HI-AM Conference

5th | 2022

HOLISTIC INNOVATION IN ADDITIVE MANUFACTURING

JUNE 21 & 22 | MONTRÉAL, QC, CANADA
nserc-hi-am.ca/2022

PARTICIPANT INFORMATION PACKAGE

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2022 HI-AM CONFERENCE PARTICIPANT INFORMATION PACKAGE

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NSERC HI-AM

Welcome Message

On behalf of the NSERC Network for Holistic Innovation in Additive Manufacturing (HI-AM), we are pleased to welcome you to the 2022 HI-AM Conference.

It has been three years since our last in-person conference in Vancouver, and we are thrilled to finally be able to come together as a network once again after two virtual conferences. Thanks to the deployment of vaccines globally and the lifting of restrictions in Canada, it was possible to host you this year in Montreal. Our fifth academic HI-AM conference gathers over 150 attendees from around the world. This event provides an exciting opportunity for HI-AM Network members, industrial partners, and international researchers to exchange ideas, to share findings, and to explore opportunities for future collaborations. As always, there are a number of networking opportunities throughout the conference, as well as exhibitors from diverse sectors related to metal AM.

We are honored to have four internationally recognized experts as our keynote speakers: Animesh Bose, VP Special Projects, Desktop Metal, United States; Wayne King, Principal ADDvisor®, The Barnes Global Advisors, United States; Sebastian Piegert, Technology Field Lead Additive Manufacturing, Siemens Energy, Germany; and James Sears, Technology Fellow, AMAERO, United States. The conference also features 108 presentations and posters on different themes related to metal AM, showcasing the cutting-edge research being conducted by our network members as well as researchers from outside the network. While we are looking forward to in-person presentations by most of our speakers, we are holding some virtual presentations to accommodate speakers who were unable to attend due to pandemic-related travel complications.

In this welcome package, you will find all the information you need to navigate the conference in person, connect with exhibitors and fellow participants, explore abstracts, and much more. We encourage you to read through this package ahead of time to ensure that you are aware of the various events so that you can plan accordingly to make the most of your conference experience.

On behalf of the Conference Organizing Committee, we extend our gratitude to all those who have contributed to the planning and organization of this event. In addition to our main supporter, the Natural Sciences and Engineering Research Council of Canada (NSERC), we would also like to express our appreciation to our exhibitors and partners, McGill University, University of Waterloo, Multi-Scale Additive Manufacturing Laboratory, Canada Makes, TraCLight, AP&C, EOS, GE Additive, Desktop Metal, Promation 3D Printing, Groupe Additive 3D, Keyence, Opti-Tech Scientific, Phaseshift Technologies, Retinex, C-Therm Technologies, and Xact Metal.

We sincerely hope that you enjoy interacting with colleagues, and we are sure that this event will mark the start of another year of exciting progress of the HI-AM Network.

Ralph Resnick
Chairman of the Board

Mathieu Brochu
Conference Co-Chair

Ehsan Toyserkani
Conference Co-chair

NSERC HI-AM Network

Additive manufacturing (AM) has the potential to change the entire manufacturing sector by 2030. Despite the recent progress in this field, there are several remaining challenges hindering the widespread industry adoption of this technology from expensive and limited metal powder feedstock to the need for increased process reliability.

The Holistic Innovation in Additive Manufacturing (HI-AM) Network has been formed to work on innovative solutions to address these challenges and to equip Canada for the era of Industry 4.0 and "digital-to-physical conversion." With major investment from the Natural Sciences and Engineering Research Council of Canada (NSERC) and Canada Foundation for Innovation (CFI), the Network investigates fundamental scientific issues associated with metal AM pre-fabrication, fabrication, and post-fabrication processing. It facilitates collaboration between Canada's leading research groups in advanced materials processing and characterization, powder synthesis, alloy development, advanced process simulation and modeling, precision tool-path planning, controls, sensing, and applications.

HI-AM is the first national academic additive manufacturing initiative in Canada. This Network builds the partnerships, develops the intellectual property, and trains the highly skilled individuals Canada needs to compete in this crucial arena of advanced manufacturing.

University of Waterloo · University of Alberta · The University of British Columbia · Dalhousie University · Université Laval · McGill · University of Toronto

NSERC HI-AM

Network Partners

ACADEMIC AND RESEARCH INSTITUTION PARTNERS

MEMBERS

- University of Waterloo
- University of Alberta
- The University of British Columbia
- Dalhousie University
- Université Laval
- McGill
- University of Toronto

COLLABORATORS

- École de technologie supérieure (ÉTS)
- University of Windsor

INTERNATIONAL

- Fraunhofer IWS
- FAU Friedrich-Alexander Universität Erlangen-Nürnberg
- Lancaster University
- NIST National Institute of Standards and Technology U.S. Department of Commerce
- Nanyang Technological University Singapore
- RMIT University
- Taipei Tech
- Technische Universität Dresden
- University of Twente The Netherlands

INDUSTRY PARTNERS

- AP&C a GE Additive company
- Autodesk
- equispheres
- Flexcap
- GKN
- KSB
- MDA
- Pratt & Whitney Canada A United Technologies Company
- Promation
- Renishaw apply innovation™
- RioTinto
- Siemens energy
- Syncrude
- TIMET

GOVERNMENT PARTNERS

- Canada NRC-CNRC
- DRDC RDDC
- InnoTech Alberta A subsidiary of Alberta Innovates

NON-PROFIT AND HEALTHCARE PARTNERS

- CM&E Canadian Manufacturers & Exporters
- canada mining innovation council
- ReMAP Refined Manufacturing Acceleration Process
- AAPF Accélération de l'amélioration des processus de fabrication
- Mount Sinai Hospital

HI-AM 2022

ABOUT THE CONFERENCE

HI-AM 2022 is the 5th annual gathering of the NSERC Network for Holistic Innovation in Additive Manufacturing and the only academic conference in Canada focused exclusively on metal additive manufacturing. Cohosted by **McGill University** and **University of Waterloo**, the focus of HI-AM 2022 is to provide a platform for presentation of recent R&D advancements in the field of metal additive manufacturing under 4 research themes:

- material development
- advanced process modeling
- process monitoring and control
- innovative AM processes/products.

VENUE

The conference venue for HI-AM 2022 is the **Montreal Convention Centre** (Palais des congrès de Montréal) located in Montreal's Quartier international at the north end of Old Montreal.

For trip planning, driving directions, and parking fees, please visit **this page**.

Address: 1001 Pl. Jean-Paul-Riopelle, Montréal, QC H2Z 1H5

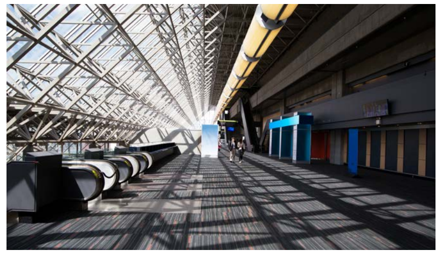


Photo Credit: Palais des congrès de montréal – congresmtl.com

HEALTH AND SAFETY PROTOCOLS DURING THE CONFERENCE

- We ask that anyone experiencing COVID-19 symptoms to please refrain from attending the conference. Registrants are encouraged to screen for COVID-19 symptoms and exposure using the Government of **Quebec's COVID-19 Self-assessment Tool** before attending the conference.
- Physical distancing is not required at the Palais des congrès but recommended where possible.
- Demonstrating proof of vaccination or a negative test is no longer required.
- Face covering in most enclosed or partially enclosed public spaces in Quebec, including the Palais des congrès, is no longer mandatory. The obligation is maintained on public transit (buses, the subway, ferries, taxis, car services, etc.) and at healthcare facilities. Even though the face covering is optional at the conference venue, it is still strongly recommended.
- Please be aware that public health conditions and the resulting requirements can change on short notice.
- For any questions about COVID-19 measures at the conference venue, contact the Palais des congrès at **info@congresmtl.com**.

FLOOR PLAN

HI-AM 2022

CONFERENCE DINNER

The Conference Dinner will be held on June 21, 6 pm to 10 pm at Hôtel Place D'Armes. The hotel is housed in four stunning 19th century neoclassical buildings, and is located near the Notre-Dame Basilica. We invite you to join us for a night of food and drink, friendly chat with AM experts, and a great view of Place d'Armes Square and Old Montreal.

6:00 – 7:30pm: Cocktail Reception at Terrasse Place D'Armes located on the 8th floor of the hotel. The Cocktail reception is co-hosted by Canada Makes and HI-AM Network.

7:30 – 10:00pm: Conference dinner at Bossa Nova Ballroom located on the 1st floor of the hotel.

Tickets for the Conference Dinner should be purchased separately at the time of registration. Badge and banquet coupons will be distributed at registration and are required for the event.

Hotel Address: 55 St Jacques St., Montréal, QC H2Y 1K9

Hôtel Place D'Armes is located at a short walking distance from the Palais des congrès:

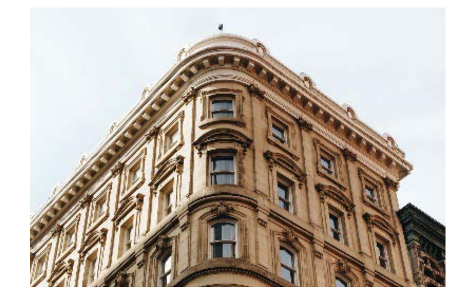
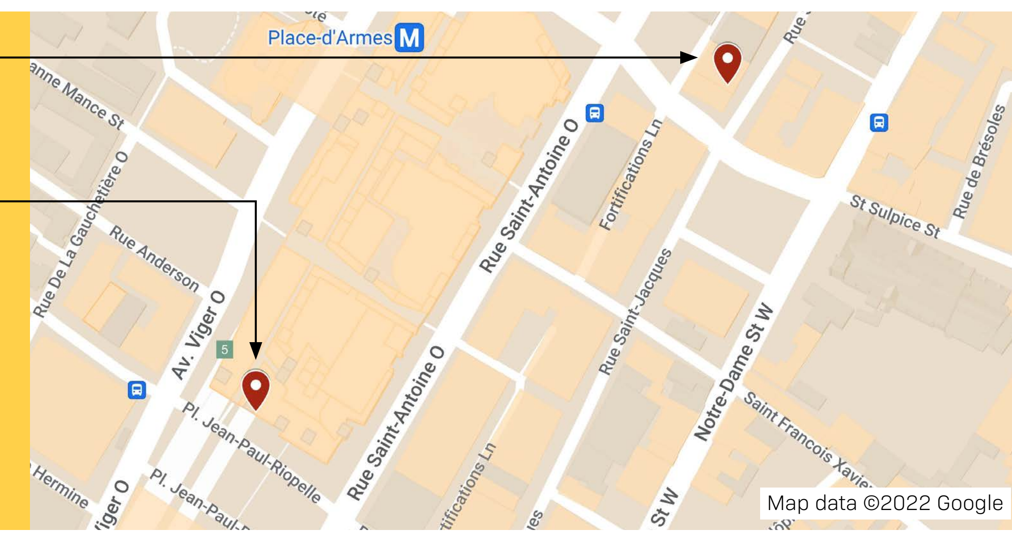


Photo Credit: Hôtel Place d'Armes Website – hotelplacedarmes.com

CONFERENCE DINNER:
Hôtel Place D'Armes
55 St Jacques St.,
Montréal, QC H2Y 1K9

VENUE:
Montreal Convention Centre (Palais des congrès de Montréal)
1001 Pl. Jean-Paul-Riopelle,
Montréal, QC H2Z 1H5



OTHER EVENTS

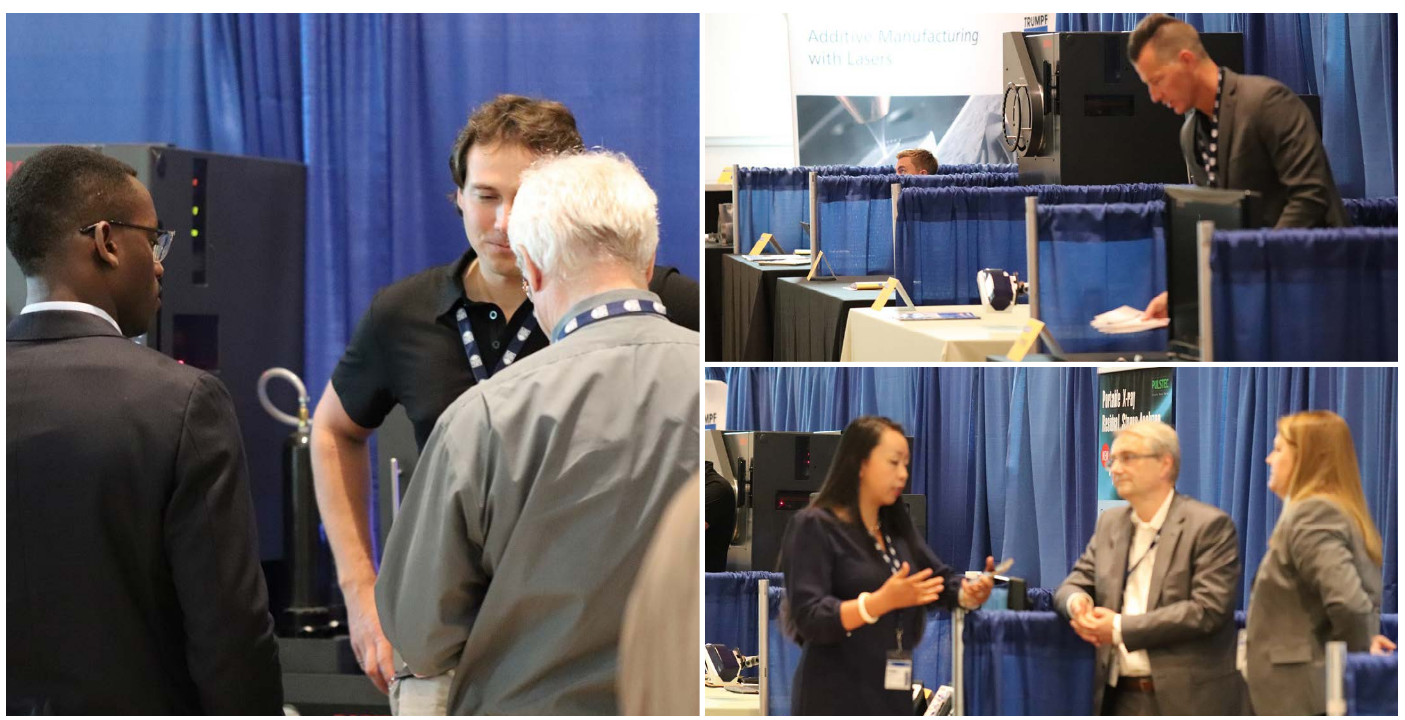
EVENT	DATE	TIME	LOCATION	COORDINATOR
Canada Makes Meeting	June 21	3:00 – 4:00pm	Room 511 a, d	Steve Kleimaker
HI-AM Scientific Advisory Committee Meeting 9	June 21	4:20 – 5:20pm	Room 512 c	Farzad Liravi
HI-AM Board of Directors Meeting 10	June 22	12:20 – 1:20pm	Room 512 c	Farzad Liravi

Exhibitor Guide

EXHIBITOR SCHEDULE

HI-AM 2022		June 21, 2022 June 22, 2022	8:00am – 5:40pm 7:30am – 5:30pm
Conference Day 1	Shipment delivery* Exhibitor set-up	June 21, 2022	8:00am – 12:00pm
	Exhibition viewing 1	June 21, 2022	12:40pm – 1:20pm
	Exhibition viewing 2	June 21, 2022	3:00pm – 4:00pm
	Conference dinner	June 21, 2022	6:00pm – 10:00pm
Conference Day 2	Exhibition viewing 3	June 22, 2022	9:40am – 10:00am
	Exhibition viewing 4	June 22, 2022	12:20pm – 1:00pm
	Exhibition viewing 5	June 22, 2022	2:40pm – 3:00pm
	Exhibitor dismantle	June 22, 2022	3:00pm – 6:00pm

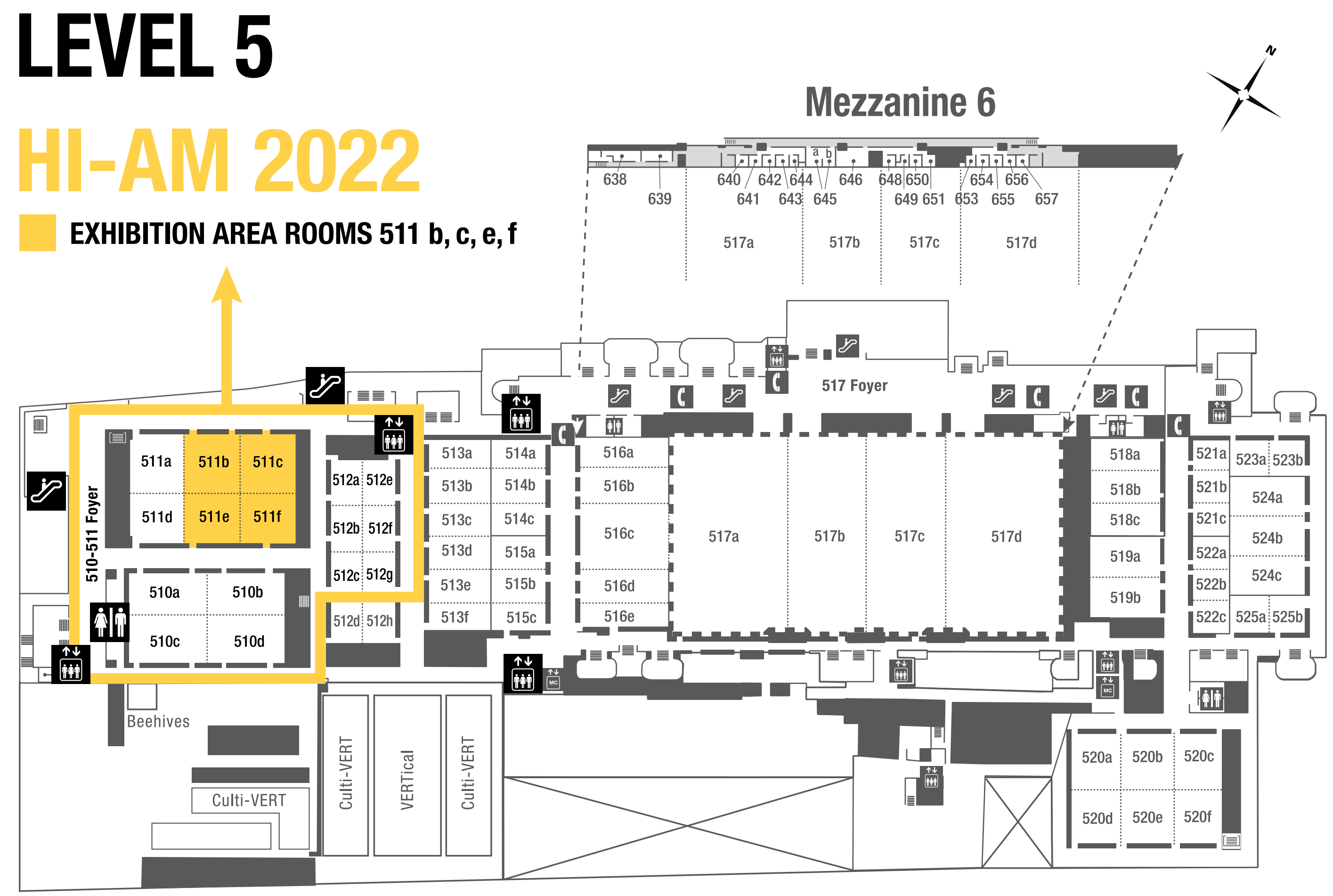
* Unless storage at GES Advance Warehouse is coordinated, the shipments should be delivered to the loading dock of Palais no earlier than the first day of the conference (June 21, 2022). Refer to Material Handling Sections (pages 12-13) for more information.



HI-AM 2019 Exhibition – The University of British Columbia

LOCATION OF THE EXHIBITION

The exhibition will take place at the Palais des congrès de Montréal in Room 511 b, c, e, f.



The **main visitor entrance** is located at:
201 Viger Avenue West, Montréal or
1001 Place Jean-Paul Riopelle, Montréal.

No delivery or pick-up of materials will be accepted at this address.

The **loading dock** is located at
163 Saint-Antoine Street West, Montréal.
Please refer to Material Handling sections for details.

The following locations are available to **park** your car:

Viger Parking - Palais des congrès de Montréal
1025 Chenneville Street
Clearance: 1,81 m (5' 11")

Quartier International de Montréal Parking
249 Saint-Antoine Street West
Clearance: 2 m (6' 7")

For trip planning, driving directions, and parking fees, please visit this **page**.

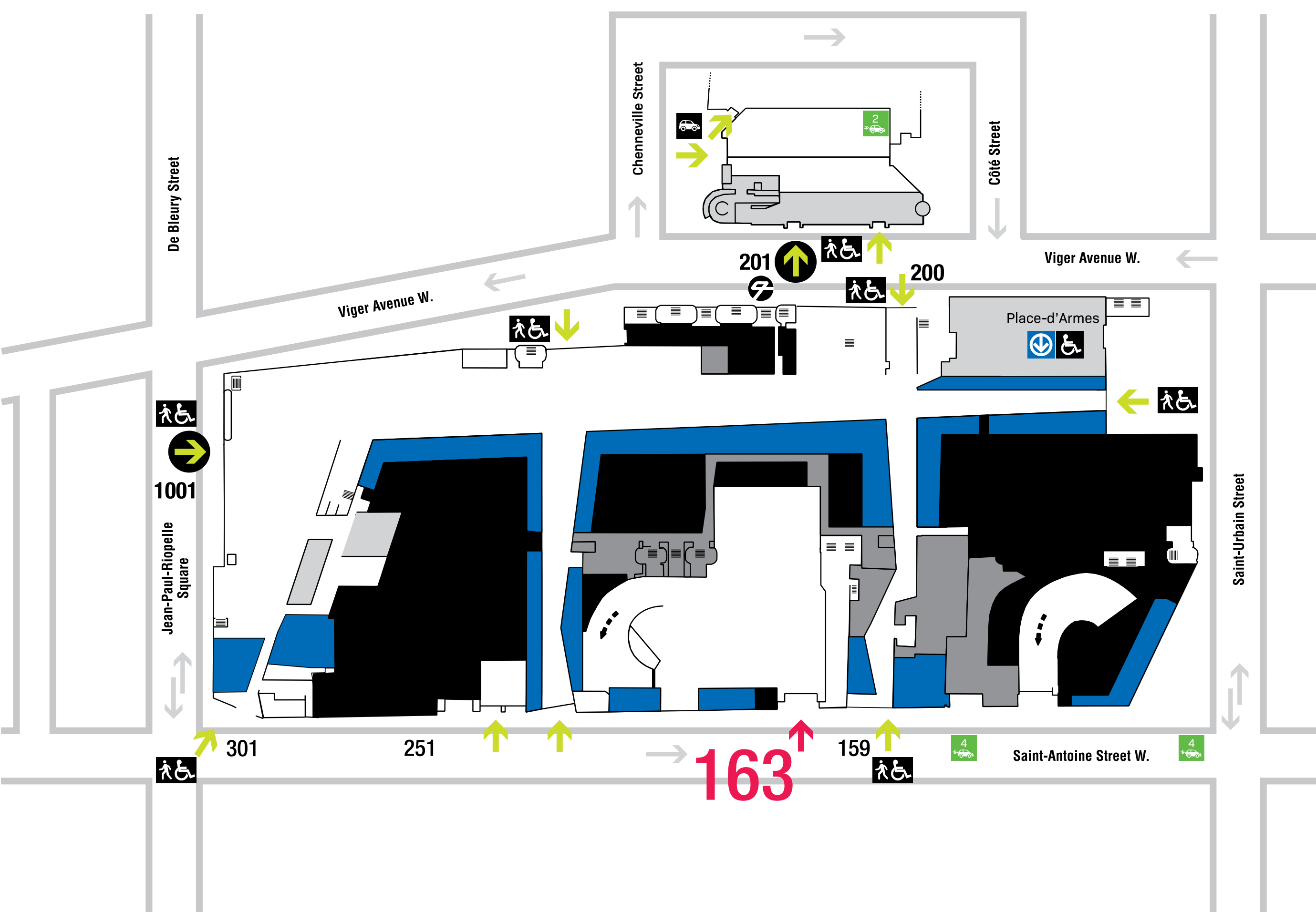
MATERIAL HANDLING BY EXHIBITORS

Exhibitors who have not ordered advance warehouse and/or material handling from GES may receive and unload their own shipment(s) provided that a representative of their company is present to receive the shipment(s) at the time of delivery, and that they are able to unload the shipment(s) without the use of a forklift.

