HI-AM Conference

6th | 2023

HOLISTIC INNOVATION IN ADDITIVE MANUFACTURING

JUNE 27 & 28 | HALIFAX, NS, CANADA

nserc-hi-am.ca/2023

PARTICIPANT INFORMATION PACKAGE

NSERC HI-AM

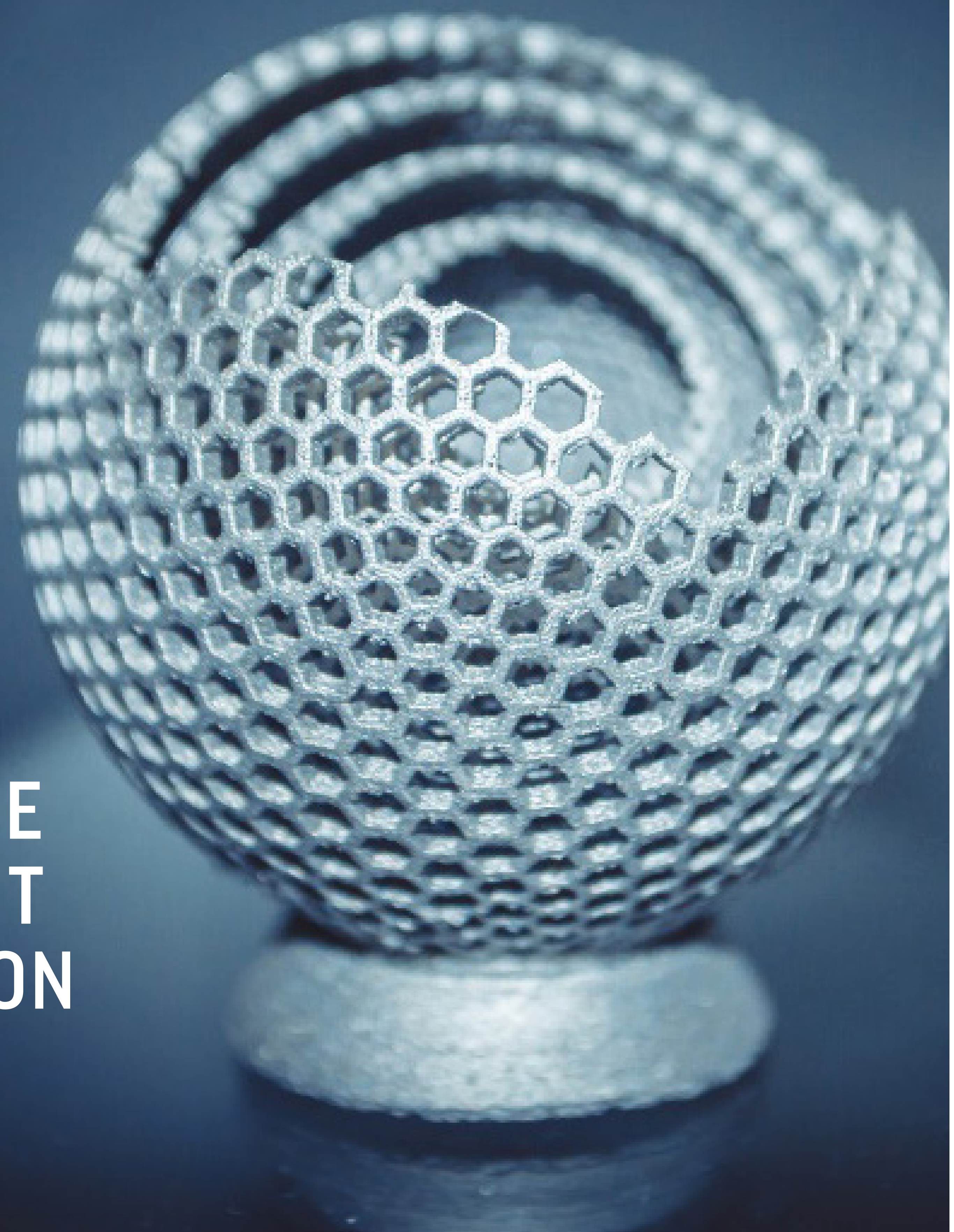
UNIVERSITY OF WATERLOO

NSERC CRSNG

INNOVATION.CA
CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION

UNIVERSITY OF WATERLOO

DALHOUSIE UNIVERSITY



2023 HI-AM CONFERENCE PARTICIPANT INFORMATION PACKAGE

Table of Contents

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 2023 HI-AM Conference.

Our sixth academic HI-AM conference gathers over 120 attendees from around the world. As always, at this annual event, we see the diverse representation that is reflected in our Network and partners, comprising different sectors, disciplines and institutions. The conference is an exciting opportunity for all of us to come together, to learn about the research being done through the Network, to exchange ideas for future research directions, and to explore new collaborations. The conference also serves as a platform for a number of formal and informal networking events, and provides attendees with opportunities to interact closely with exhibitors from diverse metal AM sectors.

We are honored to have four internationally recognized experts as our keynote speakers: Olaf Diegel, Professor of Additive Manufacturing, University of Auckland, New Zealand; Carolyn Seepersad, J. Mike Walker Professor of Mechanical Engineering, The University of Texas – Austin, United States; Tim Horn, Assistant Professor of Mechanical and Aerospace Engineering, North Carolina State University, United States; and Denis Cormier, Earl W. Brinkman Professor of Industrial and Systems Engineering, Rochester Institute of Technology, United States. We are very excited about this excellent roster of speakers, and we are sure that their presentations will inspire reflection and foster ideas for new research avenues. The conference also features 92 presentations and posters on diverse metal AM topics ranging from materials development to innovative processes and products, showcasing the cutting-edge research being done by international researchers from both within and outside of the network.

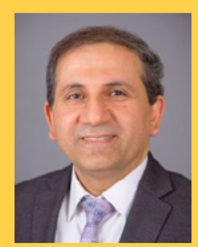
In this welcome package, you will find all the information you need to navigate the conference, including ways to connect with exhibitors and fellow participants, poster and presentation topics, schedules of events and much more. We encourage you to read through this package ahead of time to inform yourself of the various activities to ensure you can take full advantage of all that the conference has to offer.

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, Dalhousie University, University of Waterloo, Multi-Scale Additive Manufacturing Laboratory, SLM Solutions, CADMicro, Xact Metal, Indurate Alloys, Tronos, Women in 3D Printing, OU Additive, Metafold, and Renishaw.

Finally, we hope that you enjoy your stay in Halifax and take the opportunity to explore this beautiful city. We wish you a productive and enjoyable conference experience and we look forward to seeing you there!

Ralph Resnick
Chairman of the Board

Paul Bishop
Conference Co-Chair



Ehsan Toyserkani
Conference Co-chair

NSERC HI-AM

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.

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
- 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 PARTNERS

- CM&E Canadian Manufacturers & Exporters
- Canada Mining Innovation Council
- MTDG Manufacturing Technology Deployment Group, Inc.
- Mount Sinai Hospital
- ReMAP Refined Manufacturing Acceleration Process / AAPF Accélération de l'amélioration des processus de fabrication

HI-AM 2023

ABOUT THE CONFERENCE

Over the past six years, the HI-AM Conference has developed into a dynamic event, providing a platform for additive manufacturing researchers and experts from Canada and internationally to exchange ideas and discuss the latest trends and developments in metal AM. With attendees from various institutions and organizations, the conference consistently provides participants with a unique opportunity to network across sectors, and to connect with and learn from leading researchers and AM professionals from across the globe.

HI-AM 2023 marks the sixth annual convocation of the members of NSERC Network for Holistic Innovation in Additive Manufacturing, and stands as the sole academic conference within Canada that centers exclusively on metal additive manufacturing. Co-hosted by **Dalhousie University** and **University of Waterloo**, the objective of HI-AM 2023 is to serve as a forum for the dissemination of recent research and development breakthroughs in the field of metal additive manufacturing, with emphasis on four key research themes:

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

HI-AM 2018 — UNIVERSITY OF WATERLOO, Waterloo, ON

HI-AM 2019 — THE UNIVERSITY OF BRITISH COLUMBIA, Vancouver, BC

HI-AM 2020 — VIRTUAL

HI-AM 2021 — VIRTUAL

HI-AM 2022 — McGILL UNIVERSITY, Montreal, QC

HI-AM 2023 — DALHOUSIE UNIVERSITY, Halifax, NS

VENUE

The conference venue for HI-AM 2023 is the **Dalhousie Student Union Building** located on Dalhousie University's Studley Campus, about a 30-minute drive from the Halifax Stanfield International Airport and within walking distance of Downtown Halifax.

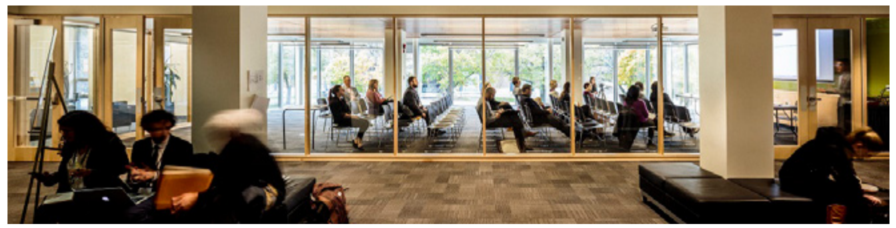


Photo Credit: Dalhousie Student Union – dsu.ca

For trip planning and driving directions **visit this website**.

For parking information **visit this website**.

Address: 6136 University Ave, Halifax, NS, B3H 4R2

HEALTH AND SAFETY PROTOCOLS DURING THE CONFERENCE

As of July 6, 2022, Nova Scotia has lifted all COVID-19 restrictions. For more information and updates, please visit **Coronavirus: Restrictions and Guidance on the Government of Nova Scotia Website.**

CONFERENCE DINNER

The Conference dinner will be held on June 27, 7 to 10 pm at **Pickford & Black**. Named after a shipping firm from the late 1800s, this waterfront pub has a great view overlooking the Halifax Harbour. We invite you to join us for a night of food and drink in the charming surroundings of Halifax Historic Properties, friendly chat with AM experts, and a great view of the harbour.

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

Address: 1869 Upper Water St, Halifax, NS, B3J 1S9

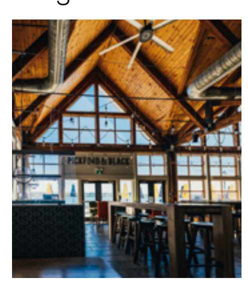


Photo Credit: Pickford & Black - pickfordblack.com

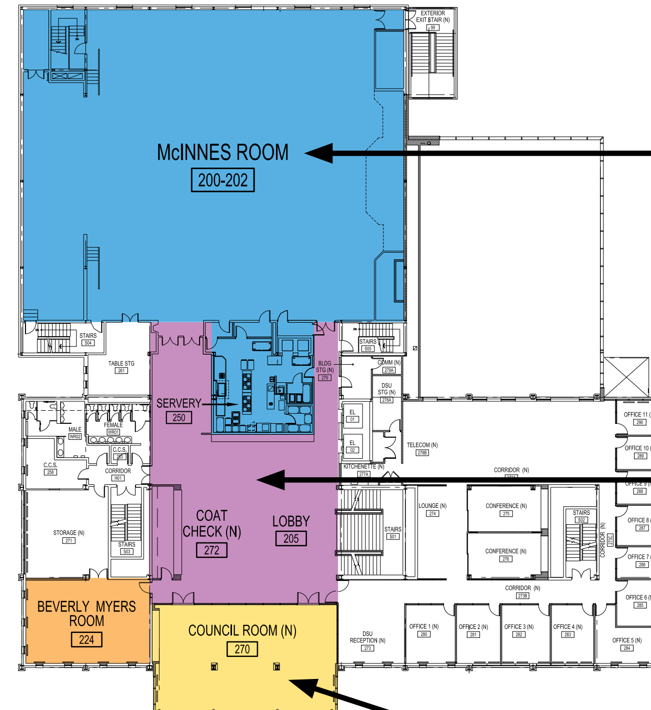
OTHER EVENTS

EVENT	DATE	TIME	LOCATION	COORDINATOR
Tour of Dalhousie AM Facilities	June 26	4:00 – 6:00 PM	1360 Barrington St, Sexton Campus, Halifax, NS B3H 4R2	Paul Bishop Kevin Plucknett
HI-AM Board of Directors Meeting 12	June 28	12:20 – 1:20 PM	Myers Room (224)	Farzad Liravi

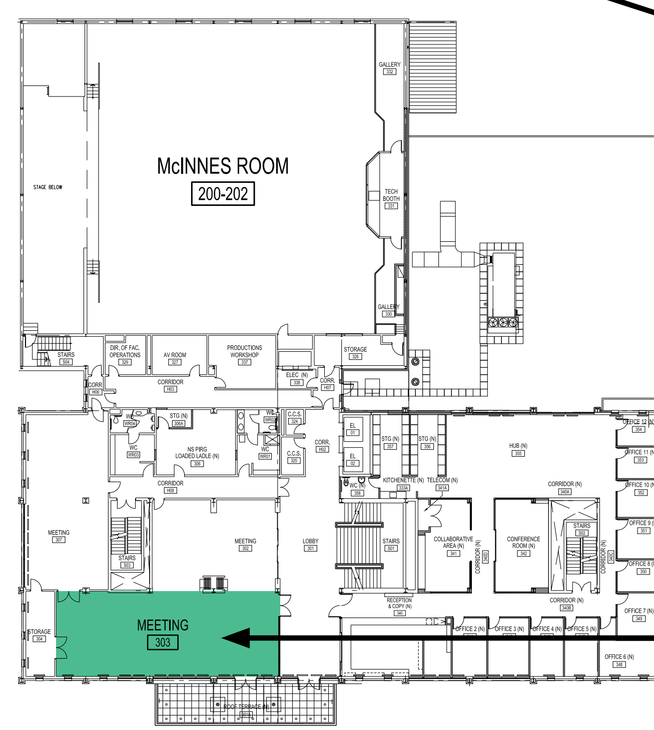
HI-AM 2023

FLOOR PLAN

SUB – SECOND FLOOR

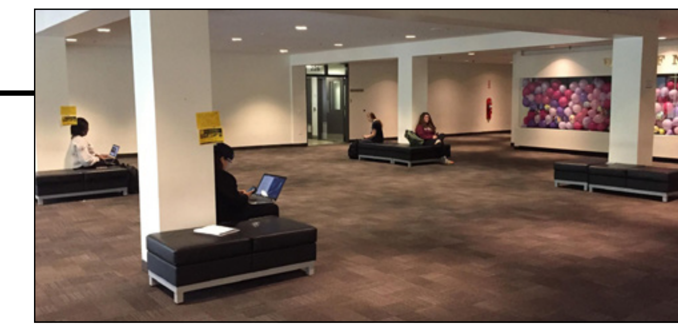


SUB – THIRD FLOOR

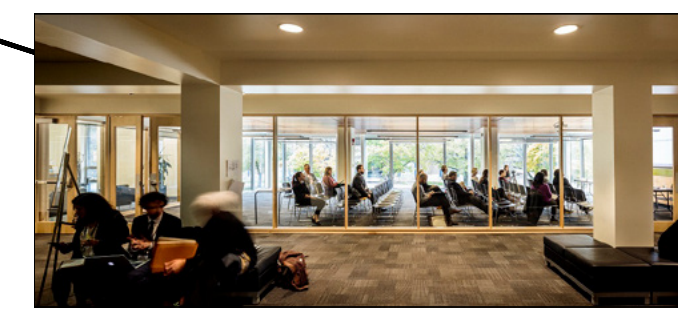


McINNES ROOM (200-202)

LOBBY & COAT CHECK



COUNCIL ROOM (270)



MEETING ROOM (303)

Exhibitor Guide

EXHIBITOR SCHEDULE

EVENT		DATE(S)	TIME(S)
HI-AM 2023		**June 27, 2023** **June 28, 2023**	**8:00 am – 5:40 pm** **7:30 am – 3:00 pm**
Conference Day 1	Exhibitor move-in*	June 27, 2023	8:00 am – 12:00 pm
	Exhibition viewing 1	June 27, 2023	12:40 pm – 1:20 pm
	Exhibition viewing 2	June 27, 2023	3:00 pm – 4:00 pm
	Conference dinner	June 27, 2023	7:00 pm – 10:00 pm
Conference Day 2	Exhibition viewing 3	June 28, 2023	9:40 am – 10:00 am
	Exhibition viewing 4	June 28, 2023	12:20 pm – 1:00 pm
	Exhibitor dismantle	June 28, 2023	1:00 pm – 3:00 pm

* Unless storage at Darwin Event Group facilities is arranged, the shipments should be delivered to the Dalhousie Student Union Building no earlier than the first day of the conference (June 27, 2023).
Refer to **Shipping, Storage, and Material Handling Section** for more information.

HI-AM 2022 Exhibition – McGill University

LOCATION OF THE EXHIBITION

The exhibition will take place at Dalhousie Student Union Building in McInnes Room.

HI-AM 2023 EXHIBITION AREA

McINNES ROOM (200-202) SUB – SECOND FLOOR

BOOTH 1
MSAM

BOOTH 2
SLM SOLUTIONS

BOOTH 3
cadmicro

BOOTH 4
XACT METAL

BOOTH 5
INDURATE ALLOYS LTD

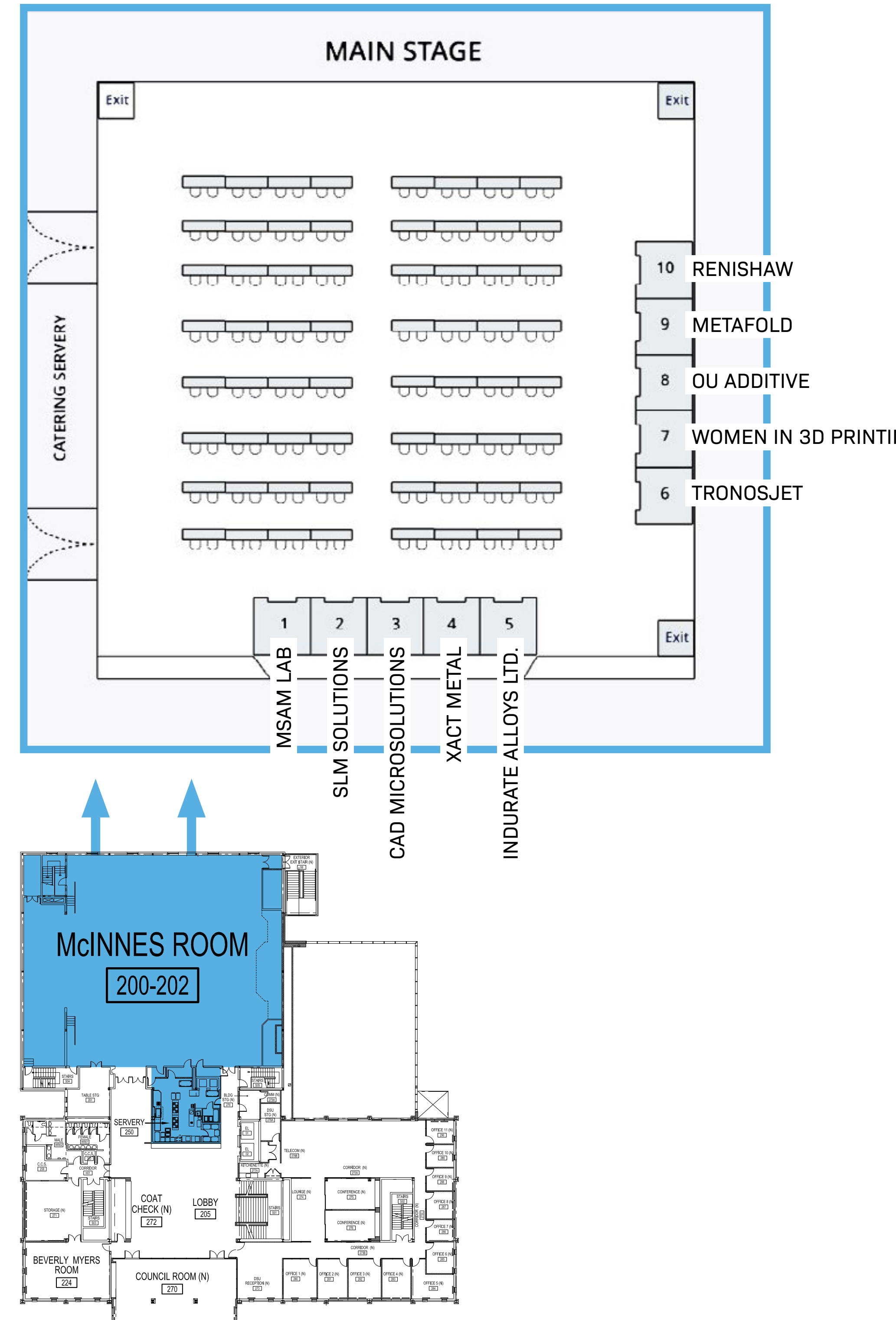
BOOTH 6
TRONOS

BOOTH 7
WOMEN IN 3D PRINTING

BOOTH 8
OU ADDITIVE

BOOTH 9
METAFOLD

BOOTH 10
RENISHAW apply innovation™



SHIPPING, STORAGE, AND MATERIAL HANDLING

Option 1: Darwin Event Group

Darwin Event Group is the exclusive service provider for material handling and pre and post show storage. Please directly contact the Darwin Event group for pricing information.

Note: Pre and post show storage and material handling services are not offered by Dalhousie Student Union. All such requests must be directed to Darwin Event Group.

