HI-AM Conference

3rd | 2020

HOLISTIC INNOVATION IN ADDITIVE MANUFACTURING

PARTICIPANT INFORMATION PACKAGE

JUNE 25 & 26
ONLINE

nserc-hi-am.ca/2020

NSERC HI-AM

UNIVERSITY OF WATERLOO

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CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION

UNIVERSITY OF WATERLOO

McGill UNIVERSITY

2020 HI-AM CONFERENCE PARTICIPANT INFORMATION PACKAGE

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NSERC HI-AM

Welcome Message

On behalf of the NSERC Network for Holistic Innovation in Additive Manufacturing (HI-AM), we are very pleased to welcome you to the 2020 HI-AM Virtual Conference.

Although we originally planned to hold the 2020 HI-AM at McGill University, the current pandemic gave us no choice but to either cancel the conference or organize it online. While the COVID-19 pandemic has thwarted many conferences and large events, there is a world of online citizens, who have got together with one goal: progressing in science and sharing research results cannot stop. To this end, the HI-AM Board of Directors decided to use available virtual conference platforms and organize the HI-AM conference online.

This first online academic AM conference in Canada gathers over 400 people from all continents. This event provides an opportunity for HI-AM Network researchers, industrial partners and international researchers to come together, share findings, explore future research directions and opportunities for collaboration. Furthermore, numerous opportunities for online networking will be provided throughout the conference platform.

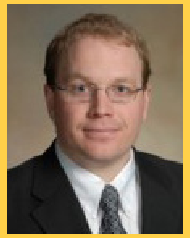
We are honored to have as our keynote speakers Dr. Javier Arreguin, AP&C, Canada; Dr. Todd Palmer, Penn State, United States; Dr. Carolyn Seepersad, UT Austin, United States; and Mr. Stuart Jackson, Renishaw, United Kingdom. The Conference also features 102 presentations and posters on cutting edge research in the area of metal additive manufacturing (AM).

In this welcome package, you can find more information about the conference online platform (Pathable) and instructions on how to navigate through it, watch the presentations, make connection with participants/exhibitors, and many more features. We encourage you to read through this package to ensure you are fully aware of the available features to get the most benefit from the conference.

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, Natural Sciences and Engineering Research Council of Canada (NSERC), we would also like to express our appreciation to our exhibitors Javelin Technologies, Keyence, KSB, EOS, Leichtbau, Multi-Scale Additive Manufacturing Laboratory, Promation 3D Printing, Proto3000, TRUMPF, and Xact Metal.

This online conference is our first ever experience, and like any first time activity, it may face with unseen issues. We hope that the conference goes forward smoothly and you enjoy and benefit from this Virtual HI-AM Conference.

Ralph Resnick
Chairman of the Board



Mathieu Brochu
Network Associate Director
Conference Co-chair

Ehsan Toyserkani
Network Director
Conference Co-chair

Exhibitors

JAVELIN is Canada's leading provider of SOLIDWORKS 3D CAD software and Additive Solutions. Since 1997 we have enabled thousands of companies with solutions for Mechanical and Electrical Design, Data Management, Training, 3D Scanning and Additive Manufacturing. We have partnered with many Canadian Industry leaders, taking their 3D design processes to the next level.

www.javelin-tech.com/3d/

KEYENCE is a global leader in metrology equipment for imaging, analysis and measurement applications. Our microscopes capture fully focused images and can perform 2D, 3D and roughness measurements, all with sub-micron resolution. Our 3D measurement device scans the entire surface as fast as 1 second for a more accurate surface analysis and is capable of CAD data comparison. Our equipment is in use by more than 10,000 companies around the globe. Visit our booth today for a live demonstration!

www.keyence.ca/Digital-Microscope
www.keyence.ca/SurfaceMetrology

KSB group is a global producer of pumps and valves with annual sales of almost 2200 million euro. KSB is a leader in metal additive manufacturing for production of pumps and valves. We are now offering consulting and testing services to others in any industry who want to implement metal additive manufacturing. With our materials science and engineering expertise, we offer services across the entire additive manufacturing process with stainless steels, nickel, titanium, aluminum alloys and other proprietary powders. We can help you with the business case, design for additive, materials development, technology selection, parameter development, quality control, testing, certification and other services to help you implement additive manufacturing into your strategy.

www.ksb.com

Exhibitors

EOS is the world's leading technology supplier in the field of industrial 3D printing of metals and polymers. Formed in 1989, the independent company is pioneer and innovator for comprehensive solutions in additive manufacturing. Its product portfolio of EOS systems, materials, and process parameters gives customers crucial competitive advantages in terms of product quality and the long-term economic sustainability of their manufacturing processes. Furthermore, customers benefit from deep technical expertise in global service, applications engineering and consultancy.

www.eos.info/en

LEICHTBAU BW is a collaborative network of more than 2,200 companies and more than 300 research facilities – which is probably the largest light weighting network in the world. For your individual needs, we select the most suitable institutions and persons and bring you into contact with suppliers, project partners and research institutes from the light weighting sector in Baden- Wuerttemberg.

www.leichtbau-bw.de/en/home.html
www.traclight-cluster.com/home.html

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

PROMATION 3D PRINTING offers laser cladding and Additive Manufacturing trial services. We are specialized in Laser Directed Energy Deposition which is an additive manufacturing process to fabricate near net shape parts. LDEF can also be used to add features or make repairs to existing parts.

www.promation.com

The PROTO3000 team helps companies leverage the transformative power of advanced manufacturing with industry-leading design, additive manufacturing, and metrology solutions. Our portfolio of products and services address the growing challenges faced in design and manufacturing across the entire product development lifecycle. We unlock innovation with design tools and services that allow you to optimize topology, lightweight, and access advanced AI-driven generative design to create unthinkable complex parts, components, and devices.

www.proto3000.com

TRUMPF Inc. is a leading manufacturer of laser technology for industrial use in North America. Among its laser portfolio are systems for laser metal fusion and laser metal deposition. This technology takes advantage of TRUMPF's high-quality laser sources to 3D print metal components for industrial applications. Founded in 1969 in Farmington, CT, the company is the largest subsidiary of the TRUMPF Group. With more than 1,000 employees in region, TRUMPF Inc. serves North American markets.

www.trumpf.com

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

www.xactmetal.com

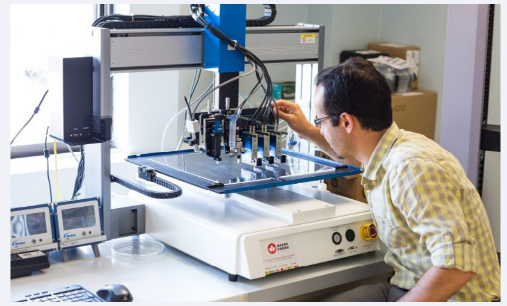
NSERC HI-AM Network

Additive manufacturing (AM) has the potential to change the entire manufacturing sector by 2030. Despite 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 the crucial arena of advanced manufacturing.

The HI-AM Conference is a platform for the Network researchers to share their findings with our Partners and the scientific community. The conference is an excellent opportunity to foster cross-theme knowledge exchange and demonstrate the value, relevance, and importance of on-going research in the HI-AM Network.



NSERC HI-AM

Network Partners

ACADEMIC AND RESEARCH INSTITUTION PARTNERS

MEMBERS

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

COLLABORATORS

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

INTERNATIONAL

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

INDUSTRY AND HEALTHCARE PARTNERS

- Autodesk
- BOCO Technology Inc
- equispheres
- FLEXCAP
- GE
- KSB
- MDA
- Mount Sinai Hospital
- GKN
- Pratt & Whitney Canada, A United Technologies Company
- PROMATION
- Renishaw apply innovation
- Rio Tinto
- Siemens Ingenuity for life
- Syncrude
- TIMET

GOVERNMENT PARTNERS

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

NON-PROFIT PARTNERS

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

Keynote Speakers

Javier Arreguin

Senior Material Project Manager
AP&C - A GE Additive Company, Montreal, Canada

Dr. Javier Arreguin is a Senior Materials Project Manager that joined AP&C, a GE Additive Company, in April 2017.

Before joining GE additive, Javier was involved in various projects supporting the adoption and certification of Additive Manufacturing technologies for Aerospace OEMs, starting from technology benchmarking through to part printing and process characterization. He gained hands-on experience with various powder metallurgy processing techniques such as laser powder bed fusion laser, electron beam melting, powder deposition, powder sintering and hot isostatic pressing.

In his current role, he oversees specialized research partnerships with key AP&C customers. Among his objectives are ensuring material optimization and process reliability. He is also parts of ASTM, ISO, SAE-AMS and NADCAP committees for Additive Manufacturing Powder Feedstock.

Javier's background is in Physics and holds Masters and Ph.D. degrees in Materials Science. He has eleven years of powder metallurgy experience and more than seven with Additive Manufacturing technologies directly.

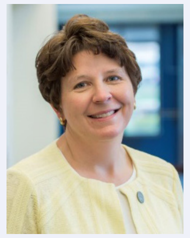
Presentation Title: AP&C Plasma Atomized Aluminum Alloys Optimized for Additive Manufacturing, Innovation and Challenges

Todd Palmer

Professor of Engineering Science and Mechanics and Materials Science and Engineering
The Pennsylvania State University, University Park, PA, United States

Dr. Todd Palmer is a Professor of Engineering Science and Mechanics and Materials Science and Engineering and the director of the Center for Innovative Sintered Products (CISP) at Penn State. Previously, he was a metallurgist at Lawrence Livermore National Laboratory and a Senior Scientist at the Applied Research Laboratory at Penn State. His current research focuses on the laser and electron beam joining and additive manufacturing of metallic materials as well as the characterization and processing of metallic powders. He has nearly 20 years of experience in high energy density joining of metallic systems and is the author of more than 80 articles and reports as well as the chair of the C7 Committee on High Energy Beam Welding and Cutting for the American Welding Society. Dr. Palmer has also recently been elected a fellow of the American Welding Society.

Presentation Title: Impact of Metal Powders Feedstock on the Properties and Performance of Additively Manufactured Materials

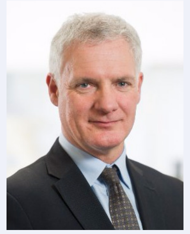


Carolyn Seepersad

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

Carolyn Conner Seepersad is the J. Mike Walker Professor of Mechanical Engineering at the University of Texas at Austin. Dr. Seepersad's research focuses on the development of methods and computational tools for engineering design and additive manufacturing. She is the author of more than 120 peer-reviewed journal and conference publications, including several best paper awards from ASME and ASEE. She is a member of the ASME Design Engineering Division Executive Committee and a member of the organizing committee for the annual Solid Freeform Fabrication Symposium. She teaches courses on engineering design and additive manufacturing, and she is a member of The University of Texas System Academy of Distinguished Teachers.

Presentation Title: Process Aware Design for Additive Manufacturing



Stuart Jackson

Business Development and Key Account Manager
Renishaw, Staffordshire, United Kingdom

Stuart joined Renishaw in 2016 as Business Development Manager for Additive Manufacturing. Based in the UK Headquarters and primarily responsible for Key Account Management. After starting a 5-year engineering apprenticeship in the 1970's his first industrial role was to introduce CNC Machines into the company's Aerospace division producing critical parts for the Westland SeaKing helicopter. In 1994 he introduced a LOM RP Machine into the UK developed by KIRA, Japan. Between 2002 & 2016 Stuart ran the UK subsidiary of EOS GmbH, Germany. Stuart is married with 3 grown-up children with interests in Motorsport, Motorbikes, classic cars and canoeing.

Presentation Title: A Short History of Metal AM and Future Needs to Meet Mass Market

Online Platform Guide

In light of the COVID-19 pandemic, the HI-AM 2020 has moved online. Although it is difficult to replace the benefits of an in-person gathering, we have tried to include all aspects of our annual conference in this online event using **Pathable** virtual event platform. Enjoy two days of virtual engagement.

ONLINE HI-AM 2020 OFFERS THE FOLLOWING FEATURES:

EDUCATION

- 4 Keynote Talks
- On-demand Presentations
- 2 Poster Sessions
- Live Q&A

NETWORKING

- Small Private Meetings
- Discussion Forums
- Private Conversations

VIRTUAL EXHIBITION

- 10 Exhibitors
- Private Conversations with Industry Representatives
- Request Product Information

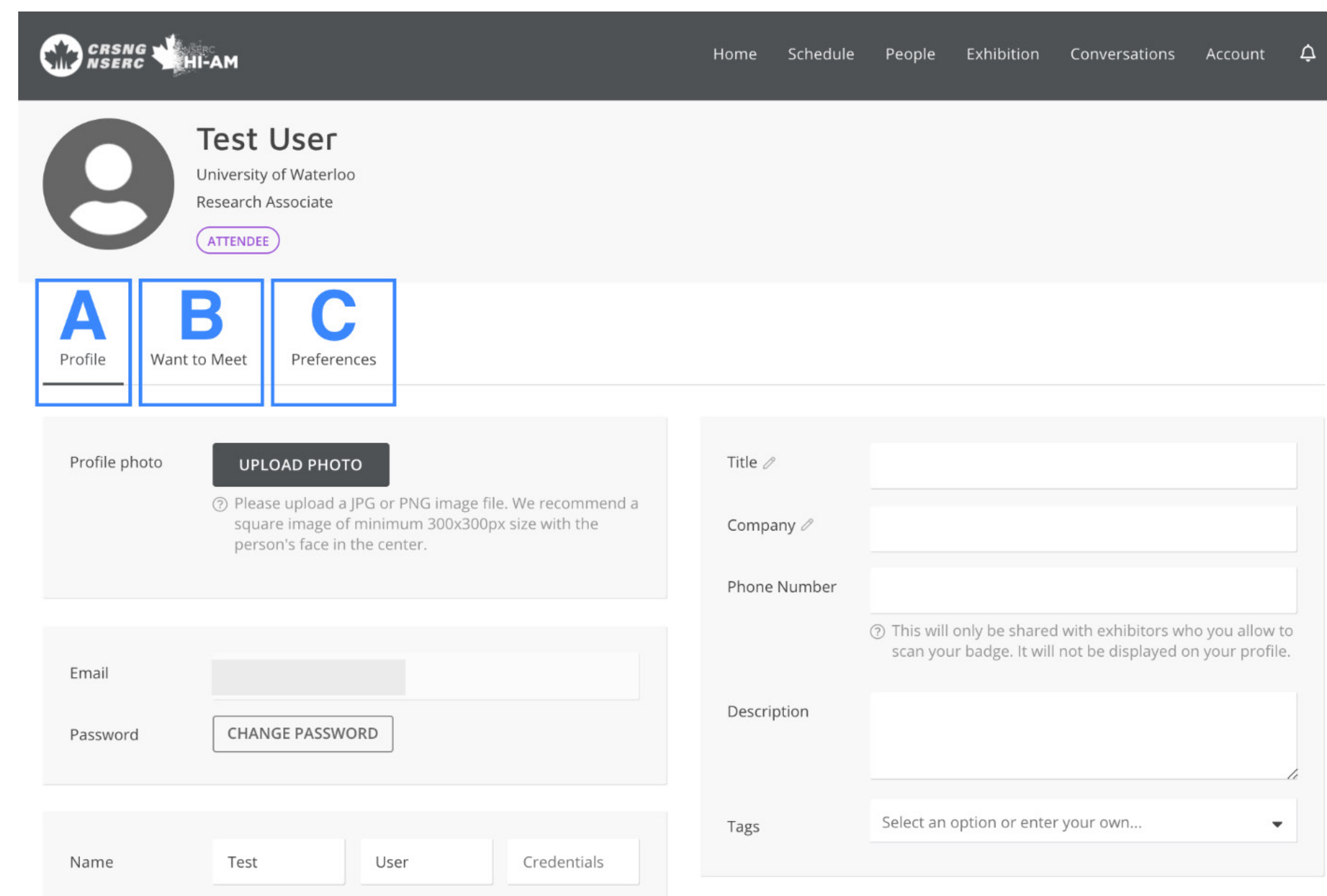
General Guidelines

LOG IN AND SET UP YOUR PROFILE

- You will receive an invitation email to access the conference app. The invitation will be sent to the email that you used to register for the HI-AM 2020 Conference.
- If you have a problem logging in, please contact the app provider by clicking on the **GET SUPPORT** button on the login page.
- Set up your password and complete your profile using the following sections:
  - **PROFILE (A)** allows you to complete your information and upload your photo. You can edit your profile information and settings later using the **ACCOUNT** button on the top bar and selecting **EDIT MY PROFILE.**
  - **WANT TO MEET (B)** allows you to access the private list of people you would like to meet during the conference. See the "Meet Presenters" Section for more information.
  - **PREFERENCES (C)** allows you to disable notifications and hide your profile. See Notes 1, 2 and 3.

NOTES:

1. You will receive notification emails when you have messages, meeting requests, etc. To disable notifications, click the checkbox next to **Do not send me any email.**
2. Your contact information will not be displayed on your profile. If you would like to completely hide your profile, click the checkbox next to **Hide my profile from other attendees.**
3. If you request information from exhibitors, your email address and other contact information added to your profile will be shared with them, even if you have opted not to share your contact information with exhibitors during registration. Requesting information is similar to allowing exhibitors to scan your badge at an exhibition.



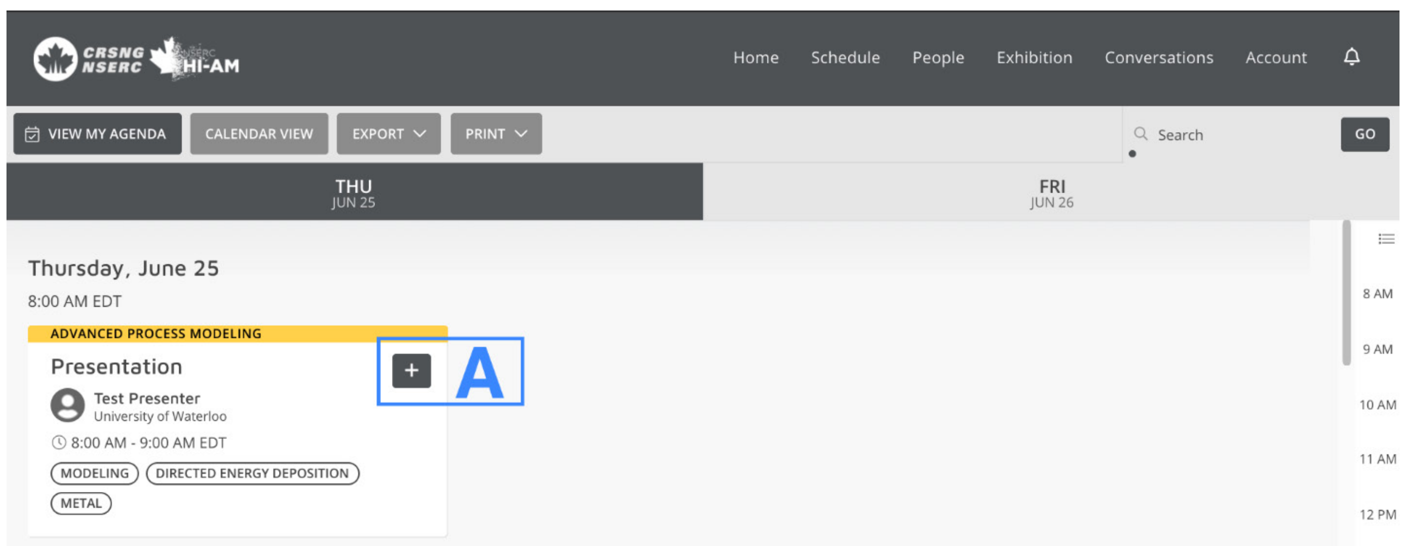
General Guidelines

BUILD YOUR AGENDA

- Log in to the conference app.
- Hover over **SCHEDULE** in the top bar.
- Select **AGENDA** to see the entire conference agenda. Presentation dates and times will be displayed in your time zone.
- Locate the presentation you are interested in and click on the **PLUS SIGN (A)** at the upper-right corner of the presentation card to add it to your agenda. Alternatively, you can click on the card to enter the presentation page to view more details and add the presentation to your agenda by clicking on the **ADD TO AGENDA** or **RESERVE A SPOT** button. See Notes 1 and 2.
- To access and edit your personal schedule, hover over **SCHEDULE** and select **MY AGENDA.**

NOTES:

1. You can only participate in the online Q&A of a presentation if you have added that presentation to your agenda.
2. You are not able to remove specific events, such as the opening and closing sessions, from your agenda.

