, iFactory3D One Pro, with nozzle tilted 45 degrees from the build belt, and a snapshot 3D scanner. Single layer prints in polylactic acid (PLA) are scanned and then automatically ejected. The G-code for the L-shaped print holds the gantry speed fixed while the extrusion flow rate is varied as a square wave signal in space. The experiment design matrix varies three variables: extrusion temperature, gantry speed, and extrusion flow rate. Time constants are fitted to bead width signal extracted from the scan data to obtain nonlinear models.

Materials: Polymers Powder Bed Fusion

Tuesday PM — Room: 416 AB
August 15, 2023 — Location: Hilton Austin

Session Chair: Camden Chatham, Savannah River National Lab

1:40 PM
Analysis of Flow Additives in Laser-based Powder Bed Fusion of Polymers: Implications for Flow Behavior, Processing, Temperature Profile, and Part Characteristics: *Simon Cholewa*[1]; Andreas Jaksch[1]; Dietmar Drummer[1]; [1]Collaborative Research Center 814: Additive Manufacturing

Powder bed fusion of polymers requires the use of flow additives to ensure adequate flowability of the feedstock material. However, information regarding flow additives and their load is limited, as is understanding of their impact on processing conditions. This study investigates the flow behavior using static and dynamic measurements under process conditions, with a particular focus on the influence of flow additives. Subsequently, processing studies are conducted using thermography to analyze the laser material interaction. The characteristics of parts produced from Polypropylene and Polyamide 12 systems are also examined. The findings of this research enhance the understanding of the impact of flow additives on the processing conditions of laser-based powder bed fusion of polymers, potentially leading to optimized process parameters and improved part quality and mechanical properties.

2:00 PM
Determination of Input Laser Energy for Melting Powder Layers of Various Thicknesses in High-speed PBF-LB/P using Near-infrared Laser and Absorbent: *Yuki Yamauchi*[1]; Takashi Kigure[1]; Toshiki Niino[2]; [1]Tokyo Metro Ind Tech Research Inst; [2]Institute of Industrial Science, the University of Tokyo

The rate of production of PBF-LB/P can be increased by increasing the layer thickness. However, this reduces the part resolution in the stacking direction. To obtain both, a high rate of production and high part resolution, layer thickness adjustment in accordance with part geometry can be effective. Optimizing the input laser energy with respect to the layer thickness ensures sufficient melting and part strength. According to previous studies, the use of a near-infrared laser and absorbent can increase penetration depth or depth of fusion. However, the optical properties of the powder bed can vary significantly depending on the layer thickness, and, therefore, the input energy that actually contributes to melting also changes with layer thickness. This study proposes a method for determining the input laser energy for various layer thickness without trial and error by estimating the amount of energy required to melt the powder layer while accounting for the optical properties of the bed.

2:20 PM
Effect of Temperature on the Cohesiveness of Polymeric Powders: Implications on Spreadability: *Aurelien Neveu*[1]; Marco Lupo[1]; Filip Francqui[1]; [1]GranuTools

The powder spreadability is an important factor in powder bed based additive manufacturing such as Selective Laser Sintering (SLS). Previous studies have already demonstrated the close relation between the powder cohesiveness and the spatial homogeneity of the produced layers during the recoated process. However, in SLS applications polymeric powders are warmed up at a temperature close to the sintering. This temperature elevation will induce changes in the strength of the cohesive interactions leading to a modification of the spreadability. Therefore, an investigation of the effect of temperature is essential to better predict the spreadability of the material inside the machine. In this study, the influence of temperature on polymeric powders (polyamide 6, polyurethane and polypropylene) on cohesion has been evaluated with a rotating drum method (GranuDrum, Granutools, Belgium). The results clearly highlight the importance of performing the characterization at a temperature close to the one seen in the printer.

2:40 PM

Enhancing the Thermal Stability of Polyamide 6 in Powder Bed Fusion via Primary and Secondary Antioxidant Incorporation: *Andreas Jaksch*[1]; Simon Cholewa[1]; Dietmar Drummer[1]; [1]University of Erlangen–Nuremberg

Polyamide 6 (PA6) is a widely used thermoplastic material in manufacturing due to its outstanding mechanical properties, such as high strength, stiffness, and toughness. However, PA6's vulnerability to thermo-oxidative aging makes it less suitable for powder bed fusion (PBF), as it results in material degradation and mechanical property deterioration over time. To address this issue, this study investigates the efficacy of antioxidants in improving PA6's aging resistance in PBF.To elucidate the physical and chemical changes in the material, process-adapted analyses are conducted using a coupled rheometer FTIR instrument. Furthermore, the study evaluates the viscosity number of the virgin and processed powder, the yellow index, and the part performance to characterize the aging occurring in the PBF process. The results indicate that addition of primary and secondary antioxidants significantly improves PA6's aging resistance in PBF, thus enhancing its potential as a suitable material for additive manufacturing applications.

3:00 PM

Fundamentals of Polymer Crystallization in Laser Powder Bed Fusion for New Material Screening: *Camden Chatham*[1]; Samantha Talley[2]; [1]Savannah River National Lab; [2]Kansas City National Security Campus

Although laser powder bed fusion (PBF/LB) was one of the first industrially viable additive manufacturing methods, polyamides remain dominant at both commercial- and research-scales. Researchers continue to develop screening methods for evaluating new polymers for PBF/LB. The so-called "SLS Process Window," which is the difference between melting and crystallization temperature measured at 10 K min-1 as originally outlined in patent literature, is perhaps the most often reported method. The method's simplistic guidelines are not sufficiently scientifically rigorous to understand how crystallization kinetics affects successful 3D printing. Common understanding of the Process Window omits details from published theories of polymer crystallization, as evidenced by assumptions in PBF/LB process modeling papers. The authors review polymer crystallization in the PBF/LB context and propose replacing the Process Window with crystallization halftime and physical gelation measurements. These measurements better indicate a lengthy coexistence of solid powder and molten polymer affecting warp-free parts.

3:20 PM

Halogen-free Flame-retardant Powder Materials for Laser Sintering: Evaluation and Process Stability Analysis: *Fabian Neitzel*[1]; Ivo Kletetzka[1]; Hans-Joachim Schmid[1]; [1]Paderborn University (DMRC)

The high flammability of components manufactured by laser sintering (LS) using standard polyamide 12 (PA12) powder still severely restricts their use in industries such as electronics, aviation, and transportation. A key factor for the further establishment of laser sintering is the expansion of the material portfolio with, for example, refreshable and halogen free flame-retardant powder materials. Accordingly, various halogen-free flame-retardants are investigated in this work and evaluated with respect to their use in LS. First, their decomposition behavior and mode of action are examined. Subsequently, the additives are dry blended with PA12 to investigate properties relevant for LS, such as particle morphology, thermal behavior and melt viscosity. In the next step, test specimens for UL94 vertical flame-retardancy tests in the LS process are produced from the blends. Finally, the process stability of the process-aged powder blends is investigated by again examining the thermal behavior and melt viscosity.

Materials: Polymers Material Extrusion

Tuesday PM | Room: 417 AB
August 15, 2023 | Location: Hilton Austin

Session Chair: To Be Announced

1:40 PM

Benchmarking the Tensile Properties of Polylactic Acid (PLA) Recycled through Fused Granule Fabrication Additive Manufacturing: *Dawood AL Nabhani*[1]; Ali Kassab[1]; Osama Habbal[1]; Pravansu Mohanty[1]; Georges Ayoub[1]; Christopher Pannier[1]; [1]University of Michigan - Dearborn

To progress toward a circular economy of thermoplastic polymers using distributed recycling by additive manufacturing, the mechanical degradation of polymers through multiple recycling cycles must be quantified. This work presents a procedure and benchmark dataset of tensile property degradation for polylactic acid (PLA) feedstock in multiple recycling passes with the fused granule fabrication process. To establish recycling with minimal processing (shredding and sieving but not pelletizing from a filament), modifications were required to the granule feeding hopper of the GigabotX 2 XLT printer. Tensile test coupons are die cut from machined sheets from a vase-like 3D printed tube shape. Tensile properties are presented for 3D prints of the virgin material and one, two, three, and four passes of recycling by additive manufacturing.

2:00 PM

Determination and Compensation of the Shrinkage Behavior of Cylindrical Elements in the FDM Process: *Thorsten Koers*[1]; Balazs Magyar[1]; [1]Paderborn University

Fused Deposition Modeling (FDM) is an additive manufacturing process to produce complex thermoplastic geometries layer by layer. The filament is melted in a nozzle, iteratively deposited and then cools down. Due to the solidification process, the deposited filament strands deviate from their intended position due to shrinkage, resulting in significant geometric deviations in the final part. In terms of dimensional accuracy, there is need for optimization, especially for local curved geometries in relation to the global part with higher nominal dimensions. The aim of this study is to investigate the size and shape deviations for cylindrical FDM elements and to compensate the expected deformations by using an in-house software with adaptive scaling factors in the x-y plane. Previous studies mainly focus on simple, non-curved objects, this study also considers the influence of curvature and global as well as local deviations on the final part.

2:20 PM

Development and Analysis of Direct-write Photopolymer, Multi-material Manufacturing Process: Kyle Holland[1]; *Allison Murray*[1]; [1]Marquette University

There is a need to develop technology that allows for the benefits of isotropy afforded by stereolithography to a direct-write UV cure, multi-material application. This work addresses this open question through a multi-nozzle, direct-write manufacturing process with local UV curing. The effects of extrusion methodology, post-process cure time and temperature, and print orientation on the ultimate strength and elastic modulus are discussed. The resulting material has near isotropic mechanical properties, as compared to the highly anisotropic effects in some other extrusion-based printing methodologies. With an eye toward particulate reinforced resins, there is an exploration of composite loaded resins with variable solids loadings printed using this methodology. Through the dual-nozzle approach, variable loadings across a part are demonstrated, thereby opening the door for tailored internal meso-structures of printed resin-based polymers.

2:40 PM
Estimating Effective Stiffness of FFF Components based on Layer-by-Layer Raster Orientation obtained from Ultrasonic Waveform Analysis: *Atik Amin*[1]; David Jack[1]; Trevor Fleck[1]; [1]Baylor University

The quality of the internal raster path of an AM product is an important factor that affects the performance of these components. To address this issue, this research proposes an automated approach using a novel ultrasonic testing method to extract the layer-by-layer raster orientation non-destructively of AM components. The proposed method uses the 2D Fast Fourier Transformation on gated ultrasonic waveforms to extract the raster path of each individual deposited layer. The results demonstrate that the approach can determine the raster orientation, with an error margin of 1°~2° for an 18 layer sample fabricated from nylon resin system, and for the PCTG and the PET-CF system the first 9-10 layers. The extracted layer information is then used to predict the effective stiffness of an ASTM D638 dog bone utilizing classical laminate theory and the results for each of the material systems are compared to physical testing of the fabricated specimen.

3:00 PM
Experimental Characterization of Enhanced Fused Filament Fabricated Tall Thin-walled Structures Using Polylactic Acid (PLA): *Parimal Patel*[1]; Rakin Ahmed[1]; Tanvir Shanto[1]; Ankur Jain[1]; Robert Taylor[1]; [1]The University of Texas at Arlington

Printing tall thin-walled structures with good mechanical properties and geometric accuracy using Fused Filament Fabrication (FFF) technique has been challenging due to weak layer-to-layer bonding. In this work, a previously demonstrated concept of providing additional thermal energy during printing is utilized to print relatively taller and larger structures compared to standard tensile test specimens. A three-point bend test is carried out on a Polylactic Acid (PLA) structure representative of functional parts printed using this technique. In addition, geometrical deviation and surface roughness are evaluated using a Faro Arm scanner and a Mitutoyo SJ210 profilometer, respectively. Results demonstrate that providing additional in-situ thermal energy more than doubles the bending strength while maintaining or exceeding geometrical accuracy and surface finish, compared to a standard specimen. These results demonstrate the potential for printing effective thin-walled components using this technique in order to meet practical strength requirements in a variety of applications.

3:20 PM
Effects of Fiber Alignment on the Thermomechnical Properties of Large-format Printed Composite Polymer Structures: *Tyler Corum*[1]; Vipin Kumar[2]; Ahmed Hassen[2]; Chad Duty[1]; [1]University of Tennessee; [2]Oak Ridge National Laboratory

Large-format additive manufacturing (LFAM) was used in this study to create a fiber reinforced structure made from 20% by weight carbon fiber reinforced acrylonitrile butadiene styrene (CF-ABS). While adding fiber reinforcements does increase stiffness and reduce the coefficient of thermal expansion (CTE) of LFAM prints, the final structure exhibits highly anisotropic thermomechanical properties. Fibers are shear aligned by the print nozzle during the extrusion process and the resulting bead has highly aligned edges or skin areas and a randomly aligned center. Since fiber reinforcements provide more resistance to thermal expansion in the longitudinal direction than the transverse, the orientation of these fibers in the print influences the CTE experienced by the structure at elevated temperatures. This study used X-ray computed tomography (X-CT) and digital image correlation (DIC) to correlate the degree of fiber alignment to the thermal expansion of LFAM structures by serial sectioning printed beads.

3:40 PM
Fatigue Life Prediction of Functionally Graded TPU and PLA Components Produced by Material Extrusion: Suhas Alkunte[1]; Mithila Rajeshirke[1]; Ismail Fidan[1]; *Orkhan Huseynov*[1]; [1]Tennessee Tech University

The objective of the present research is to examine the fatigue life estimation of functionally graded additive manufacturing (FGAM) components produced by the Material Extrusion (MEX). The current research studies demonstrate the potential of functionally graded materials (FGMs) in enhancing the mechanical properties of engineered structures. The raw materials employed for the experimentation of this study are a combination of Polylactic acid (PLA) and Thermoplastic Polyurethane (TPU). To predict fatigue life, several researchers have utilized various statistical approaches. In this investigation, an experimental study is conducted utilizing Tension-Tension (T-T) loading conditions and different stress levels (80, 60, 40, and 20% of Ultimate tensile strength), followed by the application of Basquin's Model for fatigue life prediction. The results obtained indicate that the model may be utilized to predict fatigue response. Overall, the soft-hard material combinations with adaptable properties produced through FGAM have potential applications in dental and orthopedic fields.

4:00 PM
Fused Filament Fabrication of Polymer Blends with In Situ Layerwise Chemical Modifications: *Donald Benza*[1]; Camden Chatham[1]; Jonathon Baker[1]; [1]Savannah River National Lab

Additive manufacturing (AM) promises voxel-level control over both shape and material properties; however, voxel-level control over material properties is difficult to achieve. The authors present one uniquely AM approach to material property control: layerwise chemical modification via introduction of reactive species during fused filament fabrication. Layerwise chemical modification can be accomplished by introducing a reactive gas species, such as ozone, in close contact with the molten polymer extrudate during part fabrication. Such reactions are considered "surface" reactions as they are diffusion limited. The AM benefit is that repeated modification of layer-interfaces compounds the "surface modification" across every layer. This is especially profound when printing polymer blends that natively exhibit unique behaviors at interfaces. Chemical modification at each layer interface provides an opportunity to alter blend morphology towards compatibilization during manufacturing and providing another handle for spatial control of material properties in AM parts.

Wire-fed DED: Aerospace and Others

Tuesday PM — Room: Salon A
August 15, 2023 — Location: Hilton Austin

Session Chair: Wei Li, University of Texas at Dallas

1:40 PM
Exploratory Study of In-space Wire Arc Additive Manufacturing with Modeling Approach: *Wei Li*[1]; Kishore Nagaraja[1]; Dan Bouzolin[1]; [1]University of Texas at Dallas

Countries all over the world are rushing into space exploration due to crisis of energy and resources exhaustion on the Earth. Mars is an obvious target because it has a thin atmosphere, good geological similarity, and is close by in the Solar system. For the large spacecrafts such as Mars rovers, periodic maintenance is necessary to ensure the completion of long-duration exploration missions. In-space wire arc additive manufacturing (WAAM) provides a potential solution towards sustainable maintenance with onsite repair or additive manufacturing. For in-space manufacturing, low temperature and reduced gravity are two important factors. In this work, WAAM under low temperature and reduced gravity on the Mars was studied through a multi-physics modeling approach. The metal droplet transfer, deposition geometry, thermal dissipation, and other key physics in WAAM were simulated. To validate the modeling approach, an experimental case was conducted on an in-house WAAM platform under the Earth condition.

2:00 PM
Qualification of Low-criticality AM Components in an Expeditionary Environment: *Jacob Aljundi*[1]; Jonathan Torres[2]; Aditya Pulipaka[1]; [1]Naval Surface Warfare Center Carderock Division; [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.

2:20 PM
Towards Functionally Graded Materials Using Wire-arc Technology: *Andrzej Nycz*[1]; Chris Masuo[1]; Luke Meyer[1]; William Carter[1]; Alex Walters[1]; Riley Wallace[1]; Joshua Vaughan[1]; Suresh Babu[1]; Vanshika Singh[1]; Peeyush Nandwana[1]; Yukinori Yamamoto[1]; [1]Oak Ridge National Laboratory

Wire-arc additive manufacturing is new technology suitable for creating large near net shape metal parts. It is characterized by low-cost hardware, flexibility and is often combined with robotic controls and automation. This work presents the first findings using this technology in functionally graded materials. With the increasing size of parts possible to manufacture with 3D printing, new opportunities arise. Unlike casting or other conventional methods wire-arc additive manufacrruing is not limited to using one material. The flexibility of robotics and automation combined with the robustness of Gas Metal Arc Welding technology can offers locally targeted mechanical properties addressing the performance, productivity, lead time and cost at the same time. This work summarizes the first steps in using more than one feedstock material from hardware, software, and material science point of view.

2:40 PM
NASA Technology Development for In-space Manufacturing Application: *Christopher Roberts*[1]; James Stott[2]; Curtis Hill[3]; Alexander Blanchard[2]; Frank Ledbetter[4]; Andrew Owens[5]; [1]NASA; [2]NASA MSFC; [3]NASA MSFC, ESSCA; [4]NASA MSFC, CPSS PP&C; [5]NASA LaRC

As the International Space Station's (ISS) life approaches its end, NASA intends to travel back to the Moon and establish a sustainable presence, paving a pathway towards Mars. Current logistics strategies will need to be fundamentally changed to support extended missions, and on-demand manufacturing enables reduced operations cost and increased long term sustainability. The In-Space Manufacturing project at Marshall Space Flight Center is developing additive polymers, metals, and electronics manufacturing technologies to enable a sustainable presence on the Moon and enable long duration transit missions. This presentation will provide an overview of current technologies being developed for demonstration aboard the ISS, the unique constraints when developing AM technologies for spaceflight applications, and a technology maturation plan for in space manufacturing. An emphasis will be placed on the FabLab payload which will demonstrate multi-materials printing, including bound metal additive manufacturing and thick film electronics manufacturing, aboard the ISS in 2025.

3:00 PM
Robotic Wire-fed Additive Manufacturing for Forging Industry.: *Bishal Silwal*[1]; [1]Georgia Southern University

Forging is one of the major manufacturing processes which makes a critical contribution to transportation, aerospace, energy, medical, and countless other sectors. There are different types of forging equipment and processes available and materials such as steel, aluminum can be easily forged. In high productivity, most forging operations use starting blocks and metal-forming dies. A preform is a piece of stock that resembles the final required shape of the forged part and is manufactured in conjunction with the forging process. Robotic wire-fed additive manufacturing has the potential to improve the forging process by fabricating the preform and dies. A case study was performed to analyze the differences between machining and Robotic wire-fed additive manufacturing of forging dies in terms of energy and cost parameters. In addition, a preform was also designed and fabricated using Robootic DED. A medium carbon low alloy steel was selected for this study. The results show significant cost savings can be considered if the wire-fed Robotic deposition technology is implemented.

3:20 PM
The Effect of Thermal Conditions on Process Defects in Electron Beam Directed Energy Deposition: *Ronald Aman*[1]; Alex Kitt[1]; Dan Ruscitto[2]; Luke Mohr[1]; Zach Corey[1]; Naresh Iyer[2]; [1]EWI; [2]GE Global Research

Observing process defects at size scales and with sufficient confidence relevant to qualification efforts has not yet been achieved in metal AM, so non-destructive testing (NDT) techniques are used to detect porosity within material deposited. NDT costs can be significant and may not achieve targeted resolution due to geometry and material limitations. In this work, in-process monitoring of Electron Beam Directed Energy Deposition (EB-DED) is enhanced to include three thermal history conditions; inter-pass, melt pool superheat and trailing bead temperatures. Quality scenarios are applied to simulate various process conditions during EB-DED at three different thermal conditions within production relevant use cases and resultant process defects are characterized via high throughput computed tomography. Defects are spatially and temporally registered to process conditions observed during EB-DED and statistically mapped to thermal and quality scenarios. This work is supported by the US Department of Energy office of Energy Efficiency under award DE-EE0009399.

Applications: Lattices and Cellular III

Tuesday PM — Room: Salon B
August 15, 2023 — Location: Hilton Austin

Session Chair: Vinayak Krishnamurthy, Texas A&M University

1:40 PM
Unweaving the Macrostructure of the Venus Flower Basket: From Bio-morphism to Biological Insight: *Yash Mistry*[1]; Dhruv Bhate[1]; [1]Arizona State University

The Venus flower basket has been the subject of significant study due to its hierarchical, lattice-like design. While various hypotheses have been proposed for the basis of the macrostructure of the basket, most have not been validated. In this work, we examined the literature on the structure-function relationships proposed for the basket's complex network of lattice members, including our own studies with x-ray microtomography. Three key design principles were abstracted into cylindrical designs similar to the actual biological and used to fabricate specimens using Selective Laser Sintering. These specimens were tested under three loading conditions: compression, bending, and torsion, and compared to a baseline design. Results show that each of the three design principles represents a significant, and sequential improvement in performance, mapping to growth stages in the Venus flower basket. This work argues for the use of additive manufacturing in generating analogs of natural structures to isolate structure-function relationships.

2:00 PM
Machine Learning Assisted Mechanical Metamaterial Design for Additive Manufacturing: *Jier Wang*[1]; Ajit Panesar[1]; [1]Imperial College London

Metamaterials, widely studied for its counterintuitive property, are recognised to provide foundation for superior multiscale structural designs. However, current mechanical metamaterial design methods usually relay on performing sizing optimisations on predefined topology or implementing time-consuming inverse homogenisation methods. Machine Learning (ML), as a powerful self-learning tool, is considered to have the potential of discovering metamaterial topology and extending its property bounds. This work considers the use of conditional Generative Adversarial Networks (cGANs) to speed up the generation of new topologies for metamaterials. The generator in cGANs is trained to output metamaterial microstructural topologies based on the input condition, which is the desired property. Meanwhile, changing the noise input of cGANs is expected to produce different topologies, which will consequently lead to higher design diversity in metamaterial structural design. This work highlights the potential of data-driven approaches in Design for Additive Manufacturing (DfAM) as an alternative to the time-consuming, conventional methods.

2:20 PM
Generative Design of 2D Cellular Structures through Stochastic Modification of 2-Honeycombs: *Matthew Ebert*[1]; Vinayak Krishnamurthy[1]; [1]Texas A&M University

We present a methodology for designing cellular structures through modification of a 2-honeycomb using probability density functions. A 2-honeycomb is a tessellation of the plane composed of a single space-filling prototile which can be created using Voronoi tessellation of sites created using Wallpaper symmetries. While this offers an intuitive method for obtaining interesting mechanical behaviors, the design space is limited by the uniformity of 2-honeycombs. Our method introduces an additional step to this process of structure generation using point-density functions which allow for removal of Voronoi sites resulting in explicit control of local stiffness. Since the site removal is randomized, we end up with completely different structures each time the removal is applied. Through FEA simulations, we show that generated structures created with the same parameters have similar mechanical properties. These structures can be used to modify the infill structure for a 3D printed part to minimize the material usage.

2:40 PM
Design of Three-dimensional Complex Truss Metamaterials with Graph Neural Networks: *Marco Maurizi*[1]; Desheng Yao[1]; Xiaoyu (Rayne) Zheng[1]; [1]University of California Berkeley

The rapid development of additive manufacturing technologies has enabled the fabrication of truss metamaterials, i.e., a novel class of lightweight-yet-strong materials with engineered complex hierarchical structures. Manipulating the architecture over chemical composition dramatically expands the achievable materials design space, allowing to largely control the mechanical response of metamaterials. Despite the great advances made in this area, designing three-dimensional (3D) truss metamaterials under complex or extreme conditions with programmable response is still a challenge. Here we propose a paradigm to design 3D truss metamaterials with complex programmable mechanical responses both under quasi-static and dynamic loading based on graph neural networks (GNNs). By leveraging the ability of our GNN-based model to accurately predict the mechanical response across multiple orders of magnitude, we inverse design truss metamaterials for compressive loading up to 50 % of strain and dynamic transmissibility with desired band gaps, opening the way for full materials design freedom.

3:00 PM
Design of Spatially Varying Orientation Lattice Structures using Triply Periodic Minimal Surfaces: *Chongyi Wei*[1]; Douglas Smith[1]; [1]Baylor University

Interest continues to grow for lattice structures produced by additive manufacturing methods that are described by triply periodic minimal surface (TPMS). Tunable parameters that define the TPMS provide unique design flexibility where prior research has focused on designing hybrid or functionally graded TPMS structures. In this paper, a new strategy is proposed to include an orientation angle and volume fraction of each lattice cell simultaneously when defining structures derived from TPMS. The algorithm iteratively solves an underlying partial differential equation with the finite difference method to obtain a smooth, continuous lattice structure with a spatially varying orientation angle. The resulting lattice structure can be combined with other types of TPMS models using Gaussian radial basis or sigmoid functions to achieve multi-TPMS lattice designs. The spatially varying lattice structures can also take the advantage of the directional effective modulus of TPMS to improve the strength the performance of the lattice design.

3:20 PM
Improving the Mechanical Response of the IWP Exo-skeletal Lattice Through Shape Optimization: *Joseph Fisher*[1]; Simon Miller[1]; Joseph Bartolai[1]; Timothy Simpson[1]; [1]Pennsylvania State University

Triply Periodic Minimal Surfaces have been identified as good candidates for the generation of lattice structures produced with additive manufacturing. These TPMS-based lattice structures avoid sharp features that are characteristic of strut-based lattice structures because of their constant zero mean curvature. Although studies have explored part-scale optimization using TPMS-based lattice structures, they have only varied the volume fraction by changing the level set in the approximate surface equations. By defining new parameterizations in the approximate surface equation, we can redistribute volume within the lattice structure at any volume fraction. In this paper, we introduce an approach for optimization of this new parameterization of TPMS equations using the Borg multi-objective evolutionary algorithm. We demonstrate this framework on the IWP exo-skeletal lattice under uniaxial compression. A relationship between the new parameters and the level set is derived for designs on the Pareto frontier of the optimized IWP TPxS. The performance of the Pareto optimal designs and the efficacy of the optimization approach are shown by comparing to the standard IWP lattice and four other lattices that share the same topology. The optimized designs are implemented and shared in custom nTopology blocks.

3:40 PM
Hybrid Geometry/Property Autoencoders for Multi-Lattice Transitions: *Martha Baldwin*[1]; Nicholas Meisel[2]; Christopher McComb[1]; [1]Carnegie Mellon University; [2]The Pennsylvania State University

Additive manufacturing has revolutionized structural optimization. This may be achieved through multi-lattice structures, which have emerged as promising candidates for impact reduction and other applications. However, the performance of these structures relies on the details of mesostructural elements. Many current approaches use data-driven approaches to generate multi-lattice transition regions but focus largely on the geometry of the mesostructure. Therefore, it remains unclear whether the integration of functional performance factors in the generation of multi-lattice interpolations is beneficial beyond geometry alone. To address this issue, this work implements and evaluates a VAE to create a hybrid geometric/functional latent space for generating multi-lattice transition regions. This approach allows us to test the performance of the proposed method against geometry and property defined latent spaces. Our research aims to determine whether it is necessary to incorporate physical properties into the geometrically defined latent spaces to achieve robust multi-lattice structures.

4:00 PM
Tailoring Mechanical Behaviors through Programmable Lattice Structures: Yi Sheng Liao[1]; *Xinyi Xiao*[1]; [1]Miami University

Lattice structures are cellular structures composed of periodically arranged unit cells with a high strength-to-weight ratio and remarkable properties like lightweight, energy absorption, and vibration resistance. Owing to their superior mechanical performance and properties. With the development of additive manufacturing technology, more complicated shapes and architectures of prototypes can be made for end-user products.The paper discusses the advantages and disadvantages of lattice structures and suggests ways to overcome limitations. The study uses seven structures, including BCC, Octahedron, and Cross-cube, as well as three structures composed of two of them and one structure composed of three, to analyze the relationship among the structures. The compression strength and physic-based finite element simulations were performed to analyze the quantitative relationship between the structures and the mechanical response. The results can help in the design and improvement of products made with lattice structures.

Materials: Metals-Characterization of AM Processes and Materials

Tuesday PM Room: 602
August 15, 2023 Location: Hilton Austin

Session Chair: Halsey Ostergaard, University of Sydney

1:40 PM
In- and Ex-situ Neutron Characterization of Metal Additive Processes and Microstructures: *Halsey Ostergaard*[1]; Jitendra Mata[2]; Elliot Gilbert[2]; Julie Cairney[1]; Anna Paradowska[1]; [1]The University of Sydney; [2]Australian Nuclear Science and Technology Organisation

Two novel neutron techniques in AM are demonstrated: ultra-small and small-angle neutron scattering (U/SANS) for micron and submicron precipitate analysis and in-situ diffraction during laser metal deposition (LMD). With extension into the USANS range, SANS is sensitive to precipitate structures below a few microns and provides volume-averaged data that complement other techniques. U/SANS, APT, and TEM were used to study LPBF Ni superalloy 718 and assess distribution, shape, and texture of both nano-scale intracellular strengthening precipitates as well as micron-scale intercellular delta phase precipitation. First results in 316L stainless from a new in-situ neutron system for LMD are summarized. Designed for use on multiple beamlines, the system is capable of in-situ sub-surface process monitoring in either diffraction or imaging modes. Diffraction results are correlated against ex-situ residual stress, microstructural, and hardness analyses.

2:00 PM
X-Ray Computed Tomography: A Game-Changer for Parameter Control in Additive Manufacturing: *Curtis Frederick*[1]; [1]Carl Zeiss Microscopy

Quality control of AM parts is still a major challenge due to the complex geometries, rough surfaces, and asymmetric deformation of as printed parts. X-ray computed tomography (CT) is a non-destructive technique that can provide valuable insights into the internal structure and properties of AM parts. In this presentation, we will discuss the benefits of using X-ray CT in researching AM, including the ability to detect defects such as cracks, voids, and inclusions, and to measure the density and deformation of the AM part. We will also highlight the advantages of using advanced CT techniques, such as high-resolution imaging and reconstruction enhanced by deep learning models, to gain a better understanding of the microstructure and mechanical behavior of AM parts. This presentation will share the insights gained from using X-ray CT to optimize the AM process, improve part quality, and reduce costs in various industries and applications of AM.

2:20 PM
In situ Layer-wise Optical Imaging for Defect Detection during Laser Powder Bed Fusion: *Sanam Gorgannejad*[1]; Wanda Wang[1]; Gabe Guss[1]; Steven Hoover[1]; Justin Patridge[1]; Nicholas Calta[1]; [1]Lawrence Livermore National Laboratory

Ensuring high-quality parts and process repeatability through systematic fault detection and control is a well-established goal in the laser powder bed fusion (LPBF). In situ process monitoring approaches are increasingly favored for real-time quality assurance. Despite the extensive research aimed at developing novel monitoring modalities, it is imperative to leverage the already established techniques to their fullest potential that allows for fast adaptation in manufacturing settings. Optical cameras are widely integrated into commercial LPBF machines, providing images of the powder bed subsequent to powder spread and fusion at every layer. In this study, we have adopted and developed methodologies to exploit the layer-wise images to detect printing defects and three-dimensional reconstruction of the components to facilitate part qualification prior to conducting XCT.Prepared by LLNL under Contract DE-AC52-07NA27344.

2:40 PM
Challenges and Opportunities in Acoustic Emission Monitoring for Quality Control of Directed Energy Deposition Additive Manufacturing: *Ehsan Dehghan Niri*[1]; Anusuya Vellingiri[2]; Steven Hespeler[3]; Andi Wang[1]; [1]Arizona State University; [2]New Mexico State University ; [3]New Mexico State University

Acoustic Emission (AE) is a proven nondestructive testing (NDT) method that has demonstrated effectiveness in monitoring infrastructures, testing pressure vessels, and qualifying manufactured components during and after manufacturing processes. Ultrasound stress waves captured during AE monitoring, has been found to contain useful information regarding potential incidents resulting from normal or abnormal events during manufacturing processes. Despite its maturity in monitoring infrastructures, AE encounters several challenges when applied to monitoring additive processes such as directed energy deposition (DED). This article presents a summary of the challenges and opportunities associated with using AE in this context, using several examples to illustrate key points. In particular, the article highlights the strong statistical correlation between the high frequency AE signals and the AM process parameters, as well as the quality of the metallic parts produced.