Note: Darwin Event Group will not arrange for courier or transport pick-up for exhibitor packages from their warehouse after the conference. Exhibitors are responsible for arranging pick-up of their freight from the Darwin Event Group's warehouse within 5 business days after the close of the show.

Darwin Event Group's Contact Information:

Download **Trade Show Order Form**

info@darwineventgroup.com
Tel: 877.679.7177 | Fax: 902.678.4436

HI-AM 2023 Contact:
Matthew Carruthers
mcarruthers@darwineventgroup.com

Option 2: Do It Yourself

Exhibitors can receive and unload their own shipment(s) provided 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. If unable to meet these requirements, the material handling should be ordered through Darwin Event Group.

Unless storage at Darwin Event Group facilities is arranged, shipments should be delivered to the Dalhousie Student Union Building no earlier than the first day of the conference (June 27, 2023) during the exhibitor move-in (8 am – 12 pm). Items delivered before June 27 will not be accepted. The HI-AM Conference and Dalhousie Student Union do not accept any responsibility or liability for loss or damage caused to the shipments due to early delivery.

The exhibition room is located on the second floor of the Dalhousie Student Union Building (McInnes Room). The passenger elevator located on the first floor can be used to carry smaller items to the exhibition room. Please note that the venue does not have a freight elevator and handling large shipments should be arranged through Darwin Event Group.

Delivery address

Dalhousie Student Union
6136 University Ave
Halifax, NS, Canada B3H 4R2

TECHNICAL INFORMATION AND GENERAL CONDITIONS

General Conditions

The Dalhousie Student Union (DSU) Building reserves the right to inspect all private functions. Failure to adhere to the policies/regulations of the Dalhousie Student Union, Dalhousie University and the Meeting & Event Management Department may result in the termination of the activity. The exhibitors agree to adhere to all Federal, Provincial and Municipal laws & regulations.

The DSU Building is a scent-free environment and all organizations must abide by this policy. Under no circumstances can scented products such as incense be burned in the conference rooms.

The DSU reserves the right to contact Dalhousie Security and/or HRM Police if deemed necessary.

Advertising

As per HRM By-Law S-800, advertising posters & signs are only permitted to be placed on approved community kiosks and noticeboards in the municipality. Further to this, posters placed in non-approved locations such as utility poles, trees or other public infrastructure is subject to significant fines ranging from $250 to $10,000. If the DSU or Dalhousie University incurs a fine as a result of any organization's failure to adhere to this by-law, the exhibiting organization will be responsible for any fines, penalties or legal fees that may be levied against the DSU or Dalhousie University. For more information on the by-law, please visit **www.halifax.ca/city-hall/legislation-by-laws/by-law-s-801** or call 902-490-5650.

All advertising that mentions the Dalhousie Student Union Building (SUB) must be approved by the Meeting & Event Management office prior to it being distributed to the public. If approved, advertising materials should mention the Dalhousie Student Union Building as avenue only. It should not appear as if the event is being sponsored or organized by the Dalhousie Student Union (DSU). Advertising cannot mention alcohol service or pricing.

Insurance

Exhibitors must possess their own liability insurance. The HI-AM Conference and Dalhousie Student Union assume no responsibility for any bodily harm or damage to materials, products, equipment, booths or decorations caused by fire, water or theft, in the spaces rented or during movements within the building, whatever the cause.

Decorations & Building Signage

Signs and/or posters are not to be placed on any wall surface, door or window on the interior or exterior of the facility without prior permission. Any decorations affixed to the walls and/or ceiling must be removed at the end of the event. A cleaning charge may apply if items are not removed. Confetti, or similar substitutes, is not permitted. Candles are not permitted.

Catering & Beverage Services

Alcoholic Beverage Service in the facility must be arranged through DSU Bar Services. They can be reached at (902) 494-6891. Arrangements must be in accordance with the legal requirements of the Liquor Control Act of the province of Nova Scotia. If illegal alcohol is found in the venue or on persons attending the function, then the person(s) may be asked to leave or the activity maybe terminated.

The Dalhousie Student Union's food service provider, Chartwells, is the exclusive caterer for all functions being held in the SUB. All food and beverage details as well as billing information must be finalized with catering provider. They can be reached at (902) 494-2126.

Protection of the premises

Exhibitors must take the necessary precautions to prevent any destruction or damage to the rented space or to property of other exhibitors for which they may be held responsible. All residual glue, paint or stains observed after the dismantle will be cleaned at the exhibitors' expense.

Forklifts

Use of forklifts is prohibited in the building.

Exhibitors

CAD MICROSOLUTIONS is a leading provider of advanced engineering design and manufacturing solutions in Canada that helps clients achieve their business goals and stay ahead of the competition. The company specializes in providing software, hardware and services across multiple industries. We offer design automation software, additive manufacturing solutions, 3D metrology and scanning technology and professional services, as well as training and consultation to help our clients innovate, disrupt, design, and succeed. Our mission is to enable a community of professionals across Canada on a collaboration platform to optimize the deployment of Industry 4.0 technology.

www.cadmicro.com

INDURATE ALLOYS LTD. is a Canadian owned company working in the supply of powders and equipment for Additive Manufacturing, Thermal Spray, Laser, and Plasma Transferred Arc welding processes. We are the Canadian representatives for 3D Lab's ATO Lab powder atomization equipment, and their 2Create metal printer. We are also proud to be partnered with Farsoon Technologies and Farsoon Americas as their Canadian distribution arm for Farsoon Technologies plastic and metal printing equipment.

www.induratealloys.com

METAFOLD is a software company building design/engineering software for 3D printing. Our aim is to make it easier and faster for engineers and designers to work on complex geometry for pioneering applications in additive manufacturing. Our customers are creating bioreactors, cell scaffolds, industrial mixers, lighter parts for their EV fleets, consumer products, medical devices, and much more! Our API / volumetric kernel unlock huge opportunities for automation, research, and building tools with our high speed geometry processing at the core. Our goal is to work with exciting companies doing amazing things who are looking to automate geometry processing for their AM initiatives.

www.metafold3d.com

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

OU ADDITIVE is a startup specializing in liquid metal additive manufacturing, located in Moncton, New Brunswick. Our company is currently focused on developing an innovative approach to extruding liquid metals. We have successfully created a prototype of our technology utilizing low-melting point metals.

www.ouadditive.com

apply innovation™

RENISHAW is a global company with core skills in measurement, Additive Manufacturing, motion control, spectroscopy and precision machining. We develop innovative products that significantly advance our customers operational performance from improving manufacturing efficiencies and raising product quality.

www.renishaw.com

SLM SOLUTIONS is a global provider of integrated metal additive manufacturing solutions. Leading the industry since its inception, it continues to drive the future of metal AM in every major industry with its customers' long-term success at its core. SLM Solutions is home to the world's fastest metal additive manufacturing machines boasting up to 12 lasers and enabling build rates of <1000ccm/h.

www.slm-solutions.com/de/

TRONOSJET was established on Prince Edward Island in 2004 as an aircraft trading and MRO facility. In 2016 the company established a Manufacturing Division at the Charlottetown airport with the goal of moving into Additive Manufacturing (AM) for aerospace products. 2019 saw the installation of 3 AM machines, Renishaw RenAM 250, 500Q and 500S machines operating Inconel 625 and Ti-6Al-4V. We carry AS9100 approval, as well as being a Certified Aerospace Manufacturing Facility by Transport Canada.

www.tronosjet.com

WOMEN IN 3D PRINTING is an organization dedicated to promoting, supporting and inspiring women who are using Additive Manufacturing technologies. It is a non-profit international organization.

www.womenin3dprinting.com

XACT METAL is dedicated to the next generation of innovative solutions powered by metal 3D printing.With a desire to enable manufacturers to experience the benefits of high-quality 3D metal printing at the best price possible, Xact Metal aims to change the perception that additive manufacturing is only for capital-rich companies by designing and manufacturing high-quality powder-bed fusion 3D printers at the fraction of the competitors price.

www.xactmetal.com

Speakers

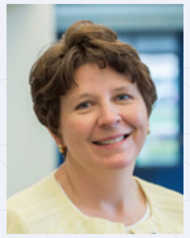
KEYNOTE SPEAKERS

Olaf Diegel

Professor of Additive Manufacturing
University of Auckland, Creative Design and Additive Manufacturing Lab, New Zealand

Olaf is a practitioner of additive manufacturing with an excellent track record of developing innovative solutions to engineering problems. He is involved in all aspects of AM and is a principal authors of the Wohlers Report, considered to be the definitive publication on AM. In his consulting practice he develops products for companies around the world. Over the past three decades he has developed over 100 commercialized new products and, for this work, has received numerous awards. In 2012, Olaf started manufacturing a range of 3D printed guitars (www.oddguitars.com) that has developed into a successful little side-business.

Presentation title: Design for Additive Manufacturing: Understanding Value



Carolyn Seepersad

J. Mike Walker Professor of Mechanical Engineering
The University of Texas at Austin, TX, United States

Carolyn Conner Seepersad is the J. Mike Walker Professor of Mechanical Engineering at The University of Texas at Austin. She is the director of the Center for Additive Manufacturing and Design Innovation and the Editor-in-Chief of the ASME Journal of Mechanical Design. Her research interests include design for additive manufacturing, simulation-based design of materials and structures, and process innovation in additive manufacturing. She is a member of the organizing committee of the annual Solid Freeform Fabrication Symposium and a member of SME's Additive Manufacturing Technical Leadership Committee. She is the author of more than 125 peer-reviewed conference and journal publications.

Presentation title: Process-Aware Design for Additive Manufacturing

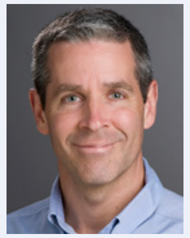
Tim Horn

Assistant Professor, Mechanical and Aerospace Engineering
North Carolina State University, NC, United States

Tim Horn is an assistant professor in the department of mechanical and aerospace engineering at North Carolina State University. He is the Director of Research for the Center for Additive Manufacturing and Logistics and the Director of the Consortium on the Properties of Additive Manufactured Copper.

Presentation title: Additive Manufacturing of Copper and Copper Alloys

KEYNOTE SPEAKERS



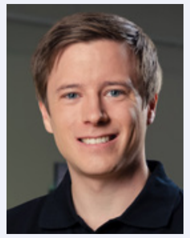
Denis Cormier

Earl W. Brinkman Professor of Industrial and Systems Engineering | AMPrint Center Director
Rochester Institute of Technology, NY, United States

Denis Cormier is the Earl W. Brinkman Professor at the Rochester Institute of Technology (RIT) where he directs the New York State funded AMPrint Center. He has close to 30 years of AM experience, much of which has been dedicated to metal AM and the design, fabrication, and testing of engineered lattice structures. He is currently focused on advancing metal jet printing technologies to include jetting of higher melting point metals with greater material deposition rates.

Presentation title: Towards High Speed Metal AM Via Molten Metal Droplet Jetting

FEATURED SPEAKERS



Martin Buscher

Head of Testing Facilities
Aconity3D, Germany

Martin Buscher studied mechanical engineering at Aachen University of Applied Science from 2011 to 2018. He graduated with a Master degree with his thesis topic: Influence of Laser Wavelength on the Processing of Copper and Copper Alloys in L-PBF. During his study he worked several years in the department of L-PBF at the Fraunhofer Institute for Laser Technology. Since 2018, he has been working at Aconity3D to develop the latest solutions for the most demanding LPBF applications and materials.

Presentation title: Enhanced L-PBF through AFX Beam Shaping

Elissa Ross

CEO
Metafold 3D, Canada

Elissa Ross is a mathematician and the CEO of Toronto-based startup Metafold 3D. Metafold makes design software for additive manufacturing, with an emphasis on supporting engineers using metamaterials, lattices and microstructures at industrial scales. Elissa has a PhD in discrete geometry, and has been working as an industrial geometry consultant for the past 8 years. Metafold is the result of observations made in that context about the challenges and opportunities of 3D printing.

Presentation title: Unlocking Industrial Metamaterials Through Design for Additive Manufacturing

FEATURED SPEAKERS

Michael Wohlfart

Senior Additive Manufacturing Consultant
EOS North America, United States

Michael Wohlfart is a Senior Additive Manufacturing Consultant of EOS North America, where he is responsible for supporting strategic customers on their path to serial production. Michael has over eight years of experience in the AM industry, sparking his passion for industrial 3D printing while working with Siemens Industrial Turbomachinery. He began his career with EOS at the headquarters in Munich, Germany, where he was working within the European Additive Minds and key account management team for more than five years before joining the EOS North America Additive Minds group.

Presentation title: EOS Smart Fusion – How a Process Monitoring Tool with a Feedback Loop Enables Support-Free Applications

Richard Grylls

Chief Engineer
Beehive Industries, United States

Richard has a 25-year career in the metal Additive Manufacturing industry, with GE Aviation, Optomec, SLM Solutions, and currently as Chief Engineer at Beehive Industries. Richard has worked in a variety of technical, applications, commercial and market roles, with the common thread being a passion to drive industrialization of metal AM as a mainstream production technique. Richard is a metallurgist by training, with a bachelor's degree in Materials Science from The University of Oxford, and a Ph.D. in Metallurgy from The University of Birmingham, UK.

Presentation title: Pathway to Material and Process Qualification for Metal AM in Aerospace Applications

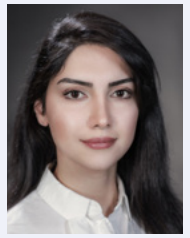
Gentry Wood

Senior Research and Development Engineer
Apollo Machine & Welding, Canada

Gentry Wood is a graduate from the Canadian Centre for Welding and Joining (CCWJ) at University of Alberta (2017) where he completed his PhD in modelling of the laser cladding process under Dr. Patricio Mendez. Dr. Wood is a process expert in the field of laser cladding for wear and corrosion protection and is actively focused on applying his research to maximize productivity of Apollo-Clad's industrial cladding processes. Recently, Gentry has pivoted his research efforts towards laser-based directed energy deposition (LB-DED) additive manufacturing. In 2022, he was inducted as a Fellow of the Canadian Welding Bureau Association.

Presentation title: Laser-Based Directed Energy Deposition of Nickel Aluminium Bronze for Naval Applications

FEATURED SPEAKERS

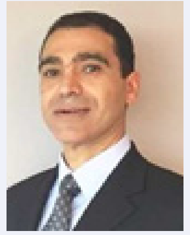


Farzaneh Farhang Mehr

Director of Additive Manufacturing Laboratory
The University of British Columbia

Dr Farzaneh Farhang-Mehr is the Director of the Additive Manufacturing Laboratory at the University of British Columbia. She specializes in failure analysis, optimization of industrial manufacturing processes, modification of metallic components' microstructure and mechanical properties, and mathematical modelling.
Dr Farhang Mehr's current focus centres on investigating the Electron Beam Powder Bed Fusion technique. She holds a B.A.Sc in Industrial Metallurgy from Iran University of Science and Technology, and a MASc and PhD in Materials Engineering from UBC. She has gained valuable industry experience through collaborations with prominent organizations such as General Motors, Nemak Canada and GE Additive.

Presentation title: Rationalization of the Modelling of Stress and Strain Evolution in Powder Bed Fusion Additive Manufacturing



Sami Arsan

Vice-President Additive and Advanced Manufacturing
voestalpine Additive Manufacturing Centers - North America, Canada

Sami Arsan, P. Eng, PMP, CAM-F Regional Vice-President, Additive and Advanced Manufacturing Technologies Sami Arsan brings over 25 years of industry experience in Business Strategy, Manufacturing processes, Equipment, and Global Supply Chain organizations including roles in sourcing, advanced manufacturing and component Engineering. He was a founding member of the voestalpine Additive Manufacturing Centers in North America. Sami holds a degree in mechanical engineering, is a Project Management Professional (PMP), a Professional Engineer (P.Eng) in the Province of Ontario and Certified in Additive Manufacturing by SME.

Presentation title: Why the 'Concept to Commercialization' Approach Is Key for Successful Implementation in Additive Manufacturing

HI-AM CONFERENCE 2023 PROGRAM SCHEDULE

DAY 1 – June 27, 2023 MORNING

ALL TIMES ARE ATLANTIC DAYLIGHT TIME (ADT TIME ZONE)

8:00am	**REGISTRATION – Location: Second Floor Lobby** **BREAKFAST – Location: Wayne Cross Room (303)**
8:45am	**CONFERENCE OPENING – Location: McInnes Room | Chair: Paul Bishop**
9:00am	**SESSION 1: Metal Additive Manufacturing I** **Location: McInnes Room | Chair: Paul Bishop**
9:00am	**KEYNOTE 1: Design for Additive Manufacturing: Understanding Value** Olaf Diegel *Professor of Additive Manufacturing* *University of Auckland, Creative Design and Additive Manufacturing Lab, New Zealand*
9:40am	**KEYNOTE 2: Process-Aware Design for Additive Manufacturing** Carolyn Seepersad *J. Mike Walker Professor of Mechanical Engineering* *The University of Texas at Austin, TX, United States*
10:20am	**MORNING TEA – Location: Wayne Cross Room (303)**
10:40am	**SESSION 2: Metal Additive Manufacturing II** **Location: McInnes Room | Chair: Ehsan Toyserkani**
10:40am	**KEYNOTE 3: Additive Manufacturing of Copper and Copper Alloys** Tim Horn *Assistant Professor, Mechanical and Aerospace Engineering* *North Carolina State University, NC, United States*
11:20am	**KEYNOTE 4: Towards High Speed Metal AM Via Molten Metal Droplet Jetting** Denis Cormier *Earl W. Brinkman Professor of Industrial and Systems Engineering | AMPrint Center Director* *Rochester Institute of Technology, NY, United States*
12:00pm	**LUNCH – Location: Wayne Cross Room (303)**

ONLINE CONFERENCE PROGRAM

HI-AM CONFERENCE 2023 PROGRAM SCHEDULE

DAY 1 – June 27, 2023 AFTERNOON

ALL TIMES ARE ATLANTIC DAYLIGHT TIME (ADT TIME ZONE)

12:40pm	**EXHIBITION – Location: McInnes Room** **POSTER VIEWING – Location: Second Floor Lobby**	
1:20pm	**SESSION 3: Material & Process Development I** **Location: McInnes Room | Chair: Carl Blais**	**SESSION 4: Modeling & Design I** **Location: Council Chambers |** **Chair: Carolyn Seepersad**
1:20pm	FEATURED **Presentation 1: Enhanced L-PBF through AFX Beam Shaping** Martin Buscher*, Marco Beckers, Florian Eibl **Presenter: Martin Buscher, Head of Testing Facilities, Aconity3D, Germany*	FEATURED **Presentation 6: Unlocking Industrial Metamaterials Through Design for Additive Manufacturing** Elissa Ross *CEO, Metafold 3D, Canada*
1:40pm	**Presentation 2: Microstructure Map of Rapidly Solidified 17-4PH Stainless Steel** Anne McDonald*, Anqi Shao*, Kimberley Meszaros**, Ahmed Qureshi*, Michel Rappaz***, Tonya Wolfe†, Hani Henein* **University of Alberta, Canada; **FLINT Corp, Canada; ***Ecole Polytechnique Federale de Lausanne, Switzerland; †Red Deer Polytechnic, Canada*	**Presentation 7: Numerical Analysis and Experimental Validation of Distortion in an Overhang Component Fabricated by the Electron Beam Powder Bed Fusion Process** Pegah Pourabdollah, Farzaneh Farhang Mehr, Steven Cockcroft, Daan Maijer *The University of British Columbia, Canada*
2:00pm	**Presentation 3: Laser Powder Bed Fusion Processing of UNS C64200 Aluminum Silicon Bronze** Kenzie Timmons, Paul Bishop *Dalhousie University, Canada*	**Presentation 8: Design for Additive Manufacturing: Redesign, Performance, and Manufacturability Analysis of a Single Non-Compressible Fluid-Flow Heat Exchanger** Joseph Orakwe*, Osezua Ibhadode**, Ali Bonakdar***, Ehsan Toyserkani* **MSAM, University of Waterloo, Canada; **Multifunctional Design and Additive Manufacturing (MDAM), University of Alberta, Canada; ***Siemens Energy, Canada*
2:20pm	**Presentation 4: Data Driven Process Optimization for 3D Printing of Metal via Direct-Ink-Writing** Terek Li, Hao Mao, Zekai Li, Jerry Chen, Hani Naguib *University of Toronto, Canada*	**Presentation 9: Development of an Efficient Multi-scale Model to Predict Residual Stresses and Distortion in the Laser Powder Bed Fusion Process for Inconel-718** Hossein Mohammadtaheri*, Ramin Sedaghati*, Marjan Molavi-Zarandi** **Concordia University, Canada; **National Research Council Canada (NRC), Canada*
2:40pm	**Presentation 5: Effect of Post-treatment on Mechanical Properties and Fatigue Behavior of Additively Manufactured Real Parts in Power Generation Industries** Yahya Aghayar, Mohsen Mohammadi *University of NewBrunswick, Canada*	**Presentation 10: Development of Refractory Metal Manufacturing Technology by Laser Powder Bed Fusion** Aurore Leclercq, Morgan Letenneur, Vladimir Brailovski *École de Technologie Supérieure de Montréal, Canada*
3:00pm	**AFTERNOON TEA – Location: Wayne Cross Room (303)** **EXHIBITION – Location: McInnes Room** **POSTER VIEWING – Location: Second Floor Lobby**	3:00pm – 3:40pm **Women in 3D Printing Happy Hour** **Location: Council Chambers**
3:20pm	**EXHIBITION – Location: McInnes Room** **NETWORKING**	