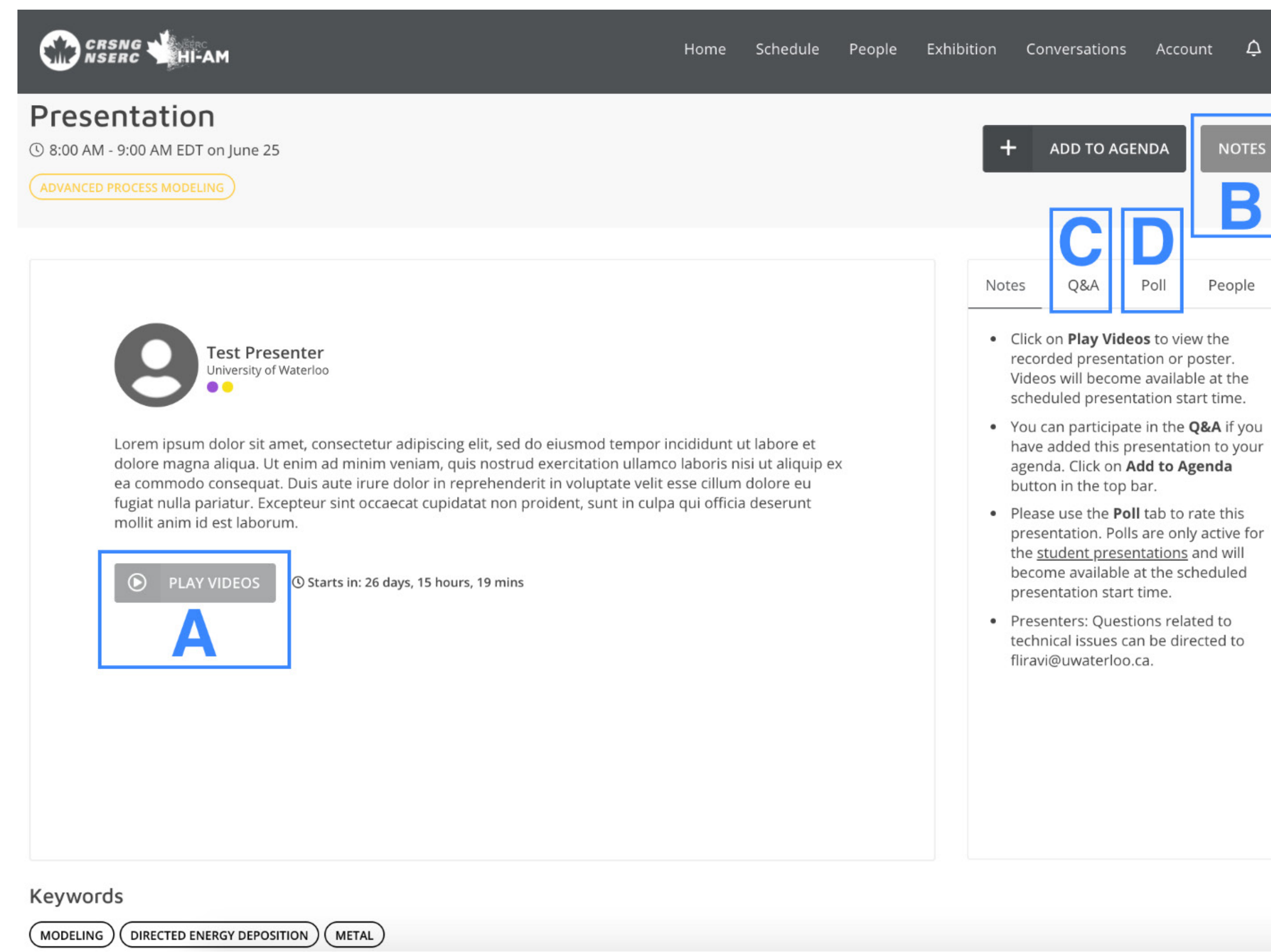


ATTEND A PRESENTATION

- The presentations you have added to your agenda are accessible from **UPCOMING EVENTS** in the main page or from **MY AGENDA.**
- Locate the presentation you want to attend and select it by clicking on the card.
- Click on **PLAY VIDEO (A)** to view the pre-recorded presentation or poster.
- Click on **NOTES (B)** to take notes during the presentation. You can download your notes.
- Use the **Q&A (C)** tab to ask your questions. See Notes 1 and 2.
- Use the **POLL (D)** tab to rate the student presentations.

NOTES:

1. Although the presenters might be available before or after their scheduled presentation time to answer your questions, the official Q&A time is the final 5 minutes of regular presentations, the final 10 minutes of Keynote presentations, and the entire duration of poster sessions.
2. Derogatory language is not acceptable. The public conversations will be regularly monitored by the conference staff and any comments containing language that is perceived to be offensive will be removed and may result in removal of the user from the conference app.



General Guidelines

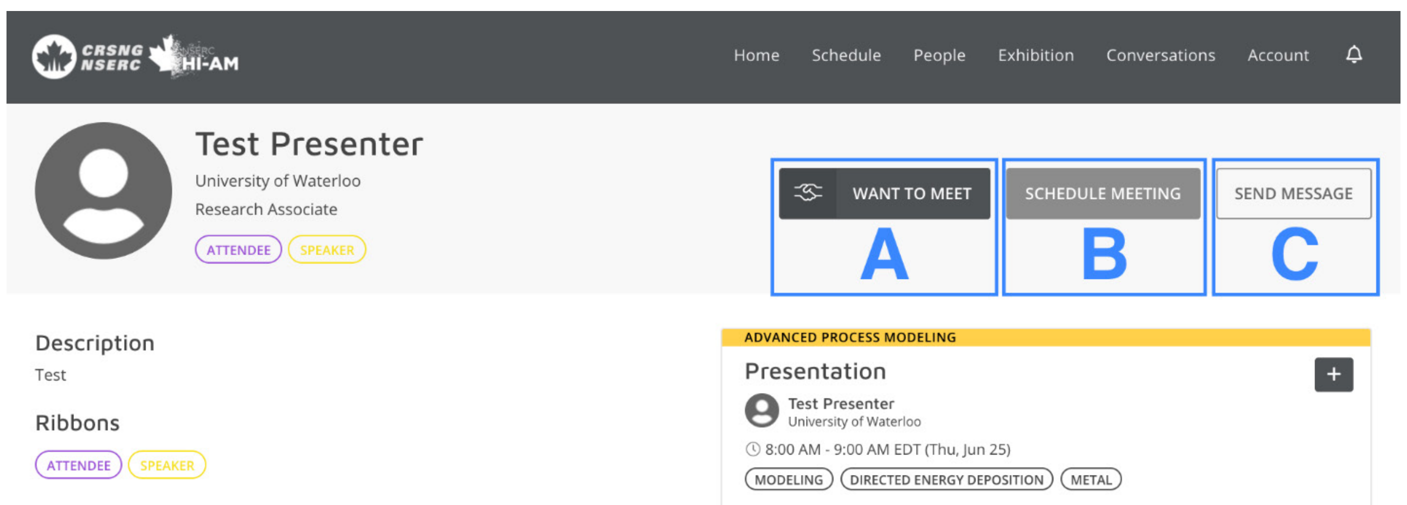
MEET PRESENTERS

- Hover over **PEOPLE** in the top bar and select **SPEAKERS.**
- Locate the speaker you would like to know more about and click on the card to view their profile.
- Click on **WANT TO MEET (A)** button to add this person to the private list of attendees you would like to meet.

  NOTE: To access your "Want to Meet" list later, hover over **ACCOUNT** and select **EDIT MY PROFILE.** The list is available from the **WANT TO MEET** tab.
- Click on **SCHEDULE MEETING (B)** and follow the steps to schedule a one-on-one Zoom meeting. You can invite others to make it a small private meeting as well.
- If invitees accept your meeting, you will be notified.

  NOTE: Once a private meeting is successfully created, a private meeting page will be added to your schedule. You can edit the details in **MY AGENDA.**
- Click on **SEND MESSAGE (C)** to start a private chat.

  NOTE: To access your inbox, click on the bell icon in the top bar.

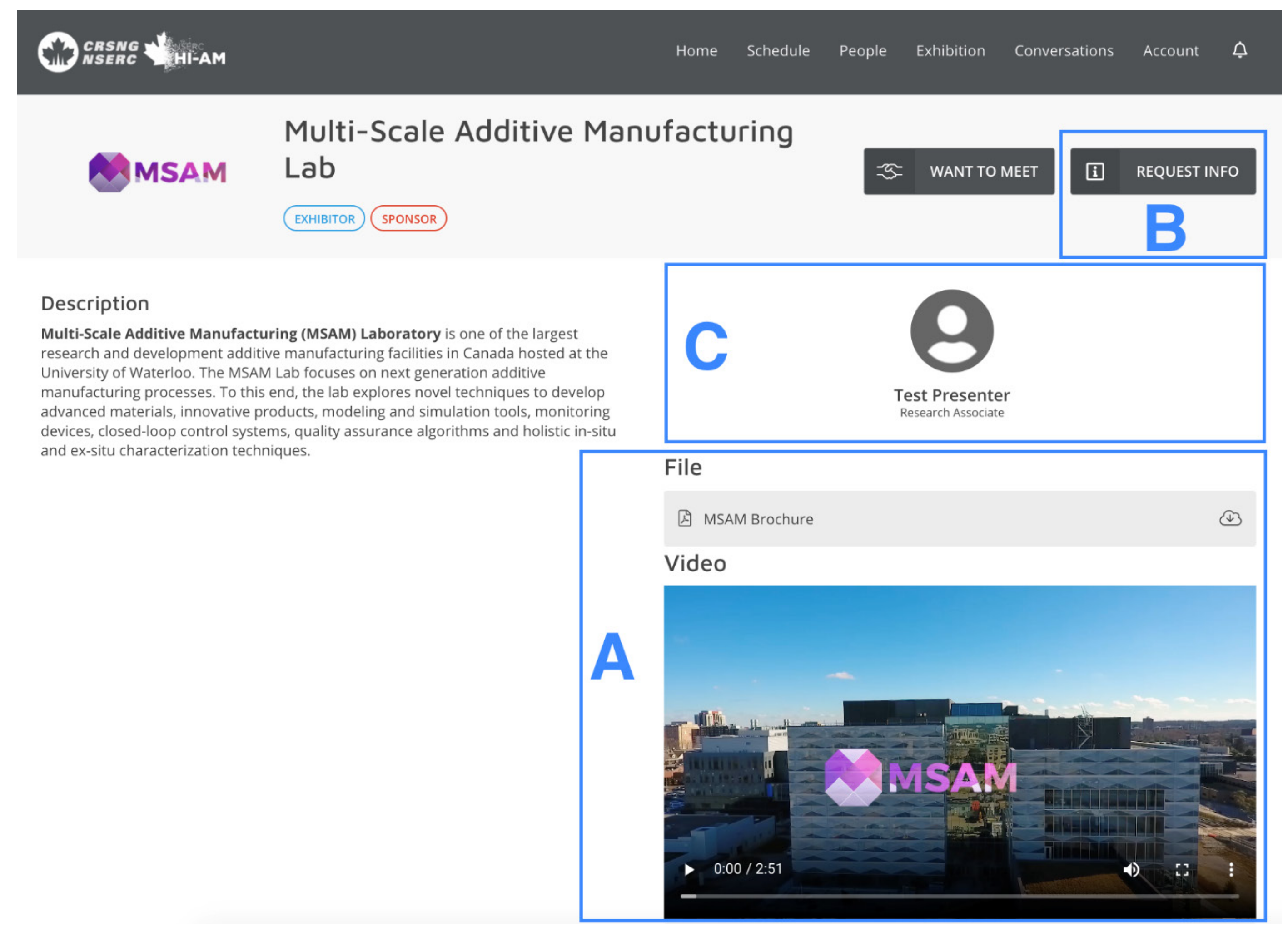


ATTEND A VIRTUAL EXHIBITION

- Exhibitor organizations have their own landing page within the conference app. You can enter the exhibition area by hovering over **EXHIBITION** in the top bar and selecting **EXHIBITORS.** It is also accessible from the Exhibition section of the main page.
- View the videos and download the digital brochures from the **FILE SECTION (A).**
- Click on **REQUEST INFO (B)** button at the upper-right to send a private message to the exhibitors. They will be in touch with you during or after the conference to provide requested information. See Note 1.
- Click on **exhibitors' name (C)** to view their profile and set up a one-on-one Zoom meeting with them (see "Meet Presenters" for details).

NOTE:

1. If you request information from exhibitors, your email address and other contact information added to your profile will be shared with them even if you have opted not to share your contact information with exhibitors during registration. Requesting information is similar to allowing exhibitors to scan your badge at an exhibition.



Guidelines for Presenters

- Take part in one of the following speaker training sessions to learn about managing your meeting page and all the features that are available to you as a speaker. You will receive a calendar invitation to join the training sessions.

  June 22, 1:00-1:30pm EDT
  June 23, 10:00-10:30am EDT

- Your meeting pages are automatically added to your agenda. You can access them from the **UPCOMING EVENTS** section of the main page or **MY AGENDA.**
- Presentation at HI-AM 2020 is very easy. To avoid common video conferencing problems, we have selected to have on-demand presentations instead of live sessions. You have done most of the work by sending us your recorded presentation or poster files before the event. Your video will become available to the participants at the scheduled time of your presentation. You just need to be available at your meeting page for the Q&A session.
- You are able to remove any comments and contents that you perceive to be offensive from the Q&A section of your meeting page:
  - Locate the message you would like to delete.
  - Click the three dots on the upper-right corner of the message.
  - Select Delete from the drop down menu.
  - Report the user to the conference staff.
- Evaluation polls are available for student presentations. Please remind your audience to take part in the evaluations. Presentations with the highest scores will receive an Award. The winners will be announced during the conference closing.

Q&A FOR ORAL PRESENTATIONS:

The final 5 minutes (10 minutes for Keynotes) of scheduled presentation times are the official Q&A periods. Please answer participants' questions during this time. You are also welcome to stay longer in your meeting page to interact with the attendees. Your presentation will remain available for viewing until June 30, 2020.

NOTE: If you would like your presentation to be removed from the conference app at any point, please contact us.

Q&A FOR POSTER PRESENTATIONS:

Please be available at your meeting page during your poster session to answer the questions of attendees. Each poster session is 1 hour and 40 minutes. Your poster will remain available for viewing until June 30, 2020.

NOTE: If you would like your poster to be removed from the conference app at any point, please contact us.

TECHNICAL SUPPORT

Technical support is available throughout the conference for presenters. Contact us at **fliravi@uwaterloo.ca** if you have any technical difficulties.

Guidelines for Exhibitors

Organizations have their own landing page within the conference app, with a number of customizable areas. You must be logged in to the app as an exhibitor to make edits to your page.

Click the **MANAGE** button in the upper-right corner of your page. On the Manage menu, there are a number of tabs on the left:

- **BASICS (A)** allows you to edit the Organization's details: Name, logo, Description, and tags/keywords. On the right, the **MANAGE YOUR TEAM** area allows you to add/remove registered members to your team. Team members have management access.
- **LEADS (B)** lists information about attendees who would like more information from you. You are able to download the leads.
- **VISITS (C)** lists information about attendees who have visited your page. Please note that these are not inquiries or hard leads and should not be treated as such.
- **POLLS (D)** allows you to configure interactive polls for attendees.
- **FILES (E)** allows you to upload files such as handouts, brochures etc. that attendees can then download.

TECHNICAL SUPPORT

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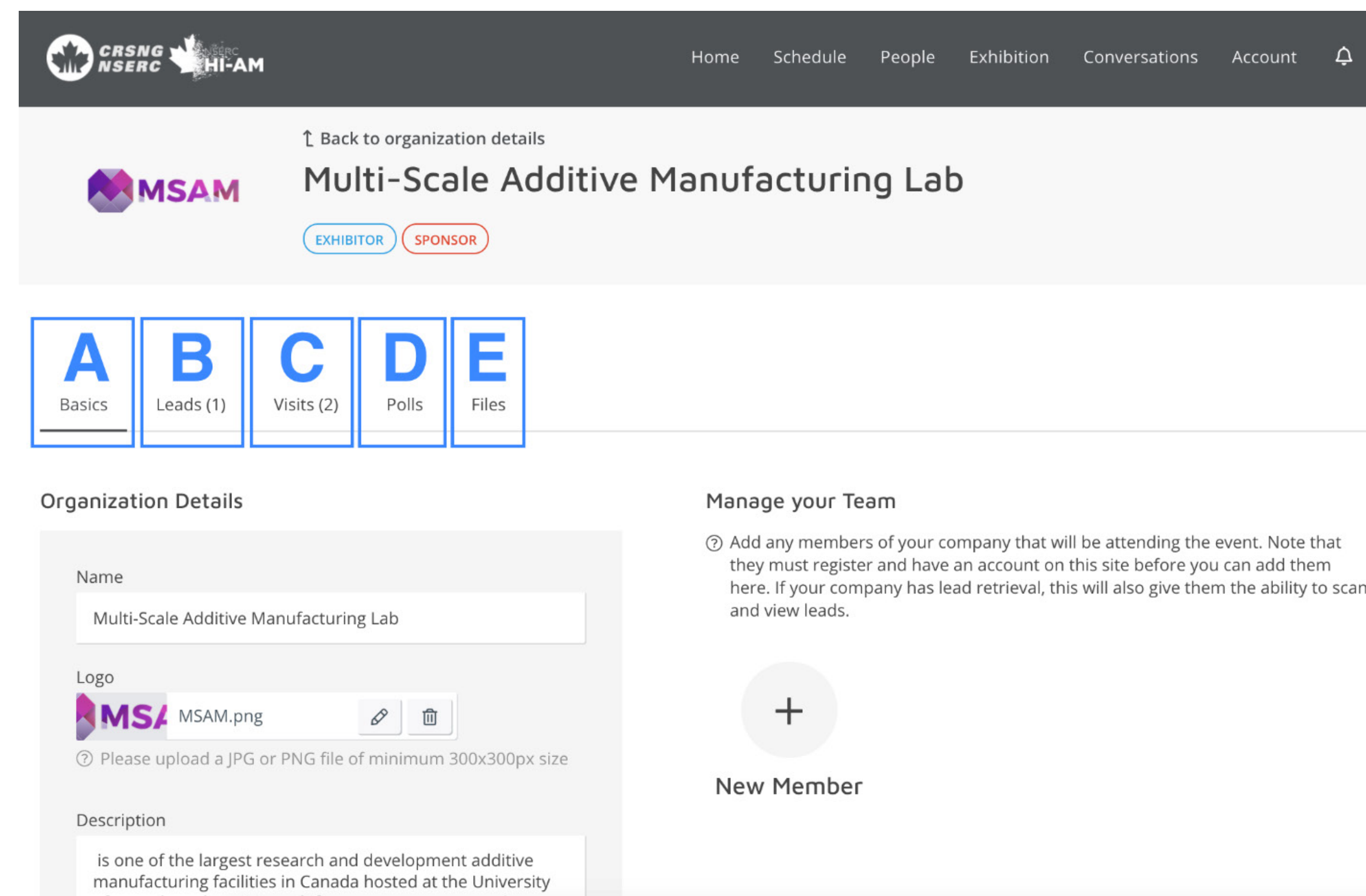

DAY 1 – June 25, 2020

ONLINE CONFERENCE PROGRAM

MORNING

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

9:20am	**CONFERENCE OPENING**
	SESSION 1: Metal Additive Manufacturing
9:40am	**KEYNOTE 1: AP&C Plasma Atomized Powders Optimized for Additive Manufacturing, Innovation and Challenges** Javier Arreguin *Senior Material Project Manager, AP&C - A GE Additive Company, Montreal, Canada*
10:20am	**KEYNOTE 2: Impact of Metal Powders Feedstock on the Properties and Performance of Additively Manufactured Materials** Todd Palmer *Professor of Engineering Science and Mechanics and Materials Science and Engineering, The Pennsylvania State University, PA, United States*
11:00am	**KEYNOTE 3: Process-Aware Design for Additive Manufacturing** Carolyn Seepersad *J. Mike Walker Professor of Mechanical Engineering, The University of Texas at Austin, TX, United States*
11:40am	**KEYNOTE 4: A Short History of Metal AM and Future Needs to Meet Mass Market** Stuart Jackson *Business Development and Key Account Manager, Renishaw, Staffordshire, United Kingdom*

AFTERNOON

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

12:20pm	**POSTER SESSION 1: Material Development | Advanced Process Modeling** **EXHIBITION VIEWING**	
	SESSION 2: Material Development I	**SESSION 3: Advanced Process Modeling I**
2:00pm	**Presentation 1 - Featured Talk: Powder Processing by RF Plasma: Towards a Circular Economy** Nicolas Gobeil *Tekna, Canada*	**Presentation 6 - Featured Talk: How Big Data can Improve 3D Printing** François Gingras *Centre de recherche industrielle du Quebec (CRIQ), Canada*
2:20pm	**Presentation 2 - Featured Talk: Predicting Powder Spreadability with the Granudrum** Filip Francqui *GranuTools, Belgium*	**Presentation 7: Prediction of Defects Based on Beam Path and Melt Pool Morphology Using Machine Learning for Laser Powder Bed Fusion** Deniz Sera Ertay, Shima Kamyab, Mihaela Vlasea, Zohreh Azimifar, Thanh Ma, Allan Rogalsky, Paul Fieguth *University of Waterloo, Canada*
2:40pm	**Presentation 3: Powder Reuse Cycles in Electron Beam Melting and their Effect on Ti-6Al-4V Powder Properties** Gitanjali Shanbhag, Mihaela Luminita Vlasea *University of Waterloo, Canada*	**Presentation 8: Development of An Autonomous In-situ Temperature Measurement System and a Heat Transfer Model of the Build Chamber in Electron Beam Additive Manufacturing** Farhad Rahimi*, Farzaneh Farhang-Mehr*, Steve Cockcroft*, Ralf Edinger**, Daan Maijer* **The University of British Columbia, Canada | **CANMORA Tech Inc., Canada*

Session 2 schedule continued on next page...