Note: The shipments should be delivered to the loading dock of Palais no earlier than the first day of the conference June 21, 2022. Items delivered before June 21 will not be accepted. The HI-AM Conference does not accept any responsibility or liability for loss or damage caused to the shipments due to early delivery.

Delivery address:
Palais des congrès de Montréal
Loading Dock
163, Saint-Antoine Street West
Montréal (Québec) H2Z 1X8

Loading dock:



MATERIAL HANDLING BY EXHIBITORS continued

Entry Procedure During Set-up

- Upon arrival, please obtain a mandatory pass from the attendant at the loading dock.
- A maximum of 15 minutes is permitted to unload your vehicle.
- Any vehicles left at the loading dock for more than 15 minutes are subject to towing or applicable parking fees.
- To assist in transporting materials, blue trolleys are readily available at the loading dock.

Exit Procedure During Dismantle

- Smaller vehicles have exclusive and priority access to the loading dock at the start of dismantle. Trucks with trailers, cube trucks and heavier vehicles will have access thereafter.
- Blue trolleys will be available from the loading dock.
- Empty boxes will be brought to booths by Palais des congrès de Montréal or GES personnel as promptly as possible, once the visitors have vacated the room. Under no circumstances will exhibitors have direct access to storage facilities.
- A pass will be given to you by the attendant at the loading dock once all materials have been delivered to your booth. You must obtain this pass to have access to the loading dock with your vehicle.
- If your materials can be transported manually without the use of trolleys, it is possible to leave the premises via the exit doors or pedestrian access doors of the exhibit room.
- Blue trolleys or other heavy transport equipment are not permitted in the common or public areas of the Palais des congrès de Montréal, including the public elevators and escalators.

Exhibitors and Partners

PARTNERS

MULTI-SCALE ADDITIVE MANUFACTURING (MSAM) LABORATORY, hosted at the University of Waterloo, is one of the largest research and development additive manufacturing facilities in Canada. The MSAM Lab focuses on next-generation additive manufacturing processes. To this end, the lab explores novel techniques to develop advanced materials, innovative products, modeling and simulation tools, monitoring devices, closed-loop control systems, quality assurance algorithms and holistic in-situ and ex-situ characterization techniques.

www.msam-uwaterloo.ca

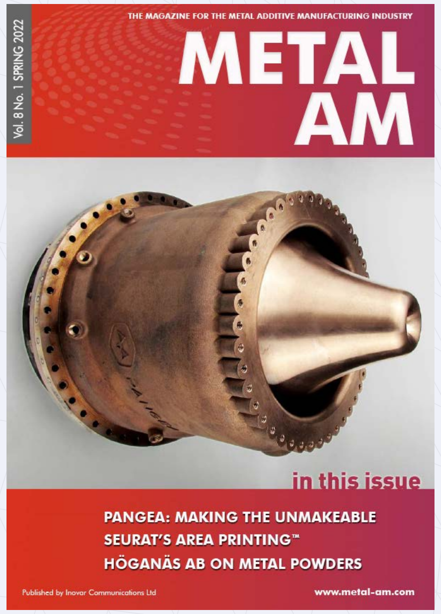
Since January 2017, the **TRANSATLANTIC CLUSTER FOR LIGHTWEIGHTING (TRACLIGHT)** has been supporting the international expansion and networking of German and North American companies and research centers. The goal is to bring together technical know-how for the development of truly unique and innovative lightweighting products through collaborative R&D projects between Germany and North America. Focus is on three technological areas: Additive Manufacturing, Joining Techniques and Multi-Material-Design. Moreover, TraCLight provides members and partners from Germany, Canada and the US with bilateral market access and intelligence. The transatlantic cluster platform deepens collaboration through a series of conferences, workshops and mutual industry visits.

www.traclight-cluster.com

CANADA MAKES is a network of private, public, academic, and non-profit entities dedicated to promoting the adoption and development of advanced and additive manufacturing (AM) in Canada. It is an enabler and accelerator of AM-adoption in Canada. The network covers a broad range of additive manufacturing technologies including 3D printing; reverse engineering 3D imaging; medical implants and replacement human tissue; metallic 3D printing and more.

canadamakes.ca

MEDIA PARTNER



Download the Spring 2022 Issue of the Metal AM **Magazine**

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EOS provides responsible manufacturing solutions via industrial 3D printing technology to manufacturers around the world. Connecting high quality production efficiency with its pioneering innovation and sustainable practices, the independent company formed in 1989 will shape the future of manufacturing. Powered by its platform-driven digital value network of machines and a holistic portfolio of services, materials and processes, EOS is deeply committed to fulfilling its customers' needs and acting responsibly for our planet.

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GOLD SPONSORS

DESKTOP METAL'S portfolio of 3D printers, materials, applications, and technologies was carefully curated to drive the future of Additive Manufacturing 2.0. Our team is passionate in the belief that production metal 3D printing can produce more advanced parts and products that can truly change the world at high, meaningful volumes.

www.desktopmetal.com

Founded in 1995, **PROMATION** – a privately owned Canadian Corporation – is a leading automation manufacturing in Oakville. We deliver custom equipment and turnkey systems to our global customers in three divisions; Nuclear, Automotive, and Industrial. We customize best-in-class automation solutions which are supported by a team of experienced PLC designers and engineering professionals with industry expertise. Striving for continuous improvement, performance and excellent workmanship, Promation adheres to established standards and strong assurance of service quality. This is our engine of sustained growth.

www.promation.com

SILVER SPONSORS

"Students who complete their training at Groupe Additive 3D, who have combined learning software specifically adapted for additive manufacturing in addition to hands-on training on 3D metal printers, will be greatly advantaged by experience they will have gained in their courses."
— Yvon Leduc, President.

GROUPE ADDITIVE 3D will have the largest number of 3D metal and polymer printers of different models to teach different applications that allow students to learn better. Groupe Additive 3D wants to ensure that students will have an advantage when they graduate – and will have hands-on experience in additive manufacturing using industrial 3D printers.

www.groupeadditive3d.com

OPTI-TECH SCIENTIFIC INC. started in 1989 as a microscope service & calibration company and evolved into the leading Canadian independent supplier of optical and digital microscopy and scientific instrumentation. Opti-Tech continues to evolve & innovate as a company while significantly expanding its product range to include instruments for metallography, hardness testing, laboratory and industrial furnaces, ovens & a wide range of metrology solutions.

www.opti-tech.ca

Exhibitors and Partners

SILVER SPONSORS

RETINEX provides a complete real time monitoring and control solution for high-temperature material processes that businesses can use to improve the quality and yield of their product manufacturing. This reduces the need for post-processing and reduces the rejection rate of finished parts. Unlike other similar companies, we offer the full package of monitoring, optimization, and control that is necessary for widespread adoption of additive manufacturing and real time welding process control.

retinex.ca

KEYENCE is a global leader in metrology equipment for imaging, analysis and measurement applications. Our microscopes capture fully focused images and can perform 2D, 3D and roughness measurements, all with sub-micron resolution. Our equipment is in use by more than 10,000 companies around the globe. Visit our booth today for a live demonstration! For product information, click links below:

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www.keyence.ca/Digital-Microscope

PHASESHIFT'S Rapid Alloy Development platform accelerates the research and development of alloys and associated process parameters using machine learning-based alloy design and computational chemistry simulation of material properties. Using our platform, we cut down the need for iterative experimentation by as much as 90%. Therefore, saving the client considerable time and resources in the process.

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C-THERM TECHNOLOGIES is the world leader in thermal conductivity instrumentation for test and measurement of polymers, ceramics, composites, insulation, textiles, and a wide range of other materials. We provide non-destructive solutions for R&D, production, and quality control applications through our Trident instrument. We are also partnered with Rigaku, selling their TMA, DSC, and STA in the US, and with Metravib, selling their DMA instrument in North America.

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BRONZE SPONSOR

At **XACT METAL™**, we're taking the essential specs for metal powder-bed fusion (commonly known as Selective Laser Melting or Direct Metal Laser Sintering) and combining them with breakthrough technology to establish a new level of price and performance for additive manufacturing. We're dedicated to supporting the next generation of innovative manufacturing solutions powered by metal 3D printing.

www.xactmetal.com

Keynote Speakers

Animesh Bose

VP, Special Projects
Desktop Metal, Inc., United States

Dr. Animesh Bose has been involved in the area of powder metallurgy for more than 40 years. He has published over 125 papers, 10 patents, and 4 books. He is a fellow of ASM International and APMI International. He was the Divisional Editor of Metal Injection Molding for the ASM Handbook, Volume 7, 2015. He served as co-chair for the MPIF MIM Conference, Powdermet, and is the founding co-organizer of Tungsten, Refractory, and Hardmaterials Conference Series. He is the Tech Board representative for the Association of Metal Additive Manufacturing (AMAM) and is the Chair for the AMAM Standards Committee.

Presentation title: Sinter-Based Metal Additive Manufacturing Technologies

Wayne King

Principal ADDvisor®
The Barnes Global Advisors, United States

Wayne King has been active in metal additive manufacturing since 2011. He served as Project Leader of the Accelerated Certification of Additively Manufactured Metals Project at LLNL. He has 30 years of experience at Lawrence Livermore National Laboratory ranging from fundamental materials research and programmatic science to research management. Dr. King received his B.A. from Thiel College in Physics and Mathematics and his Ph.D. from Northwestern University in Materials Science and Engineering. He has worked in the areas of radiation effects, high temperature oxidation, atomic structure of interfaces, grain boundary engineering, and additive manufacturing.

Presentation title: Taking Control of the Metal Additive Manufacturing Process

Sebastian Piegert

Technology Field Lead Additive Manufacturing
Siemens Energy GmbH & Co KG, Germany

Sebastian Piegert is leading the Additive Manufacturing Technology Development function within the Additive Manufacturing organization of Siemens Energy Generation division since 2014. He is also acting as the technology field lead for additive manufacturing for Siemens Energy. He started his career at Siemens as development engineer for joining and repair processes for hot gas paths components of gas turbines in 2008. Mr Piegert studied mechanical engineering at the technical university of Braunschweig (Germany). In order to deepen his expertise in high temperature materials and their applications, he subsequently conducted a doctorate at the Institute of Materials of the Technical University.

Presentation title: Ensuring High Quality Standards in Laser Powder Bed Fusion Production

James Sears

Technology Fellow
AMAERO, United States

Currently gives technical oversight to AMAERO on AM and metal powder projects. Previously held positions with Carpenter, GE-GRC, SDSMT (first facility name Additive Manufacturing Laboratory in US) and concurrently with Western Illinois University (Quad City Manufacturing Laboratory), Lockheed Martin-KAPL, Idaho National Engineering Laboratory, ALCAN (University of Birmingham, UK - IRC), Retech and Pratt & Whitney Aircraft, (RSR Team). PhD 1988 University of Illinois – PhD Thesis "Rapid Solidification of High Temperature and Reactive Metals". Master Thesis 1984 – "Dynamic Compaction of Rapidly Solidified Aluminum Alloys". Vietnam Era Veteran: US Navy, MM1 (SS), qualified submarines, USS Cavalla SSN 684.

Presentation title: Metal Additive Manufacturing: Historical Developments and the Path Towards Larger Parts

DAY 1 – June 21, 2022

ONLINE CONFERENCE PROGRAM

MORNING

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

8:00am	REGISTRATION – Location: Foyer 510-511 BREAKFAST – Location: Room 512 a,e,b,f
8:45am	CONFERENCE OPENING – Location: Room 510 b,d | Chair: Mathieu Brochu
9:00am	**SESSION 1: Metal Additive Manufacturing I** Location: Room 510 b,d | Chair: Mathieu Brochu
9:00am	**KEYNOTE 1: Taking Control of the Metal Additive Manufacturing Process** Wayne King *Principal ADDvisor®, The Barnes Global Advisors, United States*
9:40am	**KEYNOTE 2: Sinter-Based Metal Additive Manufacturing Technologies** Animesh Bose *VP, Special Projects, Desktop Metal, Inc., United States*
10:20am	MORNING TEA – Location: Room 512 a,b,e,f
10:40am	**SESSION 2: Metal Additive Manufacturing II** Location: Room 510 b,d | Chair: Ehsan Toyserkani
10:40am	**KEYNOTE 3: Ensuring High Quality Standards in Laser Powder Bed Fusion Production** Sebastian Piegert *Technology Field Lead Additive Manufacturing, Siemens Energy GmbH & Co KG, Germany*
11:20am	**KEYNOTE 4: Metal Additive Manufacturing: Historical Developments and the Path Towards Larger Parts** James Sears *Technology Fellow, AMAERO, United States*
12:00pm	LUNCH – Location: Room 512 a,e,b,f

Please help us select the best student presentations by completing the survey emailed to you on June 20. The recipients of the Student Presentation Awards in both the poster and oral presentation categories are announced at the conference closing ceremony.

If you did not receive the survey, please check your spam/junk folder; if you cannot find it, contact Farzad Liravi at fliravi@uwaterloo.ca.

You can change your answers on any survey page even after you complete the survey. You can return to the survey at any point during the conference to pick up where you left off and/or edit previous responses.

DAY 1 – June 21, 2022

AFTERNOON

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

12:40pm	EXHIBITION – Location: Room 511 b,c,e,f POSTER VIEWING – Location: Room 510 a,c	
1:20pm	**SESSION 3: Material Development I** Location: Room 510 b,d | Chair: Hani Naguib	**SESSION 4: Advanced Process Modeling I** Location: Room 511 a,d | Chair: Steven Cockcroft
1:20pm	FEATURED **Presentation 1: Stereolithographic Additive Manufacturing of Bulky Components with Functional Geometries** Soshu Kirihara *Professor, Osaka University, Japan*	FEATURED **Presentation 6: Using CALPHAD based Tools to Predict Improved Materials Data for Additive Manufacturing** Paul Mason, Adam Hope, Kaisheng Wu, Ben Sutton *Thermo-Calc Software Inc., United States*
1:40pm	**Presentation 2: Characterization and Analysis of Water Atomized Tool Steel Powders for Powder Bed Laser Fusion by Machine Learning** Denis Mutel, Simon Gélinas, Carl Blais *Université Laval, Canada*	**Presentation 7: Prediction of Melt Pool Temperature Distribution during Laser Powder-bed Fusion of Ti-Alloy: A Numerical Analysis with a Novel Hybrid Volumetric Heat Source** Mahyar Hasanabadi*, Shahriar Imani Shahabad*, Ali Keshavarzkermani*, Hamed Asgari Moslehabadi*, Adrian Gerlich**, Ehsan Toyserkani* **Multi-Scale Additive Manufacturing (MSAM), Canada; **University of Waterloo, Canada*
2:00pm	**Presentation 3: Effect of Additive Manufacturing Process on the Isothermal Aging Response and Hot Deformation Behaviour of a Maraging Stainless Steel** Trevor Ganton*, Taha Waqar*, Babak Shalchi Amirkhiz**, Amir Hadadzadeh***, Michael Benoit* **The University of British Columbia, Canada; **CanmetMATERIALS, Canada; ***University of Memphis, United States*	**Presentation 8: Machine Learning for Predicting the Mechanical Properties of Maraging Steel Manufactured by Laser Powder Bed Fusion with Different Build Orientations** Amanda Oliveira, Sydney Santos, Erik Gustavo Del Conte *Federal University of ABC, Brazil*
2:20pm	**Presentation 4: Denuded Region Formation in NiBSi-WC Metal Matrix Composites Deposited by Plasma Transferred Arc Additive Manufacturing** Dylan Rose*, Geoffrey Bonias*, Tonya Wolfe**, Hani Henein* **University of Alberta, Canada; **Red Deer Polytechnic, Canada*	**Presentation 9: Additively Built Lattices with Tunable Response through Soft Inclusions** Asma El Elmi, Damiano Pasini *McGill University, Canada*
2:40pm	**Presentation 5: Life Cycle, Aging, and Recyclability Study of 3D printable MXene** Yu-Chen Sun, Terek Li, Kyra McLellan, Hnai Naguib *University of Toronto, Canada*	**Presentation 10: A Numerical Case Study on the Thermal Balance of a Pseudo Build Environment in Electron Beam Additive Manufacturing** Farhad Rahimi, Farzaneh Farhang Mehr, Steven Cockcroft, Daan Maijer *The University of British Columbia, Canada*
3:00pm	AFTERNOON TEA – Location: Room 512 a,e,b,f EXHIBITION – Location: Room 511 b,c,e,f POSTER VIEWING – Location: Room 510 a,c	3:00 – 4:00pm **Canada Makes Meeting** **Location: Room 511 a,d**
3:20pm	NETWORKING EXHIBITION – Location: Room 511 b,c,e,f	

DAY 1 – June 21, 2022

AFTERNOON

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

4:00pm	**SESSION 5: Process Monitoring and Control I** **Location: Room 510 b,d | Chair: Sebastian Piegert**	**SESSION 6: Novel AM Processes and Products I** **Location: Room 511 a,d | Chair: Damiano Pasini**	
4:00pm	FEATURED **Presentation 11: Intelligent Process Control in Metal Additive Manufacturing** Chinedum Okwudire *University of Michigan, United States*	FEATURED **Presentation 16: Evolution of Powder Characterization for Additive Manufacturing** Yao Yao Ding *CEO, B3D Performance Inc., Canada*	
4:20pm	**Presentation 12: In-Situ Surface Roughness Detection in Laser Powder Bed Fusion using Advanced Monitoring and Machine Learning** Sahar Toorandaz, Ehsan Toyserkani *University of Waterloo, Canada*	**Presentation 17: 3D Printed Multistable Perforated P-Shellular** Jiahao Shi*, Hossein Mofatteh*, Armin Mirabolghasemi*, Benyamin Shahryari*, Gilles Desharnais**, Hamid Akbarzadeh **McGill University, Canada; **Axis Prototypes, Canada; McGill University, Canada*	**4:20 – 5:20pm** **HI-AM Network Scientific Advisory Committee Meeting** **Location: Room 512 c**
4:40pm	**Presentation 13: Toward Adapting Mobile 3D Printing to Metals and Regolith** Mohammad Azami, Pierre-Lucas Aubin-Fournier, Krzysztof Skonieczny *Concordia University, Canada*	**Presentation 18: Design and Characterization of a Cell-Size Graded Gyroid Heat Exchanger Produced Using Direct Metal Laser Sintering** Lucas Gallant, Amy Hsiao, Grant McSorley *Faculty of Sustainable Design Engineering, University of Prince Edward Island, Canada*	
5:00pm	**Presentation 14: Performance Evaluation of State-of-the-Art Machine Learning Methods in DED** Mihaela Vlasea, Gijs Houtum *University of Waterloo, Canada*	**Presentation 19: Scratch Resistance and Damage Mechanisms in TiC-Ni3Al Cermet Coatings Fabricated by Pre-placement Laser Directed Energy Deposition** Zhila Russell, Kevin Plucknet *Dalhousie University, Canada*	
5:20pm	**Presentation 15: FIR Filter Trajectory Generation for Additive Manufacturing Processes** Sharon Tam, Yusuf Altintas *University of British Columbia, Canada*	**Presentation 20: Analysis of Repair Interface Automated Hybrid Additive-Subtractive Manufacturing Process** Remy Samson*, Thomas Lehmann*, Tonya Wolfe**, Hani Henein*, Ahmed Qureshi* **University of Alberta, Canada; **Centre for Innovation in Manufacturing (CIMTAC) , Red Deer Polytechnic, Canada*	
5:40pm	**DAY 1 CLOSING**		
6:00pm	**Cocktail hour at Terrasse Place D'Armes**		
7:30 – 10:00pm	**Conference Dinner at Hotel Place D'Armes**		

DAY 2 – June 22, 2022

MORNING

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

7:30am	**BREAKFAST – Location: Room 512 a,e,b,f**	
8:00am	**SESSION 7: Novel AM Processes and Products II** **Location: Room 510 b,d | Chair: Jill Urbanic**	**SESSION 8: Process Monitoring and Control II** **Location: Room 511 a,d | Chair: Chinedum Okwudire**
8:00am	FEATURED **Presentation 21: Improving Mold Performance through Hybrid Metal AM** Thomas Houle *Director LUMEX, North America, Matsuura Machinery, United States*	FEATURED **Presentation 26: Plume Effects on Optical Signatures in Laser-Based Metal Additive Manufacturing** David Deisenroth *Mechanical Engineer, National Institute of Standards and Technology (NIST), USA*
8:20am	**Presentation 22: Magnetic Levitation for Additive Manufacturing: An Alternate Technique** Parichit Kumar, Saksham Malik, Ehsan Toyserkani, Behrad Khamesee *University of Waterloo, Canada*	**Presentation 27: Real-time Control of Thermal Dynamics in Laser Additive Manufacturing using Adaptive Model Predictive Control** Richard van Blitterswijk, Lucas Botelho, Amir Khajepour *University of Waterloo, Canada*
8:40am	**Presentation 23: Hybrid Additive-Subtractive Manufacturing of IN718** Sila Atabay*, Priti Wanjara*, Javad Gholipour*, Josh Soost**, Mathieu Brochu*** **National Research Council Canada, Canada; **Matsuura Machinery USA, Inc, United States; ***McGill University, Canada*	**Presentation 28: Challenges in Physics-driven Machine Learning in Laser Powder Bed Fusion** Jigar Patel, Mihaela Vlasea *University of Waterloo, Canada*
9:00am	**Presentation 24: Utilizing Process Maps to Engineer the Microstructure and Heat Treatment Responses of Low-alloy and Maraging Steels Fabricated by Laser Powder Bed Fusion** Mohsen Keshavarz, Sagar Patel, Mihaela Vlasea *University of Waterloo, Canada*	**Presentation 29: Powder Jet/Laser Beam Modeling for Direct Energy Deposition in Extreme Process Parameters** Jason Guy, Morgan Dal *Arts et Metiers, Institute of Technology, France*
9:20am	**Presentation 25: Laser Powder Bed Fusion of M789 Steel on Wrought N709 Steel Substrate** Kudakwashe Nyamuchiwa*, Kanwal Chadha**, Yuan Tian***, Youliang He†, Clodualdo Aranas* **University of New Brunswick, Canada; **Planetary and Space Science Centre, and Mechanical Engineering, University of New Brunswick, Canada; ***voestalpine Additive Manufacturing Centre Ltd, Canada; †CanmetMATERIALS, Natural Resources Canada, Canada*	**Presentation 30: Comparison between Absolute and Commercial Reflection Probes for Detecting Defects in Additively Manufactured Titanium and Stainless Steel Parts** Heba Farag, Behrad Khamesee *University of Waterloo, Canada*
9:40am	**MORNING TEA – Location: Room 512 a,e,b,f** **EXHIBITION – Location: Room 511 b,c,e,f** **POSTER VIEWING – Location: Room 510 a,c**	