DAY 1 – June 27, 2023 AFTERNOON

ALL TIMES ARE ATLANTIC DAYLIGHT TIME (ADT TIME ZONE)

4:00pm	**SESSION 5: Process Monitoring & Control I** **Location: McInnes Room | Chair: Olaf Diegel**	**SESSION 6: Novel AM Processes & Products I** **Location: Council Chambers | Chair: Mathieu Brochu**
4:00pm	FEATURED **Presentation 11: EOS Smart Fusion – How a Process Monitoring Tool with a Feedback Loop Enables Support-Free Applications** Michael Wohlfart *Senior Additive Manufacturing Consultant* *EOS North America, United States*	FEATURED **Presentation 16: Pathway to Material and Process Qualification for Metal AM in Aerospace Applications** Richard Grylls*, Shawn Kelly, Pablo Enrique *Presenter: Richard Grylls, Chief Engineer *Beehive Industries, United States*
4:20pm	**Presentation 12: The Effect of Domain Shift on Machine Learning Performance in Additive Manufacturing** Gijs van Houtum, Mihaela Vlasea *University of Waterloo, Canada*	FEATURED **Presentation 17: Laser-Based Directed Energy Deposition of Nickel Aluminium Bronze for Naval Applications** Gentry Wood*, Douglas Hamre *Presenter: Gentry Wood, Senior Research and Development Engineer *Apollo Machine & Welding, Canada*
4:40pm	**Presentation 13: Topological Fidelity of Additively Manufactured AlSi10Mg Gyroid Structures** Osezua Ibhadode*, Issa Rishmawi**, Mihaela Vlasea**, Mark Kirby**, Sooky Winkler*** **Multifunctional Design and Additive Manufacturing Lab, Mechanical Engineering, University of Alberta, Canada;* ***Multi-Scale Additive Manufacturing Lab, Mechanical and Mechatronics Engineering, University of Waterloo, Canada;* ****Dana Incorporated, Canada*	**Presentation 18: Wear Properties of Wrought and Directly Deposited AISI D2 Tool Steel** Samer Omar, Kevin Plucknett *Dalhousie University, Canada*
5:00pm	**Presentation 14: Correlative Analytics of Downskin Surface Roughness Outcomes Using Systematic Data Science Workflows** Jigar Patel, Sagar Patel, Mihaela Vlasea *University of Waterloo, Canada*	**Presentation 19: Surface Modification of Additively Manufactured Ti-6Al-4V Parts Using Ultrasonic Pulsed Water Jet Peening** Paria Siahpour*, Mark Amegadzie*, Andrew Tieu**, Ian Donaldson***, Kevin Plucknett* **Dalhousie University, Canada; **VLN Advanced Technologies, Canada; ***GKN Sinter Metals , Canada*
5:20pm	**Presentation 15: The Use of Convolutional Neural Network for the Improvement of Repeatability, Reproducibility, and Reliability of Automated Porosity Detection in Laser Powder Bed Fusion Parts** Catherine Desrosiers*, Fabrice Bernier**, Nicolas Piché***, Farida Cheriet*, François Guibault*, Vladimir Brailovski† **Polytechnique Montréal, Canada;* ***National Research Council Canada, Canada;* ****Object Research Systems, Canada;* *†École de technologie supérieure, Canada*	**Presentation 20: Development of Hybrid Surface Finishing Techniques for Additively Manufactured Metal Parts with Internal Channels** Manyou Sun, Ehsan Toyserkani *University of Waterloo, Canada*
5:40pm	**DAY 1 CLOSING**	
7:00pm	**RECEPTION | Location: Pickford & Black**	
8:00pm – 10:00pm	**CONFERENCE DINNER | Location: Pickford & Black**	

DAY 2 – June 28, 2023 MORNING

ALL TIMES ARE ATLANTIC DAYLIGHT TIME (ADT TIME ZONE)

7:30am	**BREAKFAST – Location: Wayne Cross Room (303)**	
8:00am	**SESSION 7: Material & Process Development II** **Location: McInnes Room | Chair: Javad Gholipour**	**SESSION 8: Process Monitoring & Control II + Modeling and Design II** **Location: Council Chambers | Chair: Steve Cockcroft**
8:00am	**Presentation 21: Non-Weldable Ni-Base Superalloys Additively Manufactured via Electron Beam Powder Bed Fusion: A Survey and a Case Study** Hamid Aghajani, Esmaeil Sadeghi, Paria Karimi, Ehsan Toyserkani *University of Waterloo, Canada*	FEATURED **Presentation 26: Rationalization of the Modelling of Stress and Strain Evolution in Powder Bed Fusion Additive Manufacturing** Pegah Pourabdollah, Farhad Rahimi, Farzaneh Farhang Mehr*, Daan Maijer, Steve Cockcroft *Presenter: Farzaneh Farhang Mehr, Director of Additive Manufacturing Laboratory *The University of British Columbia*
8:20am	**Presentation 22: Laser Directed Energy Deposition (L-DED) Fabricated Inconel 718: Microstructure and Mechanical Properties** Zahra Khodamoradi, Michael Benoit *University of British Columbia, Canada*	**Presentation 27: Leveraging Design for Additive Manufacturing to Remedy Low Internal Porosity in Metal Powder Binder Jetting** Daniel Juhasz*, Mingzhang Yang*, Allan Rogalsky*, Mohsen Keshavarz*, Mihaela Vlasea*, Martin Laher**, Amin Molavi-Kakhki*** **University of Waterloo, Canada; **MIBA Sinter Group, Austria; ***Rio Tinto, Canada*
8:40am	**Presentation 23: Process Parameter Window Determination for Laser Powder Bed Fusion of Copper Chromium Zirconium** Melissa Trask, Paul Bishop *Dalhousie University, Canada*	**Presentation 28: Fuzzy-Machine Learning Framework for Porosity Prediction Using Optical Tomography Imaging in Laser Powder-bed Fusion** Osazee Ero, Katayoon Taherkhani, Ehsan Toyserkani *University of Waterloo/Multi-Scale Additive Manufacturing (MSAM), Canada*
9:00am	**Presentation 24: The Effects of Process Parameters on the Development of Internal Strains in Laser Powder Bed Fusion Additive Manufacturing of Hastelloy-X** Amirhosein Mozafarighoraba*, Ahmed Aburakhia*, Ali Bonakdar**, Hamidreza Abdolvand* **Department of Mechanical and Materials Engineering, Western University, Canada;* ***Siemens Energy Canada Limited, Canada*	**Presentation 29: Predicting Temperature Distribution with an HDR CMOS Sensor to Monitor Material Properties in Direct Energy Deposition** Lucas Botelho, Richard van Blitterswijk, Amir Khajepour *University of Waterloo, Canada*
9:20am	**Presentation 25: Effect of TiC and TiB2 Nano-inoculants Addition on the Microstructure and Tribological Performance of a Fe-Cr-Ni-Al Stainless Steel Fabricated via Arc-directed Energy Deposition** Elham Afshari, Mahya Ghaffari, Alireza Nemani, Paul Bishop, Ali Nasiri *Dalhousie University, Canada*	**Presentation 30: Toward Sintering Predicting Densification and Distortion in Binder-Jet Additive Manufacturing** Roman Boychuk, Mihaela Vlasea, Kamyar Ghavam *University of Waterloo, Canada*
9:40am	**MORNING TEA – Location: Wayne Cross Room (303)** **EXHIBITION – Location: McInnes Room** **POSTER VIEWING – Location: Second Floor Lobby**	

DAY 2 – June 28, 2023 MORNING

ALL TIMES ARE ATLANTIC DAYLIGHT TIME (ADT TIME ZONE)

10:00am	**SESSION 9: Novel AM Processes & Products II** **Location: McInnes Room | Chair: Ahmed Qureshi**	**SESSION 10: Material & Process Development III** **Location: Council Chambers | Chair: Priti Wanjara**
10:00am	FEATURED **Presentation 31: Why the 'Concept to Commercialization' Approach Is Key for Successful Implementation in Additive Manufacturing** Sami Arsan *Vice-President Additive and Advanced Manufacturing, voestalpine Additive Manufacturing Centers – North America, Canada*	**Presentation 36: Testing the Limits of Low-viscosity Feedstock in Material Extrusion 3D printing of Highly-filled Polymer.** Emmanuel Pelletier *École de Technologie Supérieure, Canada*
10:20am	**Presentation 32: Solid and Lattice-Structured Additive Manufactured Zirconia Dental Implant Bars: In Vitro Testing and Assessment** Les Kalman *Western University, Canada*	**Presentation 37: Investigation Steels Manufactured by a Hybrid Additive/Subtractive Technology** Sheida Sarafan*, Priti Wanjara*, Javad Gholipour*, Josh Soost** **National Research Council Canada, Canada; **Matsuura Machinery USA Inc., United States*
10:40am	**Presentation 33: Optimized end-to-end Process Flow for Additive Manufacturing** Rym Gazzah *Productique Québec, Canada*	**Presentation 38: Printing Parameter and Post-processing Optimization of Selective Laser Melting Inconel 718 for Sheet Metal Stamping Application** Cho-Pei Jiang, Yuh-Ru Wang *National Taipei University of Technology, Taiwan*
11:00am	**Presentation 34: General Corrosion Behavior of Conventionally versus Additively Manufactured Nickel-Aluminum Bronze Alloys: An Overview** Khashayar MorshedBehbahani, Donald Paul Bishop, Ali Nasiri *Dalhousie University, Canada*	**Presentation 39: 3D Microstructural and Crystallographic Texture Evolution in Additively Manufactured Alloys** Sravya Tekumalla*, Stefan Zaefferer** **University of Victoria, Canada; **Max Planck Institute for Iron Research, Germany*
11:20am	**Presentation 35: Implementation of Ultrasound Particle Lensing Technology on a Laser Directed Energy Deposition Machine for Focusing of Ti6Al4V Powder Stream** *Alexander Martinez-Marchese, *Mazyar Ansari, **Asier Marzo, *Marc Wang, *Ehsan Toyserkani **MSAM, Canada; **UPNA, Spain*	**Presentation 40: Microstructure and Microhardness Variation with Build Height in Laser Powder Bed Fusion Fabricated 316L Stainless Steel** Paresh Prakash, Abdelbaset Midawi, Mary Wells *University of Waterloo, Canada*
11:40am	**LUNCH – Location: Wayne Cross Room (303)**	
12:20pm	**EXHIBITION – Location: McInnes Room** **POSTER VIEWING – Location: Second Floor Lobby**	

12:20 – 1:20pm
HI-AM Network Board of Directors Meeting 12 – Location: Beverley Myers Room (224)

DAY 2 – June 28, 2023 AFTERNOON

ALL TIMES ARE ATLANTIC DAYLIGHT TIME (ADT TIME ZONE)

1:00pm	**SESSION 11: Material & Process Development IV** **Location: McInnes Room | Chair: Hani Naguib**	**SESSION 12: Process Monitoring & Control III** **Location: Council Chambers | Chair: Mihaela Vlasea**
1:00pm	**Presentation 41: A Comparative Study of the Microstructure and Surface Properties of Additive Manufactured 316 Stainless Steel and 8620 Steel with Those of Made by Conventional Processes** Jun Jiao*, Kaleb Hood*, Sarah Ahmed*, Annie Dao*, Wen Qian**, Joseph Turner** **Portland State University, United States; **University of Nebraska-Lincoln, United States*	**Presentation 45: Manufacturing Smart Part by Embedding Fiber Bragg Gratings Sensors** Ehsan Toyserkani, Bahareh Marzbanrad *University of Waterloo , Canada*
1:20pm	**Presentation 42: Recycling Rare-Earth Magnets into AM-Grade Powder; Rewards and Challenges** Ali Asgarian*, Gaofeng Li*, Fabrice Bernier*, Jean-Michel Lamarre*, Robyn Iannitto*, Shirley Mercier*, Nicolas Cormier*, Louis-Philippe Lefebvre*, Jean-Pierre Fortin** **National Research Council Canada | Conseil national de recherches Canada, Canada; **ATIQC Inc., Canada*	**Presentation 46: ISO/ASTM 52958:2022 Best Practice for In-Situ Flaw Detection and Analysis for the Laser Beam Powder Bed Fusion (LB-PBF) Process** Katayoon Taherkhani, Ehsan Toyserkani *University of Waterloo, Canada*
1:40pm	**Presentation 43: Laser Powder Bed Fusion (LPBF) Processing of a Mixed Nickel Aluminum Bronze Powder** Addison Rayner*, Jon Hierlihy*, Melissa Trask*, Randy Cooke**, Paul Bishop* *Dalhousie University, Canada; DRDC, Canada*	**Presentation 47: Machine Learning for Defect Analysis in Laser Powder Bed Fusion** Yu Zou *University of Toronto, Canada*
2:00pm	**Presentation 44: Path to Enhance the Thermal Stability of 3D Printed Aluminum Alloys** Ehsan Marzbanrad *University of Waterloo, Canada*	**Presentation 48: Active Print Layer Temperature Control through Base Plate heat Extraction Process** Shiyu Teng, Shirin Dehghani, Ahmed Qureshi, Hani Henein *University of Alberta, Canada*
2:20pm – 2:30pm	**CLOSING REMARKS AND AWARDS – LOCATION: MCINNES ROOM | CHAIR: HANI HENEIN**	

Poster Presentation Gallery

THEME 1: Material & Process Development
Location: Second Floor Lobby

Poster 1-1: Residual Stress Induced Cracking in Laser Powder Bed Fusion Fabricated 4405 Steel Gears
Peyman Alimehr, Mohsen K. Keshavarz, Sagar Patel, Mihaela Vlasea
Multi scale additive manufacturing lab, Canada

Poster 1-2: Machine Learning-informed Density Optimization in Electron Beam-Powder Bed Fusion of Ti48Al2Nb2Cr with Various Particle Size Distributions
Tomisin Oluwajuyigbe, Zohreh Azimifar, Paria Karimi, Shima Kamyab, Esmaeil Sadeghi, Mohsen Keshavarz, Mihaela Vlasea
University of Waterloo, Canada

Poster 1-3: Oxidation Response of Cu–Ag Parts Fabricated by Laser Powder Bed Fusion
Nadia Azizi*, Hamed Asgari**, Ehsan Toyserkani*
**University of Waterloo, Canada;*
***University of New Brunswick, Canada*

Poster 1-4: Functionalization, Oxidation, and Recyclability Study of 3D Printable MXene
Yu-Chen Sun, Ben Natra Ihilov, Terek Li, Hani Naguib
University of Toronto, Canada

Poster 1-5: An Investigation into the Recyclability of Plasma-Atomized Powders Used in Laser Powder Bed Fusion
Tina Mohammadhassan
Université laval, Canada

Poster 1-6: Process Optimization of NiTi 4D Structures Produced by Laser Powder Bed Fusion Technique
Shalini Singh, Shirin Dehghai , Ahmed Qureshi
University of Alberta, Canada

Poster 1-7: Experimental Investigations of Pure Ni Porous Parts Fabricated via Laser Powder Bed Fusion
Shokoufeh Sardarian, Shirin Dehgahi, Marc Secanell Gallart, Ahmed Qureshi
University of Alberta, Canada

Poster 1-8: Effect of Boron Additions on the Sintering Response of AISI D2 and AISI 4340 Components Produced by Binder Jetting
William Bouchard, Simon Gélinas, Carl Blais
Université Laval, Canada

Poster 1-9: Artificial Intelligence Applied to the Development of Tool Steels with Low Susceptibility to Cracking for Laser Additive Manufacturing (LAM)
Justin Plante
Université Laval, Canada

Poster 1-10: Laser-Based Directed Energy Deposition of Monel 400 on a Steel Substrate
Ryan Ley, Paul Bishop
Dalhousie University, Canada

Poster 1-11: Dynamic Strain Aging Behaviour of Laser Powder Bed Fusion Made Hastelloy X Parts
Reza Esmaeilizadeh*, Xiaolong Li**, Hamid Jahed*, Ehsan Toyserkani*, Ehsan Hosseini**
**University of Waterloo, Canada; **3Empa, Swiss Federal Laboratories for Material Science and Technology, Switzerland*

Poster 1-12: Development of AlSi10Mg-AlN Metal Matrix Composites for Laser Powder Bed Fusion AM
Jonathan Comhaire*, Donald Bishop*, Ian Donaldson**
**Dalhousie University, Canada; **GKN, Canada*

Poster 1-13: Development and Characterization of an Aluminum Bronze Alloy for Laser Powder Bed Fusion
Vignesh Krishnan*, Addison Rayner*, Kenzie Timmons*, Jon Hierlihy*, Randy Cooke**, Donald Bishop*
**Net Shape Manufacturing Group - Dalhousie University, Canada;*
***Defence Research and Development Canada, Canada*

Poster 1-14: 3D Printed Wood-fiber Reinforced Architected Cellular Composites with Enhanced Flexural Properties
Ehsan Estakhrianhaghighi, Armin Mirabolghasemi, Larry Lessard, Hamid Akbarzadeh
McGill, Canada

Poster 1-15: Metallurgical Investigation of Al-Zr(-Y) Alloys for LPBF Using Laser Remelting
Jon Hierlihy*, Ian Donaldson**, Paul Bishop*
**Dalhousie University, Canada;*
***GKN Powder Metallurgy, United States*

Poster 1-16: Performance Evaluation of Machine Learning Models in the Prediction of Melt Pool Dimensions and Density in Laser Powder Bed Fusion
Donatien Campion, Vladimir Brailovski
École de technologie supérieure, Department of Mechanical Engineering, Canada

Poster 1-17: How the Rheology of Powder Affects its Spreadability?
Stéphane Caubergh*, Aurélien Neveu*, Geoffroy Lumay**, Filip Francqui*
**Granutools, Belgium; **University of Liege, Belgium*

Poster 1-18: Moderate Temperature Slow Strain Rate Compression Behaviour of a Heat-treated LPBF Fabricated Fe-Cr-Ni-Al Maraging Stainless Steel (CX)
Paresh Prakash*, Abdelbaset Midawi*, Waqas Muhammad*, Mary Wells*, Amir Hadadzadeh**
University of Waterloo, Canada; University of Memphis, United States

Poster 1-19: Comparative Study on 316L Stainless Steel Powders Produced by Conventional Plasma Arc Gas Atomization versus Novel Ultrasonic Atomization Technique
Alireza Vahedi Nemani*, Lorne Chrystal*, Dino Russo*, Mariusz Lesniak**
**Indurate Alloys Ltd / Dalhousie University, Canada;*
***3D LAB , Poland*

Poster 1-20: Laser-powder Bed Fusion of Ti-based Alloys for Biomedical Applications
Rodolfo Batalha*, André Carvalho***, Piter Gargarella**, Paulo Morais*, Ana Cabral*, Guiomar Evans***
**ISQ - Instituto de Soldadura e Qualidade, Portugal;*
***Federal University of São Carlos, Brazil;*
****Faculty of Science, University of Lisbon, Portugal*

Poster 1-21: Additive Manufacturing of Al and Ti alloys: Microstructure Characterization and Mechanical Properties Across Length Scales
Yu Zou
University of Toronto, Canada

Poster 1-22: Effect of Salt Flux and T6 Treatment on Al-Cu Alloy with Ce Addition
Marcelino Dias, Jonas Valloton, Ahmed Qureshi, Hani Henein
University of Alberta, Canada

Poster Presentation Gallery

THEME 2: Modeling & Design
Location: Second Floor Lobby

Poster 2-1: Numerical Modeling of Hybrid Additive Manufacturing of Laser Beam Powder Bed Fusion and Milling of Ti6Al4V
Surinder Pal, Xavier Velay, Waqas Saleem
Atlantic Technological University Sligo, Ireland

Poster 2-2: Characterizing Uncertain Elastic Properties of Additively Manufactured Materials for Application in Topology Optimization
Zahra Kazemi, Craig Steeves
University of Toronto Institute for Aerospace Studies (UTIAS), Canada

Poster 2-3: Evaluation of Small-scale Thin Wall AlSi7Mg Alloy LPBF Coupons under Extreme Low Cycle Fatigue Regime
Muralidharan Kumar, Mathieu Brochu
McGill university, Canada

Poster 2-4: Property and Design Assessment of a 3D-Printed Metallic Implant
Anushree Shah
University of British Columbia , Canada

Poster 2-5: Novel Accelerated Thermo-mechanical LPBF Modelling Using an Effective Heat Source
Shahriar Imani Shahabad*, Zhidong Zhang**, Ali Bonakdar***, Ehsan Toyserkani*
**University of Waterloo, Canada;*
***Northwestern Polytechnical University, China;*
****Siemens Energy, Canada; University of Waterloo, Canada*

THEME 3: Process Monitoring & Control
Location: Second Floor Lobby

Poster 3-1: A Novel Machine Learning Approach for In-situ Surface Roughness Detection during Laser Powder-Bed Fusion
Sahar Toorandaz, Ehsan Toyserkani
University of Waterloo, Canada

Poster 3-2: Machine Learning-Based Powder Characterization: Exploring Data Augmentation Techniques to Address the Material Data Limitation Challenges
Farima Liravi*, Mahdi Habibnejad**, Ehsan Toyserkani*
**University of Waterloo, Canada;*
***AP&C, a GE Additive Company, Canada*

Poster 3-3: Methods for Modeling Sensitivity Analysis Simulations for Eddy Current Testing
Heba Farag
University of Waterloo, Canada

Poster 3-4: Mechanical Performance of 3D Printed Parts Using Material Extrusion of Highly-filled Polymer
Benoit Beaulieu
École de technologie supérieure, Canada

THEME 4: Novel AM Processes & Products
Location: Second Floor Lobby

Poster 4-1: Binder Jetting Additive Manufacturing for Compliant Mechanisms
Edward Yang, Issa Rishmawi, Mihaela Vlasea, Michael Mayer
University of Waterloo, Canada

Poster 4-2: Microstructural Control during Laser Powder-bed Fusion of Ti-alloy via Laser Post-exposure Treatment
Mahyar Hasanabadi, Ali Keshavarzkermai, Hamed Asgari, Adrian Gerlich, Ehsan Toyserkani
Multi-Scale Additive Manufacturing (MSAM) Lab, University of Waterloo, Canada

Poster 4-3: Development and Applications of Benign Electrolytes for Surface Finishing of Additively Manufactured Metal Parts
Manyou Sun, Ehsan Toyserkani
University of Waterloo, Canada

Poster 4-4: Robotic 3D printing of Lunar Regolith/Polymer Composite by Simultaneous Localization and Additive Manufacturing
Mohammad Azami, Pierre-Lucas Aubin-Fournier, Krzysztof Skonieczny
Concordia University, Canada

Poster 4-5: Tailoring Microstructure and Resulting Mechanical Properties of Maraging Steel Fabricated by Laser Powder Bed Fusion
Mohsen Keshavarz*, Christopher Paul**, Michael Benoit**, Mihaela Vlasea*
**University of Waterloo, Canada;*
***University of British Columbia, Canada*

Poster 4-6: 3D Printing of Fiber ased Soft Meta-components
Yu Liu
Jiangnan University, China

Poster 4-7: Functionally Graded Additive Manufacturing of Inconel 625-CuCrZr: from Process Parameter Optimization to Microstructural Evolution and Mechanical Properties
Ali Zardoshtian, Reza Esmaeilizadeh, Saeed Maleksaeedi, Hamid Jahed, Ehsan Toyserkani
University of Waterloo, Canada

Poster 4-8: Thermal and Residual Stress Modeling of Functionally Graded Coatings Deposited by PTA-AM
Geoffrey Bonias*, Hani Henein*, Tonya Wolfe**
**University of Alberta, Canada;*
***Centre for Innovation in Manufacturing, Canada*

Abstracts

ALL TIMES ARE ATLANTIC DAYLIGHT TIME (ADT TIME ZONE)

ONLINE CONFERENCE PROGRAM

Keynotes

SESSION 1: Metal Additive Manufacturing I
JUNE 27 | 9:00am ADT

Keynote 1 | 9:00am

Design for Additive Manufacturing: Understanding Value

Olaf Diegel

Professor of Additive Manufacturing

University of Auckland, Creative Design and Additive Manufacturing Lab, New Zealand

AM is one of the most expensive manufacturing methods in the known universe. Therefore, for it to be commercially viable for production applications, it must add enough value to overcome those high costs. This talk will focus on the main factors that affect AM cost and how to design around these so that they can be transformed into value adding features. It will demonstrate how, with good design for AM (DfAM) practices, AM can be transformed from a slow and expensive technology into one that can transform products into success stories. It will present numerous real-world examples of how AM can be used to add significant value to products. This includes products in aeronautical and transport applications, heat exchangers, and even artistic applications.