DAY 1 – June 25, 2020

AFTERNOON

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

	SESSION 2: Material Development I	**SESSION 3: Advanced Process Modeling I**
3:00pm	**Presentation 4: Electrostatic Atomisation of Metals** Bilal Bharadia, Abdoul Aziz Bogno, Hani Henein *University of Alberta, Canada*	**Presentation 9: Control of Density and Microstructure in Laser Powder bed-fused Components Using a Combination of Melt Pool Modeling and Design of Experiment Approaches** Morgan Letenneur, Alena Kreitcberg, Vladimir Brailovski *École de technologie supérieure Montreal, Canada*
3:20pm	**Presentation 5: Characterization of TZM Alloy Powders and their Laser Powder Bed Fusion Additive Manufacturing Behavior** Tejas Ramakrishnan, Mathieu Brochu *McGill University, Canada*	**CANCELED Presentation 10: Role of Impinging Powder Particles on Melt Pool Hydrodynamics, Thermal Behaviour and Microstructure in Laser-Assisted Ded Process: A Particle-Scale DPM – CFD – CA Approach** Akash Aggarwal, Arvind Kumar *Indian Institute of Technology Kanpur, India*
3:40pm	**EXHIBITION VIEWING**	
	SESSION 4: Process Monitoring and Control I	**SESSION 5: Novel AM Processes and Products I**
4:00pm	**Presentation 11 - Featured Talk: Tracking and Controlling the Morphology Evolution of 3D Powder-bed Fusion in situ Using Inline Coherent Imaging** James Fraser *Queen's University, Canada*	**Presentation 16 - Featured Talk: 3D Printed Smart Molds for Sand Casting** Eric MacDonald*, Jerry Thiel** **Youngstown State University, United States* ***University of Northern Iowa, United States*
4:20pm	**Presentation 12: Microstructure Evolution and Microscale Mechanical Properties of Dual-Phase Titanium Alloy Made by Additive Manufacturing** Zhiying Liu, Yu Zou *University of Toronto, Canada*	**Presentation 17: Thermo-mechanical Modelling of Electron Beam Additive Manufacturing Process for Repair and Remanufacturing Purposes** Fatih Sikan*, Priti Wanjara**, Javad Gholipour**, Mathieu brochu* **McGill University, Canada* ***National Research Council, Canada*
4:40pm	**Presentation 13: Airborne Metal Particle Stream Focusing using an Ultrasound Phased Array and its Application in Powder-fed Directed Energy Deposition** Alexander Martinez-Marchese, Mazyar Ansari, Marc Wang, Ehsan Toyserkani *University of Waterloo, Canada*	**Presentation 18: Laser DED Cladding of Dip-Coated TiC-Ni3Al Cermets on D2 Tool Steel** Zhila Russell, Kevin Plucknett, Gianfranco Mazzanti *Dalhousie University, Canada*
5:00pm	**Presentation 14: Real-Time Simultaneous Microstructure and Geometry Monitoring of Laser Materials Processing** Lucas Botelho, Amir Khajepour *University of Waterloo, Canada*	**Presentation 19: Dynamic Mechanical Loading Characterization of an AM-Based Flexible Sensor** Jeffrey Sixt, Elham Davoodi, Armaghan Salehian, Ehsan Toyserkani *University of Waterloo, Canada*
5:20pm	**Presentation 15: A Holistic Approach for Quality Control in Metal Additive Manufacturing** Mohammed Alghamdy, Basel Alsayyed, Rafiq Ahmad *University of Alberta, Canada*	**CANCELED Presentation 20: An Overview of Wire-Arc Additive Manufacturing and an Outlook of its Application Potentials** Sheng-Hui Wang*, Stefano Chiovelli** **National Research Council, Canada* ***Syncrude, Canada*

DAY 2 – June 26, 2020

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

	SESSION 6: Process Monitoring and Control II	SESSION 7: Novel AM Processes and Products II
8:40am	**Presentation 21: Exploring Force Feedback During Powder Spreading for Binder Jetting Additive Manufacturing** Alexander Groen, Mihaela Vlasea, Kaan Erkorkmaz *University of Waterloo, Canada*	**Presentation 26 - Featured Talk: Performance of Affordable Metal Additive Manufacturing** Jonathon Hollahan *Xact Metal, United States*
9:00am	**Presentation 22: A Novel Spatter Detection Algorithm for Real-time Quality Control of Laser Directed Energy Deposition** Farzaneh Kaji*,**, Mazyar Ansari*, Mark Zimny**, Ehsan Toyserkani* **University of Waterloo, Canada* ***Promation, Canada*	**Presentation 27: 3D Printed Sustainable Architected Cellular Composites** Hamid Akbarzadeh, Ehsan Estakhrianhaghighi, Armin Mirabolghasemi, Yingnan Zhang, Larry Lessard *McGill University, Canada*
9:20am	**Presentation 23: Application of Machine Learning to Predict the Density of Binder-jet 3D Printed Parts** Somayeh Hosseini Rad, David Schlachter, Sergio Yanez Sanchez , Alice Goffin, Martin Lennox, Basil Favis, Daniel Therriault, Jason Tavares *Polytechnique Montréal, Canada*	**Presentation 28: Machine Learning Aided Design of Conformal Porous Structure** Zhenyang Gao, Yaoyao Fiona Zhao *McGill University, Canada*
9:40am	**Presentation 24: Moving Towards the Development of an Artificial-based Defect-detection Model through the Photodiodes Signals Collected from the Melt Pool of Laser Powder-bed Fusion** Katayoon Taherkhani*, Esmat Sheydaeian Arani**, Ehsan Toyserkani*, Martin Otto***, Christopher Eischer*** **University of Waterloo, Canada* ***Bundesanstalt für Materialforschung und –prüfung (BAM), Germany* ****EOS, Germany*	**Presentation 29: Additive Manufacturing of FGM Parts Using PTA** Geoffrey Bonias, Hani Henein *University of Alberta, Canada*
10:00am	**Presentation 25: A Novel Testing Bench for the Assessment of Metal Powder Spreading Behavior** Salah Eddine Brika, Vladimir Brailovski *École de technologie supérieure Montreal, Canada*	**Presentation 30: Functionally Graded Lattice Optimization based on Homogenization and its Application to Dynamic Problems** Ugur Simsek*, Cemal Efe Gayir*, Nezih Sunman**, Aykan Akbulut**, Cansu Basaran**, Polat Sendur** **General Electric* ***Özyeğin University, Turkey*
10:20am	**EXHIBITION VIEWING**	

DAY 2 – June 26, 2020

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

	SESSION 8: Advanced Process Modeling II	SESSION 9: Material Development II
10:40am	**Presentation 31: The Effect of Part Geometries on Melt Pool Dimensions in Laser Powder Bed Fusion Process (LPBF)** Shahriar Imani Shahabad*, Usman Ali*, Zhidong Zhang*, Ali Keshavarzkermani*, Reza Esmaeilizadeh*, Ali Bonakdar**, Ehsan Toyserkani** **University of Waterloo, Canada* ***Siemens, Canada*	**Presentation 36: Binder Jet Printing of Low-Cost Tool Steel Powders** Ryan Ley*, Ian Donaldson**, Donald Paul Bishop* **Dalhousie University, Canada* ***GKN, Canada*
11:00am	**Presentation 32: Design for Additive Manufacturing: A Multiphysics Topology Optimization Model for Conceptual Structural Designs under Practical Loads and Boundary Conditions** Osezua Ibhadode*, Pouyan Rahnama*, Zhidong Zhang*, Ali Bonakdar**, Ehsan Toyserkani* **University of Waterloo, Canada* ***Siemens, Canada*	**Presentation 37: Enhanced Impact Energy Absorption of 3D Printed Tessellated Sheets made from Flexible Materials** Anastasia Wickeler, Hani Naguib *University of Toronto, Canada*
11:20am	**Presentation 33: Machine Learning Assisted Manufacturability Prediction for Laser-based Powder Bed Fusion** Ying Zhang, Yaoyao Fiona Zhao *McGill University, Canada*	**Presentation 38: Thermal Insulation and Laser-based Preheating Method for Processing a Ledeburitic Tool Steel in LPBF** Gregor Graf*, Manuela Leoni**, Tobias Müller, Jörg Fischer-Bühner, Maximilian Frey**, Daniel Beckers*, Sven Donisi*, Frederik Zanger**, Volker Schulze** **Rosswag GmBH, Germany* ***Karlsruhe Institute of Technology, Germany*
11:40am	**Presentation 34: A Framework to Study the Role of Material and Morphology Defects on the Mechanical Performance of Additively Built Lattice Materials** Asma El Elmi*, David Melancon**, Meisam Asgari, Damiano Pasini* **McGill University, Canada* ***Harvard University*	**Presentation 39: Attempts at Understanding LPBF of Intermetallic Alloys** Kuanhe Li, Chao Xu, Tejas Ramakrishnan Xianglong Wang, Mathieu Brochu *McGill University, Canada*
12:00pm	**Presentation 35: Investigating the Effect of the Temperature and Stress Fields on the Geometric Tolerances of the Laser Powder Bed Fusion Printed Parts** Baltej Singh Rupal, Marc Secanell, Ahmed Jawad Qureshi *University of Alberta, Canada*	**CANCELED** **Presentation 40: Selective Laser Melting of Titanium Matrix Composites Reinforced with Hybrid (TiB+TiC) Reinforcements** Eskandar Fereiduni, Ali Ghasemi, Mohamed Elbestawi *McMaster University, Canada*
12:20pm	**POSTER SESSION 2: Process Monitoring and Control | Novel AM Processes and Products** **EXHIBITION VIEWING**	

DAY 2 – June 26, 2020

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

	SESSION 10: Material Development III	SESSION 11 – PART A: Transatlantic Cluster for Lightweighting (TraCLight)
2:00pm Presentation 41 2:10pm Presentation 46	2:00pm **Presentation 41 - Featured Talk: Deep Learning Framework for Image-based Characterization in Additive Manufacturing** Mike Marsh, Nicolas Piché *Object Research Systems (ORS)*	2:10pm **Presentation 46: What is TraCLight?** Nadja Rest*, Manuela Neuenfeldt**,*** **Leichtbau BW GmbH, Germany* ***wbk Institute of Production Science, Germany* ****KIT Karlsruhe Institute of Technology, Germany*
2:20pm	**Presentation 42: Binder Jet 3D Printing of Flexible and Multifunctional Polymer Material Using MXene Based Inks** Terek Li *University of Toronto, Canada*	**Presentation 47: Hybrid Additive Manufacturing Possibilities Based on Forging in Combination with LPBF** Sven Donisi, Gregor Graf *Rosswag GmbH, Germany*
2:40pm	**Presentation 43: Microstructural Evolution and Mechanical Properties of Aluminum-Copper Alloy and Maraging Steel Made by Selective Laser Melting** Hao Kun Sun, Gisele Azimi, Yu Zou *University of Toronto, Canada*	**Presentation 48: Additive Manufacturing of Metal Components using the ARBURG freeformer System** Daniel Kupzik, Quirin Spiller, Jürgen Fleischer *wbk Institute of Production Science,* *KIT Karlsruhe Institute of Technology, Germany*
3:00pm	**Presentation 44: Impact of the Dynamics Strain Aging and Recrystallization Processes on the High Temperature Behaviour of LPBF IN625 Components** Alena Kreitcberg, Karine Inaekyan, Vladimir Brailovski *École de technologie supérieure Montreal, Canada*	**Presentation 49: Development of H13 Repair and Hybrid Manufacturing of Extrusion Dies by DED** Alexandre Bois-Brochu*, Christian Zanetti**, Philippe Olcelli** **Quebec Metallurgy Center, Canada* ***DIENAMEX, Canada*
3:20pm	**Presentation 45: LPF-AM Processing of Beta, Near-Beta and Near-Alpha Titanium Alloys** Nick Gosse*, Gregory Sweet*, Ian Donaldson**, Donald Paul Bishop* **Dalhousie University, Canada* ***GKN, Canada*	**SESSION 11 – PART B: Process Monitoring and Control III** **Presentation 50: Detection of a Subsurface Defect in an Additively Manufactured SS 316L Sample Using Laser Ultrasonics** Alexander Martinez-Marchese, Ehsan Toyserkani *University of Waterloo, Canada*
3:40pm	**EXHIBITION VIEWING**	

HI-AM CONFERENCE 2020 PROGRAM SCHEDULE

DAY 2 – June 26, 2020

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

	SESSION 12: Novel AM Processes and Products III	SESSION 13: Advanced Process Modeling III
4:00pm	**Presentation 51 - Featured Talk: New Electron Beam Powder Bed Fusion System with Open Source Software, Tailored for Research and Development** Ulf Ackelid, Ulric Ljungblad *Freemelt AB, Sweden*	**Presentation 56 - Featured Talk: Multi-Scale Modeling of Distortion in Powder Bed Fusion** Michael Gouge, Pan Michaleris, Erik Denlinger, Jeff Irwin, Charles Li *Autodesk, Canada*
4:20pm	**Presentation 52: Fused Filament Fabrication of Metal Matrix Composites (MMC)** Nancy Bhardwaj*, Hani Henein*, Tonya Wolfe** **University of Alberta, Canada* ***InnoTech Alberta, Canada*	**Presentation 57: Abrasive Flow Machining of Laser Powder Bed Printed Components: Modeling versus Experiment** Mykhailo Samoilenko, Vladimir Brailovski *École de technologie supérieure Montreal, Canada*
4:40pm	**Presentation 53: Embedding Optical Sensors in Additively Manufactured Parts for Enhanced Functionality** Kelvin Son, Farid Ahmed, Ehsan Toyserkani *University of Waterloo, Canada*	**Presentation 58: Efficient Thermo-mechanical Finite Element Model for Simulating Selective Laser Melting Process in Part Level** Zhibo Luo, Yaoyao Zhao *McGill University, Canada*
5:00pm	**Presentation 54: Design, Optimization, and Validation of a Magnetic Levitation System for Additive Manufacturing** Parichit Kumar, Ehsan Toyserkani, Behrad Khamesee *University of Waterloo, Canada*	
5:20pm	**Presentation 55: Metallic Cellular Hip Implant with Functionally Graded Density** Elham Davoodi*,**, Reza Esmaeilizadeh*, Hossein Montazerian**, Ehsan Toyserkani* **University of Waterloo, Canada* ***University of California Los Angeles, United States*	
5:40pm	**CLOSING REMARKS**	

Poster Presentation Gallery

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

POSTER SESSION 1: June 25 | 12:20pm – 2:00pm

THEME 1: MATERIAL DEVELOPMENT

Poster 1: Additive Manufacturing of High Concentration Yttria-stabilized Zirconia Using High-Speed Drop-on-Demand Material Jetting
Haniyeh (Ramona) Fayazfar, Usman Ali, Ehsan Toyserkani
University of Waterloo, Canada

Poster 2: Primary Si Modification via Rapid Solidification and Alloying
Daniela Diaz, Abdoul-Aziz Bogno, Hani Henein
University of Alberta, Canada

Poster 3: The Microstructure, Morphology and Mechanical Properties of Rapidly Solidified Al-10wt%Si-0.4wt%Sc Alloy
Akankshya Sahoo, Abdoul-Aziz Bogno, Hani Henein
University of Alberta, Canada

CANCELED Poster 4: Heterogeneous Micromechanical Properties of Dual-phase Titanium Alloy Made by Additive Manufacturing
Zhiying Liu, Yu Zou
University of Toronto, Canada

Poster 5: An Investigation on the Tensile and Fatigue Behaviour of Laser Powder-bed Fusion Hastelloy X
Reza Esmaeilizadeh*, Ali Keshavarzkermani*, Hamid Jahed*, Ali Bonakdar**, Ehsan Toysekani*
**University of Waterloo, Canada | **Siemens, Canada*

Poster 6: Surface Finishing of Laser Powder Bed Fusion Alloys via Chemical and Electrochemical Polishing
Haniyeh Fayazfar, Issa Rishmawi, Mihaela Vlasea
University of Waterloo, Canada

Poster 7: Development of Novel Water-atomized Tool Steel Powders for Laser Powder Bed (LPB) and Direct Energy Deposition (DED)
Denis Mutel, Carl Blais
Universite Laval, Canada

Poster 8: Geometry and Surface Characterization of Additively Manufactured H13 Hot-Work Tool Steel Using Directed Energy Deposition
Owen Craig*, Kevin Plucknett*, Alexandre Bois-Brochu**
**Dalhousie University, Canada | **Centre de métallurgie du Québec, Canada*

Poster 9: Production, Characterization and Performance Evaluation of Cardanol Acetate in Alkyd Paints
Iheoma Nwuzor, Christopher Idumah, Paul Okolie, Obumneme Ezeani
Nnamdi Azikiwe University, Nigeria

CANCELED Poster 10: Development of a New Aluminum Metal Matrix Composite Using Response Surface Methodology
Raphael Ebhojiaye*, Akii Ibhadode**
**University of Benin, Nigeria | **Federal University of Petroleum Resources, Nigeria*

Poster 11: Effect of Heat Treatment on High Temperature Mechanical Properties of Rene 41 Alloy Fabricated by LPBF
Sila Atabay*, Kevin Plucknett**, Mathieu Brochu*
**McGill University, Canada | **Dalhousie University, Canada*

Poster 12: Development of Al-Zr-Y Alloys for Laser Powder Bed Fusion
Jon Hierlihy*, Ian Donaldson**, Mathiew Brochu***, Donald Paul Bishop*
**Dalhousie University | **GKN | ***McGill University*

THEME 1 - MATERIAL DEVELOPMENT

Poster 13: Comparing Mechanical Properties and Microstructure of Laser Powder Bed-fused Components Made from Maraging Stainless Steel to its Wrought Analogue
William Turnier Trottier, Alena Kreitcberg, Vladimir Brailovski
École de technologie supérieure Montreal, Canada

Poster 14: On the Tensile Property Evaluation of Additively Manufactured Ti-5553 Alloy
Nivas Ramachandiran, Hamed Asgari, Paola Russo, Chinedu Francis Dibia, Adrian Gerlich, Ehsan Toyserkani
University of Waterloo, Canada

Poster 15: Optimization of Chemical Composition of Al Alloys via Rapid Solidification in Additive Manufacturing
An Fu*, Mathieu Brochu*, Donald Paul Bishop**, Pierre Hudon*
**McGill University, Canada | **Dalhousie University, Canada*

THEME 2 - ADVANCED PROCESS MODELING

Poster 16: A Novel Post-Topology Optimization Process for Overhang Elimination in Additive Manufacturing
Osezua Ibhadode, Ehsan Toyserkani
University of Waterloo, Canada

Poster 17: Comparison of Volumetric Heat Sources in the Thermomechanical Modeling of the Laser Powder-bed Fusion Additive Manufacturing
Zhidong Zhang*, Ali Bonakdar**, Ehsan Toyserkani*
**University of Waterloo, Canada | **Siemens, Canada*

Poster 18: Machine Learning Applications in Laser Powder Bed Fusion Processes
Gijs van Houtum, Mihaela Vlasea
University of Waterloo, Canada

Poster 19: Numerical Model of Al-33wt%Cu Eutectic Growth During Impulse Atomization
Jonas Valloton, Abdoul-Aziz Bogno, Hani Henein
University of Alberta, Canada

Poster 20: Analytical Modeling of Transient Temperature in Laser Directed Energy Deposition of Ti5553
Mazyar Ansari, Mobin Khamooshi, Alexander Martinez Marchese, Ehsan Toyserkani
University of Waterloo

CANCELED Poster 21: Statistical Analysis for Improving Decisions of Industrial Internet of Things' Devices in Metal Additive Manufacturing
Basel Alsayyed, Mohammed Alghamdy
University of Alberta, Canada

Poster 22: Characterizing the Effect of Surface Roughness on Tensile Behavior of SS316L Micro-struts Fabricated by Laser Powder Bed Fusion
Abhi Ghosh, Amit Kumar, Mathieu Brochu
McGill University, Canada

Poster 23: Influence of Thickness of Coating on Adherence of 316L and Cu Coatings Deposited by Cold Gas Spraying
Rodolpho Vaz, Alessio Silvello, Javier Sánchez, Irene Garcia Cano, Sergi Dosta
Federal University of Paraná, Brazil

Poster Presentation Gallery

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

POSTER SESSION 1: June 25 | 12:20pm – 2:00pm

THEME 2 - ADVANCED PROCESS MODELING

Poster 24: Spheroidization of Al-33Cu Droplets Microstructure
Quentin Champdoizeau, Hani Henein
University of Alberta, Canada

Poster 25: Thermo-mechanical Modeling of Laser Powder Bed Fusion of Ti-6Al-4V
Pegah pourabdollah, Steven Cockcroft, Daan Maijer, Farzaneh Farhangmehr
The University of British Columbia, Canada

Poster 26: Finite Element Modelling of Residual Stresses and Metallurgical Phases for 4140 Steel
Shaun Cooke*, Keivan Ahmadi*, Rodney Herring*, Greg Sweet**, Donald Paul Bishop**
**University of Victoria, Canada | **Dalhousie University, Canada*

Poster 27: Thermal Fluid Modelling of Melt Pool Dynamics in the Electron Beam Additive Manufacturing of Ti6Al4V
Eiko Nishimura, Steve Cockcroft, Daan Maijer, Farzaneh Farhang-Mehr
The University of British Columbia, Canada

Poster 28: Meso-scale Modelling of Strain Evolution in Powder-Bed Electron Beam Additive Manufacturing
Asmita Chakraborty, Farzaneh Farhang Mehr, Daan Maijer, Steve Cockcroft
The University of British Columbia, Canada

POSTER SESSION 2: June 26 | 12:20pm – 2:00pm

THEME 3 - PROCESS MONITORING AND CONTROL

Poster 29: Development of Analytical Model for Eddy Current Applicable to Additive Manufacturing
Heba Farag, Ehsan Toyserkani, Behrad Khamesee
University of Waterloo, Canada

Poster 30: In-line Optical Measurement System for 3D Process Monitoring of a Fused Filament Fabrication (FFF) Printer
Kristof Briele, Dominik wolfschlaeger, Max Ellerich
RWTH Aachen University, Germany

Poster 31: Improving the Geometric Accuracy of Additive Manufactured Parts via 3D Metrology Feedback and CAD Morphing
Moustapha Jadayel, Farbod Khameneifar
Polytechnique Montréal, Canada

THEME 4 - NOVEL AM PROCESSES AND PRODUCTS

Poster 32: Distributed Residual Strain Measurement in Additively Manufactured Stainless Steel Cantilever using Fiber Optic Sensors
Farid Ahmed, Ehsan Marzbanrad, Ehsan Toyserkani
University of Waterloo, Canada

Poster 33: Microstructure and Hardness of 34CrNiMo6 Steel Fabricated by Solid-State Additive Manufacturing
Mohammad Hossein Sakhaei, Aziz Shafiei-Zarghani, Ali Zamani
Shiraz University, Iran

POSTER SESSION 2: June 26 | 12:20pm – 2:00pm

THEME 4 - NOVEL AM PROCESSES AND PRODUCTS

Poster 34: In-situ Volume Reconstruction for Additive Manufacturing Repairs: A Review
Remy Samson, Thomas Lehmann, Hani Henien, Ahmed Jawad Qureshi
University of Alberta, Canada

Poster 35: A Surface Roughness Constraint for Topology Optimization
Ken Nsiempba, Osezua Obehi Ibhadode, Ehsan Toyserkani
University of Waterloo, Canada

Poster 36: Manufacturing of 3D Lattice Structures by Hybrid Investment Casting
Abdoul-Aziz Bogno, Mubashir Chand Tamboli, Ahmed Jawad Qureshi, Hani Henein
University of Alberta, Canada

CANCELED Poster 37: Mechanical performance of Additively Manufactured Aluminium Auxetic Structures
Manpreet Singh, Arun Arjunan
University of Wolverhampton, United Kingdom

Poster 38: Geometric Consideration of Support Structures Design for Overhang Features of Dental Implants Fabricated by Selective Laser Melting
Arman Khobzi*, Swee Leong Sing**, Wai Yee Yeong**, Steven Cockcroft*, Daan Maijer*, Farzaneh Farhang-Mehr*
**The University of British Columbia, Canada | **Nanyang Technological University, Singapore*

Poster 39: Novel Limb Sparing Technique Using 3D-Printed Patient-Specific Endoprostheses for Tumor of the Proximal Humerus
Martin Tran Hoai Tri Thien*, Anatolie Timercan**, Bertrand Lussier***, Bernard Seguin^, Yvan Petit**, Vladimir Brailovski**
**École Centrale Paris, France | **École de technologie supérieure Montreal, Canada | ***Université de Montréal, Canada | ^Colorado State University, United States*

Poster 40: Topology Optimization of Imperfect Lattice Materials Built with Process-induced Defects via Powder Bed Fusion
Ahmed Moussa, David Melancon, Asma El Elmi, Damiano Pasini
McGill University, Canada

Poster 41: Effects of Process Parameters on Material Characteristics During Direct Energy Deposition of AISI D2 Tool Steel
Samer Omar, Kevin Plucknett
Dalhousie University, Canada

Poster 42: Cellular Structures for Application in Intervertebral Devices: Functional Requirements and Preliminary Results
Anatolie Timercan, Vadim Sheremetyev, Vladimir Brailovski
École de technologie supérieure Montreal, Canada

Poster 43: Effect of Different Production Technologies on the Miscibility of Fe-Cu and Cr-Mo
Rabia Aftab, Maksim Antonov
Tallinn University of Technology, Estonia

Poster 44: Effect of Process Parameters on Plasma Transferred Arc Additive Manufactured (PTA-AM) 17-4PH using the Taguchi Method
Sandy Ibrahim*, Jose G. Mercado Rojas*, Tonya Wolfe**, Hani Henein*, Ahmed Qureshi*
**University of Alberta, Canada | **InnoTech Alberta, Canada*

Abstracts

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

ONLINE CONFERENCE PROGRAM

Keynotes

SESSION 1: Metal Additive Manufacturing
June 25 | 9:40am – 12:20pm EDT

Keynote 1 | 9:40am

AP&C Plasma Atomized Powders Optimized for Additive Manufacturing, Innovation and Challenges

Javier Arreguin
Senior Material Project Manager
AP&C - A GE Additive Company, Montreal, Canada

Abstract: Metals Additive manufacturing (AM) is an accelerated growing technology that rapidly increase the need for feedstock options and more performant for AM needs. Controlling the quality and characteristics of powders as feedstock and potential relationship between powder properties and service properties of parts are the main challenges to manufacture parts with uniform microstructure and minimum porosity percentage. AP&C, a GE Additive company is the world leader on metal plasma atomization. The AP&C proprietary technology is optimized to produce powders specially adapted for AM needs, which exhibit high sphericity and exceptional flowability, among other properties. AP&C developed a strong knowledge to reduce particle to particle interaction, producing powders that spread uniformly across the powder bed during the full AM process. Particles morphology, density and physical properties will be discussed. AP&C innovates on technology development being the first and the only one to plasma atomize from a melt. This presentation therefore is to share the extensive experience of AP&C with metallic powders. It will be presented the available aluminum alloys powders optimized specially for AM, their physical properties and the key parameters that influence the AM process and their impact to produce reliable printed parts. In this presentation the plasma atomization technology, their quality control and change management will be also reviewed.