3:00 PM
Absorptivity Behavior of High Reflectivity Aluminum and Copper Alloys During Laser Powder Bed Fusion: *Sagar Patel*[1]; Troy Allen[2]; David Deisenroth[3]; Madison Reed[2]; Peyman Alimehr[1]; Sergey Mekhontsev[3]; James Fraser[2]; Mihaela Vlasea[1]; [1]University of Waterloo; [2]Queen's University; [3]National Institute of Standards and Technology

The higher reflectivity and conductivity of aluminium and copper alloys, when compared to other commonly used alloys, pose unique challenges when being manufactured using laser powder bed fusion (LPBF). As such, the physics of laser-material interactions are complex for LPBF of aluminium and copper alloys, leading to a costly process parameter development cycle. In this work, in situ reflectivity measurements are carried out for one aluminium and one copper alloy and compared to melt pool depths for multiple process parameters spanning the conduction, transition, and keyhole melting modes. The measurements for aluminium are carried out using an integrating sphere setup on a commercial LPBF system; while for copper, an integrating hemisphere on the LPBF testbed at NIST is used. The inferred absorptivity values are then analyzed using dimensionless parameters to develop material class specific absorptivity scaling laws, that would accelerate the process parameter development cycle for aluminium and copper alloys.

3:20 PM
Machinability of Additively Made Alloys: A Case Study of Ti64 and A205 Alloys: *Otto Randolph*[1]; Aamer Kazi[1]; Bruce Tai[1]; Ryan Zvanut[2]; [1]Texas A&M University; [2]Kansas City National Security Campus

It is widely known that additively manufactured (AM) metal parts require post-processing to achieve dimensional tolerances comparable to those of cast or wrought metals. One common post-processing technique is machining, but AM alloys can respond differently to machining due to their unique microstructures formed in the thermal cycle. This research attempts to characterize the machinability of two alloys in turning, Ti64 and A205 aluminum, using conventionally made rods as a baseline to compare to AM equivalents. The main variables are feed and speed. In each cutting test, vibrational response, specific cutting energy, surface roughness, and images of the chips and cut surface are recorded to assess the machinability. The results show noticeable differences between AM and baseline parts in vibration and surface finish. These differences are correlated to and can be explained by the differences in their microstructures. Machining recommendations are provided at the end of this study.

3:40 PM
Additively Manufactured Lunar Rover Wheel Case Study: Richard Hagen[1]; *Brian Gibson*[2]; [1]NASA JSC; [2]Oak Ridge National Laboratory

The current state of the art to manufacture Lunar Wheels can be expensive and time consuming. In an effort to reduce time and cost, Oak Ridge National Laboratory uses a large format metal additive system to produce a wheel for the Johnson Space Center to evaluate. The purpose of this case study is to compare the current VIPER wheel to an additively manufactured wheel design optimized for printing. The presentation will highlight the design differences between the current VIPER wheel and the potential improvements made possible with AM. Additionally, there will be a discussion about the metal AM process used for fabricating a large part and how well the as built part corresponds to the model. Finally, results of a performance comparison of the VIPER wheel to the printed wheel will be presented to show if there is an advantage with the new design features not currently possible.

Process Modeling

Tuesday PM — Room: 615 AB
August 15, 2023 — Location: Hilton Austin

Session Chair: To Be Announced

1:40 PM
A General Model of Hot Isostatic Pressing for Additively Manufactured Metal Component Performance Improvement: *Lei Yan*[1]; Wei Gao[1]; Nagaraja Iyyer[2]; Yuyi Mao[3]; [1]Nanjing University of Aeronautics and Astronautics; [2]Technical Data Analysis, Inc.; [3]Wuxi Institution of Inspection, Testing and Certification

Hot isostatic pressing (HIP) has become an essential post-heat treatment to eliminate internal porosities and tailor microstructure for additively manufactured metal component performance improvement. In the present work, a finite element model based on creep and plasticity that is capable of pore closure evaluation was developed for the HIP cycle process window development. HIP soak temperature, soak pressure and initial pore size effects on pore evolution were investigated on Ti-6Al-4V additively manufactured components for model validation. The proposed model is effective in predicting pore evolution during the HIP process and provides a promising tool for additively manufactured components post-heat treatment process optimization.

2:00 PM
Laser Beam Shape Optimization: Exploring Alternative Profiles to Gaussian-shaped Laser Beams to Achieve a More Stable Melt Pool: *Vijaya Holla*[1]; Philipp Kopp[1]; Jonas Grünewald[1]; Patrick Praegla[1]; Christoph Meier[1]; Katrin Wudy[1]; Stefan Kollmannsberger[1]; [1]Technical University Munich

We present a framework for laser beam shaping in L-PBF/M that uses an advection-diffusion model to compute a laser intensity profile corresponding to a desired temperature field (i.e. melt pool shape). To solve this inverse problem, we minimize the functional given by the squared difference between the predicted and the desired temperature field integrated over the domain using the adjoint-based optimization method. The melt pool dimensions produced by the computed laser intensity profile are validated using photomicrographs of experiments. However, other quantities such as temperature profiles, temperature gradients, or dynamic effects cannot be validated experimentally. To this end, the computational results are compared to high-fidelity melt pool models (using Smoothed Particle Hydrodynamics).Additionally, we will discuss how the process windows within which the presented models are valid and present new types of laser intensity profiles designed to achieve a wide, shallow, yet stable melt pool in conduction mode.

2:20 PM
An Evaluation of a Programmatic Method for the Generation of Finite Element Event Series for Additive Manufacturing Against Machine Print Paths: *Chuyen Nguyen*[1]; David Failla[1]; Matthew Register[1]; Matthew Priddy[1]; [1]Mississippi State University

A major challenge of using additive manufacturing (AM) processes is determining optimal process parameters for a specific geometry. Finite element (FE) modeling can reduce lead times and costs associated with process parameter calibration by predicting part deformation and residual stresses through the examination of different process parameters. For an accurate process-property relationship, there is a vital need for the simulated print path to resemble the real machine print path as closely as possible when using a moving heat source. This effort evaluated the difference between a new print path event series generator, AMTech, and print paths generated for usage by laser-powder bed fusion (L-PBF) AM systems for part fabrication. AMTech is a pre-processing tool that takes g-code generated with open-source software along with AM process parameters to generate print paths for use with FE simulations. Demonstrating the efficacy of AMTech will enable researchers to streamline their AM process parameter determination.

2:40 PM
Characterization of Simulated Coaxial Melt Pool Monitoring Signal Variations Due to Melt Pool Morphology: *Conor Porter*[1]; Arash Samaei[1]; Dominik Kozjek[1]; Jon-Erik Mogonye[2]; Gregory Wagner[1]; Jian Cao[1]; [1]Northwestern University; [2]Army Research Laboratory

One barrier to wider adoption of laser powder bed fusion in industry is the ability to qualify and ensure the consistency of parts produced by this process. Coaxial photodiode monitoring sensors can provide a digital signature of a part at the melt pool scale, which can expedite qualification. However, this signature currently includes considerable noise and variation in sensor signals, masking important signatures. While the sensing method and systems contribute to the noise, fluctuations in the melt pool also contribute to variations in sensor signals, which have not been well studied. This work analyzes simulated coaxial photodiode measurements of an L-PBF simulation. These simulated sensor signals are compared to fluctuations in the simulated melt pool including variations in width and area. This work provides a preliminary basis for determining how much of the apparent noise in coaxial melt pool monitoring signals may be due to fluctuations in the melt pool.

3:00 PM
Energy Flow (Bond Graph) Dynamic Modelling of Cartesian-frame FFF 3-D Printer Gantry: *Maharshi Arindom Sharma*[1]; Albert Patterson[1]; [1]Texas A&M University, College Station

Energy flow (bond graph) modelling gives important information about the flow of energy to each component of a dynamic system and is especially useful for complex non-linear mechanical systems. This work presents a systematic development of a bond graph model of fused filament fabrication (FFF) 3D printer gantry. The model incorporates structural and belt stiffness, damping and input torque. The model was checked for correctness and causality using the 20-Sim software. The model was further validated using Matlab Simulink using parameters obtained for an example printer characterized in a lab environment. The bond graph model gives a unique view into modelling of the extruder carriage dynamics in FFF and can be applied to specific problems. It will also give interesting information on the controllability and system integration of the printer hardware.

Materials: Metals-Processing Strategies I

Tuesday PM
August 15, 2023

Room: 616 AB
Location: Hilton Austin

Session Chair: Chris Ledford, Oak Ridge National Laboratory

1:40 PM

The Development of a Directed Energy Deposition (DED) Printability Framework for Improving Part Density and Performance in High Strength Martensitic Steels: Matthew Vaughan[1]; Michael Elverud[1]; Jiahui Ye[1]; Raiyan Seede[2]; Sean Gibbons[3]; Philip Flater[3]; Bernard Gaskey[3]; Alaa Elwany[1]; Raymundo Arroyave[1]; *Ibrahim Karaman*[1]; [1]Texas A&M University; [2]Lawrence Livermore National Laboratory; [3]Air Force Research Laboratory

While the additive manufacturing (AM) directed energy deposition (DED) technology provides a novel and efficient method for printing high strength steels to novel geometries, its inherent complexity merits a need for the development of a systematic DED framework that quickly identifies the ideal printability space for a given steel, and subsequently enables one to print the material to full density and dimensional accuracy. Afterwards, achieving optimal strengthening in novel high strength martensitic steels via DED and the Hall-Petch effect would be much more straightforward. To address this need, the present study develops a DED printability framework, where an advanced high strength martensitic steel known as AF9628 is printed to full density, high strength, and respectable ductility ($\rho > 99\%$, UTS > 1.2 GPa, $\varepsilon f > 10\%$. The introduced process optimization framework is easily adaptable to other high-end steels and alloys and should prove quite valuable to the AM research community.

2:00 PM

AM Process Development of NASA HR1 Alloy using Laser Powder Direct Energy Deposition (LP-DED).: *Javier Lares*[1]; Paul Gradl[2]; Colton Katsarelis,[2]; Francisco Medina[1]; Ryan Wicker[1]; Dana Godinez[1]; [1]W.M. Keck Center; [2]National Aeronautics and Space Administration

NASA HR1 alloy is an iron-nickel based material designed by NASA and derived from A286 and JBK-75 alloys. At extreme conditions, NASA HR1 possess high strength, high fatigue resistance, and high resistance to corrosion and hydrogen embrittlement resistance. The main applications include structural components and liquid rocket engine nozzles with internal cooling channels. NASA has produced HR1 using vacuum induction melting (VIM), a considerably expensive fabrication method. Aimed to explore other more affordable and accessible manufacturing methods, HR1 specimens were fabricated under different parameters using LP-DED and were heat treated through stress relief, homogenization, solution treatment and aging. The feasibility of this AM process was investigated by evaluating mechanical and microstructural analyses on specimens. This work finalizes with discussion and remarks on tensile and low-cycle fatigue properties and its relationship with microstructural features.

2:20 PM

Laser Powder Bed Fusion Process Feedback Control Based on In-situ Powder Layer Thickness: *Jorge Neira*[1]; Ho Yeung[1]; [1]National Institute of Standards and Technology

Metal laser powder bed fusion (LPBF) is a promising additive manufacturing technique for producing complex metal parts. However, the quality of the final product can be affected by various factors such as laser power, scanning speed, powder spreading quality, and layer thickness. In this study, we propose a real-time feedback control method based on the powder spreading quality and layer thickness. We employ a laser 3D scanner to measure the surface profile of each layer before and after the powder has been spread. A powder re-spreading will be triggered if an abnormality is detected on the spread powder surface. The difference between the profile is taken as the actual powder layer thickness and used to adjust the scan strategy for the next layer. The feedback control system is integrated into the customized-built LPBF testbed, and the effectiveness of the proposed feedback control system is demonstrated through a series of experiments.

2:40 PM

Towards High-throughput Assessment of Printability in Refractory Alloys Systems for Laser-powder Bed Fusion: *Peter Morcos*[1]; Brent Vela[1]; Cafer Acemi[1]; Alaa Elwany[1]; Ibrahim Karaman[1]; Raymundo Arroyave[1]; [1]Texas A&M University

Due to the brittle nature of refractory alloys, their development has been limited by difficulties associated with their processing by conventional means. However, due to their high melting temperature and high cracking susceptibility, their Laser-powder bed fusion (L-PBF) processing is challenging. Therefore, predicting the printability of refractory alloys rank order is critical. In this work, we present a framework capable of predicting the printability of alloys in-silico. We demonstrate this framework by co-designing alloys for performance and amenability to L-PBF. Performance metrics are evaluated in a high-throughput manner within the alloy space then the alloys were filtered, yielding a tractable number of candidate alloys so they can be synthesized via arc-melting. Using CALPHAD-based property models and analytical thermal models, a suite of process-parameter informed printability criteria were calculated. These criteria were then used to rank the printability of the alloys using technique for order preference by similarity to ideal solution.

3:00 PM

Effects of Preheating and Multi-laser Melting of Refractory Alloys in Laser Powder Bed Fusion: *Frank Brinkley*[1]; Christopher Ledford[1]; Michael Kirka[1]; [1]Oak Ridge National Laboratory

Processing of refractory materials and alloys via laser powder bed fusion (L-PBF) has proven difficult due to the high melting temperature, high ductile-to-brittle transition temperature, and the high cooling rates present. This work investigates the effects of high temperature build plate heating (up to 1200°C) and heat input from multiple lasers (a focused master laser and a defocused slave laser) on the melt morphology and cracking behavior of refractory alloys (Mo and W) using single laser track experiments. The effects of laser power, scan speed, beam pathing, and preheating temperature on processability are investigated.

3:20 PM

The Use of Laser Preheating for Microstructural Customization of Ti6Al4V Processed Using Diode Point Melting System: *Alkim Aydin*[1]; Kamran Mumtaz[1]; [1]University of Sheffield

The Laser Powder Bed Fusion (LPBF) process generates high-temperature gradients within a build due to the rapidly traversing high-intensity laser beam. These temperature gradients and rapid solidification rates can increase component residual stress and limit the type of microstructure that can be formed. This research aims to investigate the use of a de-focused 140W 915 Nm diode laser with beam shaping optics to pre-heat an area of 150 mm2 between 150C and 750C. It was found that using laser pre-heating reduced the cooling rate of the LPBF melt pool, cracks could be prohibited, residual stresses were decreased and Ti6Al4V microstructure and mechanical properties improved.

3:40 PM

Effect of Build Height on Microstructure and Mechanical Behavior of Ti-6Al-4V Fabricated via Laser Powder Bed Fusion (LPBF): *MohammadBagher Mahtabi*[1]; Saeed Ataollahi[2]; Aref Yadollahi[1]; Mohammad J. Mahtabi[2]; [1]Purdue University Northwest; [2]University of Tennessee at Chattanooga

Additive manufacturing is a process that involves the layer-by-layer fabrication of parts, which can result in different thermal histories (i.e. cooling rates and thermal gradients) for each layer. Consequently, the microstructural and mechanical properties of parts can be affected as the build height increases. This research aims to investigate the influence of build height on the structural integrity of Ti-6Al-4V specimens fabricated via laser powder bed fusion (LPBF). Microstructural features, microhardness values, and defect characteristics (e.g., size, location, and distribution of defects) were analyzed along the build direction. Tensile and fatigue tests were performed to determine if there is a relationship between the location of the fatigue and tensile failures and the build height. The findings of this study indicate that the build height can significantly affect the structural integrity of the part, as the majority of the fatigue specimens failed in the top half of the gage section.

4:00 PM

Influence of Silane-doped Argon Processing Atmosphere on Powder Recycling and Part Properties in LPBF of Ti-6Al-4V: *Nicole Emminghaus*[1]; Robert Bernhard[1]; Jörg Hermsdorf[1]; Ludger Overmeyer[2]; Stefan Kaierle[1]; [1]Laser Zentrum Hannover e. V.; [2]Leibniz Universität Hannover, Institut für Transport- und Automatisierungstechnik

In the additive manufacturing of metal powders the residual oxygen in the processing atmosphere plays a crucial role, especially highly reactive materials like titanium alloys. Besides oxidation of the built parts, it leads to oxygen pick-up into the unmolten powder. Since oxidized particles cannot be removed during recycling, the powder properties deteriorate after multiple uses. In this work, Ti-6Al-4V powder was processed under conventional argon atmosphere (residual oxygen content < 0.01 vol.-%) as well as silane-doped argon atmosphere (< 0.001 vol.-% silane in argon). The silane-doping leads to a residual oxygen content of < 10^{-20} vol.-%. The powder was sieved and reused 5 times for each atmosphere. The powder properties morphology, chemical composition and flowability were analyzed for virgin as well as reused powder. Furthermore, the roughness and relative density of the built parts was evaluated. It is hypothesized that oxygen-free production improves recyclability and thus resource efficiency.

Education

Tuesday PM
August 15, 2023

Room: Salon F
Location: Hilton Austin

Session Chair: Doug Sassaman, University of Texas Austin

2:40 PM

A Case Study of Cognitive Workload and Design Knowledge Gaps in Hybrid Manufacturing Teams: *Kenton Fillingim*[1]; Thomas Feldhausen[1]; [1]Oak Ridge National Laboratory

Hybrid manufacturing systems are an emerging technology hoping to emphasize the benefits, while mitigating the drawbacks, of both additive and subtractive processes in their typical, separate states. However, this also holds system operators accountable for smooth production in both processes. This is additionally challenging due to the knowledge gaps and lack of readily transferrable hybrid knowledge available. This research presents a case study identifying the cognitive load and knowledge gap impacts on operators across three hybrid manufacturing systems. Operators completed surveys consisting of a cognitive workload scale, factors contributing to cognitive load, and a part quality assessment. Operators self-reported skill, rule, and knowledge-based (SRK) errors contributing to process setbacks. Preliminary results show statistically significant changes in part quality and cognitive workload factors when reporting instances of SRK mistakes. This work provides a foundation towards improving hybrid systems workspace design by better understanding operator interaction with the system and the designer.

3:00 PM

Design For(e!) Additive Manufacturing: In Search of a Comprehensive Design Challenge Suitable Across AM Education: *Nicholas Meisel*[1]; [1]Pennsylvania State University

Design for additive manufacturing (DfAM) education tends to emphasize the use of problem-based learning (PBL) to encourage student learning. Unfortunately, dedicated DfAM education is still nascent, which results in a wide range of educators leveraging an equally wide, and often unproven, range of design challenges to support PBL. Because of this, it is possible that a chosen design challenge will not represent AM as an end-use manufacturing process nor promote a design space that benefits from full consideration of all opportunistic and restrictive DfAM concepts. In this paper, the author draws on lessons learned from years of DfAM-centric coursework at both the undergraduate and graduate levels to enumerate the need for three key aspects for a successful DfAM challenge in education: clarity, applicability, and demonstrability. In doing so, the author discusses and defends a comprehensive design challenge that is suitable across the range of AM education: a golf putter.

3:20 PM

Multi-material Design in Metal Additive Manufacturing: *Dennis Lehnert*[1]; Thomas Tröster[1]; Christian Boedger[1]; Stefan Gnaase[1]; [1]Paderborn University

Additive manufacturing has the economic potential to complement conventional manufacturing processes, particularly in producing complex, multi-material components. However, to fully realize the benefits of optimized lightweight structures, it's necessary to use dissimilar materials with different physical properties. These multi-material combinations from conventional processes aren't compatible with AM due to their differing material properties. In addition, geometric tolerances, recycling strategies for waste and the component's topology restrictions aren't yet defined. The european funded project "MADE3D" addresses these challenges by the concurrent engineering of designing materials, developing design concepts for multi-material structures, and adapting the process for L-PBF and DED. Advanced computational material engineering will aid alloy and process development, and recycling concepts for powder and will promote sustainability. These adaptations will increase process reliability and speed, facilitating the dissemination of multi-material additive manufacturing throughout the industry.

3:40 PM

Development of a Testbench for Additive Manufacturing Data Integration, Management, and Analytics: *Chen Wei Yang*[1]; Alexander Kuan[1]; Yan Lu[1]; [1]Engineering Lab, National Institute of Standards and Technology (NIST)

This presentation describes the NIST additive manufacturing (AM) data integration testbench that is setup to test AM data integration functions, including high speed in-process data acquisition, real-time feature extraction, process monitoring, process control, predictive modeling based on machine learning, and findable, accessible, interoperable and reusable data management. Through investigations based on the testbench, data integration requirements are collected, and solutions are developed for various AM data exchange and data analytics scenarios. A reference architecture, common information models and function interfaces are also developed for AM system integration. In addition, AM data streaming and integration with MES and ERP systems are also explored using a high-performance data warehouse for long-term data archiving and metadata management. The NIST AM Testbench provides a platform to conduct data and software integration tests and functionality evaluation from data collecting, data analysis to manufacturing operational intelligence. AM data integration capabilities can be optimized for AM industrialization

4:00 PM

Development of 3D Printable Part Library for Easy to Manufacture Components for Educational and Competetive Robotics: Indira Dwivedi[1]; Bharat Dwivedi[2]; Arun Rebbapragada[3]; *Rajeev Dwivedi*[4]; [1]Eastlake High School; [2]Lake Washington School District; [3]Farmers Branch ISD; [4]STEM and Robotics Academy

Educational and competetive Robotics enable hands on learning and experimentation. Despite cost effective and ease of access of controllers, drives and sensors, the structural components continue to be very expensive. Motivated by the Robotics for Everyone initiative, we are developing many easy to manufacture parts that will allow learners across the world to easily 3D print parts for (1) structural assembly of Robot Chassis (2) Sensor mounting (3) Electronic control mounting (4) power supply (5) various power drives. The ecosystem of the robotic compoenents is developed around extrusion structures and 3D printing is used for building the parts for testing and qualifying. Fixtures for moutning cameras for advanced machine learning and computer vision experiments are provided.

Economics of AM

Tuesday PM Room: Salon G
August 15, 2023 Location: Hilton Austin

Session Chair: Paul Hooper, Imperial College London

2:40 PM
Anticounterfeiting Signatures for Additively Manufactured Parts via Electromechanical Impedance Measurements: *Nathan Raeker-Jordan*[1]; Christopher Williams[1]; [1]Virginia Tech

Additive manufacturing (AM) is increasingly used to create complex end-use parts for critical systems across a distributed supply chain. However, these parts are at risk of counterfeiting by a capable attacker, either by using stolen digital designs or reverse engineering. Extrinsic part identification such as barcodes and ID numbers placed onto part surfaces can similarly be defeated. In this work, the authors explore the use of electromechanical impedance (EMI) measurements as a physically unclonable function for identifying printed parts via an attached piezoelectric sensor-actuator. As the EMI response is intrinsic to the geometry and material properties of a part, the natural variation in AM processes causes distinct EMI responses for nominally identical parts. This ability for EMI responses to serve as a "digital fingerprint" is evaluated across several AM processes, and is shown to be capable of differentiating between unique parts produced using binder jetting, material jetting, and material extrusion.

3:00 PM
Streaming in Additive Manufacturing: Analyzing the Impact on the Powder Bed Fusion of Metals Process Chain: *Moritz Kolter*[1]; Johannes Schleifenbaum[1]; [1]RWTH Aachen University - Digital Additive Production DAP

Streaming is a popular concept in the music and movie industry and has helped solve problems related to file distribution, storage capacity and intellectual property protection. In recent years, streaming has also become a research topic for the manufacturing sector, e.g., to collect data for predictive maintenance, advanced machine control concepts, or over-the-air updates. After initial studies have investigated the feasibility of streaming for additive manufacturing technologies, the question is how streaming will affect the process chain. In the music and movie industries, new business models and customer experiences have been created, leading to billion-dollar businesses and the creation of companies such as Netflix and Sportify. In this paper, the impact of streaming on the additive process chain is analyzed using Laser Powder Bed Fusion (L-PBF). The process chain is modeled for different scenarios and its potential impact on the supply chain and future research opportunities are outlined.

3:20 PM
Designing for Circular Economies: Creating Impact from Local Plastic Waste using Off-grid Containerized 3D Printers & Practice Based Learning: *Doug Sassaman*[1]; Chris Hong[1]; Sofia Valdez[1]; Yael Glazer[1]; William Stockton[2]; Michael Webber[1]; Charlotte Craff[3]; Samantha Snabes[3]; Aziz Ahmed[4]; Leela Kempton[4]; Richard Yang[5]; Tosin Famakinwa[5]; Jojibabu Panta[5]; Phan Nguyen[5]; Britney Blann[2]; Carolyn Seepersad[1]; [1]University of Texas Austin; [2]Austin Habitat for Humanity; [3]re:3D, Inc.; [4]University of Wollongong; [5]Western Sydney University

This project aims to create sustainable and user-customizable home goods from local waste plastic, and comprises four thrusts: 3D printing from waste with fused granular fabrication (FGF), life cycle analysis (LCA) of the FGF process, a minimum footprint mobile recycling and 3D printing system (Gigalab), and design in collaboration with end users. The FGF technology allows direct printing from waste plastic and was experimentally and numerically evaluated for part performance and microstructure. The Gigalab minimizes transportation and carbon footprint, and an LCA informed the design of the next generation system. The interactive framework based on topology optimization and deep learning enables users to design functional and aesthetically pleasing home furnishings while ensuring sustainability and structural integrity. The project is a case study with Austin Habitat for Humanity ReStores, using waste plastic from their reStore, involving their customers as end users, manufacturing and selling the printed goods at the ReStores.

3:40 PM
How Good is Good Enough? The Economics of In-process Monitoring in AM: *Paul Hooper*[1]; Harry de Winton[1]; [1]Imperial College London

It is widely recognised that in-process monitoring of additive manufacturing (AM) processes is crucial to providing robust quality assurance procedures, leading to increased acceptance of AM parts in critical applications. Although some of the gains of in-process monitoring are intangible, there are clear economic arguments that can be made to quantify the benefits of a system for different applications. This works aims to answer the question: what detection performance needs to achieved for an in-process system to be cost effect? We look at a range of industry case studies across the aerospace and nuclear industries that cover different production volumes, part costings and inspection requirements. Different costs models are analysed, capturing a monitoring system's ability to stop production of a defective part or replace conventional non-destructive evaluation processes. Total production savings from implementing in-process monitoring range from 0% to 40% in the case studies presented.

4:00 PM
Development of High Filled Bio-based Composites for Sustainable, Low-cost Feedstock: Processing Effects on Porosity and Fiber Alignment: *Katie Copenhaver*[1]; Meghan Lamm[1]; Amber Hubbard[1]; [1]Oak Ridge National Laboratory

PLA composite with a high loading of bio-based fibers was developed using a combination of high-AR wood pulp and low-AR wood flour along with viscosity modifiers to maximize mechanical performance, maintain processability, and lower the cost and embodied energy of the resulting AM feedstock. An optimized composite formulation was scaled up to produce pellet feedstock using twin screw extrusion, and materials were compression and injection molded to investigate the effect of fiber alignment on material performance. The feedstock was then printed on the Big Area Additive Manufacturing system at Oak Ridge National Laboratory. Print parameters including temperature gradients, screw and gantry speeds, layer times, and nozzle designs were varied to minimize sharkskinning, warpage, and porosity of the final parts. A strong effect of the nozzle size on the resulting porosity was observed, and consistent trends between decreasing porosity, increasing fiber alignment, and increasing mechanical performance were identified after printing with different nozzles, compression molding, and injection molding.

Process Develoepment: Photopolymerization and Other Processes

Wednesday AM Room: 400/402
August 16, 2023 Location: Hilton Austin

Session Chair: Michael Cullinan, University of Texas at Austin

8:00 AM
Probing Temperature and Degree-of-conversion States via Tomographic Fluorescence Imaging: *Sui Man Luk*[1]; Chi Chung Li[1]; Joseph Toombs[1]; Martin de Beer[2]; Hayden Taylor[1]; [1]University of California, Berkeley; [2]Lawrence Livermore National Laboratory

Tomographic volumetric additive manufacturing rapidly solidifies freeform objects via photopolymerization, which raises both local temperature and degree-of-conversion (DOC). In-situ monitoring of temperature and DOC during the printing process is crucial for metrology and process control. In this study, we propose a tomographic fluorescence imaging technique to detect the spatiotemporal evolution of temperature and DOC during volumetric printing. Our solution employs a fluorescent dye that is sensitive to both variations in temperature and DOC. DOC is considered as a function of, and is expressed in, the absorbed optical dose of the resin. By tomographically measuring changes in the dye's fluorescence intensity and feeding such changes to a temperature–dose–intensity calibration, the local dose and temperature during the print can be confined to a set of possible states. At exemplar locations where a priori information is known for one quantity, the other quantity can be resolved. This work illustrates the potential of and lays foundations for the development of two-wavelength spatiotemporal measurement systems that uniquely resolve both temperature and DOC.

8:20 AM

Process Modeling for Fluid Interface Supported Printing : *Siva Appana*[1]; Stacy Ross[1]; Christian Sims[1]; Amit Jariwala[1]; [1]Georgia Institute of Technology

The article discusses a new technique for conducting top-down Stereolithography (SLA) 3D printing, which reduces or eliminates the need for solid support. The technique involves printing from a thin resin layer above a static immiscible supporting fluid that prevents deflection from buoyant and gravitational forces on thin overhangs from anchored parts due to minute density differences between the supporting fluid and cured resin. The complex curing and shrinkage dynamics are a primary knowledge gap. Experimental validations reveal that curing the first overhang layer with minimal distortion and curl poses a significant challenge. The article details the latest design and implementation of the FISP prototype to enable reliable curing and presents a Multiphysics model simulated on COMSOL to characterize and model the curing process, including the effects of chemical shrinkage on the overall deformation in the part and the decay of light intensity through a volumetric intensity light model.

8:40 AM

In-situ Interferometric Monitoring of Dual-wavelength Vat Photopolymerization: *Yue Zhang*[1]; Haolin Zhang[1]; Xiayun Zhao[1]; [1]University of Pittsburgh

Dual-wavelength digital light processing based vat photopolymerization process (VPP), referred to as $VPP_{2\lambda}$, is an emerging multi-material 3D printing technology, which uses two concurrent optical masks to selectively cure different components in a single vat. The $VPP_{2\lambda}$ process will facilitate the design and fabrication of various applications including flexible electronics and small robotics. In this work, we develop a non-destructive in-situ interferometric monitoring (ICM) method to monitor the unique wavelength-selective multi-material photopolymerization process dynamics during the $VPP_{2\lambda}$. The ICM-acquired interferogram data is processed by using machine learning to accurately identify good pixels that could reflect the characteristic curing stages. The good pixels are further analyzed using a multi-beam interference based sensor model to estimate each voxel's average refractive index. A correlation model is developed to use the refractive index values to predict the profile of degree of curing (DoC) for revealing the spatially varying kinetics in $VPP_{2\lambda}$.

9:00 AM

Design and Integration of a Multi-modal Machine Safety Architecture for a Novel AM-CM System: *Paritosh Mhatre*[1]; Vipin Kumar[1]; David Nuttall[1]; [1]Oak Ridge National Laboratory

Large format Additive manufacturing (AM) technology has enabled the re-imagining of fabrication processes for complex geometries, bypassing the expensive and long-lead tooling requirements. Additionally, combining AM processes with traditional manufacturing processes has been identified to leverage the best aspects of the individual processes. Oak Ridge National Laboratory is developing one such novel process for polymer composites, combining Additive Manufacturing with Compression Molding (AM-CM), to combine the advantage of high fiber alignment possible in AM-printed parts with low porosity resulting from the improved bead-to-bead interface achieved with traditional CM. The resulting system is intended to be used in tandem mode as well as segregated mode to utilize individual processes as necessary. A custom multi-modal safety integration was therefore developed to achieve this operation of AM-CM, providing a control on operating mode and involved hazards, further reducing the cycle time by minimizing time required to control the safety state of the system.

9:20 AM

A Solid Free Form Fabrication Equipment to Manufacture Axisymmetric Parts with Improved Surface Quality: *Rajeev Dwivedi*[1]; Indira Dwivedi[2]; Arihant Panwar[3]; Bharat Dwivedi[4]; [1]STEM and Robotics Academy; [2]Eastlake High School; [3]Frisco ISD; [4]Lake Washington School District

Competetive and Hobby grade Rocket makers quite often build custom nozzles. Solid freeform fabrication is most natural choice for Manufacturing of the Nozzles. Differnt geometries can be quickly manufactured and tested. However staircase effect and limited accuracy of 2-1/2 based deposition prevents the design intent from fabrication. Additionally using differnt blends of ceramic and sustaining the geometry during curing becomes challenging. This research presents a unique 3D printing system that dispenses ceramic to enable manufacturing of axi-symmetric parts as continuous bead. Relative motion of the material dispenser and rotational substrate as well as unique path planning enables a continually sculpted surface to reduce the staircase effects.

9:40 AM

Wire + Arc Additive Manufacturing of Cryogenic Liquid Hydrogen Storage Tank Demonstrator: Muhammad Shamir[1]; Evren Yasa[1]; *James Whincup*[1]; James Hughes[1]; [1]University of Sheffield

Transportation is responsible for the largest single source of carbon emissions in the UK, making the drive to achieve net zero emissions a key goal to reduce emissions from transportation, including civil aviation. One potential solution is the use of hydrogen as a fuel source. However, this approach presents challenges such as additional storage affecting aerodynamic stability and requires specialized tank geometries. Wire Arc Additive Manufacturing (WAAM) provides design freedom to manufacture complex non-uniform shapes. To achieve cryogenic aerospace applications, aluminium 6xxx/ 2xxx alloys are preferred for aircraft LH2 storage. Nevertheless, welding aluminium can be problematic due to its high thermal/electrical conductivity and affinity to humidity leading to deposition defects. Therefore, this study aims to investigate the feasibility of depositing 2219 series by optimizing process parameters and testing mechanical properties in as-built and heat treated conditions. Moreover, it demonstrates the potential of WAAM for producing tanks suitable for LH2 storage.