The recent advent of automated design software has also created opportunities that give users the ability to automate the design of complex products. If these software technologies are combined with good design for AM practices, it can become a tremendous catalyst for increased innovation. This talk attempts to impart some practical guidance on how to design parts and use automated design software to gain the maximum benefit from what AM can offer.

Keynote 2 | 9:40am

Process-Aware Design for Additive Manufacturing

Carolyn Seepersad

J. Mike Walker Professor of Mechanical Engineering

The University of Texas at Austin, TX, United States

Additive manufacturing (AM) is making a profound impact on the way engineers realize customized parts, and it is democratizing product design and manufacturing in unprecedented ways. In this talk, we will explore the frontiers at the intersection of AM and design innovation and some of the new design capabilities under development to expand those frontiers. Specifically, we will focus on some of the challenges associated with enabling the design of highly customized additively manufactured structures, along with emerging tools and methods for process-aware and user-driven customization.

SESSION 2: Metal Additive Manufacturing II
JUNE 27 | 10:40am ADT

Keynote 3 | 10:40am

Additive Manufacturing of Copper and Copper Alloys

Tim Horn

Assistant Professor, Mechanical and Aerospace Engineering

North Carolina State University, NC, United States

The unique combination of properties exhibited by copper and copper alloys, including high thermal conductivity, low emissivity, high reflectivity, and susceptibility to contamination and cracking, pose several challenges for their additive manufacturing. This presentation will examine the difficulties and potential for this class of materials in AM, exploring recent literature and advancements in processing.

Keynote 4 | 11:20am

Towards High Speed Metal AM Via Molten Metal Droplet Jetting

Denis Cormier

Earl W. Brinkman Professor of Industrial and Systems Engineering | AMPrint Center Director

Rochester Institute of Technology, NY, United States

Dot matrix printers from the 1960's and 1970's typically printed at ~10-12 pages per minute. Today's modern digital printing presses can churn out 100-200 pages per minute in full color. This is in sharp contrast to metal AM technologies that can still have build times measured in days even for modestly sized parts. Several companies and research groups around the world are developing exciting and innovative new metal AM technologies whose aim is to achieve massively higher material deposition rates without sacrificing feature resolution. This talk will focus on one of these new technologies called metal jet additive manufacturing, or M-JAM. The talk will first provide an overview of different molten metal droplet jetting technologies and their capabilities and limitations. The talk will then turn towards a vision of the future in which arrays of nozzles jet 100-250 micron diameter molten metal droplets at frequencies of 3 kHz or higher. That vision represents the state where metal AM has progressed as far as today's digital printing presses. The talk will conclude with a discussion of the technological barriers that must be overcome before the potential is turned into reality.

Oral Presentations

SESSION 3: Material & Process Development I
June 27 | 1:20pm

1:20pm

FEATURED **Presentation 1: Enhanced L-PBF through AFX Beam Shaping**

Martin Buscher*, Marco Beckers, Florian Eibl

*Presenter: Martin Buscher, Head of Testing Facilities

Aconity3D, Germany

Influencing the characteristics of additively manufactured metallic components such as mechanical properties or microstructure is increasingly becoming a focus of research. One way to influence the process and the interaction between energy source and material in L-PBF is to vary the laser beam intensity distribution. Thus, innovative laser beam sources allow switching between Gaussian, ring and/or hybrid forms of laser beam intensity distribution within milliseconds during processing without additional optical elements. This possibility of selectively influencing material properties focuses in particular on materials such as the nickel-based superalloy IN718, which are suitable for the manufacture of complex components and/or for which high demands are placed on their properties. The crystallographic texture, as a partially heat treatment resistant material property, represents an important parameter in this context. Directionally solidified microstructures can offer advantages, especially in high temperature applications with uniaxial loading. In-depth investigations on the high temperature material IN718 revealed that the crystallographic texture of components can be strongly influenced by changing the intensity distribution under otherwise identical process conditions. Resulting in a higher ductility while maintaining or even increasing the strength in comparison to samples manufactured by conventional gaussian insensity distributions.

1:40pm

Presentation 2: Microstructure Map of Rapidly Solidified 17-4PH Stainless Steel

Anne McDonald*, Anqi Shao*, Kimberley Meszaros**, Ahmed Qureshi*, Michel Rappaz***, Tonya Wolfe†, Hani Henein*

**University of Alberta, Canada; **FLINT Corp, Canada; ***Ecole Polytechnique Federale de Lausanne, Switzerland; †Red Deer Polytechnic, Canada*

One of the challenges with developing any material for use in additive manufacturing is characterizing its solidification over the range of thermal conditions and rapid solidification rates involved in AM processes. In order to characterize the initial solidification conditions of 17-4 precipitation hardenable stainless steel, this work presents a microstructure map of the alloy over a range of cooling rates and process conditions. The final microstructure map identifies the microstructures obtained under different solidification front velocities and inverse temperature gradients for 17-4PH samples from single-layer wire and arc additive manufactured (WAAM) deposits. The goal of the map is to aid in the development of a digital database of the process-structure-property relationship for this alloy.

2:00pm

Presentation 3: Laser Powder Bed Fusion Processing of UNS C64200 Aluminum Silicon Bronze

Kenzie Timmons, Paul Bishop

Dalhousie University, Canada

This study was focused on establishing effective processing parameters for the printing Aluminum Silicon Bronze (UNS C64200) by means of laser powder bed fusion technology. Parameter sets for a series of prints were developed through design of experiments concepts and then fabricated using an open-source 3D printer. This commenced with the printing of solid cuboids while varying laser power, scan speed, and hatch spacing, to reduce defects and maximize density. All specimen were then assessed with the resultant data subjected to statistical analyses. The most effective printing parameters yielded products at near full density (99.9%). These parameters were then employed to fabricate tensile bars that were subsequently machined and then tested in the as-built and heat treated conditions. As-built specimen demonstrated a high UTS (>800MPa) but limited ductility (~5%). Heat treatment invoked a more desirable balance of properties that included a yield strength of 330MPa, UTS of 575MPa and a ductility to fracture of 25%. All properties exceeded the Defence Standard requirements for aluminum silicon bronze which presents the material as a promising candidate for further study and development.

2:20pm

Presentation 4: Data Driven Process Optimization for 3D Printing of Metal via Direct-Ink-Writing

Terek Li, Hao Mao, Zekai Li, Jerry Chen, Hani Naguib

University of Toronto, Canada

Direct-Ink-Writing (DIW) is an Additive Manufacturing (AM) method which relies on the extrusion of a gel to create 3D object. When combined with post-deposition thermal treatments, DIW can be a versatile method for the creation of metallic structures. A thorough understanding on the effect of material's rheological properties and print settings on the printed feature dimension is essential to generate successful print path that delineate the original 3D model. If such relationship is not precisely and quantitatively modelled, then the object will have feature geometries that fail to serve the intended functionalities. Traditionally a test-and-trial based approach is used to determine such relationship through repetitive prints. This approach raises several drawbacks such as minimal knowledge-transfer and material waste. Therefore, there is the need for a knowledge-based framework that is universally applicable. This research aims to address this vacancy by utilizing a data driven approach to fully explore the available design space. Through carefully designed data collection strategies, the relationship between various input parameters is deduced and modelled. The result of this work serves to minimize up-front optimization cost of implementing a new metal-based material for printing via DIW.

2:40pm

Presentation 5: Effect of Post-treatment on Mechanical Properties and Fatigue Behavior of Additively Manufactured Real Parts in Power Generation Industries

Yahya Aghayar, Mohsen Mohammadi
University of NewBrunswick, Canada

Producing parts with complex geometry is one of the distinctive features of additive manufacturing (AM) methods. According to the under-control parameters in this method, the microstructure and mechanical properties are largely controlled. One of the most effective factors in this method is the use of post-treatment to modify the microstructure. In this regard, the hot isostatic pressing (HIP) method can achieve an optimal microstructure.

For this purpose, parts were prepared and studied in different conditions including, as-build, annealed, and HIPed. In addition to microscopic studies using a scanning electron microscope (SEM) electron backscatter diffraction microscope (EBSD), the mechanical properties and fatigue behavior were performed.

The results showed that the microstructure of the samples is completely uniform after the HIP and no trace of the initial solidification structure was observed. Also, the internal defects have completely disappeared and the density of the hipped parts has increased significantly. According to the mechanical properties, although the final hardness and strength of the hipped samples do not show very different behavior compared to other samples, their toughness has increased noticeably. Moreover, the fatigue behavior of the final part passes all the standard minimums of the parts used in the industry produced from 316L material.

SESSION 4: Modeling & Design I
June 27 | 1:20pm

1:20pm

FEATURED **Presentation 6: Unlocking Industrial Metamaterials Through Design for Additive Manufacturing**

Elissa Ross
CEO
Metafold 3D, Canada

3D printing has unlocked the fabrication of metamaterials: repetitive, lattice-like geometries that can be engineered to have remarkable application-specific properties. Yet, 3D printing has also throttled the production of metamaterials at scale by a reliance on computationally expensive geometry representation and processing. In this talk I will describe some of the amazing applications facilitated by metamaterials and high surface area printing, focusing on clean technologies. I will explain the challenges of working with metamaterials and lattices at industrial scales, and provide some insights toward resolving these challenges through design for additive manufacturing.

1:40pm

Presentation 7: Numerical Analysis and Experimental Validation of Distortion in an Overhang Component Fabricated by the Electron Beam Powder Bed Fusion Process

Pegah Pourabdollah, Farzaneh Farhang Mehr, Steven Cockcroft, Daan Maijer
The University of British Columbia, Canada

The Electron Beam Powder Bed Fusion (EB-PBF) process is an advanced Additive Manufacturing (AM) method that can produce full-density metallic components with the minimum amount of residual stress. In practice, support structures are recommended to reduce distortion and bleed-through, particularly in overhang sections. In this work, a 3D numerical model was developed to investigate the distortion in an overhang component. The agglomeration methodology was utilized in the model to reduce the computational time. An inherent strain was applied in the form of an initial anisotropic thermal strain to each super layer to represent the in-plane plastic strain that is expected to develop in proximity to the melt pool. To validate the model, the overhang component was fabricated using the ARCAM Q20plus machine. The distortion in the overhang component was measured using the Keyence microscope. The model predictions were then aligned with the experimentally derived data by adjusting the magnitude of the plastic strain. The results suggest that the in-plane plastic strains are in the order of 0.001 (-) and are compressive.

2:00pm

Presentation 8: Design for Additive Manufacturing: Redesign, Performance, and Manufacturability Analysis of a Single Non-Compressible Fluid-Flow Heat Exchanger

Joseph Orakwe*, Osezua Ibhadode**, Ali Bonakdar***, Ehsan Toyserkani*
**MSAM, University of Waterloo, Canada; **Multifunctional Design and Additive Manufacturing (MDAM), University of Alberta, Canada; ***Siemens Energy, Canada*

Single-liquid forced convection heat exchangers or cold plates have been investigated to keep a variety of power electronics modules at optimal operating temperatures. Thermal-fluidic topology optimization (TO) is also becoming popular in realizing efficient microchannel heat sinks. Inspired by an interesting Puntozero design case study, this work presents a novel methodology that combines topology optimization & latticing techniques to obtain additive manufacturable high-performance heat exchangers. A redesign process to replicate, adapt & optimize the existing design was first undertaken, geared at imbuing flow improvements while retaining heat dissipation performance. Thereafter, manufacturability assessments for AM took place to uncover necessary considerations for various design variants. Finally, design studies & performance characterization via CFD simulations were undertaken to gain insightful benchmarks. The study findings indicate that the employment of two-dimensional topology optimization and lattice design strategies leads to better use of the design space. Conducted numerical investigations reveal that the flow performance has improved compared to the initial serpentine configuration, amidst better thermal performance evaluated against the base heat sink design. Manufacturability indices are also encouraging, while the need for holistic workflows to bridge all aspects of the design process is identified and targeted for future development.

2:20pm

Presentation 9: Development of an Efficient Multi-scale Model to Predict Residual Stresses and Distortion in the Laser Powder Bed Fusion Process for Inconel-718

Hossein Mohammadtaheri*, Ramin Sedaghati*, Marjan Molavi-Zarandi**
**Concordia University, Canada; **National Research Council Canada (NRC), Canada*

In the Laser Powder Bed Fusion (LPBF) process, fast solidification of molten powders and significant temperature gradients cause substantial residual stresses in the build part. This can result in excessive deformation and potential crack initiation and propagation. High-fidelity thermo-mechanical models to predict the residual stresses/distortion in the macro-scale are generally impractical owing to their high level of computational time. The modified inherent strain methodology has recently shown its capability as a viable alternative to capture an accurate and efficient prediction of residual stresses. In this study, a multi-scale finite element-based model of the LPBF process is developed to estimate the accumulated stress. The stress formation and inherent strain values were calculated in a micro-scale two-layer deposition considering the effect of real process parameters in Abaqus/standard. The material constitutive models and their effect on the evolution of plastic strain were examined. The accuracy of the prediction was investigated by the number of equivalent layers using the agglomeration method and the elements activation strategy at each time step in the part-scale analysis. The proposed framework provided the residual stresses and deformation prediction which reasonably agreed with the experimental measurement using the X-ray diffraction and optical scanning of the part-scale cubes and cantilever beams.

2:40pm

Presentation 10: Development of Refractory Metal Manufacturing Technology by Laser Powder Bed Fusion

Aurore Leclercq, Morgan Letenneur, Vladimir Brailovski
École de Technologie Supérieure de Montréal, Canada

Refractory metals, such as tungsten and molybdenum, have extremely high melting points, thus complicating the production of parts from these metals using direct AM processes, such as laser powder bed fusion (LPBF). This study aims at optimizing the LPBF parameters in order to maximize the density of printed parts, while minimizing the occurrence of processing-induced defects (pores, cracks). To this end, "volumetric energy density – build rate" processing maps are generated using a numerical model based on the simulation of a melt pool generated from a mobile heat source and calibrated using the experimental results. Also, in addition to a set of the laser-matter interaction-related metrics, the model requires the knowledge of the powder bed density. To provide this information, morphological and rheological analyses of the powders have been carried out and allowed, on one hand, to assess the powder bed density and on the other hand, to measure the size, shape and flowability of the powders and thus quantify them for LPBF.

SESSION 5: Process Monitoring & Control I
June 27 | 4:00pm

4:00pm

FEATURED **Presentation 11: EOS Smart Fusion – How a Process Monitoring Tool with a Feedback Loop Enables Support-Free Applications**

Michael Wohlfart
Senior Additive Manufacturing Consultant
EOS North America, United States

Historically, metal laser powder bed fusion has suffered from the need of support structures for angles below 45 degrees. This caused additional cost due to higher material consumption, longer build time, and increased post-processing effort. Recent developments have pushed these boundaries of this angle limitation and enabled 3D printing at significantly lower angles without the reliance on traditional support structures.

However, most commercial solutions are related to time-consuming process parameter development that hinder swift implementation or work by slowing the build process, causing a negative impact on cost-per-part (CPP).

EOS has taken this growth opportunity and developed a software tool that leverages a closed-loop feedback and thermal input control with EOSTATE Exposure OT. The solution works without slowing productivity and thereby improves CPP

In this presentation, you will learn:

- The possibilities and limitations of support-free additive manufacturing builds
- How Smart Fusion impacts these processes
- Why Smart Fusion enabled positive business cases with industrial applications

Support-free metal 3D printing with Smart Fusion leads to reduced CPP for geometries previously requiring support structures and unlocks a future of unprecedented complex applications.

4:20pm

Presentation 12: The Effect of Domain Shift on Machine Learning Performance in Additive Manufacturing

Gijs van Houtum, Mihaela Vlasea
University of Waterloo, Canada

Current machine learning (ML) modelling efforts applicable to additive manufacturing (AM) processes are focused on solving task- specific problems. Model re-use for different operating environments or machines (domain shift) is however unexplored. This research validates the state-of-the-art ML models in AM under different simulated domain shifts and provides insight into the applicability of these models to unseen, more realistic, operating environments that differ from the training data. Vision-based data from multiple laser powder-fed and wire-arc direct energy deposition processes was utilized to train and validate cross-machinery and cross-AM process domain shifts. Small and large time-based domain shifts were simulated through train/validation dataset splits ranging from random sampling to begin/end experiment splits. A range of domain shift combinations between machinery, processes and time were validated. It was found that small domain shifts (similar process/machinery/time) lead to predictive performance comparable with literature (80-90% accuracy), while large domain shifts (process/machine/time changes) lead to a significant performance decrease (<50% accuracy). The conclusions suggest that a paradigm shift in leveraging training and testing data is required to create robust and re-usable ML models for AM.

4:40pm

Presentation 13: Topological Fidelity of Additively Manufactured AlSi10Mg Gyroid Structures

Osezua Ibhadode*, Issa Rishmawi**, Mihaela Vlasea**, Mark Kirby**, Sooky Winkler***

**Multifunctional Design and Additive Manufacturing Lab, Mechanical Engineering, University of Alberta, Canada; **Multi-Scale Additive Manufacturing Lab, Mechanical and Mechatronics Engineering, University of Waterloo, Canada; ***Dana Incorporated, Canada*

Additively manufactured Triply Periodic Minimal Surfaces (TPMS), walled gyroid structures (WGS) in particular, have garnered immense research and industry attention recently, especially in realizing compact yet efficient heat exchangers. To predict and evaluate their performances, topological and geometric assessments of as-printed samples against their as-designed models are pertinent as deviations can impact heat transfer rates and energy dissipation. In this study, 7 WGS samples with cell sizes and relative densities ranging from 3 mm to 7 mm and 25% to 52% respectively were manufactured via laser powder bed fusion (LPBF) in AlSi10Mg. Geometric (3D) and layer-wise (2D) topological fidelity analyses were done by comparing micro x-ray computed tomography (μ-CT) scans of the WGS samples with corresponding computer-aided designed (CAD) models. Metrics such as the degree of overlap, underprint, overprint, and geometric conformity were defined and quantitatively assessed. Results show bonded partially melted powder particles on downfacing surfaces resulting in higher average surface roughness of up to 32μm on these surfaces. Topological conformities in terms of the degree of layer-wise overlap, and the degree of overprints and underprints improve as the ratio of the relative density to cell length increases from 6 to 9 (% per mm).