Keynote 2 | 10:20am

Impact of Metal Powders Feedstock on the Properties and Performance of Additively Manufactured Materials

Todd Palmer
Professor of Engineering Science and Mechanics and Materials Science and Engineering
The Pennsylvania State University, PA, United States

Abstract: The Additive Manufacturing (AM) of metallic materials has advanced significantly over the past decade and is demonstrating great promise in driving innovation in advanced manufacturing technologies. Significant challenges still exist, though, in matching the properties and reliability obtained through more traditional material processing routes. In response to several identified knowledge gaps, current research efforts are primarily directed at developing material property databases and tools for sensing and monitoring the complex processing conditions prevalent in laser and electron beam based powder bed fusion (PBF) and directed energy deposition (DED) processes. While these efforts are building a more fundamental understanding of the AM process, significant knowledge gaps still exist in the understanding of how powder feedstock properties, such as starting powder size, morphology, and chemistry, can impact the properties and performance of AM components. The role of chemistry, in particular, has been shown to impact the as deposited and post processed structures and properties of a range of commonly used titanium, nickel, and ferrous based alloys. In many cases, small changes in chemistry in both substitutional and interstitial alloying elements, even within standard accepted composition ranges, have led to new and unique properties. A review of recent work involving common alloy systems used in both PBF and DED processes is provided to show many of the challenges and opportunities available through the exploitation of knowledge of the powder feedstocks and how they can lead to improved performance of existing alloys and the development of vastly improved alloy systems.

Keynote 3 | 11:00am

Process-Aware Design for Additive Manufacturing

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

Abstract: Additive manufacturing (AM) is making a profound impact on the way engineers realize customized parts, but fully realizing the manufacturing freedom afforded by AM requires some significant advances in engineering design methods and tools. For some additive manufacturing applications, simulation-based design tools may be required to explore a hierarchy of features, ranging in size from microns to meters. When these features are fabricated, however, AM systems typically induce significant deviations from intended geometry and mechanical performance. Designers need comprehensive statistical models that characterize this variability. Furthermore, they need design exploration tools that use these models to provide real-time feedback on the constraints and process-structure-property relationships relevant to specific AM technologies, and this Design-for-AM feedback is needed during the design process, rather than at the end. To address these challenges, this presentation describes design exploration approaches that have been established for hierarchical, process-aware design of lattice structures and metamaterials. They make use of statistical characterization of geometric features and size- and orientation-dependent material properties to identify designs that are more robust to process-induced variability.

Keynote 4 | 11:40am

A Short History of Metal AM and Future Needs to Meet Mass Market

Stuart Jackson
Business Development and Key Account Manager
Renishaw, Staffordshire, United Kingdom

Abstract: Starting with a short look back into the origins of Metal AM including key patents that have shaped the early developments. Moving to the present and looking at industry feedback suggesting where Metal AM needs to evolve to meet market demands and to take it from a successful niche technology into the mass market arena.

Oral Presentations

SESSION 2: Material Development I
June 25 | 2:00pm – 3:40pm EDT

2:00pm

Presentation 1: Powder Processing by RF Plasma: Towards a Circular Economy FEATURED TALK

Nicolas Gobeil
Tekna, Canada

Abstract: Selecting metallic powders is a vital consideration in Additive Manufacturing, Metallic powders can be manufactured by many processes, but only a limited number can produce powders specifically designed for meeting the requirements of the various additive manufacturing (AM) technologies. This presentation will review the main techniques used to produce AM powders, namely gas atomization and plasma technologies. We will then focus on AM powder reconditioning by RF plasma, allowing the transformation of out-of-spec recycled AM powders (feedstock) into high quality in-spec powders (end product), thus extending the service life of AM powders.

2:20pm

Presentation 2: Predicting Powder Spreadability with the Granudrum FEATURED TALK

Filip Francqui
GranuTools, Belgium

Abstract: In powder bed fusion processes, successive thin layers of powder are created with a ruler or with a rotating cylinder and partially sintered with an energy beam. The spreadability of the powder, related to its cohesiveness, influence the layer homogeneity and thus the quality of the build parts. Therefore, relating the powder characteristics to its spreadability during the recoating process beforehand should allow to classify and select the optimal powder and recoating speed combinations.

The rotating drum measurement method has been applied to assess the powder spreadability without applying a compressive load during the powder testing what fits with the conditions seen by powder in the AM processes. Four metallic powders (AlSi7Mg06, Scallmaloy®, Inconel®, Inconel® fine) have been investigated. Powders spreadability has been determined with the GranuDrum instrument (GranuTools®), a rotating drum enabling to measure the influence of cohesion and shear-thinning/shear-thickening behavior. Powder bed homogeneity has been quantified with in situ measurements in a SLM printer, where a CCD camera is used to take several snapshots at different recoater speeds. An image analysis algorithm is then applied to determine spatial fluctuations of the layer. A good correlation between spreadability assessments and real performance in the printer has been found.

2:40pm

Presentation 3: Powder Reuse Cycles in Electron Beam Melting and their Effect on Ti-6Al-4V Powder Properties

Gitanjali Shanbhag, Mihaela Luminita Vlasea
University of Waterloo, Canada

Abstract:

A path to lowering the economic barrier, associated with the high cost of metal additively manufactured components, is to reduce the waste via input powder reuse (powder cycled back into the process) and recycling (powder chemically, physically, or thermally processed to acquire original properties) strategies. In EBM, 95 - 98% of the powder that is not melted could be used again after blasting and sieving. However, systematic studies focused on quantifying the effect of reuse on powder performance metrics such as size, rheometry and flowability remain scarce. This study presents results on the influence of the EBM process on Ti-6Al-4V powder, by comparing the properties of virgin powder, reused powders and blends of virgin and reused powders, in order to benchmark the sensitive powder characteristics. Conclusions on the comparative properties of the various powder types will be made based on morphology, size distribution, flowability and rheometry tests.

3:00pm

Presentation 4: Electrostatic Atomisation of Metals

Bilal Bharadia, Abdoul Aziz Bogno, Hani Henein
University of Alberta, Canada

Abstract: The increased demand for metal powders in the additive manufacturing industry requires reliable, economical and efficient methods for producing metal powders with consistent mechanical, chemical and physical properties. This paper reports on electrostatic atomisation, a metal powder production technique based on using electrostatic forces to spray liquid metal into fine droplets. The basic physical parameters have been identified and explored, and the conditions under which electrostatic atomisation is achieved have been determined. Drawing from the principles of electro-hydrodynamics and electrostatics and depending on the different electro-mechanical properties of the liquid metal, an electro-spraying model has been created to better understand the electrostatic forces induced Taylor cone formation, and thus predict the droplet sizes. Preliminary experiments have also been conducted and have shown to produce spherical powders accordingly with the experimental parameters. This study shows promise of an alternative from existing powder production techniques, and a valuable contribution to the development of additive manufacturing.

3:20pm

Presentation 5: Characterization of TZM Alloy Powders and their Laser Powder Bed Fusion Additive Manufacturing Behavior

Tejas Ramakrishnan, Mathieu Brochu
McGill University, Canada

Abstract: Laser powder bed fusion additive manufacturing (LPBF-AM) is an emerging material manufacturing technology that enables the fabrication of complex parts with much ease, beyond the limitations of conventional manufacturing techniques. Various material systems including steels, aluminum, titanium, nickel alloys and some refractory metals have been extensively studied for processing through LPBF-AM. Molybdenum and other refractory alloys are being considered as candidate for high temperature applications in turbine blades for higher efficiency aircraft jet engines and as nuclear reactor components due to their higher melting point, thermal conductivities, high temperature strength and resistance. Limitations in the processing of these alloys through conventional techniques hinders their adoption in the listed applications. LPBF has opened a manufacturing avenue to potentially overcome these hurdles. Studies were conducted to characterize the behavior of TZM alloy under LPBF-AM. Using powder characterization via various techniques, recoating step was optimized. Test constructs were fabricated out next, with the aim of producing high density parts. Microstructural characterization using various techniques will be used to discuss the grain size, morphology and texture.

SESSION 3: Advanced Process Modeling I
June 25 | 2:00pm – 3:40pm EDT

2:00pm

Presentation 6: How Big Data can Improve 3D Printing

FEATURED TALK

François Gingras
Centre de recherche industrielle du Quebec (CRIQ), Canada

Abstract: Additive manufacturing (AM) is becoming more mainstream for prototyping, tooling and production. However, industry has pointed out that there is a clear need to create accessible expertise on “which technology for which application for which AM process/technology/material.” What if the solution could be more than “just” training our engineers and hiring new talents? What if the combination of 3D printing expertise and know-how with another technology could bolster the adoption of AM? Investissement Québec – CRIQ is currently participating in a collaborative project with multiple partners in which the major goal is to combine engineering experience through data-mining and machine-learning methods with advanced analysis concepts to create an AM knowledge base that can assist engineers and business developers with all major AM steps. In this presentation, François Gingras, Director, Technological Development and Support, will explain how the combination of AM and machine learning could change our use of 3D printing.

2:20pm

Presentation 7: Prediction of Defects Based on Beam Path and Melt Pool Morphology Using Machine Learning for Laser Powder Bed Fusion

Deniz Sera Ertay, Shima Kamyab, Mihaela Vlasea, Zohreh Azimifar, Thanh Ma, Allan Rogalsky, Paul Fieguth
University of Waterloo, Canada

Abstract: One of the challenges in Laser Powder Bed Fusion (LPBF) is to manufacture high-density parts. Some of the factors, that can cause low density, are process parameters, powder characteristics, and processing conditions. Furthermore, the scan path plays a significant role in energy density distribution. Hence, its contribution to pore formation is unavoidable. It is observed that the effect of the scan path becomes more significant at path discontinuities as the boundary conditions change. In this study, a pore prediction algorithm is proposed where the effect of the process parameters and the scan path on sub-surface pores is investigated. A synthetic dataset is created for each layer, which combines the melt pool morphology and the scan path. X-ray Computed Tomography (CT) is registered with the synthetic dataset and used as ground truth for the pore predictor. Machine learning models, Conditional Variational AutoEncoder (CVAE) and a Convolutional Neural Network (CNN) are trained to predict pores using the synthetic and the CT datasets. The performance of CNN and CVAE is compared and quantitative results are represented. It is observed that having CT images only in the training phase of CVAE leads the model to superior performance over CNN.

2:40pm

Presentation 8: Development of An Autonomous In-situ Temperature Measurement System and a Heat Transfer Model of the Build Chamber in Electron Beam Additive Manufacturing

Farhad Rahimi*, Farzaneh Farhang-Mehr*, Steve Cockcroft*, Ralf Edinger**, Daan Maijer*
**The University of British Columbia, Canada | **CANMORA Tech Inc., Canada*

Abstract: The temperature in a component being fabricated in an electron beam powder bed additive manufacturing (EB-PBAM) process can directly control the mechanical properties and dimensional accuracy of the final part, thus, temperature monitoring and feedback control during the build process are critical. Acquiring accurate temperature data from the build chamber represents a significant challenge in the operating environment present in the EB-PBAM process – e.g. high vacuum environment/high-voltage electron beam. Therefore, one solution to this issue is to design and develop in-situ monitoring and feedback control apparatus. The other solution is to develop a numerical model that can predict the thermal history of the build chamber and the printed part. The purpose of the present research is to design an autonomous in-situ temperature measurement system (AiTMS) that is capable of working in a high vacuum environment and develop a 3D heat transfer model to predict the thermal history of the build chamber during the process. The benefits of the AiTMS are to provide adequate data to develop efficient computational models while at the same time avoiding the need to make changes to the design and operation of a commercial EB-PBAM machine.

3:00pm

Presentation 9: Control of Density and Microstructure in Laser Powder bed-fused Components Using a Combination of Melt Pool Modeling and Design of Experiment Approaches

Morgan Letenneur, Alena Kreitcberg, Vladimir Brailovski
École de technologie supérieure Montreal, Canada

Abstract: The process of additive manufacturing induces a high uncertainty in the mechanical properties of 3D-printed parts, which constitutes one of the main barriers for a wider AM processes adoption. To address this problem, a new time-efficient density and microstructure prediction algorithm was proposed for the laser powder bed fusion (LPBF) process. Based on the combination of the melt pool modeling with design of experiment approaches, this algorithm was used to predict the density and the microstructure (grain size/aspect ratio) of materials processed by EOS M280 and Trumpf TruPrint1000 LPBF systems, including IN625, TiNbZr, Fe and FeC alloys. This approach was successfully validated using experimental and literature data, thus demonstrating its potential efficiency for the optimization of different LPBF powders and systems. In addition, since the prediction of the microstructure involves along-the-track cooling rate and thermal gradient calculations, this algorithm also provided insights into the risks of hot cracking and distortions during printing with these materials. It was also demonstrated that this approach could easily be adapted for the neural network interpolation, which would further improve the quality and rapidity of calculations.

3:20pm

CANCELED Presentation 10: Role of Impinging Powder Particles on Melt Pool Hydrodynamics, Thermal Behaviour and Microstructure in Laser-Assisted Ded Process: A Particle-Scale DPM – CFD – CA Approach

Akash Aggarwal, Arvind Kumar
Indian Institute of Technology Kanpur, India

Abstract: In this work, we develop a coupled multi-physics particle-scale approach utilizing discrete phase method for particle trajectory prediction, computational fluid dynamics for free-surface thermo-fluidic modelling and cellular automata method for grain growth evolution. In the model, the governing physical phenomena, such as laser-powder interaction, in-flight particle heating, phase change, free-surface evolution, molten pool hydrodynamics and impinging particles-melt interaction have been considered. Experiments for deposition of Inconel-625 on an Inconel-625 substrate are carried out. The simulation results reveal highly oscillatory, chaotic and random melt flow attributed to the impinging powder particles. During the deposition, it is found that the role of the Marangoni convection is less significant as compared to the momentum imparted by the impinging powder particles in the melt pool. Using the thermal undercooling data, cellular automata-based grain growth simulation predicts elongated columnar dendrites in the melt pool that grows epitaxially from the melt pool interface and stretches towards the centre. Using the Kurz-Fisher model, the effect of local thermodynamic solidification conditions on the size of dendritic microstructure is also described. The predicted melt pool geometry, temperature field and grain structure compare well with the experimental measurements.

SESSION 4: Process Monitoring and Control I
June 25 | 4:00pm – 5:40pm EDT

4:00pm

Presentation 11: Tracking and Controlling the Morphology Evolution of 3D Powder-bed Fusion in situ Using Inline Coherent Imaging FEATURED TALK

James Fraser
Queen's University, Canada

Abstract: Selective laser melting, a variant of metal additive manufacturing, has received considerable interest with promise of greater design freedom, material and energy savings, and graded or even unprecedented material properties. Despite this, functional metal components with acceptable properties have only been achieved with costly material, machine and part specific parameter optimization, post-processing and part by part inspection. Even under optimal conditions, the complex phenomena underlying the laser writing process can lead to stochastic and irreproducible outcomes. We exploit inline coherent imaging, a broadband interferometric technique, to monitor topology of spread powder, melt pool, and formed track on a layer-by-layer basis [Kanko, Fleming]. Defects can be detected immediately and corrected with the same laser used for melting (but exploiting different pulse settings). Parallel ongoing efforts include in situ monitoring of laser absorptance during processing to better understand energy coupling into the workpiece [Allen].

Kanko et al., Journal of Materials Processing Technology 231: 488 (2016) https://doi.org/10.1016/j.jmatprotec.2015.12.024

Fleming et al., Additive Manufacturing 32: 100978 (2020) https://doi.org/10.1016/j.addma.2019.100978

Allen et al., Physical Review Applied, accepted (2020)

4:20pm

Presentation 12: Microstructure Evolution and Microscale Mechanical Properties of Dual-Phase Titanium Alloy Made by Additive Manufacturing

Zhiying Liu, Yu Zou
University of Toronto, Canada

Abstract: Thermal treatment is an effective method to improve mechanical property of materials made by additive manufacturing. However, the partitioning of alloying elements during heat treatment, accompanying the $\alpha \leftrightarrow \beta$ phase transformation, determines the local composition of the microstructure, and thus significantly influences the micromechanical properties (e.g., hardness and modulus) of $\alpha+\beta$ titanium alloys. Nanoindentation is a powerful tool for exploring micromechanical properties of alloys involving multiple phases, and hardness and Young's modulus of different phases can be outputted. In this work, dual-phase titanium alloy made by additive manufacturing are annealed, and micromechanical properties of the alloy are measured using high throughput nanoindentation tests. It is shown that α phase is harder than β phase. Interestingly, distribution of hardness and modulus in one specific phase is heterogeneous, also, hardness varies in phases with different morphology. The heterogeneous micromechanical properties are attributed to partitioning and segregation of alloying elements during heat treatment elements, which is demonstrated by elements analysis. Al and Mo are the main elements to determine the mechanical properties. Therefore, the relationship between heat treatment, local microstructure and composition, and micromechanical properties of additive manufactured titanium alloy is finally bridged, which benefits for microstructure/composition optimization.

4:40pm

Presentation 13: Airborne Metal Particle Stream Focusing using an Ultrasound Phased Array and its Application in Powder-fed Directed Energy Deposition

Alexander Martinez-Marchese, Mazyar Ansari, Marc Wang, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: One of the issues in the powder-fed directed energy deposition (DED) process is the powder stream deviation causing low catchment efficiency, which is the fraction of all particles that reach the melt pool. Experiments and numerical modeling of a new method, based an ultrasound phased array, were performed to acoustically focus Ti64 particles with an average particle size of 80 microns and speed of 0.58 m/s. The method uses an ultrasound phased array to produce a small volume of high-intensity ultrasound with the needed period averaged sound intensity profile. This novel setup offers a better controllability over the powder stream profile to effectively focus the metal powder stream during the powder-fed DED process. This will in turn improve the feature resolution and catchment efficiency as well as provide other possible DED control applications.

5:00pm

Presentation 14: Real-Time Simultaneous Microstructure and Geometry Monitoring of Laser Materials Processing

Lucas Botelho, Amir Khajepour
University of Waterloo, Canada

Abstract: In this research, a concentric camera system is discussed to monitor the thermal properties and geometry of Laser Materials Processing (LMP). To monitor all the relevant information during LMP a thermal and vision camera are both implemented. The thermal camera monitors the peak temperature, heating rate, and cooling rate to arrive at the microstructure properties of the deposition while the vision camera is used to monitor the geometry, which is necessary to determine the cladded material's height during Laser Additive Manufacturing (LAM). A concentric camera system consists of both the thermal and vision camera integrated within the same housing with the optics designed in such a way that both cameras capture the same field of view. There are several benefits to this type of system including: (1) the compact size allows the concentric cameras to be easily retrofitted to LMP systems. (2) Sharing the field of view allows the information from both cameras to be compared directly. (3) Allowing for the careful design of the optics for both cameras, which is usually limited by the availability of infra-red optical components. This system can be used not only for the process monitoring but for the closed-loop control of laser materials processing.