Process Development: Direct Ink Writing and Jetting

Wednesday AM — Room: 408
August 16, 2023 — Location: Hilton Austin

Session Chair: Richard Hague, University of Nottingham

8:00 AM

Understanding Electrospray of MoS2 for Scalable Additive Manufacturing: *Bo Shen*[1]; Scott Williamson[1]; Wan Shou[1]; [1]University of Arkansas

MoS2 is a promising functional material for various applications, including tribological coatings, and flexible electronics. While solution-based coating or printing can realize MoS2 additive manufacturing (AM), the evaporation of the solvent can affect the manufacturability, and post-drying can complicate the manufacturing process. In this paper, we introduce a dry powder-based electrospray process for scalable AM of MoS2 film and surface, which is critical for further functional applications. To achieve optimal performance, we will understand the electrospray process for dry MoS2 powder manufacturing, and establish the relationship between the manufacturing process (e.g., voltage, spray distance, and pressure) and structures (e.g., density, and uniformity).

8:20 AM

Thin Strand Printing of Silicone Ink with Direct Ink Write Process: *Siddharthan Selvasekar*[1]; Todd Weisgraber[1]; Joseph Bartolai[2]; [1]Lawrence Livermore National Laboratory; [2]The Pennsylvania State University

Direct ink write AM of sub-millimeter diameter thixotropic elastomer struts is discussed. These thin strut films have use cases in applications such as soft robotics and flexible electronics. Consistent dimensional properties are important to ensure performance repeatability for high precision applications. The design features that are analyzed for quality are strut diameter and hatch spacing. Thin strut quality is measured using optical microscopy. Tool feed rate, material deposition rate, and deposition nozzle diameter are shown to each have an effect on thin strut quality. Experimental results for optimal process parameters for production of thin silicone elastomer struts are reported.

8:40 AM
Simulation Based Optimization for High Frequency Piezo-actuated Molten Metal Droplet Jetting: *Kareem Tawil*[1]; Irtaza Razvi[1]; David Trauernicht[1]; Denis Cormier[1]; [1]Rochester Institute of Technology

Metal additive manufacturing via liquid metal droplet jetting has a range of potential advantages that include use of non-powder feedstock materials (ingot, rod, wire), the potential to fabricate non-weldable alloys, and high material deposition rates with fine feature resolution compared with other high-rate metal AM processes. Typical droplet jetting frequencies for the two commercially available LMJ systems are in the 300-450 Hz range. Inkjet document printers, on the other hand, routinely jet at frequencies in excess of 3 kHz. This talk will present results of multi-physics simulation modeling whose aim is to optimize both ejection chamber geometry and jetting waveforms to allow higher frequency jetting. Simulation results together with experimental validation using a piezo-actuated LMJ test fixture will be presented.

9:00 AM
Liquid Metal Jetting of Aluminum Parts with Salt Support Structures: *Benedikt Kirchebner*[1]; Christoph Weidner[1]; Maximilian Ploetz[1]; Christoph Rehekampff[1]; Wolfram Volk[1]; Philipp Lechner[1]; [1]Technical University of Munich

Liquid metal jetting (LMJ) bears the potential of being a fast part manufacturing technology while using a cheap raw material. LMJ is a subtype of material jetting (MJT) and the parts are built by successively depositing droplets of molten metal onto a build platform. For full 3D capability, support structures are necessary which must be removed in subsequent processes. In previous investigations, we proposed the usage of water-soluble salt as a support material, selected a suitable salt, and analyzed the influence of this material on aluminum parts made in LMJ. In the present work, we show a duplex MJT print head for the processing of aluminum alloys and KCl-NaCl salt. Various printing strategies and support structure types are compared. The results show that the sequence of printing aluminum and salt is crucial. Furthermore, the use of thin layers of support material as a release layer appears promising.

9:20 AM
Further Developments of a Novel Low Cost Material Jetting platform for 3D Printing: *Craig Sturgess*[1]; [1]Added Scientific Ltd

A talk on the progress of creating a low-cost Material Jetting platform focusing on removing the boundaries for researchers around the hardware cost and closed nature. This talk focuses on the potential advantages of having full control, open system. The system is designed to be simple to use, assemble, and of low cost. It combines the use of Xaar inkjet print heads, with Added Scientific drives and mounts, on a consumer grade FDM printer. This system enables four different materials to be printed, allowing for three unique build materials. The presentation follows the workflow of using a new material on a platform without a drop watcher and how through full control this process is greatly simplified. Finally, the results include data on the accuracy of printed parts, minimum feature sizes, and repeatability when using hobby level FDM platforms.

9:40 AM Break

10:10 AM
Exploring Additively Manufactured Heterostructures of Functional Materials: Focus on Interfaces: Jonathan Austin[1]; Feiran Wang[1]; Negar Gilani[1]; Yundong Zhou[2]; Gustavo Trindade[2]; Ian Gilmore[2]; Christopher Tuck[1]; Richard Hague[1]; Ricky Wildman[1]; Lyudmila Turyanska[1]; *Geoffrey Rivers*[1]; [1]University of Nottingham; [2]National Physical Laboratory

Inkjet 3D printing offers opportunities for additive manufacturing of multi-material electronic devices, which we successfully demonstrated previously with a variety of low dimensional material heterostructures: 2D/2D [Adv. Funct. Mater. 31, 2007478, 2021], 0D/2D [Nanoscale 15, 2134, 2023], 2D/polymer and 0D/polymer [Addit. Manuf. 66, 103452, 2023]. However, the performance of these devices strongly relies on the quality of the printed material interfaces, which are yet to be fully explored and understood. We explored the interfaces of inkjet-printed heterostructures based on combinations of 2D (graphene, hBN) and 0D (perovskite nanocrystals and metal nanoparticles) materials, and also conductive (PEDOT:PSS) and dielectric [PVP, PEG] polymers using complementary Time-of-Flight Secondary Ion Mass Spectrometry and Focused Ion Beam-Scanning Electron Microscopy, revealing infiltration and intermixing between layers. Furthermore, we examined the effects of the layer composition and deposition/post-deposition parameters on the quality of the interfaces, seeking to establish strategies for control of the interface properties.

10:30 AM
Effects of Double-pulse Waveform on Piezoelectric Inkjet Printing Speed: *Chao Sui*[1]; Wenchao Zhou[1]; [1]University of Arkansas

Inkjet technology has gained widespread usage across various industrial applications due to its high resolution and versatility in printing with different materials. However, its printing speed has limited its application in high-volume production. This paper discusses the extension of a previously developed model for predicting the effects of a single-pulse driving signal on inkjet printing speed to include the effects of double-pulse waveforms. It is hypothesized that the use of double-pulse waveforms can further improve the printing speed of inkjet technology by producing large droplets at a higher frequency. The model is then used to understand the effects of double-pulse waveform parameters on the printing speed. Optimization is then performed to obtain parameters that can achieve maximum printing speed. The results are validated experimentally, which indicates the optimized double-pulse signal can successfully achieve jetting with a significant increase in equivalent printing speed compared to the single-pulse waveform.

10:50 AM
Development of Dual-head MetalJet System for Drop-on-demand Multi-metal Deposition: *Xiangyun Gao*[1]; Mark East[1]; Negar Gilani[1]; Marco Simonelli[1]; Nesma Aboulkhair[1]; Richard Hague[1]; [1]University of Nottingham

Recent advancements in liquid metal deposition technologies have fostered innovative additive manufacturing solutions. This study introduces the MetalJet 3.0 system, a dual-head drop-on-demand (DoD) metal deposition platform, which advances upon previous MetalJet research to facilitate multi-material 3D printing in a single build process. The complex mechatronic control system combines an FPGA, integrating two independent deposition heads, an induction heater, a waveform generator, in-situ monitoring cameras, and high-precision linear stages with encoders in a LabVIEW program. The system applies Magnetohydrodynamics (MHD) to create jetting pulses and is equipped with a strobe camera to configure the jetting. This voxel-defined Drop-on-demand process has achieved an accuracy of 50um, giving it the potential to accelerate progress in materials and functional structures across industries such as microelectronics, robotics, and medical implants. Experimental evaluation using Sn in both heads asses printing accuracy and alignment. The dual-head DoD system exhibits promising potential in fabricating voxel-defined complex multi-material structures, free-standing structures and FGMs, underscoring its potential to revolutionize additive manufacturing.

11:10 AM
Investigation of Multi-Material Liquid Metal Jetting with Copper Materials: *Maximilian Ploetz*[1]; Florian Heckmeier[1]; Benedikt Kirchebner[1]; Wolfram Volk[1]; Philipp Lechner[1]; [1]Technical University of Munich

Components are typically subject to a variety of requirements that may be in conflict with each other. Multi-material components can be a way to overcome such conflicting goals. For the manufacturing of multi-material copper components with high geometric complexity, Liquid Metal Jetting (LMJ) can be a promising additive manufacturing process. Since LMJ builds up a part droplet by droplet, there are no mixed powders after the building process. In addition, LMJ offers the possibility of changing materials from droplet to droplet. In previous studies, we have shown that it is possible to produce copper alloy components using LMJ. To investigate the manufacturing of multi-material copper components, we developed a duplex print head that can eject droplets of two different copper materials and produced multi-material copper parts. The investigations show that the quality of the compound and the microstructure depend significantly on the thermal process parameters used.

11:30 AM
Comparison of High-resolution Aerosol Jet Printing of Silver Inductors on Rotary and Linear Stages: *Max Tafoya*[1]; Joshua Tarantino[1]; Alfred Thibodeaux[1]; Lok-Kun Tsui[2]; Yongkun Sui[1]; Judith Lavin[1]; [1]SNL New Mexico - Albuquerque; [2]University of New Mexico

Aerosol Jet Printing (AJP), a direct write form of additive manufacturing, enables versatile and high-resolution fabrication of printed electronics. Inductors, one of the types of passive electrical components, are used in printed transformers, wireless charging, torque sensors, and electromagnets, etc. AJP can deposit conductive lines with a width of 10–50 microns. For spiral inductor fabrication, the smoothness of the spiral arc determines the smallest pitch. With commonly used X-Y linear stages, the smoothness of arc is limited by the resolution of the motor and the tuning of motion parameters (speed, acceleration, etc.). This work will demonstrate high resolution AJP of silver inductors using a polar system consisting of rotary and linear stages. A comparison of spirals printed using cartesian and polar systems will be made by microscopy and profilometry. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

Process Development: Powder Bed Fusion Monitoring and Imaging III

Wednesday AM Room: 410
August 16, 2023 Location: Hilton Austin

Session Chair: David Deisenroth, Institute of Standards and Technology

8:20 AM
Laser Induced Breakdown Spectroscopy for In-situ Monitoring of Laser Powder Bed Fusion Processing: *Justin Krantz*[1]; Cody Lough[2]; Ben Brown[2]; Robert Landers[1]; Edward Kinzel[1]; [1]Univ. of Notre Dame; [2]Kansas City National Security Campus

Laser powder bed fusion is the most widely used powder-based additive manufacturing process. A major hurdle for laser powder bed fusion processes is identification and addressing of flaws in the as-built part. In-situ monitoring of laser powder bed fusion processes allows for identification of flaws and the potential to address them during the build. A particular emphasis is placed on the ability to capture information about the material composition through laser-induced breakdown spectroscopy. An ultrafast pulsed laser is coaligned with a continuous wave process laser for simultaneous application. The ultrafast laser is used to probe the melt pool of in-process laser powder bed fusion build, creating a plasma from which signals are collected. The use of the ultrafast laser minimizes adverse effects on the melt pool during processing. This process allows for superior emission collection capabilities compared to techniques such as optical emission spectroscopy.

8:00 AM
Infrared Camera (IR) Feature Extraction for Defect Detection in Laser Powder Bed Fusion: *Shawn Hinnebusch*[1]; Berkay Bostan[1]; David Anderson[1]; Albert To[1]; [1]University of Pittsburgh

Part qualification is a critical step in advancing additive manufacturing. This work uses an infrared (IR) camera to construct features for a machine learning algorithm to predict defects with +90% accuracy. A custom heating module with thermocouples was employed to calibrate the IR camera with various scanning strategies from room temperature up to 500 . Another custom plate enables angle perspective corrections accounting for distortion caused by the rotation or angle effects of the camera. After image correction, a voxel mesh is superimposed on top of the IR data to distinguish between the powder and the part. The images are separated by layer to analyze layerwise heat accumulation, cooling rates, heat intensities, melt pool spatter, spatter landing location, and scanning strategy. A machine learning algorithm uses the 3D reconstruction as the input to predict defects in a lack of fusion part.

8:40 AM
Layer-wise In-process Monitoring-and-Feedback System Based on Surface Characteristics Evaluated by Machine-Learning-Generated Criteria: *Toshi-Taka Ikeshoji*[1]; Makiko Yonehara[2]; Kenta Aoyagi[3]; Kenta Yamanaka[3]; Akihiko Chiba[3]; Hideki Kyogoku[1]; Michiaki Hashitanani[2]; [1]Kinki University K.U.RING; [2]TRAFAM; [3]Tohoku University

In the laser powder bed fusion (PBF-LB) process, a set of parameters that are considered optimal are selected. Still, a set of parameters cannot accommodate complex model geometries, model placement in the build chamber, and unforeseen circumstances, leading to internal defects. Therefore, a new in-situ monitoring and feedback system has been developed to suppress the occurrence of lack-of-fusion (LOf) defects in the PBF-LB process. This system measures surface properties after each laser irradiation to predict whether LOf defects occur. Then, if necessary, a feedback process is performed to re-melt the same surface. Evaluation thresholds are defined by a combination of aerial surface texture parameters created in advance by machine learning of surface properties and defect occurrence. For example, a square pillar of Inconel 718 alloy built with feedback had a higher relative density than one without feedback.

9:00 AM
Multi-laser Diode Area Melting of Ti6Al4V: A Novel Alternative Approach to Traditional Laser Powder Bed Fusion: *Mohammed Alsaddah*[1]; Kristian Groom[1]; Kamran Mumtaz[1]; [1]The University of Sheffield

Laser Powder Bed Fusion (LPBF) selectively melts thin layers of metallic powder. The process depends on a high-power fibre laser at a wavelength of 1060nm using a galvo scanning system to create 3D complex parts. However, this method presents related challenges, such as scalability, processing efficiency (due to poor radiation absorption and wall-plug efficiency), and high thermal gradient due to rapid solidification. An alternative approach has been developed called Diode Area Melting (DAM) offers better process efficiency, scalability and controllable thermal gradient (lower cooling rate) during the process by incorporating several individually controllable, low-power (4.5W) with a short wavelength (808nm) using fibre-coupled diodes lasers into a single laser head traversing over the powder bed. This work demonstrates the potential of using DAM to process Ti6Al4V material by employing multiple lasers with different beam profiles to improve the process efficiency, mechanical properties, and microstructure of the final parts.

9:20 AM
Multimodal Process Monitoring to Predict Outcomes during Laser Powder Bed Fusion: *Nicholas Calta*[1]; Sanam Gorgannejad[1]; Yuchen Sun[1]; Maria Strantza[1]; Aiden Martin[1]; Gabe Guss[1]; Michael Juhasz[1]; Jenny Nicolino[1]; [1]Lawrence Livermore National Laboratory

Process monitoring is a significant area of ongoing research in the laser powder bed fusion (LPBF) community because of its potential to accelerate part certification and qualification. A variety of different monitoring modalities have been applied to LPBF including approaches based on thermal emission, plasma emission, acoustic emission, optical and infrared imaging, and others. These disparate monitoring approaches provide different and often complimentary information about process stability. This talk will give an overview of how multiple monitoring approaches can be used in a complimentary fashion to identify both process stability and defect formation events. This is accomplished by selecting monitoring modalities that probe orthogonal aspects of the physical process. The primary focus will be on optical and acoustic emission monitoring in concert with high speed X-ray imaging, but other modalities will also be discussed. Prepared by LLNL under Contract DE-AC52-07NA27344.

9:40 AM Break

10:10 AM
Optical Metrology for Laser-matter Interaction in LPBF: Challenges and Opportunities: *David Deisenroth*[1]; [1]National Institute of Standards and Technology

Recent studies in optical metrology of laser powder bed fusion (LPBF) indicate that there remains insufficient understanding of the optical phenomena that occur during laser-matter interaction, which limits the accuracy of non-contact measurements for multiphysics model validation applications. One of the first challenges is accurate measurement of the power density distribution (often a two-dimensional gaussian profile) of high-power lasers under conditions of interest for LPBF. Furthermore, process byproducts (including metal vapor, condensate, and ejecta) can interact with the light propagating to (and from) the melt pool, which can attenuate, scatter, or otherwise distort the power density distribution that is delivered to the melting surface; preliminary results of measuring the effects of process byproducts are discussed. Finally, metrology for quantifying the total laser power reflected from the laser-matter interaction (used to approximate laser absorption), as well as for visualizing the directional distribution of reflected laser power, will be discussed.

10:30 AM
The Detection of Defects Caused by Reduced or Interrupted Shield Gas Flow in Laser Powder Bed Fusion: *James Bell*[1]; [1]Imperial College London

Without proper shield gas flow in laser powder bed fusion (LPBF), soot and condensate in the plume escaping the melt pool will interfere with the laser causing porosity. In this study gas flow was varied for several layers while building columnar parts located across the build plate, and the effect of blocking sections of the outlet while building was also investigated. Co-axial monitoring with a high-speed camera was used to determine whether the reduction in, and interruption of gas flow could be detected by changes in the melt pool geometry and other features indicative of suboptimal melting conditions. The flow speed was measured across the build chamber. Results showing the changes in monitoring signal due to reduced and interrupted gas flow are presented, as well as the induced differences in part quality. Transferability of the findings to a production system using a photodiode for melt pool monitoring will be discussed.

10:50 AM
Time-resolved Optical Spectroscopy in Metal Powder Bed Fusion: *Matthias Beuting*[1]; Luis Escano[1]; Lianyi Chen[1]; Scott Sanders[1]; [1]University of Wisconsin-Madison

Our work addresses the challenge of understanding the dynamics of the interaction between partially evaporated metal and the melt pool in powder bed fusion. So far, few contactless sensing strategies have been developed for measuring metal vapor temperature, density, and composition - information crucial for modeling the influence of plume recoil pressure on the microstructure of the part being built. We used optical emission spectroscopy (OES) and tuned diode-laser absorption spectroscopy (TDLAS) to study the vapor plume during the processing of Ti-6Al-4V. The use of novel blue diode lasers allowed for time-resolved measurement of the temperature of gaseous vanadium using TDLAS in selective laser melting (SLM) and electron beam melting (EBM). The fast repetition rate of 20 kHz provided further insights into the transient plume conditions in EBM, revealing a roughly symmetrical shape with uniform temperature.

11:10 AM
Using In-situ Two-color Thermal Imaging to Validate Multi-physics CFD Melt Pool Models for LPBF: *Alexander Myers*[1]; Guadalupe Quirarte[1]; Francis Ogoke[1]; Amir Barati Farimani[1]; Jack Beuth[1]; Jonathan Malen[1]; [1]Carnegie Mellon University

An experimental method to image melt pool temperature with a single color camera was developed, and the in-situ measurements were used to better understand melt pool physics. The experimental approach leverages the principle of two-color thermal imaging, which negates the need for a priori knowledge of melt pool emissivity. The high-speed color camera's ability to accurately measure temperature was validated with a NIST blackbody source. It was then used to image 316L stainless steel single beads off-axis on the TRUMPF TruPrint3000 laser powder bed fusion machine. Multi-physics computational fluid dynamics models (CFD) are used to simulate metal melt pools, but some parameters are not well characterized for metals. Fitting a FLOW-3D model to ex-situ measurements of the melt pool cross-sectional geometry identifies multiple combinations of model parameters. Comparing the simulated temperatures to the in-situ measurements narrows the parameter selection, motivating the need for thermal imaging to advance CFD model validation.

11:30 AM
Two-color Thermal Imaging of WC-Ni Cermet Melt Pools in Laser Powder Bed Fusion: *Guadalupe Quirarte*[1]; Alex Gourley[1]; Alexander Myers[1]; B. Jayan[1]; Jack Beuth[1]; Jonathan Malen[1]; [1]Carnegie Mellon University

Resolving the melt pool temperature distribution in additive manufacturing processes is key to understanding the underlying physics and developing improved process monitoring tools. This project applies a new method to measure dense tungsten carbide (WC)-17 wt.% nickel (Ni) composite melt pool temperatures in laser powder bed fusion (L-PBF) using a high-speed color camera two-color technique. Conventional manufacturing of cermets like WC-Ni is difficult compared to metal alloys, but these materials can have advanced performance and can be made by additive processes. One of the major challenges associated with experimental temperature measurement methods in L-PBF is the accelerated and localized heating and cooling of the process. Measuring the melt pool temperature using conventional infrared imaging techniques or pyrometry lack the temporal and spatial resolution needed for measuring LPBF melt pool temperature profiles. Separate measurements of WC-Ni cermet thermal conductivity enables improved thermal models that are compared with the experimental temperature measurements.

Data Analytics: Laser Powder Bed Fusion

Wednesday AM — Room: 412
August 16, 2023 — Location: Hilton Austin

Session Chair: Paul Hooper, Imperial College

8:00 AM
Self-repair of Defects: The Achilles Heel for In-process Detection of Small Pores?: Richard Williams[1]; Sebastian Larsen[1]; Harry de Winton[1]; *Paul Hooper*[1]; [1]Imperial College London

Pores created in laser powder bed fusion are frequently repaired as a natural part of the manufacturing process. This self-repair occurs because the melt pool spans several layers in depth, remelting material that contains pores created in previous layers. This self-repair presents a problem for in-process defect detection. Some pores that are detected will not be present in the final part, leading to high false positive rates even for a perfect system. In this work we conduct layer-wise ex-situ micro-CT scanning, where the build sample is removed from the machine after each layer, to observe pore locations and self-repair over a number of layers. In-process monitoring using off-axis illuminated imaging and co-axial melt-pool imaging is performed during the processing of each layer to look for signatures of pore formation and healing. Results showing links between the previously melted layer, the monitoring signals and the subsequent layer will be presented.

8:20 AM
Unveiling Melt Pool Defect Signatures with Interpretable Machine Learning: *Sebastian Larsen*[1]; Paul Hooper[1]; [1]Imperial College London

As machine learning (ML) becomes an essential part of in-situ monitoring, model interpretation is needed to ensure robustness and alignment. In this study, we use interpretable ML methods to better understand melt pool defect predictors captured from co-axial high-speed imaging of the laser powder bed fusion process. The methods explored include a variety of explainable AI tools, such as saliency maps and feature importance metrics, to visualise and quantify melt pool features. Results from three datasets are presented: single tracks, laser defocus, and localised defects. The analysis enables a comparison between high-speed imaging and an equivalent photodiode, with each source of improvement measured. Through this analysis, key descriptors can be better understood, providing a deeper understanding of the melt pool behaviour.

8:40 AM
Real-time Melt Pool Characterization in Laser Powder Bed Fusion Using Acoustic and Photodiode Monitoring: *Haolin Liu*[1]; Christian Gobert[1]; Brandon Abranovic[1]; Hongrui Chen[1]; Kevin Ferguson[1]; Jack Beuth[1]; Anthony Rollett[1]; Levent Burak Kara[1]; [1]Carnegie Mellon University

As the demand for high-quality fabrication grows, the need for real-time monitoring of the laser powder bed fusion (LPBF) process has also grown, leading to the incorporation of a range of online sensing methods such as acoustic sensing and high-speed imaging. In practice, real-time high-resolution melt pool image capture remains computationally demanding. In this work, we propose a cost-effective monitoring approach that can replace the need for direct visual sensing in LPBF. In particular, we utilize acoustics and photodiode-based data to predict highly time-resolved visual melt pool characteristics in a nearly real-time fashion. Our approach enables a data-driven mapping within a time window of 2.0 ms. Our work demonstrates the feasibility of using a cost-effective method to achieve online visual melt pool characterization and contributes to the advances in quality control for LPBF.

9:00 AM
Process Parameter Optimization Using Photodiode Intensity in Laser Powder Bed Fusion: *Amit Verma*[1]; Gabe Guss[1]; Saad Khairallah[1]; Ava Ashby[1]; CE Kim[1]; Ibo Matthews[1]; [1]LLNL

One limiting factor towards the wider adoption of laser powder bed fusion (LPBF) process, in regard to complex geometries, is the time required to optimize the machine parameters. Currently, most commercial LPBF printers include an in-situ photodiode sensor to monitor the melt-pool, which can be leveraged for this optimization in a timely manner. In this talk, we will present a 1D-CNN framework which leverages photodiode data to optimize process parameters. Since this framework leverages experimental data, we will comment on training prints & their limitations, experimental validation of the model on new prints, feature engineering to capture 2d & 3D geometric constraints in a 1D model, and how it relates to improving dimensional accuracy for features such as overhangs, thin walls, down-skins, etc. Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy, National Nuclear Security Administration under Contract DE-AC52-07NA27344.

9:20 AM
Monitoring of Single-track Quality in Laser Powder Bed Fusion using In-situ Thermionic Sensing: *Benjamin Bevans*[1]; Philip DePond[2]; Aiden Martin[2]; Nick Calta[2]; J-B Forien[2]; Gabe Guss[2]; Brian Giera[2]; Prahalada Rao[1]; [1]Virginia Tech; [2]Lawrence Livermore National Laboratory

This work concerns the laser powder bed fusion (LPBF) additive manufacturing process. In this work track quality was monitored in-situ using a novel thermionic sensing approach. It is important to monitor the quality of the track in LPBF as it is the basic building block of the part. In this work, track quality is defined as track width and the percent continuity of the track. The objective of this work is to detect the onset of track deviations using signatures extracted from a novel thermionic sensor. This thermionic sensor is attached to the substrate and measures the voltage response of the electrons released when the laser interacts with the build plate. The signals from the thermionic sensor are analyzed using empirical mode decomposition, and the derived signatures are used subsequently within elementary machine learning models to predict the quality of track.

9:40 AM Break

10:10 AM
Mining Complex Feedstock-Geometry-Process-Quality Relationships for Powder Bed Fusion Thin Features using Graphical Model: *Naresh Koju*[1]; Xiaoyu Chen[1]; Li Yang[1]; [1]University of Louisville

Thin features (thin walls and thin struts) in the strut-based and planar lattice structure show a powder feedstock-geometry-process-quality (PGPQ) characteristic. However, the relationship between the input variables (powder feedstock, laser Power, scan speed, feature type, and feature dimension) and their properties are complex to understand. Besides input variables, the intermediate variables such as dimension (dimensional variability within a sample), porosity and pore size distribution, and even the grain sizes are expected to correlate to the quality/mechanical properties of these thin features. Therefore, the main objective of this study is to explore the complex graphical relationship between the input variables, intermediate variables, and the final flexural properties of thin features by utilizing a graphical model-based machine learning (ML) model. The ML model depicts the influence of some of the intermediate variables (e.g. porosity) on the flexural properties of the thin features, which helps revealing the complex PGPQ characteristics.

10:30 AM
Distilling Thermal Signatures from Reduced Order Physics Models for Electron Beam Powder Bed Fusion Processing: *Patxi Fernandez-Zelai*[1]; Sebastien Dryepondt[1]; Amir Ziabari[1]; Michael Kirka[1]; [1]Oak Ridge National Laboratory

Extracting meaningful process-structure trends from spatiotemporal thermal data simulation can be extremely challenging. Model parameter uncertainty, simplified physics, and idealized conditions, introduced model bias which further makes difficult the quantification of salient thermal features. In this work we propose an approach to encode the spatiotemporal outputs from a reduced order thermal model into a compact latent space representation. This is achieved using a self-supervised video-transformer machine learning framework. The identified latent representation summarizes the relevant physics and, given sufficient data, allows for calculation of similarity measures. As an example the approach is used to establish a data-driven process-structure model for an additively manufactured Ni-based superalloy. This methodology is well suited to be used towards in-situ process monitoring, scan pattern design, and component qualification.

10:50 AM
Detecting Failures in Laser Powder Bed Fusion Additive Manufacturing of Complex Lattice Structures using Multi-sensor Data and Machine Learning: Anis Asad[1]; *Benjamin Bevans*[1]; J-B Forien[2]; Aiden Martin[2]; Nick Calta[2]; Philip DePond[2]; Gabe Guss[2]; Brian Giera[2]; Prahalada Rao[1]; [1]Virginia Tech; [2]Lawrence Livermore National Laboratory

The goal of this work is to detect the probability of strut failures in complex lattice structures built using laser powder bed fusion (LPBF). In pursuit of this goal, the objective is to predict the probability of strut failure as a function of heterogeneous sensor data from a pyrometer and a photodiode placed coaxially (in-line) via supervised machine learning models. The result is a 3D digital twin of the lattice created to demarcate areas of failure. This model was trained on a single lattice structure with artificially generated broken struts and tested on an additional lattice with smaller broken struts than the training lattice. In this work we show that the developed approach is capable of accurately detecting broken lattice struts with a statistical fidelity exceeding 80% (F-score) even when transferred to a different lattice geometry with finer resolution of breakage.

11:10 AM
Data-driven Local Porosity Prediction in Laser Powder Bed Fusion via In-situ Monitoring: *Berkay Bostan*[1]; Shawn Hinnebusch[1]; David Anderson[1]; Albert To[1]; [1]University of Pittsburgh

In this study, the geometry-agnostic deep learning scheme has been developed for defect detection during the laser powder bed fusion (LPBF) process. DNNs model has been trained that gives +90% accuracy with a relatively smaller dataset. Inputs to DNNs include various thermal signatures (interpass temperatures, heat intensities, and cooling rates) and spatter locations. At the same time, when making predictions, the DNNs architecture considers the features of not only the relevant pixel, but also neighboring pixels in all directions (desired order of neighbors in the current, upper, and lower layers). The potential outcomes of this study are simultaneous defect prediction during manufacturing and repairing the defects by rescanning the concerned region. Furthermore, defect formation mechanisms have been investigated by SHAP (SHapley Additive exPlanations) feature importance analysis method, and it is observed that spattering is the most dominant factor for defect formation until the melt pool reaches a certain size.

11:30 AM
3D Geometry Reconstruction of Overhang Part: A Machine Learning Approach Using In-situ Monitoring Data: *Zhuo Yang*[1]; Jaehyuk Kim[2]; Yan Lu[2]; Brandon Lane[2]; Yande Ndiaye[2]; [1]Georgetown University; [2]NIST

Real-time control through the use of sensors and controllers is being applied in powder bed fusion AM systems to manage in-situ process features like melt pool size and temperature. Despite this technology, geometry deviation and surface roughness defects still persist due to difficulty of obtaining accurate geometric information during the build. Although in-situ monitoring captures several in-process data, precise geometric information is challenging to acquire. To address this problem, a machine learning approach is proposed to predict material formation in 3D, particularly the geometry of overhang surface using process parameters and coaxial melt pool images. The output of this predictive approach will be incorporated into a visualization model to reconstruct the overhang part geometry for quality evaluation. The preliminary results from an experiment involving four overhang parts, with 100,000 melt pool images generated, indicate that the proposed method provides a solution for real-time control of part geometry and surface roughness.

Materials: Metals-Novel AM Methods I

Wednesday AM	Room: 415 AB
August 16, 2023	Location: Hilton Austin

Session Chair: Aaron Liao, University of Texas at Austin

8:00 AM
Formation of Easy-to-Remove Support Structures in Metal LPBF with En-situ Powder Bed Doping.: McKay Sperry[1]; David Carter[1]; *Nathan Crane*[1]; [1]Brigham Young University

Laser Powder Bed Fusion (LPBF) is a popular Additive Manufacturing (AM) technique used commonly for metals. Metal parts formed by LPBF generally require supports connecting the part to the print bed to hold up the structure, remove heat, and reduce residual stresses. Because of these supports, finished parts must be cut away from the build plate, and generally require additional machining to achieve the desired geometry. In this study, a carbon suspension was deposited in the 316L stainless steel powder bed at the interface between the support and the finished part. This helped the finished part to break free from the supports without any need for machining, simplifying post-processing. The added carbon reduced the corrosion resistance of the 316L, allowing excellent heat transfer and mechanical support during printing, but causing the modified supports to etch preferentially in an electrolyte bath and release the part.

8:20 AM
Reduced Silver Consumption using Particle-free Reactive Silver Inks for Low-temperature Solar Cell Metallization: *Steven DiGregorio*[1]; Michael Martinez-Szewczvk[2]; Subbarao Raikar[1]; Mariana Bertoni[2]; Owen Hildreth[1]; [1]Colorado School of Mines; [2]Arizona State University, Ira A. Fulton Schools of Engineering

Particle-free reactive metal inks are an alternative conductive ink technology to nanoparticle metal inks for printed electronics. Reactive inks offer simpler synthesis, greater ink stability, and, most importantly, lower processing temperatures than particle-based inks. These low-processing temperatures enable printed electronics on thermally sensitive substrates, such as silicon heterojunction (SHJ) solar cells. This work investigates how ink heat treatment, formula, and printing parameters impact the electrical properties of reactive silver inks, emphasizing the properties pertinent to solar cell metallization. 4-point resistance measurements and top-down and cross-section microscopy characterized the printed silver fingers, and IV measurements characterized the photovoltaic performance. The best-performing ink achieved silver fingers with resistivities of 3.1 μΩ·cm and contact resistivities of 3.2 mΩ·cm2 when printed at 61 °C. This ink metallized a full-sized SHJ cell and consumed 90% less silver compared to standard metallization processes.