5:00pm

Presentation 14: Correlative Analytics of Downskin Surface Roughness Outcomes Using Systematic Data Science Workflows

Jigar Patel, Sagar Patel, Mihaela Vlasea

University of Waterloo, Canada

Laser Powder Bed Fusion (LBPF) is a widely adopted AM technology owing to the demonstrated benefits in design freedom and part consolidation for complex components. However, due to the complex and multiscale process physics that governs the process, ensuring consistent quality is an ongoing challenge. Data science is a promising tool to better understand the interaction between the LPBF process physics and the uncertainty in laser-material interaction phenomena. In this study we attempt to correlate downskin surface roughness outcomes to parameterized and simulated process inputs. The study specifically focusses on data collected from 4405 and maraging steel specimens built with different overhang angles. The data from multiple builds was consolidated and subjected to a systematic and data-centric analytics workflow. In our study, the dataset quality guides the process of developing descriptive, diagnostic and predictive insights. We share these insights, along with broader implications of using data-centric workflows.

5:20pm

Presentation 15: The Use of Convolutional Neural Network for the Improvement of Repeatability, Reproducibility, and Reliability of Automated Porosity Detection in Laser Powder Bed Fusion Parts

Catherine Desrosiers*, Fabrice Bernier**, Nicolas Piché***, Farida Cheriet*, François Guibault*, Vladimir Brailovski†

**Polytechnique Montréal, Canada; **National Research Council Canada, Canada; ***Object Research Systems, Canada; †École de technologie supérieure, Canada*

Laser powder bed fusion is a cutting-edge technology of the 4.0 industrial era streamlining the optimization and customization of structural components. Despite all the benefits, access to a repeatable, reproducible, and reliable nondestructive testing (NDT) workflow of printed parts remains a challenge. X-ray computed tomography (XCT) distinguishes itself from other NDT techniques by its ability to provide location and geometry of processing-induced flaws. Nonlinearity of the signal and inherent variability of XCT acquisitions influence the reconstructed volume histograms, thus limiting the performance of conventional defect segmentation algorithms. Segmentation is critical for porosity analysis since it determines the detection ability and quality of the XCT analysis workflow. To improve the outcome, a convolutional neural network (CNN) automated segmentation algorithm is proposed and its repeatability and reproducibility are studied on Ti6Al4V artifacts with intentionally seeded porosity. Next, a multimodal correlative study using higher-resolution microscopy observations is used for a multi-scale pore-to-pore comparison, enabling calculations of the classification evaluation metrics (accuracy, precision, recall) and the comparison of the porosity analysis distributions. Results show that the CNN segmentation is not only more repeatable and reproducible than the conventional thresholding measurements, but it is also more reliable, being closer to the ground truth microscopy values.

SESSION 6: Novel AM Processes & Products I
June 27 | 4:00pm

4:00pm

FEATURED **Presentation 16: Pathway to Material and Process Qualification for Metal AM in Aerospace Applications**

Richard Grylls*, Shawn Kelly, Pablo Enrique

**Presenter: Richard Grylls, Chief Engineer*

Beehive Industries, United States

Additive Manufacturing (AM) has gained significant attention in the aerospace industry due to its potential to improve design flexibility, reduce lead time, and enable weight-saving. However, the certification and qualification process for AM parts in aerospace applications is challenging due to the complex interaction between material properties, process parameters, and part geometry. The focus will be on the key steps and best practices for material characterization, process parameter optimization, and mechanical testing to ensure the quality and reliability of AM parts. Examples of AM qualification methods in aerospace applications will be presented, highlighting the critical role of collaborative efforts between industry, academia, and regulatory bodies in advancing the adoption of AM in the aerospace sector. The presentation will provide valuable insights into the challenges and opportunities associated with AM in aerospace and offer practical guidance on how to establish a robust qualification process for metal AM parts.

4:20pm

FEATURED **Presentation 17: Laser-Based Directed Energy Deposition of Nickel Aluminium Bronze for Naval Applications**

Gentry Wood*, Douglas Hamre

**Presenter: Gentry Wood, Senior Research and Development Engineer*

Apollo Machine & Welding, Canada

Metal additive manufacturing has been demonstrated as a viable technology for re-manufacturing of naval components. This modern form of manufacturing opens opportunities for repair of existing and out-of-date components and is well suited for dissimilar metal applications. In this work, a 1070nm fiber laser was used to deposit grade C63020 Nickel Aluminum Bronze (NAB) powder on matching wrought base material chemistry with a catchment efficiency of >90%. Challenges of low surface absorption of NAB to the infrared laser wavelength were overcome with high laser power levels to establish a stable directed energy deposition (DED) process. A thickness of >0.25in. was printed in a series of 13 subsequent passes where moderate distortion of the base material was observed. The resulting samples were post-weld heat treated using a standard heat treatment for these materials to develop strength and rigorously analyzed using a combination of metallographic and mechanical testing. The analysis showed excellent metallurgical quality of the deposit free of defects with mechanical performance that was comparable to the wrought base material properties of the same heat treatment. The success of the procedure demonstrates the opportunity to use DED for repair of industrial scale NAB components at reduced manufacturing time and cost.

4:40pm

Presentation 18: Wear Properties of Wrought and Directly Deposited AISI D2 Tool Steel

Samer Omar, Kevin Plucknett

Dalhousie University, Canada

This research assessed the wear properties of wrought and directly energy deposited (DED) processed AISI D2 tool steel. For DED, the AISI D2 tool steel powder was deposited onto an annealed AISI D2 substrate to build multi-layered specimens. Regarding the wrought D2 samples, they were heat treated under different heat treatment scenarios, including quenching, and double tempering. The ball-on-flat reciprocating wear test was utilised to evaluate the wear characteristics by calculating the specific wear rate for different test durations. The wear rates were determined from measurement of the wear track volumes using confocal laser scanning microscopy. The microstructural damage within the wear tracks of the DED and wrought D2 samples were investigated using scanning electron microscopy, with associated compositional analysis using energy-dispersive X-ray spectroscopy. It was observed that the DED processed samples showed higher wear rates than as-quenched, and lower than as-received D2 tool steel.

5:00pm

Presentation 19: Surface Modification of Additively Manufactured Ti-6Al-4V Parts Using Ultrasonic Pulsed Water Jet Peening

Paria Siahpour*, Mark Amegadzie*, Andrew Tieu**, Ian Donaldson***, Kevin Plucknett*

**Dalhousie University, Canada; **VLN Advanced Technologies, Canada; ***GKN Sinter Metals , Canada*

Additive manufacturing (AM) of titanium alloys has received considerable attention in medical and aerospace applications since the early adoption of this technology, due to providing flexibility in design and fabrication. However, surface integrity of the AM Ti parts is a critical aspect in determining their functionality (e.g., fatigue life of the components). Therefore, post-process surface modification is often required to ensure the quality of the parts. This paper presents the results of research on ultrasonic pulsed water jet (UPWJ) peening of laser powder bed fusion (L-PBF) Ti-6Al-4V components. UPWJ is capable of producing smooth surface textures, high compressive residual stresses, resistance to corrosion, and improved fatigue strength. L-PBF Ti-6Al-4V samples were subjected to water jet at a traverse speed of 800 mm/s, using a jet pressure of 69 MPa, to characterize and check the viability of the process in optimizing the surface condition without causing any detrimental damage. Here, the microstructure, topography, surface roughness, and residual stress of the treated surface were analyzed using confocal laser scanning microscopy, scanning electron microscopy, and X-ray diffraction.

5:20pm

Presentation 20: Development of Hybrid Surface Finishing Techniques for Additively Manufactured Metal Parts with Internal Channels

Manyou Sun, Ehsan Toyserkani

University of Waterloo, Canada

Although additive manufacturing (AM) has the capability to fabricate complicated structures, poor surface quality is one of the drawbacks for metal AM. Conventional surface finishing techniques are able to provide solutions to external surfaces of simple geometries, however, surface finishing of internal channels still remains a great challenge for metal AM field. In this work, a hybrid surface finishing technique is proposed to enhance the surface finishing of internal channels, using the synergistic effect of electrochemical dissolution, ultrasonic cavitation and abrasion to reduce the surface roughness. An analytical model on the novel process containing material removal effect of electrochemical finishing, ultrasonic cavitation and abrasive finishing is built to explain the scientific mechanisms. Experiment results on surface finishing of internal channels are also presented to show the feasibility of the proposed technique. Meanwhile, to reduce negative environmental effects and hazards posed to operators, non-toxic and non-corrosive chemical agents are designed and used in this work.

SESSION 7: Material & Process Development II
June 28 | 8:00am

8:00am

Presentation 21: Non-Weldable Ni-Base Superalloys Additively Manufactured via Electron Beam Powder Bed Fusion: A Survey and a Case Study

Hamid Aghajani, Esmaeil Sadeghi, Paria Karimi, Ehsan Toyserkani
University of Waterloo, Canada

Nickel-base superalloys are promising materials for critical high temperature applications. Additive manufacturing (AM) processes are able to fabricate customized complex shape parts in a single step, as opposed to conventional multi-step manufacturing methods. Among the AM processes, electron beam-powder bed fusion (EB-PBF) process is one of the most promising techniques for fabricating non-weldable Ni-base superalloys due to its high preheating temperatures, which reduces thermal stresses. In the present study, a survey on the manufacture of non-weldable Ni-base superalloys via EB-PBF is presented. The role of variable process parameters and material compositions will be explained. In addition, a case study will be presented in which a systematic approach for the design of process will be explained. The microstructural evolutions and crack formation were thoroughly scrutinized using optical microscopy (OM), scanning electron microscopy (SEM), electron backscatter diffraction (EBSD) analysis, and X-ray computed tomography (X-CT).

8:20am

Presentation 22: Laser Directed Energy Deposition (L-DED) Fabricated Inconel 718: Microstructure and Mechanical Properties

Zahra Khodamoradi, Michael Benoit
University of British Columbia, Canada

Laser-directed energy deposition (L-DED) is a flexible additive manufacturing (AM) method that is particularly useful for refurbishing and repairing components, such as aero engine disks and blades made from Inconel 718. The objective of this study is to evaluate the effect of wall thickness on the microstructure and mechanical properties of L-DED fabricated Inconel 718. Sample walls 5 mm tall were fabricated, and the wall thickness varied from 0.75 mm (2 tracks) to 2 mm (4 tracks). Several analyses were used to evaluate the grain structure, porosity, microsegregation, and orientation of grains. Furthermore, local mechanical properties along the build height were evaluated using Profilometry-based Inverse FEM Indentation Plastometry (PIP) and traditional microhardness. Based on the spherical geometry of the pores, it was concluded that they were formed due to entrapped gas, and the porosity decreased with increasing wall thickness. Finally, the refinement of the grain structure was noted as the wall thickness increased due to reduced thermal gradient during solidification. Thus, it is concluded that an increased wall thickness resulted in reduced porosity and a slightly finer grain structure.

8:40am

Presentation 23: Process Parameter Window Determination for Laser Powder Bed Fusion of Copper Chromium Zirconium

Melissa Trask, Paul Bishop
Dalhousie University, Canada

Cu-Cr-Zr is commonly used in applications such as heat exchangers due to its advantageous blend of electrical, thermal, and mechanical properties. As such, laser powder bed fusion (LPBF) is an attractive process to produce difficult to machine heat exchangers from this alloy. However, the complexity of the LPBF process necessitates the development of process parameters for specific alloys, as the process is sensitive to small chemical changes. This purpose of this work is to clarify the process window for laser power, scan speed, and hatch spacing through a systematic empirical approach. Utilizing design of experiments principles, a series of experiments were used to model density as a response. This model was used to predict the process parameters that would result in high density parts. Using the optimized parameters, up to 98.4% theoretical density was achieved, and a window of process parameters was established.

9:00am

Presentation 24: The Effects of Process Parameters on the Development of Internal Strains in Laser Powder Bed Fusion Additive Manufacturing of Hastelloy-X

Amirhosein Mozafarighoraba*, Ahmed Aburakhia*, Ali Bonakdar**, Hamidreza Abdolvand*
**Department of Mechanical and Materials Engineering, Western University, Canada; **Siemens Energy Canada Limited, Canada*

The microstructure, texture, and performance of the specimens produced by laser powder bed fusion (LPBF) additive manufacturing (AM) are significantly affected by process parameters. Elastic and plastic anisotropy, along with the development of internal strains in different directions are all affected by texture development. This study focuses on the effects of laser power and scanning speed during LPBF-AM of Hastelloy-X. The evolution of lattice strains and mechanical anisotropy are investigated using in-situ neutron diffraction experiments. In addition, electron backscatter diffraction (EBSD) measurements are conducted to study the effects of such parameters on the specimens' microstructures. The acquired EBSD maps are mapped into a crystal plasticity finite element (CPFE) model to investigate how different process parameters affect the development of internal lattice strains. At lower specific energy (SE) inputs defined as laser power divided by scanning speed and hatch spacing, random texture is observed, while at higher SEs heavily textured samples with columnar grains are observed. A significant anisotropy is observed in the evolution of internal strains. Further, it is observed that LPBF-AM process parameters have significant impact on the magnitude of surface and internal residual stresses measured with neutron diffraction.

9:20am

Presentation 25: Effect of TiC and TiB2 Nano-inoculants Addition on the Microstructure and Tribological Performance of a Fe-Cr-Ni-Al Stainless Steel Fabricated via Arc-directed Energy Deposition

Elham Afshari, Mahya Ghaffari, Alireza Nemani, Paul Bishop, Ali Nasiri
Dalhousie University, Canada

The effects of TiC and TiB2 nano-inoculants addition during arc-directed energy deposition of a Fe-Cr-Ni-Al stainless steel on the microstructure and tribological performance of the alloy were investigated. The scratch and reciprocating sliding wear tests were performed to assess the tribological performance of the as-printed and heat-treated components. The microstructural analysis of the as-printed parts showed that the introduction of the inoculants resulted in the refinement of the grains structure, increase of the retained austenite content, the formation of more isotropic microstructure, and precipitation of M3B2-type borides for the TiB2-inoculated condition. Although TiB2-inoculated sample showed the highest hardness and scratch resistance, the best wear resistance was achieved in the TiC-inoculated sample. The better wear performance of the TiC-inoculated sample was ascribed to its higher content of retained austenite in the as-printed microstructure, which undergoes strain-induced martensite transformation during reciprocating wear testing. Besides, post-printing solutionizing and aging heat treatments were found to further improve the hardness and scratch resistance of TiC/TiB2-inoculated samples due to precipitation of nano-sized β-NiAl phases, while TiB2-inoculated sample showed inferior wear resistance due to the accumulation of M3B2 phase in the intergranular regions during the aging process. The wear micro-mechanisms of each condition will be discussed in detail.

SESSION 8: Process Monitoring & Control II + Modeling and Design II
June 28 | 8:00am

8:00am

FEATURED **Presentation 26: Rationalization of the Modelling of Stress and Strain Evolution in Powder Bed Fusion Additive Manufacturing**

Pegah Pourabdollah, Farhad Rahimi, Farzaneh Farhang Mehr*, Daan Maijer, Steve Cockcroft
**Presenter: Farzaneh Farhang Mehr, Director of Additive Manufacturing Laboratory*
The University of British Columbia

There has been a tremendous body of work recently appearing in the literature focused on Additive Manufacturing (AM) including experimental-based investigations, numerical investigations and combinations of the two. These studies generally focus on understanding and mitigating defect generation to improve product quality while minimizing cost. One defect of concern is residual component distortion and stress. In this paper, a strategy is proposed for developing a computationally efficient approach to predict residual stresses and distortion in a component manufactured using the Electron Beam Powder Bed Fusion (EB-PBF) process. The major challenges in developing an accurate model are discussed with reference to the lessons learned in modelling thermal stress generation and in-elastic strain accumulation in casting processes. Key areas requiring careful consideration include the high temperature constitutive and thermal strain behaviour as the material transitions from powder, through a semi-solid state, to a fully liquid and finally to solid material.

8:20am

Presentation 27: Leveraging Design for Additive Manufacturing to Remedy Low Internal Porosity in Metal Powder Binder Jetting

Daniel Juhasz*, Mingzhang Yang*, Allan Rogalsky*, Mohsen Keshavarz*, Mihaela Vlasea*, Martin Laher**, Amin Molavi-Kakhki***
**University of Waterloo, Canada; **MIBA Sinter Group, Austria; ***Rio Tinto, Canada*

Metal binder jetting additive manufacturing (BJAM) is a powerful AM technology capable of producing highly complex metallic parts. However, the high porosity of sintered parts is an ongoing technological limitation, which must be addressed. Previous work with water-atomized 4405 low-alloy steel has suggested a correlation between internal porosity of BJAM parts and the localized reducing potential during sintering, wherein higher porosity was observed at the core of a part due to poor gas flow and subsequent trapping of reduction by-products at these core locations. In this study, we propose addressing core porosity using a design-driven approach. We investigate the feasibility of printing gas flow channels within 4405 low-alloy steel parts and their effects on core porosity. To this effect, solid body blocks were manufactured alongside hybrid lattice/solid blocks, each encapsulating near-shape tensile specimens in their solid regions. High-resolution computed tomography (CT) data will elucidate the efficacy of enhanced gas flow through the lattice architecture vs. solid block in mitigating entrapped porosity in the gage section of specimens. Additionally, low-resolution CT and microscopy will elucidate the influence of the solid-lattice boundary interface on geometric fidelity of specimens. Lastly, tensile testing will demonstrate the mechanical performance of the two classes of specimens.

8:40am

Presentation 28: Fuzzy-Machine Learning Framework for Porosity Prediction Using Optical Tomography Imaging in Laser Powder-bed Fusion

Osazee Ero, Katayoon Taherkhani, Ehsan Toyserkani
University of Waterloo/Multi-Scale Additive Manufacturing (MSAM), Canada

Process defects such as porosity induced from lack of fusion and/or keyhole phenomena could be detrimental to the quality of parts made by laser powder-bed fusion (LPBF). The stochasticity of the LPBF process makes it challenging to develop effective monitoring algorithms that can be deployed across multiple machines configuration and process parameter choices to detect these defects. In this study, we propose a fuzzy-machine learning framework consisting of a neural network clustering model, a set of fuzzy rules and a U-Net segmentation model applying on collected in-situ optical tomography (OT) data to identify porosity induced when printing a real-life geometry with complex structures. The prediction results are validated by a CT scan of the fabricated part. The robustness of the proposed approach

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is that it does not require a custom dataset to train the model; thus, computationally inexpensive. Also, an expert understanding of the monitoring system is incorporated into the model using the fuzzy logic method to quantify the severity of the defects. Lastly, the approach can be applied in real-time using the trained U-Net model to predict porosity within each layer of the print.

9:00am

Presentation 29: Predicting Temperature Distribution with an HDR CMOS Sensor to Monitor Material Properties in Direct Energy Deposition

Lucas Botelho, Richard van Blitterswijk, Amir Khajepour

University of Waterloo, Canada

In direct energy deposition (DED), it is critical to know the material properties of the final product. Monitoring the temperature distribution, particularly the cooling rate, can offer insight on the final material properties of the product. Currently, these measurements can be captured with an infrared (IR) camera, which is expensive and limited for real time monitoring and control. In this research, a monitoring system is proposed which utilizes a high dynamic range (HDR) complementary metal–oxide–semiconductor (CMOS) camera which is calibrated with a pyrometer to predict the temperature distribution. A CMOS camera is more cost-effective than an IR camera while also featuring a higher resolution and higher framerate. Moreover, a CMOS camera has more available settings to be changed to optimize the quality of images captured. Data is captured in real time during DED with a CMOS camera to capture images and a pyrometer to map the images to an approximate temperature distribution. These images are captured with various materials and camera settings to create an algorithm with a large temperature range. Once the algorithm is developed to predict the temperature distribution of DED in real time, the measurements can be correlated to material properties to validate its effectiveness.

9:20am

Presentation 30: Toward Sintering Predicting Densification and Distortion in Binder-Jet Additive Manufacturing

Roman Boychuk, Mihaela Vlasea, Kamyar Ghavam

University of Waterloo, Canada

Binder-jet additive manufacturing (BJAM) is a popular 3D printing process for producing parts from metal or ceramic materials at a comparatively low cost compared to other modes of manufacturing. In order to attain high densities and high corresponding part strength, parts must be sintered at high temperatures to shrink and densify. However, a complex part can also experience distortion due to gravity acting on the part in a softened state. A rudimentary sintering model based on the Skorohod-Olevsky Viscous Sintering (SOVS) model is presented to model the distortion of samples printed from gas-atomized 4340 low-alloy steel in the solid-phase sintering region. Cantilevered samples are sintered in an optical dilatometer furnace, and the corresponding images are used as training and validation data for the sintering model. A derivative-free optimization approach is used to find the optimal parameters for the sintering model. The results show good contour prediction, despite the relatively simple nature of the sintering model used. The method establishes a basis for further sintering modeling informed by in-situ thermo-optical measurements.

SESSION 9: Novel AM Processes & Products II
June 28 | 10:00am

10:00am

FEATURED **Presentation 31: Why the 'Concept to Commercialization' Approach Is Key for Successful Implementation in Additive Manufacturing**

Sami Arsan

Vice-President Additive and Advanced Manufacturing

voestalpine Additive Manufacturing Centers - North America, Canada

Additive manufacturing (AM) empowers innovative design with unprecedented benefits. With this rapidly advancing technology, it is crucial to integrate process disciplines and expertise to ensure an optimized product that achieves the desired quality and functionality while avoiding costly mistakes. In order to fully capitalize on AM's potential; companies must choose a provider that can link the full AM production chain together under one roof. Given the interdependent and highly specialized nature of AM, manufacturers can best exploit this technology by taking advantage of partners that offer a one-stop-shop. Metal Additive Manufacturing is now being used for serial production. Components that would not have been possible just a few years ago can now be made to high standards using a wide range of metal powders. AM promises to enhance production by optimizing design for lighter-weight, more effective parts and tools and reducing waste, tooling, and inventory. For producers looking to leverage these advantages, the greatest value can be gained by working with a full-service AM provider with extensive knowledge of the customer's applications and mastery of the key AM disciplines. This integrated approach is vital to ensuring AM products are not only superior in design but also reliable, robust, and durable.