5:20pm

Presentation 15: A Holistic Approach for Quality Control in Metal Additive Manufacturing

Mohammed Alghamdy, Basel Alsayyed, Rafiq Ahmad
University of Alberta, Canada

Abstract: Quality issues in Metal Additive Manufacturing (MAM) can be attributed to many factors such as design requirements/specifications, process parameters, and/or material-specific behavior. Microstructure analysis of common materials used in MAM have been well established driven by application-specific products. On the other hand, optimization of design tools and standards remains a challenge in MAM. In the same manner, process parameters create uncertainties along the part creation process. statistical models allow early prediction of assigned to a given MAM process. Real-time monitoring further ensures quality in processing stage. The present holistic approach utilizes quality control methods to link the three levels as: design, process and, material selection aiming at improving reliability and ensuring optimum quality in MAM production lines.

Keywords: Quality Control, Metal Additive Manufacturing, Statistical Analysis, Reliability.

SESSION 5: Novel AM Processes and Products I
June 25 | 4:00pm – 5:40pm EDT

4:00pm

Presentation 16: 3D Printed Smart Molds for Sand Casting
FEATURED TALK

Eric MacDonald*, Jerry Thiel**
**Youngstown State University, United States | **University of Northern Iowa, United States*

Abstract: Additive manufacturing is transforming sand casting by enabling the fabrication of complex molds and cores. Lattice structures, consolidated structures, and customized, low-volume, high-value castings are now possible. However, the enabled design freedom complicates the thermodynamics and metallurgy given the complex geometries. One previously unleveraged benefit of sand printing includes the introduction of unique mold cavities specifically for embedding wireless sensors (Internet of Things) deep within molds and cores. This presentation describes

proof-of-concept trials in which 3D printed molds and cores have been instrumented with disposable wireless sensors to monitor temperature, humidity, vibration, rotation, and the presence of metal in specific mold cavities. By collecting process data from remote locations deep within a mold in an unprecedented manner, the quality and yield can be improved.

4:20pm

Presentation 17: Thermo-mechanical Modelling of Electron Beam Additive Manufacturing Process for Repair and Remanufacturing Purposes

Fatih Sikan*, Priti Wanjara**, Javad Gholipour**, Mathieu brochu*
**McGill University, Canada | **National Research Council, Canada*

Abstract: The objective of this research was to develop a repair methodology using electron beam additive manufacturing (EBAM) for Ti-6Al-4V to highlight critical factors affecting repair integrity and efficiency. The research included development and validation of a finite element model to predict the repair conditions and process parameters. The developed model could be utilized to minimize residual stresses and distortion on the substrate through repair planning. Within the scope of this study, challenges, such as understanding the importance of thermo-physical material properties, along with metallurgical phenomenon and effects of fixturing strategies on the development of residual stresses were examined. Microstructural and mechanical property characterization of the repaired parts was undertaken to allow comprehensive understanding of the inter-relationships between the process, structure and performance.

4:40pm

Presentation 18: Laser DED Cladding of Dip-Coated TiC-Ni3Al Cermets on D2 Tool Steel

Zhila Russell, Kevin Plucknett, Gianfranco Mazzanti
Dalhousie University, Canada

Abstract: D2 tool steel is widely used in applications such as forming dies, due to its high wear resistance and strength. To further extend die life, improvements are being sought by incorporating laser deposited coatings. This study investigates the use of laser direct energy deposition (DED) for applying TiC-based cermet coatings onto D2 substrates. The cermet composition is applied by dip coating the steel substrate into a suspension of TiC-NixAly-Ni, prior to laser cladding. The rheological behavior of the suspensions has been examined at 40 to 70 wt.% solid contents. Process optimization gives well-adhered, pre-placed feed stock material on the surface of the substrate, with a uniform thickness. After drying, the pre-placed film was subjected to laser DED processing using various laser powers and scanning speeds. Microstructural and mechanical characterisation of single and multi-track clad layers were subsequently undertaken. The clad surface was analyzed by confocal laser scanning microscopy, scanning electron microscopy and energy dispersive X-ray spectroscopy, to assess the elemental distribution and the morphologies of the interface and phases formed. It is anticipated that preliminary wear (scratch testing) and corrosion behaviour of the coated surfaces will also be reported.

5:00pm

Presentation 19: Dynamic Mechanical Loading Characterization of an AM-Based Flexible Sensor

Jeffrey Sixt, Elham Davoodi, Armaghan Salehian, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: The field of wearable sensors presents opportunities for enhancement of robotics, prosthetics, and consumer products. An important characteristic of effective wearable sensors is geometry customizability. Additive Manufacturing (AM) techniques allow for flexible design of complex geometries, such that wearable sensors may be customized for different end-users, applications, and sensing locations. As well, high strain rate detection is necessary for many wearable sensor applications (e.g. for heart pulse sensing or slip detection of a hand/gripper). This work presents the mechanical dynamic characterization of a highly-flexible silicone rubber piezoresistive sensor. The sensor is created using a dip-coating and casting process with a 3D printed mould, employing graphene nanoplatelets as the conduction medium. Vibration tests are performed by fixing one sensor end while subjecting the other end to a shaker base excitation. The characterization focuses on 10-100 Hz sensor vibrations at uniaxial strain rates up to 282 mm/s. For these parameters, the relationship between sensor gauge factor and mechanical strain input is examined. Results are presented in the time domain for multiple sensors. Additional observations are made concerning sensor durability from cyclic loading. The AM-based design flexibility presents the opportunity for further sensor iterations targeting specific wearable vibration-sensing applications.

5:20pm

CANCELED **Presentation 20: An Overview of Wire-Arc Additive Manufacturing and an Outlook of its Application Potentials**

Sheng-Hui Wang*, Stefano Chiovelli**
**National Research Council, Canada | **Syncrude, Canada*

Abstract: As compared to laser- and electron beam-based metal additive manufacturing processes, wire-arc additive manufacturing (WAAM) engages cost-effective arc welding equipment, capable of fabricating large parts with high deposition rates; relatively, however, dimensional accuracy and surface finishing as well as the resultant material performance can be inferior. In this talk, current status of WAAM is overviewed, and its application potentials are shortly discussed especially from the perspective of resource sector. Briefly mentioned are also initial R&D efforts in exploring WAAW at the National Research Council of Canada, currently undertaken in collaboration with Syncrude Canada Limited and the University of British Columbia.

SESSION 6: Process Monitoring and Control II
June 26 | 8:40am – 10:20am EDT

8:40am

Presentation 21: Exploring Force Feedback During Powder Spreading for Binder Jetting Additive Manufacturing

Alexander Groen, Mihaela Vlasea, Kaan Erkorkmaz
University of Waterloo, Canada

Abstract: Additive manufacturing is gaining popularity in industry due to perceived cost savings, but many issues with reliability still exist. Binder jetting is one of the additive processes where parts are consolidated in a powder bed via an aqueous binder in a layer by layer manner before sintering to solidify. It has been observed that powder spreading can have a significant effect on the part density and eventual quality. A possible strategy for improving the bed quality is to impart a compaction force during the spreading, with contributing parameters being spreading speed and roller speed. Current powder spreading systems work without feedback and instead typically use a single parameter set for entire prints; consequently, trial and error is required to determine suitable parameters. This is a major deterrent for industry and contributes to technology adoption barriers. In this work, pressure monitoring of the build bed is proposed via capacitive force sensors in the 4.5lb and 45lb range. This will allow for the spreading system to monitor the compacting pressure and detect defects such as powder depletion or inconsistency, which can lead to unnecessary print failures. This work seeks to relate force on the build bed to spreading quality for in-situ monitoring.

9:00am

Presentation 22: A Novel Spatter Detection Algorithm for Real-time Quality Control of Laser Directed Energy Deposition

Farzaneh Kaji*,**, Mazyar Ansari*, Mark Zimny**, Ehsan Toyserkani*
**University of Waterloo, Canada | **Promation, Canada*

Abstract: Real-time monitoring of laser directed energy deposition (LDED) process has increasingly gained importance lately. The spatters created during the power-fed LDED process have essential information that could be correlated to the part quality. In this research, a novel real-time image-processing algorithm is implemented to detect the spatters using high dynamic range (HDR) camera, which has an advantage of higher pixel depth that is preferred in monitoring of the fusion processes. A shape similarity and frame comparison algorithms are used to detect the spatters and the spatters' velocity. Area, average gray-value and centroid position of the spatters are extracted from the image and are used to find the efficiency of process. These parameters were compared to the melt-pool features such as width and height to find the relationship between the deposition quality and the spatter parameters. This study tries to improve the quality of LDED made parts through the development of an artificial intelligence algorithm correlating the spatters density and part quality, where the visual detection and image processing can quantify the spatters and their features.

9:20am

Presentation 23: Application of Machine Learning to Predict the Density of Binder-jet 3D Printed Parts

Somayeh Hosseini Rad, David Schlachter, Sergio Yanez Sanchez , Alice Goffin, Martin Lennox, Basil Favis, Daniel Therriault, Jason Tavares
Polytechnique Montréal, Canada

Abstract: Binder-jet 3D printing is a promising method to produce complicated and highly detailed design. The mechanical properties of the printed and sintered parts are dominated by many process parameters such as feedstock material properties, printing parameters and post-processing conditions. However, finding the relationship between all processing parameters and the target final properties is challenging due to the extensive experimental characterization required. Machine learning is an emerging method to capture the underlying nonlinear relationships between processing conditions as inputs and estimate the properties as an output based on primary data. In this work, we applied a Random Forest (RF) machine learning model to predict the density of metallic additive manufactured parts, as a function of printing and post-processing parameters. We trained the RF model by 70% of our 500 sets of experiments, while the other 30% were used to evaluate the model accuracy. The simulation results reveal that the mean absolute prediction error and coefficient of determination magnified by the RF model are 15.5% and 0.711, respectively, which confirm the adequacy of the RF model. This combination of binder-jet 3D printing and machine learning has demonstrated a great potential for optimization of process parameter and properties of additively manufactured parts.

9:40am

Presentation 24: Moving Towards the Development of an Artificial-based Defect-detection Model through the Photodiodes Signals Collected from the Melt Pool of Laser Powder-bed Fusion

Katayoon Taherkhani*, Esmat Sheydaeian Arani**, Ehsan Toyserkani*, Martin Otto***, Christopher Eischer***
**University of Waterloo, Canada | **Bundesanstalt für Materialforschung und –prüfung (BAM), Germany | ***EOS, Germany*

Abstract: The advancement of additive manufacturing (AM) has been playing a transformational role in metal manufacturing. For many years, AM has been known to address "economies of scope" in which customization, prototyping and low volume manufacturing have been the main foci. However, in recent years, AM has positioned itself to deploy for "economies of scale", i.e., mass production, without compromising the economies of scope. This promotion from prototyping to a series and mass production platform has opened up many R&D opportunities. Like all conventional techniques, quality assurance procedures/tools (either online or offline) are of the utmost importance to aid manufacturers in quality management and certification when it comes to serial production.

This research aims to investigate the feasibility of applying in-situ monitoring for laser powder bed fusion (LPBF) to detect disturbances in the melt pool and obtain correlations with physical defects created in the parts. To this end, a set of experiments has been devised to assess the role of defects, artificially incorporated into the parts, on the melt pool characteristics such as instability in the emitted light. The variations in the emitted light have been recorded by the commercially available EOSTATE Meltpool monitoring system, including two photodiodes

10:00am

Presentation 25: A Novel Testing Bench for the Assessment of Metal Powder Spreading Behavior

Salah Eddine Brika, Vladimir Brailovski
École de technologie supérieure Montreal, Canada

Abstract: The laser powder bed fusion process (LPBF) is sensitive to powder feedstock variations, yet the link between the powder properties and the process performances is still not well established, thus complicating the process development and powder selection and quality control. An accurate assessment of the powder characteristics and a deep understanding of its behavior during recoating is important. Such an evaluation involves, in particular, the characterization of the flow properties and the packing density of the powder, which are not inherent properties but rather dependent on the applied conditions in a given application. While different standards and methods exist to quantify the powder flowability and density, there is presently no equipment available to test the powder under conditions replicating the LPBF recoating process. Therefore, a novel testing bench, which tends to reproduce the LPBF powder spreading procedure, is developed, allowing the evaluation of the powder bed density, spreading forces, and surface uniformity as functions of the powder size and shape distributions, layer thickness, recoating blade type and speed. Such an equipment could be used for the research and development purposes as well as a quality control tool.

SESSION 7: Novel AM Processes and Products II
June 26 | 8:40am – 10:20am EDT

8:40am

Presentation 26: Performance of Affordable Metal Additive Manufacturing FEATURED TALK

Jonathon Hollahan
Xact Metal, United States

Abstract: One of the largest barriers to widespread adoption of metal additive manufacturing is the high cost of metal 3D printing equipment. Xact Metal is working to increase and accelerate the adoption of laser powder bed fusion (LPBF) metal 3D printing, while maintaining a high level of performance that is competitive with higher-priced solutions. Xact Metal's flagship product, the XM200C, has achieved this goal– producing parts of excellent quality, while maintaining a low price point. This has been achieved primarily by using the Xact CoreTM technology at the heart of the XM200C. The Xact Core replaces the galvanometer scanner system found in traditional LPBF metal 3D printers with a linear x-y gantry architecture, significantly reducing the cost and complexity of the system. The quality of parts produced has been determined by a variety of testing methods, which are explored in detail.

9:00am

Presentation 27: 3D Printed Sustainable Architected Cellular Composites

Hamid Akbarzadeh, Ehsan Estakhrianhaghighi, Armin Mirabolghasemi, Yingnan Zhang, Larry Lessard
McGill University, Canada

Abstract: Sustainability of our material supplies used in industrial sectors is among the major goals of United Nation development program to reduce the environmental footprints. To achieve these goals, bio-based composites made of sustainable materials are considered as a green alternative for replacing petroleum-based plastics. There are also important concerns over the prospect of environmental pollution caused by consumption of fossil fuels. This is a main reason why weight reduction is one of the major design criteria in industrial sectors, to increase energy efficiency and decrease fossil fuel consumption. Developing novel strategies for transforming waste materials into value-added, environmentally-benign, and structurally durable advanced martials is a turning point in advanced material community. As a renewable resource of cellulose, wood chips are transformed in this study to reinforce bio-based thermoplastic filaments for fused deposition modeling (FDM). A new methodology is developed for adding wood-fibers to polylactic acid (PLA) biopolymers to produce wood-fiber reinforced PLA filaments to 3D print high-performance composites. We show that using wood-fiber reinforced composites for FDM 3D printing of architected cellular solids is a promising approach to not only program the material properties of biopolymers but to also offer a new class of lightweight sustainable structural materials.

9:20am

Presentation 28: Machine Learning Aided Design of Conformal Porous Structure

Zhenyang Gao, Yaoyao Fiona Zhao
McGill University, Canada

Abstract: The porous cooling system has been proved to have significant advantages over traditional 2D conformal cooling channels due to its rapid and uniform cooling performance during the injection molding process. The conformal porous structures (CPS) have been proven to have even more uniform cooling performance compared to conventional porous systems. However, the temperature variance problem due to the unevenly distributed part thickness values remains unsolved, and there is a lack of optimization efforts on developing an optimal CPS structure with varying cooling cell sizes to achieve better cooling performances. Thus, a machine learning aided design and optimization of CPS is proposed in this work to solve the temperature variance problem. The results indicate that the machine learning aided CPS is able to achieve a 76% reduced temperature variance comparing to conventional CPS.

9:40am

Presentation 29: Additive Manufacturing of FGM Parts Using PTA

Geoffrey Bonias, Hani Henein
University of Alberta, Canada

Abstract: The mining and oil and gas sector currently bears heavy maintenance costs due to wear and abrasion. Functionally graded AM printed parts wear resistance and in-service time is expected to be higher than for coated parts, and their use would allow for significant savings for this industry. A strategy must be developed for the printing process that includes the compositional gradient profile, and an adaptive evolution of the process parameters as the composition changes layer by layer. The materials investigated are the tungsten carbide reinforced NiCrBSi metal matrix composite progressively replacing the stainless-steel substrate as the deposition advances. One of the critical issues this strategy must address are the residual stresses developed after thermal shrinkages. The MMC will tend to shrink less than the stainless-steel due to the presence of the tungsten carbide component, and each layer will therefore behave differently in this regard. The quality of bonding between each layer, and the phases and microstructure developed are an equally important concern for defining this strategy. Models and their experimental supports are therefore designed in order to address these issues in the process of optimizing the compositional gradient.

10:00am

Presentation 30: Functionally Graded Lattice Optimization based on Homogenization and its Application to Dynamic Problems

Ugur Simsek*, Cemal Efe Gayir*, Nezih Sunman**, Aykan Akbulut**, Cansu Basaran**, Polat Sendur**
**General Electric | **Özyeğin University, Turkey*

Abstract: Advances in Additive Manufacturing (AM) technologies have made recently the fabrication of lattice structures possible. Among these, functionally graded lattice (FGLs) structures obtained by topology optimization (TO) stand out owing to their extraordinary traits in energy absorption, heat transfer and high stiffness to weight ratio. In this paper, a new design for additive manufacturing (DfAM) technique of FGL structures is proposed based on an integrated TO strategy. As a first step, a new material penalization formula obtained using homogenization-based material model is implemented into solid isotropic material with penalization (SIMP) algorithm allowing for the direct mapping of TO relative densities. Unlike standard techniques where the optimized results are modified prior to TPMS unit cell conversions, the direct integration of the homogenized formula prevents post-processing associated performance deterioration. In the second step, resulting element densities extracted from TO analysis, are mapped with trilinear interpolation in order to construct FGL geometries in an efficient and robust manner. The robustness and effectiveness of the approach is demonstrated for the design of a cantilever beam to achieve a desired bandgap response and validated by modal testing.

SESSION 8: Advanced Process Modeling II
June 26 | 10:40am – 12:20pm EDT

10:40am

Presentation 31: The Effect of Part Geometries on Melt Pool Dimensions in Laser Powder Bed Fusion Process (LPBF)

Shahriar Imani Shahabad*, Usman Ali*, Zhidong Zhang*, Ali Keshavarzkermani*, Reza Esmaeilizadeh*, Ali Bonakdar**, Ehsan Toyserkani**
**University of Waterloo, Canada | **Siemens, Canada*

Abstract: Laser Powder Bed Fusion (LPBF) is currently dominating the industry market for producing complex geometries cost-efficiently. However, the process is really sophisticated which needs a thorough investigation of the complex phenomenon happening during the building process. Simulation and modeling of the melt pool during the process enables us to predict the microstructure behavior and estimating the quality of the final part. On the other hand, the geometry of the parts has a significant effect on melt pool geometries. In this paper, different parts (wall) with different thicknesses are printed in order to study the effect of wall thickness on melt pool geometries. Results showed that a thinner wall thickness increases the melt pool dimensions due to the heat accumulation.

11:00am

Presentation 32: Design for Additive Manufacturing: A Multiphysics Topology Optimization Model for Conceptual Structural Designs under Practical Loads and Boundary Conditions

Osezua Ibhadode*, Pouyan Rahnama*, Zhidong Zhang*, Ali Bonakdar**, Ehsan Toyserkani*
**University of Waterloo, Canada | **Siemens, Canada*

Abstract: To obtain optimal structural designs for additive manufacturing irrespective of complex multiphysics scenarios, topology optimization can be developed to handle a variety of load cases/conditions such as temperature, pressure, body/inertia, centrifugal forces, and even fluid flow. Although some related studies have attempted to model for these phenomena, practical load and boundary conditions are rarely used. This study presents a minimum compliance topology optimization model for structures under realistic thermal, pressure and centrifugal loads. Due to the high nonlinear and non-monotonic behavior of this form of structural optimization, convergence is difficult to attain and a global optimum is not guaranteed. In an attempt to tackle these problems, we propose some weighted parameters in the objective function that are functions of the model sensitivities. In addition, we select proper material interpolation schemes and gradient-based optimizers.

11:20am

Presentation 33: Machine Learning Assisted Manufacturability Prediction for Laser-based Powder Bed Fusion

Ying Zhang, Yaoyao Fiona Zhao
McGill University, Canada

Abstract: While Additive Manufacturing (AM) has been widely adapted in both academics and industrials due to its freedoms in the design of highly complex structures, they still impose some challenges on determining the manufacturability of the given design for part fabrication. To avoid printing failure in the Laser-based Powder Bed Fusion (LPBF) process, which is one of the AM processes, predictive analysis of the manufacturability to determine whether the design is printable through the LPBF process is highly needed. In this paper, a machine learning assisted manufacturability prediction is proposed. A volumetric-based Convolutional Neural Network (CNN) for analyzing the design aspects is combined with a Neural Network (NN) model for analyzing the process aspects to make the prediction of the manufacturability of the given design through the LPBF process. The prediction is resulted as first to determine whether the entire part is printable or not, and then if it is not printable, the indication of the potential failure area will be highlighted. The approach is validated in terms of the accuracy and the Intersection over Union (IOU) as the evaluation metrics.

11:40am

Presentation 34: A Framework to Study the Role of Material and Morphology Defects on the Mechanical Performance of Additively Built Lattice Materials

Asma El Elmi*, David Melancon**, Meisam Asgari, Damiano Pasini*
**McGill University, Canada | **Harvard University*

Abstract: Additive manufacturing goes beyond the limitations of conventional manufacturing techniques allowing to manufacture cellular materials with complex architecture and multiscale features. Despite the high precision offered by these techniques, several manufacturing induced defects can be identified. This work investigates the role of four sets of as-manufactured defects: surface, microstructure, solid material property, and lattice morphology. A systematic approach integrating Micro-computed tomography, Atomic Force Microscopy, mechanical testing, defect quantification involving statistical analysis of imperfections, and numerical analysis is performed to generate statistically representative models. The method allows to assess the impact of morphological defects and base material imperfections on the mechanical properties of metallic lattices.