DAY 2 – June 22, 2022

MORNING

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

10:00am	SESSION 9: Advanced Process Modeling II Location: 510 b,d | Chair: Tonya Wolfe	SESSION 10: Material Development II Location: Room 511 a,d | Chair: Priti Wanjara
10:00am	**Presentation 31: Semi-analytical Modeling of Temperature Field in Laser Powder Bed Fusion of Cu-Cr-Zr Alloy** Mazyar Ansari, Nadia Azizi, Mahyar Hasanabadi, Elahe Jabari, Ehsan Toyserkani *University of Waterloo, Canada; Multi-Scale Additive Manufacturing (MSAM), Canada*	FEATURED **Presentation 36: NRC-Brookside: Canada's newest Additive Manufacturing R&D Center** Ehab Samuel *Research Officer, NRC, Canada*
10:20am	**Presentation 32: Numerical Evaluation of the Effect of the Support Structure Design on the Deformation of Overhang Parts Manufactured by the Electron Beam Powder Bed Fusion (EB-PBF) Process** Pegah Pourabdollah, Farzaneh Farhang Mehr, Steven Cockcroft, Daan Maijer **UBC, Canada*	**Presentation 37: Influence of Heat Treatment on Microstructure and Mechanical Properties of Al40Si Fabricated by AM** An Fu, Satish Tumulu, Priti Wanjara, Mathieu Brochu *McGill university , Canada*
10:40am	**Presentation 33: In situ Processing of Rapidly solidified Al-33wt%Cu Droplets** Jonas Valloton*, Najia Mahdi**, Loraine Rabago*, Jason Chung*, Hani Henein* *University of Alberta, Canada; Norcada Inc., Canada*	**Presentation 38: AM Using Novel A8 Tool Steel Powders Produced by Water Atomization** William Chaîné, Carl Blais *Université Laval, Canada; Université Laval, Canada*
11:00am	**Presentation 34: Modelling of Single Pass Wire and Arc Additive Manufacturing** Anqi Shao*, Anne MacDonald*, J Borrelli*, Kim Meszaros**, Jonas Valloton*, Ahmed Qureshi*, Hani Henein* **University of Alberta, Canada; **MattCo Engineering Solutions Inc., Canada*	**Presentation 39: Copper infusion in to LPBF-AM Mo Alloy Lattice Structures for Tailored CTE Heatsinks** Tejas Ramakrishnan, Mathieu Brochu *McGill University, Canada*
11:20am	**Presentation 35: Particle-scale Simulation of Powder Spreading in the Presence of Gas in Additive Manufacturing** Sorush Khajepor, Sina Haeri *University of Edinburgh, United Kingdom*	**Presentation 40: Microstructural Characterization of Functionally Graded H13 Tool Steel and Copper using Directed Energy Deposition** Owen Craig*, Kevin Plucknett*, Scott Halliday**, Joshua Toddy**, Nylana Murphy* **Dalhousie University - Mechanical Engineering, Canada; **Navajo Technical University, United States*
11:40am	LUNCH – Location: Room 512 a,e,b,f	
12:20pm	EXHIBITION – Location: Room 511 b,c,e,f POSTER VIEWING – Location: Room 510 a,c	

12:20 – 1:20pm
HI-AM Network Board of Directors Meeting – Location: Room 512 c

HI-AM CONFERENCE 2022 PROGRAM SCHEDULE

DAY 2 – June 22, 2022

AFTERNOON

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

1:00pm	SESSION 11: Advanced Process Modeling + Process Monitoring and Control III Location: Room 510 b,d | Chair: Ali Bonakdar	SESSION 12: TraCLight Location: Room 511 a,d | Chair: Lena Wollbeck
1:00pm	**Presentation 41: A Deep-Learning-based In-Situ Surface Anomaly Detection in Laser Directed Energy Deposition-Powder Fed** Farzaneh Kaji*,**, Alikasim Budhwani*,**, Jinoop Narayanan*,**, Mark Zimny**, Ehsan Toyserkani* **University of Waterloo, Canada; **Promation, Canada*	**Presentation 46: Lithography based Metal Manufacturing of Nickel Titanium Alloys – Challenges and Chances of the Novel Manufacturing Process** Lucas Vogel*, Martina Zimmermann**, Carlo Burkhardt* **Institute for Precious and Technology Metal, Pforzheim University, Germany; **Institute of Materials Science, Technical University Dresden, Germany*
1:20pm	**Presentation 42: Development of Intermittent Controllers for Laser Powder-bed Fusion** Katayoon Taherkhani*, Gerd Cantzler**, Christopher Eischer**, Ehsan Toyserkani* **UWaterloo, Canada; **EOS , Germany; EOS, Germany*	**Presentation 47: Optimization for Automated Design of Novel Alloys for Additive Manufacturing** Fazal Mahmood *Phaseshift Technologies Inc., Canada*
1:40pm	**Presentation 43: Design, Development and Validation of an Instrumented Powder Testing Apparatus for Powder bed-based AM Applications** Salah Eddine Brika, Vladimir Brailovski *Ecole de technologie superieure, Canada*	**Presentation 48: Characterization of a New Tool Steel Alloy for Laser Additive Manufacturing** Manuela Neuenfeldt*, Gregor Graf**, Tobias Müller***, Jörg Fischer-Bühner†, Daniel Beckers**, Volker Schulze*, Frederik Zanger* **wbk Institute of Production Science, Germany; **Rosswag GmbH, Germany; ***Gühring KG, Germany, †Indutherm Gießtechnologie GmbH and BluePower Casting Systems GmbH, Germany*
2:00pm	**Presentation 44: Rapid Prediction of Thermal and Stress Distributions in LPBF Process Using a Finite-difference Modeling Approach** Shahriar Imani Shahabad*, Gholamreza Karimi**, Ehsan Toyserkani* **University of Waterloo, Canada; **Shiraz University, Iran*	**Presentation 49: LPBF and DED Process Development for Newly Developed Hot Work Tool Steel (HIPTSLAM)** Alexandre Bois-Brochu*, Justin Plante**, Edem Dugbenoo***, Carl Blais**, Mathieu Brochu*** **Quebec Metallurgy Center, Canada; **Université Laval, Canada; ***McGill University, Canada*
2:20pm	**Presentation 45: Powder and Vapor Consideration for Additive Manufacturing LPBF Simulation** Morgan Dal*, Yaasin Mayi**, Kevin Marchais***, Patrice Peyre† **Arts et Metiers, Institute of Technology, PIMM laboratory., France; **Safran, France; ***Arts et Metiers, Institute of Technology, PIMM laboratory., I2M, France; †Arts et Metiers, Institute of Technology, PIMM laboratory., CNRS, France*	**Presentation 50: Most Wanted: New materials for Metal AM** Gregor Graf *Rosswag GmbH, Germany*
2:40pm	AFTERNOON TEA – Location: Room 512 a,e,b,f EXHIBITION – Location: Room 511 b,c,e,f POSTER VIEWING – Location: Room 510 a,c	

DAY 2 – June 22, 2021

AFTERNOON ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

3:00pm	**SESSION 13: Novel AM Processes and Products III** **Location: Room 510 b,d | Chair: Ahmed Qureshi**	**SESSION 14: Material Development III** **Location: Room 511 a,d | Chair: Paul Bishop**
3:00pm	**Presentation 51: In Vitro Testing and Assessment of Additive Manufactured Lattice-Structured & Solid Titanium Dental Implant Overdenture Bars** Les Kalman *Western University , Canada*	**Presentation 58: Practical Collaboration for Science** Mark Zimny *President, Promation, Canada*
3:20pm	**Presentation 52: Key Performance Specifications Of An Affordable Metal Powder-Bed Fusion Printer** Dave Jankowski *Xact Metal, United States*	**Presentation 59: Effects of TiB2 in an Al-Cu-Sc Alloy in the Hybrid Investment Casting Process** Jose Dias Filho, Aleeza Batool, Yifan Li, Ahmed Qureshi, Hani Henein *University of Alberta, Canada*
3:40pm	**Presentation 53: Availability and Cost efficiency by Digitalization of Metal Spare Parts Manufacturing – Integration of Qualified WAAM Parts in the Industrial Supply Chain** John Manley *Machine Tool Systems Inc.*	**Presentation 60: Structure of LMJ Aluminum** Colin Fletcher *Xerox, United States*
4:00pm	**Presentation 54: Unlocking the Previously Impossible Geometries of Metal Additive Manufacturing by Reducing Cost-Per-Part** Michael Wohlfart *EOS, United States*	**Presentation 61: Influence of Post-processing Conditions on the Microstructure and Fatigue Resistance of Laser Powder Bed Fused Ti-6Al-4V Components** Alena Kreitcberg, Erika Herrera-Jimenez, Etienne Moquin, Morgan Letenneur, Vladimir Brailovski *École de technologie supérieure, Canada*
4:20pm	**Presentation 55: Validation of Multi-Laser Printing Technology for Additive Manufacturing** Donald Godfrey *SLM Solutions, United States*	**Presentation 62: Laser Powder Bed Fusion (LPBF) Processing of UNS C63020 Nickel Aluminum Bronze Powder** Addison Rayner, Jon Hierlihy, Melissa Trask, Randy Cooke, Paul Bishop *Dalhousie University, Canada*
4:40pm	**Presentation 56: Investigation of Organic Binders and Aluminum Powder Interactions and Sinterability of Aluminum Compacted Powder Parts** Solgang Im, Arunkumar Natarajan *GE Additive, United States*	**Presentation 63: Multiscale Mechanical Characterization of Multiphase Materials Made by Additive Manufacturing** Yu Zou *University of Toronto, Canada*
5:00pm	**Presentation 57: Wear Resistant Materials Produced by Additive Manufacturing Technologies** David Waldbillig, Marcus Ivey *Exergy Solutions, Canada*	**Presentation 64: Production-Ready Ti-6242 Printing Parameters for Laser Powder Bed Fusion Technology (L-PBF)** Javier Arreguin *AP&C, a GE Additive Company, Canada*
5:20 - 5:40pm	**CONFERENCE CLOSING AND AWARDS – Location: Room 510 b,d | Chair: Paul Bishop**	

Poster Presentation Gallery

THEME 1: MATERIAL DEVELOPMENT
Location: Room 510 a,c

Poster 1-1: Laser Directed Energy Deposition of CuCrZr Alloy: From Process Parameters Optimization to Microstructural Characterization
*Ali Zardoshtian, *Mazyar Ansari, **Hamid Jahed Motlagh, *Ehsan Toyserkani
**Multi Scale Additive Manufacturing Lab, Department of Mechanical and Mechatronics Engineering, University of Waterloo, Canada; **Department of Mechanical and Mechatronics Engineering, University of Waterloo, Canada*

Poster 1-2: Additive Manufacturing of Alumina – Metal Composite via Laser Powder-bed Fusion
Mohammad Azami*, Zahra Kazemi**, Amir Hadian***
**Concordia University, Canada; **Institute for Aerospace Studies, University of Toronto, Canada; ***Empa - Swiss Federal Laboratories for Materials Science and Technology, Switzerland*

Poster 1-3: Fatigue Resistance of Laser Powder Bed Fused Ti64 Components with Intentionally-seeded Porosity
Etienne Moquin, Vladimir Brailovski, Morgan Letenneur
École de technologie supérieure, Canada

Poster 1-4: Integrated Experimental/Statistical Optimization of High-Power Laser Powder Bed Fusion of Cu-Cr-Zr Alloy
Nadia Azizi, Elahe Jabari, Ehsan Toyserkani
University of Waterloo, Canada

Poster 1-5: Anisotropy in Ti-5553 Parts Made by Laser Powder Bed Fusion
*Nivas Ramachandiran, *Hamed Asgari, *Francis Dibia, **Roger Eybel, *Adrian Gerlich, *Ehsan Toyserkani
**University of Waterloo, Canada; **Safran Landing Systems, Canada*

Poster 1-6: Effect of α Case and Transition Zone on the Tensile Strength of Laser Powder Bed Fused and Heat-treated Ti-5553 Parts
*Nivas Ramachandiran, *Hamed Asgari, *Francis Dibia, **Roger Eybel, *Adrian Gerlich, *Ehsan Toyserkani
**University of Waterloo, Canada; **Safran Landing Systems, Canada*

Poster 1-7: Laser Powder Bed Fusion of Cu-Ag Elemental Powder Blend
Nadia Azizi, Hamed Asgari, Ehsan Toyserkani
University of Waterloo, Canada

Poster 1-8: Effect of Cooling Rate on the Microstructure of Rapidly Solidified 17-4PH Stainless Steel
Anne McDonald*, Hani Henein*, Tonya Wolfe**
**University of Alberta, Canada; **Red Deer Polytechnic, Canada*

Poster 1-9: Development of AlSi10Mg-AlN Metal Matrix Composites for Laser Powder Bed Fusion AM
Jonathan Comhaire*, Paul Bishop*, Ian Donaldson**
**Dalhousie University, Canada; **GKN Sinter Metals, United States*

Poster 1-10: Rapid Solidification of Al-10Si-0.4Sc (wt%): Precipitation Behaviour and its Influence on Mechanical Properties
Akankshya Sahoo*, Abdoul-Aziz Bogno**, Jonas Valloton*, Douglas Ivey*, Hani Henein*
University of Alberta, Canada; Equispheres Inc, Canada

Poster 1-11: Comparison of Laser Powder Bed Fusion Processing and Laser Remelting of an Al-Zr Alloy
Jon Hierlihy*, Ian Donaldson**, Paul Bishop*
**Dalhousie University, Canada; **GKN Powder Metallurgy, United States*

Poster 1-12: 4D Precipitation Printing of Shape Memory Polymer Blends for Foamed Strain Sensors
Kyra McLellan, Terek Li, Yu Chen Sun, Hani Naguib
University of Toronto, Canada

Poster 1-13: Facile 3D Printing of Conductive Polymer
Terek Li, Hani Naguib
University of Toronto, Canada

Poster 1-14: Observing the Effect of Boron on D2 and 4340 for Binder Jetting Application
William Bouchard, Carl Blais
Université Laval, Canada; Université Laval, Canada

Poster 1-15: Effect of Surface Condition on High Temperature Fatigue Response of LPBF Hastelloy X
Reza Esmaeilizadeh*, Xiaolong Li**, Mathias Kuhlow**, Ali Keshavarzkermani*, Hamid Jahed*, Ehsan Toyserkani*, Ehsan Hosseini**
**University of Waterloo, Canada; **Swiss Federal Laboratories for Material Science and Technology, Switzerland*

Poster 1-16: Property Enhancement of Binder Jet 3D Printed SS316L Parts using Cu Nanoparticles-enriched Binder
Elahe Jabari, Daniel Juhasz, Mohsen Keshavarz, Issa Rishmawi, Mariah De Torres, Caleb Davis, Mihaela Vlasea
University of Waterloo, Canada

THEME 2: ADVANCED PROCESS MODELING
Location: Room 510 a,c

There will be no posters in Theme 2.

THEME 3 - PROCESS MONITORING AND CONTROL
Location: Room 510 a,c

Poster 3-1: Analysis of the Porosity Production in LPBF Process Using Designed Porosity and Process Parameters
Shokoufeh Sardarian, Shirin Dehghai, Marc Secanell, Ahmed Qureshi
University of Alberta, Canada

Poster 3-2: Machine Learning for Defect Detection Using Optical Tomography Signals
Osazee Ero, Ehsan Toyserkani
University of Waterloo, Canada

Poster 3-3: Policy Gradient Optimization of Bead Geometry in Robotic Wire Arc Additive Manufacturing
Yeon Kyu Kwak, Thomas Lehmann, Mahdi Tavakoli, Ahmed Qureshi
University of Alberta, Canada

Poster 3-4: 3D Scan Data-Based Shape Compensation using Graph U-Nets to Correct the Systematic Geometric Errors of Additive Manufacturing Parts
Moustapha Jadayel, Farbod Khameneifar
Polytechnique Montreal, Canada

Poster 3-5: Detection of Defects in Additively Manufactured AlSi10Mg and Ti64 Samples Using Laser Ultrasonics and Phase Shift Migration
Alexander Martinez-Marchese, Reza Esmaeilizadeh, Ehsan Toyserkani
MSAM, Canada; MSAM, Canada; MSAM, Canada

Poster Presentation Gallery

THEME 3 - PROCESS MONITORING AND CONTROL
Location: Room 510 a,c

Poster 3-6: Toward Predicting the Powder Characteristics for Metal Additive Manufacturing Using Machine Learning
Farima Liravi*, Mahdi Habibnejad**, Ehsan Toyserkani*
**University of Waterloo, Canada; **GE additive - AP&C, Canada*

Poster 3-7: In situ Measurement of the Pressure Required to Extrude Low-viscosity Feedstock in Material Extrusion Additive Manufacturing of Highly-filled Polymer (MEAM-HP)
Raphaël Côté*, Olivier Miclette*, Vincent Demers*, Nicole Demarquette*, Jérémie Soulestin**
**École de technologie supérieure, Canada; **École nationale supérieure Mines-Télécom Lille-Douai, France*

Poster 3-8: Sintering Densification and Distortion Prediction Using the Skorohod Olevsky Viscous Sintering Model
Roman Boychuk*, Kamyar Ghavam**, Mihaela Vlasea*
*University of Waterloo - Multi-Scale Additive Manufacturing Laboratory, Canada; **University of Waterloo, Canada

Poster 3-9: Baseplate Design and Inverse Heat Conduction Modeling for Improved Predictive Accuracy of COMSOL Model for Laser Powder Bed Fusion Printing of Metallic Alloy Powders
Paresh Prakash, Emre Ogeturk, Yu Wang, Mary Wells
University of Waterloo, Canada

THEME 4 - NOVEL AM PROCESSES AND PRODUCTS
Location: Room 510 a,c

Poster 4-1: Heat Treatment of Multi-material Additively Manufactured Maraging Steel and Stellite Alloy
*Jubert Pasco, *Clodualdo Aranas, *Kanwal Chadha, **Yuan Tian
**University of New Brunswick, Canada; **Voestalpine Additive Manufacturing, Canada*

Poster 4-2: Thermal and Residual Stress Modeling of Functionally Graded Deposits Using the PTAAM
Geoffrey Bonias, Hani Henein, Tonya Wolf
University of Alberta, Canada

Poster 4-3: Embedding Fiber Bragg Gratings in Curved Channels of Additively Manufactured Parts for Temperature and Strain Sensing
Bahareh Marzbanrad, Ehsan Toyserkani
University of Waterloo, Canada

Poster 4-4: Electromagnetic Levitation for Additive Manufacturing Applications
Saksham Malik, Parichit Kumar, Ehsan Toyserkani, Behrad Khamesee
University of Waterloo, Canada

Poster 4-5: Electrochemical-assisted Hybrid Surface Treatment Techniques for Additively Manufactured Metal Parts
Manyou Sun, Ehsan Toyserkani
University of Waterloo, Canada

Poster 4-6: Process Optimization and Characterization of SS316L Wall and Bulk Structures Built Using a Robotic Laser Directed Energy Deposition System
Jinoop Arackal Narayanan*,**, Farzaneh Kaji*,**, Ali Zardoshtian*, Mark Zimny**, Ehsan Toyserkani*
**University of Waterloo, Canada; **Promation, Canada*

Poster 4-7: Multiaxial Mechanical Properties of Diamond and Gyroid Lattice Structures for Spinal Cages
Anatolie Timercan, Vladimir Brailovski
École de technologie supérieure, Department of Mechanical Engineering, Canada

Poster 4-8: Influence of Layer Thickness upon Material Characteristics of AISI D2 Steel Manufactured Using Directed Energy Deposition
Samer Omar, Kevin Plucknett
Dalhousie university, Canada

Poster 4-9: Laser Powder Bed Fusion of NiTi Shape Memory Alloys
Ali Safdel, Mohamed Elbestawi
McMaster University, Canada

Poster 4-10: Designing Topology Optimized Graded Porous Structures considering Additive Manufacturing Constraints
Osezua Ibhadode, Ehsan Toyserkani
University of Waterloo, Canada

Poster 4-11: Evaluation of Al-Si-Mg Small Scale LPBF Coupons under ELCF
Muralidharan Kumar, Mathieu Brochu
McGill University, Canada

Poster 4-12: Effect of Substrate Condition and Initial Residual Stresses on Electron Beam Wire Fed Additive Repair
Fatih Sikan*, Priti Wanjara**, Javad Gholipour Baradari**, Mathieu Brochu*
**McGill University, Canada; **National Research Council Canada, Canada*

Poster 4-13: Safer and Simpler Metal AM with Liquid Metal Jetting (LMJ)
Ally Abel, John Erley, Ryan Hayford
Xerox Elem Additive, United States

Poster 4-14: Development of an In-situ Failure Detection System for Fused Deposition Modelling Process through the Object Detection Model and Nozzle Camera
Xingchen Liu*, Haoliang Zhou**, Sabir Hossain***, Jiachun Wang*, Zhibin Bao***, Yaohui Zou†, Xunchao Zhang†, Heng Xue*, Xianke Lin**, Yu Zou*
**University of Toronto, Canada; **Mech Solutions Ltd.,Canada; ***Ontario Tech University, Canada; †University of Waterloo, Canada*

Poster 4-15: Novel Additive Manufacturing Approach for the Fabrication of High-precision Micro Parts
Juan Schneider, Panteha Fallah, Luc Jacob, Steve boa, Guillaume Villeneuve, Antoine Lombardo, Samuel Schneider
**Nanogrande Inc., Canada*

Poster 4-16: The Downside of Downskin: Digital Evaluation of Manufacturability of Lattice Metamaterials by Laser Powder Bed Fusion Additive Manufacturing
Martine McGregor, Sagar Patel, Adam Yu, Kevin Zhang, Stewart McLachlin, Mihaela Vlasea
University of Waterloo, Canada

Abstracts

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

ONLINE CONFERENCE PROGRAM

Keynotes

SESSION 1: Metal Additive Manufacturing I
June 21 | 9:00am EDT

Keynote 1 | 9:00am

Taking Control of the Metal Additive Manufacturing Process

Wayne King
Principal ADDvisor®, The Barnes Global Advisors, United States

Abstract: Metal additive manufacturing relies on the optimization of a fairly large set of parameters to achieve materials whose properties and performance meet design and safety requirements. Despite continuous improvements in the process over the years, the quality of additive manufactured parts remains a major concern for manufacturers. Today, machine manufacturers are starting to move from discrete geometry dependent parameters to continuously variable or dynamically changing parameters that are geometry and scan aware. This approach has become known as a priori or feedforward control. In this presentation, I discuss the origins of feedforward control, the early implementations of feedforward in additive manufacturing, the current state of the art, and path forward to the broad adoption of feedforward control.

Keynote 2 | 9:40am

Sinter-Based Metal Additive Manufacturing Technologies

Animesh Bose
VP, Special Projects, Desktop Metal, Inc., United States

Abstract: Additive manufacturing (AM) has expanded the tool free manufacturing of metal parts in a disruptive manner. Metal AM is a relatively new technology that is becoming accepted as an established manufacturing process. Metal AM has been dominated by melt-based AM technologies. Sinter-based metal AM processes that have many advantages over melt-based AM technologies, have created a resurgence of interest in the area of metal AM. Sinter-based metal AM processes can cover a wide range of productivity including rapid prototyping and low volume serial prototyping techniques (Bound Metal Deposition) to high volume mass production process (Binder Jet). This presentation will discuss a couple of the established sinter-based metal AM processes along with a few of the relatively new and emerging sinter-based AM technologies.

SESSION 2: Metal Additive Manufacturing II
June 21 | 10:40am EDT

Keynote 3 | 10:40am

Ensuring High Quality Standards in Laser Powder Bed Fusion Production

Sebastian Piegert
Technology Field Lead Additive Manufacturing, Siemens Energy GmbH & Co KG, Germany

Abstract: Laser powder bed fusion is a technology that has been in development from the embryonic stage to the cusp of a fully industrialized technology completely in the information age. The immense amount of publications on the technology has made visible the high complexity of influencing factors and the challenges of process control in L-PBF. The L-PBF process has many influencing variables which cause potential users to question whether quality assurance including repeatability and reproducibility can be managed and maintained in a large-scale production environment. This presentation contends that despite the number of influencing factors on the process, the resulting product quality is not only controllable with the correct measures but can be more reproducible and repeatable than other conventional manufacturing process routes. The significant influencing factors for L-PBF are identified and how the deviations highlighted in literature can be one by one either ruled out, controlled or minimized to reducing process deviations to a manageable level. In addition, real production data is displayed, analyzed, and compared from a well-controlled full-scale production to demonstrate the capability of the technology. Utilizing own examples on industrially scaled production components will provide a proof of the identified measures to stabilize the process.

Keynote 4 | 11:20am

Metal Additive Manufacturing: Historical Developments and the Path Towards Larger Parts

James Sears
Technology Fellow, AMAERO, United States

Abstract: A brief history of Metal Additive Manufacturing will be discussed starting with the onset of the computer age. This discussion will include the key developments that happened over the years that brought to the state-of -the -art today. A further elaboration will analyze the current technology gapes. The discussions will be limited to both types of laser-based solutions (Direct Deposition and Powder-Bed) and Binder-Jet. A projection on the needs for maturation of both laser-based and binder-jet technologies will be presented. A path towards larger part fabrications will be postulated.