10:20am

Presentation 32: Solid and Lattice-Structured Additive Manufactured Zirconia Dental Implant Bars: In Vitro Testing and Assessment

Les Kalman

Western University, Canada

Dental implant bars are exclusively fabricated through milling, which represents a workflow that is costly and inefficient. Additive manufacturing is having a significant impact on dentistry, due to efficiency, cost effectiveness and sustainability. Recently, additive manufacturing in zirconia has been introduced as a result of advances in technology. This investigation will fabricate solid and lattice-structured implant bars through AM in zirconia, and assess flexural strength and stiffness, fit, finish and denture compatibility. A dental implant solid and lattice bar will be optimized with software and fabricated using AM with LithaCon 210 3Y zirconia. The solid and lattice bar will be printed twelve and five times, respectively. Bars will be post processed (cleaned, debinded, sintered and inspected). The bars will be subjected to mechanical testing to assess flexural strength and stiffness. Bars will also be fitted to the simulated patient model and assessed for (1) clinical acceptance (2) surface finish and (3) support and retention of a denture (all in progress). The findings of this study will provide new and important data regarding the AM workflow of zirconia implant bars and offer critical metrics for clinical translation.

10:40am

Presentation 33: Optimized end-to-end Process Flow for Additive Manufacturing

Rym Gazzah

Productique Québec, Canada

The ""Optimized end-to-end process flow for additive manufacturing "" is a new value stream mapping addressing the limitations of traditional sequential workflow for producing high-quality parts. Productique Québec, a College centre for the transfer of technology introduces an alternative approach that emphasizes the importance of feedback throughout the designing, printing and post-processing phases, allowing for real-time adjustments and optimizing the final product. The use of generative design sheds light on the benefits of AM optimizing the design assessments and producing parts that are not only functional but also cost-effective and lightweight. While AM allows the production of complex geometries, advanced machining is a paramount post processing step to ensure part tolerance requirements. Establishing the optimized tactical workflow has shown that merging both manufacturing processes promises a more accurate final product reducing the need to rework since all the machining and printing needs have been introduced and planned during the AM overall process. By implementing this innovative workflow, organizations can take their AM capabilities to the next level, delivering high-quality parts with fewer iterations, less wasted time and cost. The new workflow will be illustrated with recent industry examples.

11:00am

Presentation 34: General Corrosion Behavior of Conventionally versus Additively Manufactured Nickel-Aluminum Bronze Alloys: An Overview

Khashayar MorshedBehbahani, Donald Paul Bishop, Ali Nasiri

Dalhousie University, Canada

The soaring demand for highly corrosion-resistant materials with satisfactory mechanical characteristics has lately drawn significant attention of the manufacturing sector to the family of nickel-aluminum bronze (NAB) alloys for a wide range of end-use applications in aerospace, ocean, and defense industries. The outstanding corrosion performance of NABs originates from developing a duplex corrosion product film on the alloy's surface with a protective nature and complex microstructure. Evidently, processing routes and post-production treatments can substantially alter the microstructural features of these alloys. Recent advancements in the maturation of different additive manufacturing (AM) technologies with unlimited freedom in design have led to the establishment of AM as a superior technique for the production of near-net-shape NAB parts with complex geometries. In this presentation, we discuss and critically review the general corrosion properties of conventionally produced and additively manufactured NAB alloys along with their microstructural characteristics. To reinforce the findings and address the knowledge gaps on the corrosion performance of AM produced NAB alloys, preliminary experimental data comparing the corrosion characteristics of cast and laser-powder bed fused (L-PBF) NAB are also presented. In addition, the fundamental mechanisms governing the uniform corrosion of NABs under different environmental conditions will be elucidated.

11:20am

Presentation 35: Implementation of Ultrasound Particle Lensing Technology on a Laser Directed Energy Deposition Machine for Focusing of Ti6Al4V Powder Stream

*Alexander Martinez-Marchese, *Mazyar Ansari, **Asier Marzo, *Marc Wang, *Ehsan Toyserkani

**MSAM, Canada; **UPNA, Spain*

The wide adoption of laser directed energy deposition via powder-feeding (LDED-PF) in manufacturing will require process improvements such as an increase of the possible part sizes, while maintaining fabrication speed. This may be achieved by controlling the powder stream to print selectively fine and coarse features while also maintaining a high catchment efficiency. This work describes the first implementation of an electronic control method for powder stream shape in an LDED-PF machine; ultrasound particle lensing (UPL). UPL uses an ultrasound array to produce high-intensity ultrasound that can be used to focus a metal powder stream. The ability of UPL to focus a powder stream is demonstrated by printing Ti6Al4V tracks on a Ti substrate. An improvement of 111% in catchment efficiency was observed when using UPL. The track features under different ultrasound volumes will be discussed.

SESSION 10: Material & Process Development III
June 28 | 10:00am

10:00am

Presentation 36: Testing the Limits of Low-viscosity Feedstock in Material Extrusion 3D printing of Highly-filled Polymer.

Emmanuel Pelletier

École de Technologie Supérieure, Canada

Material extrusion (MEX) of highly-filled polymer is an additive manufacturing process that received significant attention over the past few years to produce dense metallic parts. The process takes three steps including the printing, the debinding, and the sintering bringing powder-binder feedstock up to a finished metallic part. In this study, the feedstock was formulated from 17-4PH powder and a paraffine wax-based binder to tailor the feedstock viscosity within 50 to 120 Pa·s required to guarantee the success of the printing stage. This work aims to test the printing limits of such low-viscosity feedstock using a commercial rod-based (DesktopMetal) and an in-development plunger-based (ÉTS) printers. Parts geometry, internal defects, and printing capabilities of these two printing approaches were compared in order to quantify the performances of this new generation of low-viscosity feedstocks. Dimensional properties and occurrence of defects were quantified using a prismatic geometry, while the printing capabilities were assessed using a complex shape part exhibiting different overhang angles.

10:20am

Presentation 37: Investigation Steels Manufactured by a Hybrid Additive/Subtractive Technology

Sheida Sarafan*, Priti Wanjara*, Javad Gholipour*, Josh Soost**

**National Research Council Canada, Canada; **Matsuura Machinery USA Inc., United States*

This research study explored additive/subtractive manufacturing of 18Ni-300 maraging and 316L stainless steels using a Matsuura LUMEX Avance-25 system that integrates laser powder bed (LPB) fusion technology with machining in one envelope. Coupons were produced utilizing 160 W, 240 W, 320 W and 380 W laser powers for the LPB fusion process with a machining pass integrated after every ten deposited layers; on completion of hybrid manufacturing, select surfaces were machined with a final finishing pass. Among the different process parameters investigated, a laser power of 160 W was found to have insufficient energy density to fully melt the powder, as evidenced by the presence of interconnected lack of fusion defects in the coupons, which affected the density and tensile mechanical properties. By contrast, at laser powers above 160 W, the isolated nature of small pores and near-full-density (>99%) led to tensile properties surpassing the requirements stipulated in standards for wrought equivalent material. The dimensional changes examined by comparing the 3D scanned deposit versus the computer-aided design (CAD) model indicated low deviations for coupons manufactured using a hybrid approach and demonstrates the effectiveness of this technology for net-shape manufacturing of steel products.

10:40am

Presentation 38: Printing Parameter and Post-processing Optimization of Selective Laser Melting Inconel 718 for Sheet Metal Stamping Application

Cho-Pei Jiang, Yuh-Ru Wang

National Taipei University of Technology, Taiwan

The mechanical property of Inconel718 is suitable for the sheet metal stamping application of punches and dies. However, the parameters of selective laser melting (SLM) with Inconel 718 powder need to be optimized to meet the needs of the stamping application. In this study, the Taguchi method was adopted to investigate the effects of processing parameters such as laser power, scan speed, path spacing, laser spot diameter and layer thickness on the mechanical properties of SLMed parts.The parameters optimized by the Taguchi method were validated by SLAMed specimen and subjected to heat treatment to increase the mechanical properties. The experimental results show that the maximum ultimate tensile strength of the SLMed specimen with the parameters of laser power 180 W, scanning speed 600 mm/s, path spacing 0.105 mm, and layer thickness 40μm is 1070.88 MPa. Applying optimized heat treatment parameters can improve the ultimate tensile strength to 1532.22 MPa. After polishing the surface of the SLMed piece, the surface roughness is less than 2.07μm, the internal hardness is HRC 46, which meets the requirements of sheet metal stamping.

11:00am

Presentation 39: 3D Microstructural and Crystallographic Texture Evolution in Additively Manufactured Alloys

Sravya Tekumalla*, Stefan Zaefferer**

**University of Victoria, Canada; **Max Planck Institute for Iron Research, Germany*

Owing to the high cooling rates and thermal gradients, additive manufacturing (AM) of metals results in the formation of hierarchical microstructures such as melt pools, grains, cellular/dendritic structures, and copious amounts of dislocations. These features govern the complex layer-wise solidification within a melt pool and epitaxial growth of grains between layers which results in the formation of potentially strong textures. In this work, we use laser powder bed fusion (LPBF) technique to produce two differently processed samples from an in-situ alloyed β Ti alloy (bcc crystal structure) with differing textures i.e., a cube texture and a near random texture. We use our newly designed, fully automated 3D electron backscattered diffraction (EBSD)-based large volume 3D microstructure characterization system, ELAVO 3D, to understand the complex solidification and grain orientation selection mechanisms within and across the 3D volume of the melt pools which eventually results in the texture of the bulk part. The 3D observation reveals that grains may extend through the build length and undergo characteristic crystal lattice rotations which can span several tens of degrees and various rotation axes. The results from this work provide insights to advance the current knowledge on microstructure and texture formation mechanisms in metal AM.

11:20am

Presentation 40: Microstructure and Microhardness Variation with Build Height in Laser Powder Bed Fusion Fabricated 316L Stainless Steel

Paresh Prakash, Abdelbaset Midawi, Mary Wells

University of Waterloo, Canada

This research characterizes the microstructure and microhardness variation along the building height of LPBF fabricated 316L steel samples. The solidifying powder layer experiences very different heat conduction close to the build plate and away from it, which affects the microstructure development. Additionally, the deposition and fusion of subsequent layers result in the re-melting and re-solidifying of certain layers below, which develop a heat-affected zone and that affects the microstructure and the corresponding mechanical properties. Considering these aspects of the LPBF process, the microstructure and mechanical properties of the material are expected to vary along the build height. In the present research, this variation for 316L steel powder has been characterized. Nearly fully dense samples were printed up to 55 mm in height using a Renishaw AM 400 Pulsed LPBF Machine at 175 W, using a point distance of 60 μm, exposure time of 70 μs, hatch distance of 100 μm, and a layer thickness of 30 μm. Microhardness testing was performed close to the build plate, along the building height, and on the topmost printed layers, and the trends in hardness values were explained based on the EBSD microstructural features at these locations.

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SESSION 11: Material & Process Development IV
June 28 | 1:00pm

1:00pm

Presentation 41: A Comparative Study of the Microstructure and Surface Properties of Additive Manufactured 316 Stainless Steel and 8620 Steel with Those of Made by Conventional Processes

Jun Jiao*, Kaleb Hood*, Sarah Ahmed*, Annie Dao*, Wen Qian**, Joseph Turner**

**Portland State University, United States; **University of Nebraska-Lincoln, United States*

Metal additive manufacturing (AM) is an emerging technology with an array of possibilities for manufacturing various part geometries that are not conveniently produced through conventional manufacturing (CM), especially, for easy fabrication of metal alloys and composites, and the reduction of material waste. However, the microstructures, the surface morphologies, the surface chemistry, and the mechanical properties of the AM metal materials in comparison with their counterparts made by the CM processes are less studied. In this report, a systematic investigation of AM 316 stainless steel (SS) and AM 8620 steels with the CM 316 and CM 8620 were carried out. The AM steels were produced by a selective laser melting (SLM) processes while the CM steels samples were purchased commercially. High-resolution digital optical microscopy and laser scanning confocal microscopy, the Raman spectroscopy, the scanning electron microscopy, and energy dispersive X-ray spectroscopy results were obtained. An effort to develop graphene coating techniques on the metal surface aimed at protecting the AM/CM metals from corrosive conditions was investigated. The electrochemical testing results using a Gamry Reference 600 Potentiostat/Galvanostat on the AM/CM 316SS/8620 steels with graphene coatings and without graphene coatings will be discussed.

1:20pm

Presentation 42: Recycling Rare-Earth Magnets into AM-Grade Powder; Rewards and Challenges

Ali Asgarian*, Gaofeng Li*, Fabrice Bernier*, Jean-Michel Lamarre*, Robyn Iannitto*, Shirley Mercier*, Nicolas Cormier*, Louis-Philippe Lefebvre*, Jean-Pierre Fortin**

**National Research Council Canada | Conseil national de recherches Canada, Canada; **ATIQC Inc., Canada*

The new era of clean energy, electrification, and technological advancements has significantly increased the demand for Rare-Earth (RE) permanent magnets as they are widely used in wind turbines, hybrid and electric vehicles, and electronic components, among others. There are, however, rising worries around the supply chain of RE elements, like Nd and Dy, as only a small number of countries have the reserves and/or the infrastructure to produce these elements. This has expedited research and development activities on recycling RE magnets from end-of-life products as well as on additive manufacturing (AM) of RE magnetic parts.

This work presents the recycling of end-of-life NdFeB magnets into high-grade powder qualified for AM. The challenges of recycling process including hydrogen decrepitation (HD) and grinding are discussed. It is well-known that the feedstock powder for AM shall meet strict chemical and morphological specifications, including particle sphericity. Sadly, NdFeB powder produced by HD process, is extremely irregular exhibiting low flowability. The process of powder spheroidization using an induction plasma system is systematically studied. The other complexity faced in this work is maintaining magnetic properties post high-temperature plasma treatment. This topic is also discussed in relation with plasma operating conditions and crystalline structure of powder.

1:40pm

Presentation 43: Laser Powder Bed Fusion (LPBF) Processing of a Mixed Nickel Aluminum Bronze Powder

Addison Rayner*, Jon Hierlihy*, Melissa Trask*, Randy Cooke**, Paul Bishop*

Dalhousie University, Canada; DRDC, Canada

Conventional Nickel Aluminum Bronze (NAB) alloys processed via laser powder bed fusion (LPBF) have exhibited improved strength and corrosion properties over their wrought counterparts. However, the scarcity of unique powder chemistries such as those that correlate to Defence Standard (Def Stan) grade NAB alloys has limited the practical application of LPBF in a marine defence context. In this study, the fabrication of builds compliant with Def Stan 02-833 NAB chemistry was investigated by ad-mixing widely available powders into a lower cost, readily attainable feedstock system. Solid test specimen were printed from the mixed powder using a linear manipulation of the laser power and scan speed while holding the hatch spacing and spot size constant. The microstructures of as-printed test specimen were analyzed using laser confocal microscopy and the density was measured. SEM-EDS and XRD were employed to further characterize the microstructures, assess chemical homogeneity, and identify the phases present. The LPBF parameters that produced the highest specimen density were identified and the effects of post-build heat treatment were considered.

2:00pm

Presentation 44: Path to Enhance the Thermal Stability of 3D Printed Aluminum Alloys

Ehsan Marzbanrad

University of Waterloo, Canada

Aluminum alloys (AA) have low thermal stability: if AA exposes to high temperatures (150°C to 450°C) for a very short period, they will drastically lose their strength. Hence, the upper service temperature for AA in the aerospace industry has limited to 80°C. To enhance the thermal stability of a metal, thermally activated degradation mechanisms such as recovery, recrystallization, and grain growth should be disabled. One way to achieve this goal is to disperse ceramic nanoparticles in the structure. However, traditional methods for producing a uniform metal matrix composite aren't feasible if not impossible. Moreover, the agglomeration of ceramic particles in composites increases the chance of catastrophic failure. Nanoparticle decoration is a cost-effective method for producing composite feedstock powder for metal 3D printers. In this research, the AA-6061 particles decorate with 30 nm Al2O3 nanoparticles, and the powder was used as feedstock for manufacturing parts. Then the effect of temperature on the printed parts was evaluated. The experiments demonstrated the printed AA-6061 has high thermal stability when heat treated to 430°C for one hour: the grain structure remains intact, and the mechanical strength does not show a considerable change compared to the pure AA-6061 parts with the same thermal history.

SESSION 12: Process Monitoring & Control III
June 28 | 1:00pm

1:00pm

Presentation 45: Manufacturing Smart Part by Embedding Fiber Bragg Gratings Sensors

Ehsan Toyserkani, Bahareh Marzbanrad
University of Waterloo, Canada

Continuous monitoring of machine components with embedded sensors during service provides a chance to prevent harmful situations; therefore, using smart parts offers one more degree of freedom for engineers to best optimize the design of mechanical systems. However, embedding a sensor in these parts requires tiny and sometimes geometrically complex shape channels from the surface to the hot spot, making the manufacturing process complicated, expensive, and even impossible for traditional manufacturing routes. Additive manufacturing unlocks the possibility of printing parts with complicated three-dimensional internal channels. Therefore, designing smart parts equipped with sensors will be accessible. The Fiber Bragg Grating sensor (FBGs), is a hair-thin filament recording the strain and temperature changes, working based on light refractions. Multiple senores can be written on a single fiber optic for simultaneous measurements. In this research, we demonstrated the capability of AM for printing parts with a complex geometric tiny channel for embedding FBGs. The response of the distributed embedded FBGs in curved channels of the 3D-printed titanium parts has been examined. Our investigations demonstrated the capability of the embedded FBGs for measuring the strain under loading, which can be converted to stress, as well as temperature changes.

1:20pm

Presentation 46: ISO/ASTM 52958:2022 Best Practice for In-Situ Flaw Detection and Analysis for the Laser Beam Powder Bed Fusion (LB-PBF) Process

Katayoon Taherkhani, Ehsan Toyserkani
University of Waterloo, Canada

This presentation aims to explain a drafted standard that is on the ballot. It provides a workflow required for indirect flaw detection during laser bean powder bed fusion (LB-PBF) by analyzing the in-situ signals received from a coaxial photodiode. This practice can be implemented in cases when the Lack-of-Fusion (LOF) is induced in printed components. An in-situ photodiode dataset is first corrected for chromatic and monochromatic distortion. To identify anomalies, the corrected data can be analyzed by two detection algorithms: (1) statistical and (2) machine learning. These algorithms should be systematically optimized and customized to detect LOF flaws more effectively. To this end, intentionally seeding flaws are first added to the design of coupons to tune the parameters of the algorithms. Then, the customized algorithm is tested by detecting randomized/stochastic flaws created by LB-PBF with intentionally decreased energy density. A comparison between the detection results and the CT data is applied through a volumetric approach for the abovementioned goal.

1:40pm

Presentation 47: Machine Learning for Defect Analysis in Laser Powder Bed Fusion

Yu Zou
University of Toronto, Canada

The in situ X-ray imaging method has attracted significant attention in the metal additive manufacturing community for characterizing keyhole dynamics and defect generation during laser-material interaction processes, particularly for laser powder bed fusion. Due to a high temporal and spatial resolution in this method, a vast volume of data are generated and collected, leading to a challenge for data processing and analysis. In this study, we present an accurate, robust, and powerful image analytical approach that can identify the high-fidelity automated features and extract important information from X-ray images. In total, we train six semantic segmentation models and six object detection models using 628 X-ray images obtained from two recent literature. Our study demonstrates that the U net+MobileNet model is the overall best choice among 12 models to recognize and extract desired regions, in terms of accuracy, time consumption, and dataset sensitivity. Using this model, we have collected and summarized geometric features and dynamic behaviors of the keyholes and generated bubbles. The image segmentation approach may pave the path for unveiling new mechanisms that might not be easily identified using conventional analysis methods in additive manufacturing processes.

2:00pm

Presentation 48: Active Print Layer Temperature Control through Base Plate heat Extraction Process

Shiyu Teng, Shirin Dehghali, Ahmed Qureshi, Hani Henein
University of Alberta, Canada

Wire Arc Additive Manufacturing (WAAM) has been considered an ideal cost-effective method to manufacture large-scale metal parts due to the high-deposition rate. This method uses welding arc heat as the source to fabricate the product. One of the challenges of the WAAM technique is the heat accumulated inside the printing part, which affects the geometrical quality and stability of the part. In addition, the accumulated heat in the part also dramatically interferes with the cooling cycle of each layer in the process leading to in-situ heat treatment, and can lead to the evolution of undesired microstructure. This study proposes heat mitigation by a base plate heat extraction process. This cooling system can positively dissipate the heat from the part to compensate for the heat accumulated in the part during the process. This allows the part to cool down to ensure a comparatively low temperature before printing the next layer to avoid heat over-accumulation. The cooling system is mounted on a sensor-fused WAAM system has been used in which in-situ monitoring which can record the part's temperature and geometry data during the processing. Various characterization technique like SEM and XRD has been employed to investigate the microstructure of the part.