12:00pm

Presentation 35: Investigating the Effect of the Temperature and Stress Fields on the Geometric Tolerances of the Laser Powder Bed Fusion Printed Parts

Baltej Singh Rupal, Marc Secanell, Ahmed Jawad Qureshi
University of Alberta, Canada

Abstract: Laser powder bed fusion (LPBF) is one of the most reliable metal additive manufacturing (AM) processes. It has found applications in areas such as custom biomedical implants and aerospace components, where geometrical precision is an essential requirement. Part deviation and geometric tolerance study for precision AM parts is conducted using standardized Geometric Dimensioning and Tolerancing (GD&T) characteristics. Commercial simulation tools and literature study present methods to predict part deviations using the thermo-mechanical simulations based on the finite element method (FEM).

However, the effect of the temperature and stress fields during the LPBF printing on the GD&T based geometric tolerances is still an open area of research. This article presents the initial results of the investigation conducted on the geometric tolerances of the features to be printed on the LPBF process. To do so, the geometric tolerance results obtained from the thermo-mechanical simulations and the layer-by-layer temperature and stress field analysis is performed. It is followed by a correlation study between the temperature fields and the geometric tolerances. A simple case study is presented to demonstrate the applicability of the procedure. For that, a cylindrical feature is considered, and the correlation of the temperature fields on the cylindricity is shown.

SESSION 9: Material Development II
June 26 | 10:40am – 12:20pm EDT

10:40am

Presentation 36: Binder Jet Printing of Low-Cost Tool Steel Powders

Ryan Ley*, Ian Donaldson**, Donald Paul Bishop*
**Dalhousie University, Canada | **GKN, Canada*

Abstract: Water atomization is utilized extensively in the high-volume production of iron and steel powders for use in press-and-sinter powder metallurgy (PM) technology. This variant of atomization maintains a low operating cost and typically produces particles that are relatively coarse (D50~120μm) and irregular in shape, which are not necessarily ideal traits for AM. However, with appropriate adjustment of the atomization parameters, a nearly spherical powder with reduced D50 can be achieved. The objective of this research was to investigate this concept, initially, in the context of binder jet printing. As such, a water atomized D2 tool steel powder was produced targeting a nominally spherical shape and reduced D50 to aid spreadability and post-print sintering response. The starting powder was characterized using laser light scattering, optical microscopy, SEM, and DSC. Preliminary builds were then printed, de-bound, and vacuum sintered under various conditions in a thermal dilatometer to assess densification behaviour and the temperatures at which key metallurgical transitions occur. It was determined that the optimal sintering temperature for maximizing density while minimizing distortion was in the range of 1220°C-1260°C with a hold time of 30 minutes. Secondary testing was then performed to verify these conditions with larger samples to assess mechanical properties.

11:00am

Presentation 37: Enhanced Impact Energy Absorption of 3D Printed Tessellated Sheets made from Flexible Materials

Anastasia Wickeler, Hani Naguib
University of Toronto, Canada

Abstract: The structural shapes of tessellated materials can create improvements in material properties, such as increases in specific strength, and impact energy absorption. This research will utilize 3D printing to manufacture multiple configurations of flexible tessellated sheets, which will be mechanically tested to compare their ability to absorb impact energy. The shapes of the tessellations were inspired by sheets of origami, which have repeatable unit cells. Three different patterns will be tested, along with a flat unpatterned sheet for comparison. The three chosen shapes will be printed with multiple pattern dimensions and thicknesses to determine the effects of changing parameters on impact force absorption properties. All the samples are printed using a Stratasys Objet30 printer, with polyjet technology, from a proprietary rubber-like material. This will allow some flexibility in the printed tessellated sheets, so that impact loads can be absorbed. These materials will be ideal for use in applications that require impact energy absorption, such as padded layers in sports equipment and insoles to cushion footwear.

11:20am

Presentation 38: Thermal Insulation and Laser-based Preheating Method for Processing a Ledeburitic Tool Steel in LPBF

Gregor Graf*, Manuela Leoni**, Tobias Müller, Jörg Fischer-Bühner, Maximilian Frey**, Daniel Beckers*, Sven Donisi*, Frederik Zanger**, Volker Schulze**
**Rosswag GmBH, Germany | **Karlsruhe Institute of Technology, Germany*

Abstract: As part of a GER-CAN research project (HiPTSLAM), the development and holistic processing of high-performance tool steels for AM is a promising topic regarding the acceptance of LPBF technology for functional optimized die, forming and cutting tools.

One of the primary problems at processing hardly weldable tool steels with increased carbon contents (≥ 0,4 wt%) in LPBF is the high risk of hot cracking due to the local stresses associated with the martensitic transformation. Possible solutions on this issue are based on complex external preheating systems from the top (e.g. infrared radiators) or the bottom (e.g. base plate heaters) to reduce the thermal gradients and thus the risk for hot cracking during solidification. Within the HiPTSLAM project another more efficient possibility should be examined, which consists of a preheating strategy with the two already available 400 W laser sources on a SLM®280 and a thermal insulation layer to keep the temperature inside the base plate and the part as constant as possible.

The new preheating method will be tested with a newly developed, ledeburitic tool steel with a carbon content of more than 1,3 wt%. The results will be validated against a commercially available 500 °C preheating system.

11:40am

Presentation 39: Attempts at Understanding LPBF of Intermetallic Alloys

Kuanhe Li, Chao Xu, Tejas Ramakrishnan, Xianglong Wang, Mathieu Brochu
McGill University, Canada

Abstract: Intermetallics, such as Ti-Al, Ni-Al and Fe-Al based systems have unique properties emerging from the significant covalent bonding volume fraction. Such characteristic is however complexifying its AM processability. The goal of this project is to investigate the feasibility of LPBF of these systems by understanding the fundamental relation between solidification and cracking. The results to be presented were obtained for the FA-129 alloy (Fe_3Al based) with laser powder bed fusion process.). The characterization of the samples has been done with optical microscopy, scanning electron microscopy, X-ray diffraction, and Vickers indentation microhardness test.

12:00pm

CANCELED **Presentation 40: Selective Laser Melting of Titanium Matrix Composites Reinforced with Hybrid (TiB+TiC) Reinforcements**

Eskandar Fereiduni, Ali Ghasemi, Mohamed Elbestawi
McMaster University, Canada

Abstract: Titanium matrix composites (TMCs) were fabricated by selective laser melting (SLM) of the 5wt.% B_4C/Ti-6Al-4V composite powder feedstock achieved by the ball milling process. The developed composite powder benefitted from spherical/quasi-spherical Ti-6Al-4V particles fully decorated by the irregular-shaped B_4C particles. The composite powder was subjected to the SLM process using varying laser energy densities. The formation of in-situ TiB and TiC reinforcements was observed and discussed based on a mechanism proposing the dissolution of the B_4C in the surrounding melt. The degree of dissolution was found to be a significant function of the energy density and the guest particle size. The microstructural evolutions during the SLM of 5wt.% B_4C/Ti64 composite was studied, and the non-equilibrium solidification sequence was suggested based on the microstructural observations and the equilibrium solidification path. The extremely high cooling rates induced by the SLM process inhibited some of the liquid and solid-state transformations in the studied TMCs. This was confirmed by investigating the microstructural evolution in the arc-melted parts fabricated by the same composite powder feedstock.

SESSION 10: Material Development III
June 26 | 2:00pm – 3:40pm EDT

2:00pm

Presentation 41: Deep Learning Framework for Image-based Characterization in Additive Manufacturing FEATURED TALK

Mike Marsh, Nicolas Piché
Object Research Systems (ORS)

Abstract: Quality assurance for additively manufactured (AM) parts is well served by research-grade imaging technology at multiple stages in the manufacturing process. Critical defects in printed devices may arise from various causes ranging from suboptimal powderbed fusion parameters to flaws in a batch of metal powder feedstock. Imaging by scanning electron microscopy (SEM) and x-ray micro-computed tomography (micro-CT) permit quantitative inspection of microstructure for both powder and printed devices. We describe here a framework that integrates Deep Learning methods with interactive image analysis and visualization tools. We consider applications for powder characterization, but also image enhancement for manufactured parts. We discuss image pre-processing and reconstruction adjustments that can strongly mitigate imaging artifacts (such as x-ray scatter and beam hardening) in microCT; and Deep Learning for object detection to accelerate processing micoCT tomograms. We showcase how these methods improve detection of defects and how they benefit from a framework that integrates measurement, analysis, and reporting tools.

2:20pm

Presentation 42: Binder Jet 3D Printing of Flexible and Multifunctional Polymer Material Using MXene Based Inks

Terek Li
University of Toronto, Canada

Abstract: Electrical conductivity is one of the bottleneck properties that hinders the implementation of binder jet 3D printed flexible electronics. Our previous work utilized graphene-oxide based inks to produce flexible printed parts, which reached conductivity as high as 1.4 S/m. Multiple strategies with variable degrees of success were studied to further improve conductivity by increasing additive loading as well as creating a segregated network to promote formation of conductive pathway. Metal based inks have always been an area of interest. However, due to the low aspect ratio of conventional metal, a high loading is often required to be conductive. Hereby we will demonstrate a new ink formulation based on 2D clay-like-metal known as MXene, with a chemical formula of Ti3C2. MXene is produced from its MAX phase (Ti3AlC2) and has comparable conductivity to graphene but disperses better in water due to its higher surface energy. This facilitates us to significantly increase additive loading while maintaining ink stability, which will inevitably aid to reach electrical percolation threshold for maximum conductivity. Furthermore, new effective surfactant and its respective concentration will be chosen to optimize the printability of this new ink. The end goal is to 3D print flexible and highly conductive polymer composites.

2:40pm

Presentation 43: Microstructural Evolution and Mechanical Properties of Aluminum-Copper Alloy and Maraging Steel Made by Selective Laser Melting

Hao Kun Sun, Gisele Azimi, Yu Zou
University of Toronto, Canada

Abstract: Selective laser melting (SLM), as one of the most popular methods for metal additive manufacturing, fabricates the products with near net shape, and thus improves the efficiency of manufacturing. Maraging steel and aluminum alloys are widely used in the industry because their outstanding mechanical performance. In this study, we applied the SLM method to produce Al-Cu alloys from the powder mixture (50 at% aluminum and 50 at% copper) and maraging steels from pre-alloyed powder. We investigated the morphology, microstructure, and chemical composition of the samples using optical microscope, scanning electron microscopy, and energy dispersive X-ray spectroscopy. Mechanical properties were investigated using a tensile test machine and nanoindentation. In-situ alloying of aluminum and copper showed both columnar and equiaxed grains with various chemical composition, intermetallic compounds including Al2Cu, AlCu, and Al3Cu4 were also observed. Hardness of these intermetallics was measured using nano-indentation. Maraging steel consisted of dendritic structure along with martensite and austenite phases. Non-metallic inclusions were detected from both the surface and cross section of the samples. Superior tensile properties and hardness illustrated the outstanding mechanical performance of maraging steel. This study suggested a possible manufacturing method to produce Al-Cu alloys and maraging steel using the SLM method.

3:00pm

Presentation 44: Impact of the Dynamics Strain Aging and Recrystallization Processes on the High Temperature Behaviour of LPBF IN625 Components

Alena Kreitcberg, Karine Inaekyan, Vladimir Brailovski
École de technologie supérieure Montreal, Canada

Abstract: IN625 specimens were fabricated by laser powder bed fusion (LPBF) and subjected to either stress relief (SR) annealing or to a combination of SR annealing and solution treatment (ST). The LPBF specimens were then tensile-tested in the 25-870°C temperature range, along with the wrought specimens of the same composition. At room temperature, ductility of the LPBF specimens was comparable to that of the wrought alloy, but at 760°C, it was from 45% (SR) to 85% (ST) lower. The analysis performed before and after tensile testing revealed that the ductility loss in the ST specimens was caused by the strain-induced formation of carbides and oxides (dynamic strain aging). On the contrary, dynamic recrystallization dominated during high temperature testing of the SR specimens, which explains their relatively higher ductility. The greatest degree of dynamic recrystallization and, therefore, the highest ductility at 760°C (70% of elongation) was observed in the wrought alloy. It was concluded that at high temperature, the trade-off between the two opposite dynamically activated processes depends on the processing route and must be controlled to improve the high temperature mechanical properties of 3D-printed IN625 alloy.

3:20pm

Presentation 45: LPF-AM Processing of Beta, Near-Beta and Near-Alpha Titanium Alloys

Nick Gosse*, Gregory Sweet*, Ian Donaldson**, Donald Paul Bishop*
**Dalhousie University, Canada | **GKN, Canada*

Abstract: The objective this research was to explore the processing response of titanium alloys of different compositions to laser powder-fed additive manufacturing (LPF-AM). The alloys chosen for examination were Ti-6242 (near-alpha alloy), Beta 21-s (beta alloy), and Ti-5553 (near-beta alloy) in light of their widespread use in traditional manufacturing and potential for use in AM. A common suite of experimental methods was applied to each alloy. In the first, 1cm3 samples were fabricated with systematic variations to laser power and scan speed. The density (MPIF Standard 42 and optical micrography) and hardness (HRC) were assessed and set as the dependent variables. In the second stage of work, laser power and scan speed were varied over a more refined range with hatch spacing and layer thickness introduced as additional variables. Again, density and hardness were assessed and utilized as the dependent variables. In the final stage of work, the most successful parameter sets were then employed to fabricate larger samples needed for tensile testing (ASTM E-8M) and more comprehensive microstructural assessment.

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

SESSION 11: PART A: Transatlantic Cluster for Lightweighting (TraCLight)
June 26 | 2:10pm – 3:20pm

2:10pm

Presentation 46: What is TraCLight?

Nadja Rest*, Manuela Neuenfeldt**,***
**Leichtbau BW GmbH, Germany | **wbk Institute of Production Science, Germany | ***KIT Karlsruhe Institute of Technology, Germany*

2:20pm

Presentation 47: Hybrid Additive Manufacturing Possibilities Based on Forging in Combination with LPBF

Sven Donisi, Gregor Graf
Rosswag GmbH, Germany

Abstract: By combining the manufacturing processes open die forging and Laser Powder Bed Fusion, a holistic process chain is created to manufacture massive and high complex metal parts in an efficient way.

The hybrid process chain bypasses the existing restrictions from both manufacturing processes. This is achieved by combining the advantages in specific volume segments of the part. The resulting, resource and cost-efficient manufacturing process enables the production of massive metal parts with complex and functional-optimized internal structures. The basic idea of the hybrid process is to manufacture the massive volume segments of the part near neat shape with open die forging procedures. On this highly stressable raw part the complex structure is added afterwards by LPBF. These added structures can for example contain complex internal cooling channel structures.

By the possibility of metal powder production based on the resulting forging residues, the hybrid part could even be manufactured out of a uniform alloy composition.

2:40pm

Presentation 48: Additive Manufacturing of Metal Components using the ARBURG freeformer System

Daniel Kupzik, Quirin Spiller, Jürgen Fleischer
wbk Institute of Production Science, KIT Karlsruhe Institute of Technology, Germany

Abstract: Metal powder injection molding is a manufacturing technology that is characterized by the near-net-shape production of geometrically complex components with outstanding mechanical properties. In this process, green bodies are molded with an injection molding machine, which are then debound and sintered. Due to the necessary tool form, an economic production is only reasonable from correspondingly high quantities. Additive manufacturing processes offer the possibility of economic production from piece number one.

ARBURG plastic freeforming represents an additive manufacturing process which uses commercially available plastic granulate for the production of components. This molding process offers the potential to use feedstocks from the metal powder injection molding sector to manufacture green parts. This makes it possible to economically produce metal components with comparable properties to metal powder injection molding from a quantity of 1 piece.

In this presentation, the process and the interrelationship between the process parameters and the mechanical properties of the component are presented. The temperature of the nozzle, temperature of the build volume and printing speed are optimized regarding mechanical properites. The second presented goal of optimization is to increase the service life of the nozzle. An increase by 255% could be achieved by tempering and plasma nitriding the nozzle.

3:00pm

Presentation 49: Development of H13 Repair and Hybrid Manufacturing of Extrusion Dies by DED

Alexandre Bois-Brochu*, Christian Zanetti**, Philippe Olcelli**
**Quebec Metallurgy Center, Canada | **DIENAMEX, Canada*

Abstract: After years characterized by off-shoring processes to low cost countries, several framework programs (e.g. Horizon 2020 in Europe, AMP in the United States, Industry 4.0 in Germany) have been launched, being the main aim to foster innovative production and to get as close as possible to the customers.

Most initiatives have converged on shifting from mass production to mass customization. In this context, Aluminium extrusion dies, made of H13 steel, are complex parts submitted to high stress and thus suffering from severe wear following use. The development of hybrid components, either while manufacturing or repairing such dies, can bring added value to this product and improve its life. For this reason, Dienamex has been cooperating with CMQ to develop additive manufacturing products and processes, to enhance the standard business proposition.

A state of the art of the development of DED process parameters of H13 steel is herewith presented. In addition, the evaluation of mechanical properties of manufactured parts and the end user perspective on final quality is investigated, based on industrial applications of hybrid extrusion dies.

SESSION 11: PART B: Transatlantic Cluster for Lightweighting (TraCLight)
June 26 | 3:20pm – 3:40pm EDT

3:20pm

Presentation 50: Detection of a Subsurface Defect in an Additively Manufactured SS 316L Sample Using Laser Ultrasonics

Alexander Martinez-Marchese, Ehsan Toyserkani
University of Waterloo, Canada

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

A test sample with a trapped powder spherical inclusion was printed and scanned using a ZEISS Xradia 520 Versa 3D X-ray Nano-CT scanner and then an ultrasound A-scan of the sample was obtained using the LUKS-1550-TWM laser ultrasonic system from Optech Ventures LLC.

The reconstructed image from the A-scan using the synthetic aperture focusing technique (SAFT) is compared with the CT scan data. Estimates of the acquisition time for both methods for the same volume are also compared.

Further work on improving the LU experimental setup as well as image reconstruction algorithms specifically tailored to the LPBF process will be described.

SESSION 12: Novel AM Processes and Products III
June 26 | 4:00pm – 5:40pm EDT

4:00pm

Presentation 51: New Electron Beam Powder Bed Fusion System with Open Source Software, Tailored for Research and Development FEATURED TALK

Ulf Ackelid, Ulric Ljungblad
Freemelt AB, Sweden

Abstract: Additive manufacturing provides opportunities for improving properties of existing alloys and developing new material compositions. Materials produced with powder bed fusion (PBF) often exhibit unique microstructures, due to the small melt pool and rapid solidification associated with PBF. Unfortunately, most commercial PBF systems are intended for production only. They are too big for small scale experiments, have limitations in terms of beam control and cannot be modified to the needs of an R&D user. This paper describes Freemelt ONE, a new electron beam PBF system for R&D, providing benefits such as:

- Open source software in combination with an e-beam scanning speed up to kilometers/second offers unsurpassed freedom to explore innovative beam scanning strategies
- Small build volume and low powder consumption
- Short turnaround time
- High tolerance to powder morphology and easily adjustable recoater parameters
- High vacuum environment for highly reactive materials
- High e-beam power (6kW) enables very hot powder bed, >1100 °C (>2000 °F), beneficial for crack-sensitive materials such as advanced nickel-base superalloys
- Easy attachment of R&D equipment, e.g. IR cameras, high-speed cameras, backscatter electron detectors, X-ray spectrometers or residual gas analyzers, giving endless possibilities for in-situ process monitoring and control.

4:20pm

Presentation 52: Fused Filament Fabrication of Metal Matrix Composites (MMC)

Nancy Bhardwaj*, Hani Henein*, Tonya Wolfe**
**University of Alberta, Canada | **InnoTech Alberta, Canada*

Abstract: Fused Filament Fabrication (FFF) has been widely used for the Additive Manufacturing of polymer-based components. Due to the versatility of equipment used in FFF, the feasibility to incorporate other classes of materials, such as metallic and ceramic powders, into the feed material comprised of polymer filament is an attractive option. When metallic powders are incorporated into the polymer, FFF provides the opportunity to retain the fine structure of the rapidly solidified powder. This work will discuss the random loose porosity for mixtures of metal matrix composite (MMC) powders containing Nickel alloy, Titanium and Tungsten carbides. The packing of fine and non-spherical particles for these powder mixtures will provide a datum for determining the maximum packing achievable for increasing carbide content, and for predicting the flow characteristics of composite filaments containing polymer and MMC fillers for use in FFF. The printability of the composite filaments in relation to particle packing will also be discussed.

4:40pm

Presentation 53: Embedding Optical Sensors in Additively Manufactured Parts for Enhanced Functionality

Kelvin Son, Farid Ahmed, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: The aim of this study is to explore the potential of embedding sensors in additively manufactured metal parts towards smart-product development. There are challenges both in the construction of appropriate channels (for sensor embedding) in Metal Additive Manufacturing (AM) and in packaging the sensor in an AM part for application specific specimen measurements. Thus, this work investigates the feasibility of incorporating specific channels in AM parts for sensor embedding, packaging of the senor in the parts, and the characterization of the sensor for sensing of a given measurement. Optical fiber Bragg grating (FBG) has been chosen for their compact size, ability to operate in hazardous environments, and their immunity to electromagnetic radiation. With such considerations, the channels in the bulk of AM parts were designed for the purpose of embedding FBG sensors. However, once fabrication of such channels are mastered and it is repeatable, this work can be easily customized for embedding other types of sensors.

5:00pm

Presentation 54: Design, Optimization, and Validation of a Magnetic Levitation System for Additive Manufacturing

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

Abstract: Applications of magnetic levitation are of interest in several fields, such as energy harvesting, transportation, micro-robotics, etc. Magnetic Levitation has also found itself to be of interest in the field of Additive Manufacturing (AM). The principle of Eddy Current (EC) levitation is used to build the levitation system. The primary objective of the work presented here is to validate the viability of this EC levitation system within the AM environment through FEA (Finite Element Analysis). This validation of this levitation system includes the computation of levitation forces in the vertical axis, restoration forces in the x-y plane and temperature increase. The optimization of the dimensions of the levitator and the embedded coils are also described here. A strong emphasis is also placed on the determination of the levitation ability of various aluminum alloys with applications in the AM environment. Following this, input parameters (frequency and magnitude of AC supplied to the system) are computed through the principle of least square curve fitting. These parameters are validated through FEA. Through the work conducted here, it was concluded that EC levitation is feasible for AM.