8:40 AM
Solid-state Production of Uniform Metal Powders for Additive Manufacturing by Ultrasonic Vibration Machining: Yaoke Wang[1]; *Malachi Landis*[1]; Ping Guo[1]; [1]Northwestern University

This work presents a new technique to generate uniform and micron-sized metal powders for advanced additive manufacturing. By collecting discrete chips resulting from ultrasonic vibration machining, we demonstrate the feasibility of generating consistent powders with tight dimensional tolerance, the ability to control powder geometry, and good efficiency. It offers a new route for sustainable and low-cost manufacturing of high-quality metal powders. The powder generation mechanism is analyzed with a special tool path design to ensure consistent dimensions over multiple cuts. Aluminum and brass powders with critical dimensions of 25 by 50 μm are demonstrated and verified with selective laser melting.

9:00 AM
Surface Roughness of Machined 316L Stainless Steel Fabricated by FDM/FFF 3D Printing Technology: Suleiman Obeidat[1]; *Eduardo Rodriguez*[1]; Iftekhar Basith[1]; [1]Sam Houston State University

We investigate the effect of the raster angle and the building direction on the surface roughness after milling 316L stainless steel parts printed using FDM/FFF technology. BASF Ultrafuse 316L metal 3D printing filament of 1.75 mm diameter will be used. Samples of 316L stainless steel are printed using Method X 3D printer made by Makerbot with the capability of printing parts using filaments of metal particles embedded in resin. The parts are printed at different raster angles that include 0˚, 30 ˚, 45˚, and 90˚ in two different building directions (flat and on the edge). The printed parts are sintered in a pipe furnace to obtain pure stainless-steel samples. The milling operation is performed in different directions with respect to the raster angle then we will measure the surface roughness and correlate it with the raster angle.

9:20 AM
Amorphous Magnetic Alloys Printed from Carbonyl Based Metal-organic Decomposition Inks: Collin Miller[1]; *Owen Hildreth*[1]; [1]Colorado School of Mines

Amorphous metals are exciting because the lack of crystal structure gives them interesting and unique physical, electric, and magnetic properties. One major drawback to these materials is how difficult they are to manufacture. They often require very large temperature gradients that cause fast cooling rates in order to kinetically freeze them. This work demonstrates the ability to electrohydrodynamically print amorphous soft magnetic alloy materials using a reactive ink precursor without rapid cooling. This is possible because they are formed through a chemical reaction rather than a melt. Particle-free Iron – Cobalt reactive inks were made by dissolving organometallic metal carbonyls, such as Iron Pentacarbonyl and Cobalt Octacarbonyl, in organic solvents. These inks can be printed in an inert atmosphere using electrohydrodynamic printing then thermally decomposed into their metallic state using a heated bed at temperatures below 300 °C.

9:40 AM Break

10:10 AM
Binder Evaporation During Powder Sheet Additive Manufacturing: *Joerg Volpp*[1]; Wenyou Zhang[2]; William Abbott[2]; Asli Coban[2]; Riccardo Casati[3]; Ramesh Padamati[2]; Rocco Lupoi[2]; Silvia Marola[3]; [1]Luleå University of Technology; [2]Trinity College Dublin; [3]Politecnico di Milano

Several Additive Manufacturing methods are well established and found access into regular production in multiple sectors. For processing metals, typically wire or powder is used as feedstock. For additive processes very fine powder is used. Such fine powders can be a health risk for humans (aspiration, skin integration). Therefore, an alternative process was developed that provides the powder not as free powder particles but in form of powder sheets. For enabling the necessary bonding between the particles, a binder is used. In order to understand the impact of the binder during laser processing of the powder sheets, single pulse and line treatments were produced and recorded with high-speed imaging. Recordings show the vaporization of the binder and the related ejections of powder particles. At lower energy input, the binder evaporation led to less spattering, which indicates that a binder heating at low heating rates induces less pressure on the particles.

10:30 AM

Embedding of Luminescent Pigments within 316L Stainless Steel Matrix by Laser Powder Bed Fusion for Optical Functionalities: *Christina Baslari*[1]; Hicham Maskrot[1]; Wilfried Pacquentin[1]; Sonia De Sousa Nobre[2]; Daniel Zambon[3]; Rachid Mahiou[3]; [1]Université Paris-Saclay, CEA; [2]Université Grenoble Alpes, CEA; [3]Université Clermont Auvergne

Corrosion-related degradation of metallic components presents economic, safety and environmental issues in high-tech industries. In a circular economy approach, it would be relevant to propose new eco-designed solutions for extending the service life of metallic parts. The proposed method consists in incorporating luminescent particles into metallic parts by additive manufacturing in order to track their corrosion rate, using photoluminescence to monitor the materials degradation. In this study, laser powder bed fusion was used to successfully incorporate for the first time Ce3+ doped yttrium aluminum garnet (YAG:Ce) into a 316L stainless steel matrix by controlling the influence of process parameters. Chemical compositions and microstructural changes related to phosphors incorporation have been observed by energy dispersive spectroscopy (EDS) and backscatter diffraction (EBSD) respectively. Laser induced photoluminescence spectra of embedded particles revealed new optical features. Finally, preliminary tests in nitric environment have been carried out to monitor the corrosion rate of 316L.

10:50 AM

Embedding Temperature Sensors with the Use of Laser-Foil-Printing Additive Manufacturing: *Tunay Turk*[1]; Maxwell Dougan[1]; Logan Hendrix[1]; Aaron Reed[1]; Cesar Dominguez[2]; Austin Sutton[2]; Jonghyun Park[1]; Ming Leu[1]; [1]Missouri University of Science and Technology; [2]Los Alamos National Laboratory

Laser foil printing (LFP) is a metal additive manufacturing (AM) process using laser-based melting of metal foil technique. Using metal foils in AM has advantages over common laser powder-feed processes, allowing for efficient heat transfer and resolving the drawbacks of powder-based AM, such as potential powder inhalation health hazards, balling, spattering, and high powder costs. In this study, we demonstrate the advantage of LFP for embedding sensors into structures using 304L stainless-steel foil as the feed material and two different types of temperature sensors. The first type is a resistance temperature detector (RTD) platinum sensor (Pt 100), and the second type is a k-type thermocouple probe. A detailed study of the sensor embedment through LFP revealed that laser power, dwelling duration, and scanning strategy significantly affect product quality. As a result of this study, we demonstrated the feasibility of fabricating functional parts with embedded sensors using the LFP process.

11:10 AM

Novel Welding Strategies in High Deposition Rate Laser-Assisted Double-Wire Welding Process with Nontransferred Arc: *Kai Biester*[1]; Nick Schwarz[1]; Jörg Hermsdorf[1]; Stefan Kaierle[1]; [1]Laser Zentrum Hannover e.V.

Laser-assisted double wire welding with non-transferred arc melts the material using an arc between two conveyed wires. Driven by gravity the molten metal drops onto the substrate. A laser beam is oscillated on the melt pool to bond the weld beads to the substrate without undercuts. Claddings at high deposition rates (11.64kg/h) were performed with 316L on mild steel. The first welding strategy (AAA) is to weld adjacent beads (A) with a varied track spacing of 7 to 9mm. The second strategy (ABA) consists of beads (A) welded at a distance of 14 to 18mm from each other, so that a third bead (B) can be deposited in the space between. Claddings with the determined track spacing for AAA of 9mm and ABA 18mm were created in order to compare the resulting surface properties. The ABA cladding achieved a more uniform surface and less waviness than the AAA cladding.

11:30 AM

A Novel Coating Method Used to Enable Multilayer Structures with Microscale Selective Laser Sintering: *Aaron Liao*[1]; Dipankar Behera[1]; Michael Cullinan[1]; [1]University of Texas at Austin

The microscale selective laser sintering process (μSLS) is an additive manufacturing technique that enables the creation of metal features with sub-5 μm in-plane resolution. In this process, a layer of metal nanoparticle ink is deposited onto a substrate and positioned beneath an optical subsystem with a nanopositioning stage. Using a digital micromirror device, a laser is spatially modulated to selectively heat up particles in desired regions to cause sintering. The substrate is then moved to a coating station where a new layer of nanoparticle ink is applied atop the sintered features. Initially, the slot-die coating process was adopted as the recoating method for this technique. However, due to challenges with depositing consistent ink thickness across the recoated part and limitations with the minimum layer thickness achievable, a new approach inspired by blade coating has been developed to achieve layer thicknesses of less than 1 μm.

Applications: Topology Optimization

Wednesday AM — Room: 416 AB
August 16, 2023 — Location: Hilton Austin

Session Chair: Mehran Tehrani, University of California, San Diego

8:00 AM

Topology Optimization of Continuous Fiber-reinforced Composites Considering Manufacturing Constraints: *Janet Wong*[1]; Emily Sanders[1]; David Rosen[1]; [1]Georgia Institute of Technology

Additive manufacturing (AM) has enlarged the design space of variable stiffness and continuous fiber-reinforced composites (FRCs) by enabling increased freedom in the geometric layout of continuous fibers. Fiber layout optimization has been integrated with topology optimization (TO) to harness such design freedom; however, additional constraints are needed to ensure manufacturability in extrusion-based AM of continuous FRCs. We directly integrate constraints on fiber path curvature and gaps/overlaps between fiber paths into the TO framework. Alongside density design variables defining the structure's topology, we define radial basis functions (RBFs) with fiber angle design variables defined on the RBF support points. The RBFs promote fiber path continuity and allow us to define functions related to their curl and divergence, which we use as differentiable manufacturing constraints on curvature and gaps/overlaps, respectively. Several numerical examples are provided to illustrate tradeoffs between structural performance and manufacturability of optimized, continuous FRCs when such constraints are considered.

8:20 AM

Off the Grid: Re-defining Design Resolution in Inkjet 3D-printing for Sub-droplet Position Control and Facile Geometry Improvement: *Oliver Nelson-Dummett*[1]; Geoffrey Rivers[1]; Negar Gilani[1]; Marco Simonelli[1]; Christopher Tuck[1]; Richard Hague[1]; Ricky Wildman[1]; Lyudmila Turyanska[1]; [1]University of Nottingham

Inkjet 3D printing (IJ3DP) is critical technology for next generation multi-material or graded-material printed devices. IJ3DP patterns mainly utilise per-layer bitmaps, traditionally selecting resolution based on droplet size, coupling droplet size and position. This traditional method results in pixelation and discontinuity in small features, and limited control of edge definition and layer flatness. Therefore, we introduce "Off the Grid" ('OtG'): new pattern design methods which decouple droplet size from droplet positioning, compatible with existing 3DIJP systems and applicable to 3D structure optimisation. We demonstrate: printing fine features one droplet wide with reductions in geometry error, forming smooth continuous paths where the traditional pattern methodology did not; up to 10× increase of feature position control (Traditional: 60 μm increments, minimum gap 45μm; OtG: 6 μm increments, minimum gap 5μm); adjustable print resolution across a patterned layer; 2.5× reduction in surface waviness and control of surface texturing.

8:40 AM

Designing for Cleanability: A Topology Optimization Approach for Electron Beam Melted Parts: *Alptug Öztaskin*[1]; Evren Yasa[2]; [1]Addpark Advanced Engineering; [2]AMRC North West University of Sheffield

Residual sintered powder is a fundamental problem in Electron Beam Melting (EBM). Although this problem is widely recognized by those who perform Design for Additive Manufacturing (DfAM), a commonly used AM design methodology, topology optimization processes often lack this constraint as either a penalty or criterion of acceptance. To address this issue, we model cleaning tools and/or media (e.g., sandblasting guns) as simple shapes formed of line segments. We measure the accessibility of the mesh surface using simple models based on a series of simplifying assumptions. We perform sampling on the mesh to reduce the number of operations, and we perform ray tracing with different elevation and azimuth angles with respect to the sample point normal. The accessibility of the points is normalized based on the intersections, and the normalized values are used in topology optimization as penalties as well as for validating final designs.

9:00 AM

Design Optimization, Multi-axis Additive Manufacturing, and Mechanical Evaluation of Continuous-fiber Composite Structures: *Joseph Kubalak*[1]; Kieran Beaumont[1]; Christopher Williams[1]; [1]Virginia Tech

Multi-axis material extrusion (MEX) enables reorientation of the deposition tool relative to the part (via industrial robotics) such that every deposition can be aligned to arbitrary (e.g., 3D) load paths. In combination with continuous fiber-reinforced materials, this manufacturing capability can achieve unprecedented part performance. However, designing and manufacturing structures that exploit these capabilities is challenging. Here, we leverage both (1) a topology and toolpath optimization workflow that optimizes the distribution and orientation of a continuous fiber-reinforced composite for multi-axis MEX and (2) a novel deposition tool that enables printing and cutting of such materials. Optimization constraints (tailored for continuous fiber materials) are imposed to improve design printability and fiber length. Output designs are fabricated on a multi-axis deposition platform outfitted with a custom co-extrusion tool (capable of simultaneously metering continuous carbon fiber with a thermoplastic matrix). The resultant structures, featuring optimized layer-less toolpaths, are then mechanically evaluated.

9:20 AM

Design for Internal Lattice Structures with Application in Additive Manufacturing: Donald Palomino[1]; Ryan McClelland[2]; Mike Grau[3]; Ryan Watkins[4]; *Bingbing Li*[1]; [1]California State University Northridge; [2]NASA Goddard Space Flight Center; [3]Autodesk Inc; [4]NASA Jet Propulsion Laboratory

Internal lattice structures have the potential to significantly reduce the mass of an existing metal component, which is a desirable characteristic in the aerospace and automobile industries. However, there are still uncertainties on whether or not internal lattice structures can outperform a solid version of the same mass. Additionally, internal lattice structures can only be produced via additive manufacturing methods, bringing more challenges to resolve. To determine the viability of internal lattice structures, a study will be performed to compare its mechanical properties with solid, hollow, and mass penalty designs of equivalent masses using Autodesk Fusion 360. A performance baseline will be established by running multiple simulations on simple geometries to obtain the maximum displacement, first four modes, and first buckling mode. A generative design part, better known within NASA Goddard Space Flight Center as A15, will undergo the same simulations and have its results analyzed to determine feasibility.

9:40 AM Break

10:10 AM

Continuous Fiber Reinforced Composites: Design for Additive Manufacturing: Timothy Yap[1]; Ali Tamijani[2]; *Mehran Tehrani*[3]; [1]University of Texas at Austin; [2]Embry-Riddle Aeronautical University; [3]University of California, San Diego

The design freedom enabled by additive manufacturing (AM) allows for intricate fiber steering and strategic placement, resulting in composite structures with enhanced stiffness and strength tailored to the specific needs of the structure. This presentation discusses both stiffness- and strength-based optimization of continuous fiber-reinforced composites produced using AM. To ensure successful printing, designs with optimized fiber path and geometry are converted into G-codes and post-processed to meet AM constraints, The parts are then subjected to experimental validation, comparing finite element analysis (FEA) results with digital image correlation (DIC) measurements. The findings demonstrate significant improvements in performance and weight reduction, highlighting the benefits of combining advanced optimization techniques with AM for composite materials.

10:30 AM

Discovery of Next-generation Battery Electrodes using Topology Optimisation: *Chikwesiri Imediegwu*[1]; Milo Shaffer[1]; Mary Ryan[1]; Ajit Panesar[1]; [1]Imperial College London

Energy storage systems (ESSs) are essential components for the delivery of uninterrupted renewable energy of the future. A key stride towards the development of these systems revolves around the design of insertion-electrode battery chemistries such as Li-ion and Na-ion cells. These batteries lie at the heart of technological advances in battery design due to their high energy density and rate capabilities. However, conflicting cell requirements and the historical slurry cast technique for manufacturing electrodes serve as limitations to performance optimisation. This work presents a physics-informed strategy for the control of electrode nano-architecture towards optimising cell performance. This search for optimal electrode topology is gradient-driven, constrained only by the governing ion-transport and electrical conduction mechanisms within the cell material phases. Preliminary results are promising with physically optimized topologies derivable by additive manufacturing.

10:50 AM

A Case Study on Lightweight Design of a Robot Leg: Integrating Topology Optimization and Lattice Configuration: *Shujie Tan*[1]; Liping Ding[1]; Lei Yan[1]; Yicha Zhang[2]; Huaizhi Zong[3]; [1]Nanjing University of Aeronautics and Aestronautics; [2]UTBM; [3]Zhejiang University

Additive manufacturing (AM) provides designers with increased flexibility to create highly complex and lightweight designs. Topology optimization (TO) and lattice configuration (LC) have emerged as the two primary strategies for achieving lightweight structures in the design for additive manufacturing (DfAM). However, both approaches exhibit certain limitations when redesigning intricate components, such as a robot leg. This paper integrates TO and LC technologies for lightweight design and proposes a novel hybrid lightweight design methodology. To illustrate the effectiveness of the proposed approach, a case study involving the lightweight design of a robot leg fabricated using the selective laser melting (SLM) process is presented. The results demonstrate that the hybrid lightweight design methodology outperforms the singular TO approach in terms of manufacturability and stress distribution.

11:10 AM

Constrained Topology Optimization using Mechanical Homogenization: *Ehsan Haghighat*[1]; Clarissa Gutierrez[1]; Kyle Kloster[1]; Saigopal Nelaturi[1]; [1]Carbon Inc.

Additive Manufacturing (AM) has transformed part design, making it possible to create intricate geometries that traditional manufacturing techniques cannot. Mechanical Homogenization (MH) offers a faster approach to explore the average mechanical characteristics of prescribed topologies. However, MH can have poor correspondence when scaled to complex parts. To overcome this limitation, we propose a homogenization-based topology-optimization (TO) approach to produce optimized topologies using MH while satisfying part-level constraints. Our MH model captures different deformation regimes, from linear elastic to plateau and densification regimes that are the result of buckling and self-contact of individual struts. Incorporating such constraints in classical TO approaches is nearly impossible. We demonstrate the effectiveness of our approach through an insole optimization problem. By incorporating homogenization into the TO process, we aim to make the design process more efficient and accessible to a wider range of users.

Applications: Finishing Techniques and Partameters

Wednesday AM Room: 417 AB
August 16, 2023 Location: Hilton Austin

Session Chair: To Be Announced

8:00 AM
Effect of Printing Parameters on the Internal Geometry of Products Manufactured by Fused Filament Fabrication (FFF): *Benjamin Moreno Nunez*[1]; Cecilia Trevino-Quintanilla[2]; Juan Espinoza-Garcia[1]; Enrique Cuan-Urquizo[2]; Esmeralda Uribe-Lam[1]; [1]School of Engineering and Sciences, Tecnologico de Monterrey, QRO; [2]Institute of Advanced Materials for Sustainable Manufacturing, Tecnologico de Monterrey, QRO

The internal geometry of a 3D printed product determines its mechanical properties. In Fused Filament Fabrication (FFF) the filaments that build up the internal geometry suffer from variation that have not been sufficient studied. This research focused on identifying the parameters that most affect the filaments and finding the optimum values to reduce their variations. To detect the printing parameter effects on FFF products it was used a fractional factorial design and the results were analyzed using statistics with a specialized statistical software (MINITAB), been the layer height the parameter that most affect the extruded filament width. Additionally, a response optimization was done to obtain six regression models that can predict the width of extruded filaments based on the printer and material used, the printing parameters and interactions that most affect the FFF product.

8:20 AM
Assessing the Impact of Melt Pool Variability on Fatigue Life in Laser Powder Bed Fusion: *Justin Miner*[1]; Tharun Reddy[1]; Austin Ngo[2]; Christian Gobert[1]; Jack Beuth[1]; Anthony Rollett[1]; John Lewandowski[2]; Sneha Narra[1]; [1]Carnegie Mellon University; [2]Case Western Reserve University

Stress intensities created by sharp, lack-of-fusion (LOf) defects, hinder fatigue life of laser powder bed fusion components. LOf defects result from insufficient melt pool overlap which depends on process parameters, layer thickness and hatch spacing. The delineation between parameters producing parts with and without LOf defects is the LOf boundary. However, recent studies hypothesize that infrequent LOf defects can occur outside of the LOf region through melt pool instabilities. To evaluate this problem, this work utilizes spectral analysis of single and multi-tracks and computed tomography of the bulk samples to evaluate the geometric variability of melt tracks produced within the process window as determined by melt pool geometry-based LOf modeling. The results suggest that melt pool variation generates LOf defects within the process window near the LOf boundary. Because of the impact of LOf pores on fatigue life, a conservative process window accounting for melt pool geometric variation is needed.

8:40 AM
Comparison of Surface Texture from Various Surface Morphology Techniques for Evaluating As-built Ti6Al4V Laser Powder Bed Fusion: *Alex De La Cruz*[1]; Luke Weston[2]; Thao Gibson[3]; Fank Medina[1]; Edel Arrieta[1]; Mark Benedict[2]; [1]University of Texas El Paso; [2]Air Force Research Laboratory; [3]University of Dayton Research Institute

Without post-processing, AM components contain a variety of flaws, such as surface roughness and porosity. Surface roughness is a flaw present for every as-built AM surface that serves as an array of sites for material failure to initiate. Common surface roughness measurements involve the use of optical and contact stylus profilometry. However, x-ray Computed Tomography (xCT) is already the most widely used method of analyzing AM parts for porosity, inclusions, and a variety of other flaws.In this study, we compared three surface characterization technologies, xCT, optical profilometry, and contact stylus profilometry. The comparison of these technologies is being done on as-built Laser Powder Bed Fusion (L-BPF) Ti6AI4V four-point bending fatigue samples. Preliminary results show Sa, Sz, Sv, and Sku values are comparable between the three methods.

9:00 AM
Fatigue Endurance Investigation of Post-processed Surfaces of L-PBF Ti-6Al-4V under Flexural Stress: *Cristian Banuelos*[1]; Brandon Ramirez[1]; Alex De la Cruz[1]; Shadman Nabil[1]; Edel Arrieta[1]; Francisco Medina[1]; Ryan Wicker[1]; [1]W.M. Keck Center for 3D Innovation

Numerous research works can be found focusing on fatigue properties of AM components, however most of this literature is focused on uniaxial testing. Because the very few actual components under uniaxial loading conditions found in any application, it is also important to investigate fatigue performance under loads that produce combined stresses, such as bending. This project investigates the fatigue endurance of LPBF Ti-6Al-4V specimens subjected to five different surface finishing prost-processes (milled, ground, polished and abrasive media). The test consisted of a force-controlled cyclic load applied on the specimen in 4-point bending setup until fracture. The study incorporated mechanical and optical techniques to measure and quantify the characteristic surface roughness of the post-processes. Additionally, failure mechanisms are discussed on fractographs. The data analyses suggested that internal defects commonly present in additively manufactured parts had a more significant impact on the fatigue life than surface roughness of post-processed parts.

9:20 AM
Investigating the Effects of Chemical Smoothing on Mechanical Properties and Surface Roughness of Additive Manufactured Polymer Parts: *Paul Oehlmann*[1]; [1]BMW Group

The surface of laser-based powder bed fusion of polymer parts (PBF-LB/P) is known for its rough texture and external appearance, whereby the surface roughness has a significant influence on the mechanical properties. Chemical smoothing with solvents is a well-known method for influencing the surface texture of PBF-LB/P components. Due to the further development and industrialization of the process, the post-processing method is becoming increasingly attractive for the use in the automotive industry. Chemical smoothing reduces the surface roughness and seals the surface, which leads to a change in the functional properties. Due to the significant increase in elongation at break at a near constant tensile strength after smoothing, this post-processing method has the potential to expand the range of applications for PBF-LB/P parts in the automotive industry. This paper is investigating the influence of the chemical smoothing process on the mechanical properties and surface roughness of polyamide 12 (PA12) parts.

9:40 AM Break

10:10 AM
Improving Fatigue Performance of PBF Metals using Self-terminating Etching Processes: Subbarao Raikar[1]; Steven DiGregorio[1]; *Owen Hildreth*[1]; [1]Colorado School of Mines

The poor surface finish of Ti-6Al-4V (Ti64) and GRCop42 parts fabricated from Powder Bed Fusion has detrimental effects on their fatigue performance. With the help of post-processing techniques, the surface finish needs to be improved before the parts are operation ready for better fatigue performance. Self-terminating etching process (STEP) is one such post-processing technique that decreases the surface roughness by as much as 8× and increases the fatigue life by 340% compared to as-printed specimens for Ti64. In this work, we study the fatigue performances of Ti64 using sulfur-based STEP and GRCop42 using iodine-based STEP for surface finishing. The PBF specimens are studied in as-printed, stress-relieved, and post-STEP conditions by characterizing the surface roughness and microstructure.

10:30 AM

Investigating the Effects of Thermal Post-processing Parameters on Interfacial Delamination of Bimetallic 3D Printed Parts: *Erik Inman*[1]; Chaitanya Mahajan[2]; Srikanthan Ramesh[1]; [1]Oklahoma State School of Industrial Engineering and Management; [2]Kettering University

The rise of heated metal filament extrusion 3D printing has simplified on demand production of unique and supply chain restricted parts. This process involves layer-by-layer material deposition to produce a 3D part, which is then thermally debound, leaving a porous metal part. A secondary thermal sintering heat cycle is then used to create a solid, finished product. While this process is readily deployable, the concept of bimetallic printing presents an opportunity for innovation. Bimetallic Copper (Cu) and Stainless Steel (SS 316L) parts can be produced using a dual extrusion system. One of the challenges in printing bimetallic parts that this study seeks to address is interfacial delamination during thermal sintering. The study intends to develop predictable and functional sintering parameters of Cu/SS 316L bimetallic 3D printed parts. Material coalescence and the delamination interface will be characterized with X-ray diffraction (XRD), scanning electron microscopy (SEM), and microcomputed tomography (Micro CT) equipment.

10:50 AM

Mechanical Surface Treatment of Polymer Parts Produced by FFF: *Stefan Dietrich*[1]; Benjamin Karcher[1]; Uwe Popp[2]; Julian Scholz[2]; [1]KIT; [2]Apium Additive Technologies GmbH

The surface structure in the form of waviness and roughness as well as near surface density of FFF parts represents a major issue with respect to mechanical performance especially under fatigue loading. Mechanical surface treatments like shot peening or rolling are commonly used techniques, especially for metal components, to reduce surface roughness, increase surface densification and create beneficial residual stress states in the surface layer. In this study, a rolling process has been applied intermittently with the layer-wise FFF process and the effect on the surface state has been investigated using laser scanning and optical microscopy as well as micro-computed tomography. A process window with different rolling tools and rolling paths has been identified and analysed. The results show clearly advantageous properties regarding an improved surface roughness, with a higher densification gradient in the first perimeter tracks of the FFF extrusion strategy as well as sharper corners being realized.

11:10 AM

Optimizing the Surface Texture and Chemistry of Laser Powder Bed Fusion (LPBF) Haynes

282 for Increased Solar Absorptance: *Junwon Seo*[1]; Andrea Ambrosini[2]; Erfan Rasouli[3]; Ansel Blumenthal[2]; Vinod Narayanan[3]; Anthony Rollett[1]; [1]Carnegie Mellon University; [2]Sandia National Laboratories; [3]University of California, Davis

The topology and chemistry of surfaces play a crucial role in dictating the overall properties of the material, especially for samples with high surface-to-volume ratios. The ability to control the surface characteristics becomes useful for additive manufacturing since the process can be used to fabricate complex geometries with a high surface area. In this research, we investigate ways to induce various textures and chemistry on the surface of Haynes 282 fabricated by LPBF. Samples are fabricated with various combinations of infill and contour parameters as well as different CAD geometries and are gone through post-processing steps. Topological features are extracted by applying computer vision techniques to optical profilometer measurements and computed tomography data, whereas diffraction experiments are utilized to obtain the chemical information of various surfaces. We show that our methods are effective in modifying surface characteristics by measuring the optical absorptance of the samples.

11:30 AM

Complex Laser Beam Shaping for Improved Process Control in Metal Additive Manufacturing: *Thej Tumkur*[1]; John Roehling[1]; Gabe Guss[1]; Kaila Bertsch[1]; Manyalibo Matthews[1]; [1]Lawrence Livermore National Lab

Process instabilities in laser powder bed fusion additive manufacturing (AM), arise from insufficient optothermal control induced by Gaussian beams at the melt pool scale. We incorporate laser beams shaped in amplitude, phase and polarization, to deliver controlled and modulated optothermal profiles on the powder bed. Unique optical properties of such beams (such as non-diffractive propagation and phase singularities) result in an improved combination of reduced spatter, keyholing and porosity, and results in improved tensile properties across a broad scan parameter range, compared to conventional beams. We employ Multiphysics simulations and highspeed imaging for feedback and validation for printing SS 316 and Inconel 625. Prepared by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS-846873

Wire-fed DED: Materials and Experiments

Wednesday AM
August 16, 2023

Room: Salon A
Location: Hilton Austin

Session Chair: Carolyn Seepersad, Georgia Tech

8:00 AM

Challenges in Wire-Arc Additive Manufacture of Nickel Aluminum Bronze: *Bradley Jared*[1]; Tiffany Quigley[1]; Joshua Penney[1]; Devon Goodspeed[1]; Steven Williams[1]; Matthew Roach[1]; William Hamel[1]; Jakub Preis[2]; Somayeh Pasebani[2]; [1]University of Tennessee, Knoxville; [2]Oregon State University

Nickel aluminum bronze (NAB) is a complex alloy commonly selected for marine applications due to it cavitation strength and bio-fouling resistance. Historically a cast alloy, recent work has explored wire-arc additive manufacturing (WAAM) of NAB for large scale metal structures using cold metal transfer (CMT) welding. Process development started by exploring parameters informed by literature descriptions of welding and standard metal inert gas (MIG) deposition. Such MIG parameters proved inadequate as process development was performed to establish stable deposition parameters using CMT. Critical process parameters will be discussed such as interpass temperature, heat input, contact to workpiece distance and shielding gas coverage. Progress in printing complex part geometries, resulting material microstructures and tensile properties will also be presented. Finally, future research needs for WAAM of NAB will be highlighted.

8:20 AM

Failure Mechanisms in Grading Inconel 625-GRCop 42 via Hybrid Wire-powder Directed Energy Deposition: *Somayeh Pasebani*[1]; Kuba Preis[1]; Sriram Manoharan[1]; Brian Paul[1]; Donghua Xu[1]; [1]Oregon State University

Multi-metal additive manufacturing requires the joining of dissimilar metals yielding joints that are prone to increased residual stress and the precipitation of brittle intermetallic phases. Compositionally graded alloys (CGAs) are materials in which two alloys are joined via transition layers with compositions selected to help avoid brittle phases and minimize residual stress. Although CGAs have been demonstrated across multiple material systems, a holistic design strategy for CGAs has yet to proposed. In this work, two CGAs are designed from Inconel 625 to GRCop42 and from Inconel 625 to a nickel-aluminum-bronze alloy by use of CALculation of PHAse Diagrams (CALPHAD) and a derived dissimilar metal residual stress coefficient. The CGAs are printed via a hybrid wire-powder directed energy deposition process. Failure mechanisms are discussed, and the ability to minimize brittle phases and residual stress is demonstrated.

8:40 AM

Framework Development for Optimization of DED Parameters using Nickel-Aluminum Bronze Feedstock and Arc Wire Directed Energy Deposition: *Jack Canaday*[1]; Jennifer Semple[1]; Matthew Dantin[1]; Charles Fisher[1]; [1]Nswc Carderock Division

Selection of appropriate process parameters for directed energy deposition (DED) is critical to build success but presently requires a prohibitive quantity of time, capital, and experience. To reduce decision-making risk, a framework is proposed to support statistical optimization using an experimentally derived process model. The developed framework was demonstrated using nickel-aluminum-bronze (NAB) feedstock with the arc wire DED process pursuing application requirements of as-built surface condition and global productivity for thin-wall geometry. Quantitative analytical metrics were devised apply structured light metrology and thermal simulation for each trial condition to establish the process model. The obtained process model was used to select an optimized set of process parameters which enabled fabrication of a thin-wall component geometry in an optimized condition. The described framework is intended to be tailorable based on process, material, and application requirements through selection of process inputs, defined analytical criteria, and experimental geometry investigated.

9:00 AM

Process-integrated Alloy Adjustment in Laser Deposition Welding with Two Wires: *Laura Budde*[1]; Nick Schwarz[1]; Jörg Hermsdorf[1]; Stefan Kaierle[1]; Ludger Overmeyer[1]; [1]Laser Zentrum Hannover e.V.

For DED with wire as filler material, the material selection is mostly limited to commercially available welding wires. This limits the achievable material properties for cladding and Additive Manufacturing purposes. Using a coaxial deposition welding head, in which two different wires can be fed and controlled individually, the alloy composition can be adjusted in the common process zone in-situ.In this study, the two wire materials X2CrNiMo19-12 and G4Si1 are used in different mixing ratios to fabricate single weld seams. The different mixing ratios are achieved by varying the wire feed rates. The material content in the weld is varied between 0% and 100% in 20% steps. The weld seams are examined with regard to the distribution of alloying elements, hardness and microstructure. Homogeneous mixing of the two materials was achieved at all mixing ratios. The hardness depends on the mixing ratio and varies between 170HV0.1 and 428 HV0.1.

9:20 AM

Process Development for the Wire Arc Additive Manufacturing of AlSi10Mg: *Moritz Baldauf*[1]; Tobias Hauser[1]; Kamalesh Bharadwaj[1]; Philipp Lohrer[1]; Lucas Jauer[2]; Johannes Henrich Schleifenbaum[2]; [1]BMW Group; [2]RWTH Aachen

Wire Arc Additive Manufacturing (WAAM) is an additive manufacturing process based on robotic arc welding that enables the flexible, tool-less production of large-scale metal components. WAAM of aluminum alloys is particularly challenging due to their low melting temperature and high thermal conductivity, which result in a small process window. In this work, the processing of the cast alloy AlSi10Mg (EN AW-4046) by WAAM was investigated. For this purpose, a basic parameter development for WAAM of Al 4046 was carried out. Consecutively, first simple thin-walled geometries were built and analyzed regarding their mechanical properties, porosity, and surface properties. By adjusting the parameters, correlations between weld settings, path planning and the resulting properties have been identified. Furthermore, it was observed that the process tends to be sensitive to wire quality, which can be compensated by increasing the energy input.