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Poster Presentations

THEME 1: Material & Process Development

Poster 1-1: Residual Stress Induced Cracking in Laser Powder Bed Fusion Fabricated 4405 Steel Gears

Peyman Alimehr, Mohsen K. Keshavarz, Sagar Patel, Mihaela Vlasea
Multi scale additive manufacturing lab, Canada

Laser powder bed fusion (LPBF), as the most common metal additive manufacturing (AM) method, has been adopted in the production of functional parts. Extensive optimization efforts have been made to fabricate defect-free parts and to generate processing maps for material systems of interest. A vast number of process parameters can affect the formation of lack-of-fusion, keyhole, and balling defects. Furthermore, residual stress is an inherent phenomenon that occurs in LPBF parts due to the high thermal cycles occurring inter- and intra-layer, which can lead to the cracking and delamination of printed components. Therefore, it is critical to understand, predict and control the driving parameters that alter the residual stress and remarkably impact the fatigue behavior of the parts. This study investigates the residual stress induced cracking in LPBF fabricated 4405 medium-carbon steel through experimental and simulation approaches to evaluate the effective parameters in crack mitigation. The X-ray diffraction technique is used to measure the part scale residual stress values on gears with different relative densities while Ultrasonic testing is employed to non-destructively extract the 3D map of cracks within the parts. Also, FEA simulation is used to model the process based on the employed parameters, material properties, and geometry of the gears.

Poster 1-2: Machine Learning-informed Density Optimization in Electron Beam-Powder Bed Fusion of Ti48Al2Nb2Cr with Various Particle Size Distributions

Tomisin Oluwajuyigbe, Zohreh Azimifar, Paria Karimi, Shima Kamyab, Esmaeil Sadeghi, Mohsen Keshavarz, Mihaela Vlasea
University of Waterloo, Canada

The aerospace sector currently favors using lightweight, heat-resistant materials for low-pressure turbine blades to improve energy efficiency. One material of interest is Ti48Al2Nb2Cr (γ-TiAl), which has a low weight-to-density ratio and high-temperature performance. However, the low ductility and fracture toughness feature of γ-TiAl causes conventional machining to be expensive. Electron beam-powder bed fusion (EB-PBF) offers a solution to produce γ-TiAl with reduced processing and optimized properties at a lower cost due to the specified geometry and beam energy flexibility. The EB-PBF process requires refinement of process parameters for high relative density (>98%). Three different powder size distributions (45-150 μm, 38-150 μm, and 38-180 μm) were examined in the study, and each experienced an identical process parameter range. The relative density of each γ-TiAl sample was measured using x-ray computed tomography at a 10μm resolution. Regression and classification models were developed using CT scan data, input features (such as beam current and speed, focus offset, line offset, layer thickness, and powder D10, D50, D90 etc.), and bulk density as labels were considered for supervised learning to inform better TiAl density outcomes. An ML-based data analytic tool was designed to optimize our ML parameter recommendations and material specifications.

Poster 1-3: Oxidation Response of Cu–Ag Parts Fabricated by Laser Powder Bed Fusion

Nadia Azizi*, Hamed Asgari**, Ehsan Toyserkani*
**University of Waterloo, Canada; **University of New Brunswick, Canada*

The present study investigates the oxidation behavior of Cu–2wt.%Ag alloy processed by laser powder bed fusion (LPBF). Thin-walled samples of Cu–2Ag alloy were successfully printed using a mixture of elemental Cu and Ag powders. The oxidation rate of LPBF-made Cu and Cu–2Ag samples was measured by thermogravimetric analysis (TGA) in air (~20% O2) with a flow rate of 20 ml/min at 300 °C and 600 °C for 5 hours. The values of the mass gain obtained at 300 °C were 0.20 mg and 0.29 mg for Cu and Cu–2Ag, respectively. Oxidation tests at 600 °C revealed slightly different results, with mass gains of 0.37 mg and 0.44 mg for Cu and Cu–2Ag, respectively. Overall, no significant difference was observed between the oxidation rates of pure Cu and Cu–2Ag at 300 °C and 600 °C for 5 hours. However, it was found that a parabolic law governs the oxidation rate of Cu and Cu–2Ag at 300 °C, while a linear oxidation rate law controls their oxidation performances at 600 °C. This variation in oxidation behaviour could be related to the formation and transformation mechanisms of Cu2O and CuO oxides at different temperatures.

Poster 1-4: Functionalization, Oxidation, and Recyclability Study of 3D Printable MXene

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MXene is a type of new generation 2D nanomaterial with unique electronic and photonic properties due to both its special nanostructure and elemental compositions. Among all type of MXene, the Ti3C2Tx formulation has been widely studied due to its high electronic and capacitance performance. In its nanoparticle form, MXene can be dispersed in different organic solvent for creating 3D printable conductive inks. However, one major challenges for such 3D printable ink is its lifetime, as MXene can be easily oxidized once expose to air, thus the overall performance may be reduced. The focus of this study is to investigate the oxidation mechanism, life cycle, and the recyclability of the fabricated MXene nanoparticles under ambient condition. The fabrication of pristine MXene starts with the synthesis of the MAX precursor for MXene and ends with fully oxidized MXene. To further improving the lifetime and to minimize oxidation, the pristine MXene is also functionalized with sodium ascorbate for creating a new variant, SA-MXene. For studying the impact of oxidation on the electrical behavior, the electrical conductivity is measured periodically. Lastly, 3D printable MXene and SA-MXene inks are prepared for demonstrating its 3D printing potential as a functional device.

Poster 1-5: An Investigation into the Recyclability of Plasma-Atomized Powders Used in Laser Powder Bed Fusion

Tina Mohammadhassan
Université laval, Canada

The cost-effectiveness of metal parts produced by laser powder bed fusion (LPBF) method is a key concern to the manufacturing industry. Fortunately, an advantage of this process is that unutilized particles can be reused after each production cycle, which reduces waste and makes this technology economically feasible. However, there is a lack of knowledge about the changes in powder properties as they are recycled and their impact on subsequent manufacturing runs. This work investigates the effect of recycling on the characteristics of plasma-atomized Inconel 718, Ti-6Al-4V (Grades 5 and 23), and stainless steel 316L powders used in LPBF. The overall objective of this project is to reduce the unnecessary waste of powders by shedding light on how recycling affects the properties of four important materials commonly used in LPBF. For this purpose, virgin and used powders were analyzed to identify changes in the characteristics of the particles and the powders. According to the results, Ti-6Al-4V powders in grades 5 and 23 were highly influenced by subsequent reuse, while recycled Inconel 718 and stainless steel 316L powders were found to be much more similar to virgin powders.

Poster 1-6: Process Optimization of NiTi 4D Structures Produced by Laser Powder Bed Fusion Technique

Shalini Singh, Shirin Dehghai , Ahmed Qureshi
University of Alberta, Canada

Shape Memory Alloy (SMA) structures are necessary for actuator and vibration damper applications in Micro Electro Mechanical System (MEMS) devices. Laser powder bed fusion technique (LPBF) -NiTi structures have advanced rapidly in recent years because of it's intricate internal features, complicated shapes, and high levels of dimensional accuracy. Process parameters of LPBF such laser power, scan speed , hatch spacing and layer thickness determine final part's quality. The choice of parameters was particularly critical to the fully dense parts production and performance of LPBF-NiTi parts. In this work, using design of experiments (DoE) approach using a central composite design (CCD), LPBF process parameters have been optimized. The Porosity, microstructure, phase transition characteristic, and mechanical properties of LPBF-NiTi shape memory alloys were investigated through various characterization methods such as X-ray tomography, X-ray diffraction, scanning electron microscopy, differential scanning calorimetry and hardness testing.

Poster 1-7: Experimental Investigations of Pure Ni Porous Parts Fabricated via Laser Powder Bed Fusion

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

The porous material is necessary for many major technical applications such as lightweight constructions, capillary structures, filter components, medical implants, and tissue engineering. Laser powder bed fusion as additive manufacturing technology is utilized for the generation of a pure nickel part with defined porosity characteristics. The objective of this investigation is to fabricate a sample of pure nickel that exhibits a high degree of porosity using a Laser Powder Bed Fusion method by varying parameters such as laser power, scan speed, and hatch spacing. The resulting porous samples are characterized using high-resolution microcomputed X-ray tomography in order to measure the porosity, radius, and shape of pores.

Poster 1-8: Effect of Boron Additions on the Sintering Response of AISI D2 and AISI 4340 Components Produced by Binder Jetting

William Bouchard, Simon Gélinas, Carl Blais
Université Laval, Canada

The growing demand for parts manufactured by binder jetting (BJ) requires the development of new metal powders that are specifically tailored for this additive manufacturing (AM) process. Furthermore, the sintering of BJ parts is usually performed at high temperatures and for extended periods of time to maximize densification. This work focuses on the optimization of the chemical composition of AISI 4340, a highly hardenable steel, and of AISI D2, a tool steel used for wear resistance, to create specific steel grades for BJ that can be sintered at lower temperatures in conventional belt furnaces without limiting densification. Small additions of boron lead to the formation of a boron-rich liquid phase in steels at approximately 1 200℃, which significantly increases densification kinetics through permanent liquid phase sintering. The effect of boron content on densification and tensile properties was studied for both steel grades. The results showed that small additions of boron can indeed substantially improve densification of AISI 4340 and D2 at temperatures no higher than 1 200°C.

Poster 1-9: Artificial Intelligence Applied to the Development of Tool Steels with Low Susceptibility to Cracking for Laser Additive Manufacturing (LAM)

Justin Plante
Université Laval, Canada

Laser Additive Manufacturing (LAM) presents numerous advantages over conventional manufacturing techniques for the tooling industry, such as the possibility to repair worn components and the production of complex parts with conformal cooling channels. So far, most tool steels investigated for their use in AM have similar chemistries to those of wrought alloys, which were not designed for the specificities inherent to LAM. The latter include ultra-fast solidification and multiple heating/cooling cycles which increase sensitivity to hot cracking in AM components. This type of defect is obviously detrimental to obtaining high mechanical properties. Thus, avoiding cracking is a crucial challenge to overcome to make AM suitable for applications in the tooling industry. While a great number of studies focus on the optimization of process parameters to mitigate cracking, the development of tool steel powders specific for AM has been studied to a much lesser extent. This work presents a strategy using knowledge from fusion welding and thermodynamic simulations to predict the cracking susceptibility of experimental tool steel powders. The study proposes the utilization of a machine learning approach based on Bayesian optimization to accelerate the identification of suitable chemical compositions to develop novel AM tool steel powders with low susceptibility to cracking.

ALL TIMES ARE ATLANTIC DAYLIGHT TIME (ADT TIME ZONE)

Poster 1-10: Laser-Based Directed Energy Deposition of Monel 400 on a Steel Substrate

Ryan Ley, Paul Bishop
Dalhousie University, Canada

Laser-based directed energy deposition (L-DED) is often employed to produce and repair metallic products. Although a growing number of alloys have been assessed in this context, few studies have emphasized Monels. One member of this family that bears a high commercial relevance to the Canadian marine sector is Monel 400 (Ni-32Cu). This corrosion resistant alloy is in widespread use and is frequently applied as a manually welded overlay on steel to enhance service longevity in a saltwater environment. Since welding generates a significant heat flux, an overlay of pure nickel must be applied to the steel first to minimize dissolution of the Monel 400 coating and thereby retain its exceptional corrosion performance. L-DED is apt to be a more effective solution as its comparatively low energy density minimizes dissolution and may thereby eliminate the need for the intermediate pure nickel overlay entirely. The objective of this research was to examine the feasibility of this concept in the context of laser cladding Monel 400 powder on an HY-80 steel substrate. Preliminary work has sought to identify effective cladding parameters through the production of single-track deposits, thin walls, and multi-layer claddings using systematic adjustments in process parameters.

Poster 1-11: Dynamic Strain Aging Behaviour of Laser Powder Bed Fusion Made Hastelloy X Parts

Reza Esmaeilizadeh*, Xiaolong Li**, Hamid Jahed*, Ehsan Toyserkani*, Ehsan Hosseini**
**University of Waterloo, Canada; **3Empa, Swiss Federal Laboratories for Material Science and Technology, Switzerland*

This study evaluates the tensile response of laser powder bed fusion (LPBF) fabricated Hastelloy X (HX) coupons compared with those of conventionally manufactured HX over the temperature range of 22-800°C and strain rate of 10−4-10−2 s−1. Pronounced evidence of dynamic strain aging (DSA) was observed during tensile testing at temperatures from 300°C to 600°C and also limited evidence of DSA at 200° and 700°C. The transition from type-A/B to type-C DSA for LPBF HX happens at lower temperatures than conventionally manufactured HX. Furthermore, the activation energy for DSA is 66 kJ/mol for LPBF HX, which is lower than the reported 80-130 kJ/mol for conventionally manufactured HX. The observed differences in the tensile and DSA responses of the two variants of HX were attributed to the differences in their dislocation microstructure, observed through scanning transmission electron microscopy.

Poster 1-12: Development of AlSi10Mg-AlN Metal Matrix Composites for Laser Powder Bed Fusion AM

Jonathan Comhaire*, Donald Bishop*, Ian Donaldson**
**Dalhousie University, Canada; **GKN, Canada*

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, particulate size, 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 for a comprehensive assessment of microstructure, matrix/ceramic interfaces, and mechanical properties in the as-built and stress-relieved conditions. Data for a series of AlN-laden systems will be presented and compared against the baseline performance of AlSi10Mg.

Poster 1-13: Development and Characterization of an Aluminum Bronze Alloy for Laser Powder Bed Fusion

Vignesh Krishnan*, Addison Rayner*, Kenzie Timmons*, Jon Hierlihy*, Randy Cooke**, Donald Bishop*
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Aluminum bronze alloys are widely used in marine applications owing to their superior combination of strength, ductility, and corrosion resistance in seawater. These alloys are typically produced in wrought or cast form and have received little attention in the context of metal additive manufacturing (AM) to date. In the current study, laser powder bed fusion (LPBF) of an aluminum bronze powder with a nominal composition of CuAl10Fe1 was investigated and optimized for the first time to reliably produce samples with density greater than 99.5%. The as-built microstructure consisted primarily of β' martensite in lath and plate morphologies, with electron back-scatter diffraction images suggesting the existence of a defined property threshold delineating their formation during rapid solidification. The martensitic as-built microstructure produced high strength (offset yield = 519 MPa; UTS = 721 MPa) but relatively low ductility (12%) when compared to the properties of chemically comparable wrought (C61800) and cast (C95300) alloys. Heat treatment invoked the precipitation of globular α within the microstructure and increased ductility to 24% with limited reductions in yield and UTS. Thus, the optimal AM product exhibited high ductility along with yield and tensile strengths that were ~100-200 MPa above those of competing wrought and cast alloys.

Poster 1-14: 3D Printed Wood-fiber Reinforced Architected Cellular Composites with Enhanced Flexural Properties

Ehsan Estakhrianhaghighi, Armin Mirabolghasemi, Larry Lessard, hamid Akbarzadeh
McGill, Canada

Enhancing the mechanical and flexural properties of biobased composites by utilizing cellulose-based compounds paves the way for developing sustainable materials. This study investigates the flexural mechanical properties of sustainable 3D printed polylactic acid (PLA) composites reinforced with different amounts of waste wood fibers. First, wood-fiber reinforced filaments with a variety of waste wood-fiber weight percentages (are produced, and then test samples are 3D printed by an FDM printer according to the mechanical test standards. The experimental results demonstrate increased flexural stiffness, flexural rigidity, flexural strength, and reduced overall density of the composite coupons with the addition of wood fiber into the PLA polymeric matrix. In addition, following the growing interest in cellular solids, three rectangular architected composite cells consisting of composites members with different fiber content are designed to not only show enhanced flexural rigidity but also engineered quasi-isotropic flexural rigidity properties. The wood-fiber-reinforced engineered cellular composites offer a sustainable strategy to additively manufacture materials with enhanced and rationally designed structural properties.

Poster 1-15: Metallurgical Investigation of Al-Zr(-Y) Alloys for LPBF Using Laser Remelting

Jon Hierlihy*, Ian Donaldson**, Paul Bishop*

**Dalhousie University, Canada; **GKN Powder Metallurgy, United States*

The scope of commercially available aluminum alloys for laser powder bed fusion (LPBF) is limited despite their growing demand. Additionally, many industrial applications of Al-based LPBF mandate the use of alloy with enhanced thermal stability. Historically, such materials have been premised on alloys containing transition metal (TM) additions that formed refractory aluminides as the principal strengthening addition. In following this concept, the Al-TM the ternary Al-Zr-Y system was considered in this research. Investigation of this novel system invariably mandates that multiple alloys be converted into a powder form which is costly and time consuming. To expediently evaluate this system, Al-Zr-Y plates were cast with varying Zr and Y content. They were subsequently rastered with a Yb-fibre laser with a range of laser energies to produce remelted regions. Tracks were then examined (laser confocal, SEM, EBSD) to characterize the remelted microstructure and identify defects (cracking, porosity, epitaxial growth), as well as to identify the effects of Y additions at varying Zr-contents. In turn, a precursory sense of the processability of the Al-Zr-Y system in PBF-AM and was gained.

Poster 1-16: Performance Evaluation of Machine Learning Models in the Prediction of Melt Pool Dimensions and Density in Laser Powder Bed Fusion.

Donatien Campion, Vladimir Brailovski

École de technologie supérieure, Department of Mechanical Engineering, Canada

Integrating new metals and metallic alloys into the portfolio of Laser Powder Bed Fusion (L-PBF)-ready materials is a non-trivial problem requiring an expensive and time-consuming development. During the last decade, machine learning (ML) performances have grown substantially, especially with the development of new deep learning (DL) algorithms. These algorithms have been applied in additive manufacturing for different purposes including quality assessment, design for additive manufacturing, and material development. For the latter, Artificial Neural Network (ANN), Support Vector Machine (SVM) and Gaussian Process Regression (GPR) algorithms were considered appropriate, but no consensus has yet been reached which one is the most efficient. In this work, ANN, SVM and GPR models were built and their capabilities to predict melt pool dimensions and densities of printed parts were compared. The training databases were built using an in-lab developed analytical model of the melt pool created in a powder bed by a moving laser beam. The models were then iteratively optimized, by fine tuning the hyperparameters, and finally compared in terms of their predictive capabilities for different materials under different processing conditions.

Poster 1-17: How the Rheology of Powder Affects its Spreadability?

Stéphane Caubergh*, Aurélien Neveu*, Geoffroy Lumay**, Filip Francqui*

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Metallic powders are widely used in Additive Manufacturing (AM) processes, with for example Selective Laser Melting (SLM) and Selective Laser Sintering (SLS). During such operations, successive thin layers of powder are created with a ruler or with a rotating cylinder and then partially sintered with an energy beam. The layer thickness defines the vertical resolution, a thin layer leads to a better resolution. To obtain a thin layer, the powder is as fine as possible. Unfortunately, when the grain size decreases, the cohesiveness increases and the spreadability decreases. Consequently, the spreadability must be good enough to obtain homogenous successive layers.

In this study, in situ evaluations of the spreadability of metal powders have been correlated with their cohesive properties. The powder spreadability, associated with the spatial homogeneity of the powder bed, has been evaluated directly inside the printer (SLM280, SLM Solutions). The powder rheology is evaluated with a rotating drum (GranuDrum, Granutools), allowing it to mimic a stress state closer to the one the powder sees during the recoating. Also, a specific focus has been put on understanding how the recoater velocity influences the spreadability depending on the powder's rheological behavior.

Poster 1-18: Moderate Temperature Slow Strain Rate Compression Behaviour of a Heat-treated LPBF Fabricated Fe-Cr-Ni-Al Maraging Stainless Steel (CX)

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The present research investigates the uniaxial compression behavior of a novel Fe-Cr-Ni-Al maraging stainless steel from the EOS GmbH (manufactured under the brand name CX) at temperatures of 400 °C and 500 °C and a strain rate of 0.0001 s-1. The samples were built using the EOS M290 printer, using the EOS GmbH prescribed processing parameters for the maximum density of the printed material. Prior to the compression, the samples were heat treated according to the EOS GmbH prescribed schedule. The research aims to determine how moderate temperature exposure to compressive load will lead to deformation and microstructural changes within the part made during its service life. Microstructural investigations were performed using EBSD and TEM, while room-temperature mechanical properties before and after the deformation were accessed using microhardness and instrumented micro-indentation techniques. The results show that major microstructural changes occur in the material during prior heat treatment, which subsequently affects the compressive behavior of the material at the tested temperatures. The results are discussed based on the grain size, NiAl precipitation, hot flow stress curves, and mechanical properties of the various heat-treated and deformed samples.

Poster 1-19: Comparative Study on 316L Stainless Steel Powders Produced by Conventional Plasma Arc Gas Atomization versus Novel Ultrasonic Atomization Technique

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The substantial progresses in Additive Manufacturing (AM) during the past decade has led to a growth in demand for highly spherical powders with a narrow particle size distribution (PSD). Most feedstock powders for AM are produced through conventional Plasma Arc Gas Atomization (PAGA). Recently, a novel technology based on electric arc melting followed by Ultrasonic Atomization (UA) has emerged. The study revealed that the UA powders have a narrower PSD, with a minimal scrap rate, higher sphericity, better flowability, and higher density. The higher density in the UA powders could be attributed to the lower pressure (~1 barA) used in the UA system compared to the high-pressure gas stream (30–60 barA) utilized in the PAGA method. In addition, microscopic observations of the UA powders showed no agglomeration, deformed powders, and satellite particles, which are usually typical in PAGA powders. To investigate the potential differences between the 3D-printed parts using UA and PAGA powders, test coupons were fabricated using Laser Powder Bed Fusion, followed by microstructural characterizations, porosity level measurements, and mechanical properties evaluations. A comparative analysis of AM-fabricated samples using UA and PAGA powders confirmed that both feedstocks could yield acceptable properties that meet AISI 316L specification requirements.