5:20pm

Presentation 55: Metallic Cellular Hip Implant with Functionally Graded Density

Elham Davoodi*,**, Reza Esmaeilizadeh*, Hossein Montazerian**, Ehsan Toyserkani*
**University of Waterloo, Canada | **University of California Los Angeles, United States*

Abstract: Porous implants are known to be preferred over the solid counterparts as they allow tissue ingrowth and thereby promote fixation. Triply periodic minimal surfaces (TPMS) offer unprecedented flexibility in design of cellular hip implants which can better mimic the behavior of actual bone tissue. TPMS satisfies the interconnectivity of pores which promotes bone growth. Here, a new approach toward the design of functionally graded cellular implants is introduced, where density is low at the interface with tissue to both allow enhanced tissue ingrowth and prevent stress shielding by lowering local elastic modulus. Density tends to become higher deep into the center of the implant for high mechanical strength. To optimize the architecture of the implants, the effect of pore shape, size, and density on printability and the performance of the porous structures were characterized on simple cubic samples fabricated via laser powder bed fusion (LPBF). Then, the cellular titanium implants with the best-performing pore size and shapes with graded and uniform density were compared in terms of mechanical performance. The osteointegration properties of the implants with optimized architecture can be further characterized through in vitro and in vivo studies.

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

SESSION 13: Advanced Process Modeling III
June 26 | 4:00pm – 5:20pm EDT

4:00pm

Presentation 56: Multi-Scale Modeling of Distortion in Powder Bed Fusion FEATURED TALK

Michael Gouge, Pan Michaleris, Erik Denlinger, Jeff Irwin, Charles Li
Autodesk, Canada

Abstract: Distortion of parts during construction remains a key impediment to the wider adaptation of Additive Manufacturing (AM). Eliminating distortion through iterative builds, measurements, and redesigns adds unpredictable delays and expense to AM based component construction. This may reduce or eliminate the economic advantages over more traditional manufacturing methods, slowing AM adoption. Finite Element based simulations of AM processes can predict distortion prior to deposition. Predicted distortions can be used then to inform warpage mitigation strategies. A multi-scale modeling strategy is presented which can efficiently simulate Laser Powder Bed Fusion based AM a priori. Experimental results are compared against predicted deformations to validate the model. Comparisons of computational versus manufacturing times for industrial sized components shows numerous simulations may be completed in the same time required to manufacture the part, allowing for timely feedback on the expected distortion. Simulation may also be used to inform the likelihood of support structure failure, recoater blade jams, lack of fusion, and hotspot induced defects during LPBF. Using simulated predictions of distortion to pre-compensate the geometry prior to building is shown to significantly reduce warpage in manufactured parts, reducing the number of iterative prints required to produce a usable component.

4:20pm

Presentation 57: Abrasive Flow Machining of Laser Powder Bed Printed Components: Modeling versus Experiment

Mykhailo Samoilenko, Vladimir Brailovski
École de technologie supérieure Montreal, Canada

Abstract: The majority of 3D printed metal parts require surface finish improvement after manufacturing. Abrasive flow machining (AFM) is considered as one of the best-suited candidates for the polishing of complex 3D-printed components. However, this process leads to mass loss and consequent alteration of the part geometry and dimensions. A numerical tool is needed to reduce the number of time-consuming and labor-intensive experimental trials and allow the prediction of machining allowances for the final geometry and surface finish of AFM-processed parts.

A combined numerical-experimental approach to predict the results of such a polishing process was developed at ETS. The model simulates the indentation of abrasive grains to a workpiece and takes into account the initial surface roughness of the part as well as the velocity and pressure of a polishing medium abrading the surface, the latter obtained via computational fluid dynamics (CFD) simulations. After computation of the indentations along the polishing surface, the material allowances are added to the initial part geometry, resulting in the generation of a final CAD adapted for the consequent AFM process. To validate the model, CMM, 3D microscope and surface roughness measurements were performed on tubular EOS SS CX specimens produced by laser powder bed fusion.

4:40pm

Presentation 58: Efficient Thermo-mechanical Finite Element Model for Simulating Selective Laser Melting Process in Part Level

Zhibo Luo, Yaoyao Zhao
McGill University, Canada

Abstract: Selective laser melting (SLM) is a commonly used powder bed fusion additive manufacturing process which fabricates a part through layer-wised method. However, rapidly changing thermal cycles in the melt pool induce a periodically changed thermal stress in solidified layers. To reduce the fabrication defects induced by these thermal stresses, many studies have been focused on developing numerical methods to estimate transient temperatures and thermal stress distributions around the melt pool. The big challenge using numerical methods is to reduce its high computational cost. In this research, an efficient thermo-mechanical finite element (FE) method aiming to reduce the computational cost is developed to model the SLM process in part level. First, an efficient transient finite element heat conduction model is established. After transient thermal analysis of each step, a thermo-elasto-plastic constitutive model was established to predict the quasi-static mechanical behavior of the material and to calculate the deformation and thermal stress of the deposited layers. The simulation speed is 12 ~ 18 folds faster compared with the conventional simulation scheme. The simulation results were compared with experimental results. The comparison demonstrated that each point in the simulation experienced the same thermo-mechanical cycles as in the experiment.

Poster Presentations

POSTER SESSION 1
June 25 | 12:20pm – 2:00pm EDT

Theme 1: Material Development

Poster 1: Additive Manufacturing of High Concentration Yttria-stabilized Zirconia Using High-Speed Drop-on-Demand Material Jetting

Haniyeh (Ramona) Fayazfar, Usman Ali, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: A novel in-house-developed hybrid drop-on-demand material jetting system (DODMJ) has been employed to deposit a highly viscous paste (up to 72 wt% solid content, a viscosity of 2100 mPa.s) of yttria-stabilized-zirconia (YSZ), with approximately 20 times higher speed than the current material jetting methods, for the first time. We aimed tetragonal zirconia polycrystal containing 8 wt% Y2O3 (5Y-TPZ) which is commonly used to produce dental restorations by subtractive manufacturing. The printability of several visible light-curable zirconia pastes in terms of rheology, paste composition, solid content, and printing parameters, density and porosity measurements, as well as two-stage sintering process, to get fully dense and crack free parts, were investigated. The microstructure and internal features of the printed parts were also explored by X-ray nano-computed tomography (CT) scanner and scanning electron microscopy. Vickers hardness and fracture toughness of the optimized sintered 5Y-TPZ parts has been also reported. The outcomes led to successful printing of nearly full dens, crack-free and high strength zirconia parts with adequate mechanical and structural properties for dental restorations.

Poster 2: Primary Si Modification via Rapid Solidification and Alloying

Daniela Diaz, Abdoul-Aziz Bogno, Hani Henein
University of Alberta, Canada

Abstract: This study reports on morphology modification of primary Si modification by Rapid Solidification (RS) and chemical alloying. Three alloys were used for this purpose: Al-40Si, Al-40Si-3.7Fe-2.8Mn, and Al-40Si-1.5Ce (compositions in wt%). For each alloy, powders of various thermal histories (cooling rates and undercooling) were produced by Impulse Atomization. The resulting powders were characterized using Optical and Scanning Electron Microscopy. Thus, the morphology transitions, size, and volume fraction of primary Si can be explored as a function of cooling rate and undercooling. The three selected alloys fall under different categories of modification. Al-40Si was set as a baseline for how RS induces primary Si modification. Al-40Si-3.7Fe-2.8Mn was designed to limit the equilibrium volume fraction of primary Si and provide an approach for RS to fully modify the Si morphology. Al-40Si-1.5Ce was selected due to the interest for Ce modification of Si that currently exists in literature. The modification mechanism at play is not well understood, but it is generally agreed that local equilibrium during solidification has a strong impact on modification. As such, this study contributes insight on the applicability of Ce as a chemical modifier for Al-Si alloys used in RS processes.

Poster 3: The Microstructure, Morphology and Mechanical Properties of Rapidly Solidified Al-10wt%Si-0.4wt%Sc Alloy

Akankshya Sahoo, Abdoul-Aziz Bogno, Hani Henein
University of Alberta, Canada

Abstract: Scandium addition in Al-alloys has been found to promote excellent precipitation hardening, microstructure refinement and morphology modification. Recent research has also explored the evolution of microstructure at various stages of additive manufacturing (AM) and found rapid solidification (RS) also greatly affects the morphology/ properties of hypoeutectic Al-Si alloys. However, the combined effect of both RS and Scandium addition on the conditions leading to these morphologies and properties in Al-Si alloys are not understood in a quantitative and reproducible way. Using DSC and a novel containerless solidification technique (Impulse Atomization), hypoeutectic Al-10Si alloy with 0 wt% and 0.4 wt% Sc addition was produced with a wide range of cooling rates (0.1-10^4K/s). The effect of Scandium addition to the microstructure and mechanical properties of the atomized droplets will be reported. Microstructural analyses of the samples were carried out using Differential Scanning Calorimetry (DSC), X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), Energy Dispersive X-ray spectroscopy (EDX), and Electron Microprobe as well as Micro Vickers Hardness tests. Aging experiments have also been conducted to understand the precipitation of Scandium and its precipitation hardening effect on the alloy. The results from these analyses will be discussed.

CANCELED Poster 4: Heterogeneous Micromechanical Properties of Dual-phase Titanium Alloy Made by Additive Manufacturing

Zhiying Liu, Yu Zou
University of Toronto, Canada

Abstract: Thermal treatment is an effective method to improve mechanical property of materials made by additive manufacturing. However, the partitioning of alloying elements during heat treatment, accompanying the α↔β phase transformation, determines the local composition of the microstructure, and thus significantly influences the micromechanical properties (e.g., hardness and modulus) of α+β titanium alloys. Nanoindentation is a powerful tool for exploring micromechanical properties of alloys involving multiple phases, and hardness and Young's modulus of different phases can be outputted. In this work, dual-phase titanium alloy made by additive manufacturing are annealed, and micromechanical properties of the alloy are measured using high throughput nanoindentation tests. It is shown that α phase is harder than β phase. Interestingly, distribution of hardness and modulus in one specific phase is heterogeneous, also, hardness varies in phases with different morphology. The heterogeneous micromechanical properties are attributed to partitioning and segregation of alloying elements during heat treatment elements, which is demonstrated by elements analysis. Al and Mo are the main elements to determine the mechanical properties. Therefore, the relationship between heat treatment, local microstructure and composition, and micromechanical properties of additive manufactured titanium alloy is finally bridged, which benefits for microstructure/composition optimization.

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

Poster 5: An Investigation on the Tensile and Fatigue Behaviour of Laser Powder-bed Fusion Hastelloy X

Reza Esmaeilizadeh*, Ali Keshavarzkermani*, Hamid Jahed*, Ali Bonakdar**, Ehsan Toysekani*
**University of Waterloo, Canada | **Siemens, Canada*

Abstract: The mechanical performance of parts under quasi-static and cyclic loadings is highly depending on the manufacturing process. Laser powder-bed fusion (LPBF) was used to fabricate nearly full-dense Hastelloy X samples. Microstructural characterization, such as optical and scanning electron microscopy techniques, defect analysis by computed tomography, and surface roughness measurement by laser confocal profilometer were used to study the resultant part features. Quasi-static tensile response and fatigue behaviour in HCF and LCF regions were investigated to understand the material behaviour in various loading conditions. Due to high density of LPBF parts consistent tensile behaviour, such as high ductility (~60%), yield strength (~470 MPa), ultimate tensile strength (~700 MPa) were achieved. In LCF region, a significant plastic strain accumulation (ratcheting behaviour) was observed due to high ductility of printed samples. It is observed in HCF and LCF tests that cracks always start from rough surface as opposed to small internal porosities. The result of fatigue tests was used to calculate the Basquin parameters of the printed Hastelloy X.

Poster 6: Surface Finishing of Laser Powder Bed Fusion Alloys via Chemical and Electrochemical Polishing

Haniyeh Fayazfar, Issa Rishmawi, Mihaela Vlasea
University of Waterloo, Canada

Abstract: The surface imperfections inherent to AM cannot be addressed by AM process optimization alone, due to the physics of the laser-powder interaction. Looking at the costs factors for post-processing of AM parts, more cost-effective methods are needed to address finishing of complex surfaces. This study reports the surface finishing of Invar36 parts produced via laser powder bed fusion with various part orientations with respect to the building platform by using solution-based methods. Since the roughness of an AM-built surface strongly depends on its orientation, the polishing process have been studied and optimized using test specimens comprising surfaces of different build orientations. In this research, innovative systems and processes through two general categories; electropolishing and chemical polishing (chempolishing) has been investigated and compared. Chempolishing is found suitable for any complicated AM shape and geometry. Electropolishing, by contrast, requires a counter electrode positioned in the proximity of the surface to be polished and thus complex geometries may pose issues. Optical profilometry and scanning electron microscopy have been done to investigate the difference between electropolishing and chempolishing methods for effective decreasing the roughness of the internal or external surfaces of Invar36 printed parts.

Poster 7: Development of Novel Water-atomized Tool Steel Powders for Laser Powder Bed (LPB) and Direct Energy Deposition (DED)

Denis Mutel, Carl Blais
Universite Laval, Canada

Abstract: The development of tool steels for additive manufacturing (AM) is particularly interesting for the fabrication of dies or toolings with complex geometry. Currently, H13 tool steel is the most popular candidate for fabricating such components in AM. Nevertheless, other tool steels have similar properties than H13 tool steel with strategic benefits in terms of resistance to wear (A8 tool steel) and shock loading (S7 tool steel). The objective of this work is to develop novel water-atomized formulations of tool steel to optimize their properties for use in Laser Powder bed (LPB-AM) and Directed Energy Deposition (DED). Powder characterization was performed in terms of morphology, rheological properties and chemical composition. Test specimens fabricated by LPB and DED were characterized in terms of tensile properties, microstructure and relative density and compared to results obtained with commercial H13 powders.

Poster 8: Geometry and Surface Characterization of Additively Manufactured H13 Hot-Work Tool Steel Using Directed Energy Deposition

Owen Craig*, Kevin Plucknett*, Alexandre Bois-Brochu**
**Dalhousie University, Canada | **Centre de métallurgie du Québec, Canada*

Abstract: This research, in partnership with the Centre de Métallurgie du Québec (CMQ), focused on the geometry and surface roughness of directed energy deposition (DED) processed H13 hot-work tool steel. This was achieved by varying laser scanning speed and powder feed rate, while the laser power reminded constant at 400 W. Single track and multi-track clads were deposited, while simple-shaped 3D multi-layer components were also produced. Under these conditions, the length and width measurements did not vary, but DED layer height was significantly impacted by the scanning speed. Increasing the scanning speed resulted in 'under building', while decreasing the scan speed resulted in 'over building'. For the surface roughness measurements of rectangular samples, the system parameters selected showed no clear trend in the finish. The top surface roughness of the sample was consistently higher than the side surfaces. However, single clad and multi clad samples showed that decreasing the scanning speed increased the surface roughness. Adding a draft angle when building 3D parts reduced the side surface roughness. Finally, changing the layer thickness will impact the desired height, but has no clear surface roughness trend. The effects of process conditions on instrumented indentation hardness and scratch resistance will also be discussed.

Poster 9: Production, Characterization and Performance Evaluation of Cardanol Acetate in Alkyd Paints

Iheoma Nwuzor, Christopher Idumah, Paul Okolie, Obumneme Ezeani
Nnamdi Azikiwe University, Nigeria

Abstract: The utilization of cashew nut shell liquid (CNSL) is currently being focused on by chemical industries, as one of the most important renewable chemicals. Experimental results revealed that CNSL used in this study contained cardanol, cardol, anacardic acid and 6- methyl cardol. The cardanol obtained and cardanol acetate synthesized was characterized using international standard methods. The functional groups present in the raw CNSL, cardanol and cardanol acetate was determined using FTIR spectroscopy. Results showed that the CNSL contained saturated and unsaturated fatty acids that are essential in oil. The cardanol acetate served as reactive diluent in the alkyd paints. The dry paint films were generally hard and the thickness of the dry paint films were in the range of 0.32 – 0.37mm on a 0.4mm scale. The tensile strength of

the formulated paints increased with increases in the reactive diluent but showed decreased elongation at break. The chemical reactivity test of the paints showed good chemical resistance to acids an indication of good anticorrosive properties. The TGA results exhibited thermal stability. The paint films were generally glossy. The coating formulated was less VOC, non-toxic and environmentally friendly and can be utilized for both architectural (interior and exterior).

CANCELED Poster 10: Development of a New Aluminum Metal Matrix Composite Using Response Surface Methodology

Raphael Ebhojiaye*, Akii Ibhadode**
**University of Benin, Nigeria | **Federal University of Petroleum Resources, Nigeria*

Abstract: A new aluminum metal matrix composite was developed as a lightweighting material for internal combustion engine parts. The Central Composite Design (CCD) method of Response Surface Methodology (RSM) was used to carry out the experimental design. Three input variables were used in the design – commercially pure aluminum, periwinkle shell (PS) and palm kernel shell (PKS). A total of six response variables were investigated: wear, creep, density, tensile strength, hardness and melting temperature. The values of the various properties of the fabricated specimen were fed into the response surface methodology (RSM) of Design Expert Software. The optimization process required the minimization of wear, creep and density; and maximization of tensile strength, hardness and melting temperature. The overall solution of the optimization process was to determine the optimum values of each input variable that could be used to produce the aluminum metal matrix composite. The results show that a blend of x1% aluminum, x2% PS and x3% PKS will produce an engineering composite material with particular values of the response variables. Analysis of the coefficient of determination (R2) of results shows that there is no significant difference between the optimal blend solution obtained from the RSM analysis and the experimental values.

Poster 11: Effect of Heat Treatment on High Temperature Mechanical Properties of Rene 41 Alloy Fabricated by LPBF

Sila Atabay*, Kevin Plucknett**, Mathieu Brochu*
**McGill University, Canada | **Dalhousie University, Canada*

Abstract: Rene 41 is a Ni-based superalloy widely used in hot section parts of jet aircraft engines and divergent seal and flap components, exhaust nozzles in military turbine engines due to its excellent high temperature properties. These properties are primarily achieved through strengthening of this alloy via precipitation of γ' phase after solutionizing and an age hardening heat treatment. Therefore, final high temperature properties are highly dependant on the applied heat treatment.

In this study defect free Rene 41 parts were produced via laser powder bed fusion. Two different heat treatments (one sub-solvus one super-solvus) were applied to evaluate the effect of solutionizing temperature on the final microstructure. Difference in γ' size, shape and fraction along with the grain morphology of the parts after both heat treatments were studied. Elevated temperature tensile properties were tested in as fabricated state and after applied heat treatments. Effect of microstructure on those properties will be discussed in detail.

Poster 12: Development of Al-Zr-Y Alloys for Laser Powder Bed Fusion

Jon Hierlihy*, Ian Donaldson**, Mathiew Brochu***, Donald Paul Bishop*
**Dalhousie University | **GKN | ***McGill University*

Abstract: The scope of aluminum alloys commercially available for laser powder bed fusion (LPBF) is limited yet the demand for them is growing aggressively. In many cases, end-users are particularly interested in those that offer enhanced thermally stability. Historically, a number of such materials were premised on alloys that incorporated transition metal (TM) additions which formed refractory aluminides as the principal strengthening addition. In following this same concept, the Al-TM system of interest in this research was the Al-Zr-Y ternary. Investigation of this system invariably mandates that multiple alloys be converted into a powder form which is costly and time consuming. To expediently downsize to the most promising alloys, plates of Al-xZr-yY (x = 0 to 5; y = 0 to 5) were cast and machined. Plates were then ablated with a Yb-fibre laser operated under a range of parameters (power, scan speed, etc.) to produce single and multi-track configurations. Each was then examined (optical, SEM, laser confocal) to determine if defects were present (cracking, porosity, etc.) and in turn, gain a precursory sense of the feasibility of each system for LPBF.

Poster 13: Comparing Mechanical Properties and Microstructure of Laser Powder Bed-fused Components Made from Maraging Stainless Steel to its Wrought Analogue

William Turnier Trottier, Alena Kreitcberg, Vladimir Brailovski
École de technologie supérieure Montreal, Canada

Abstract: Laser powder bed fusion (LPBF) is an additive manufacturing technology with a great potential to revolutionize the way toolmaking design is perceived. The capacity of generating parts with very complex geometries gives the chance to tooling designers to optimize their product for specific applications. For example, cooling canal placement in injection molds can offer an optimal cooling of the molded part. However, these types of molds require high hardness, good toughness and in certain cases excellent corrosion resistance. Even though some materials, such as EOS Stainless Steel CX (SS CX) (EOS GmbH, Germany), could fill these requirements, researches on these alloys are sparse. The focus of this project is to compare the microstructure and mechanical properties of specimens produced by laser powder bed fusion of SS CX powders with those machined from a chemically analogous wrought maraging stainless steel (Corrax® Uddeholm AB, Sweden). This comparison follows the conventional workflow: 3D-printing (milling), solution treating and aging, and targets a combination of a high hardness (~51 HRC) with an acceptable elongation to failure (~7%), as specified by EOS GmbH.

Poster 14: On the Tensile Property Evaluation of Additively Manufactured Ti-5553 Alloy

Nivas Ramachandiran, Hamed Asgari, Paola Russo, Chinedu Francis Dibia, Adrian Gerlich, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: A recently developed near β-titanium alloy, Ti-5Al-5V-5Mo-5Cr (Ti-5553), is a promising candidate for fabricating aircraft landing gear parts, offering superior mechanical properties and excellent heat treatability. Available resources in literature have confirmed the printability of Ti-5553 through Laser Powder Bed Fusion (LPBF) process. However, the mechanical properties of the LPBF-Ti5553 parts fabricated through LPBF are inferior compared to those processed through conventional routes, due to differences in the thermal and mechanical processing.

In this research work, uniaxial tensile and impact tests are carried out on samples printed at the established process parameters with a continuous laser. The results are compared and correlated with microstructural changes related to differences in process parameters and hence their respective thermal cycles. The as-printed samples exhibited a 200% higher elongation compared to previously reported values for Ti-5553 processed through LPBF. The higher elongation is expected to be an outcome of the grain boundary globular α particles. However, poor impact toughness measurements of the as-printed samples remain to be a challenge in property optimization.