9:40 AM Break

10:10 AM

Process Stability and Monitoring for WAAM-CMT of Aluminum Alloys: *Austen Thien*[1]; Kathryn Kelly[1]; Caroline Massey[1]; Christopher Saldana[1]; [1]Georgia Institute of Technology

Wire-arc additive manufacturing (WAAM) has become a cost-efficient metal additive manufacturing process. However, depositing aluminum with WAAM is challenging due to its sensitivity to heat input (linear energy density), which can cause undesirable surface topology waviness if not controlled. Thus, a process window is needed that can produce stable geometry and deposition conditions while minimizing production times. In this study, 5183 aluminum alloy wire is used to deposit 10-layer walls with varying wire feed speeds (WFS) and traverse speeds (TS) (at a constant WFS/TS ratio) and varying interlayer temperature (IPT). In-situ process data consisting of optical contact-tip-workpiece-distance (CTWD) and current/voltage measurements are collected to determine process condition stability throughout the build. Part geometry is measured using a 3D scanner and build porosity is characterized via digital X-ray. A process window is identified that produces stable surface topology and process conditions at a minimal production time.

10:30 AM

Simulation of Anisotropic Mechanical Behavior of Additively Manufactured Ti-6Al-4V Wall Structures using VPSC: *Rajib Halder*[1]; Anthony Rollett[1]; Jake Benzing[2]; [1]Carnegie Mellon University; [2]National Institute of Standards and Technology

This work explores the effect of processing parameters on texture development in Ti-6Al-4V wall components fabricated by wire-feed Directed Energy Deposition process, one of the additive manufacturing techniques. Microstructure and texture were characterized using scanning electron microscopy (SEM) and electron backscatter diffraction (EBSD). An open-source software package, MTEX, was used to perform grain reconstruction, orientation analysis, variants selection analysis, and generate IPF maps. A strong variation in texture was observed along the build direction in laser hot wire deposited single walls. A viscoplastic self-consistent (VPSC) model was used to simulate the deformation response under uniaxial tension applied along vertical, horizontal, and diagonal directions with respect to the build direction of the single wall component. An excellent fitting was achieved between the simulated and experimental stress-strain curves. VPSC simulation successfully captured the tension-compression asymmetry and the anisotropic response of Ti-6Al-4V single walls.

10:50 AM

Solidification Behavior, Texture Evolution, and Mechanical Behavior of Large Scale Fusion Additively Manufactured Steels: Interplay Between Chemistry and Unique Processing Conditions: *Saket Thapliyal*[1]; Patxi Fernandez-Zelaia[1]; Yousub Lee[1]; Andrzej Nycz[1]; Sarah Graham[1]; Andres Rossy[1]; Michael Kirka[1]; [1]Oak Ridge National Laboratory

The multiphysics in DED wire-arc additive manufacturing (WAAM) process can differ significantly from other powder-based fusion additive manufacturing processes. This engenders the need for investigating the chemistry-processing-structure-properties relationships for DED WAAM processed alloys. In this work, we investigate the effect of interplay between multiple physical phenomena on process thermokinetics, solidification behavior, solute segregation behavior, microstructural evolution and ensuing mechanical behavior of the DED WAAM processed stainless steels. Insights on factors determining a single crystal-like texture in DED WAAM processed austenitic steels are provided. The implications of spatially-varying thermokinetics for undercooling, solute segregation and phase transformation behavior in steels are also discussed. Furthermore, we discuss the effects of hierarchical deformation mechanisms in moderate stacking fault energy steels on room and high temperature mechanical behavior. This work is expected to improve the understanding of chemistry-processing-structure-properties relationships in DED WAAM processed stainless steels, and thus facilitate microstructure design of steels with DED WAAM.

11:10 AM

Wire Arc Additive Manufacturing in Steel Foundries: *Eric Weflen*[1]; Matthew Frank[1]; Frank Peters[1]; [1]Iowa State University

This work presents the system design of a robotic hybrid additive and subtractive manufacturing system for steel foundries to reduce supply chain disruptions caused by a skilled labor shortage and harsh working conditions. Automation promises to ease the labor shortage but falls short in environments with high variation and ambiguous decision-making. These challenges were overcome by leveraging human adaptability and ambiguous decision-making, paired with automation conducting repetitive tasks in harsh environments. Generative user research revealed the current welding process for removing and refilling metalcasting production anomalies. Tasks were divided into those suited for automation and those best suited for a human operator. The operator continues to identify and remove anomalies while sensing and robotics automate weld preparation by machining, refilling using Wire Arc Additive Manufacturing (WAAM), and surface blending by grinding. This research serves as a case study for integrating hybrid manufacturing into production environments.

11:30 AM

Additive Manufacturing of ODS Steels using Powder Feedstock Atomized with Elemental Yttrium: *Seongun Yang*[1]; Donghua Xu[1]; Dongqing Yan[1]; Marc Albert[2]; Somayeh Pasebani[1]; [1]Oregon State University; [2]Electric Power Research Institute

This study investigates the microstructure and mechanical properties of an austenitic ODS steel produced by the Laser Directed Energy Deposition (LDED) process using powder feedstock atomized with elemental yttrium. The Microstructure of the samples was characterized by electron microscopy, and mechanical properties were measured using a tensile test and nanoindentation. Further, the thermal stability of the LDED-produced ODS steels were evaluated. As-printed samples showed a cellular structure with Si-Mn-Y-O-enriched nanoparticles that were found to be amorphous. After 100 hrs at 1000°C in an argon atmosphere, a partially recrystallized microstructure with a decrease in the number density of Y-O-enriched nanoparticles with crystalline structure was revealed. The as-printed (600 W, 600 mm/min) samples exhibited an ultimate tensile strength of 774 MPa and an elongation at a break of 22%. A lower ultimate tensile strength of 592 MPa and higher elongation of 42% was measured after 100 hrs at 1000°C.

Applications: Lattices and Cellular IV

Wednesday AM — Room: Salon B
August 16, 2023 — Location: Hilton Austin

Session Chair: Rich Crawford, Univ of Texas

8:00 AM

Deformation Pattern 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 research focuses on the investigation of the deformation behavior and mechanical response 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. In addition, the effects of build orientation and interface polarity were also included in the study. Utilizing both finite element analysis and experimental characterization, the deformation characteristics and fracture patterns of these structures were investigated. The results show that the failure of the interlocking interface is significantly influenced by geometry design, printing orientation and the intrinsic material interfacial bonding strength. In particular, the choice of interface geometry design appears to be related to the intrinsic material interfacial bonding strength between the two materials, indicating design flexibility with this design concept.

8:20 AM

Comparison of tensile and compressive behavior of triply periodic minimal surface lattices fabricated by laser powder bed fusion: *Bharath Bhushan Ravichander*[1]; Shweta Hanmant Jagdale[1]; Akib Jabed[1]; Golden Kumar[1]; [1]University of Texas at Dallas

Fabrication of sheet-based triply periodic minimal surface (TPMS) lattices was carried out using laser powder bed fusion, employing 316L stainless steel. The dimensional accuracy and printing defects of various unit cell types (diamond, gyroid, fischer, IWP, and primitive) were assessed using scanning electron microscopy. The tensile and compressive behaviors of TPMS structures were examined, including elastic modulus, yield strength, and energy absorption. Results demonstrated that these properties exhibited similar dependence on the lattice topology for both compression and tension. Notably, the fischer structure displayed superior mechanical performance compared to the previously studied sheet-based diamond TPMS lattice, exhibiting remarkable compressive and tensile properties, which are reported here for the first time in relation to metallic materials. Most sheet-based TPMS structures exhibited high stiffness and plateau stress, indicating deformation dominated by stretching. However, the primitive structure exhibited lower resistance to deformation, likely due to a significant contribution from bending. Understanding the mechanical properties of TPMS lattices will facilitate their selection and utilization in various potential applications.

8:40 AM

A Review on the Joining Mechanisms of Multiple Materials using Additive Manufacturing: *Sumit Paul*[1]; Li Yang[1]; [1]University of Louisville

Multi-material manufacturing imposes various challenges due to the difference between the properties of constituent materials. With the advancement of additive manufacturing (AM), the use of multiple materials opens up more application spaces due to the enhanced design freedom with materials. With unique process principle, AM multi-material structures often exhibit unique joining/bonding mechanisms between multiple constituent materials. In addition, the geometry design flexibility with AM also enables new joining concepts. This paper attempts to provide a brief review about joining/bonding mechanisms during multi-material AM from both the perspectives of process principles and structural types. The discussion also attempts to summarize some rather novel multi-material bonding/joining mechanisms that are uniquely enabled by AM. This paper aims to provide some additional insights into the technological challenges of multi-material AM as well as future research opportunities.

9:00 AM

3D Printed Intelligently Graded Functional Stiffness Foam for Sturdier Multi Stiffness Materials: *Brett Emery*[1]; Daniel Revier[1]; Masa Nakura[1]; Vivek Sarkar[1]; Jeffrey Lipton[2]; [1]University of Washington; [2]Northeastern University

Foams are ubiquitous, being used in applications such as padding, insulation, and noise isolation. Bonding different density foams together produces undesired stress concentrations and boundary effects. Creating controlled gradients in foam properties has been a challenge for traditional and AM processes. Here we show how to use a form of material extrusion called viscous thread printing (VTP) to produce foams with multiple stiffnesses and continuous gradients between different stiffnesses. We do so by varying the path speed during extrusion to control the production of microstructures. We compare the process of producing discrete components and those with gradients, showing that those with gradients have higher strength in plane during tension, have no discontinuities in out of plane stiffness, and are less prone to forming cracks at the boundaries. We demonstrate the process in thermoplastic polyurethane (TPU).

Materials: Metals-Creep and Fatigue

Wednesday AM — Room: 615 AB
August 16, 2023 — Location: Hilton Austin

Session Chair: Joy Gockel, Colorado School of Mines

8:00 AM

Evolution of Creep Damage of 316L Produced by Laser Powder Bed Fusion: *Alexander Ulbricht*[1]; [1]Bundesanstalt fuer Materialforschung und -pruefung

Laser powder bed fusion (PBF-LB/M) tends to produce unique microstructures arising from rapid, directional cooling. These microstructures impact the damage mechanisms of metallics components manufactured by PBF-LB/M compared to conventionally manufactured variants of the same alloys. In particular, we present results of a study of the evolution of creep damage in stainless steel 316L specimens produced by PBF-LB/M. We used X-ray computed tomography to unravel the influence of the process-specific microstructure from the influence of the initial void distribution on creep damage mechanisms. To that end, the void distribution specimens tested at 600 °C and 650 °C was analyzed before the creep test, after an interruption, and after rupture. We conclude that the formation of damage is not connected to the initial void distribution. Instead, an accumulation of damage at grain boundaries resulting from extensive intergranular cracking is observed. We compared intergranular damage of PBF-LB/M/316L to hot rolled 316L.

8:20 AM
Effects of Surface Roughness, Process Parameters, and Heat Treatments on the Fatigue Properties of Laser Powder Bed Fusion of 316L Stainless Steel: *Jorge Ramirez Lujan*[1]; Joy Gockel[1]; [1]Colorado School of Mines

This presentation will discuss how surface roughness, process parameters, and heat treatments affect the fatigue properties of 316L stainless steel produced by Laser Powder Bed Fusion (PBF-LB). The experimental methods and results will be highlighted, including microstructure analysis, surface roughness measurements, and fatigue testing. Previous studies have only considered total fatigue life, which is influenced by both surface roughness and microstructure, making the actual effect of surface roughness convoluted with microstructural influence. The presentation will cover fatigue results of specimens tested in both as-built and heat-treated microstructure conditions with as-printed and treated surfaces. The findings suggest that these factors significantly affect the fatigue properties of 316L stainless steel produced by PBF-LB. Understanding the separated influence of surface roughness and microstructure provides guidance toward processing development and qualification requirements for critical additive manufacturing components.

8:40 AM
Effect of Heat Treatment on High-cycle Fatigue of Additively Manufactured 17% Chromium 4% Nickel Precipitation Hardened Stainless Steel: *Julianna Posey*[1]; [1]University of Maryland

Precipitation hardenable stainless steels have been identified for applications that require increased corrosion resistance and high strength capabilities. Alloyed 17% Chromium - 4% Nickel (17-4 PH) rectangular block structures were manufactured using an EOS M290 powder bed fusion AM system. Fatigue specimens are selectively harvested in horizontal- and vertical-to-build-direction orientations. Typically, this alloy undergoes a standard solutionizing and annealing heat treatment prior to industrial implementation. In this case, the melt pool and grain boundary interactions through lower-than-standard temperature heat treatments are documented. Resulting fatigue behavior in the high-cycle regime is examined. Microstructural characteristics in heat-treated AM steel are explored from the lens of fatigue behavior prediction and the unique fracture mechanics inherent in AM components.

9:00 AM
Fatigue Strength Prediction of Additively Manufactured 17-4 PH Stainless Steel Specimens with Various Geometries: *Jade Welsh*[1]; Indrajit Nandi[2]; Jutima Simsiriwong[1]; Shuai Shao[2]; Nima Shamsaei[2]; [1]University of North Florida; [2]Auburn University

It is known that the shape and size of additively manufactured parts can significantly affect their volumetric defect population/structure, which subsequently influences their fatigue resistance. In this study, a defect-based model developed on a fracture mechanics concept is utilized to predict the fatigue strength of 17-4 precipitation-hardened (PH) stainless steel (SS), manufactured via laser-powder bed fusion (L-PBF). Uniaxial fully-reversed fatigue experiments are conducted on L-PBF and wrought 17-4 PH SS with various specimen geometries using conventional and ultrasonic fatigue test setups. Based on the fractography analysis, crack initiation mechanisms, as well as the size and location of the volumetric defects responsible for crack initiation are obtained, to explain the fatigue behavior and utilize in the defect-based fatigue model. The applicability of the utilized model is validated by comparing the predicted fatigue strengths with the ones obtained experimentally.

9:20 AM
A Vibration Fatigue Life Prediction Model for Additively Manufactured Metal Components: *Lei Yan*[1]; Wei Gao[1]; Nagaraja Iyyer[2]; Meng Jia[1]; [1]Nanjing University of Aeronautics and Astronautics; [2]Technical Data Analysis, Inc.

Fatigue life prediction accuracy has been an issue that hinders the adoption of laser powder bed fusion (LPBF) processed metal components to fatigue critical applications. In the present work, a vibration fatigue life model considering internal defects and microstructure is proposed and validated with LPBF-processed SS316 double-notch beams. A few AA7075 and AA2024 conventional CNC double notch beams were also included to check out the vibration fatigue performance and narrow down the critical factors that downgrade LPBF components' fatigue performance. The developed model brings new ideas to the LPBF components qualification and certification research.

9:40 AM Break

10:10 AM
Metal Additive Manufacturing of Rollers for Railroad Bearings: Rolling Contact Fatigue Performance: *Joseph Turner*[1]; Luz Sotelo[2]; Allen Fuller[3]; Cody Pratt[1]; Boone Gray[1]; Nathanial Matz[1]; Guru Madireddy[1]; Rakeshkumar Karunakaran[2]; Michael Sealy[2]; Timothy Liebe[3]; [1]University of Nebraska-Lincoln; [2]Purdue University; [3]Amsted Rail Brenco

We report on progress with respect to rolling contact fatigue (RCF) performance of railroad bearing rollers manufactured from 8620HC steel powder with laser powder bed fusion (LPBF). The print parameters were first studied using several measurements: material density, optical microscopy, ultrasound, and residual stress. Then a set of tapered cylindrical rollers was manufactured and integrated within a railroad tapered roller bearing. The bearings were subjected to accelerated fatigue and a simulated service life test with RCF typical of in-service bearings (~250,000 equivalent miles). After these tests, the AM rollers were removed, inspected, and compared with conventionally manufactured rollers subjected to the same loading conditions. The performance of the AM rollers was judged to be in-line with rollers manufactured using traditional methods. These results provide a clear foundation for additional AM roller designs that can exploit the unique capabilities of AM for challenging applications associated with fracture and fatigue performance.

10:30 AM
Uniaxial Fatigue Behavior and Life Prediction of Additively Manufactured Inconel 718 with Different Grain Morphology: Muztahid Muhammad[1]; Sajith Soman[1]; *Nabeel Ahmad*[1]; Douglas Wells[2]; Shuai Shao[1]; Nima Shamsaei[1]; [1]Auburn University; [2]NASA Marshall Space Flight Center

Understanding the fatigue behavior and failure mechanisms is essential for qualifying and standardizing additively manufactured metallic components. This study investigates the uniaxial fatigue behavior and failure mechanisms of laser powder bed fused (L-PBF) Inconel 718 (IN718) specimens with different grain sizes obtained by altering the process parameters and heat treatment. Uniaxial, fully-reversed, and strain-controlled fatigue tests were conducted on specimens with machined and polished surface conditions. Microstructural analysis and fractography using a scanning electron microscope were performed to measure the sizes of grains and facets. Fatigue cracks were initiated at the persistent slip bands near or at the surfaces rather than process-induced volumetric defects in all cases. The fatigue behavior of L-PBF IN718 specimens was correlated with the sizes of grains and facets. Fatigue life estimation incorporating the NASGRO equation and √area of the grain sizes was performed and shown to predict fatigue life within scatter bands of five.

10:50 AM
Corner Effects on Fatigue for As-printed Surfaces in Alloy 718: *Rachel Tullis*[1]; Joy Gockel[2]; Nathan Klingbeil[1]; Luke Sheridan[3]; [1]Wright State Universtiy; [2]Colorado School of Mines; [3]Air Force Research Laboratory

Component geometry is an important factor in the life of parts subjected to repeated loadings. Prior studies have shown that cracks initiate at sharp corners in most rectangular fatigue specimens. This is likely due to the large stress intensity factors of flaws that are located on sharp corners, although the extent of this relationship has not yet been studied for additively manufactured metals with as-printed surfaces. Using four different cross-sectional geometries (squares, hexagons, octagons, circles), this work has investigated the relationships between sharp corners and fatigue life in as-printed additively manufactured nickel superalloy 718. Additionally, fracture surface analysis has been performed to determine the location of crack initiation for each test, allowing for further investigation of the fatigue crack mechanisms in each specimen. The results of this work highlight the effects of cross-sectional geometry in as-printed additively manufactured parts, providing guidelines for the design of components under fatigue loading conditions.

11:10 AM
The Effect of Near-surface Pores on Fatigue Life of Ti-6Al-4V Components: *Christine Cummings*[1]; Jayme Keist[1]; Edward Reutzel[1]; [1]Pennsylvania State University

The assurance that parts will not fail prematurely is one of the largest obstacles to the widespread adoption of additive manufacturing for use in critical applications. Despite finely tuned processing parameters, pores can form stochastically during Laser Powder Bed Fusion (LPBF). A better understanding of the smallest pore that may initiate premature failure informs on the resolution required to ensure that failure-critical pores are identified during inspection. This work investigates the effect of pore size and shape on fatigue life of unHIP'd Ti-6Al-4V specimen manufactured via LPBF. Intentional near-surface pores with varying sizes and aspect ratios were included programmatically in fatigue specimen. The results quantify the effect of pores and begin to determine a maximum allowable pore size. Additionally, within a sub-selection of fatigue specimen, in-situ repair was attempted by increasing the laser power on the layer immediately following the pore. These results indicate how repair may impact fatigue properties.

11:30 AM
Comparing the Effects of Different Chemical Treatments on Surface Texture and Fatigue Behavior of U-notched Additive Manufactured AlSi10Mg: *Nabeel Ahmad*[1]; Erfan Maleki[1]; Shuai Shao[1]; Nima Shamsaei[1]; [1]Auburn University

Manufactured parts by laser powder bed fusion (L-PBF) with complex geometries, such as notched ones, have high surface anomalies due to the presence of overhangs which can detrimentally affect the mechanical properties and fatigue behavior. Therefore, applying post-processing can play a crucial role in addressing these issues leading to improved mechanical properties. In this study, the effects of different chemical surface post-treatments of chemical polishing (CP), chemical brightening (CB), and electro-chemical polishing (ECP) as well as T6 heat treatment (HT) on the surface texture, microstructure, and rotating bending fatigue behavior U-notched L-PBF AlSi10Mg specimens were investigated comprehensively through various experiments. The obtained results indicated that chemical treatment was very influential on surface texture modification of the very narrow notched parts, resulting in considerable fatigue life improvement.

Materials: Metals-Processing Strategies II

Wednesday AM — Room: 616 AB
August 16, 2023 — Location: Hilton Austin

Session Chair: To Be Announced

8:00 AM
Effect of Initial Carbon Content on Tailoring the Mechanical Properties of Additively Manufactured High-strength Martensitic Steels: *Stephanie Pestka*[1]; Matthew Vaughan[1]; Sean Gibbons[2]; Philip Flater[2]; Alaa Elwany[1]; Ibrahim Karaman[1]; Raymundo Arryoave[1]; [1]Texas A&M University; [2]Air Force Research Laboratory

Laser powder bed fusion (L-PBF) of a newly developed high strength steel known as AF96 has received notable attention due to its unique microstructure and superior mechanical properties. The current study investigates the influence of initial alloy carbon content on the mechanical properties of AF96 fabricated via L-PBF. A process parameter development study was first performed to determine optimal processing parameters that result in near defect-free as-printed parts. Test specimens were then fabricated using optimized parameter combinations for mechanical and microstructural characterization. This process was completed for three compositions of AF96 powder containing varying amounts of initial carbon content. Preliminary results show a significant increase in both yield strength and ultimate tensile strength with increasing initial carbon content.

8:20 AM
Effectiveness of Ex-situ Heat Treatment of L-PBF AM 17-4PH Stainless Steel Specimens Intentionally Exposed to Different As-built Thermal Histories: *C. Hasbrouck*[1]; Joseph Bartolai[1]; Darren Pagan[1]; Simon Miller[1]; [1]The Pennsylvania State University

The presented research demonstrates the effectiveness of H900 heat treatment in eliminating microstructural and mechanical property differences between additively manufactured 17-4PH stainless steel samples of varying thermal histories. For this effort, 17-4PH stainless steel was manufactured using laser-based powder bed fusion on an EOS M280 machine in two geometries: ASTM Standard E8 subsize rectangular tensile specimen geometry with thicknesses of 2mm and 6mm. Thermal histories were manipulated by adding secondary laser passes on each layer at varying levels of reduced power. All samples were heat treated after the build following H900 procedures. No mechanical property or microstructural differences were discovered through uniaxial quasi-static tensile testing and electron backscatter diffraction.

8:40 AM
Effect of Process Parameters on Microstructure and Properties for the Application of 316L Additively Manufactured Medical Device Components: *Fabienne Riester*[1]; [1]KARL STORZ SE & Co. KG

Additive manufacturing using laser powder bed fusion (LPBF) provides a great potential for the serial production in medical technology. In addition to the design freedom, function integration and weight optimization, the processability of biocompatible materials such as SS316L is particularly crucial. The good corrosion resistance and sufficiently high material characteristics serve as a basis for the optimization of further properties through the targeted variance of process parameters.For the application of additive manufacturing of 316L stainless steel by LPBF for medical instruments, the influences of the process parameters on the microstructure and the relevant component properties of surface roughness and density are investigated. By means of statistical evaluations, laser focus, filling contours and remelting are considered in addition to the most influential parameters of laser power and scanning speed. Finally, a set of process parameters is defined, which serves as a basis to produce a medical product.

9:00 AM
The Influence of Heat Treatments on the Microstructure and Tensile Properties of Additively Manufactured Inconel 939: *Rukesh Gusain*[1]; Mohammad Dodaran[1]; Paul Gradl[2]; Shuai Shao[1]; Nima Shamsaei[1]; [1]Auburn University; [2]NASA Marshall Space Flight Center

The variations in microstructure and tensile behavior of laser powder bed fusion Inconel 939 subjected to three different heat treatments are investigated in this study. The heat treatment schedule involves combinations of annealing temperature and soaking time, followed by multi-stage aging. The subsequent microstructural changes were analyzed using scanning electron microscopy. Tensile tests were performed at room temperature to examine the influence of the resultant microstructure on the mechanical behavior. The microstructural analysis showed that the higher solution temperatures led to the partial removal of dendritic microstructure and resulted in better homogenization, which was not so significant at the lower solution temperatures studied. Moreover, variations in the distribution of precipitates with aging temperature were also observed in this study. The optimal heat treatment schedule, which yielded a superior combination of strength and ductility, was identified in this study.

9:20 AM
Exploring IN718 Alloy Production with Bidirectional Raster and Stochastic Spot Melting Techniques using an Open-source Electron Beam Melting System: *Shadman Tahsin Nabil*[1]; Cristian Banuelos[1]; Brandon Ramirez[1]; Alex De La Cruz[1]; Kurtis Watanabe[1]; Edel Arrieta[1]; Ryan B Wicker[1]; Francisco Medina[1]; [1]University of Texas at El Paso

This study compares the fabrication of IN718 alloy using bi-directional raster and stochastic spot melting techniques with the open-source FreemeltOne Electron Beam Melting (EBM) system. The research aimed to produce dense parts using both scanning strategies, employing custom python code for raster melt beam path generation and PixelMelt software for stochastic spot melting. After optimizing process parameters, 10mm builds for each scanning strategy were fabricated, and their microstructure, hardness, and density were analyzed using optical microscopy and Scanning Electron Microscopy (SEM), vickers microhardness scale, and a pycnometer. The findings reveal valuable insights into the effects of scanning strategies on the microstructure, hardness, and density of IN718 alloy components, advancing additive manufacturing knowledge.

9:40 AM Break

10:10 AM
Effects of Build Orientation and Heat Treatment on the Porosity Distribution and Morphology within Inconel 625 Fabricated via Laser Powder Bed Fusion: *Mohanish Andurkar*[1]; Bart Prorok[2]; John Gahl[3]; Scott Thompson[3]; [1]Kansas State University; [2]Auburn University; [3]University of Missouri

The effects of build orientation, i.e., vertical, or diagonal (45º), and heat treatment on the porosity characteristics within Inconel 625 (IN625) fabricated via laser powder bed fusion (L-PBF) was experimentally investigated. Selected samples were heat treated at 1050 □ for 1-hour to promote evolution of pores. X-Ray Computed Tomography (XCT) was performed on samples to generate three-dimensional porosity maps. Volume Graphics (VG) software was used to inspect and quantify porosity distributions. Results indicate that build orientation and heat treatment influence measured porosity count. As-built (no heat treatment) sample microstructure was observed to have lower porosity count when compared to heat-treated samples. The vertically built sample was observed to have lower porosity relative to its diagonally built counterpart. The porosity morphology or diameter was observed to vary after heat treatment. On the other hand, the sphericity of pores was not affected by different build orientation and heat treatment.

10:30 AM
Microstructural and Microhardness Variations of Laser Powder Bed Fusion (L-PBF) Additively Manufactured Inconel 718 Due to Machine Variability and Thickness for Aerospace Applications: *Anannya Doris*[1]; Leslie Trujillo[1]; Dana Godinez[1]; Edel Arrieta[1]; Ryan Wicker[1]; Paul Gradl[2]; Colton Katsarelis[2]; Francisco Medina[1]; [1]University of Texas at El Paso; [2]Marshall Space Flight Center, NASA

This paper reports on a study investigating the microstructure and microhardness of thin walls fabricated by Laser Powder Bed Fusion (L-PBF) from sixteen geometric feature build plates. The study evaluated any variance in those properties with the variation in thickness by characterizing the XY and YZ planes of seven thin walls of different thicknesses and the base parts. Electron Backscatter Diffraction (EBSD) analysis with inverse pole figure (IPF) mapping was done for four samples from four different machine manufacturers. From the EBSD grain boundary map, the microstructure is composed of equiaxed grains with a lower threshold angle with smaller grains in the border area. Compositional analysis for both the powders and the resulting fully heat-treated LPBF-ed material was analyzed for alloy element stability and contaminants using 10 gm samples. The paper concludes by showing the relationship between composition and microstructural properties.

10:50 AM
Numerical and Experimental Investigations on Manufacturability of Al-Si-10Mg Thin Wall Structures Made by LB-PBF: *Mahyar Khorasani*[1]; Martin Leary[1]; David Downing[1]; Stuart Bateman[1]; Eric MacDonald[2]; [1]RMIT; [2]University of Texas at El Paso

This research aims to investigate the effect of power, inclination angle and the number of laser passes upon dimensional deviation, distortion and porosity of Thin Wall Structures (TWS) made by LB-PBF. Investigating the mentioned parameters is useful to determine the capability of LB-PBF to produce Al-Si-10Mg TWS as well as the manufacturability of these structures. To identify the effect of inclination angle, number of laser passes and laser power on dimensional deviation, distortion and porosity a full factorial Design of Experiments (DOE) has been selected. To discuss the results statistical analyses and simulation of LB-PBF are implemented. Simulations have been carried out using computational fluid dynamic software (Flow-3D V12) and the depth and width of the meltpool are predicted. The obtained dimensions of the melt-track are then generalised based on the thickness of the TWS to confirm the accuracy of the simulation.

11:10 AM
Controlling Chemical Composition Changes in Laser Powder Bed Fusion of AlSi10Mg: *Bochuan Liu*[1]; Gregory Gibbons[1]; [1]University of Warwick

Due to the large energy input during the laser powder bed fusion process, some elements of metal alloy will reach vaporisation temperature. Significant difference between the volatility of various elements in the alloy may change the chemical composition after manufacturing. This study will use this preferential evaporation effect to control the final composition to a targeted value, potentially for alloy and component tracing. Microstructure and mechanical properties changes associated with various compositions will be investigated.

11:30 AM
Compositional Variation Effect on the Microstructure and Nanomechanical Properties of Additively Manufactured AlCuFeNiTi High Entropy Alloy: *Sandeep Khadka*[1]; Hubert Bilan[1]; Tao Ma[2]; Philip Yuya[1]; [1]Clarkson University; [2]University of Michigan

An equiatomic AlCuFeNiTi high entropy alloy (HEA) was successfully fabricated for the first time using pre-alloyed powder with directed energy deposition method. The alloy was characterized using microscopy techniques and nanoindentation to provide insight into the relationship between its microstructural and nanoscale mechanical properties. The microstructure has a dominant dendritic region with an ordered Heusler structure (L21) and an interdendritic region with FCC structure with traces of C14 Laves region. During solidification, dendritic fragmentation occurs, contributing to the alloy having mostly equiaxed grains rather than the commonly observed columnar grains. Nanoindentation results showed that the interdendritic regions present soft zone while Laves phase presents the hardest region. The presence of laves phase inside the grain boundaries strengthens the region. The results of the current study highlight the synthesis of an equiaxed HEA with one of the highest combinations of elastic modulus and hardness values determined using nanoindentation.

Process Development: Powder Bed Fusion Process

Wednesday PM
August 16, 2023

Room: 400/402
Location: Hilton Austin

Session Chair: Lianyi Chen, University of Wisconsin-Madison

1:10 PM
Revealing and Controlling Process Instabilities for Defect Lean Metal Additive Manufacturing: *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. In this talk, I will first present our research on revealing the process instabilities by in-situ high-speed high-energy synchrotron x-ray imaging and diffraction. Then, I will introduce the defects mitigation approaches we developed based on the new mechanisms we discovered and the new insights we obtained from the in-situ characterization study for achieving defect lean metal additive manufacturing.

1:30 PM

Acoustic Mechanisms of Laser Powder Bed Fusion through an Analogous Whistle Model: *Yuchen Sun*[1]; Aiden Martin[1]; Sanam Gorgannejad[1]; Jenny Wang[1]; Maria Strantza[1]; Nicholas Calta[1]; [1]Lawrence Livermore National Laboratory

In laser powder bed fusion (LPBF), various non-destructive in situ diagnostic techniques are being developed including pyrometry, plasma spectroscopy, and acoustic monitoring, where acoustic monitoring represents an inexpensive, low spatial footprint, and computationally lightweight approach. Recent works have correlated acoustic signals from the printing process with print parameters and overall print quality. This work furthers the correlative understanding of acoustic monitoring and introduces a mechanistic understanding of acoustic generation in LPBF. We first present time-resolved frequency-domain acoustic data of Ti64 to demonstrate its correlation with laser energy density. We then perform non-dimensionalized analyses using Strouhal's number and analogize the LPBF vapor depression to hole tone systems—exemplified by steam kettle whistles. This comparison reveals two mechanisms of acoustic generation: Helmholtz resonance at lower laser powers, duct resonance and vortex shedding at higher laser powers. This mechanistic understanding of vapor depressions further demonstrates the diagnostic capacity of acoustic monitoring in LPBF.This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

1:50 PM

Surface Roughness Formation and Measurement for Metals Built with Laser Powder Bed Fusion: *Edwin Glaubitz*[1]; Joy Gockel[1]; Jason Fox[2]; Orion Kafka[2]; Claire Casey[1]; [1]Colorado School of Mines; [2]National Institute of Standards and Technology

As-Built surfaces in laser powder bed fusion (PBF-LB) have rougher and more complicated surfaces than those from conventional techniques. Several surface features are unique to additive processes: layering artifacts, adhered particles, and large valleys. Surface valleys have been shown to negatively influence the fatigue life by serving as locations for crack initiation, while adhered particles can obstruct measurement of mechanically relevant surface features from contact and optical measurement techniques. Standard PBF-LB metals such as nickel superalloy 718, AlSi10Mg, and stainless steel 316L are built with a wide range of contour parameters and across multiple types of machines. Contour melt pool size and shape are measured and characterized. The surfaces are measured using laser confocal scanning microscopy and X-ray micro-computed tomography. Understanding of relationships between contour melting behavior and resulting surface roughness will inform process parameter development and improve correlations between measurement and part performance.