Oral Presentations

SESSION 3: Material Development I
June 21 | 1:20pm

1:20pm

FEATURED **Presentation 1: Stereolithographic Additive Manufacturing of Bulky Components with Functional Geometries**

Soshu Kirihara
Professor
Osaka University, Japan

Abstract: In stereolithographic additive manufacturing (STL-AM), 2-D cross sections were created through photo polymerization by UV laser drawing on spread resin paste including nanoparticles, and 3-D models were sterically printed by layer lamination. The lithography system has been developed to obtain bulky components with functional geometries. As the row material of the 3-D printing, nanometer sized metal and ceramic particles were dispersed into acrylic liquid resins at about 60 % in volume fraction. These materials were mixed and deformed to obtained thixotropic slurry. The resin paste was spread on a glass substrate at 50 μm in layer thickness by a mechanically moved knife edge. An ultraviolet laser beam of 355 nm in wavelength was adjusted at 50 μm in variable diameter and scanned on the spread resin surface. Irradiation power was changed automatically for enough solidification depth for layer bonding. The composite precursors including nanoparticles were dewaxed and sintered in the air atmosphere. Though the computer aided smart manufacturing, design and evaluation (Smart MADE), practical materials components were fabricated to modulate energy and material transfers in potential fields between human societies and natural environments as active contributions to Sustainable Development to Goals (SDGs).

1:40pm

Presentation 2: Characterization and Analysis of Water Atomized Tool Steel Powders for Powder Bed Laser Fusion by Machine Learning

Denis Mutel, Simon Gélinas, Carl Blais
Université Laval, Canada

Abstract: In additive manufacturing (AM), powders need to achieve specific flow characteristics in order to be considered suitable for the spreading process. The characterization of the rheological properties is therefore fundamental. Although there are several methods to quantify these properties, for example the Hall Flowmeter and the Granudrum apparatus, the relationship between the powder flow and the morphological characteristics of individual particles can be difficult to establish. Although individual particles can be visualized, for example by scanning electron microscopy (SEM) and characterized by image analysis, part of the problem is the lack of tools to enable quantitative analysis on a sufficiently large scale. In this regard, modern developments in artificial intelligence (AI) provide techniques that can be used to increase the scope and reach of an image analysis approach. The results summarized in this study originate from the segmentation of individual particles in micrographs taken with a SEM. The information collected on individual particles are then process using different machine learning (ML) approaches, supervised or unsupervised, in order to associate these information with the rheological properties. The developed approach was applied to the characterization of water atomized tool steel powders intended for laser powder bed fusion (LPBF) AM process.

2:00pm

Presentation 3: Effect of Additive Manufacturing Process on the Isothermal Aging Response and Hot Deformation Behaviour of a Maraging Stainless Steel

Trevor Ganton*, Taha Waqar*, Babak Shalchi Amirkhiz**, Amir Hadadzadeh***, Michael Benoit*
**The University of British Columbia, Canada; **CanmetMATERIALS, Canada; ***University of Memphis, United States*

Abstract:

In this presentation, we will discuss the effect of the choice of additive manufacturing (AM) process on the isothermal aging response and hot deformation behaviour of a maraging stainless steel. Samples were produced by wire + arc AM (WAAM) and laser powder bed fusion (LPBF). Samples produced by both AM processes were subjected to an isothermal aging treatment (530°C, 3hrs), and cylindrical samples were subjected to compressive loading at 530°C and several strain rates using a Gleeble thermomechanical simulator. WAAM samples had a higher hardness in the as-printed condition compared to LPBF samples (402HV vs. 329HV). However, LPBF samples experienced a significant increased in hardness after isothermal aging (499HV) while WAAM samples had a negligible increase (414HV). Samples produced by both AM processes demonstrated strain rate sensitivity during compression at 530°C. The maximum flow stress of LPBF samples was found to exceed 1.1GPa, whereas the maximum flow stress of WAAM samples was less than 900MPa. The isothermal aging and deformation behaviour was explained through detailed microstructure characterization. It was concluded that the selection of the AM process can significantly impact the properties of maraging stainless steel.

2:20pm

Presentation 4: Denuded Region Formation in NiBSi-WC Metal Matrix Composites Deposited by Plasma Transferred Arc Additive Manufacturing

Dylan Rose*, Geoffrey Bonias*, Tonya Wolfe**, Hani Henein*
**University of Alberta, Canada; **Red Deer Polytechnic, Canada*

Abstract: A directed energy deposition additive manufacturing method that uses plasma transferred arc as the energy source allows for the deposition of Ni based-WC metal matrix composites (MMCs) for abrasive wear applications. The wear resistance is governed by the volume loading and distribution of WC within the Ni matrix, with conventional Ni based-WC overlays containing a maximum of 60wt% WC. At carbide volume fractions greater than 60wt% WC, defects such as pores and denuded regions begin to form. Denuded regions are spherical regions in the MMC that are entirely void of primary WC and drastically reduce the MMC's ability to resist abrasive wear. Ni-WC's high-temperature kinetics and thermodynamics under rapid heating and solidification conditions, and their involvement in denuded region formation have not been explored. Additionally, the effects of alloying elements on denuded region formation, such as B, Si, and Fe, are unknown. The microstructure evolution of NiBSi-WC MMCs deposited using plasma transferred arc additive manufacturing will be assessed, with a particular focus on the formation of denuded regions.

2:40pm

Presentation 5: Life Cycle, Aging, and Recyclability Study of 3D printable MXene

Yu-Chen Sun, Terek Li, Kyra McLellan, Hnai Naguib
University of Toronto, Canada

Abstract: MXene is a next generation, graphene-like 2D nanosheets material that consists of titanium carbides (Ti 3 C 2 T x). Due to its unique structure and superior electrical properties, MXene has a great potential to be utilized in many applications, including 3D printable flexible electronics. However, the recyclability and the aging process of the MXene powder need to be fully characterized and investigated. The focus of this study is on recycle aqueous MXene dispersion into MXene powder, which can be redispersed to formulate ink for printing. Furthermore, MXene oxides exponentially faster when stored in aqueous solution, therefore, unused MXene dispersion must be filtered into powder to mitigate oxidation. Additionally, the life cycle inventory of MXene is reported. This analysis starts with the synthesize of MAX precursor for MXene and ends with fully oxidized MXene. This cradle to grave approach considers the impact of MXene overall its full life cycle. To demonstrate the recyclability, a new approach to synthesize 3D printable conductive polymer (PEDOT:PSS) is proposed. The recycled MXene is re-dispersed in this conductive polymer formation. The MXene-PEDOT:PSS ink has the potential to be 3D printed as the sensing material for a temperature sensor.

SESSION 4: Advanced Process Modeling I
June 1 | 1:20pm EDT

1:20pm

FEATURED **Presentation 6: Using CALPHAD based Tools to Predict Improved Materials Data for Additive Manufacturing**

Paul Mason, Adam Hope, Kaisheng Wu, Ben Sutton
Thermo-Calc Software Inc., United States

Abstract: During additive manufacturing of metals, extremely high cooling rates and thermal cycling in the build layer can lead to different material properties than traditional cast or wrought materials which are more commonly found reported in data sources such as handbooks. Even published thermophysical property data, often used in FEA codes to model additive processes, can be unsuitable for conditions typical of additive manufacturing processes. To fill the data gaps, CALPHAD based tools can be used to simulate this highly non-equilibrium process and aid in the design of new alloys suited to additive manufacturing.

Specifically, CALPHAD tools can be used to calculate the following as a function of material chemistry and temperature:

- Thermophysical properties such as heat capacity, enthalpy, and density under non-equilibrium conditions arising from rapid cooling for input into FEA codes
- Microsegregation during solidification
- Precipitate evolution and growth during heating and cooling cycles
- Selecting temperatures for optimal post-build heat treatments

In this talk such examples will be given along with more recent developments. Coupled with FEA codes, these can be used to predict localized material properties by linking chemistry and processing conditions to microstructure in ICME frameworks.

1:40pm

Presentation 7: Prediction of Melt Pool Temperature Distribution during Laser Powder-bed Fusion of Ti-Alloy: A Numerical Analysis with a Novel Hybrid Volumetric Heat Source

Mahyar Hasanabadi*, Shahriar Imani Shahabad*, Ali Keshavarzkermani*, Hamed Asgari Moslehabadi*, Adrian Gerlich**, Ehsan Toyserkani*
**Multi-Scale Additive Manufacturing (MSAM), Canada; **University of Waterloo, Canada*

Abstract: Laser Powder-bed Fusion (LPBF), as a metal Additive Manufacturing (AM) method, is considered a feasible fabrication method to produce complex-shaped parts with customized properties. During the LPBF process, the input parameters will affect the melting and solidification of the powder, and influence the microstructure and properties. Hence, to achieve a desired microstructure and properties, it is necessary to correlate process parameters with melting and solidification conditions. Since the measurement of thermal variables during melting and solidification is almost impossible, heat transfer simulation be used to investigate the influence of parameters on thermal conditions during processing. In the current research, a numerical heat transfer modelling with a novel hybrid volumetric heat source has been developed. The proposed hybrid model, by considering a physics-based approach, can provide reliable estimated thermal variables (e.g. temperature gradient (G) and solidification rate (R)), for any location of the melt pool and at any time of the melting/solidification period. To validate and calibrate this simulation, several Ti-5553 single tracks, with different laser power and scanning speed were printed and evaluated experimentally. The simulated results very well agreed with experimentally measured melt pool dimensions, grain morphology, grain direction, and dendrite size.

2:00pm

Presentation 8: Machine Learning for Predicting the Mechanical Properties of Maraging Steel Manufactured by Laser Powder Bed Fusion with Different Build Orientations

Amanda Oliveira, Sydney Santos, Erik Gustavo Del Conte
Federal University of ABC, Brazil

Abstract: Processing parameters of Laser Powder Bed Fusion (LPBF) like build orientation can be managed to improve the product performance. Moreover, the LPBF-induced anisotropy may interfere in the product predictability mainly when this technology is combined with a post-processing step. In this sense, additive manufacturing technologies can take advantage of machine learning techniques to avoid a trial-and-error approach during process planning and boost a 4.0 Industry-based manufacturing structure. However, applying this kind of data modeling still needs further investigations regarding additively manufactured materials associated with post-processing (heat treatments). Thus, this study aimed to model critical mechanical properties of maraging steel manufactured with LPBF with XZ, ZX-45, and ZX build orientations before and after aging at 480 ºC for 3 hours. The bootstrapping of experimental results of the maraging steel obtained with tensile tests allowed modeling the ultimate tensile strength, elongation at break, and modulus of elasticity based on the investigated LPBF parameters using machine learning techniques. The more accurate models obtained in the study reached coefficients of determination higher than 0.95. These findings highlight a possible data-driven approach to guide process planning for getting the expected properties of maraging steel manufactured with LPBF.

2:20pm

Presentation 9: Additively Built Lattices with Tunable Response through Soft Inclusions

Asma El Elmi, Damiano Pasini
McGill University, Canada

Abstract: Additive manufacturing of hyperelastic polymers enables the fabrication of compliant porous structures for a wide range of applications including soft robotics, smart structures, and logic devices. In this work, we present a class of soft planar lattices with rationally designed imperfections and show how their often undesired embedding can be exploited to generate novel functionalities and unusual mechanical responses. Using a combination of numerical simulations and mechanical testing, we unveil the emerging mechanics and mechanisms that trigger instability and non-trivial non-linear responses. Our findings contribute to uncover principles that help us understand how the lattice geometry, such as pore geometry, and the hyperelasticity of the base material can result in the emergence of complex – yet exploitable and programmable – properties in soft systems.

2:40pm

Presentation 10: A Numerical Case Study on the Thermal Balance of a Pseudo Build Environment in Electron Beam Additive Manufacturing

Farhad Rahimi, Farzaneh Farhang Mehr, Steven Cockcroft, Daan Maijer
The University of British Columbia, Canada

Abstract: Developing a numerical model can help characterise the heat balance inside the build environment during an Electron Beam Powder Bed Fusion (EB-PBF) process. In this research, a 3D heat transfer model incorporating cavity radiation was developed to predict the temperature evolution and the heat balance within a simplified build environment during a heating experiment in the absence of powder. The pseudo build environment was constructed in an electron beam button furnace using a simplified ARCAM Q20Plus heat shield. The 3D model was validated using the data extracted from the experiments. Finally, four numerical cases were modelled to analyse the effect of the beam heating pattern size, initial preheat, powder deposition sequence and post powder deposition preheat on the thermal behaviour of the pseudo build environment. The results indicated that including these elements can influence the energy balance (input energy – heat losses) and evolution of temperature within the pseudo build environment. These numerical cases provided preliminary insight into future model development that can potentially characterise the thermal field within the build environment during the EB-PBF process.

SESSION 5: Process Monitoring and Control I
June 21 | 4:00pm EDT

4:00pm

FEATURED **Presentation 11: Intelligent Process Control in Metal Additive Manufacturing**

Chinedum Okwudire
Associate Professor
University of Michigan, United States

Abstract: Laser powder bed fusion (LPBF) additive manufacturing is gaining a lot of traction in industry for its ability to create fully-dense metal parts with intricate features and high tolerances. However, LPBF process parameters are often selected via trial-and-error or heuristics, leading to poor or inconsistent part quality. To address this problem, we propose an intelligent process control approach that is guided by physics-based and data-driven models combined with online optimization. As a specific case study of this approach, I will present our intelligent scanning algorithm, SmartScan, which uses thermal models to optimally determine laser scan sequences that minimize temperature gradients, part deformations and residual stresses in LPBF. In laser marking of stainless steel plates, compared to existing heuristic approaches, SmartScan has been shown to improve thermal uniformity by up to 42% and reduce part deformations by up to 45% with minimal sacrifice to printing time. I will discuss future work on extending SmartScan to more complex case studies, including multi-laser systems, as well as planned work for intelligent control of meltpool morphology and microstructure in LPBF.

4:20pm

Presentation 12: In-Situ Surface Roughness Detection in Laser Powder Bed Fusion using Advanced Monitoring and Machine Learning

Sahar Toorandaz, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Metal additive manufacturing (AM) has been increasingly adopted by major industries such as healthcare, defense, automotive, and aerospace in the last few decades. Despite its many advantages over subtractive processes, high surface roughness remains one of its downsides. Quality control and robust in-situ monitoring during production may thus have a significant impact on the process and foster the process reliability to arrive at high-quality and cost-efficient production. In this presentation, we will propose a novel integrated monitoring and machine learning approach that collects the light intensity emitted from the melt pool when a machine learning algorithm is adopted to predict the surface roughness of each layer in parts printed by laser powder bed fusion (LPBF). Unlike many other studies in this area that use images to predict surface roughness, the aim of this study is to predict surface roughness using in-situ time series photodiode signals. A number of algorithms are adopted among which Deep Neural Network (DNN) generally shows better results among those used. Based on preliminary results, a promising correlation can be found between light intensity and surface roughness in the LPBF-made parts.

4:40pm

Presentation 13: Toward Adapting Mobile 3D Printing to Metals and Regolith

Mohammad Azami, Pierre-Lucas Aubin-Fournier, Krzysztof Skonieczny
Concordia University, Canada

Abstract: This research presents a promising method for additive manufacturing (AM) of a large-scale part in segments via mobile 3D printing. The robot's position while printing each segment between motions is localized precisely through simultaneous localization and additive manufacturing (SLAAM), enabling the joining of subsequent segments while also maintaining overall geometric compliance of the printed part. SLAAM achieves sub-mm accuracy on objects over 400 mm long, despite the current printer's low dimensional accuracy and small (100 mm) workspace, and significant odometry error. SLAAM fuses local (3D scanner) and global (total-station range finder) sensing, and maintains estimates of key planar features of the printed part geometry in a global frame. Fused Filament Fabrication (FFF) was employed for the project's first phase. As the printing aspect and the navigation-localization aspect are decoupled, no inherent limitations prevent this approach from being combined with various 3D printing techniques or different materials. Next, we aim to print large-scale parts out of lunar-like regolith (granular igneous rock) and/or metal using the developed system coupled with a new 3D printer. Candidate AM approaches to combine with SLAAM include wire arc additive manufacturing (WAAM) to print metal parts and slurry extrusion combined with stereolithography (SLA) for regolith.

5:00pm

Presentation 14: Performance Evaluation of State-of-the-Art Machine Learning Methods in DED

Mihaela Vlasea, Gijs Houtum
University of Waterloo, Canada

Abstract: Current machine learning (ML) modelling efforts within additive manufacturing are often trained and validated on relatively small and non-diversified datasets. This can potentially provide an unrealistic sense of high performance to unseen data or operating environments. In this research, the current state-of-the-art ML modelling architectures in direct-energy-deposition (DED) focused on melt-pool geometry prediction based on in-situ monitoring technologies, are implemented, trained and tested on a larger and diverse dataset, encompassing multiple machine operating modes (variety of sensor positions, process parameters), multiple machines, and multiple in-situ sensor technologies. Results from this study will be presented in detail. This work provides therefore provides a more realistic evaluation of the performance of the current state-of-the-art ML methods on real-world data acquired from industry itself.

5:20pm

Presentation 15: FIR Filter Trajectory Generation for Additive Manufacturing Processes

Sharon Tam, Yusuf Altintas
University of British Columbia, Canada

Abstract: Trajectory generation and material deposition both are key factors that affect the final part quality of additive manufacturing processes. Most trajectory generation techniques used in additive manufacturing processes result in a rougher surface finish compared to methods used in CNC machining that produce much smoother movement. Current CNC trajectory generation methods include interpolation of the reference toolpath using splines or finite impulse response (FIR) filters. This study presents the use of FIR filters for trajectory generation with ongoing work in optimizing trajectory based on axes limitations and the material deposition rate of an additive manufacturing process. The reference toolpath is split into segments consisting of lines and circular arcs with corresponding velocity pulse signals. Cascaded FIR filters are applied to velocity pulse commands to smooth out the velocity and acceleration commands sent to the axes servo controllers which leads to avoiding inertial vibrations and irregular deposition of the material. Velocity pulses are overlapped at the junctions of path segments to achieve smooth transition of axes motions. The trajectory model is also used to predict the total manufacturing cycle time of a part.

SESSION 6: Novel AM Processes and Products I
June 21 | 4:00pm EDT

4:00pm

FEATURED **Presentation 16: Evolution of Powder Characterization for Additive Manufacturing**

Yao Yao Ding
B3D Performance Inc., Canada

Abstract: Additive manufacturing (AM) is a disrupting manufacturing technology with a growing popularity in numerous industries. Powder bed fusion (PBF) as one of the seven AM methods classified according to ASTM F2792, has gained most attention in metallic parts fabrication due to its high strength and dimensional accuracy. PBF-AM, critically relies on the interaction between the energy source and the thin layers of powder that conform the powder bed. In order to ensure a reliable and high quality of the part being built, it is imperative to understand and quantify the properties of metallic powder feedstock not only in its bulk state, but also as a thin layer in an operating PBF machine. For quantifying the powder bed density in AM, most approaches are using an estimate from measurement techniques traditionally used in powder metallurgy ruled by ASTM standards. Recently, state of the art technologies based on old methods, such as the shear test and the rotating drum technique, have found a niche of application in the AM sector. They provide information on the dynamic bulk properties such as resistance to flow and cohesion. However, technologies are yet to be developed for determining the real powder bed formation inside a printer.

4:20pm

Presentation 17: 3D Printed Multistable Perforated P-Shellular

Jiahao Shi*, Hossein Mofatteh*, Armin Mirabolghasemi*, Benyamin Shahryari*, Gilles Desharnais**, Hamid Akbarzadeh
**McGill University, Canada; **Axis Prototypes, Canada; McGill University, Canada*

Abstract: Shellulars are comprised of a periodic 3D unit cell of continuously smooth and non-self-intersecting shells. Shellulars offer less sensitivity to stress concentration and architectural defects than other cellular solids, and therefore are promising candidates for realizing ultralight architected materials with enhanced stiffness, strength, and resilience. They are routinely developed based on triply periodic minimal surfaces (TPMS) (e.g. Schwarz P , Schwarz D , and Gyroid) with zero mean curvature. The pre-fabricated topological features of TMPS hold great promise for creating shell-like metamaterials with unparalleled multifunctional properties for applications in bionic scaffold, catalytic converters, heat exchanger, and microbatteries. The geometry of shell surfaces can be also tailored in the post-fabrication state by harnessing structural instability. In this study, we present a novel design route for 3D printing of programmable and previously inaccessible deployable multistable shellular metamaterials by introducing delicate perforations on the surface of Schwarz's Primitive shellular. Two perforation design strategies are introduced and the mechanical properties and structural stability characteristics of the perforated shellular metamaterials are analyzed by simplified theoretical mechanics models, finite element simulations, and mechanical testing on SLS 3D printed samples. The developed perforated shellulars demonstrate controllable rigidity, enhanced energy dissipation, and a plethora of stable configurations.

4:40pm

Presentation 18: Design and Characterization of a Cell-Size Graded Gyroid Heat Exchanger Produced Using Direct Metal Laser Sintering

Lucas Gallant, Amy Hsiao, Grant McSorley
Faculty of Sustainable Design Engineering, University of Prince Edward Island, Canada

Abstract: Direct metal laser sintering (DMLS) additive manufacturing allows for the realization of part designs with complex geometries, such as triply periodic minimal surfaces (TPMS). One promising application of these printed lattice structures is in next-generation heat exchangers due to their high surface area to volume ratios. However, with small unit cell sizes, these designs suffer from large pressure drops and limited inlet/outlet designs. This work presents the modeling, print, and characterization of a cell-size graded gyroid heat exchanger design with an improved inlet/outlet. Pressure drop and heat transfer performance of the cell structure and design are analyzed by computational fluid dynamics simulation. Heat exchanger models were also printed on an EOS M290 printer using default exposure parameters and a parameter set optimized for improved quality of overhanging geometries. The print success of both printed parts was assessed through surface roughness and porosity measurements. The proposed TPMS heat exchanger with improved surface quality is evaluated as a potential design in applications where pressure drop and fouling are key considerations.

5:00pm

Presentation 19: Scratch Resistance and Damage Mechanisms in TiC-Ni3Al Cermet Coatings Fabricated by Pre-placement Laser Directed Energy Deposition

Zhila Russell, Kevin Plucknet
Dalhousie University, Canada

Abstract: To explore the practicality in repair and surface enhancement of tool steels by direct energy laser deposition, instrumented hardness analysis was performed. TiC-Ni3Al composite powder, pre-deposited on D2 and H13 tool steel by dip-coating, was subjected to selective area laser heating for the fabrication of well-adhered protective clads with negligible porosity. The mechanical performance of the clads under contact load and the induced microstructural response were examined by means of scratch testing. A high-frequency multichannel data acquisition system was used for instantaneous observation of possible submicron contacts while the coefficient of friction was recorded simultaneously for detection of frictional shifts during the test. Scratched surfaces, at applied various loads, were analyzed to quantify the extent of damage and critical failure modes. A combination of scanning electron microscopy and confocal laser scanning microscopy was utilized for the assessment of the worn tracks. A correlation was established by linking the observed hardness profile to the process-induced microstructural descriptions of the clad layer, including the role of dendritic formation and growth of carbides during laser processing of the TiC-based cermets. Comparison of calculated values for scratch hardness Hs with those obtained from untreated surfaces, confirms the effectiveness of the proposed technique.

5:20pm

Presentation 20: Analysis of Repair Interface Automated Hybrid Additive-Subtractive Manufacturing Process

Remy Samson*, Thomas Lehmann*, Tonya Wolfe**, Hani Henein*, Ahmed Qureshi*
**University of Alberta, Canada; **Centre for Innovation in Manufacturing (CIMTAC) , Red Deer Polytechnic, Canada*

Abstract: This paper will focus on automated scan-assisted in-situ remanufacturing using hybrid additive-subtractive manufacturing technology. Hybrid additive-subtractive manufacturing technology can be used to repair the mechanical parts with partial damage and have the potential to mitigate the need to scrap the damaged part and require complete replacement through a new purchase. This has a significant effect on the sustainability of the operation and reduces the cost of maintenance repair and overhaul. We present a CAD/CAM integrated hybrid manufacturing process for repairing damaged aluminum parts using subtractive and additive manufacturing. A damaged 6061 sample part is assessed and repaired with the hybrid manufacturing process. Automated damage identification is carried out by a 3D area scanner, followed by surface preparation by a vertical end mill. This is followed by a GMAW deposition source and Al-4043 0.89 mm filler wire for additive manufacturing repair. The paper presents initial results on the quality of the repair through a visual inspection and macroscopic evaluation of the cross-section of the repair.