Poster 1-20: Laser-powder Bed Fusion of Ti-based Alloys for Biomedical Applications

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This work aims to process new biocompatible Ti alloys by laser-powder bed fusion (L-PBF), a metal additive manufacturing (AM) technology. A design of experiments was developed to investigate the effect of L-PBF processing parameters such as laser power, hatch distance, and scanning speed on the samples' relative density and surface roughness. The results of the addition of a second particle and the influence of the scanning strategy on the microstructure of the Ti-based alloys were also investigated, showing the possibility for in-situ tailoring the material properties in the L-PBF process. Finally, some prototypes were manufactured with the novel biocompatible Ti alloy, demonstrating the possibility of manufacturing parts of Ti-based biocompatible alloys with complex geometry by L-PBF.

Poster 1-21: Additive Manufacturing of Al and Ti alloys: Microstructure Characterization and Mechanical Properties Across Length Scales

Yu Zou

University of Toronto, Canada

Part 1: AlSi10Mg components produced by laser powder bed fusion (LPBF) typically exhibit higher strength but lower ductility than those made by conventional mature processing technologies. The effects of melt pool boundaries on the ductility and fracture behavior of the LPBF-produced AlSi10Mg have not been systematically studied. The focus of this work is to investigate the local strain evolution, microvoid growth, and crack formation in the melt pool boundary regions using in situ tensile testing and synchrotron-based X-ray microtomography. we offer a new opportunity to fabricate AlSi10Mg products with an excellent combination of high strength and ductility.

Part 2: Laser-based directed energy deposition (LDED) enables rapid near-net-shape fabrication of large-scale titanium components for aerospace applications. However, the poor tensile ductility of most as-deposited titanium alloys, particularly near-α alloys, hinders their wide usage for critical load-bearing structures. Here we report that a high density of microscale shear bands (MSBs) can be activated in an LDED-produced Ti-6Al-2Zr-1Mo-1V alloy with dispersed microscale α colonies to enhance its tensile ductility. U Our study demonstrates that activating the MSBs provides a new opportunity to effectively enhance the ductility of LDED-produced titanium alloys and expedite the adoption of this additive manufacturing technology for critical structural applications.

Poster 1-22: Effect of Salt Flux and T6 Treatment on Al-Cu Alloy with Ce Addition

Marcelino Dias, Jonas Valloton, Ahmed Qureshi, Hani Henein

University of Alberta, Canada

Aluminum-copper alloys are highly valued in various industries like aerospace and automotive, owing to their exceptional mechanical properties and formability. Nevertheless, researchers continuously explore ways to enhance their microstructure and mechanical properties. In this regard, rare-earth elements have emerged as a promising avenue for achieving this objective. This study aimed to investigate a novel alloy for the hybrid investment casting process, in the form of Al-4.5wt%Cu-1.6%Ce alloy, on the microstructure and mechanical properties of aluminum-copper alloys. The casting process was utilized to create two alloys – one with the addition of a salt purification agent and one without. They were subjected to Argon gas to remove impurities and degas the alloys before casting in a mold. Subsequently, both alloys were subjected to T6 treatment. The study's findings indicate that adding salt flux had a significant effect on the Fe content of the alloy. The microstructure and microhardness of the alloys were also observed.

THEME 2: Modeling & Design

Poster 2-1: Numerical Modeling of Hybrid Additive Manufacturing of Laser Beam Powder Bed Fusion and Milling of Ti6Al4V

Surinder Pal, Xavier Velay, Waqas Saleem
Atlantic Technological University Sligo, Ireland

Hybrid manufacturing combines both additive manufacturing (AM) and subtractive approaches (SA) to create parts and overcome limitations faced in additive manufacturing. The combination exhibits the application of intricate external features and complex geometries that involve high accuracy for the biomedical, dental, and aerospace industries. This study presents the finite element analysis in two steps; The first simulation of the laser beam powder bed fusion is conducted to predict the thermomechanical behavior of Ti6Al4V, then a milling simulation of AM sample is performed to evaluate the finished product characteristics. The milling process was carefully observed by means of machineability, stress, and thermal analysis. However, the numerical modeling helped in optimizing processing parameters by reducing the need for experimentation. The validation of the FE method was demonstrated through comparison with reported experimental data. The proposed modeling offers an understanding of the simulations showing thermal profiles during the development of AM Ti6Al4V. Moreover, the results showed the substantial potential of milling in hybrid manufacturing and improved overall efficiency. In conclusion, these techniques can achieve the precision of the Ti6Al4V parts, which further leads to enhanced specific dimensional tolerances and mechanical properties, which makes it a viable choice for industries where accuracy is critical.

Poster 2-2: Characterizing Uncertain Elastic Properties of Additively Manufactured Materials for Application in Topology Optimization

Zahra Kazemi, Craig Steeves
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The layering approach associated with fused filament fabrication (FFF) additive manufacturing technology allows for complex designs generated by topology optimization to be manufactured. However, quality and reliability issues have been observed in additively manufactured materials. Defects associated with the layer-by-layer process are commonly observed in the fusion regions (the thin regions connecting deposited filaments), introducing considerable variability in the local elastic modulus. Accordingly, additively manufactured components designed by topology optimization will not achieve the desired performance if variations in material properties are not addressed at the design stage. Accurate quantitative measurements of the distribution of the elastic modulus of printed material are essential to achieve robust and reliable optimized designs. This research presents an approach to measuring the randomness in the elastic modulus of materials fabricated by the FFF method. A machine learning algorithm is developed that can estimate the spatial variations in the elastic modulus. The model is trained on a dataset of two-dimensional strain fields generated by finite element analysis of simulated DIC elastic modulus fields, with known random distributions in the corresponding elastic modulus fields. The results indicate that the trained model can approximate randomness in the simulated elastic modulus field from the corresponding strain field.

Poster 2-3: Evaluation of Small-scale Thin Wall AlSi7Mg Alloy LPBF Coupons under Extreme Low Cycle Fatigue Regime

Muralidharan Kumar, Mathieu Brochu
McGill university, Canada

Using the geometric freedom offered by Additive Manufacturing (AM), LPBF enables the fabrication of complex parts through a layer-by-layer approach. A recent push towards the DFAM of components is yielding parts with higher complexity involving thinner geometrical sections. However, the mechanical properties and surface conditions of the small additive manufactured 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 understanding of the failure sequence of such small-scale components under extreme cyclic loading conditions. This work explores the testing methodology and failure prediction of the LPBF printed thin wall section in different cross-sectional geometries under an alternate cyclic bending regime. Fully reversed and strain controlled Extreme Low Cycle Fatigue (ELCF) testing (N_f < 100) for small-scale thin wall coupons having thickness ≤ 0.5mm were carried out. This method was studied on AlSi7Mg alloys under various conditions. Factors linking heterogeneity, surface morphology, and GD&T with their mechanical responses will be presented.

Poster 2-4: Property and Design Assessment of a 3D-Printed Metallic Implant

Anushree Shah
University of British Columbia, Canada

Electron Beam Powder Bed Fusion (EB-PBF) can produce geometrically complex and customizable implants with a faster turnaround time. However, there are still challenges associated with osseointegration that may be addressed by creative design. This project focuses on implant design exploration, assessment of the mechanical and surface properties and structural compliance of the printed components. For this study, biocompatibility – the interaction between the implant, the host and the material properties – is of utmost importance. Therefore, Ti-6Al-4V powder will be used to print the components due to its corrosion resistance, high strength-to-weight ratio and biocompatibility.

Poster 2-5: Novel Accelerated Thermo-mechanical LPBF Modelling Using an Effective Heat Source

Shahriar Imani Shahabad*, Zhidong Zhang**, Ali Bonakdar***, Ehsan Toyserkani*
**University of Waterloo, Canada; **Northwestern Polytechnical University, China; ***Siemens Energy, Canada; University of Waterloo, Canada*

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 modelling and simulation are beneficial tools for predicting residual stresses and deformation of LPBF printed parts. However, the computational cost for conducting large-scale thermo-mechanical LPBF modelling is extremely expensive. In this presentation, a novel thermo-mechanical model is developed that incorporates the effective heat flux for accelerating the LPBF process simulation. The residual stresses and deformation of the cube and cantilever geometries are predicted for a various range of process parameters. X-ray analyzer and optical scanner devices are used to validate the simulation results. The simulation results demonstrate that implementing the effective heat flux reduces computational time while providing acceptable accuracy.

THEME 3: Process Monitoring & Control

Poster 3-1: A Novel Machine Learning Approach for In-situ Surface Roughness Detection during Laser Powder-Bed Fusion

Sahar Toorandaz, Ehsan Toyserkani
University of Waterloo, Canada

In recent decades, metal additive manufacturing has become increasingly popular in many industries. While it has considerable advantages over subtractive processes, high surface roughness remains a drawback. Surface roughness is undoubtedly a crucial aspect of the process, affecting both quality and performance of final products. Therefore, quality control and in-situ monitoring can have a significant impact on the process and enhance the process's efficiency, reliability, and repeatability. This presentation aims to extend our achievements on a novel integrated machine learning and monitoring approach for in-situ surface measurement over the last year. The light intensity emitted from the melt pool is collected and analyzed using various machine learning methods to predict the surface roughness of laser powder-bed fusion parts. An approach has been proposed to measure the surface roughness of the vertical wall of the same components through the analysis of stacked data within a predefined segment. Contrary to most studies in this field, this study uses time series photodiode signals to predict surface roughness which can be very beneficial for the industry. Several algorithms, such as Gradient Boosting, Deep Neural Networks, and Long Short-Term Memory are adopted. According to preliminary results, light intensity and surface roughness of components are promisingly correlated.

Poster 3-2: Machine Learning-Based Powder Characterization: Exploring Data Augmentation Techniques to Address the Material Data Limitation Challenges

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Feedstock characteristics of metal powder play a major role in the quality of laser powder bed fusion (LPBF) parts. By influencing power bed quality and powder spreading, these characteristics determine variations in powder melting, melt pool properties, and final parts' quality. Therefore, it is essential to develop data-driven machine learning (ML)-based powder characterization algorithms to replace the time- and cost-inefficient conventional powder characterization methods. However, a significant gap exists in the LPBF literature about developing ML algorithms for characterization of powder feedstock, mainly due to insufficient data on material properties. Augmenting data could provide effective solutions to the challenges of data limitation in ML applications. Throughout this study, three different approaches are examined to implement data augmentation on a small dataset of Ti-6Al-4V (Ti64) powder properties: conditional general adversarial networks (CGAN), variational auto-encoders (VAE), and synthetic minority oversampling (SMOTE). The key objective of the research is to identify the most suitable technique of data augmentation aimed at improving the performance of the pre-developed ML regression models that predict Ti64 powder flowability (hall flow). In the initial results of hall flow prediction, the decision tree regressor trained on regular auto-encoder-generated data outperformed the model trained on CGAN data.

Poster 3-3: Methods for Modeling Sensitivity Analysis Simulations for Eddy Current Testing

Heba Farag
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Eddy current non-destructive testing technique is one of the most promising techniques to be used in additive manufacturing. There are different challenges that face using eddy current technique in detecting different types of flaws in additive manufactured parts. Using finite element modelling helps to understand and evaluate the performance of using the eddy current technique during testing. Different models were created in ANSYS Maxwell to detect subsurface defects in parts made of titanium Ti6Al4V and stainless steel 316L. Several simulation models were created to explore the effect of temperature, lift-off distance and effect of edges on the detected defect signal. The effect of permeability and conductivity changes in the material and its effect on the impedance of the probe have been explored as well.

Poster 3-4: Mechanical Performance of 3D Printed Parts Using Material Extrusion of Highly-filled Polymer

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The Material Extrusion (MEX) of highly-filled polymer process involves extruding a high-concentration metal-based feedstock through a nozzle to print layer-by-layer a 3D object. Due to the inherent surface geometry generally obtained with such kind of extrusion-based 3D printing methods, the printed parts may exhibit an anisotropy that could limit their mechanical performance. To address this limitation, the influence of surface finish on mechanical properties will be assessed. To that end, filters commonly used as compression algorithms (such as the one used for JPEG and MP3) will be employed to filter out noise from 3D scans of the surface. The method involves flattening a high-resolution scan of the part retaining only surface information, the application of 2D Fast Fourier Transform (FFT) and filters, an analysis of the resulting distribution to output a constraint sensitivity index and the modulation of a typical net-shaped Finite Element Analysis model through inverse FFT. The approach is similar to determining the tone of digitalized audio from a record player by correlating it with the uneven surface of the record. The study expects to correlate the mechanical behavior with the surface geometry of printed parts by MEX.

THEME 4: Novel AM Processes & Products

Poster 4-1: Binder Jetting Additive Manufacturing for Compliant Mechanisms

Edward Yang, Issa Rishmawi, Mihaela Vlasea, Michael Mayer

University of Waterloo, Canada

Compliant mechanisms are a class of mechanisms that rely on the bending of structural elements called flexures within a design to provide the desired degrees of motion. Compliant mechanisms have numerous advantages, including monolithic construction, repeatability, and scalability. Additive manufacturing provides a way to build complex compliant mechanisms, that can target small scales, which can then be used to produce biomedical devices that treat conditions with minimal impact to the surrounding area. A review of the prior work done to combine these two concepts is conducted, identifying trends in additive manufacturing technologies used to produce compliant mechanisms. This work will then present compliant mechanism design primitives that have been printed using binder jetting additive manufacturing in 316L stainless steel, along with post-processing methods to tailor the mechanical response of these parts. The challenges of such an approach are discussed, with regards to the design process, manufacturing, geometric fidelity characteristics, and performance simulation and testing, along with ways to mitigate these as future steps.

Poster 4-2: Microstructural Control during Laser Powder-bed Fusion of Ti-alloy via Laser Post-exposure Treatment

Mahyar Hasanabadi, Ali Keshavarzkermai, Hamed Asgari, Adrian Gerlich, Ehsan Toyserkani

Multi-Scale Additive Manufacturing (MSAM) Lab, University of Waterloo, Canada

Microstructural control of additively manufactured parts is very important to reach the desirable mechanical behaviour. This research explores the feasibility of additively manufacturing tailored microstructures through laser post-exposure treatment during the laser powder-bed fusion process. Laser post-exposure treatment is a secondary laser scan with significantly lower energy input, resulting in the development of more uniform, uninterrupted, and elongated grains. Using electron backscatter diffraction and optical microscopy, it has been found that while the average length of the elongated grains was 845 μm for a post-exposure-treated sample, this value for the same sample in the absence of the post-exposure treatment was 321 μm. This microstructure resembles the characteristics of directionally solidified (DS) parts, which are utilized extensively in industry due to their superior creep and fatigue performance.

Poster 4-3: Development and Applications of Benign Electrolytes for Surface Finishing of Additively Manufactured Metal Parts

Manyou Sun, Ehsan Toyserkani

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Poor surface roughness is one of the problems for metal additive manufacturing (AM) and surface finishing is always needed after printing to meet the industrial requirements on surface roughness. Compared with mechanical and laser-based surface finishing techniques, chemical finishing methods, including chemical polishing and electrochemical polishing, have the capability of offering access to internal complex surfaces, making them ideal for reducing the surface roughness of complex parts made via AM. However, the commonly used electrolytes for these processes are highly toxic and corrosive, which poses significant safety hazards to operators and strong negative impacts to the environment. In this work, benign electrolytes including alcohol-salt systems, deep eutectic solvents and other non-toxic non-corrosive chemicals which react with metals are tested on Ti6Al4V parts made via laser powder bed fusion. Results from the study proves the feasibility of using benign chemicals for chemical surface finishing of metal parts made via AM.

Poster 4-4: Robotic 3D printing of Lunar Regolith/Polymer Composite by Simultaneous Localization and Additive Manufacturing

Mohammad Azami, Pierre-Lucas Aubin-Fournier, Krzysztof Skonieczny

Concordia University, Canada

Humankind plans to develop outposts and infrastructure on the Moon in the coming decades. Additive manufacturing (AM) is a perfect fit for in-space manufacturing. Expanding the size range of the printable parts through small robots while keeping the dimensional accuracy is an important research area. This research presents a promising approach for 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).

On the other hand, it is costly to deliver raw materials to the Moon, making in-situ resource utilization (ISRU) a particularly attractive option. To decrease the usage of off-site materials, we aim to print large-scale parts out of lunar-like regolith (granular igneous rock)/Polyether ether ketone (PEEK) composite, using the developed system coupled with a new 3D printer. The high-temperature fused filament fabrication (FFF) is the AM approach to be combined with SLAAM. First, the regolith–polymer filament is prepared through high-shear mixing and extrusion. Then, the regolith/PEEK ratio and the process parameters are optimized using a FFF machine. The next step is to print large-scale parts via SLAAM, and then to study the samples through mechanical testing and micrography.

Poster 4-5: Tailoring Microstructure and Resulting Mechanical Properties of Maraging Steel Fabricated by Laser Powder Bed Fusion

Mohsen Keshavarz*, Christopher Paul**, Michael Benoit**, Mihaela Vlasea*

**University of Waterloo, Canada; **University of British Columbia, Canada*

The utilization of microstructural engineering to modify the performance of a material can yield a competitive advantage to metal additive manufacturing (AM) processes, surpassing the advantages of design freedoms that are inherently associated with AM. The utilization of laser powder bed fusion (LPBF)-based metal AM enables in-situ manipulation of solidification and phase transformation via careful selection of process parameters. Studies have been conducted on LPBF aimed to optimize process parameters using process maps, to produce defect-free prints. Furthermore, process mapping approaches may be utilized to predict the solidification behavior and the resultant microstructure. Maraging steel 300 is an alloy, which is regularly utilized in different applications, which require a combination of diverse and/or functionally graded mechanical characteristics; thus, the microstructure should be adjusted contingent on the use. In this study, the ability of employing process regions (conduction, transition, and keyhole) of the LPBF process maps to spatially control the as-built microstructures of maraging steel 300 was explored. To this end, the mechanical properties of tailored microstructures were analyzed using profilometry-based indentation plastometry (PIP). The results showed that tensile strengths obtained from three different process map regions ranged from 1200 MPa to 1400 MPa while elongation varied between 1 to 9%.

Poster 4-6: 3D Printing of Fiber ased Soft Meta-components

Yu Liu

Jiangnan University, China

Soft components are crucial for flexible wearables, advanced robotics, and healthcares. Present device designs are limited in their functionalities but also with somer super mechanics. This presentation will share technical innovations in device designs and multi-materials process development. Structure – function correlations will be presented on how to build metaproperties to prompt functional performance. More particularly, self-powered sensor network will be discussed, and right demons will be given on how to scale up the whole design and manufacturing. Also in this presentation, multi-scale process will be screened with discussing on how to utilize the scale-based properties in right match with device sub designs. Some comments and perspectives will be discussed as well.

Poster 4-7: Functionally Graded Additive Manufacturing of Inconel 625-CuCrZr: from Process Parameter Optimization to Microstructural Evolution and Mechanical Properties

Ali Zardoshtian, Reza Esmaeilizadeh, Saeed Maleksaeedi, Hamid Jahed, Ehsan Toyserkani

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Functionally Graded Additive Manufacturing (FGAM) is a layer-by-layer fabrication process that involves the in-situ variation of composition and/or microstructure within a component to achieve locally tailored properties. A new type of FGAMs made of the highly-conductive CuCrZr alloy with Inconel 625 superalloy has gained tremendous attention for the aerospace application to benefit from both the high heat dissipation of the former and the excellent mechanical properties of the latter alloy. In this study, a systematic investigation has been done to properly fabricate single-track wall FGAM that began with 100% Inconel 625 on the bottom and gradually reached 100% CuCrZr on the top via laser directed energy deposition (LDED) technique. To preserve the structural integrity of such an FGAM product, an understanding of the metallurgical phenomena taking place in the deposition is essential. Therefore, microhardness indentation as well as optical microscopy, SEM, EDS, and EBSD were performed on the transversal cross-section to reveal the hardness and microstructure of different compositionally varied regions. Results from microhardness indentation show the variation of hardness in different regions. EBSD analysis results reveal the grain structure from hundreds of micrometers to a few micrometers in line with compositional variation through the cross-section.

Poster 4-8: Thermal and Residual Stress Modeling of Functionally Graded Coatings Deposited by PTA-AM

Geoffrey Bonias*, Hani Henein*, Tonya Wolfe**

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Despite the adoption of hard and tough coatings, the energy and mining sectors are experiencing high maintenance costs due to severe abrasive wear of components. Significant tensile residual stresses may accumulate during the coating process, resulting in the premature failure of a component. Applying a functional gradient to the material composition of the coating can result in a reduction of these residual stresses. The primary purpose of this research is to create an optimal material gradient in an additively built composite made of a WC-Ni alloy graded in WC deposited through a Plasma Transferred Arc (PTA). First, the thermal history of the WC and Ni alloy powders as they transit through the plasma and deposit on the substrate is simulated to produce a more detailed study of the deposition process. The initial temperature of each deposited bead is calculated based on the WC content. The results from this study are utilised to forecast the temperature and thermal stress history of the solidifying deposit. After the deposit has cooled down to room temperature, residual stress trends are derived as a function of the WC gradient chosen. The observed trends are quantitatively compared before opting on the most favourable gradient.

Author Index

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* As the NSERC HI-AM Network is reaching its end, we are currently seeking funding to ensure the continuation of the HI-AM Conference. The occurrence of HI-AM 2024 is dependent on the availability of funding, and the location of the conference may be subject to change.

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