2:10 PM

Quality Prediction of AM Processes Using Volumetric CNNs with Spatialized Representations of Structure-borne Sound Sensor Data: *Jork Groenewold*[1]; Lukas Weiser[1]; Florian Stamer[1]; Gisela Lanza[1]; [1]wbk Institute of Production Science, Karlsruhe Institute of Technology (KIT)

The low reproducibility of process quality is a challenge in additive manufacturing processes like powder bed fusion by laser beam melting (PBF-LB/M). Therefore, in-process monitoring is often used to detect process defects such as pores. One possible measurement technique are structure-borne sound sensors, which allow the laser-induced sound emissions to be monitored. Currently, the measured signals are evaluated individually for each manufactured layer. A key drawback of this approach is that the spatial arrangement of the measured data over multiple layers is not considered. This paper presents a new approach that aims to improve model performance by better exploiting the spatial context within the data. The approach consists of three steps: (1) data-preprocessing for three-dimensional assembly (2) optimization of a volumetric convolutional neural network and (3) training of models. The overall goal is to enable the models to close a quality control loop and thus enable reproducible process quality.

2:30 PM

Pushing Boundaries: Machine Learning Applied to Selective Laser Melting: *Mary Daffron*[1]; Steven Storck[1]; Brendan Croom[1]; Timothy Montalbano[1]; Salahudin Nimer[1]; [1]Johns Hopkins University Applied Physics Lab

A primary concern in advancing selective laser melting (SLM) is developing a method to rapidly establish laser parameters for the end application. Establishing a set of processing parameters is complicated by the infinite number of possible combinations of machine variables. Additionally, certain processing domains can be unstable resulting in failure to extract valuable statistical information. Leveraging total machine capacity while balancing laser processing parameters is vital to the scalability of AM at quality. Intelligent parameter development via machine learning techniques unlocks the full processing space to enable unrealized potential including application specific properties. Rapid characterization techniques combined with strategic evaluation of microstructure inform the machine learning model and parameter development process. This results in a thorough exploration of the processing space in fewer build cycles. Examples will be presented showing the identification of new processing domains with increased density and targeted mechanical behavior optimization compared manufacturer recommended parameter sets.

2:50 PM Break

3:20 PM

Localized Porosity Prediction in Laser Powder Bed Fusion via Deep Learning of Multi-modal Melt Pool Signatures: *Haolin Zhang*[1]; Chaitanya Krishna Vallabh[2]; Alexander Caputo[3]; Richard Neu[3]; Xiayun Zhao[1]; [1]University of Pittsburgh; [2]Stevens Institute of Technology; [3]Georgia Institute of Technology

Laser powder bed fusion (LPBF) additive manufacturing utilizes laser to sinter or melt powders for fast production of complex parts. However, due to the complex interplays among laser, powder, printed part, and gas flow, the LPBF process tends to generate severe defects such as pores, which are detrimental to the final part performance. In this work, we develop a deep learning aided porosity prediction framework utilizing in-situ monitored melt pool signatures including multiple thermal, geometrical, and spatter metrics that are derived from our high-speed on-axis single-camera two-wavelength imaging pyrometer and an off-axis camera jointly. Scalograms, transformed from the obtained time-domain MP signatures are used as input to train deep convolutional neural network models for correlating to ex-situ porosity characterization data from X-ray computed tomography. The developed method is shown to be capable of quantifying localized porosity and holds promise to qualify LPBF processes and parts.

3:40 PM

Investigation of the Influence of Process Parameters to Increase Productivity in the LPBF Process for the Material Inconel 718: *Christian Bodger*[1]; Stefan Gnaase[1]; Dennis Lehnert[1]; Thomas Tröster[1]; [1]Paderborn University

The nickel-based alloy Inconel 718, which is used in aerospace technology, poses a great challenge to machining due to its high work hardening and toughness. Here, the LPBF process offers an alternative with potential savings if sufficiently high productivity can be achieved. Based on the parameter study carried out, starting from the standard parameters for the production of components exposure parameters could be developed to realize manufacturing with 120 µm and 150 µm layer thickness. For this purpose, the process parameters of laser power, focus diameter, hatch distance and scan speed were varied. The negative defocusing of the laser showed a positive effect on the density of the parts, realizing densities ≥ 99.94 %, with high dimensional stability and good mechanical properties. Considering the reduced manufacturing time of up to 61 %, a significant increase in productivity was achieved.

4:00 PM
High Frequency Ultrasonic Detection of Security Markers in Additive Manufacturing Components: Farhang Honarvar[1]; Sagar Patel[2]; Katayoon Taherkhani[2]; Peyman Alimehr[2]; *Mihaela Vlasea*[2]; [1]K. N. Toosi University of Technology; [2]University of Waterloo

Embedding security markers in additive manufacturing (AM) components have been investigated in literature as means to ensure product authentication and mitigate risks of counterfeiting and reverse engineering. These security markers have been previously detected using X-ray computed tomography (XCT), which is a method also commonly used for defect detection in AM. Ultrasonic testing (UT) has been used for offline detection of defects in AM, but UT has not been implemented for complex security markers such as QR codes in AM. In this work, UT and image processing are used for the first time in successfully detecting QR codes in laser powder bed fusion (LPBF) parts, with feature sizes as low as 0.5 mm. Additionally, UT is also implemented as means to detect and differentiate LPBF parts with lack of fusion and keyhole mode defects, which presents a low-cost alternative to XCT for defect detection in AM.

Applications: Biomedical

Wednesday PM	Room: 408
August 16, 2023	Location: Hilton Austin

Session Chairs: Fay Claybrook, Loughborough University; Mazher Mohammed, Loughborough University

1:10 PM
Additive Manufacturing of Person Specific Diabetic Foot Insoles with Adjustable Cushioning Properties using TPMS Lattice Structures: *Fay Claybrook*[1]; Mazher Mohammed[1]; Darren Southee[1]; [1]Loughborough University

Complications associated with diabetes are numerous, including foot problems which can lead to amputations. Nerves loose sensation and raised blood sugar can damage the circulation, making healing slower. Current management involves the use of foam diabetic foot insoles (DFI) to provide cushioning, however load bearing capacity is limited, and designs often do not provide a comfortable or efficacious fit. This study aspires to resolve problems using digital fabrication workflows. We explore the potential of 3D scanning of anatomical data, parametric modelling, and additive manufacturing to create a patient specific DFI. We demonstrate that patient scanning data provides means to create a custom fitting insole template, improving overall fit. We also demonstrate use of triply periodic minimal surface (TPMS) structures, fabricated in Thermoplastic Polyurethane, as cushioning structures, whereby unique lattice designs allow regionally tailored mechanical loading properties of the insole concept. The final insole realises a superior alternative to tradition DFI.

1:30 PM
Assembly-free Hybrid Printing of Microfluidic Devices for Biosensing: *Yipu Du*[1]; Julius Reitemeier[2]; Qiang Jiang[1]; Yuxuan Liao[1]; Paul Bohn[1]; Yanliang Zhang[1]; [1]University of Notre Dame; [2]Univerisity of Notre Dame

The advent of 3D printing has facilitated the creation of microfluidic devices that are accessible and cost-effective. However, producing complex microfluidic devices with integrated structural and functional electronic components remains a challenge, often requiring complicated post-fabrication assembly steps. Here, we introduce a hybrid printing method that streamlines the production of multicomponent microfluidic devices with embedded channels and electrodes at microscale resolution without post-fabrication assembly. Using this approach, we successfully fabricated microfluidic sensors comprising microscale interdigitated electrode arrays for the amperometric sensing of lactate in sweat. The amperometric sensors demonstrated a sensitive response with a limit of detection of 442 nM and a linear dynamic range of 1 - 10 mM, which are performance characteristics relevant to physiological levels of lactate in sweat. The proposed hybrid printing method is straightforward, versatile, and cost-effective, making it suitable for a wide range of point-of-use monitoring and sensing applications.

1:50 PM
Evaluation of the Performance of 3D Printed Cutting Guides for Canine Caudal Maxillectomy: Aidan Chambers[1]; Marine Traverson[1]; *Satyanarayana Konala*[1]; Shelby Neal[1]; Ola Harrysson[1]; [1]North Carolina State University

Canine caudal maxillectomy is a surgical procedure commonly performed on dogs to remove cancerous tumors in the caudal portion of the maxilla. However, the procedure is associated with significant risks such as major hemorrhage and high recurrence rates due to incomplete resection of the cancerous bone. To address these issues, cutting guides were designed and printed in resin using SLA and surgery was performed by three groups: an experienced surgeon (SG), a novice surgical resident (NG), and a surgeon performing a freehand procedure (SF). Each group performed five cuts on cadaveric heads, and the accuracy of the cuts was evaluated. The highest absolute mean linear deviation recorded in SF, NG, and SG groups were 5.46±4.28 mm, 3.19±1.64 mm, and 1.98±0.81 mm, respectively, and occurred at the orbit osteotomy. However, the procedure duration was found to be significantly longer for guided surgery ($p < 0.001$).

2:10 PM
Fabrication of Thick Vascularized Tissues using Sacrificial Ink-assisted Embedded 3D Bioprinting: *Bing Ren*[1]; Yong Huang[1]; [1]University of Florida

Engineering three-dimensional (3D) in vitro vascularized tissue models remains a great challenge. Herein, a strategy integrating the sacrificial ink-assisted embedded bioprinting with cellular self-assembly is proposed to create thick vascularized tissues with macro- and micro-vessels. Perfusable channel structures are fabricated by embeddedly printing a sacrificial ink in an endothelial cell-laden and gelatin microgel-based yield-stress composite matrix. The sacrificial ink is removed to form channels as engineered macro-vessels after printing is completed and the matrix is crosslinked; micro-vessels are formed by self-assembly of encapsulated endothelial cells in the matrix. This embedded bioprinting approach has been implemented to print a composite matrix-based human alveolar model with vascularized air and fluid channels that are seeded with alveolar epithelial cells and endothelial cells, respectively, as well as composite matrix-based thick structured meat with macro-vessels seeded with endothelial cells and micro-vessels assembled by endothelial cells.

2:30 PM
Improving Food 3D Printing Through Texture Modification of Designed Food Inks: Stefania Chirico-Scheele[1]; Gabriel Goncalves[1]; William Clearman[1]; Martin Binks[1]; *Paul Egan*[1]; [1]Texas Tech University

Three-dimensional food printing is well-suited for producing foods with desired textural properties for consumers. However, it is difficult to fabricate desirable foods that print accurately and are nutritious. Here, we conduct texture measurements of designed food inks to determine printability and consumer appeal. Food ingredients include soy protein powder, strawberry powder, and cream cheese powder. The texture of food inks, specifically the firmness, was measured by compression testing, and resulted in firmness measurements of 206 g, 99 g, and 53 g, respectively. Strawberry and soy did not print accurately, but when combined homogenously in a 50 % / 50 % mixture, printing accuracy was improved while firmness reduced to 40 g. Consumer assessment experiments revealed that participants rated foods printed with the highest fidelity as the most desirable, which motivates the design of food inks to improve appeal through texture and printability modulation to support future delivery of personalized foods.

2:50 PM Break

3:20 PM

Materials Screening Methodology for Additive Manufacturing in Bioreactor Technology: *Johann Schorzmann*[1]; Hannes Gerstl[1]; Zhixin Tan[1]; Lys Sprenger[1]; Hsuan-Heng Lu[2]; Sarah Taumann[1]; Marco Wimmer[1]; Sahar Salehi-Müller[1]; Aldo R. Boccaccini[2]; Frank Döpper[1]; [1]University of Bayreuth; [2]Institute of Biomaterials, University of Erlangen-Nuremberg

Biofabrication is used to fabricate complex organs and mimic tissue structures from bio-inks (biopolymers enriched with living cells) using additive manufacturing (AM). Electroactive cells such as skeletal muscle function via electrical signals and therefore, their optimum in vitro functionality requires electrical stimulations. AM can be used to precisely fabricate a bioreactor for a dynamic culture of cells and bioengineered tissues with selective electrical conductivity and electrical stimulation of the cells. In this study, we focused on a material selection methodology for AM of bioreactors based on Reuter. Fulfilling all material requirements, biocompatibility, chemical stability, electrical conductivity, and sterilization, are the main criteria in the fabrication of bioreactor. But there is no standardized procedure for selecting materials in AM.Our study comprises four phases which deductively narrowed down the material selection (Phase I-IV: determination of material requirements; pre-selection of suitable materials; fine selection and assessment; evaluation/ validation of material properties).

3:40 PM

A Study of Additively Manufactured Ti-6Al-4V ELI Surface Roughness Coupons with Differing Processing Parameters: *Lucas Becker*[1]; [1]AddUp Inc.

Additive manufacturing, particularly laser powder bed fusion (LPBF), allows for increased complexity and robustness of medical parts and implants. Bio-compatible materials like Ti-6Al-4V ELI play a key role in the creation of these and thus need to be studied for their as-printed and post-processed physical properties like surface roughness for adoption in real-life applications. In this study, surface roughness was investigated with respect to printing process parameters using a roller recoating system. In addition, surface roughness was analyzed across the build plate under different post-build thermal conditions. Some of the samples were post-processed to see how effective bead blasting is at improving the surface finish. This study implies that printing parameters and post processing conditions can be utilized to alter the surface finish of the LPBF processed parts.

Applications: Techniques for End Use Parts

Wednesday PM — Room: 410
August 16, 2023 — Location: Hilton Austin

Session Chair: Timothy Phillips, University of Texas Austin

1:10 PM

Guided Manual Design for Additive Manufacturing of Topologically Optimized Legacy Tooling Parts: Hannah Luben[1]; *Nicholas Meisel*[1]; [1]Pennsylvania State University

While some of the choices made in Design for Additive Manufacturing (DFAM) become second nature to seasoned AM designers, inexperienced designers may not know the nuances involved in what is still a developing manufacturing technology. Topology Optimization (TO) in particular can result in organic shapes that may not be immediately conducive to printing through AM. This paper proposes a comprehensive workflow tool to guide a designer, no matter their level of experience, through the decision-making process inherent to DFAM. The tool helps the designer manually edit a legacy tooling design into a topologically optimized part that is readily manufacturable through AM. Several case studies follow the outline of the design tool to exemplify its use. After the best possible TO part is generated, the flowchart culminates with a guide to choosing the best part between the original legacy design, the raw TO part, and the redesigned TO part.

1:30 PM

Hybrid Electromagnetics: Printed RF Sensitive Structures, Circuits, and Sensors Integrated with Non-traditional Electromagnetic Substrates: Lucas Unger[1]; *Christopher Molinari*[1]; Basil Vanderbie[1]; Samuel Fedorka[1]; Gary Walsh[2]; Corey Shemelya[1]; [1]University of Massachusetts Lowell; [2]U.S. Army DEVCOM Soldier Center

Nonprinted, nontraditional substrates have seen increasing use in printed RF electronics applications. However, these substrates present significant design challenges to overcome, such as coarse surfaces, flexibility, and multilayer designs. For example, the performance of RF structures printed upon textiles or multilayer laminates are limited by uneven ink deposition, “bleeding” effects, poor ink adhesion, and poor component adhesion. This work demonstrates solutions to many of these problems including methods for blind, multilayer fabrication, extrudable RF encapsulants, printable surface wetting materials, and reliable adhesion and alignment devices for RF ICs. As a case study, we demonstrate an encapsulated RF sensing circuit printed directly atop a polyethylene fiber laminate using direct-write printing methods, alongside a multi-layer frequency selective surface embedded within an RF radome laminate. Our work can offer innovative ideas for how additively manufactured RF circuits and ICs can be integrated “on-demand” to meet new and novel goals.

1:50 PM

3D Printing of Complex Wire Geometries for Tailored Resistance Response: *Timothy Phillips*[1]; Jared Allison[1]; Joseph Beaman[1]; [1]University of Texas Austin

Additive manufacturing (AM) is a rapidly growing field that enables production of complex geometries without tooling. AM has gained traction as a method of producing complex electronic circuits not possible using traditional techniques. The method explored in this manuscript involves post-build infiltration of conductive inks into complex channels to create resistive elements with tunable properties. A Polyjet printer is used to enable high-precision multi-material components with custom mechanical properties. Further, the conductive pathway geometry can be designed to achieve different resistive responses. These properties allow for decoupling of the stress-strain response and resistance-strain response to produce custom strain gauges with engineered properties.

2:10 PM

Additive Compliant Mechanisms for Deployable Space Structures: Christine Gebara[1]; *Savannah Sunez*[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 additively manufacturing torsion springs embedded in the mechanism structure, novel geometries are possible. Thus, increasing performance while decreasing complexity and part count. JPL will present on the latest research to monolithically print compliant mechanisms for spaceflight applications.

2:30 PM

Process and Design Strategies for Fluid Wicking in Additively Manufactured Inconel 718 for Monolithic Heat Pipes: *Cameron Noe*[1]; Zachary Goode[1]; Dhruv Bhate[1]; [1]Arizona State University

The ability to integrate heat pipes into monolithic structures using additive manufacturing is a promising avenue for advanced thermal management. A monolithic heat pipe structure is a geometry where the part, heat pipe walls, and the fluid wicking structure are all fabricated as one integrated component. In this work we examine the use of the laser powder bed fusion process for creating wicking structures out of Inconel 718 for use in heat pipes. Specifically, three different approaches are studied for their fluid wicking performance: structured, rastered and sintered, which use design and process strategies for creating porous wicks. The wicks are evaluated based on their porosity, manufacturability, and fluid rate of rise, using X-ray tomography, SEM, mass measurements, IR thermal imaging and CFD simulations for the investigation. Results include a discussion of the advantages and disadvantages of the three strategies as well as on their potential for future system integration.

2:50 PM Break

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Additively Manufactured Inconel718-Methanol Heat Pipe: Fabrication and Low Temperature Thermal Testing: *Adnen Mezghani*[1]; Edward Reutzel[2]; Douglas Wolfe[2]; [1]Pennsylvania State University; [2]The Applied Research Laboratory

Effective thermal management is crucial in hypersonic flight (Mach > 5) due to extremely high aerodynamic heating located at leading edges. Historically, passive and active thermal protection systems (TPS) have been used to achieve this purpose. Among passive TPS methods are two-phase thermal management systems, also known as heat pipes. Heat pipes can achieve extremely high thermal conductivity which makes them an attractive TPS solution. However, conventional fabrication methods for heat pipes and other two-phase thermal management devices require multiple manufacturing and assembly steps which limit design space. Additive manufacturing is a fabrication technology in which components are fabricated layer-by-layer to achieve net-shape geometry from CAD. AM is able to create complex geometries, incorporate internal channels, and consolidate assemblies. Hence, the ability to additively manufacture leading-edge heat pipes would bypass conventional manufacturing limitations and achieve a larger design space for lightweight, highly conductive leading-edge concepts. This presentation presents the fabrication and low-temperature thermal testing of a notional inconel718 leading edge heat pipe fabricated via laser-powder bed fusion AM and filled with methanol. This work serves as a proof of concept and precedes simulated-environment high-temperature thermal performance assessment of additively manufactured inconel718 leading-edge heat pipes filled with sodium.

3:40 PM

Mechanical and Dimensional Characterization of Polymer Powder Bed Fusion Parts for Non-assembly Mechanisms: Nava Khatri[1]; Johnathan Smith[1]; *Paul Egan*[1]; [1]Texas Tech University

Polymer powder bed fusion (PBF) is promising for fabrication of non-assembly mechanisms in applications such as prosthetics needing rotational parts with mechanical strength. Here, PBF feasibility is studied for mechanical systems using a form fuse printing system with nylon 11 by printing and mechanically testing lattices, springs, and rotational mechanisms. Elastic moduli of specimens tested according to ASTM D638 type IV were about 43 MPa and demonstrated low anisotropy. BC-Cube lattices were printed at 30% and 50% relative densities with measured effective elastic moduli from 25 MPa to 55 MPa. Printed helical spring stiffness was approximately 0.2 N/mm to 16.8 N/mm for 3 mm to 7 mm wire diameters. Functional prosthetic fingers were operable for gap sizes printed within the range of 200 to 800 µm to avoid fusion of joints while enabling free rotation. Results demonstrate PBF's feasibility for printing non-assembly parts for functional components in diverse engineering applications.

4:00 PM

Using Solid Freefrom Fabrication to Develop and Test Unique Texture on Mecanum Wheel Rollers and the Ground for Improved Robot Position Accuracy: Indira Dwivedi[1]; Bharat Dwivedi[1]; *Rajeev Dwivedi*[2]; [1]Eastlake High School; [2]STEM and Robotics Academy

Mecanum wheels enable mobile robots to move omnidirectionally. The unique movement is enabled by combination of multiple wheel speeds and the friction between the rollers and surface. Variation of friction as well as wear and tear impact the accuracy of Robot navigation. We propose unique texture on the surface of the wheel rollers as well as the ground to improve the accuracy and repeatability of trajectory. Where sustaining the textures is limited, the specially textured surface is presented at specific intervals. The spacing and texture is driven by error propagation estimates. Solid Freeform fabrication is used to develop and test differnt textures.

4:20 PM

Rapid Foam Foundry: The Future of Foam Foundry: *Gopal Gote*[1]; Pushkar Kamble[1]; Yash Mittal[1]; Yogesh Patil[2]; Ashik Kumar Patel[3]; Avinash Mehta[1]; K. P. Karunakaran[1]; [1]Indian Institute of Technology Bombay; [2]Indian Institute of Technology; [3]National Institute of Industrial Engineering

Investment casting (IC) is one of the oldest and most extensively used manufacturing processes for metals, where expendable wax patterns are transferred into metal casting. IC can produce precise and complex castings; despite this, it has limitations in large, complex, and thin castings. Along with this, the cost of the wax pattern and its dewaxing makes the IC costlier. Lost Foam Casting (LFC) overcomes these issues because of its ability to produce large near-net-shape complex castings, cheaper and lighter pattern material, and environmental friendliness. Worldwide, conventional foundries are adopting LFC technology. Lost foam foundries uses Expanded Polystyrene (EPS) foam as a pattern material which uses the molding route for pattern making. The molding route of pattern-making limits the LFC applications for mass production because of the high initial die cost and relatively less complex castings because of the manufacturability of the die. To address these difficulties, this article presents the Rapid Foam Foundry (RFF) concept, which is the synergic integration of the hybrid Foam Additive Manufacturing (FAM) machine into conventional foam foundry. In this article, the idea of "CAD to Cast" has been introduced the field of foam casting. The indigenously developed hybrid FAM machine has unique kinematics and a novel slicing approach. It realizes the part through one additive (gluing) and two subtractive (hot wire slicing and machining) processes. A Hybrid FAM machine will be add on to the conventional foam foundries, which will enhance the capacity of the conventional foam foundries by its ability to produce more complex patterns, which will be difficult to manufacture using the molding route. And it has the great potential to manufacture patterns for batch production and for a few specific parts. The present article also includes a lab-scale case study to prove the concept of RFF. In the Lab-scale case study, we created the EPS foam pattern through a hybrid FAM machine, and that foam pattern was transferred into the shell through the foam evaporation at 2500C for 15 min, followed by shell firing has been performed at 7500C for 1hr. Finally, the casting has been manufactured by pouring the LM6 aluminum alloy. Visual inspection shows no surface-casting defects. The 18µm and 25µm surface roughness has been recorded on the flat surface of the casting and foam pattern.

4:40 PM

Material Jetting of Suspension System Components: *Jeffrey Lipton*[1]; [1]Northeastern University

Material Jetting has demonstrated great promise in being able to produce complex functionalities using multimaterial printing. Despite this potential material jetting has struggled to find applications in direct part production. Here we show how material jetting can be used to produce viscoelastic energy absorbers for large displacement applications in harsh environments. We generate printed components to act as the core of a suspension system on a recumbent trike. We test the printed viscoelastic dampers through large displacements and high payloads on a DMA to characterize the nonlinear performance and compared them with standard molded components. The 3D printed dampers allowed for finer control and customization of the ride experienced. Through long term exposure studies, we demonstrate that techniques and methods previously applied to the absorption of vibration in indoor power tool applications can be extended to outdoor environments.

Wire-fed DED: Gas and Thermal Management and Analysis

Wednesday PM — Room: 412
August 16, 2023 — Location: Hilton Austin

Session Chair: To Be Announced

1:10 PM
A Small Volume, Local Shielding Gas Chamber with Low Gas Consumption for Laser Wire Additive Manufacturing of Bigger Titanium Parts: *Alexander Barroi*[1]; Nick Schwarz[1]; Joerg Hermsdorf[1]; Thomas Bielefeld[2]; Stefan Kaierle[1]; [1]Laser Zentrum Hannover e.V.; [2]Premium AEROTEC GmbH

This paper shows how additive manufacturing of large size titanium parts can be achieved by means of a mobile shielding gas chamber, without the consumption of excessive amounts of shielding gas. While welding, the oversized cover of the chamber can be slid to the sides without opening it. The laser head is only partly inserted into the chamber through the cover. This enables a small sized chamber and allows a quick filling with argon. Since the chamber has a low leakage, only small amounts of argon (5 l/min) are needed to maintain a sufficient welding atmosphere with less than 300 ppm oxygen. For large sized parts, the chamber can be repositioned on the substrate. It has flexible parts which can be fit to the already welded structures that otherwise would prevent the chamber from being put flat on the substrate. The limited build space inside the chamber requires a new welding strategy, which is suggested.

1:30 PM
Comparison of Process Control Methods for Wire-arc Directed Energy Deposition of Low Carbon Steels with In-situ Temperature Measurement: *Ahamed Ameen*[1]; Vit Janik[2]; Joanna Nicholas[3]; Xiang Zhang[2]; Cui Er Seow[3]; [1]Coventry University / National Structural Integrity Research Centre; [2]Coventry University; [3]TWI Ltd

Additive manufacturing (AM) techniques enable the production of near-net shape parts. Wire-arc direct energy deposition (DED) can achieve a higher deposition rate among metal AM methods. Conventional arc welding requires a maximum interpass temperature to limit any reduction in mechanical properties, but this may not be practicable for wire-arc DED. In this study, two inter-pass process control methods, one with maximum interpass surface temperature and the other with constant dwell time, were adopted to deposit low-carbon steel walls while maintaining the same feedstock and heat input values. Thermocouples were inserted at three different positions in the walls during deposition, to record the thermal profiles. Testing of samples extracted from walls exhibited comparable tensile strength (~10 MPa difference) and consistent hardness values. Microstructural evaluation showed the presence of interlayer regions with alternating coarse and fine bands of ferrite grains, irrespective of interpass control method suggesting dwell time control for better productivity.

1:50 PM
Efficient Thermomechanical Simulation for WAAM using Automated GPU-based Modeling: *Xavier Jimenez*[1]; Albert To[1]; [1]University of Pittsburgh

Simulating the wire arc additive manufacturing (WAAM) process can be challenging due to the large part size. An improved workflow that combines automation and GPU accelerated modeling using the Pittsburgh Additive Manufacturing Simulator (PAMSIM) has been implemented. Although thermal simulations are very fast, thermomechanical simulations can take 10 to 20 times more time and thus become impractical to implement before every print. This work focuses on implementation of an automated computational framework for the flash heating method combined with the temperature dependent inherent strain. The improved workflow helps to accelerate the manufacturing process of new parts using WAAM, through thermal and residual stress results at the part scale level.

2:10 PM
Inter-pass Temperature Impact in Wire-Arc Additive Manufacturing: *Steven Williams*[1]; Evan Gitto[1]; Bradley Jared[1]; [1]University of Tennessee

In wire-arc additive manufacturing (WAAM), variations in bead geometry often lead to defects and unintended part geometries. Several factors influence the bead geometry including the material deposited or process inputs. In this study, ER70S-3 wire was deposited onto steel build plates at surface temperatures from ambient to 300°C using different weld parameter sets. To control build plate surface temperature, a preheat stage was designed and implemented. Then, steel beads were deposited onto the build plate surface and subsequently measured to determine their geometric properties. Initial results indicate that as the preheat temperature increases, resulting bead height decreases, bead height variation decreases, and bead width increases. Further analysis is being conducted and will be discussed to determine the impact of preheat on the resulting bead microstructure. The results of these experiments will be used to create process maps which will serve as a foundation for bead geometry control during printing.

2:30 PM
Localized Shielding Gas Lens and Inert Enclosure Effects on Titanium GMAW for Wire-Arc Additive Manufacturing: *Harold Walters*[1]; Christopher Masuo[1]; Andrzej Nycz[1]; Peter Wang[1]; Joshua Vaughan[1]; Bill Carter[1]; Riley Wallace[1]; Jonathan Paul[2]; Jason Flamm[2]; [1]Oak Ridge National Laboratory; [2]Lincoln Electric

Depositing titanium and titanium alloys using gas-shielded metal arc welding (GMAW) presents a challenge for Wire-Arc Additive Manufacturing (WAAM) of maintaining weld quality due to the susceptibility of titanium to oxidation. GMAW utilizes an envelope of inert gas around the arc to create a small, stable environment that oxygen cannot enter to protect the weld during deposition. This standard approach falls short for shielding titanium depositions because the hot trailing bead continues to be vulnerable to oxidation during solidification. One alternative is to utilize a shielding gas device that mounts to the end effector and provides additional shielding to the trailing bead. Another alternative to this is to utilize an inert enclosure, which encompasses the entire work piece. This analysis seeks to characterize and compare the effects of utilizing a shielding gas device system to an inert enclosure for WAAM when depositing titanium beads to determine the most cost-effective process.

2:50 PM Break

3:20 PM
Prediction of Inter-pass Temperature for Large-scale Double Sided Component Fabricated Electron Beam Wire Additive Manufacturing: Guru Madireddy[1]; Zachary Corey[2]; Ron Aman[2]; Matt Bement[3]; *Yousub Lee*[3]; [1]Sentient Science; [2]Edison Welding Institute; [3]Oak Ridge National Laboratory

Wire-based direct energy deposition (DED) technologies have been rapidly adopted for manufacturing of large structural components in aerospace and aircraft power generation industries. As the part size becomes larger, the deposition often requires expected/unexpected pauses (e.g., wire-spool change, flipping part for double-sided part) for the completion of part. The pauses lead to change of thermal profile and heat build-ups during printing and cooling that can result in inhomogeneity in distribution of defects or residual stresses. Therefore, understanding and predicting the effect of process parameters on dynamic variation of thermal profile during printing and cooling are crucial for tight control of qualifying the material/mechanical properties. In this research, we developed a part-scale thermal model for validation of inter-pass temperatures for the double-sided additive component, i.e., Droplink (> 700 mm in length). The prediction showed a good agreement in trend and values within 10% error to the pyrometer measured temperature.

3:40 PM
Process Parameters and Interpass Temperature Effects on WAAM Inconel 718: *Xavier Jimenez*[1]; Jie Song[2]; Yao Fu[2]; Albert To[1]; [1]University of Pittsburgh; [2]Virginia Tech

Inconel 718 is an alloy widely used by many industries due to its great performance at high temperatures. Wire arc additive manufacturing (WAAM) can be used to create larger parts with medium to low complexity with a reduced cost and faster manufacturing times than traditional methods. The presence of niobium in this alloy makes it prone to severe segregation during solidification which creates a liquid film and low melting-laves phases that can lead to hot cracking. This work focuses on the effect that process parameters and interpass temperature have on melt pool dimensions and the occurrence of hot cracking in MIG-based WAAM. Understanding this effect allows users to choose the most productive process parameters while maintaining geometric consistency and avoid cracking.

4:00 PM
Shielding Gas Flow Analysis for Wire-Arc Additive Manufacturing using Schlieren Imaging: *William Carter*[1]; Christopher Masuo[1]; Luke Meyer[1]; Alex Walters[1]; Riley Wallace[1]; Andrzej Nycz[1]; Joshua Vaughan[1]; Jonathan Paul[2]; Jason Flamm[2]; [1]Oak Ridge National Laboratory; [2]Lincoln Electric

Proper shielding gas flow is crucial to the wire-arc additive manufacturing process. Improper shielding of the deposition process can lead to voids in the deposited material, an unstable weld arc, and excessive oxidation of the printed part. Several factors can affect the flow of the shielding gas in wire-arc additive manufacturing including nozzle design, wire stickout, gas flowrate, and the location of the nozzle over the part. Schlieren imaging, a technique that uses mirrors, a point light source, and a knife edge to view air currents, was used to examine the effects of these factors on gas coverage. Images and videos will be presented along with strategies for optimizing gas coverage under various conditions.