SESSION 7: Novel AM Processes and Products II
June 22 | 8:00am EDT

8:00am

FEATURED **Presentation 21: Improving Mold Performance through Hybrid Metal AM**

Thomas Houle
Director LUMEX, North America, Matsuura Machinery, United States

Abstract: My case-study driven presentation will highlight how implementing the technologies available through Hybrid Metal AM will enhance Mold and Die performance in the areas of Cycle time Reduction, Mold/Die Manufacturing Time, Mold/Die Development Time and Part Quality. I focus on the the following technologies for Mold/Die manufacturing – Conformal Cooling/Heating. Controlled Porosity for Mold/Die Venting and Hybrid AM machining techniques that all result in substantial benefits to the Mold/Die industry. In addition, because Hybrid AM is such a specialized and unique manufacturing process my presentation highlights the process and techniques utilized in Hybrid AM and how they can be applied to the Mold/Die market. A portion of my presentation also highlights the benefits of a one-process/one-machine approach to manufacturing in terms of skilled labor – and the shortage of it experienced worldwide, and addresses the supply chain benefits of controlling your manufacturing process in a Hybrid environment. Lastly my presentation will provide real-world financial impacts that a successful implementation of Metal Hybrid AM can achieve for a Mold/Die manufacturing operation.

8:20am

Presentation 22: Magnetic Levitation for Additive Manufacturing: An Alternate Technique

Parichit Kumar, Saksham Malik, Ehsan Toyserkani, Behrad Khamesee*
University of Waterloo, Canada

Abstract: Magnetic levitation techniques have found significant applications within a wide variety of fields like energy harvesting transportation systems, amongst several others. The key objective of this research was to investigate the feasibility of magnetic levitation for additive manufacturing (AM) applications and subsequently develop the apparatus of facilitating the levitation. Having successfully developed a free levitation system capable of steady-state levitation of a non-magnetic material, the capabilities of the system developed are expanded through the employment of an alternative technique. The system consists of two concentric coils that carry current in the same directions and lateral stability maintained through the use of external stands. The compatibility of different materials used within AM environments is also tested through the development of a 'Levitation Ability' parameter. Conventional techniques to determine the compatibility of materials with magnetic levitation applications is heavily reliant on experimental analyses. A strong understanding of the material performance can be obtained through the developed parameters without experimental testing since the developed parameters are a function of only the material property. The parameter is subsequently verified using ANSYS Maxwell, a world-renowned software for magnetic applications.

8:40am

Presentation 23: Hybrid Additive-Subtractive Manufacturing of IN718

Sila Atabay*, Priti Wanjara*, Javad Gholipour*, Josh Soost**, Mathieu Brochu***
**National Research Council Canada, Canada; **Matsuura Machinery USA, Inc, United States; ***McGill University, Canada*

Abstract: Inconel®718(IN718) is a precipitation-hardenable nickel-based superalloy designed for strength, creep resistance, and fatigue life at temperatures up to 700°C. Additionally, it is known to have good weldability due to its relatively sluggish precipitation kinetics. Thereby, IN718 is used in aircraft engine components, making up more than 30% of the total weight of a modern aircraft engine. Nevertheless, conventional machining and forming processes possess difficulties due to the high hardness and low thermal conductivity of IN718, especially for complex geometries. Laser powder bed fusion (LPBF) enables fabrication of near-net-shape components with complex geometries, yet the produced parts have poor surface finish and require post-process machining. Hence, it would be of interest to use a hybrid manufacturing technique – involving both LPBF and subtractive processes in a single work envelope – to produce complex parts with high-quality surface finishes. In this study, benchmarking coupons of IN718 were fabricated by hybrid manufacturing using Matsuura LUMEX-Avance-25. The surface finish of the components was investigated after LPBF and high-speed machining processes. Microstructural and mechanical property characterization of the hybrid manufactured IN718 were conducted in the as-fabricated condition and after a standard solutionizing and age hardening heat treatment. Finally, the fracture behavior of the parts was examined.

9:00am

Presentation 24: Utilizing Process Maps to Engineer the Microstructure and Heat Treatment Responses of Low-alloy and Maraging Steels Fabricated by Laser Powder Bed Fusion

Mohsen Keshavarz, Sagar Patel, Mihaela Vlasea
University of Waterloo, Canada

Abstract: The ability to engineer the performance of material by tailoring microstructure can boost the value-added by metal additive manufacturing (AM) processes beyond the inherent design freedom offered by AM. In fusion-based metal AM techniques, this can be achieved by controlling the solidification and phase transformation during the process. In laser powder bed fusion (LPBF), the process parameter optimization efforts via process maps have been studied to achieve defect-free builds. Employing physics-based process mapping approaches can also offer a tool to predict the solidification behavior and microstructure. In this study, the potentials of utilizing LPBF process maps to guide the outcomes of the as-built microstructure and consecutive heat treatments in low-alloy and maraging steels were investigated. These alloys have been widely used in different applications where a combination of various mechanical properties is required thus depending on the application, the microstructure and heat treatment procedure need to be tailored.

9:20am

Presentation 25: Laser Powder Bed Fusion of M789 Steel on Wrought N709 Steel Substrate

Kudakwashe Nyamuchiwa*, Kanwal Chadha**, Yuan Tian***, Youliang He†, Clodualdo Aranas*
**University of New Brunswick, Canada; **Planetary and Space Science Centre, and Mechanical Engineering, University of New Brunswick, Canada; ***voetalpine Additive Manufacturing Centre Ltd, Canada; †CanmetMATERIALS, Natural Resources Canada, Canada*

Abstract: Laser powder bed fusion (LPBF) was used to produce and deposit a newly developed alloy, M789, on top of a 13-8 Mo-based wrought precipitation hardening steel, N709. A fully dense M789 was achieved together with a void-free interface. EBSD and XRD analysis confirmed a completely martensitic structure with less than 1% retained austenite in the as printed state and less than 3% after direct aging. In the as printed state, the M789 had a lower hardness of 550HV compared to 680 HV for N709 and after direct aging, the M789 section hardness peaked above 700 HV due to strengthening η-phase precipitates. After tensile testing, failure in the as-printed state was detected in the M789 section with a peak strength of 1019 MPa, consistent with the nanoindentation measurement across the M789-N709 interface. The application of heat treatment of the hybrid alloy shifted the failure zone to the N709 alloy with a peak strength of 1600 MPa.

SESSION 8: Process Monitoring and Control II
June 22 | 8:00am EDT

8:00am

FEATURED **Presentation 26: Plume Effects on Optical Signatures in Laser-Based Metal Additive Manufacturing**

David Deisenroth
Mechanical Engineer,
National Institute of Standards and Technology (NIST), USA

Abstract: Thermal emission and reflected laser radiation are two primary optical signatures which can be used for LPBF process monitoring and control, as well as understanding the fundamentals of the process for model validation. These signatures can be significantly affected by the byproducts of laser-matter interaction, such as metal vapor, condensate, and ejecta, and these effects depend on multiple process parameters, including protective gas flow speed and direction, angle of the laser beam incidence, etc. This presentation discusses (1) some observed signature variabilities, which indicate the possible significance of the plume effects on optical signatures of LPBF, (2) potential mechanisms of these effects and experimental approaches to their quantification, and (3) preliminary results of an experimental study with aims of better understanding and compensation of such effects. Finally, we will talk about further studies of fundamentals of laser-matter interaction in the context of laser-based additive manufacturing of the metals.

8:20am

Presentation 27: Real-time Control of Thermal Dynamics in Laser Additive Manufacturing using Adaptive Model Predictive Control

Richard van Blitterswijk, Lucas Botelho, Amir Khajepour
University of Waterloo, Canada

Abstract: In this research, an adaptive model predictive control algorithm is developed with the capability of controlling the thermal dynamics of Laser Additive Manufacturing (LAM) process in real-time. LAM is sensitive to disturbances in the process inputs resulting in variations in the melt-pool size and cooling-rate. These variations directly impact the material and mechanical properties of the processed material. Since these variations are caused by complex metallurgical phenomena, it is important to control the thermal dynamics in real-time. Real-time control systems ate usually error-based and do not have the ability to predict the effect of the control action on the system, deal with constraints, or relate LAM process variables with the material and mechanical properties of the processed materials. Therefore, Model Predictive Control (MPC) will be used since a simple thermal model can be developed using the finite difference method to predict the thermal dynamics in real time. Also, to compensate for modeling errors and to improve the model prediction accuracy, adaptive model optimization, using real-time monitoring is used, resulting in an adaptive thermal model. The adaptive model, together with MPC, can then be used to control the thermal dynamics in real-time.

8:40am

Presentation 28: Challenges in Physics-driven Machine Learning in Laser Powder Bed Fusion

Jigar Patel, Mihaela Vlasea
University of Waterloo, Canada

Abstract: Laser Powder Bed Fusion is one of the most widely adopted metal Additive Manufacturing technologies. Despite the clear benefits of design freedoms and near-net shape manufacturing, ensuring process stability and reliable prediction of manufacturing defects remain as ongoing challenges in the field. Recently, a significantly increasing body of research literature has deployed data-driven prediction of process outcomes. In such approaches, machine learning techniques have shown efficacy towards predicting process anomalies using annotated training data; however, most studies use a training dataset of limited scope and size. Therefore, predictions made are limited to a material system or certain processing conditions only. This presentation reviews the work done in literature so far and weighs the benefits and challenges of developing a large training dataset that spans wide range processing conditions, machines, material systems and sensor sources. Future directions on how to leverage such data are discussed.

9:00am

Presentation 29: Powder Jet/Laser Beam Modeling for Direct Energy Deposition in Extreme Process Parameters

Jason Guy, Morgan Dal*
Arts et Metiers, Institute of Technology, France

Abstract: Direct Energy Deposition is a versatile additive process uses for metallic parts reparation, 3D printing or coating. Some of these applications require significantly high or low dilution factor (i.e., the fraction of the molten pool below the substrate surface) – within a range of 5 to 90 %. This enhances powder jet-laser coupling phenomena like laser attenuation which occur via extreme process parameters. Nevertheless, accurate quantification of these couplings as 3D fields is a challenging goal in both experimental and simulation frameworks. Our approach intends to model the gas as well as the powder distribution flowing out and inside the nozzle, with different numerical methods: A discrete one as particle tracing, a continuous one as Euler-Euler model and a hybrid one as cloud tracking. Comparison with experimental characterizations of the jet by optical means allows to conclude on the importance of the fluid turbulences, the inelasticity of particles bounces on the nozzle or the consideration of the whole nozzle geometry on the powder jet shape. Finally, a coupling is performed with a ray tracing description of the laser in order to predict the heating of the particles and the attenuation of the laser beam.

9:20am

Presentation 30: Comparison between Absolute and Commercial Reflection Probes for Detecting Defects in Additively Manufactured Titanium and Stainless Steel Parts

Heba Farag, Behrad Khamesee
University of Waterloo, Canada

Abstract: Laser Additive Manufacturing (LAM) involves many process parameters such as laser power, hatch spacing, scan speed, layer thickness and powder morphology. All these parameters affect the quality of LAM-produced parts if not chosen properly. One of the challenges that LAM encountered is pores and cracks created within LAM-made parts. In this study, different eddy-current based probe designs (absolute and commercial reflection) were investigated to assess the feasibility of detecting defects with different sizes and at different depths in parts made of stainless steel (316) and titanium (TI-64) using LAM. Both probes can detect subsurface defects on stainless steel samples with surface roughness 11.6 μm and titanium samples with surface roughness of 8.7 μm. The absolute probe bottom surface is encapsulated with a coating layer which works as a filter to smooth out the detected signal from any ripples. The smallest subsurface defect size detected using both probes is a notch with 0.07 mm width and 25 mm length. Also, both probes detected subsurface blind holes in the range of 0.17 mm – 0.3 mm radius. The absolute probe is more suitable to detect cracks and incomplete fusion holes. The reflection probe is more suitable to detect small diameter.

SESSION 9: Advanced Process Modeling II
June 22 | 10:00am EDT

10:00am

Presentation 31: Semi-analytical Modeling of Temperature Field in Laser Powder Bed Fusion of Cu-Cr-Zr Alloy

Mazyar Ansari, Nadia Azizi, Mahyar Hasanabadi, Elahe Jabari, Ehsan Toyserkani
University of Waterloo, Canada; Multi-Scale Additive Manufacturing (MSAM), Canada

Abstract: Cu-Cr-Zr alloys have recently received extensive attention in metal additive manufacturing (AM) field owing to their combination of excellent thermal conductivity, strength, and fatigue resistance. The laser absorption coefficient of Cu-Cr-Zr alloys is relatively lower than the conventional AM materials. Hence, AM of this alloy is challenging and it needs a reliable and fast temperature simulation for process optimization. To accelerate the identification of suitable processing conditions in laser powder bed fusion (LPBF), this work presents a semi-analytical methodology that combines two heat sources to simulate the melt pool in both conduction and keyhole modes. The novelty of this approach lies behind the accuracy and time-efficiency of the model in the 3D simulation of the melt pool. The reliability of the model is then verified by the experimentally measured melt pool size in the case of LPBF-printed Cu-Cr-Zr alloy.

10:20am

Presentation 32: Numerical Evaluation of the Effect of the Support Structure Design on the Deformation of Overhang Parts Manufactured by the Electron Beam Powder Bed Fusion (EB-PBF) Process

Pegah Pourabdollah, Farzaneh Farhang Mehr, Steven Cockcroft, Daan Maijer
UBC, Canada

Abstract: Support structures are required for overhang parts fabricated by the Electron Beam Powder Bed Fusion (EB-PBF) process to prevent distortion and warping. However, the support structures require post-processing for their removal and represent material waste. Optimization of support structures can therefore reduce production time and costs. This work investigates the effect of different support structure designs on the distortion of the overhang portion of a component manufactured by the EB-PBF process. A 3D numerical model was developed to simulate the thermo-mechanical response of the component during and after the EB-PBF process. The data extracted from the Arcam Q20plus EBM, including the power and time associated with processing each layer, were imported into the model. A time-averaged heat input strategy and the agglomeration method were implemented in the model to reduce the computational time. The model was validated by comparing the predicted distortion against the measured values obtained from a coordinate measurement machine. The results showed a good agreement between the predicted and measured distortions.

10:40am

Presentation 33: In situ Processing of Rapidly solidified Al-33wt%Cu Droplets

Jonas Valloton*, Najia Mahdi**, Loraine Rabago*, Jason Chung*, Hani Henein*
University of Alberta, Canada; Norcada Inc., Canada

Abstract: Under rapid solidification conditions, Al-33wt%Cu eutectic droplets develop a microstructure composed of two different morphologies: an undulated eutectic, assumed to grow during recalescence, followed by a lamellar eutectic growing post recalescence. In situ heat treatments are applied to Al-33wt%Cu droplets rapidly solidified using Impulse Atomization to investigate the dynamic effect of temperature and time on the two eutectic morphologies. The samples are aged in situ in a SEM using a heating stage developed by Norcada. The undulated region coarsens faster than the regular eutectic, with fine lamellae still visible at 500°C. At 525°C, both regions are indistinguishable from each other. Coarsening rates are evaluated for both regions and compared to established models. At 550°C the droplet is fully liquid, but retains its shape due to the oxide skin. This allows in situ solidification experiments. The resulting eutectic morphologies and spacings are analyzed as a function of the imposed cooling rates.

11:00am

Presentation 34: Modelling of Single Pass Wire and Arc Additive Manufacturing

Anqi Shao*, Anne MacDonald*, J Borrelli*, Kim Meszaros**, Jonas Valloton*, Ahmed Qureshi*, Hani Henein*
**University of Alberta, Canada; **MattCo Engineering Solutions Inc., Canada*

Abstract: Wire and arc additive manufacturing (WAAM) is a type of direct energy deposition method and one of the additive manufacturing (AM) processes with the highest throughput. It is based on welding technology, using an electric arc as a heat source and a metallic wire as feedstock. Motion can be provided using a robotic arm or a gantry system. When melted, the feedstock material is deposited onto a substrate in the form of beads. A layer of metallic material is created as the beads coalesce. The process is then repeated layer by layer until the metal part is completed. In this work, single strands or stringers of ER70S-6 (UNS K11140) are deposited with the WAAM process. The strands are then modeled using the Additive Manufacturing module of Abaqus. The cooling rate and solidification time of the deposited layer thus obtained are modeled and compared to microstructural examination of the stringer sample. This approach is aimed to determine the initial solidification structure of any layer deposited during an AM build of a component.

11:20am

Presentation 35: Particle-scale Simulation of Powder Spreading in the Presence of Gas in Additive Manufacturing

Sorush Khajepor, Sina Haeri
University of Edinburgh, United Kingdom

Abstract: Powder bed fusion (PBF) is a versatile AM technology for rapidly creating intricate parts. A blade or roller spreads a thin layer of powder on a bed. A laser beam fuses a cross-section of the part on the layer. Layer over

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

layer, the process is repeated until the final part is produced. The spreading parameters can lead to higher bed roughness and porosity that degrade the quality of the final product. There have been studies on the effect of inert gas-particle interactions during the spreading process using CFD-DEM. However, the goal that differentiates this work from others is that we accomplish this task at a particle scale. We study the dynamics of the inert gas around particles and spreaders where each particle is fully resolved by many fluid cells. The powder is Inconel 718 which is characterised in the lab using SEM, Nano-Tomography and angle of repose tests. The drag force on particles is compared with contact forces. We show that the existence of gas can heavily affect bed solid fraction and surface roughness for low cohesive powder. The gas effect on high cohesive powder is less apparent, but the distribution of void spaces on the bed is noteworthy.

SESSION 10: Material Development II
June 22 | 10:00am EDT

10:00am

FEATURED **Presentation 36: NRC-Brookside: Canada's newest Additive Manufacturing R&D Center**

Ehab Samuel
Research Officer, NRC, Canada

Abstract: The NRC – Canada's leading scientific and R&D entity – recently established a large-scale collaborative effort with the University of Manitoba, in order to dedicate the coming years to the advancement of additive manufacturing as a disruptive technology that is increasingly being adopted by Canadian industry. As such, the newly opened NRC-Brookside facility serves as an R&D hub not only to promote cutting-edge additive manufacturing (AM) technologies, but also to build upon Manitoba's AM expertise – in both industry and academia – as well as that cultivated at NRC's Boucherville site. Equipped with both a production-level quad-laser powder bed fusion (LPBF) printer and a binder jetting 3D printer, in addition to expertise in metallurgy, mechanical testing, automation and machine learning, NRC-Brookside is committed to aiding its clients, especially with the shift towards Industry 4.0. In collaboration with the University of Waterloo's Multi-Scale Additive Manufacturing (MSAM) lab, the AM applications initially investigated include conformally-cooled maraging steel tooling using LPBF for efficient die casting operations, as well as the mass customization of high-throughput aluminium alloy parts using binder jetting. This presentation shall highlight some of the work already taking place at NRC-Brookside in addition to what is on the horizon.

10:20am

Presentation 37: Influence of Heat Treatment on Microstructure and Mechanical Properties of Al40Si Fabricated by AM

An Fu, Satish Tumulu, Priti Wanjara, Mathieu Brochu
McGill university , Canada

Abstract: Hypereutectic Al-Si alloys have wide industrial applications such as aircraft, automobile, electronic packaging, as driven by their high specific strength, desired wear and corrosion resistance, high thermal conductivity, low coefficient of thermal expansion and so on. The mechanical properties of hypereutectic Al-Si alloys can be considerably enhanced by Additive Manufacturing (AM), in which microstructure refinement, increased solid solubility of strengthening elements, desired grain morphology can be achieved by rapid solidification. Meanwhile, the microstructure and mechanical performance of hypereutectic Al-Si can be further modified by heat treatment.

In this study, Al-40Si samples with different geometries were fabricated by Laser Powder Bed Fusion (LPBF) using optimized parameters, the as-built samples were heat treated at different temperatures and durations. A series of microstructure characterizations and mechanical tests were performed on as-built and heat-treated samples, in order to systematically investigate the effect of heat treatment on microstructure and mechanical properties of Al-40Si samples.

10:40am

Presentation 38: AM Using Novel A8 Tool Steel Powders Produced by Water Atomization

William Chaîné, Carl Blais
Université Laval, Canada; Université Laval, Canada

Abstract: Most additive manufacturing processes use gas atomized metal powders as input material. Development of metal powders for AM produced by water atomization could bring significant advantages related to cost reduction. Obviously, water atomization is not appropriate for all the alloys of interest in AM, but it certainly is for tool steels. This is even more the case since recent development allows the production of regular (near spherical) particles by water atomization. By producing powders using water atomization and treating them, it is possible to obtain powders with similar and even better properties than gas atomized powders. This study shows properties of AM components made of A8 tool steel powders that were water atomized and improved by different techniques such as plasma spheroidization and heat treatment.

11:00am

Presentation 39: Copper infusion in to LPBF-AM Mo Alloy Lattice Structures for Tailored CTE Heatsinks

Tejas Ramakrishnan, Mathieu Brochu
McGill University, Canada

Abstract: Laser powder bed fusion additive manufacturing (LPBF-AM) is a manufacturing technology that enables the fabrication of complex parts that are difficult to fabricate using conventional processes such as casting, machining, or forming, with ease for a variety of materials. Steel, aluminum, titanium, nickel alloys and refractory metals are some material systems that have been extensively studied under LPBF-AM processing. Lattice structures have been produced and studied for many of these alloy systems and demonstrated for refractory metals. TZM is an alloy of Molybdenum suitable for various high temperature applications due to its higher melting point, thermal conductivity, high temperature strength and resistance, and low coefficient of thermal expansion (CTE). TZM is an ideal candidate material to replace Mo in Mo-Cu laminate or composite components used as heat-sinks in power electronics. In this study, we report the fabrication and characterization of TZM lattice structures. Following this, we demonstrate infusion of oxygen-free high conductivity (OHFC) copper into the TZM lattice structure under an inert atmosphere and evaluate the thermal expansion behavior, particularly the influence of high CTE copper. We also discuss the impact of the thermal loading of the TZM lattices and Cu-infused TZM lattices on their microstructure, CTE, and cracking resistance.

11:20am

Presentation 40: Microstructural Characterization of Functionally Graded H13 Tool Steel and Copper using Directed Energy Deposition

Owen Craig*, Kevin Plucknett*, Scott Halliday**, Joshua Toddy**, Nylana Murphy*
**Dalhousie University - Mechanical Engineering, Canada; **Navajo Technical University, United States*

Abstract: This research varied laser power settings to deposit H13 and copper (Cu) into a single, compositionally graded sample, known as a functionally graded material (FGM), using directed energy deposition (DED). This began with single layer and 3-layer tracks of varying mixtures of H13/Cu to determine if printing is possible with the system parameters. Two rectangular samples were printed using two different powers to examine the ability to print a functionally graded material of H13/Cu. The FGM's were printed starting from pure H13 tool steel at the substrate to pure Cu with six compositional changes in the build direction (z+). From this, it was noted that there is transverse cracking, porosity, and micro-porosity in the layers containing larger amounts of copper. The porosity is mainly situated in the copper regions of the deposit. Separation of the copper and steel occurred and is attributed to the low solubility of copper in iron. This created iron-rich and copper-rich zones in the deposited material. From the selected parameters, depositing H13 and Cu into a functionally graded part was unsuccessful. Improvements to the FGM build may be achievable by adding a 'buffer layer' or altering the parameters depending on the varying compositions.

SESSION 11: Advanced Process Modeling + Process Monitoring and Control III
June 22 | 1:00pm EDT

1:00pm

Presentation 41: A Deep-Learning-based In-Situ Surface Anomaly Detection in Laser Directed Energy Deposition-Powder Fed

Farzaneh Kaji*,**, Alikasim Budhwani*,**, Jinoop Narayanan*,**, Mark Zimny**, Ehsan Toyserkani*
**University of Waterloo, Canada; **Promation, Canada*

Abstract: Laser Directed Energy Deposition via Powder Fed (LDED-PF) based Metal Additive Manufacturing suffers from inferior dimensional accuracy mainly due to thermal cycling, localized heat accumulation, inconsistency in the speed of the motion system and powder focus, etc. In-situ monitoring, along with defect detection algorithms can be used for avoiding unpredictable build failures while minimizing the time and cost of exhaustive ex-situ characterization techniques. Existing surface quality assessment techniques for LDED-PF mainly focus on intermittent process monitoring, data acquisition, data post-processing, feature extraction, and error identification. The present work investigates the development of a novel in-situ monitoring software platform that can be used for surface anomaly detection of the LDED-PF parts using machine learning techniques. A novel method is developed to calibrate the laser line scanner with respect to the robotic end-effector. Subsequently, 2D surface profiles obtained from LDED-PF built part surface using the laser scanner are stitched together to create an accurate 3D point cloud representation. Further, the point cloud data is processed, and defect detection is carried out using unsupervised learning and supervised (deep) learning techniques. The study paves the way for the development of automatic tool path generation for the LDED-PF process to build high-quality components.