Materials: Metals-Novel AM Methods II

Wednesday PM — Room: 415 AB
August 16, 2023 — Location: Hilton Austin

Session Chair: Yaguo Wang, University of Texas at Austin

1:10 PM
A Hybrid Aerosol Jet Printing and Electrochemical Deposition Process for Manufacturing Multi-layer Inductors and Transformers: *Lok-kun Tsui*[1]; Yongkun Sui[2]; Thomas Hartmann[2]; Joshua Dye[2]; Judith Lavin[2]; [1]University of New Mexico; [2]Sandia National Laboratories

A hybrid additive manufacturing approach combining aerosol jet printing (AJP) and electrochemical deposition process was developed for manufacturing multi-layer inductors and transformers. AJP deposits metals and dielectrics with high resolution for printed electronics applications; however, nanoparticle inks have lower conductivity than bulk. Electrochemical deposition is used to address the low conductivity of the printed metal. An Ag seed layer is aerosol printed followed by the electrochemical deposition of high density, high conductivity Cu and Ni, decreasing the resistance and passivating the inductor surface respectively. We manufactured 8-layer spiral inductors with inductances of 2.5 µH. Flyback transformers consisting of 2-layer primary and 2-layer secondary spiral inductors were manufactured using this hybrid method. These transformers took an input voltage of 17V at 400 kHz and output a voltage of 1250 volts, a gain of 73.5. COMSOL modelling validated the designs. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

1:30 PM
Double-pulse Femtosecond Laser Sintering of Metal Nanoparticles on Flexible Substrate: *Janghan Park*[1]; Yaguo Wang[1]; [1]University of Texas at Austin

Selective laser sintering (SLS) is a branch of additive manufacturing, utilizing powder beds and laser irradiation. SLS is a promising manufacturing method for flexible electronics because it does not require a high-temperature environment, which is not suitable for flexible substrates. Femtosecond laser (fs-laser) has received attention due to its ultra-short irradiance time which is less than electron-phonon coupling time, resulting in minimized heat-affected zones. Despite the advantages, it has been challenged to utilize fs-laser due to a high possibility of having ablation caused by hot electron blast effects. Here, we propose double-pulse fs-laser sintering which can reduce ablation by avoiding high peak power. We verified there is a suppression of metal nanoparticle ablation with double-pulse laser for spot sintering. We plan to further develop our study from spot sintering to line sintering on flexible substrate. Lowering surface roughness and enhanced electrical properties are expected with applying double-pulse sintering.

1:50 PM
Effect of Surface State and Material on Surface Quality Enhancement by Dual Laser Powder Bed Fusion: *Daniel Ordnung*[1]; Jitka Metelkova[1]; Brecht Van Hooreweder[1]; [1]KU Leuven

Parts produced by Laser Powder Bed Fusion typically exhibit a limited surface quality often requiring systematic post-processing. The KU Leuven AM team recently developed a Dual Laser Powder Bed Fusion strategy to improve the quality of inclined up-facing surfaces during building. It consists of two steps: (1) a pulsed laser induces shock waves to remove powder from inclined surfaces, followed by (2) in-situ laser remelting of the newly exposed surfaces. The first part of this paper covers the effect of the used material and initial surface state on the powder removal efficiency using shock waves. A design of experiments was performed for horizontal samples of tool steels, titanium and aluminium alloys. The second part deals with the powder removal efficiency for inclined surfaces of variable initial surface state ($Ra<20\mu m$, $Ra>30\mu m$). Finally, the third part demonstrates the surface quality improvement, resulting in a reduction of Ra by 48% for 15° inclinations.

2:10 PM
Fabrication of Crack-free Aluminum Alloy 6061 Parts using Laser Foil Printing Additive Manufacturing Process: Yu-Xiang Wang[1]; *Chia-Hung Hung*[1]; [1]National Cheng Kung University

In this paper, aluminum alloy 6061 (AA6061) parts were fabricated using a laser foil printing (LFP) process. The process window of AA6061 in LFP was investigated to optimize the process parameter for eliminating the formation of pores and cracks. Although AA6061 is challenging for laser additive manufacturing, the optimal laser power (700 W) and scanning speed (100 mm/s) were used to fabricate AA6061 parts with a high relative density (99.8%). The line energy density was controlled properly to effectively reduce porosity and no micro-cracks were found in any LFP-fabricated AA6061 parts. The hardness, X-Ray diffraction, and tensile strength of LFP-fabricated parts were measured and compared with the original foils. The hardness was enhanced from the original foil of 41 HV to the LFP-fabricated part of 70 HV. The orientation of preference of column grains in LFP-fabricated part was [200].

2:30 PM
Identification of Nanoparticles Dispersion Mechanism in 316L Matrix Additively Manufactured Byhybrid Process of Ink Jetting and Laser Powder Bed Fusion: *Somayeh Pasebani*[1]; Milad Ghayoor[1]; Joshua Gess[1]; Bryce Cox[1]; [1]Oregon State University

Oxide dispersion strengthened (ODS) alloys are metal-matrix composites in which oxide nanoparticles suppress grain boundary mobility at elevated temperature; enhancing grain growth and creep resistance. In this work, two different additive manufacturing processes were proposed to disperse nanoparticles of Al2O3 into the 316L stainless steel matrix with the aid of laser powder bed fusion (LPBF), and the microstructural evolution was investigated. First, 316L SS powder and alumina particles were mixed and used as feedstock for producing 316L ODS alloy. Second, ink-jetting in the LPBF process was utilized to manufacture 316L ODS. The ink, containing Al13 nanoclusters, was selectively deposited into the 316L powder bed, and then laser consolidated metal powder and nanoclusters into nanocomposite. Detailed microstructural characterization revealed that both Al2O3 and Al13 were melted, precipitated as Al-enriched nanoparticles, and homogenously dispersed in the matrix upon solidification.

2:50 PM Break

3:20 PM
Liquid Metal Jet-on-Demand Printing of Al-6061: *Eric Elton*[1]; Kellen Traxel[1]; Andrew Pascall[1]; Jason Jeffries[1]; [1]Lawrence Livermore National Laboratory

Many traditional aluminum alloys, including 6000 and 7000 series alloys, are difficult to additively manufacture using laser-based techniques due to hot tearing, problems with microstructure, and other issues. To avoid these problems, much effort has been placed on developing new alloys with similar properties. Here we demonstrate droplet-based printing of Al-6061 and produce nearly fully dense parts from rod feedstock. We show that by heating the build plate to sufficiently high temperatures, hot tearing can be avoided. Furthermore, by post-processing the printed parts using the traditional Al-6061 T6 heat treatment, the part microstructure and strength becomes comparable to traditionally manufactured Al-6061. Finally, we demonstrate that the tensile parts of printed tensile bars are comparable to wrought parts. This suggests that droplet based methods are a suitable way to additively manufacture Al-6061 parts with comparable properties to traditionally manufactured parts. Prepared by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS-847001.

3:40 PM
Advancing the Process Window for Reliable Metal Droplet-on-demand Manufacturing: *Nicholas Watkins*[1]; Phillip Paul[1]; Viktor Sukhotskiy[1]; Jason Jeffries[1]; Andrew Pascall[1]; [1]Lawrence Livermore National Laboratory

Liquid metal droplet-on-demand additive manufacturing is an attractive alternative to the industry-standard, laser-based techniques: powder-free, low feedstock footprint, minimal material waste, less contamination and inclusions from feedstock, and compatible with a large range of materials. Despite substantial ink jetting research in the past, little effort has been made to understand the parameter space to reliably eject stable, satellite-free liquid metal droplets. We previously empirically mapped the extreme region of a droplet-on-demand printability window based on the Ohnesorge and Weber jet numbers, showing that satellite-free ejections are possible for any molten metal. We continue to map an unexplored intermediate region of this window using our custom printer, finding that additional parameters to the Ohnesorge and Weber jet numbers may be needed to fully describe the printability space. This added dimensionality may permit the printability window to inform essentially any droplet-on-demand process using any feedstock. Prepared by LLNL under Contract DE-AC52-07NA27344. LLNL-ABS-846903

4:00 PM
Diode Area Melting – A Multi-laser Alternative to Traditional Laser Powder Bed Fusion: *Anqi Liang*[1]; Mohammad Alsaddah[2]; Alkim Aydin[2]; Kristian Groom[2]; Kamran Mumtaz[2]; [1]University of Southampton; [2]University of Sheffield

The traditional Laser Powder Bed Fusion (LPBF) processing methodology relies on a galvo-scanning approach with high-power fiber lasers (1070nm wavelength) to selectively melt thin layers of feedstock from a powder bed. This approach creates challenges with regard to LPBF system scalability, processing efficiency (due to poor laser absorption and wall-plug efficiency) and thermal process control due to rapid melt-pool solidification. Diode Area Melting (DAM) is an alternative approach, integrating multiple individually addressable low-power fiber-coupled diode lasers into a laser head, these traverse across a powder bed to melt powdered feedstock. The highly scalable and compact diode lasers operate at a shorter wavelength (450-808nm) and lower powers (3-4W) compared to traditional LPBF fiber lasers, enabling a more efficient energy absorption with reduced cooling rates. This work presents DAM processing of Ti64 feedstock with multiple 450nm and 808nm laser sources examining effects on melt pool formation and resultant microstructures.

4:20 PM
Nanoparticle-modification of NiCu-based Alloy 400 for Laser Powder Bed Fusion: *Jan-Philipp Roth*[1]; Ivo Šulák[2]; Jörg Fischer-Bühner[3]; Ulrich Krupp[4]; Katrin Jahns[1]; [1]Osnabrück University of Applied Sciences; [2]Institute of Physics of Materials; [3]INDUTHERM Gießtechnologie GmbH; [4]Steel Institute IEHK, RWTH Aachen University

Alloy 400 is a widely used material being known for its excellent corrosive resistance. Within the chemical industry and in contrast to conventional manufacturing processes, Laser Powder Bed Fusion (LPBF) of Alloy 400 opens up for functional components that withstand harsh environments. On the basis of a holistic process route, the present work focusses on modifying the chemical composition of the base material with Titanium in order to allow the formation of TiN nanoparticles during powder production. Parameter optimization for gas atomization and LPBF is carried out and the microstructure of both powders and parts is examined. It was found that agglomerates of Ti and N existed for the powders while for the parts, single Ti precipitates instead of TiN were present. Ti-enhanced parts resulted in superior mechanical properties due to these Ti dispersoids. Hence, nanoparticle integration proved to be feasible and effective for the present alloy system.

Materials: Metals-Graded Compositions

Wednesday PM — Room: 416 AB
August 16, 2023 — Location: Hilton Austin

Session Chair: Anthony Stair, Carnegie Mellon University

1:10 PM
Compositionally Graded Transition from Tungsten to Ferritic-martensitic Steels via Directed Energy Deposition: Deniz Ebeperi[1]; Tim Graening[2]; Ying Yang[2]; Yutai Katoh[2]; *Ibrahim Karaman*[1]; [1]Texas A&M University; [2]Oak Ridge National Laboratory

Nuclear fusion reactors utilize W and W-based alloys as plasma facing components, which require joining into steel cooling structures based on the state-of-art divertor designs. Direct joining between W and steels lead to formation of brittle intermetallics. Joining with filler alloys are not compatible for high temperature applications as the microstructure may degrade and promote a critical failure. Directed energy deposition technique enables deposition of multiple pre-alloy or elemental powders simultaneously, in a layer-by-layer fashion, with a precise control of the composition to avoid formation of intermetallic or detrimental phases. In addition, its ability to fabricate compositionally graded transitions reduces the coefficient of thermal expansion mismatch between adjacent interlayer alloys. In this study, we demonstrated a framework to optimize the processing parameters for each alloy, generated processability maps and successfully fabricated a dense, multilayered, linear compositional gradient fromW to Gr91 steel, using V-based and Fe-based alloys as transition elements.

1:30 PM
Directed Energy Deposition of Stainless Steel 304L to Inconel 625 Gradients: Print Strategies and Defects: *Anthony Stair*[1]; Jack Beuth[1]; Bryan Webler[1]; Maarten de Boer[1]; [1]Carnegie Mellon University

The bonding of dissimilar metals via additive manufacturing can create structures with different properties based on the location withing the geometry of the component. Bonding of dissimilar metals is difficult due to formation of unintended intermetallic phases and mismatches in thermal properties like thermal conductivity, melting temperature, and coefficient of thermal expansion. By using process parameters to control the dilution of the stainless steel 304L build plate into the melt pool in single layer builds, we have avoided gross defects such as large voids, cracks, or deleterious phases. Tensile testing of specimens printed with a defect free parameter set showed that the gradient between the two materials was stronger than stainless steel 304L. Some unsuccessful experiments contained cracking. The compositions and build parameters of experiments which resulted in cracking are compared to those of experiments that did not crack to determine what the cause of the cracking is.

1:50 PM
Microstructural Investigations on SS316L-Cu Graded Deposition Prepared using Wire Arc Additive Manufacturing: *Bunty Tomar*[1]; Shiva S.[1]; [1]Indian Institute of Technology Jammu

Fabrication of steel and copper-based functionally graded material (FGM) through cold metal transfer-based wire arc additive manufacturing is a novel exploration. Components combining Cu and steel show significant usage in many industrial applications as they combine high corrosion resistance, ductility, thermal conductivity, and wear resistance to excellent mechanical properties. Joining steel and copper is challenging due to the mismatch in their thermo-mechanical properties. In this experiment, a functionally graded material (FGM) structure of pure copper (Cu) and 316L stainless steel (SS) was successfully developed using cold metal transfer-based wire arc additive manufacturing (CMT-WAAM). The interface of the fabricated samples was characterized under optical microscopy, field emission scanning electron microscopy, and X-ray diffraction techniques. Detailed EBSD and TEM analysis was performed to analyze the grain orientation, strain distribution, grain boundary misorientations, and formation of metastable and intermetallic phases. This works paves the way to use CMT-WAAM to fabricate steel/copper FGMs.

2:10 PM Break

Particulate and Dispersoid Reinforced Metals

Wednesday PM — Room: 416 AB
August 16, 2023 — Location: Hilton Austin

Session Chair: Jared Allison, University of Texas Austin

4:20 PM
Effect of Solidification Conditions on the Evolution of Dispersoids in a Ni-20Cr + 1 wt% Y_2O_3 ODS Alloy Fabricated with Laser Powder Bed Fusion: *Nathan Wassermann*[1]; Alan McGaughey[1]; Sneha Narra[1]; [1]Carnegie Mellon University

Oxide dispersion strengthened (ODS) alloys contain a high number density of nano-scale oxide dispersoids, offering exceptional high-temperature creep strength. Though these alloys offer a range of desirable properties, existing manufacturing methods are inconsistent, costly, and often yield anisotropic microstructures. While ODS alloys have been researched in the additive manufacturing (AM) literature, the evolution of nano-oxide dispersoids during AM processing is not well-understood. In this investigation, laser powder bed fusion (L-PBF) is used to fabricate samples of a Ni-20Cr + 1 wt% Y_2O_3 ODS alloy. A range of power-velocity combinations are applied, and differences in the evolution of nano-oxide dispersoids are evaluated across the processing space. Results from a heat transfer model are integrated with a model for inclusion growth, which is connected to the microstructure of the fabricated samples. The results of this investigation contribute to AM process design for ODS alloys.

3:20 PM
Oxide Dispersion Strengthened (ODS) SS316L Prepared by Laser Powder Bed Fusion: Analysis of Microstructure and Hardness Properties: *Changyu Ma*[1]; Yu-Keng Lin[2]; Tianqi Zheng[2]; Philip Mallory[3]; Y. Morris Wang[2]; Xiaochun Li[2]; Bruce Kang[3]; Bingbing Li[1]; [1]California State University Northridge; [2]University of California Los Angeles; [3]West Virginia University

Dense oxide dispersion strengthened (ODS) SS316L with 0.5wt.% Y2O3 fabricated by laser powder bed fusion (L-PBF) additive manufacturing using spherical SS316L powder embedded with nano-Y2O3 and different building patterns. The density, grain growth, phase formation, and microhardness of the as-printed ODS SS316L were investigated through optical microscopy (OM), scanning electron microscopy (SEM), energy dispersive X-Ray Spectroscopy (EDX), and Vickers hardness testing, respectively. The results showed that there was uniform dispersion of Y-rich nanoparticles in dense ODS SS316L printed with meander and chessboard patterns owing to the ultrafine Y2O3 in powder feedstock, contributing to a fine-grain structure in the as-printed ODS SS316L. A smaller molten pool was observed in ODS SS316L printed with a chessboard pattern compared to meander strategy, and enhanced microhardness was observed in ODS SS316L compared to pristine SS316L. Based on the above findings, the Y2O3 effects on microstructure evolution and reinforcing mechanisms of microhardness were discussed.

3:40 PM
Influence of TiC-Nanoparticles on the Material Properties of AlSi10Mg Manufactured by Laser Powder Bed Fusion: *Victor Lubkowitz*[1]; Torsten Scherer[2]; Frederik Zanger[1]; Volker Schulze[1]; [1]wbk Institute of Production Science, Karlsruhe Institute of Technology (KIT); [2]INT Institute of Nanotechnology, Karlsruhe Institute of Technology (KIT)

Additive manufacturing enables the production of complex lightweight components. However, the poor usage of atomized metal powders is a challenge, as fine particles must be removed from the powder feedstock to ensure flowability. Further new high strength aluminum alloys are needed. Some investigations show that the mechanical properties of AlSi10Mg can be improved by adding TiC nanoparticles. The aim of this study is to determine if the influence of small amounts of TiC additions, which are normally used to improve the flowability of fine powders, is also sufficient to improve the mechanical properties. It was found that the addition of 0.46 wt% TiC-Nanoparticles with a size of 50 nm led to a homogeneous grain size distribution and an increase of 16 % in yield strength compared with pure AlSi10Mg. Further a strong median grain size reduction from 5.08 to 2.74 µm could be observed by adding 0.96 wt% of TiC-Nanoparticles.

4:00 PM
Process Structure Relationships of Carbide Containing Molybdenum Alloys Produced via Electron Beam Powder Bed Fusion: *Christopher Ledford*[1]; Patxi Fernandez-Zelaia[1]; Michael Kirka[1]; [1]Oak Ridge National Laboratory

Recent success in the processing of refractory materials using additive manufacturing shows the viability of using these techniques to process more complex refractory alloys. Carbide containing molybdenum alloys exhibit good high temperature properties but are difficult to traditionally manufacture. Here we show the use of electron beam powder bed fusion to fabricate highly dense crack free material of two different carbide containing molybdenum alloys (Mo-TiC and MoReHfC). Process structure relationships are explored for each alloy along with effect of heat treatments on those properties.

Poster Session

Tuesday PM — Room: Salon JK
August 15, 2023 — Location: Hilton Austin

A Pilot Study on Temperature Monitoring and Morphology of the Meltpool in EB-PBF of Copper using Numerical and Analytical Models: *Elmira Sharabian*[1]; [1]UTEP University

In this research, a pilot study on temperature monitoring of electron-beam powder bed fusion of copper has been investigated. Two different methods including an analytical model and a numerical simulation were tested to estimate the temperature and morphology of the meltpool. The analytical model was developed based on process parameters (beam power and speed) and thermophysical properties of the material. The analytical heat transfer model was developed for copper and the results were compared with numerical outcomes. Experimental tests were used to verify both the analytical and numerical models. Results demonstrated that the developed analytical model containing the conduction of the material has great accuracy. Statistical analysis showed process parameters have a significant effect on morphology of meltpool and temperature. The proposed model and simulation can be useful to predict the meltpool morphology which drives the bonding quality of the subsequent layer and the overall quality of the printed parts.

Data Pipelines for Direct Ink Write Digital Twins: *alex caviness*[1]; [1]LLNL

We present on automated data capture and storage for machine learning-aided digital twins, with a focus on mechanical test data streams. Our pipeline connects mechanical test measurement data using a web interface, test hardware API, and a database, allowing for efficient and accurate data collection for our digital twin platform. These digital twins can then be used for process and part evaluation, which can help optimize the design and performance of parts. We present the benefits of using automated data capture and storage, including improved data quality, reduced time and resources required for data collection, and improved accuracy and consistency of data. Though rooted in Direct Ink Write, this work is extendable to other additive manufacturing techniques in which data science can establish a link between the fabrication process and part performance.

Design of Lightweight 3D Printed Structures for the 7th Annual 3D Printed Aircraft Competition: *Robert Taylor*[1]; Orie Nzere[1]; Son Pham[1]; Andy Huynh[1]; Thomas Allsup[1]; Emma Yang[1]; [1]University of Texas Arlington

The University of Texas at Arlington (UTA) hosts the 7th Annual 3D Printed Aircraft Competition on July 8, 2023, to provide undergraduate and graduate student teams from a range of universities a competitive event to learn and apply principles of aircraft design, lightweight structural design, and effective design for additive manufacture. The competition requirement for a fully 3D printed airframe and a limitation on power duration during the flight motivates students to develop lightweight designs that effectively integrate knowledge of structural mechanics with 3D printing process mechanics. This poster discusses fixed and rotary wing aircraft designs from student teams at the University of Texas at Arlington using Fused Filament Fabrication (FFF), Continuous Fiber Fabrication (CFF), and MultiJet Fusion (MJF) 3D printing technologies. Design and process considerations are discussed as well as lessons learned. The poster also presents competition results.

Development of Joint Manufacturing and In-line Metrology System for the Patterning of 3D Holographic Structures in Roll-to-roll Processes: *Barbara Groh*[1]; Cody Lee[1]; [1]University of Texas at Austin

Roll-to-roll (R2R) fabrication at the micro and nano scales promises to increase manufacturing throughput and reduce unit cost while providing avenues for unique product applications. By exploring the potential of creating 3D structures with a single pattern and being able to confirm pattern success in-situ, existing overlay error can be mitigated. This paper demonstrates steps being taken to combine a R2R 3D nanolithography tool and an AFM-based in-line metrology tool into a functional system for patterning precise 3D structures. The existing manufacturing system will be adapted to pattern complex structures with a flexible PDMS mask currently being proven on stationary substrates. Modifications to the AFM system will include a focus on imaging patterns with varying mechanical properties and tailoring the system to include gathering mechanical information as well as imaging. By mapping surface features, the AFM tool will identify surface imperfections and predict failures occurring within the 3D structure.

Dissimilar Vacuum Brazing of Additive Manufactured 17-4PH Stainless Steel to Conventional 304 and 17-4 Stainless Steel by BNi-2 Brazing Filler Material: *Tansu Göynük*[1]; Orkun Umur Önem[1]; Evren Yasa[2]; İshak Karakaya[3]; [1]ROKETSAN A.S.; [2]AMRC; [3]Middle East Technical University

With the development of technology, it has become critical to be able to produce parts with complex geometry at once without using other production technology. Additive manufacturing methods have taken their place in the competitive market saving both time and cost. Vacuum brazing of additive manufactured 17-4PH stainless, conventional AISI304 and 17-4PH stainless steel alloys were examined. In this work, parts were brazed under 10-6 Torr, at 1050°C for 20 minutes using BNi-2 filler material. Vacuum brazed parts were examined in terms of microstructure, wetting, and mechanical strength. Wetting behaviour of brazing on different materials was evaluated by measurement of contact angle and wetted area using optical microscopy on different materials. Microstructures were examined by SEM and EDS. Finally, tensile testing was done on joints to evaluate whether the surface roughness and brazing of different materials affects strength of brazed parts.

Fabrication of Solid-state Electrolytes Using 3D Printing for Lithium Metal Batteries: *John Obielodan*[1]; Jacob Ferguson[1]; Josh Beyer[1]; Zhezhen Fu[2]; [1]University of Wisconsin-Platteville; [2]Penn State Harrisburg

3D printing offers several benefits including the capabilities for flexible battery architectures. Solid-state batteries are being developed to overcome the drawbacks of lithium-ion batteries such as low energy density and fire safety concerns. In this work, colloidal pastes of ceramic type Li-garnet solid-state electrolyte (Li6.75La3Zr1.75Ta0.25O12) mixed with photocurable resin were used to 3D print test samples. The pastes demonstrated promising printing behaviors that allow the fabrication of various structures. The samples were sintered at temperatures between 900oC and 1250oC for durations ranging from 1 to 12 hours. X-ray diffraction shows that they maintain single cubic Li-garnet phase. They were densifiable to high relative densities based on SEM observations. The ionic conductivities of the samples were obtained. The results shows that 3D printing is a promising route for fabricating solid-state batteries.

Influence of In-process Layer-wise Surface Property on the Mechanical Properties of Laser Powder Bed Fusion Products: *Haolin Zhang*[1]; Heyang Zhang[1]; Alexander Caputo[2]; Chaitanya Krishna Vallabh[3]; Richard Neu[2]; Xiayun Zhao[1]; [1]University of Pittsburgh; [2]Georgia Institute of Technology; [3]Stevens Institute of Technology

Laser powder bed fusion (LPBF) additive manufacturing has the potential of efficiently producing components with high resolution and complex geometry. However, during LPBF the as-manufactured layers usually possess rough surfaces that lead to porosity formation and unsatisfactory mechanical properties, necessitating extensive post-processing prior to being deployed for practical applications. Fringe projection profilometry (FPP) is a cost-effective, non-invasive technology that has been developed for in-situ LPBF surface measurement. In this work, we first develop a FPP measurement data analytics framework to extract in-process layer surface features, which can serve as implications of potential defects that could be caused by spatters, balling, or shrinkage. Then, we conduct different regression analyses to correlate the inferred layer-wise surface defects and the FPP-measured thickness profiles with the ex-situ characterized part properties including hardness, fatigue life, and critical crack locations. The proposed FPP-based framework can help optimize or control LPBF processes for achieving improved mechanical properties.

Modifying Glass Surface Morphology via Temperature-controlled Laser Melting: *Andre Bos*[1]; Douglass Meredith[1]; Robert Landers[2]; Edward Kinzel[2]; John Bernardin[1]; [1]Los Alamos National Laboratory; [2]University of Notre Dame

Glass Laser Additive Manufacturing is an emerging technology with a wide range of applications in chemistry, biology, optical science, and engineering. A custom printer was developed utilizing a 4-axis motion system, infrared radiation-based thermal sensors, and a CO2 laser to heat glass filaments above their working temperatures and deposit them into various shapes. Complex path planning is needed to deposit the glass to maintain a constant pulling action with the rod and maintain a melt pool between the rod and substrate or previous layer for printing. Similar path planning algorithms along with a feedback control system are used to alter the surface morphology of the deposited glass. To mitigate undesirable defects from overheating the glass, a closed-loop feedback algorithm automatically modifies the laser duty cycle given IR camera measurements to maintain a constant melt area temperature.

PEEK Parameter Optimization for Fused Deposition Modeling: *Quang Ha*[1]; Deborah Hagen[1]; Evan Hagin[1]; [1]Sandia National Laboratory

Polyetheretherketone (PEEK) is an engineering grade thermoplastic with high performance and high reliability. PEEK has excellent mechanical properties and chemical compatibility. Another desirable property of PEEK includes the ability to operate in much higher temperature environments compared to other commonly used additive manufacturing polymers. However, PEEK can be very difficult manufacture through Fused Deposition Modeling (FDM) due to the properties mentioned above and requires high nozzle temperature and a heated build chamber. Some printing defects of FDM PEEK include inaccurate dimension, poor layer adhesion, varying surface topography, and excessive warping. To minimize the defects during the printing process, we optimized print parameters which include print speed, extrusion/retraction rates, and print process temperature. This resulted in improved part characteristics while benefitting from FDM style additive manufacturing to create complex structures.

Wide-field Low-coherence Interferometry for Keyhole Depth Measurements in Laser Powder Bed Fusion: *Matthias Beuting*[1]; Kayvan Samimi[1]; Sayed Hojjatzadeh[1]; Erick Oberstar[1]; Melissa Skala[1]; Lianyi Chen[1]; Scott Sanders[1]; [1]University of Wisconsin-Madison

We present a method for measuring keyhole depth and high-frequency melt pool fluctuations in laser powder bed fusion using optical interferometry. Previous studies utilized a technique called inline coherent imaging (ICI) based on the same principle involving scanning a focused interrogation beam across the area of interest to measure melt pool topography. In contrast, our proposed approach uses an enlarged beam fixed in position relative to the process laser to cover the entire keyhole area. We demonstrate that depth information can be reconstructed from this signal, enabling the identification of the lowest point within the keyhole. Eliminating the need for precise mechanical beam steering can improve time resolution while reducing the complexity and cost of on-machine sensors.

Photoinhibition Aided Vat Photopolymerization (PinVPP) Additive Manufacturing: *Yue Zhang*[1]; Yousra Bensouda[1]; Xiayun Zhao[1]; [1]University of Pittsburgh

Vat photopolymerization (VPP) among other additive manufacturing processes have a great potential to rapidly print complex 3D components out of a matrix of photo-curable resin. Photoinhibition has been demonstrated by leading research groups to be able to form a thicker deadzone that enables faster print and vertical micro-topography. However, the potential application of photoinhibition to improve VPP can be extended for lateral over-curing control. In general, photoinhibition aided VPP (PinVPP) employs two simultaneously projected optical masks for initiating and inhibiting the polymerization, respectively, at disparate wavelengths. In this work, we present two study cases of PinVPP – one general VPP print for polymeric parts and one VPP of ceramic slurry. Our initial experiment aims to understand the correlation of the two-wavelength exposure intensities with the inhibition zone thickness, the working curve thus the critical energy and depth of penetration, and the effects on print speed and geometric properties in PinVPP.

Comparative Success of EBM and SLM for Fabrication of Lattice Structures in Metal Orthopaedic Implants: Zeynep Kirimlier[1]; Ece Tutsak[1]; *Onur Demirak*[2]; Alptuğ Öztaşkın[3]; İpek Döş[3]; [1]Trabtech Advanced Implant Technologies; [2]Ankara University; [3]Middle East Technical University

Lattices are applied to the surface of implants to create the trabecular intersection that mimicks cancellous bone. The producibility of lattice structures with EBM and SLM are still being investigated since these PBF-AM methods have differences in principle and operation. The objective of this study is to conduct comprehensive analysis of different types of lattices manufactured by EBM and SLM in terms of producibility, quality, mechanical and biological characteristics.Eight different lattice unit cells available in the nTopology were selected to design lattices considering porosity, strut thickness, and cell size. A Python wrapper script was implemented, a finite element analysis has been conducted. Similar lattices to the cancellous bone were selected. To obtain optimum process parameters, bulk samples were produced for both SLM and EBM. Density test and microstructural analysis were performed. With the optimum process parameters, lattice samples were produced. SEM examination, compression, cytotoxicity and osseointegration tests were conducted.

Investigation of Electrical Properties in TPU/CNT Conductive Composites: *Hansol Kim*[1]; Jongho Jeon[1]; Sangmin Lee[1]; Jungho Cho[1]; Sang-Woo Han[1]; [1]Chungbuk National University

Conductive composites used in flexible circuits have a wide range of applications, such as wearable sensors, proximity sensors, and pressure sensors. Polymers and carbon nanotubes (CNTs) are representative materials in conductive composites. Polymers provide flexibility, while CNTs impart electrical properties, making them suitable for this purpose. In this study, conductive composites were produced by blending thermoplastic polyurethane (TPU) with CNTs and investigating their electrical properties using fused filament fabrication (FFF). The melting mixing method was used for composite fabrication. As the wt% of CNTs increased, the electrical resistance decreased, and the resistance showed a decreasing trend with increasing applied voltage. In cases where the wt% of CNTs was low, the resistance decrease with increasing voltage was relatively high, which can be explained by the tunneling conduction mechanism in the conductive composite.

Mechanical and Corrosion Response of Minor and Trace Elements in CoCrMo Alloy Powders on Additively Manufactured Dental Crowns and Bridges: Ipek Dös[1]; *Ece Tutsak*[1]; Zeynep Kırımlıer[1]; [1]TraBtech

SLM is an additive manufacturing method for producing dental crown and bridges (DCB) using CoCrMo alloy powders. The powder composition plays a crucial role in the mechanical and chemical bonding of metal and ceramic materials. This study investigates the effect of minor and trace percentage in the composition on CoCrMo powder alloys. Three CoCrMo alloy powders that have different minor and trace component weight percentages have been analyzed. Density and microstructural analysis were carried out to determine the optimal SLM process parameters and heat treatment for bulk specimens. Tensile, corrosion and de-bonding crack initiation tests were performed on the samples. Results show that slight differences in chemical composition can impact the mechanical and corrosion responses, highlighting the importance of carefully selecting the powder composition for successful SLM manufacturing of dental parts.

3D Bio Printed Biodegradable Composite Material for Pediatric Craniomaxillofacial Implants: *Ipek Dös*[1]; Ece Tutsak[1]; Zeynep Kırımlıer[1]; Onur Demirak[1]; [1]TraBtech

Developing an ideal bone substitute material for repairing bone deformities is a challenge in clinical orthopedics. Conventional methods are inadequate for creating complex anatomical geometries. Additive manufacturing is a growing field in bone tissue engineering due to its reproducibility, high accuracy, and rapid production of patient-specific scaffolds. (PLGA)- based artificial bone substitutes show promise in biocompatibility, mechanical properties, degradability, and ability to promote bone regeneration. This study is dedicated to pediatric craniomaxillofacial implant treatments using PLGA and hydroxyapatite nanoparticles (nHA) to fabricate 3D porous scaffolds by Fused Deposition Modelling. Gyroid lattice geometries were chosen for osteointegration and self-supporting features. Optimum nHA weight percentages and production parameters were determined, and mechanical and biological tests were completed. The producibility of innovative patient-specific geometry design with this biodegradable composite material is discussed. This study provides a solution for CMF implant treatments that do not hinder the physical growth of developing children.

Development of Soft Gripper Pneumatic Control System Based on Deep Reinforcement Learning: *Seongyeon Kim*[1]; Kiseong Kim[1]; Jongho Shin[1]; [1]Chungbuk National University

As interest in soft grippers soared, many studies have been performed to control the soft gripper. For the soft gripper control, a soft gripper model is required first. Usually the soft gripper modeling has been done through finite element analysis, which takes lots of time and is effective only in limited situations. Therefore, research on deep learning-based modeling with a small amount of FEM results has been extensively conducted, and some satisfactory results have been reported. However, since the model is expressed in the form of a neural network, it is difficult to utilize general control methods, so research on optimal control or deep reinforcement learning is being attempted. In this study, we propose a pneumatic control system for the soft gripper control based on the DRL. To this end, the soft gripper and DRL-based controller are directly developed, and experiments are performed and the results are analyzed.