1:20pm

Presentation 42: Development of Intermittent Controllers for Laser Powder-bed Fusion

Katayoon Taherkhani*, Gerd Cantzler**, Christopher Eischer**, Ehsan Toyserkani*
**UWaterloo, Canada; **EOS , Germany; EOS, Germany*

Abstract: This research aims to shed some light on the methodology needed for the development of intermittent controllers for healing porosity created during laser powder-bed fusion. As the first step, defects are identified by different machine learning methods, such as the Self-Organizing Map (SOM) algorithm. Then, the identified pores are clustered using the K-means algorithm as one defect in the specific area of the build plate. After that, the targeted area around the center of each cluster is optimized as the position at which the laser power should be changed. To validate the concept and method, two sets of experiments incorporating artificial and randomized defects are designed and manufactured to evaluate the performance of the controller. Finally, the results were validated with a micro CT scan. The comparison uncovered that the use of the controller resulted in increasing the density of coupon samples with randomized defects up to 1%.

1:40pm

Presentation 43: Design, Development and Validation of an Instrumented Powder Testing Apparatus for Powder bed-based AM Applications

Salah Eddine Brika, Vladimir Brailovski
Ecole de technologie superieure, Canada

Abstract: Selection and quality control of powder feedstock for the powder bed-based additive manufacturing (PBAM) processes is challenging since the link between the powder intrinsic characteristics and the process performances is not clearly defined yet. Suitability of the conventional rheological characterization methods for PBAM feedstock is debatable, since the conventional testing conditions differ significantly from those involved in the application of interest. Moreover, outputs of the conventional testing methods are difficult to link to the relevant powder characteristics to be optimized for the PBAM processes. To be capable of speeding up the powder spreading, while maximizing the powder bed density, minimizing the spreading forces and preserving the powder bed uniformity, a novel mechanized and instrumented apparatus is developed to replicate the operating conditions of an industrial PBAM equipment. This apparatus allows the measurements of powder bed density, surface uniformity and spreading forces as functions of the powder characteristics, spreading speed and the type of spreading mechanism.
A comparative study case is presented to validate the capabilities of the apparatus and its relevance for the powder feedstock quality control and as a research and development tool dedicated for PBAM applications.

2:00pm

Presentation 44: Rapid Prediction of Thermal and Stress Distributions in LPBF Process Using a Finite-difference Modeling Approach

Shahriar Imani Shahabad*, Gholamreza Karimi**, Ehsan Toyserkani*
*University of Waterloo, Canada; **Shiraz University, Iran*

Abstract: The laser Power-bed Fusion (LPBF) process suffers from the induced residual stresses in printed parts due to the inherent high-temperature gradient during the process. A trial-and-error experimental approach would be inefficient for minimizing the residual stresses. Therefore, numerical modeling and simulation are beneficial tools for predicting residual stresses and deformation of LPBF printed parts. However, the computational cost for conducting the thermo-mechanical LPBF modeling is extremely expensive. In this presentation, a transient 3D LPBF model has been developed for Hastelloy X using thermal resistance and capacitance network. Gaussian distribution with variable penetration depth has been assigned to the moving laser beam while scanning a powder bed. Governing equations along with the boundary conditions have been solved using the finite difference approach through Alternating-direction implicit (ADI) technique. The transient temperature profiles have been used to predict the melt pool geometry, evaporating zone, and the resulting thermal stress distributions within the built material. A parametric study has been conducted to assess the effect of laser operating conditions (scanning speed, laser power) on the melt pool dimensions. The simulation results demonstrate that by using the developed model the computational time is reduced significantly while providing acceptable accuracy.

2:20pm

Presentation 45: Powder and Vapor Consideration for Additive Manufacturing LPBF Simulation

Morgan Dal*, Yaasin Mayi**, Kevin Marchais***, Patrice Peyre†
*Arts et Metiers, Institute of Technology, PIMM laboratory., France; **Safran, France; ***Arts et Metiers, Institute of Technology, PIMM laboratory., I2M, France; †Arts et Metiers, Institute of Technology, PIMM laboratory., CNRS, France*

Abstract: The Laser Powder Bed Fusion (LPBF) process, studied here, is clearly one of the most complex processes due to its multiphysic and multiphasic aspects. In this process the beam is thin (1 m/s) and the whole material phases (powder, liquid, gas and solid) can interact together and with the beam, producing instabilities and complex behaviors. Thus, due to these extreme operating parameters, experimental investigations are not trivial. In parallel, numerical tools become more and more efficient and allow currently to manage, with reasonable computation times, these kinds of highly coupled physical problems.

In this paper, authors propose a thermo-hydrodynamic simulation of the LPBF process at the mesoscale. Indeed, a major part of defects comes from the close environment of the laser beam and the molten pool.

The model includes the gas/vapor atmosphere, the powder and the substrate materials in static laser configurations. A realistic powder bed is set in the model thanks to powder spatial distribution and particle radii coming from another numerical analysis (Discrete Element Method). The metal-gas interface is tracked by the Eulerian Phase-Field method. A particular caution has also been taken in the realistic representation of the vaporization process.

SESSION 12: TRACLIGHT
June 22 | 1:00pm EDT

1:00pm

Presentation 46: Lithography based Metal Manufacturing of Nickel Titanium Alloys – Challenges and Chances of the Novel Manufacturing Process

Lucas Vogel*, Martina Zimmermann**, Carlo Burkhardt*
*Institute for Precious and Technology Metal, Pforzheim University, Germany; **Institute of Materials Science, Technical University Dresden, Germany*

Abstract: Lithography based metal manufacturing (LMM) is an upcoming sinter-based additive manufacturing (AM) process, to print with advantages in precision, minimal feature size and surface roughness. Development of new materials for the technology is key to implementation in the industry and expansion of applications. The stereolithography shaping process enables the technology to print stable green parts with excellent strength and small feature sizes. However, it also creates a couple of challenges in the further process chain due to its used materials. Nickel – titanium alloys (NiTi) are often used in medical applications, not only because of their mechanical and chemical properties, but also because of their functional properties known as shape memory effect. A challenge with the powder metallurgical fabrication of these alloys is the needed purity to reach their full potential. This article gives an introduction in the LMM technology and categorize it into the range of sinter based additive manufacturing processes. Also, it presents a project to develop production NiTi for the LMM technology focusing on the characteristics both the manufacturing process and the alloys challenges.

1:20pm

Presentation 47: Optimization for Automated Design of Novel Alloys for Additive Manufacturing

Fazal Mahmood
Phaseshift Technologies Inc., Canada

Abstract: Historically, the performance of components has been highest when they are made from alloys that have been tailored to the specific demands of the manufacturing process by which they are made. Additive Manufacturing is not likely to be any different. Most legacy alloys were developed for traditional manufacturing techniques, like casting or forging, and as a result, the performance of AM components can be sub-par. Data-driven processes, such as Machine Learning (ML)-based Bayesian Optimization (BO), have proved to be a very powerful tool in the discovery of new alloys optimized across the full range of design parameters. Here we discuss, how Phaseshift's Rapid Alloy Development (RAD) platform, based on similar data-driven processes, can be used to automate the design of new alloys with an order of magnitude fewer experiments. Additionally, the platform's applicability in designing new alloys for Additive Manufacturing will be discussed.

1:40pm

Presentation 48: Characterization of a New Tool Steel Alloy for Laser Additive Manufacturing

Manuela Neuenfeldt*, Gregor Graf**, Tobias Müller***, Jörg Fischer-Bühner†, Daniel Beckers**, Volker Schulze*, Frederik Zanger*
**wbk Institute of Production Science, Germany; **Rosswag GmbH, Germany; ***Gühring KG, Germany, †Indutherm Gießtechnologie GmbH and BluePower Casting Systems GmbH, Germany*

Abstract: The development of high-strength tool steels for AM is a promising topic for the acceptance of laser powder bed fusion (PBF-LB) in the field of function-optimized die, forming and cutting tools. As part of a GER-CAN research project (HiPTSLAM), the new Specialis® maraging tool steel was developed with the requirements in these areas in mind. When qualifying new materials for the AM process, the entire process chain must be taken into account. The holistic approach of development is demonstrated by a case study using the Specialis® tool steel alloy. This steel was developed specifically for the PBF-LB process to achieve beneficial performance properties. In this project, the influence of the atomization process on the PBF-LB process is investigated and an effective qualification method for a new alloy in the PBF-LB process is established. In addition, the influence of an in-situ heat treatment strategy is analyzed by using a second laser. Based on the initial microstructure analyses, a set of promising parameters was used to generate samples for heat treatment studies, mechanical characterization and post-processing by machining. In particular, the drilling and milling processes on additively manufactured components are investigated here.

2:00pm

Presentation 49: LPBF and DED Process Development for Newly Developed Hot Work Tool Steel (HIPTSLAM)

Alexandre Bois-Brochu*, Justin Plante**, Edem Dugbenoo***, Carl Blais**, Mathieu Brochu***
**Quebec Metallurgy Center, Canada; **Université Laval, Canada; ***McGill University, Canada*

Abstract: The HIPSTLAM project aims to develop tool steels compositions designed specifically for additive manufacturing processes for applications in the wood cutting industry, aluminium extrusion and high pressure die casting. The objective is to develop improvements on A8 and H13 tools steels with increased high temperature strength, toughness, wear resistance and thermal conductivity. A state of the art of the development of DED process parameters of H13 steel is presented with a specific aim at the competition between productivity and mechanical properties. The development and characterization of DED and preliminary development of LPBF for newly developed Nordics powders as an alternative to H13 in AM will be discussed.

2:20pm

Presentation 50: Most Wanted: New materials for Metal AM

Gregor Graf
Rosswag GmbH, Germany

Abstract: The very limited choice of materials for metal 3D printing is a key obstacle to the industrialization of this disruptive manufacturing technology. More qualified materials lead to more industrial applications, for example in lightweight construction, which have great potential for increased resource and cost efficiency over the product life cycle by means of function-optimized component geometries. Through an innovative process chain with attached metal powder production, new materials for metal 3D printing can be qualified to a high level of industrial maturity with minimal time and resource input. Thus, more users from different industries can be enabled to use additive manufacturing technology advantageously in the shortest possible time. Examples of qualified materials and implemented applications demonstrate this potential and provide a positive outlook regarding the further development of additive manufacturing technology.

SESSION 13: Novel AM Processes and Products III
June 22 | 3:00pm EDT

3:00pm

Presentation 51: In Vitro Testing and Assessment of Additive Manufactured Lattice-Structured & Solid Titanium Dental Implant Overdenture Bars

Les Kalman
Western University , Canada

Abstract: The implant bar overdenture remains a predictable treatment option for the edentulous patient. Fabrication of the implant bar is accomplished through milling (subtractive manufacturing) that has been considered inefficient and costly. Additive manufacturing provides alternative fabrication that seems to be more efficient and cost-effective. This project investigated metal additive manufacturing of lattice-structured and solid dental implant bars. The AM bars were compared to milled bars for (1) flexural modulus (2) maximum strength (3) fit and (4) denture compatibility. Results indicated a mean flexural modulus and maximum strength of (i) 150.3 GPa and 6.88 kN, for AM solid bars, (ii) 118.9 GPa and 5.72 kN for AM lattice-structured bars and (iii) 97.0 GPa and 5.95 kN for milled bars, respectively. The milled bar values may have been inaccurate due to a small structural defect, which was a location of stress concentration. Fit was evaluated through visual and radiographic assessment of the bars, which were torqued onto implants on a patient model. All bars were acceptable. All bars were compatible with an overdenture, with acceptable support and retention. Further physical testing may be required to address the structural variation. This investigation bridged knowledge gaps regarding AM lattice-structured and solid dental implant bars.

3:20pm

Presentation 52: Key Performance Specifications Of An Affordable Metal Powder-Bed Fusion Printer

Dave Jankowski
Xact Metal, United States

Abstract: A key limitation to the adoption of metal powder-bed fusion printing technology by more industries has been a prohibitive high price. This presentation will discuss the key performance specifications of a recently introduced affordable galvanometer-based metal powder-bed fusion printer including successful applications in prototyping, tooling, dental, and workforce development.

3:40pm

Presentation 53: Availability and Cost efficiency by Digitalization of Metal Spare Parts Manufacturing – Integration of Qualified WAAM Parts in the Industrial Supply Chain

John Manley
Machine Tool Systems Inc.

Abstract: DED WAAM gets an increased attention in the industries along with steadily improved industry readiness. Cost efficient fabrication and short lead-times of large metal components are a huge asset of the WAAM technology. Industrial players benefited already at various applications from the integration of WAAM manufactured parts in their products and supply chains. The task is now to transfer the made experiences and develop and scale WAAM capacities to further applications and uses. Learn from concrete examples from GEFERTEC/ Germany, one of the leading WAAM supplier globally, how qualified WAAM components can be developed and integrated into the industrial supply chain. The focus lays on WAAM technology and its integration in industries such as transportation, energy, machine building, aviation, defence and the maritime sector.

4:00pm

Presentation 54: Unlocking the Previously Impossible Geometries of Metal Additive Manufacturing by Reducing Cost-Per-Part

Michael Wohlfart
EOS, United States

Abstract: The OEMs of laser powder bed fusion systems in metal additive manufacturing (AM) have historically focused on the improvement of reliability and productivity. While this is a major part of the OEM equation, there is another important variable, which is influenced by the systems' productivity – cost-per-part (CPP) reduction. The increase in productivity was achieved by introducing multi-laser systems, but CPP reduction still has the opportunity to improve through real innovation.

EOS has taken this growth opportunity and developed multiple software and hardware tools to overcome this challenge.

In this presentation you will learn:

- What strategic software strategies such as specialized exposure for shallow application angles can reduce the number of support structures required per build and thereby lower CPP.
- How power modulation of the laser can enable previously impossible thin-walled geometries.
- Why Beam Shaping can be used instead of traditional fixed spot diameter lasers with a gaussian intensity profile to achieve higher build rates.

Combining these new tools and leveraging them for more successful 3D printing results will lead to CPP reduction and unlocked, previously impossible, application geometries for future metal AM production.

4:20pm

Presentation 55: Validation of Multi-Laser Printing Technology for Additive Manufacturing

Donald Godfrey
SLM Solutions, United States

Abstract: The aviation market (defense and commercial) is a risk mitigation industry and designers must have material property data (material strength data) so components can be designed without the fear of failure. Customers / insurance organizations require accurate engineering and science be applied to components designed using manufacturing methods that involve additive manufacturing. While Additive Manufacturing is being accepted more frequently, there is still some cultural resistance in the design community and is viewed as an introduction of risk. This perspective increases when one begins printing with multiple lasers. Large machine build areas are required to implement multi-laser technology. This presentation will explain the multi-laser printing approach and show comparisons of single versus dual laser tensile specimens results. The presentation will show using objective evidence that dual laser technology from SLM will produce printed components with the same material strengths as with single laser technology and both are superior to casting technology.

4:40pm

Presentation 56: Investigation of Organic Binders and Aluminum Powder Interactions and Sinterability of Aluminum Compacted Powder Parts

Solgang Im, Arunkumar Natarajan
GE Additive, United States

Abstract: Binder Jet Additive Manufacturing (BJAM) is an interesting alternative to other additive manufacturing (AM) modalities since it does not require melting to fuse powder material but selectively adheres powder with a binder. GE has successfully shown printability and processibility of large parts with complex geometries for a number of customer applications using BJAM with metal alloys such as SS316, SS304, 17-4PH, Ni and Cu alloys using GE Additive's Series 2 Binder Jet Line. Binder jetting of aluminum powder has progressively gained industry interest, especially from automotive and aerospace, for the fabrication of lightweight products. However, the interactions between the organic binders and oxidative behavior of aluminum powder – and therefore its printability and processability – have not yet been extensively studied by researchers. The current research focuses to understand the impact of different organic binders on the final quality of the fabricated sample through performing composition and porosity analyses on the debound and sintered samples. The resulting impurity levels and final density are evaluated to identify the most compatible organic binder for aluminum powder. The alcohol solvent-based binder is identified as a suitable candidate as it provides the highest densification with minimal chemical interactions between the binder and aluminum powder.

5:00pm

Presentation 57: Wear Resistant Materials Produced by Additive Manufacturing Technologies

David Waldbillig, Marcus Ivey
Exergy Solutions, Canada

Abstract: Wear resistant materials are used in many industries to enhance the reliability of parts in challenging service conditions but are difficult to produce using additive manufacturing techniques. This presentation will discuss various additive manufacturing technologies used to produce wear resistant materials and will compare microstructural, mechanical, and wear resistance properties of samples produced by additive manufacturing to conventionally produced wear resistant materials. A new class of additively manufactured wear resistant materials produced using Electron Beam Melting (EBM) systems from GE Additive Arcam and from Wayland Additive will be introduced and the benefits of using additive manufacturing to improve lead times, cost, and reliability for real-world energy applications will be discussed.

SESSION 14: Material Development III
June 2 | 3:40pm – 5:20pm EDT

3:00pm

Presentation 58: Practical Collaboration for Science

Mark Zimny
President, Promation, Canada

Abstract: NSERC/CFI Network for HI-AM is set up for collaborations between universities and for collaborations of universities with industry. Results of a survey on the status and health of ongoing collaborations are presented jointly by Promation, a member of industry group and by UoW. The survey's results are to inspire the Network to innovate and to improve the collaborations. Promation presents an innovative concept of a practical collaboration when a single 3D Printing System might be utilized by multiple parties. The parties obtain secured valuable scientific data for their individual research.

3:20pm

Presentation 59: Effects of TiB2 in an Al-Cu-Sc Alloy in the Hybrid Investment Casting Process

Jose Dias Filho, Aleeza Batool, Yifan Li, Ahmed Qureshi, Hani Henein
University of Alberta, Canada

Abstract: Al-Cu alloys are largely used in the automotive and aerospace area, but with the advance of technology new alloys are necessary. Sc additions show an effect to improve the performance of Al-Cu alloys. This work shows the characterization of Al-4.5wt%Cu-04wt.%Sc alloy with and without TiB2 addition in the hybrid investment casting of lattices process. The experimental proceeding consists of PLA 3D printer lattice attached to the rubber base using polymer clay, pouring the plastic cast ceramic slurry into the flask with print inside, burnout cycle to eliminate wax/polymer in the mold, pouring the alloy in a preheat mold attached with an applied vacuum. Microstructure and microhardness were observed. This work aims to also explore the effect on microstructure and hardness of TiB2 as the refined grainer for Al-4.5wt%Cu-04wt.%Sc alloy.

3:40pm

Presentation 60: Structure of LMJ Aluminum

Colin Fletcher
Xerox, United States

Abstract: 4008 aluminum alloy parts produced by Liquid Metal Jetting (LMJ) possess a unique microstructure consisting of both features typical of 300-series aluminum casting alloys and structures resulting from the liquid metal jetting process. 4008 is an alloy designation registered with the Aluminum Association and is equivalent to casting alloy A356. Wire feedstock used by the ElemX printer is produced under the 4008 designations as a wrought product, and parts produced using this material are referred to as 4008 Al. This presentation aims to describe typical microstructural features produced by LMJ process and recommended techniques for specimen preparation and evaluation.

4:00pm

Presentation 61: Influence of Post-processing Conditions on the Microstructure and Fatigue Resistance of Laser Powder Bed Fused Ti-6Al-4V Components

Alena Kreitcberg, Erika Herrera-Jimenez, Etienne Moquin, Morgan Letenneur, Vladimir Brailovski
École de technologie supérieure, Canada

Abstract: The microstructure, static and fatigue mechanical properties of laser powder bed fused (LPBF) Ti-6Al-4V components subjected to three different post-processing treatments are compared. The first treatment included stress relief and low-temperature annealing (SR-BA), the second included stress relief, beta solution and overaging (SR-BSTOA), and the third, hot isostatic pressing, beta solution and overaging (HIP-BSTOA). It was demonstrated that the SR-BA treatment leads to the decomposition of α' martensite inherited from the LPBF process and the formation of an α/β lamellar microstructure (average α lamellae width ~3μm). The SR-BSTOA and HIP-BSTOA treatments lead to a coarser lamellar structure (~8 and 4μm, respectively) and to the formation of semi-equiaxed grains (~300 and 500μm, respectively) compared to columnar grains (~100μm-width, ~300μm-long) after the SR-BA treatment. Results of the stress-controlled fatigue testing showed a superior fatigue strength of the SR-BA specimens compared to their HIP-BSTOA and SR-BSTOA counterparts: 725 MPa after SR-BA, 500 MPa after SR-BSTOA and 680 MPa, after HIP-BSTOA (all on the base of 10E6 cycles). These observations demonstrate that a two-step SR-BA thermal treatment of LPBF Ti64 components could be a valuable and less expensive alternative to the three-step SR-BSTOA and HIP-BSTOA treatments, when fatigue life is the main concern.

4:20pm

Presentation 62: Laser Powder Bed Fusion (LPBF) Processing of UNS C63020 Nickel Aluminum Bronze Powder

Addison Rayner, Jon Hierlihy, Melissa Trask, Randy Cooke, Paul Bishop
Dalhousie University, Canada

Abstract: Nickel Aluminum Bronze (NAB) alloys are widely used in marine applications due to their high strength and superior corrosion resistance. NAB components are traditionally cast and exhibit complex microstructures consisting of intermetallic κ phase precipitates distributed in α and β solid solution phases. Laser powder bed fusion (LPBF) is an additive manufacturing technique that selectively fuses layers of metal powders into a desired part geometry. Materials processed using LPBF experience very high cooling rates, which lead to microstructural refinement and better control of phase precipitation through heat treatment. As a result, NAB alloys processed via laser AM have exhibited improved strength and corrosion properties. In the present work, both blended elemental and fully prealloyed NAB powders corresponding to UNS C63020 chemistry were processed using LPBF. Preliminary laser ablation trials were performed to determine suitable machine parameters for LPBF processing. Solid test specimen were fabricated using a linear manipulation of the laser power and scan speed. The surface roughness and cross sections of the as-printed test specimen were analyzed using laser confocal microscopy. SEM-EDS was employed to characterize the microstructures and identify the phases present. Multiple LPBF parameter sets were identified which could produce fully dense NAB in both powders tested.

4:40pm

Presentation 63: Multiscale Mechanical Characterization of Multiphase Materials Made by Additive Manufacturing

Yu Zou
University of Toronto, Canada

Abstract: Throughout history, exploration of material properties at different length scales, both large and small, have fundamentally reshaped human understanding of the physical world and catalyzed industrial growth. Towards this vision, my presentation will focus on mechanical properties of materials in the size ranging from a few micrometers to about one hundred nanometers. I will share insights on using novel in-situ tensile testing and high-speed nanoindentation techniques to characterize the mechanical properties of tool steels, titanium alloys, aluminum alloys and nickel alloys made by various additive manufacturing techniques. In closing, I will talk about future research directions of my group about the combinatorial development of structural materials through additive manufacturing and machine learning.

5:00pm

Presentation 64: Production-Ready Ti-6242 Printing Parameters for Laser Powder Bed Fusion Technology (L-PBF)

Javier Arreguin
AP&C, a GE Additive Company, Canada

Abstract: Ti64 (Ti-6Al-4V) is the main titanium alloy used in additive manufacturing today (AM). But its usage is limited to environments with temperatures below 400°C. The industry needs alloys that withstand higher temperatures. Ti6242 (Ti-6Al-2Sn-4Zr-2Mo-0.08Si), a near-alpha alloy, is a great candidate because it has the highest temperature stability of common Ti-alloys and can be used in environments with temperatures up to 500°C. Ti6242 was the object of the first industry standard for titanium additive manufacturing powder by AMS — AMS7014, so the interest in the alloy is obvious. However, until now, no L-PBF machine OEM had industrialized this crack-prone material. Using plasma atomized powder with best-in-class density and flowability from AP&C, GE Additive successfully developed printing parameters for this alloy on the M2 Series 5 machine. The printed part microstructure shows extremely low porosity, without the appearance of cracks, and outstanding tensile properties exceeding the properties of Ti6242 forgings (AMS4976) even at high temperatures. With Ti6242, GE brings to market a high-temperature titanium alloy with potential aerospace applications, including turbine components, afterburner structures and various applications in the hot zone of the airframe.

Poster Presentations

Theme 1: Material Development

Poster 1-1: Laser Directed Energy Deposition of CuCrZr Alloy: From Process Parameters Optimization to Microstructural Characterization

*Ali Zardoshtian, *Mazyar Ansari, **Hamid Jahed Motlagh, *Ehsan Toyserkani
**Multi Scale Additive Manufacturing Lab, Department of Mechanical and Mechatronics Engineering, University of Waterloo, Canada; **Department of Mechanical and Mechatronics Engineering, University of Waterloo, Canada*

Abstract: Recently, CuCrZr alloy has caught the attention of industry to be developed by metal additive manufacturing (AM) methods due to their unique properties, such as high heat flux required for aerospace and power-plant applications. Among metal AM methods, Laser Directed Energy Deposition (LDED), has shown its unique capabilities in terms of relatively high deposition rate, low material waste, and large printing envelope to be utilized in the AM of CuCrZr alloy. However, due to the low laser energy absorption factor and its high heat conductivity, laser materials processing is challenging for this alloy. To tackle this issue, this study aims to conduct a systematic investigation on the LDED of a CuCrZr alloy from a single-track to multilayer scales. To achieve an acceptable track geometry and maximize the deposition rate, process parameters were optimized using statistical methods. Further, the hardness of the depositions is studied by microhardness testing. The results show a smooth transition of hardness from the top of the bead to the bottom of the melt pool. The microstructure of the tested samples is investigated by OM, SEM, and EBSD techniques. Finally, a correlation between process parameters, such as power and laser scanning speed, and grain size is established.

Poster 1-2: Additive Manufacturing of Alumina – Metal Composite via Laser Powder-bed Fusion

Mohammad Azami*, Zahra Kazemi**, Amir Hadian***
**Concordia University, Canada; **Institute for Aerospace Studies, University of Toronto, Canada; ***Empa - Swiss Federal Laboratories for Materials Science and Technology, Switzerland*

Abstract: In this research, an alumina-based composite bonded with the Fe-Ni-Cu alloy is developed via laser powder bed fusion (LPBF) additive manufacturing (AM) technology. The LPBF process parameters were carefully adjusted to achieve good quality printed samples. To promote the bonding between the ceramic and metallic phases, the as-printed structures were subjected to a sintering cycle under an inert atmosphere. The sintering cycle increased the average Vickers hardness of the green samples from 1475 Hv to 1960 Hv. As-sintered samples showed improved mechanical properties even though the pores generated during the LPBF could not be entirely eliminated after sintering. In order to reduce internal porosities and microcracks, the sintered specimens were immersed in a polymeric solution. Mercury porosimetry results confirmed that the porosities are relatively reduced (from 36% to 27%) after the sintering and the polymer immersion steps. It was also observed from the mechanical evaluations that immersing the specimens in the polymeric solution led to a significant improvement in the compression strength of the specimens (from 56 to 120 MPa). Microstructural examinations demonstrated that a uniform distribution of the steel particles in the alumina matrix could be achieved using LPBF.

Poster 1-3: Fatigue Resistance of Laser Powder Bed Fused Ti64 Components with Intentionally-seeded Porosity

Etienne Moquin, Vladimir Brailovski, Morgan Letenneur
École de technologie supérieure, Canada

Abstract: To study the influence of processing-induced porosity of the fatigue life of laser powder bed fused Ti-6Al-4V components, testing specimens were printed using low, optimal and high energy densities (LED, OED, HED) to intentionally seed porosity of different levels, morphologies and distributions. Before fatigue testing, all the specimens were individually inspected using a X-ray microtomography scanner (XT H 225).The OED printing resulted in specimens with less than 0.01% of porosity, while both the LED and HED printing resulted in specimens with similar levels of porosity and mean equivalent pore diameter (~0.03% and ~59 µm), but different pore morphologies: LED specimens with elongated (aspect ratio 0.5) and partially-aligned pores and HED specimens with more spherical (aspect ratio 0.75) and randomly-distributed pores. While the static properties of all the specimens were similar (YS=890and UTS=990 MPa), force-controlled fatigue testing (R=0.1) showed that the 10^7-cycles runout corresponded to a maximum stress of 550 MPa for the OED specimens, 500 MPa for the HED specimens, and 400 MPa for the LED specimens. The tests results were related to the scan data to establish a critical pore characteristic limiting the fatigue life of printed specimens.

Poster 1-4: Integrated Experimental/Statistical Optimization of High-Power Laser Powder Bed Fusion of Cu-Cr-Zr Alloy

Nadia Azizi, Elahe Jabari, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Cu-Cr-Zr alloys are commonly used in many industrial applications as promising materials for heat exchangers, induction coils, and rocket combustion chamber lining, owing to their excellent mechanical strength and high electrical and thermal conductivity. Cu-Cr-Zr alloys also possess a higher laser absorption coefficient compared to copper and other copper alloys, while maintaining moderately high thermal conductivity, making these alloys an attractive choice for Laser Powder Bed Fusion (LPBF) Additive Manufacturing (AM) processes. However, their lower absorption coefficient compared to conventional AM materials necessitates LPBF processes with higher laser power to increase speed and elevate productivity. In this research, a customized LPBF system, equipped with a 1 kW Yb-fiber laser, is deployed. The 1 kW laser power increases productivity with higher build rates and thicker layers, ideal for serial manufacturing of industrial metal parts. The LPBF process parameters are optimized to achieve enhanced physical properties of the printed Cu-Cr-Zr parts, including relative density, surface roughness, and hardness. A Plackett-Burman design, supported by an experimental analysis, is developed to identify the most significant process parameters. Finally, a central composite design (CCD) is developed to tailor the experiments for further optimization of the process parameters.

Poster 1-5: Anisotropy in Ti-5553 Parts Made by Laser Powder Bed Fusion

*Nivas Ramachandiran, *Hamed Asgari, *Francis Dibia, **Roger Eybel, *Adrian Gerlich, *Ehsan Toyserkani
**University of Waterloo, Canada; **Safran Landing Systems, Canada*

Abstract: Directional heating involved in laser- or electron-based additive manufacturing of metals and alloys causes the growth of a columnar-grained microstructure along the building direction, which results in anisotropy. In this work, anisotropy in laser powder bed fused Ti-5553, a metastable β titanium alloy, is investigated. Samples printed normal (vertically printed), and parallel (horizontally printed) to the building direction were subjected to uniaxial tensile tests. In comparison, samples printed parallel to the building direction exhibit a significantly higher strength of 960±3 MPa, whereas the samples printed normally to the building direction reached 804±12 MPa. Fracture initiation and propagation were investigated using partially tensile tested samples. The cross-sections of partially tensile tested surfaces reveal the development of slip bands into a series of linear pores that coalesce into cracks. Electron backscatter diffraction results indicate that the grain boundaries act as favorable locations for fracture initiation, particularly when aligned perpendicular to the loading direction. Conversely, fracture in samples printed parallel to the building direction was predominantly transgranular, which is expected to be a major contributing factor for the higher strength observed.

Poster 1-6: Effect of α Case and Transition Zone on the Tensile Strength of Laser Powder Bed Fused and Heat-treated Ti-5553 Parts

*Nivas Ramachandiran, *Hamed Asgari, *Francis Dibia, **Roger Eybel, *Adrian Gerlich, *Ehsan Toyserkani
**University of Waterloo, Canada; **Safran Landing Systems, Canada*

Abstract: In this work, laser powder bed fused Ti-5553 parts subjected to solution treatment at 800°C followed by aging at 500 to 700°C for 30 minutes to 4 hours were characterized. Irrespective of the aging condition, a 20–50 µm α case followed by a 200–250 µm thick transition zone, comprising coarse α rich grain boundaries and detrimental to the tensile performance, were observed. Microhardness measurements revealed a hard and brittle outer case whose depth approximately matched the α case and the transition zone identified earlier. During uniaxial tensile testing, the specimens prematurely fractured at ultimate tensile strength (UTS) values ranging from 620–858 MPa. Fractured surfaces revealed a bi-modal fracture exposing a brittle failure along an outer ring whose thickness was comparable with the combined thickness of the α case and transition zone. Away from the outer ring, the fracture was predominantly ductile in nature. Removing the α case and the transition zone by surface turning after heat treatment substantially improved the UTS by ~200%, maintaining an acceptable ductility. The samples aged at 600°C for 30 minutes registered the best set of tensile properties with a UTS of 1482±19 MPa and a fracture strain of 6.7±0.8 %.

Poster 1-7: Laser Powder Bed Fusion of Cu-Ag Elemental Powder Blend

Nadia Azizi, Hamed Asgari, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: In the present study, Cu-2wt.%Ag alloy samples from a mixture of elemental copper and silver powders were successfully fabricated using laser powder bed fusion (LPBF). The Plackett-Burman design screening phase was initially conducted to determine the most significant process parameters. The surface roughness and relative density of printed samples were measured using confocal microscopy and Archimedes' principle, respectively. Statistical analysis of the results along with central composite design was then employed to find the optimal process parameters. Considering the requirements of an industrial application of this alloy, a series of quality, including roughness of less than 15 um and relative density of greater than 97%, was assessed. Microscopy methods such as optical, scanning electron and orientation imaging were used to investigate the microstructure of the printed samples. Furthermore, macro-texture measurement and phase analysis were conducted by X-ray diffraction, while structural integrity and defect population of samples were studied by X-ray computed tomography. The composition of oxide layers formed during oxidation tests was determined using X-ray photoelectron spectroscopy. It was concluded that process parameters, particularly laser power and scan speed, play a key role in determining the microstructural evolution and structural integrity of printed samples, which in turn dictate the oxidation behavior of the alloy.

Poster 1-8: Effect of Cooling Rate on the Microstructure of Rapidly Solidified 17-4PH Stainless Steel

Anne McDonald*, Hani Henein*, Tonya Wolfe**
**University of Alberta, Canada; **Red Deer Polytechnic, Canada*

Abstract: 17-4 precipitation hardened stainless steel is widely used in many industrial applications throughout the aerospace, chemical, and mining industries. To better understand the solidification behaviour of 17-4 PH in its new use in additive manufacturing, 17-4 PH powder was atomized using an impulse atomization system to produce samples with a known thermal history. Using the secondary dendrite spacing (SDAS) measurements of the different particle sizes, a relationship can be drawn between the known cooling rate of the steel and the final microstructure. This relationship provides the initial solidified structure of an additively manufactured part, something that is difficult to achieve in practice due to the repeated thermal cycles of the process. The overall relationship between SDAS and cooling rate is presented for a range of cooling rates.

Poster 1-9: Development of AlSi10Mg-AlN Metal Matrix Composites for Laser Powder Bed Fusion AM

Jonathan Comhaire*, Paul Bishop*, Ian Donaldson**
**Dalhousie University, Canada; **GKN Sinter Metals, United States*

Abstract: AlSi10Mg has evolved to become a standard aluminum alloy utilized in additive manufacturing, owing to a robust response to processing and desirable properties such as a high strength-weight ratio. Despite these promising traits, the stiffness, thermal conductivity, and thermal stability of AM AlSi10Mg remains inadequate for certain applications. In an effort to bolster performance in these areas, coupling the alloy with controlled levels of ceramic particulate is under investigation. Specifically, the authors have completed research on the incorporation of aluminum nitride (AlN) additions and how these influence the processability of AlSi10Mg in the context of laser powder bed fusion. Using a design of experiments (DOE) approach, the effects of AlN concentration, laser power, scan speed, and hatch spacing on final part density were studied. With an effective processing window established, positive combinations of parameters were utilized in the fabrication of additional specimen needed extended for a comprehensive assessment of microstructure, matrix/ceramic interfaces, mechanical properties, and thermal properties. Data for a series of AlN-laden systems will be presented and compared against the baseline performance of AlSi10Mg.

Poster 1-10: Rapid Solidification of Al-10Si-0.4Sc (wt%): Precipitation Behaviour and its Influence on Mechanical Properties

Akankshya Sahoo*, Abdoul-Aziz Bogno**, Jonas Valloton*, Douglas Ivey*, Hani Henein*
University of Alberta, Canada; Equispheres Inc, Canada

Abstract: Hypereutectic Al-Sc alloy (Sc < 0.55wt%) has been known to yield good grain refinement in Al castings, due to the precipitation of primary Al3Sc during solidification, which also acts as a recrystallization inhibitor and a favorable nucleation site for strengthening phases. However, because of its low market availability and high cost, it is economically more interesting to use Sc in hypoeutectic level (<0.55wt %), while benefiting from rapid solidification induced grain refinement, solid solution and precipitation hardening. As such, Sc has a great potential for minor elemental addition to Al-alloys for Additive Manufacturing (AM), such as the widely used industrial hypoeutectic Al-Si alloys. This work investigates the effects of minor Sc addition (0.4wt %) on the rapidly solidified Al-10wt%Si. The phase identification, solidification behaviour, precipitate distribution and mechanical properties of the alloy at a wide range of processing conditions were carefully characterized. A relationship between the processing parameters, the precipitation distribution and the resultant mechanical properties will be presented, demonstrating that the high performance of rapidly solidified Al-10wt%Si-0.4wt%Sc alloy could be tailored to contribute to alloy and process development in Additive Manufacturing.

Poster 1-11: Comparison of Laser Powder Bed Fusion Processing and Laser Remelting of an Al-Zr Alloy

Jon Hierlihy*, Ian Donaldson**, Paul Bishop*
**Dalhousie University, Canada; **GKN Powder Metallurgy, United States*

Abstract: The selection of aluminum alloys commercially available for laser powder bed fusion (PBF) is very limited despite an aggressively growing demand. In many cases, end-users are particularly interested in alloys that offer enhanced thermally stability. Historically, a number of such materials were premised on chemistries that incorporated transition metal (TM) additions which form refractory aluminides as the principal strengthening addition. Investigation of such systems invariably mandates that multiple alloys be converted into a powder form which is costly and time consuming. To rapidly downsize to the most promising systems, precursory investigation via laser remelting (LRM) of cast substrates is becoming increasingly common as it can impart thermal conditions akin to those encountered in PBF. To assess the utility of this concept, solid PBF specimens were produced from gas atomized Al-0.5Zr (wt.%) powder while cast plates of the same chemistry were remelted in multi-track configurations. In both instances, processing was completed under an inert gas atmosphere using a Yb-fibre laser operated over a range of energy densities. Microstructures were characterized (optical, SEM/EDS, laser confocal) and examined for defects (cracking, gas porosity, lack of fusion, etc.) to gain a sense of the applicability of LRM in developing this alloy for PBF.

Poster 1-12: 4D Precipitation Printing of Shape Memory Polymer Blends for Foamed Strain Sensors

Kyra McLellan, Terek Li, Yu Chen Sun, Hani Naguib
University of Toronto, Canada

Abstract: Precipitation printing is a novel printing technique which involves directly printing a polymer ink into a solvent bath where a solvent exchange process occurs. The ink solvent and bath solvent are mutually miscible and result in precipitation of the polymer, solidifying it into a printed structure. Compared to traditional printing techniques such as Direct Ink Writing (DIW), this method offers several benefits including faster ink solidification and a foamed morphological structure which can be utilized to create high sensitivity strain sensors. In this work, Shape Memory Materials (SMM) are used to create a printable ink which after printing can be thermally activated via the Shape Memory Effect (SME) to actuate from a temporary position to an original position. A polymer blend of Polylactic Acid (PLA) and Thermoplastic Polyurethane (TPU) are combined to create a matrix with superb SME, while conductive nanoparticles such as Carbon Nanotubes (CNT) or Graphene provide an electrically conductive network for strain sensing. Print parameters are optimized and the final printed structures are evaluated in terms of their mechanical performance, foam morphology, strain sensing capabilities, and shape memory performance. A soft robotics demonstration is provided wherein, the potential of this novel printing method and material are highlighted.

Poster 1-13: Facile 3D Printing of Conductive Polymer

Terek Li, Hani Naguib
University of Toronto, Canada

Abstract: Direct ink writing (DIW) is a form of 3D printing where a colloidal or gel-like high viscous ink is extruded through a nozzle onto a substrate in a layer-by-layer fashion. The ink features both shear-thinning rheological behavior to ensure it can be smoothly and continuously ejected by a mechanically controlled nozzle as well as favorable viscoelastic behavior to ensure direct printing of mechanically stable architectures without collapsing. Progress in the research of DIW has expanded the compatible materials library to include metal, liquid metal, clays, and ferromagnetic elastomers. Conductive polymer (CP) is the most promising material for electronic applications due to its environmental stability and high electrical conductivity. While substantial efforts have been devoted to DIW of CP, the printed structure is either limited to nanowires or requires an extensive preparation process. In this work, a novel and facile technique is demonstrated to prepare DIW printable CP ink using super-absorbent-polymer beads. This process significantly reduces the preparation time of 3D printable CP ink from three days to eight hours without the use of any specialized equipment. Furthermore, The effect of secondary dopants on the rheological and electrical properties of the synthesized ink is also studied.

Poster 1-14: Observing the Effect of Boron on D2 and 4340 for Binder Jetting Application

William Bouchard, Carl Blais
Université Laval, Canada; Université Laval, Canada

Abstract: Additive manufacturing (AM) is a novel field with an increasing number of new fabrication methods. Among them is binder jetting (BJ), which is gaining traction for facilitating the mass production of custom-made components. Typically, most AM technologies use either an electron beam or a laser beam, while BJ combines a binder with a powder bed to build parts. Also, numerous materials are used for BJ, such as polymers, ceramics, and metallic alloys. Most metallic alloys used in BJ are stainless steels. Compelling alternative steel alloys are available, such as D2, a tool steel that provides great abrasive properties and AISI 4340, which is a high hardenable and high tensile steel that offers great versatility. However, using metallic alloys in BJ has its drawbacks, namely, the necessity of a second step after building the part. Usually, this step is sintering, which allows the binder to burn, while also increasing densification. An interesting alloying element that further increases densification, via liquid phase sintering, is boron. Therefore, in this work, boron is added to D2 and 4340 and its subsequent effect after sintering is observed.

Poster 1-15: Effect of Surface Condition on High Temperature Fatigue Response of LPBF Hastelloy X

Reza Esmaeilizadeh*, Xiaolong Li**, Mathias Kuhlow**, Ali Keshavarzkermani*, Hamid Jahed*, Ehsan Toyserkani*, Ehsan Hosseini**
**University of Waterloo, Canada; **Swiss Federal Laboratories for Material Science and Technology, Switzerland*

Abstract: This study investigates the fatigue behavior of Hastelloy X (HX) fabricated through the laser powder-bed fusion (LPBF) process. Fully-reversed ($R_\varepsilon = -1$) strain-controlled fatigue experiments were conducted on LPBF-HX specimens at 700 °C with as-built (AB) and machined (M) surface conditions. The comparison of AB-LPBF-HX and M-LPBF-HX strain-life fatigue curves shows a significant effect of surface finish on the fatigue life of the alloy. The machined samples exhibited superior fatigue resistance at elevated temperatures for all the examined strain amplitudes in the current study. Scanning electron microscopy (SEM) of fracture surfaces revealed crack initiation from the surface of the samples for both surface conditions, followed by stable fatigue crack growth and final fracture. Although cracks were initiated from surface roughness valleys for the as-built samples, the machined samples showed semi-elliptical crack initiation morphology.

Poster 1-16: Property Enhancement of Binder Jet 3D Printed SS316L Parts using Cu Nanoparticles-enriched Binder

Elahe Jabari, Daniel Juhasz, Mohsen Keshavarz, Issa Rishmawi, Mariah De Torres, Caleb Davis, Mihaela Vlasea
University of Waterloo, Canada

Abstract: Binder Jet Additive Manufacturing (BJAM) technology can be adopted to produce a wide range of metallic parts for specific applications at a lower cost and shorter lead time compared to other AM techniques. One of the most well-known types of stainless steels conventionally used by various industries is SS316L, which has been extensively manufactured using BJ technology, mostly for electrochemical or biomedical applications. Of the main challenges of BJAM process are low green part density,

inconsistent densities near the edges of the printed part, and costly high temperature sintering processes to achieve fully dense parts. Moreover, sintered stainless steel has lower corrosion resistance compared to either cast or wrought counterparts due to a crevice corrosion mechanism taking place at the pores. There exists a need to overcome these challenges by tuning the BJAM process and material system parameters to affect the final part properties. This work is focused on enhancing physical and mechanical properties, as well as corrosion resistance of BJ printed SS316L samples by layer-wise deposition of Cu nanoparticles (CuNPs) dispersed in a liquid binder. The physical, mechanical, and corrosion resistance properties of these samples after addition of CuNP-enriched binder revealed significant improvements.

Theme 2: Advanced Process Modeling

There will be no posters in Theme 2.

Theme 3: Process Monitoring and Control

Poster 3-1: Analysis of the Porosity Production in LPBF Process Using Designed Porosity and Process Parameters

Shokoufeh Sardarian, Shirin Dehghahi, Marc Secanell, Ahmed Qureshi
University of Alberta, Canada

Abstract: Laser powder bed fusion (LPBF) is one of the additive manufacturing (AM) processes that fabricate complex 3D components by fusing material layer by layer using a computer-aided-design (CAD) model which offers a faster, cheaper, and easier method compared to conventional technologies. Some applications in biomedical and energy storage industries require carefully produced porous environments in the components. This study aims to provide an insight into developing intentionally-seeded porosity using laser powder bed fusion (LPBF). 17-4 PH stainless steel which has excellent properties such as corrosion resistance, thermal resistance, high strength, and hardness was selected for this work. Two approaches are employed to fulfill this aim. First, a disc-shaped design consisting of holes with different interspacing distances is employed to determine the potential of the LPBF process to create very small holes in the part. Second, the effect of different process parameters in the LPBF such as laser power, laser speed, and hatch distance is evaluated to study the void formation and porosity development in the printed part. In this study, micro X-ray computed tomography (μCT) which is the most commonly used tool to investigate the pore size and distribution has been employed to study the porosity measurement in the printed samples.

Poster 3-2: Machine Learning for Defect Detection Using Optical Tomography Signals

Osazee Ero, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Process defects such as porosity induced from lack of fusion or keyhole phenomena could be detrimental to the quality of laser powder-bed fusion (LPBF_ manufactured parts). Current monitoring strategies involve using optical devices to record melt-pool signatures. These monitoring systems usually require high sampling rates as a result of the fast dynamics of the process, as thus, large data storage is required while analyzing them is quite challenging. Combining optical tomography signals with machine learning (ML) technique is a possible solution for mitigating this challenge thus facilitating part quality assurance. In this study, we investigated the correlation of optical tomography signals to lack-of-fusion defects within the process, by designing artificial defects embedded within samples to mimic these defects. We developed custom ML algorithms to automatically detect these process deviations using optical tomography signals, validating the results from the CT scans of the samples. The developed ML technique was then applied to detect actual randomized lack-of-fusion defects.

Poster 3-3: Policy Gradient Optimization of Bead Geometry in Robotic Wire Arc Additive Manufacturing

Yeon Kyu Kwak, Thomas Lehmann, Mahdi Tavakoli, Ahmed Qureshi
University of Alberta, Canada

Abstract: Wire Arc Additive Manufacturing (WAAM) is a manufacturing technology that can fabricate a large-scale metallic part in a layer-by-layer fashion. It is receiving great attention from industries as a viable method of manufacturing due to its high deposition rate and cost-efficiency. However, there still exist numerous challenges that need to be overcome to ensure the geometrical accuracy of the part produced. WAAM process is highly non-linear and multi-dimensional and is difficult to model the input process parameters to the output geometrical quality of the final part, especially with an increasing number of materials introduced to WAAM. To overcome this challenge, a supervised learning control algorithm is implemented to search for a parameterized welding process while optimizing the geometry of a single-track multi-layer bead. The input parameters include torch travel speed, wire feed speed, previous layer's geometrical data, and dwell time. The output parameter is the geometry of the printed bead. The proposed algorithm is implemented and validated on a 3-axis gantry WAAM system.

Poster 3-4: 3D Scan Data-Based Shape Compensation using Graph U-Nets to Correct the Systematic Geometric Errors of Additive Manufacturing Parts

Moustapha Jadayel, Farbod Khameneifar
Polytechnique Montreal, Canada

Abstract: Additive manufacturing (AM) is changing the prototyping and manufacturing process by enabling the quick fabrication of parts with complex geometries. However, AM is not known for precision manufacturing. The relatively low geometric accuracy of AM parts can be attributed to the machine's mechanical errors, warping, and other thermo-mechanical deformations. A 3D shape compensation methodology can reduce systematic geometric deviations of the parts. However, using the existing methods, to isolate systematic deviations from random errors, multiple sacrificial parts are necessary. We present a Neural Network algorithm that analyses the 3D scan data of a single 3D printed part to filter the random errors of the part. This Neural Network outputs a compensated mesh, using only one sacrificial part. The network training and validation process is presented, followed by a comparison between the outcomes of classical compensation with a single part, compensation with five sacrificial parts, and compensation with one part through the Neural Network algorithm.