Distortion and Residual Stress Mitigation of Large Parts for Wire-arc Additive Manufacturing: *Wen Dong*[1]; Xavier Jimenez[1]; Carter Gassler[1]; Albert To[1]; [1]University of Pittsburgh

Wire arc additive manufacturing (WAAM) has drawn increasing attention due to its ability to print large metal parts. However, thermal gradients during the process can result in significant residual stress and distortion, negatively affecting product quality and making post-processing more difficult. In the present work, we have implemented several strategies when printing a part ~900 mm long to mitigate these issues. Firstly, a fixture designed based on topology optimization is attached to the baseplate to reduce distortion. However, cracks were observed in the baseplate near the deposit ends after the first trial. Then, we carefully examined and modified the deposit and baseplate shapes to further reduce the residual stress. The second trial successfully printed a part that met the required specifications. Due to its high accuracy and low cost, the modified inherent strain (MIS) method is employed to predict the distortion and residual stress for fixture design and shape modification.

Efficient Thermomechanical Simulation for WAAM using Automated GPU-based Modeling: *Xavier Jimenez*[1]; Albert To[1]; [1]University of Pittsburgh

Simulating the wire arc additive manufacturing (WAAM) process can be challenging due to the large part size. An improved workflow that combines automation and GPU accelerated modeling using the Pittsburgh Additive Manufacturing Simulator (PAMSIM) has been implemented. Although thermal simulations are very fast, thermomechanical simulations can take 10 to 20 times more time and thus become impractical to implement before every print. This work focuses on implementation of an automated computational framework for the flash heating network combined with the temperature dependent inherent strain. The improved workflow helps to accelerate the manufacturing process of new parts using WAAM, through thermal and residual stress results at the part scale level.

A Data-driven Distortion Compensation Method and the Necessity to Consider Spatial Effects 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 process-induced sintering distortion may result in parts with unacceptable geometric accuracy with the extent heavily dependent on the initial green density of the part. The current work investigates the effect of part size and location within the print build on the green density and proposes an approach to compensate input geometry based on mechanistic simulations using a data-driven method. Finally, the proposed approach's efficacy is validated both numerically and experimentally by comparing the deformed sintered shape against the target.

Electrochemical Stability of 3D Printed Separators and Gaskets for Shape-conformable Lithium-ion Batteries: *Christian Fernandez*[1]; Eva Schiaffino Bustamante[1]; Ana Aranzola[1]; Ana Martinez[1]; Alexis Maurel[1]; Eric MacDonald[1]; [1]University of Texas at El Paso

As the demand for rechargeable batteries increases, the concept of utilizing 3D printing technologies to produce tailored battery components with complex geometries that can be customized for a specific application has gained relevance. This work focuses on 3D printing via vat polymerization of separator and gasket components using commercially available and laboratory-made photocurable resins as material feedstock. In-depth electrochemical, rheological, and mechanical characterization steps are performed. In particular, the 3D printed samples are tested by means of linear sweep voltammetry, a common stability analysis, to ensure their electrochemical inertness during the charge and discharge of a classical lithium-ion battery. This work paves the way towards the development of shape-conformable battery individual components and fully 3D printed energy storage devices.

Elucidating the Role of Local Preheat Temperature on Multi-track Melt Pool Morphology Variation for Inconel 718 Laser Powder Bed Fusion via CIFEM: *Seth Strayer*[1]; William Frieden Templeton[2]; Alaaeldin Olleak[1]; Florian Dugast[1]; Sneha Narra[2]; Albert To[1]; [1]University of Pittsburgh; [2]Carnegie Mellon University

Despite advancements in finite element (FE) thermal simulation techniques for laser powder bed fusion (L-PBF), these models employ an effective heat source model, which invokes a tedious calibration process and provides inaccurate thermal fields compared to high-fidelity computational fluid dynamics (CFD) simulations. Accordingly, the driving force behind melt pool size variation, especially in the multi-track case, has remained enigmatic up to this point. In this work, the authors extend CIFEM to multi-track scenarios for Inconel 718 L-PBF to help address these issues. CIFEM's data-driven heat source model is trained to predict the thermal fields from multi-track CFD simulations with different scan lengths to establish the role of a local preheat temperature metric. By imposing these fields on the desired FE solution domain, the simulated melt pool sizes are within 10% error regarding experimental measurements up to five consecutive tracks while providing substantially more accurate thermal fields to traditional FE models.

Enabling Part-scale Melt Pool Prediction in Laser Powder Bed Fusion via a Global-local Thermal Process Simulation Model: *Shawn Hinnebusch*[1]; William Templeton[2]; Alaa Olleak[1]; Praveen Vulimiri[1]; Florian Dugast[1]; Sneha Narra[2]; Albert To[1]; [1]University of Pittsburgh; [2]Carnegie Mellon University

Predicting accurate thermal history in laser powder bed fusion (LPBF) is a challenging problem. Layerwise simulations are geometry dependent for calibration and cannot capture the local heat accumulation due to the laser scanning process. Scanwise simulations are far more accurate but are restricted in size to just a few millimeters. An infrared (IR) camera is mounted on an LPBF system to calibrate and validate the interpass temperatures. Using a GPU-accelerated finite element based solver, the geometry-agnostic layerwise calibration was completed with less than 6% mean absolute percentage error. The layerwise simulation provides an accurate thermal boundary condition for the local scanwise simulations at a reduced computational cost. Melt pool width and depth can be predicted in any location before printing. Integrating high-speed layerwise simulations with scanwise simulations results in a low-cost yet accurate thermal history that identifies problematic regions before costly builds.

Fabrication of 3-Dimensional Flexible Tactile Sensor using Pressure Sensitive Material: *Chae Young Park*[1]; Ho-Chan Kim[2]; Chiyen Kim[3]; In Hwan Lee[1]; [1]Chungbuk National University; [2]Andong National University; [3]Cheongju Campus of Korea Polytechnics

In this study, sensors of various shapes were fabricated through the additive manufacturing process using pressure sensitive material. Furthermore, various response characteristics were observed with several 3-dimensional shapes. The flexible tactile sensors were fabricated by stacking Multi walled carbon nanotube-based pressure sensitive materials in layer-by-layer manner. The response characteristics according to shape and the number of layers were studied for given mechanical stimuli. In the case of curved sensors, the initial resistance and resistance change decreased as the number of layers increased. However, there was no significant difference in response time and recovery time depending on the number of layers.

A Local Preheat Temperature Dependent Stochastic Finite Element Heat Source Model for Inconel 718 Laser Powder Bed Fusion: *Seth Strayer*[1]; Albert To[1]; [1]University of Pittsburgh

Thermal field prediction of laser powder bed fusion (L-PBF) via the finite element method can help optimize the process while avoiding the cost of experiments. However, these models abstract critical physics into an effective heat source model that does not readily capture the experimentally-measured melt pool size magnitude and variance, especially for multi-track cases. This work presents a novel local preheat temperature dependent stochastic heat source model to help address these issues. First, the heat source parameters are calibrated to the mean melt pool sizes for Inconel 718 L-PBF multi-track experiments. These parameters are predicted during the simulation to establish the role of a local preheat temperature metric. Second, random sampling techniques are employed to match the experimentally-measured variance within each track. Accordingly, the simulated melt pool sizes are within 10% error regarding experimental measurements up to five consecutive tracks while more closely matching the measured melt pool size variance.

Accelerating Design and Additive Manufacturing of Polymer Matrix Composites: *Olivia Fulkerson*[1]; Akash Deep[1]; Srikanthan Ramesh[1]; [1]Oklahoma State University

Polymer matrix composites (PMCs) offer exceptional mechanical performance and low weight, making them ideal for various applications. 3D printing enables the efficient production of functional composite parts with customized mechanical properties. However, the current optimization process for 3D printing PMCs involves trial-and-error, which is time-consuming and costly. To address this, a Bayesian optimization (BO) framework is proposed in this project to accelerate the design and production of high-strength, low-weight 3D printed PMCs. The BO framework models the 3D printing process as a black-box function using minimal experimental data. A probabilistic model is developed to recommend the next set of experiments iteratively until the optimized process parameters are reached. Our results demonstrate that the proposed method can efficiently find the global optima for black-box functions, such as 3D printing. This research has potential to benefit the additive manufacturing industry by providing a scalable approach that can accelerate the process workflow.

Mechanical Test Plan of Niobium Alloy C103 for Laser Powder - Direct Energy Deposition: *Hugo Garcia*[1]; Brandon Colón[1]; Kurtis Watanabe[1]; Francisco Medina[2]; [1]University of Texas at El Paso; [2]W.M. Keck Center for 3D Innovation

Niobium Alloy C103 is a material with a shorter background in Laser Powder - Directed Energy Deposition when compared to other materials. However, C103 stands out in having relatively strong mechanical properties at high temperatures. Thus, making it a great candidate for applications such as propulsion, hypersonics, nuclear and more. This poster will present a test plan for quasi-static testing of thin wall specimens to better understand the mechanical response of C103. Thin wall geometries were printed using RPM Innovations' 222XR LP-DED with a single pass beam. There are several tensile specimens proposed with their corresponding finite element analysis which are discussed in detail in the poster. A total of 4 specimen conditions are proposed: as built, stress relieved (SR), and 2 different hot isostatic press (HIP) heat treatment to then be later subjected to a tensile test.

Additively Manufactured LiCoO2-based Photocurable Resin as Positive Electrode for Lithium-ion Batteries: *Ana Aranzola*[1]; Eva Schiaffino[1]; Alexis Maurel[1]; Ana Martinez Maciel[1]; Eric MacDonald[1]; [1]University of Texas at El Paso

Rapidly advancing technology demands equally advanced subcomponents. Multi-material additive manufacturing (AM) has the potential to transform the production of lithium-ion batteries by enhancing the battery structural design to enable three-dimensional ion diffusion, as opposed to the one-dimensional diffusion observed in commercial lithium-ion batteries. In turn, 3D diffusion allows to maximize the battery power performances. This work focuses on the development and 3D printing of a novel photosensitive material loaded with lithium cobalt oxide (LiCoO2) electroactive active material to act as the positive electrode. Using the Vat Photopolymerization (VPP) printing technique, the material was successfully printed at varying battery material loadings. After thermal post-processing that did not compromise mechanical integrity, promising electrochemical specific capacity values were obtained, approaching commercial values of lithium-ion batteries. These results pave the way towards newly designed 3D printed batteries promising better performance and non-obtrusive, conforming shapes to specific designs for different applications.

Monitoring of Process Stability in Laser Wire Directed Energy Deposition using Machine Vision: Anis Asad[1]; *Benjamin Bevans*[1]; Jakob Hamilton[2]; Iris Rivero[2]; Prahalada Rao[1]; [1]Virginia Tech; [2]Rochester Institute of Technology

The goal of this work is to mitigate flaw formation in parts made using the laser wire directed energy deposition (LW-DED) additive manufacturing process. As a step towards this goal, the objective of this work is to use real-time data from a meltpool imaging sensor to detect process instabilities. This is an important area of research, as LW-DED process tends to incessantly drift due to poorly understood thermophysical phenomena and stochastic effects. To realize the foregoing objective, we developed a machine learning model that acquires real-time imaging data, and automatically classifies the process state into one of four possible regimes: stable, dripping, stubbing, and incomplete melting. Through single track experiments conducted over 128 conditions, we show that the approach is capable of accurately classifying the process state with a statistical fidelity approaching 90% (F-score).

Monitoring of Single-track Quality in Laser Powder Bed Fusion using In-situ Thermionic Sensing: *Benjamin Bevans*[1]; Philip DePond[2]; Aiden Martin[2]; Nick Calta[2]; J-B Forien[2]; Gabe Guss[2]; Brian Giera[2]; Prahalada Rao[1]; [1]Virginia Tech; [2]Lawrence Livermore National Laboratory

This work concerns the laser powder bed fusion (LPBF) additive manufacturing process. In this work track quality was monitored in-situ using a novel thermionic sensing approach. It is important to monitor the quality of the track in LPBF as it is the basic building block of the part. In this work, track quality is defined as track width and the percent continuity of the track. The objective of this work is to detect the onset of track deviations using signatures extracted from a novel thermionic sensor. This thermionic sensor is attached to the substrate and measures the voltage response of the electrons released when the laser interacts with the build plate. The signals from the thermionic sensor are analyzed using empirical mode decomposition, and the derived signatures are used subsequently within elementary machine learning models to predict the quality of track.

Building Blocks for Understanding Triply Periodic Surfaces: A Visual and Tactile Learning Aid: *Joseph Fisher*[1]; Simon Miller[1]; Joseph Bartolai[1]; Michael Yukish[1]; Timothy Simpson[1]; [1]Pennsylvania State University

We present an additively manufactured visual and tactile teaching aid to show how Triply Periodic Minimal Surfaces (TPMS) divide space and how we can generate multiple unique lattice structures from one surface. TPMS can be used as the basis for the design of lattice structures for additive manufacturing, and they divide space into two interwoven volumes that remain separate throughout three-dimensional space. The surface itself can be offset and used as a lattice structure and the interwoven volumes are also of interest because they can act as the fluid domains in a heat exchanger or can be modeled on their own to be used as unique lattice topologies. To produce this aid, we have subdivided lattice structures based on the IWP TPMS into regions that can be assembled separately or together without geometric interference. We use keyed patterns of magnets to make assembly of the lattices faster and easier.

Structural Analysis and Design of Mantis Shrimp-inspired Composites for Enhanced Impact Resistance: *Ailin Chen*[1]; Ran Tao[2]; Alexander Landauer[2]; Sangryun Lee[3]; Jiyoung Jung[1]; Daniel Lim[1]; Ukamaka Ezimora[4]; Grace Gu[1]; [1]University of California Berkeley; [2]National Institute of Standards and Technology; [3]Ewha Womans University; [4]University of California Merced

The mantis shrimp's club possesses both destructive power and exceptional energy-absorbing properties. It has attracted the interest of researchers seeking to develop protective systems with leap-ahead properties. The club's unique microstructure includes a tough, fibrous interlayer that exhibits a sinusoidal periodicity. Prior research has primarily focused on mimicking either the material composition or fiber orientation of the mantis shrimp, typically under static loading conditions. Here we merge the club's sinusoidal interlayer design into a composite microstructure and fabricate it using a dual-material 3D printer. A computational model is developed to reveal the structure's failure mechanism under low-velocity impact loading. Experimental drop-tower testing is used to validate model predictions. Using this model, we further investigate the structure's response to high-velocity impact and optimize its components for enhanced energy absorption. This work improves our understanding of the shrimp's crack propagation mechanisms under dynamic loading, enabling the development of better amphibious protective systems.

Characterization of Thermoset Feedstocks for Laser Powder Bed Fusion: *Malik Blackman*[1]; Meisha Shofner[1]; Camden Chatham[2]; [1]Georgia Institute of Technology; [2]Savannah River National Laboratory

As additive manufacturing (AM) technology has developed and progressed, a constant topic of research in the area has been to expand the library of materials that may be used with these techniques. Among AM methods that use polymers, laser powder bed fusion (L-PBF) has preferentially used thermoplastic polymers as its starting materials, but the deposition and material joining method employed in L-PBF may be compatible with powdered thermoset polymer precursors as feedstocks. Therefore, the objective of this work is to examine how thermosetting polymers may be used more widely with L-PBF. Specifically, materials characterization experiments are designed to assess how aspects of L-PBF processing will affect curing behavior, part formation, and material properties. The outcomes of this work will establish a methodology for evaluating candidate thermosetting polymer feedstocks for use with L-PBF and an understanding of the sensitivity of material behavior and properties to different L-PBF process parameters.

Data-driven Local Porosity Prediction in Laser Powder Bed Fusion via In-situ Monitoring: *Berkay Bostan*[1]; Shawn Hinnebusch[1]; David Anderson[1]; Albert To[1]; [1]University of Pittsburgh

In this study, the geometry-agnostic deep learning scheme has been developed for defect detection during the laser powder bed fusion (LPBF) process. DNNs model has been trained that gives +90% accuracy with a relatively smaller dataset. Inputs to DNNs include various thermal signatures (interpass temperatures, heat intensities, and cooling rates) and spatter locations. At the same time, when making predictions, the DNNs architecture considers the features of not only the relevant pixel, but also neighboring pixels in all directions (desired order of neighbors in the current, upper, and lower layers). The potential outcomes of this study are simultaneous defect prediction during manufacturing and repairing the defects by rescanning the concerned region. Furthermore, defect formation mechanisms have been investigated by SHAP (SHapley Additive exPlanations) feature importance analysis method, and it is observed that spattering is the most dominant factor for defect formation until the melt pool reaches a certain size.

Metal Additive Manufacturing of A36 Steel to Improve Techno-economic Performance of Marine Renewable Energy Technology: *Hyein Choi*[1]; Jesse Adamczyk[1]; Kasandra Herrera[1]; Erin Karasz[1]; Michael Melia[1]; Shaun Whetten[1]; Michael Heiden[1]; [1]Sandia National Laboratories

Marine renewable energy has the potential to bolster clean energy production on a global scale. However, these technologies need to be more economical to counter traditional energy generation. Wave energy converters (WEC) are one facet within this realm that have high costs associated with fabricating heavy, structural A36 steel parts. Additive manufacturing (AM) methods such as wire arc additive manufacturing (WAAM) have the potential to produce more cost-effective marine energy components by producing higher complexity, lightweight parts and reducing lead time. In this study, WAAM and wrought A36 steel tensile coupons were produced, and mechanical properties were compared under dry and wet conditions. WAAM-produced A36 steel retained significantly higher mechanical properties in both dry and long-term corrosion conditions. The solidification microstructure was investigated to better understand how WAAM's manufacturing route improved performance for renewable energy applications.SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

Computer Vision for Powder Mass Flow Rate Measurement in Blown Powder Directed Energy Deposition: Callan Herberger[1]; Alan Burl[2]; *Erik LaNeave*[1]; Janely Villela[1]; Juan Villela[1]; Lauren Heinrich[3]; James Haley[3]; Thomas Feldhausen[3]; Chris Saldana[2]; Eric MacDonald[1]; [1]University of Texas at El Paso; [2]Georgia Tech; [3]Oak Ridge National Laboratory

Laser Powder Directed Energy Deposition can deliver metallic powder to a structure coincident with the focused beam of a laser to deposit metal with 3D control. Monitoring the mass flow rates of these powders is crucial to ensure quality and yield. Moreover, although less explored, the ability to combine two or more powders in the delivery system can enable in situ alloying with compositional changes throughout a structure. The present work explores an unobtrusive method to measure mass flow rate of a single type of metal powder through a delivery system to the deposition head. With high-speed imaging through a transparent tube inserted in the delivery system prior to reaching the deposition head, computer vision can verify the mass flow rates to avoid over or under building of the intended geometry. Furthermore, the potential exists to distinguish different metal powders to ensure correct metallurgical composition just prior to deposition.

Layer-wise Prediction of Microstructure Evolution in Laser Powder Bed Fusion Additive Manufacturing using Physics-based Machine Learning: *Alexander Riensche*[1]; Benjamin Bevans[1]; Grant King[2]; Ajay Krishnan[3]; Kevin Cole[2]; Prahalada Rao[3]; [1]Virginia Tech; [2]University of Nebraska-Lincoln; [3]Edison Welding Institute

In this work we developed a framework to predict microstructure formation in the laser powder bed fusion (LPBF) of Inconel 718 parts. The microstructure is predicted as a function of sub-surface cooling rate estimated from a rapid part-level computational thermal model within elementary machine learning models. In this work, the microstructure evolved is quantified layer-by-layer in terms of three aspects: meltpool depth, grain size (primary dendritic arm spacing), and microhardness. The approach predicts the microstructure evolved with statistical fidelity exceeding 85% (R2). This is substantial improvement over existing microstructure prediction which are only able to predict the microstructure of a small region (~1 mm3) and not of the entire part.

Enhancement of Profile Data for Repetitive Process Control Measurements in DED Additive Manufacturing: *Kyle Saake*[1]; Elias Snider[1]; Douglas Bristow[1]; [1]Missouri University of Science and Technology

Layer-to-layer repetitive process control (RPC) is a powerful tool in minimizing defects for direct energy deposition (DED) additive manufacturing, specifically for blown powder systems. Layer-to-layer feedback control structures require a profile scanner (a Keyence profilometer in this work) to be integrated between layers for error measurements. Obtaining quality scans while minimizing scanning downtime is important for reducing cost in such control structures. An approach for collecting quality scanner data by combining multiple scans is presented. Fitting optimizations are discussed which align scans to produce high-fidelity profiles of printed parts. Example datasets are presented with relevant analysis of data confidence and validation metrics. Integration of the scanning algorithm into the existing RPC structure is discussed with implications on the build process.

Increasing Precision Towards NiTi Lattice Structure using PBF-EB: *Zeyu Lin*[1]; Sasan Dadbakhsh[1]; Amir Rashid[1]; [1]KTH

The electron beam powder bed fusion (PBF-EB) is limitedly used to manufacture complex structures such as delicate lattices. Nickel-titanium (NiTi) has been chosen for fabricating the lattice structure due to its wide utilization in the biomedical sector. However, issues may arise when manufacturing angled trusses while the dimensional inaccuracy increases with the increase of the angle between the truss member and the vertical build direction. Therefore, two different scan strategies: spot melting and linear melting were used to manufacture the lattice structures respectively to compare the dimensional accuracy of different structures. This investigation highlights that linear melting is prone to maintain the geometrical accuracy of line-based structures with a limited influence from the scan speed while spot melting is more capable of manufacturing the point-based structure with a higher geometrical resolution.

Data Management for Additive Manufacturing Process Monitoring: *Matthew Roach*[1]; Dominik Kozjek[2]; Clayton Cooper[3]; Kathy Babusci[4]; Bradley Jared[1]; [1]University of Tennessee, Knoxville; [2]Northwestern University; [3]Case Western Reserve University; [4]Ohio State University

Managing process monitoring data generated from additive manufacturing presents multiple challenges. These challenges come from every step in the workflow including acquisition, transfer, storage, archive, standardization, analysis, and visualization. Acquisition systems need to be robust to collect different data formats while maintaining a synchronized timeline. Data transfer needs to be reliable, secure, and fast. Data storage and archive needs to be secure and maintain redundant. Once the data is collected, it must be processed and visualized quickly and in a method that is easily available for a wide audience of users. Many of these aspects should work autonomously and if done well can expedite research discoveries and promote conversations on analysis and visualization results. This project aims to begin a collaborative effort among researchers to solve these AM specific challenges and design information organization structures and methods that are easy to use and standardized across laboratories.

Development of Flexible Circuits using Epoxy-based Flexible Electrical Conductors: *Jongho Jeon*[1]; Kim Hansol[1]; Lee Sangmin[1]; Han Sang-Woo[1]; Lee In Hwan[1]; Cho Jungho[1]; [1]Chungbuk National University

In this study, we fabricated flexible circuits using a Direct Writing system based on a silver epoxy-based conductive material developed in previous studies, and evaluated their electrical properties for potential applications. As a result, we confirmed that the flexible circuits fabricated using the Direct Writing system are suitable for wearable applications, as they are able to maintain their structural integrity and electrical conductivity even while flexing and bending. Our findings suggest that Direct Writing technology has the potential to be used as a method for producing wearable electronics due to its ability to create precise and intricate circuits with minimal material waste. Furthermore, these results may have significant implications for the future development and advancement of flexible electronics, particularly in the field of biomedical applications.

Fabrication of Superhydrophobic Surfaces using Waste PET: Tae Gyun Kim[1]; *Na Kyoung Kim*[1]; Geon Hwee Kim[1]; [1]Chungbuk National University

Superhydrophobicity means that a water contact angle is greater than 150°, and many materials and manufacturing techniques have been conducted for superhydrophobic surfaces. Methods for making superhydrophobic surfaces include lithography, electroplating, chemical etching, spray coating, but they have environmental issues and process complexity. Electrospinning is a process of making superhydrophobic surfaces, which is fast and simple method, and a large amount of nanostructures can be made with a small amount of polymer solution. In this study, nanostructures were created through electrospinning and electrospraying of PET(Polyethylene Terephthalate), and superhydrophobic surfaces were successfully manufactured. It is meaningful that waste PET was used as an electrospinning solution and no additional process was required for superhydrophobic implementation. The fabricated PET membrane's water contact angle was confirmed about 151°, and this technology can be used for hydrophobic films, electronics such as solar panels, and building windows.

Robot-aided selective embedding of a spatially steered fiber in polymer composite parts made using vat photopolymerization: Vivek Khatua[1]; *G. K. Ananthasuresh*[1]; B. Gurumoorthy[1]; [1]Indian Institute of Science

Fiber-Reinforced Polymer Composite (FRPC) parts are predominantly laminates, shells, or surfaces wound with 2+D fiber patterns even after the emergence of additive manufacturing. Making FRPC parts with embedded continuous fibers in 3D is not reported previously even though topology optimization demonstrates that such designs are optimal. Earlier attempts in *3D* fiber reinforcement include making parts with channels into which fibers are inserted or co-extruding fiber with resin. In this work, we developed a 3D printer and a process for concurrent embedding of spatially steered continuous fibers inside the matrix by extending vat photopolymerization. We embed a single continuous fiber spatially by using a robot to gradually steer the fiber as the part is built layer upon layer. We also show that multiple continuous fibers can be steered in a part. We tested a few parts for strength and stiffness to illustrate the importance of spatially embedding fibers in specific patterns.

Spreading and Packing of Ceramic Powder Using a Displacement-controlled Roller in SLFS: *Kaya Bayazitoglu*[1]; Matthew Cassoli[1]; Joseph Beaman[1]; Desiderio Kovar[1]; [1]University of Texas at Austin

Selective Laser Flash Sintering (SLFS) combines aspects of Selective Laser Sintering (SLS) and Flash Sintering to neck ceramic particles together. A traditional ceramic sintering process is then used to densify the necked particles. The density of the ceramic powder bed impacts attainable density of the final part. To achieve the required density in the powder bed a packing method using a displacement-controlled roller is tested and compared to a traditional method of pressing ceramic powder into a pellet using a die and hydraulic press. Packed regions were sintered to final densities to evaluate the efficacy of a roller-based packing process.

3D Printing of Gel Polymer Electrolytes via Vat Photopolymerization for Lithium-ion Batteries: *Eva Schiaffino Bustamante*[1]; Christian Fernandez Soria[1]; Ana Aranzola[1]; Alexis Maurel[1]; Ana Martinez Maciel[1]; Eric MacDonald[1]; [1]University of Texas at El Paso

As classical lithium-ion batteries are based on a planar architecture consisting of the 2D stacking of components (current collectors, electrodes, separator/electrolyte), 3D printing technologies have the potential to revolutionize the production of shape-conformable batteries, with increased specific surface area, ion diffusion, and improved power performances. This study presents the preparation of several UV photocurable resins with different liquid electrolyte-to-polymer matrix ratios, designed to act as gel polymer electrolytes (GPE) once printed by the vat photopolymerization (VPP) 3D printing process. Printing parameters are optimized to ensure print quality and accuracy. The 3D-printed GPE is examined through electrochemical impedance spectroscopy to maximize the ionic conductivity while ensuring satisfactory printability. Finally, electrochemical testing of the 3D-printed GPEs is performed to demonstrate their functionality in a classical lithium-ion battery. This work seeks to achieve the 3D printing via VPP of a complete lithium-ion battery, a world first.

A Data Driven-based Geometric Compensation Method for Laser Powder Bed Fusion: *Wen Dong*[1]; Basil Paudel[1]; Albert To[1]; [1]University of Pittsburgh

The residual stress and deformation induced during the laser powder bed fusion (L-PBF) process can degrade the performance and quality of the products and increase the difficulty of post-processing like machining and cutting. The present work develops a data driven-based geometric compensation method to reduce the part distortion in L-PBF processes. The method includes four steps: (1) collect distortion data based on both numerical simulations and experimental measurement; (2) implement principal component analysis to reduce the data size and extract features that account for 99.99% of the total energy; (3) train the Gaussian process model for each feature to establish relationships between the initial and as-built shape of a part; (4) apply the trained model to generate the compensated geometry so that the as-built shape is the desired one. The experimental validation shows that the proposed approach is able to effectively improve the geometric accuracy of the as-built part.

FE Predictions of Residual Stresses in L-PBF Generated Ti-6Al-4V NIST Bridges: *Caitlin Luke*[1]; Courtney Morgan-Barnes[1]; Brad Sampson[1]; Haley Doude[1]; Matthew Priddy[1]; [1]Mississippi State University

The ability to characterize and predict residual stresses in parts produced via additive manufacturing (AM) methods is vital in both the understanding and performance of as-built structures. Currently, there is a need for improving the modeling and prediction of residual stresses in as-built samples for the purposes of toolpath optimization. This work studied the residual stresses in laser powder bed fusion (L-PBF) structures with a sequentially coupled thermo-mechanical finite element (FE) modeling framework for the prediction of residual stresses in as-built Ti-6Al-4V NIST bridges. Nine variations of layer thickness, scan strategy, and scan speed were examined for parameter variation effects on residual stress formation. Thermal history data collected from the experimental builds was used to perform thermal calibration/validation of the FE models. This investigation of NIST bridge residual stress formation will provide greater insight to the process-property relationship for Ti-6Al-4V L-PBF structures.

Towards Large-scale Grain Growth Modeling in Powder Bed Fusion: *Michael Paleos*[1]; Albert To[1]; [1]University of Pittsburgh

Grain growth models in the context of additive manufacturing are dealing with both the inherent complexity of the process and the computational expense of thermal process simulations. Cellular automata models have been successful in approximating the true physics of melt pool solidification, but they are typically confined to relatively small spatial domains. Building on recent advances in powder bed fusion process and microstructure modeling, we propose an integration framework based on several computational schemes that can lead to accurate simulations on unprecedented scales. For that purpose, we leverage and properly combine both the recently developed matrix-free FEM-based PAMSIM process simulator and the open-source ExaCA software. Our work centers around efficiently capturing information about several thermal signatures that would then guide grain growth in a decoupled manner. This framework would enable the computational study of microstructure (and property) heterogeneity and of the effect of unconventional scanning strategies.

Experimental Evaluation of Hierarchical Functionally Graded Lattices Using Digital Image Correlation and Micro-CT: *Junyang Ye*[1]; Ata Babazadeh-Naseri[1]; Benjamin Fregly[1]; C. Higgs[1]; [1]Rice University

Hierarchical meta-materials based on functionally-graded lattices (FGLs) have the benefit of customizable material properties. However, the effects of sharp transitions on the effective properties of FGLs have yet to be evaluated. This experimental study focused on characterizing the compressive properties of hierarchical FGLs built with smooth or sharp gradings. A total of 12 samples were 3D-printed in Ti6Al4V alloy and tested in axial compressive loading. Digital image correlation (DIC) was used to measure displacements and deformations. The 3D-printing quality of FGLs was also evaluated by micro-CT imaging of 5 samples. The results showed that the cross-sectional areas of struts in FGLs with sharp transitions were 26% smaller than uniform lattices and FGLs with smooth transitions. Compression testing also confirmed a lower average elastic modulus in FGLs with sharp gradings. These results will provide insights for incorporating adjustment factors to account for the loss of strength in FGLs.

Characterization and Validation Experiments for a Binder Jet 3D Printing Modeling Framework: *Wesley Combs*[1]; Joshua Wagner[1]; C.Fred Higgs III[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 jetting. 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.

Exploring Capillary Suspension Technique to Develop 3D Printable Oxide Based Lithium Electrolytes for All Solid-state Batteries by Direct Ink Writing: *Siri Vaishnavi Thummalapalli*[1]; Venkat Kamavaram[2]; Ganesh Kumar Arumugam[2]; Arunachala Kannan[1]; Kenan Song[1]; [1]Arizona State University; [2]Oceanit Laboratories

The development of solid-state batteries is a bottleneck to replacing the current lithium-ion batteries with liquid electrolytes for enhancing safety and energy density. Lithium garnet materials such as Li7La3Zr2O12(LLZO), are ceramic lithium conductors that have several unique properties. The challenge for developing a Solid-State Electrolyte (SSE) for Lithium-ion batteries is the limitation of relatively low ionic conductivity and high interfacial resistance between electrolyte and electrode. Although SSE has shown significant improvements in performance in recent years, they still face dendrite propagation issues due to planar geometries and random porosities. Herein, we present all solid-state 3D printable electrolytes using Ta-doped LLZTO garnet material using Direct Ink Writing (DIW) technique. Direct Ink Write (DIW) involves a controlled selective deposition of material according to a pattern. DIW techniques are capable of single or multi-layer patterning of material onto flat as well as conformal surfaces. Furthermore, multiple ink formulations have been developed with optimized rheological behavior using the capillary suspension technique. Compared to conventional methods, printable electrolytes can be tailored with different structural hierarchies (e.g., surface patterning) for diffused interface between electrode-electrolyte to block the dendrite and achieve a more stable battery performance. The major objective of this study is to optimize printable electrolyte ink composition and rheology, electrolyte conductivity, interfacial resistance, and energy density of solid-state battery through systematic materials characterization and cell testing.

Laser Synthesized Molybdenum Trioxide (MoO3) Nanoparticles for Energy Storage Applications: *Amiri Thorpe*[1]; Gracie Boyer[2]; Jonghyun Park[2]; [1]Florida A&M University; [2]Missouri University of Science and Technology

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 jetting. 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.

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