Poster 3-5: Detection of Defects in Additively Manufactured AlSi10Mg and Ti64 Samples Using Laser Ultrasonics and Phase Shift Migration

Alexander Martinez-Marchese, Reza Esmaeilizadeh, Ehsan Toyserkani
MSAM, Canada; MSAM, Canada; MSAM, Canada

Abstract: Laser ultrasonics (LU) is a non-contact and non-destructive method with high data acquisition rate, making it an attractive candidate for in-situ monitoring of defects in the laser powder bed fusion (LPBF) and laser powder-fed (LPF) additive manufacturing (AM) processes as well as final part quality inspection.

Various test samples with all the major types of artificial defects found in the literature, through side-hole, bottom blind hole and trapped powder defects, were fabricated with LPBF, using AlSi10Mg and Ti64 powder. The samples were tested using the LUKS-1550-TWM laser ultrasonic system from Optech Ventures LLC, and the data was used to reconstruct the defects using a Fourier space technique called phase shift migration (PSM), with a stationary phase approximation. The technique was tailored for a fixed offset LU setup and for computationally efficient filtering of the data in Fourier space.

The effect of the artificial defect type and reconstruction algorithm on the resulting reconstructed images, as well as the effect of the generation laser on the surface of the samples, will be discussed.

Poster 3-6: Toward Predicting the Powder Characteristics for Metal Additive Manufacturing Using Machine Learning

Farima Liravi*, Mahdi Habibnejad**, Ehsan Toyserkani*
**University of Waterloo, Canada; **GE additive - AP&C, Canada*

Abstract: The rheological and morphological properties of the powder have a major impact on the characteristics of the powder layer in laser powder bed fusion process. To obtain a high-quality layer which is thin, dense, and homogeneous, and consequently a final product with acceptable mechanical properties, a feedstock with optimized particle size, shape and flow is required. The conventional methods for gaining insight into the powder behavior are mainly experimental and are highly time and cost inefficient. The artificial intelligence-based methods, in contrast, are capable of extracting information from various data types and draw highly accurate predictions for new unseen specimens quickly and efficiently. This project is focused on adopting a combination of multiple machine learning (ML) techniques for prediction of various powder properties such as flowability based on the morphological and physical features of the powder, e.g., sphericity and particle size distribution (PSD). The models are trained on a numerical dataset consisting of Ti-6Al-4V powder characteristics in multiple ranges of particle size distribution. The initial results demonstrate the AI-based methods provide a viable alternative for fast and inexpensive characterization of powder feedstock in AM.

Poster 3-7: In situ Measurement of the Pressure Required to Extrude Low-viscosity Feedstock in Material Extrusion Additive Manufacturing of Highly-filled Polymer (MEAM-HP)

Raphaël Côté*, Olivier Miclette*, Vincent Demers*, Nicole Demarquette*, Jérémie Soulestin**
**École de technologie supérieure, Canada; **École nationale supérieure Mines-Télécom Lille-Douai, France*

Abstract: Material extrusion additive manufacturing of highly-filled polymer (MEAM-HP) is a relatively new 3D printing approach to produce dense metallic parts with complex shapes. This process consists of extruding a molten feedstock (metallic powder and polymeric binder) through a capillary nozzle over a 3-axis build platform. The printed parts are then debound and sintered to produce a dense metallic part. In this work, a new printer design with a plunger-based approach was developed to print low-viscosity feedstocks using low printing pressure. This new MEAM-HP printer has the potential to extrude a wide variety of feedstocks at low cost. This printer prototype is also equipped with a pressure sensor located in the printing head to monitor the printing pressure, indirectly enabling a precise control of the printing flow rate. The experimental results were useful to detect printing defects originated by faulty flow rates, in addition to validate numerical printing simulations using Autodesk Moldflow. The device presented in this communication therefore addresses one of the principal limitations of plunger-based approach in the additive manufacturing technique, which is the difficulty to precisely control the flow rate.

Poster 3-8: Sintering Densification and Distortion Prediction Using the Skorohod Olevsky Viscous Sintering Model

Roman Boychuk*, Kamyar Ghavam**, Mihaela Vlasea*
**University of Waterloo - Multi-Scale Additive Manufacturing Laboratory, Canada; **University of Waterloo, Canada*

Abstract: The Skorohod-Olevsky Viscous Sintering (SOVS) model is a phenomenological model which predicts the densification and deformation of a powder compact as it undergoes sintering. Although the model is intended for ceramics, its simplicity and reliance on empirical coefficients makes it easy to implement and fit to a metal powder compact undergoing sintering. In this presentation, preliminary coefficients are obtained using a simplified lumped version of the SOVS equation, and fitting it to existing push-rod dilatometry data for gas atomized 4340 steel powder produced via binder jet additive manufacturing (BJAM). The full SOVS equations are implemented in COMSOL Multiphysics using creep and ODE subroutines, and used to study simple cube and cylinder geometries, as well as a semi-complex 2D cantilever section which is expected to deform and slump during sintering. Model behavior is validated against 1D push-rod dilatometry, and 3D scan data of the deformed sintered BJAM parts.

Poster 3-9: Baseplate Design and Inverse Heat Conduction Modeling for Improved Predictive Accuracy of COMSOL Model for Laser Powder Bed Fusion Printing of Metallic Alloy Powders

Paresh Prakash, Emre Ogeturk, Yu Wang, Mary Wells
University of Waterloo, Canada

Abstract: A methodology to measure in-situ temperatures during melting and solidification of metallic powder layers in a laser powder bed fusion (LPBF) process was developed and validated by conducting printing experiments without and with powder (Hastelloy X powder on 316 stainless steel substrate). A COMSOL numerical model was used to validate the design of a baseplate, with provisions for embedding two k-type thermocouples, for this purpose. An Inverse heat conduction (IHC) model was developed in MATLAB. Further, the thermocouple data from the experiments was used as input for the IHC model, resulting in the boundary condition estimations for the LPBF experiments. The in-situ temperature measurement methodology serves to validate the COMSOL model and has application potential in real-time process control, while the IHC model provides a method to model the heat source more realistically for the LPBF process.

Theme 4: Novel AM Processes and Products

Poster 4-1: Heat Treatment of Multi-material Additively Manufactured Maraging Steel and Stellite Alloy

*Jubert Pasco, *Clodualdo Aranas, *Kanwal Chadha, **Yuan Tian
*University of New Brunswick, Canada; **Voestalpine Additive Manufacturing, Canada*

Abstract: The potential in combining the fabrication of a multi-material assembly of parts with difficult geometry to a single part with sectional variation of properties has attracted research interest in multi-material Additive Manufacturing (AM). Accordingly, the present work integrated the dual-metal Laser Powder Bed Fusion (LPBF) technique to produce a Stellite alloy (MP1) and maraging steel (MS1) structure under a single printing process. The research also attempted to identify the appropriate heat treatment strategy for these alloys. Diffusion and thermodynamic simulations suggest consistent amounts of intermetallic precipitation on both regions of each alloy. Electron Backscatter Diffraction (EBSD) analysis and Kernel average misorientation (KAM) maps of the heat-treated samples also reveal complete homogenization of the MP1 region and no traces of the cellular microstructure in the MS1 region. Martensitic growth along the building direction was also observed close to the interface. In addition, nanoindentation tests resulted to a substantial hardness increase in the MS1 region but a slight decrease of hardness in the MP1 region after heat treatment, which can be early evidence of the successful application of the heat treatment strategy to both base alloys. Finally, tensile tests reveal a slight improvement in ductility and retention of the as-printed strength.

Poster 4-2: Thermal and Residual Stress Modeling of Functionally Graded Deposits Using the PTAAM

Geoffrey Bonias, Hani Henein, Tonya Wolf
University of Alberta, Canada

Abstract: High maintenance costs due to significant abrasive wear of components is experienced in the energy and mining sectors despite the current use of tough and hard coatings. During the coating process significant detrimental residual stresses may build up and result in premature failure of a component. These stresses can be reduced by adopting functionally graded structures of the composite. The main goal of the present study is to design an ideal additively manufactured path and print functionally graded geometries using plasma transferred arc (PTA) using WC-Ni alloy composite. To achieve this goal, this project is divided into several phases of which the modelling phase of the project is presently discussed. To develop a comprehensive analysis of the functionally graded deposit, the thermal history of the WC and Ni alloy powders must first be simulated as they travel through the plasma and deposit on the substrate. Predictions of particle trajectories in the plasma are compared to experimentally tracked powder particles. The temperature predictions are compared to recordings from an infrared camera. Subsequently, residual stresses are predicted using Abaqus. Future work is aimed at validating the residual stress model and establishing the wear characteristics of the graded deposits.

Poster 4-3: Embedding Fiber Bragg Gratings in Curved Channels of Additively Manufactured Parts for Temperature and Strain Sensing

Bahareh Marzbanrad, Ehsan Toyserkani
University of Waterloo, Canada

Additive manufacturing unlocks the possibility of printing parts with complicated three-dimensional internal channels, which has not been achievable with traditional manufacturing. This technology can be employed for designing smart parts equipped with sensors for controlling, monitoring, and enhancing the performance of structures. The concept of smart parts with embedded sensors in curved channels has been exemplified in this study. For this, a highly sensitive and versatile sensor, the Fiber Bragg Grating sensor (FBGs), is selected for measuring the thermal and mechanical stimulus. Titanium cubic parts with three curved channels radii and three diameters are printed by Laser Powder Bed Fusion. The teardrop cross-sections with different angles are designed for the channels to prevent their collapse. CT scanning is conducted to examine clogging issues and demonstrate the possibility of the embedding sensor. Single and multiple FBGs are then embedded in the selected channels to create smart additively manufacturing parts. The smart parts are exposed to thermal and mechanical stresses to illustrate the sensitivity of the sensors in this configuration. This study can be considered as proof of the concept for the smart part paradigm, and the FBGs show their capability to detect the thermal and mechanical changes in the specific configuration.

Poster 4-4: Electromagnetic Levitation for Additive Manufacturing Applications

Saksham Malik, Parichit Kumar, Ehsan Toyserkani, Behrad Khamesee
University of Waterloo, Canada

Abstract: Electromagnetic levitation of objects is a promising field, which has the potential to be paired with additive manufacturing (AM) to enhance AM capabilities. This paper identifies strategies to levitate a conducting AM compatible material, by altering the magnetomotive strength of electromagnetic (EM) coils, using an analytical approach. The magnetomotive force (MMF) of EM coils is an important property that leads to the validation of the proper functioning of an electromagnetic levitation system. An experimental approach is adopted to calculate the inductance and its counteractive impedance effects for a multi-coil multi-core electric system. An analytical model is developed to understand the impact of external variable resistance on the magnetomotive strength of coils. Furthermore, this model is implemented experimentally to achieve stable levitation. The system is fit to be deployed into an AM environment to study metal powder impact effects.

Poster 4-5: Electrochemical-assisted Hybrid Surface Treatment Techniques for Additively Manufactured Metal Parts

Manyou Sun, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Poor surface quality is one of the drawbacks of metal parts made by additive manufacturing (AM). Post-processing operations are needed to have ready-to-use parts. As the subcategory of chemical surface treatments, electrochemical surface finishing methods have the advantage of offering access to the internal complex surfaces. However, the application of strong acid as commonly used electrolyte as well as the lack of process efficiency at high initial surface roughness pose challenges to the electrochemical surface treatments of metal AM parts. For example, for electropolishing, in order to have the desired surface finish, mechanical polishing must be applied before electropolishing, which increases the process time to a large extent. The aim of the current work is to design an electrochemical-assisted hybrid surface treatment technique which involves the combination of electropolishing, ultrasonic effect and abrasive behaviors, trying to increase the process efficiency of electropolishing. Meanwhile, a green electrolyte is designed and used for making the process much safer.

Poster 4-6: Process Optimization and Characterization of SS316L Wall and Bulk Structures Built Using a Robotic Laser Directed Energy Deposition System

Jinoop Arackal Narayanan*,**, Farzaneh Kaji*,**, Ali Zardoshtian*, Mark Zimny**, Ehsan Toyserkani*
**University of Waterloo, Canada; **Promation, Canada*

Abstract: Laser Directed Energy Deposition (LDED) based Additive Manufacturing is a revolutionizing technology due to its unique combination of shape and material design freedom. Among the different materials processed using LDED, SS316L is the most commonly used material for engineering applications owing to its excellent mechanical properties and corrosion resistance. The basic building blocks for fabricating SS316L engineering components using LDED are thin walls and bulk structures. Thus, in the present work, a comprehensive investigation is carried out on the process optimization and characterization of SS316L thin wall and bulk structures built using an in-house developed robotic LDED system. Initially, a statistically-driven process window is identified for continuous deposition of SS316L using single track deposition. Further, process optimization is carried out for the deposition of thin walls and bulk structures by considering minimal geometrical deviation and minimum porosity. The effect of process parameters on the geometrical features and density is also investigated. Subsequently, thin wall and bulk structures deposited at optimum process parameters are subjected to microstructural and mechanical characterizations and compared with conventionally built SS316L parts. The study provides a path for the development of dense and stable thin walls and bulk structures to build high-quality SS316L components.

Poster 4-7: Multiaxial Mechanical Properties of Diamond and Gyroid Lattice Structures for Spinal Cages

Anatolie Timercan, Vladimir Brailovski
École de technologie supérieure, Department of Mechanical Engineering, Canada

Abstract: Spinal health problems are increasingly common and in extreme cases require intervertebral fusion surgery. Currently used commercial intervertebral devices present complication risks such as lack of fixation, implant migration and subsidence. To provide a better control of mechanical properties and the possibility of osseointegration, the use of additively manufactured devices integrating lattice structures represent a promising solution. An adequate understanding of the mechanical response of such lattice structures under varying loading modes is necessary for the optimal design of these devices. Two types of lattice structures were selected: strut-based diamond and sheet-based gyroid. Structures with an equivalent pore size of ~750μm and porosity levels of 50, 60, 70 and 80% were designed and manufactured from Ti-6Al-4V powder using a laser powder bed fusion system. The resulting components were subjected to computed-tomography analyses to measure the CAD/Print deviations and evaluate the level of processing-induced porosity. Mechanical testing of these structures allowed the measurement of their apparent mechanical properties under tension, compression and torsion loading modes to simulate flexion/extension, compression and rotation of the human spine. Analogous numerical simulations were carried out and compared to the experimental results. The validated numerical models were used to fine-tune the mechanical response of intervertebral devices.

Poster 4-8: Influence of Layer Thickness upon Material Characteristics of AISI D2 Steel Manufactured Using Directed Energy Deposition

Samer Omar, Kevin Plucknett
Dalhousie university, Canada

Abstract: In this research, the influence of layer thickness upon the material characteristics of directed energy deposition (DED) processed AISI D2 tool steel was assessed. For DED, the AISI D2 tool steel powder was deposited onto an annealed AISI D2 substrate, in order to build multi-layered rectangular specimens. The DED parts were built employing various layer thicknesses, while the other parameters were kept fixed. Microstructures of the DED samples were investigated using scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDS), and X-ray diffraction (XRD). The results demonstrated that a dendritic morphology, with columnar grains, was observed for the DED processed samples. In addition, the primary crystalline phase of the dendritic structure was found to be austenite.

Poster 4-9: Laser Powder Bed Fusion of NiTi Shape Memory Alloys

Ali Safdel, Mohamed Elbestawi
McMaster University, Canada

Abstract: NiTi alloys are a remarkable class of materials, capable of exhibiting superior functional properties such as shape memory effect (SME) and superelasticity (SE). These unique properties in addition to NiTi's notable biocompatibility have led to extensive applications of these smart materials in the biomedical industry. Stents, as one of the main target products, are tubular mesh-like structures that are deployed within the vessels or other organs in the body to restore and repair the original condition of passage. In this research, the process-structure-property relationship in additively manufactured NiTi alloys is primarily scrutinized and investigated by focusing on mechanical properties and microstructural evolution during the Laser Powder Bed Fusion (LPBF) process. In this regard, not only the optimum processing parameters to manufacture defect-free dense NiTi structures are introduced, but also the required post-processing steps to obtain enhanced superelasticity are discussed. Lastly, the feasibility of fabricating differently designed patient-specific stent structures with ultra-thin struts is explored and valuable novel insights regarding the stents' structural integrity, microstructure, texture, mechanical properties, and surface characteristics will be provided.

Poster 4-10: Designing Topology Optimized Graded Porous Structures considering Additive Manufacturing Constraints

Osezua Ibhadode, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Porous structures are extensively used in structural designs and two major applications are lightweight structures and scaffolds/implants. Very often, lattice structures alone or combined with topology optimization are adopted to design porous structures usually with decent effectiveness. However, there is some level of intuitiveness during their functional design especially in the selection of fundamental variables such as lattice type, cell size, patterning strategy, etc. Although the integration of topology optimization can assist in optimizing their designs, these critical variables can be eliminated by designing porous structures through a strict topology optimization approach. In this study, we develop a region-biased local volume-constrained topology optimization method to design graded porous structures while considering additive manufacturing constraints. Using a p-norm function to construct the local volume constraint, we generate regions in the domain assigned with different porosity values. The multi-porous design formulation is further constrained for manufacturability by introducing a filter for overhang elimination and a projected density filter for feature size control. Several test cases are printed via LPBF and FDM to validate their manufacturability.

Poster 4-11: Evaluation of Al-Si-Mg Small Scale LPBF Coupons under ELCF

Muralidharan Kumar, Mathieu Brochu
McGill University, Canada

Abstract: Laser Powder Bed Fusion (LPBF) facilitates the fabrication of complex part geometries through a layer-by-layer approach that would be challenging to produce by conventional subtractive manufacturing. A recent push towards the DFAM of components is yielding parts with higher complexity involving thinner geometrical sections. Unfortunately, the mechanical properties and surface conditions of the small AM features are not always sufficient, particularly for fatigue performance. The adoption of complex and thin-feature structures is restrained by the lack of reliable mechanical properties data and understand of the failure sequence of such small-scale components under extreme dynamic loading conditions. This study proposes a methodology for Extreme Low Cycle Fatigue (ELCF) testing for small scale cylindrical/ thin wall coupons having a diameter/ thickness of ≤1mm. This method was studied on LPBF Al-Si-Mg alloys. Factors linking heterogeneity, surface morphology, and GD&T with their mechanical responses will be presented.

Poster 4-12: Effect of Substrate Condition and Initial Residual Stresses on Electron Beam Wire Fed Additive Repair

Fatih Sikan*, Priti Wanjara**, Javad Gholipour Baradari**, Mathieu Brochu*
**McGill University, Canada; **National Research Council Canada, Canada*

Abstract: Additive repair of aerospace components is gaining ever-increasing attention due to strategic material cost and manufacturing sustainability issues. However, there is limited knowledge on how to repair procedures should vary for components with different microstructures or damage intensities. In this regard, reliable, cost-effective, and part-specific repair procedures are critical for both wrought and additively manufactured parts. The objective of this study was to understand the effect of the initial substrate condition on repair integrity and efficiency during wire-fed electron beam additive manufacturing (EBAM) of Ti-6Al-4V for repair purposes. The research included several substrate sample conditions with different initial microstructures and residual stress profiles that were manufactured by both additive and conventional manufacturing methods. Residual stress and distortion profiles of each substrate condition were analyzed before and after EBAM repair. Alterations in the grain structure of the substrate plates were investigated through microstructural characterization. Repair integrity and mechanical properties of the repaired parts were undertaken to allow a comprehensive understanding of the inter-relationships between process, structure, and performance.

Poster 4-13: Safer and Simpler Metal AM with Liquid Metal Jetting (LMJ)

Ally Abel, John Erley, Ryan Hayford
Xerox Elem Additive, United States

Abstract: Metal additive manufacturing technologies have evolved and advanced over the last several years. Comparing powder bed fusion (PBF) to ElemX liquid metal jetting (LMJ), in particular, showcases two vastly different approaches to producing a metal part. Here we discuss the variations between PBF and LMJ technologies focusing on the overall operational functionality of each by simple comparison per common application vetting processes. In many cases, LMJ typically delivers 40% cost savings while also providing quicker cycle time. Safety concerns revolving around PBF have been a major drawback of that specific technology whereas LMJ provides a much safer work environment. The results of this competitive evaluation suggest that LMJ advantages outweigh several PBF benefits.

Poster 4-14: Development of an In-situ Failure Detection System for Fused Deposition Modelling Process through the Object Detection Model and Nozzle Camera

Xingchen Liu*, Haoliang Zhou**, Sabir Hossain***, Jiachun Wang*, Zhibin Bao***, Yaohui Zou†, Xunchao Zhang†, Heng Xue*, Xianke Lin**, Yu Zou*
**University of Toronto, Canada; **Mech Solutions Ltd. , Canada; ***Ontario Tech University, Canada; †University of Waterloo, Canada*

Abstract: Fused deposition modelling (FDM), a prevalent additive manufacturing (AM) process, has been widely applied in a variety of practical applications. However, this technique is subject to a high failure rate because of a lack of enough nozzle-bed adhesion, impeding the expansion of FDM to other industries. Since the failure print occurs around the nozzle, this paper aims to equip a camera close to the nozzle tip and develop an innovative object detection (OD) model to monitor the printing process and terminate the process immediately when a spaghetti failure occurs. As the first phase of this project, dataset acquisition was performed involving image collection and annotation using bounding boxes. Then, the data was augmented and pre-processed to improve accuracy. Next step, the single-shot detector OD model was selected to train, and its hyperparameters were optimized to obtain the best mAP value. In the end, the validation result indicates that the output confidence sore can achieve more than 90%, and the detection speed could reach 14 FPS, performing a real-time detection. As a result, this system could replace human supervision for the time-consuming monitoring of the FDM process and reduce the waste of filament and energy, leading to a broader FDM application.

Poster 4-15: Novel Additive Manufacturing Approach for the Fabrication of High-precision Micro Parts

Juan Schneider, Panteha Fallah, Luc Jacob, Steve boa, Guillaume Villeneuve, Antoine Lombardo, Samuel Schneider
**Nanogrande Inc., Canada*

Abstract: Additive manufacturing (AM) technology has been found to be a promising approach for fabrication of complex parts with limited post processing operations. However, additive manufacturing at high-precision metal parts using particles smaller than 30 μm without the need for the subsequent post processing is still challenging. Particles smaller than 30 μm have stronger cohesive forces between them as compared to gravity, resulting in the agglomeration of the particles rather than the fabrication of a smooth and uniform layer. Our fluid bed patented technology combines assembling highly packed multilayers using particles as small as nanometers binding them with laser sintering or binder jetting. This technology allows for the fabrication of ultra high-resolution parts while controlling the thickness and process parameters. As a result, cost and time will be diminished due to the improved quality and adaptability of the system.

Poster 4-16: The Downside of Downskin: Digital Evaluation of Manufacturability of Lattice Metamaterials by Laser Powder Bed Fusion Additive Manufacturing

Martine McGregor, Sagar Patel, Adam Yu, Kevin Zhang, Stewart McLachlin, Mihaela Vlasea
University of Waterloo, Canada

Abstract: Lattice metamaterials are hierarchical design structures which allow for control of strength-to-weight and surface area-to-volume ratios through fine tuning of design parameters. Additive manufacturing can help realise the true potential of lattice metamaterials due to its inherent capability of enabling the fabrication of complex structures. The basic features of the lattice design primitives and the interconnectivity of such primitives to form complex lattice structures may introduce excessive downskin surfaces that cannot be supported and thereby limit the manufacturability by metal additive manufacturing technologies such as laser powder bed fusion (LPBF). This study quantifies the relationship between downskin surface area and manufacturability for lattice metamaterials produced by LPBF. The downskin surface areas of nine unique lattice designs were analyzed on an image processing software to develop quantitative metrics for evaluating LPBF manufacturability. The nine lattices were then manufactured by LPBF using maraging steel and subjected to X-ray computed tomography (XCT). The manufacturability evaluation metrics were validated by geometric fidelity comparisons of the lattice designs and XCT of the manufactured lattices. Downskin surface area and interconnectivity were found to be correlated to the manufacturability of a given lattice design. The feasibility of creating a set of manufacturability scores is proposed.

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