Poster 15: Optimization of Chemical Composition of Al Alloys via Rapid Solidification in Additive Manufacturing

An Fu*, Mathieu Brochu*, Donald Paul Bishop**, Pierre Hudon*
**McGill University, Canada | **Dalhousie University, Canada*

Abstract: One significant advantage of Additive Manufacturing is rapid solidification because it extends solid solubility of strengthening elements and promotes mechanical properties of Al alloys. In binary alloy system e.g. Al-Er, the solid solubility can be extended to a large extent, using extremely high cooling rates. However, in ternary or quaternary Al alloy systems, different elements are likely to interact with each other, which might mutually affect their solid solubilities in the Al matrix. Therefore, the optimized alloying composition is expected to be found for each type of alloy, with the focus on the solidification behaviors of various Al alloys under different cooling rates.

The test of several Al alloys by Differential Scanning Calorimetry (DSC) revealed the effect of cooling rate on microstructural evolutions and approximate phase transformations, with the cooling rate comparable to Arc Additive Manufacturing. In the next step, Direct Energy Deposition of Al alloys, is going to be performed at higher cooling rates and the corresponding microstructure will be analyzed.

Meanwhile, in analogy to the TMK model developed for eutectic Al-Si alloy, the possibility to develop new models for the other Al alloys will be evaluated and discussed, based on the current studies.

Theme 2: Advanced Process Modeling

Poster 16: A Novel Post-Topology Optimization Process for Overhang Elimination in Additive Manufacturing

Osezua Ibhadode, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Common part design-based challenges in Additive Manufacturing (AM) are overhanging features, thin struts, and enclosed cavities. These challenges can either reduce part quality or inhibit print success altogether. This study presents a novel post topology optimization model to eliminate overhanging features consequently eradicating the need for internal support structures in the part. Many existing methodologies are integrated into the topology optimization workflow requiring often complex or embedded functions thereby increasing inconvenience and difficulty in sensitivity calculations. In addition to circumventing tedious sensitivity calculations, this novel method is optimizer-independent and enables ample design freedom such as selecting overhang angle threshold, feature size limit and the degree to overhang elimination. This methodology which is applicable to any AM technology has been used to design sample parts manufactured by Laser Powder-Bed Fusion (LPBF) and Fused Deposition Modelling (FDM).

Poster 17: Comparison of Volumetric Heat Sources in the Thermomechanical Modeling of the Laser Powder-bed Fusion Additive Manufacturing

Zhidong Zhang*, Ali Bonakdar**, Ehsan Toyserkani*
**University of Waterloo, Canada | **Siemens, Canada*

Abstract: Laser powder-bed fusion (LPBF) additive manufacturing is one of the most important additive manufacturing techniques, in which geometrically complex parts can be made by selectively melting layers of powder. However, residual stress is among the challenges of printing parts in LPBF, which impedes the widespread industrial applications of LPBF. In order to predict the residual stress during this process, a three-dimensional thermomechanical model is developed. Eight different volumetric heat sources are employed to simulate a single-layer laser scanning. Then, the simulation results under different heat sources, such as cooling rate, temperature gradient, and residual stress, are summarized and compared. Moreover, the simulation results are validated with the experimental results. This work is a relatively comprehensive study about the influences of heat-source models on the residual stresses within the LPBF parts. Recommendations on choosing a heat source model in LPBF are given and explained.

Poster 18: Machine Learning Applications in Laser Powder Bed Fusion Processes

Gijs van Houtum, Mihaela Vlasea
University of Waterloo, Canada

Abstract: Additive manufacturing processes are complex, involving many subsystems deployed to achieve layer-wise part fabrication by fusing units of material together. These processes are driven by a large number of process parameters and building materials. Analytical modeling of the material fusion phenomena has been studied in abundance in recent literature, specifically for laser powder bed fusion (LPBF). The complexity of the LPBF process has led many researchers to the use of design of experiments paired with statistical analysis methods to map the relationship between process parameters and part quality. Machine learning (ML) has increased in popularity the last years as an empirically trained predictive tool. As such, AM researchers are adopting ML methods to model the relation between parameters and part quality.

This research provides an overview of ML methods applied in AM. The overview describes and categorizes the available ML algorithms and where they are applied within the available AM processes. The overview also illustrates the gaps in research which could possibly benefit from the application of ML methods. Additionally, a case study is presented in which an empirical ML algorithm is developed to model the relation between skin angle and surface roughness in a LPBF process.

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

Poster 19: Numerical Model of Al-33wt%Cu Eutectic Growth During Impulse Atomization

Jonas Valloton, Abdoul-Aziz Bogno, Hani Henein
University of Alberta, Canada

Abstract: Rapid solidification of Al-Cu droplets of eutectic composition was carried out using Impulse Atomization in an argon atmosphere. Two distinct morphologies were observed within the Al-33wt%Cu droplets: an irregular undulated eutectic assumed to form during recalescence, followed by a regular lamellar eutectic post-recalescence. The volume fraction of each morphology was measured as a function of droplet size and nucleation undercooling was deduced using the hypercooling limit. A model of the eutectic solidification was then developed assuming that the kinetics of both the undulated and regular regions is the same and follows scaling laws experimentally established for α-Al-Al2Cu eutectic. Modelling results show that the solid fraction forming during recalescence matches the experimental undulated eutectic fraction, confirming the hypercooling limit assumption for nucleation undercooling. Furthermore, the heat balance of the droplet with the surrounding gas confirms the adiabatic nature of the solidification during recalescence. Good agreement is found between the model and experimental measurements of lamellar spacing for the regular eutectic. However, the predicted spacing of the undulated zone is much lower than what is observed experimentally. This is either due to coarsening induced by the latent heat released during recalescence or the undulated eutectic does not follow the established eutectic kinetics.

Poster 20: Analytical Modeling of Transient Temperature in Laser Directed Energy Deposition of Ti5553

Mazyar Ansari, Mobin Khamooshi, Alexander Martinez Marchese, Ehsan Toyserkani
University of Waterloo

Abstract: Although laser directed energy deposition through coaxial powder feeding (LDED-CPF) has been explored for the manufacturing of metallic parts, the process is very dependent on processing parameters. A key and cost-effective solution for process control and optimization is modeling. This research aims to develop a time-efficient physics-based model for transient temperature in LDED-CPF. The transient temperature solution is constructed based on a moving point heat source. A process model is developed for single-track deposition and experimental validation is conducted by depositing a titanium alloy (Ti-5553) at different laser powers, laser moving velocities, and powder feed rates. Moreover, an alternative method is established to estimate the deposit height based on the melt-pool projection and model the deposition bead. Using the developed model, the geometry and temperature field can be predicted with more than 80% accuracy. The high prediction accuracy and high computational efficiency allow the temperature prediction for the multi-track deposition, and process-parameter planning through inverse analysis.

CANCELED **Poster 21: Statistical Analysis for Improving Decisions of Industrial Internet of Things' Devices in Metal Additive Manufacturing**

Basel Alsayyed, Mohammed Alghamdy
University of Alberta, Canada

Abstract: Higher utilization of connected devices using Industrial Internet of Things (IIoT) in Metal Additive Manufacturing (MAM) production lines have been growing drastically. Giving the probability of failing elements along MAM systems, there is a pressing need for more reliable production lines to ensures higher quality products. Statistical analysis can detect, predict, and improve reliability and repeatability of MAM processes. This work attempts to improve the reliability of AM production lines through statistical analysis of selected MAM operations. Analyzed data is then fed into IIoT devices in multi-stage feedback loops allowing these devices to make better decisions, which lead to improved quality in MAM processes.

Poster 22: Characterizing the Effect of Surface Roughness on Tensile Behavior of SS316L Micro-struts Fabricated by Laser Powder Bed Fusion

Abhi Ghosh, Amit Kumar, Mathieu Brochu
McGill University, Canada

Abstract: The surface to volume ratio in thin struts fabricated by laser powder bed fusion is increasing the contribution of the surface in dictating the mechanical properties. Specifically, thin struts are heavily influenced by the degree of surface roughness. In the current work, SS316L vertical struts of diameters ï ¾250ï m and ï ¾500ï m were fabricated with ï ¾99.98% density. Roughness and the associated dimensional deviation in struts were characterized using x-ray micro-tomography. Based on the three-dimensional x-ray imaging, mechanical tests were performed to highlight the effect of roughness on tensile performance. First, characterization and comparison of elongation and failure of as-built struts and electropolished struts using in-situ electron microscopy provided several key differences in tensile behavior. Second, elasto-plastic flow characterization at microstructural-level using spherical nano-scale indentations aimed to extract flow behavior in struts without any influence of surface roughness or near-surface microstructures. Lastly, finite element based elasto-plastic damage model was developed to simulate the effect of roughness on necking and fracture behavior of struts.

Poster 23: Influence of Thickness of Coating on Adherence of 316L and Cu Coatings Deposited by Cold Gas Spraying

Rodolpho Vaz, Alessio Silvello, Javier Sánchez, Irene Garcia Cano, Sergi Dosta
Federal University of Paraná, Brazil

Abstract: Cold Gas Spraying is a thermal spray process capable to produce dense and thick coatings and it makes possible the use of Cold Gas Spraying to fill cavities, worn, eroded, or corroded areas on damaged special alloys structural parts, saving the costs for the fabrication of a new component. Thick coatings, also interpreted as additive manufacturing, can be obtained by single or multiples passes and this amount of layers has influence on the properties of the coating and the substrate. The quantity of passes has influence on the residual stress and on the adherence of the coating on the substrate. In this work, were evaluated the adherence, morphology, and hardness of 316L and Cu coatings, 3, 6, and 9 passes, on two thickness carbon steel substrates. The results show that thicker coatings had lower adherence, but the morphology and hardness had no effective changes. These variations of adherence were less evident on coatings sprayed on a thinner substrate.

Poster 24: Spheroidization of Al-33Cu Droplets Microstructure

Quentin Champdoizeau, Hani Henein
University of Alberta, Canada

Abstract: Under rapid solidification conditions, Al-33Cu droplets develop a particular microstructure composed of two different eutectic morphologies. An undulated eutectic is assumed to grow during recalescence followed by a regular eutectic growth during near equilibrium solidification. The undulated region present generally a finer and more isotropic microstructure with greater Vickers hardness. However, it's possible to apply a heat treatment on the Al-33Cu droplets to refine and homogenize the microstructure yielding to better mechanical properties.

Heat treatment act as a molecular diffusion activator that can help reshaping the regular eutectic lamellar microstructure. Generating grooves in the lamellar microstructure create triple junctions at the Al-CuAl2 interface that will develop with time depending on the heat treatment temperature applied until the lamellae is broken in two. If the heat treatment continues however, coarsening will occur resulting in poorer mechanical properties.

This project aims at understanding the groove development process at the Al-CuAl2 eutectic interface and building a model to predict the optimal heat treatment time of application depending on the temperature and the droplet size. The final objective is to control the spheroidization of the regular lamellar eutectic zone and achieve better mechanical properties for rapidly solidified Al-33Cu droplets.

Poster 25: Thermo-mechanical Modeling of Laser Powder Bed Fusion of Ti-6Al-4V

Pegah pourabdollah, Steven Cockcroft, Daan Maijer, Farzaneh Farhangmehr
The University of British Columbia, Canada

Abstract: The study of the residual stresses in powder bed additive manufacturing (PBAM) processes is critical to better controlling and minimizing component deformation. In fact, the distortion and residual stresses not only degrade the dimensional accuracy and mechanical performance of components, but also increase the manufacturing costs. Consequently, an accurate estimation of residual stresses and distortion is essential to achieve dimensional accuracy and prevent delamination, premature fatigue failure and buckling of metallic parts. Even though experimental methods play an important role to measure residual stresses, they can be expensive and time consuming. Therefore, a validated fundamental-based numerical model can predict the entire stress state and reduce the experimentations needed to optimize process parameters. In this research, a macroscale thermomechanical model is developed to simulate the build process. The model can calculate temperature gradients and the residual stress for Ti–6Al–4V build. Lumping or layer agglomeration method is used to speed up the computations. The predicted results are compared to the results from a literature-based study.

Poster 26: Finite Element Modelling of Residual Stresses and Metallurgical Phases for 4140 Steel

Shaun Cooke*, Keivan Ahmadi*, Rodney Herring*, Greg Sweet**, Donald Paul Bishop**
**University of Victoria, Canada | **Dalhousie University, Canada*

Abstract: Numerical modelling of the additive manufacturing process can provide opportunities to optimize the mechanical properties of the printed metal through mapping the residual stresses and grain morphology. Residual stresses, specifically tensile, can cause serious premature mechanical failure due to enhanced crack propagation. Additionally, mapping the volume fractions of each metallurgical phase can give a better idea of what specific post-processing treatments need to be imposed. This research is in collaboration with Dalhousie University to model their current direct energy deposition (DED) metal printer for 4140 steel. A G-code interpolator was developed in Python to discretize the commands into spatial coordinates and corresponding laser power for the finite element software at each timestep, providing the capability to model complex geometries. A thermal, mechanical and metallurgical finite element analysis of the process is being conducted to model the residual stresses and grain morphology of as-built 4140 steel. Upon completion of this model, machine process parameters such as hatch spacing, scanning speed, laser power and dwell time can be altered to achieve optimal residual stresses and microstructures.

Poster 27: Thermal Fluid Modelling of Melt Pool Dynamics in the Electron Beam Additive Manufacturing of Ti6Al4V

Eiko Nishimura, Steve Cockcroft, Daan Maijer, Farzaneh Farhang-Mehr
The University of British Columbia, Canada

Abstract: The generation and behaviour of melt pool affect pore formation, temperature history and grain size during Additive manufacturing (AM). These, in turn, have an impact on the mechanical properties of final built parts. In the current research, a series of quantitative experimental and numerical analyses were conducted during a Powder-Bed Electron Beam Additive Manufacturing (PB-EBAM) process. These analyses were done on different scan paths and with different scan speeds.

The experimental procedure included single and double-track beam paths melting on CPTi substrate and CPTi substrate with Ti64 powder. The numerical analyses include the development of a thermal-fluid model of the single and double-track melting using Flow3DTM software. The following phenomena were included in the model: a free upper surface, a moving surface-based heat flux (Gaussian Distribution), heat transfer, recoil pressure due to evaporation, and buoyancy and Marangoni forces. In conclusion, a reasonable agreement between the experimental and modelling results was achieved.

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Poster 28: Meso-scale Modelling of Strain Evolution in Powder-Bed Electron Beam Additive Manufacturing

Asmita Chakraborty, Farzaneh Farhang Mehr, Daan Maijer, Steve Cockcroft
The University of British Columbia, Canada

Abstract: Components fabricated by Powder-Bed Electron Beam Additive Manufacturing (PB-EBAM) technique are often susceptible to distortion and residual stress development. Those parts undergo recurrent heating, melting, solidification and cooling during AM which adversely affects the service life of the components [1,2]. The load transfer due to the deformation at the interface between fresh powder and the solidified layer is dependent on the evolution of elastic, plastic and thermal strains [3]. There is limited research in the area of the complex interaction between the powder, the previously consolidated layer and the AM process parameters, namely, beam spot radius, speed, power, et cetera. In this research, a sequentially coupled thermomechanical model is developed to investigate the strain accumulation during the solidification of the melt zone at the meso-scale level.

POSTER SESSION 2
June 26 | 12:20pm – 2:00pm EDT

Theme 3: Process Monitoring and Control

Poster 29: Development of Analytical Model for Eddy Current Applicable to Additive Manufacturing

Heba Farag, Ehsan Toyserkani, Behrad Khamesee
University of Waterloo, Canada

Abstract: Laser Additive Manufacturing (LAM) involves many process parameters such as laser power, hatch spacing, scan speed, layer thickness and powder morphology. All of these parameters affect the quality of LAM-produced parts if not chosen properly. some of the challenges that LAM encountered are porosities and cracks created within the layers of LAM-made parts. In this study, different eddy-current based probe designs were investigated to assess the feasibility of the detection of defects with different sizes and at different depths in parts made by conductive materials using LAM. An analytical model of a surface defect embedded between the layers of the material is done using the Cauchy's Argument Principle to define the complex Eigenvalues that satisfies the electromagnetic interface condition between the defect area and the material.

Poster 30: In-line Optical Measurement System for 3D Process Monitoring of a Fused Filament Fabrication (FFF) Printer

Kristof Briele, Dominik wolfschlaeger, Max Ellerich
RWTH Aachen University, Germany

Abstract: Controlling part geometry and the assessment of suitable print parameters are still two of the greatest challenges in implementing Additive Manufacturing processes in the producing industry. Therefore, this study aims for developing a self-optimizing printer by integrating an in-line monitoring system. The in-line optical measurement system presented on the poster features two laserline sensors and a position sensor mounted into a FFF printer and is the basis for any process control. The light section sensors are mounted on the movable cross-beam and measure the surface geometry after each printed layer. Thus, both the inner structure and outer part geometry are measured with a high resolution of approximately 50 µm to identify misplaced filament and voids. The target model represents the entire filament structure as stated in the g-code with a cross section approximated by a chamfered rectangle. Both 3D models are compared using the Hausdorff distance calculating the deviation for each point. Currently, the measurement system detects local errors such as missing filament, defects and excess material; global geometry deviations are detected as areas of high deviation. With model reduction, the goal is to extract distinct and explicit part errors as input for the control system.

Poster 31: Improving the Geometric Accuracy of Additive Manufactured Parts via 3D Metrology Feedback and CAD Morphing

Moustapha Jadayel, Farbod Khameneifar
Polytechnique Montréal, Canada

Abstract: Additive manufacturing (AM), like any other manufacturing process, produces parts that deviate from their nominal designed geometry. There are several causes for geometric deviations of AM parts including temperature-induced material contraction, the staircase effect, CAD model tessellation inaccuracies, and machine errors. The geometric variation of manufactured parts must be kept within the limits of specified tolerances to ensure the parts' functionality. We propose a method based on 3D metrology feedback to detect geometric deviations and produce a tessellated model (STL) that can be used to print a part with improved geometric accuracy. This method uses a structured-light 3D scanner to scan any test or production 3D printed part. The point cloud data produced by this scan is then compared to the original CAD model to determine the deviations of the printed part. The deviations are applied as vector fields to the scanned data, which allows smoothing it to reduce noise. A new STL is then created using a novel extrapolation-based morphing method with the vector field of the deviations and the CAD geometry. Case studies demonstrate that printing this new STL on the same machine produces a part with reduced systematic errors and thus more accurate geometry.

Theme 4: Novel AM Processes and Products

Poster 32: Distributed Residual Strain Measurement in Additively Manufactured Stainless Steel Cantilever using Fiber Optic Sensors

Farid Ahmed, Ehsan Marzbanrad, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Thermal gradients induced in layer-by-layer printing of laser powder-bed fusion (LPBF) processes results in residual stress in the final part. Understanding of inborn residual stress and deformation (when supports are removed) is crucial to both the design and successful printing of metallic components. This work uses fiber Bragg grating (FBG) sensors embedded in cantilever beams to measure distributed residual strain when supports are cut one-by-one. As the supports are cut, the magnitude of the spring-back distance of the cantilever arm gradually increases. For each deflection of the cantilever beam, the embedded FBG experience a proportional compressive load and thus shows a spectral red-shift. Such spectral shift can be utilized in this study to measure distributed residual strain in the cantilever beam. 17-4 PH stainless steel powder was used to print the cantilever beams using LPBF technique.

Poster 33: Microstructure and Hardness of 34CrNiMo6 Steel Fabricated by Solid-State Additive Manufacturing

Mohammad Hossein Sakhaei, Aziz Shafiei-Zarghani, Ali Zamani
Shiraz University, Iran

Abstract: Within the next few years, additive manufacturing is likely to become an important component in the 4th industrial revolution. Among all additive manufacturing methods, solid-state techniques are attracting considerable interest due to their several advantages such as using low energy to produce parts and their ability to fabricate dense objects with wrought microstructure without solidification related imperfections. The aim of this study is to optimize the processing parameters in friction surfacing additive manufacturing of 34CrNiMo6 steel and to analyze the microstructure and mechanical properties of fabricated parts in different directions. For this purpose, different values of rotational speeds, traveling speeds, and feeding rates were used as processing parameters, and also the amount of axial force and temperature for each set of parameters were recorded during the process. Optical and scanning electron microscopy studies of longitudinal and cross-sections of fabricated samples revealed that the final microstructures consist of needle shape and Widmanstatten ferrite type. Plus, microhardness measurements showed that the maximum achieved hardness values of samples is approximately 730 HV which is significantly more than that of the initial rod. In the following, we will assess the relationship between parameters, microstructures and microhardness profiles in different directions of fabricated parts.

Poster 34: In-situ Volume Reconstruction for Additive Manufacturing Repairs: A Review

Remy Samson, Thomas Lehmann, Hani Henien, Ahmed Jawad Qureshi
University of Alberta, Canada

Abstract: Highly complicated and expensive components often get defects and deformation such as cracks or dents that need to be repair before a new operation. Additive manufacturing plays a significant role in these field by decreasing the repairing time and price. The pre-processing is divided into three steps, which are :locate the damages in the worn part, evaluate the volume of damages, and select the proper pre-repair

process. The goal of this paper is to provide the main processes and algorithms already used to go through these three parts and, at the end, figure out a systematic practical pre-processing methodology. This review will deal with the following assumptions: the damage location is determined using a 3D scanner. The obtained scan file is compared to the scan or the CAD version of the nominal one. The volume and

the shape of the damage is computed using several algorithms. A pre-repair intervention by subtractive manufacturing is considered in case where a direct repair by additive manufacturing cannot be applied.

Poster 35: A Surface Roughness Constraint for Topology Optimization

Ken Nsiempba, Osezua Obehi Ibhadode, Ehsan Toyserkani
University of Waterloo, Canada

Topology optimization (TO) is the reorganization of material layout based on forces and constraints within a design space. Historically, T.O. has mainly been just a theoretical process for the years preceding the adoption of more adequate manufacturing processes. Processes such as additive manufacturing (AM) or even injection molding have allowed T.O. results to be manufacturable. However, despite the advancement in their ability to manufacture complex geometries, AM technologies still have a hard time manufacturing some features. Several reviews have been done to describe the existing approaches done to incorporate those manufacturing constraints in T.O. programs. However, one thing that has less been discussed, is the ability to manage two manufacturing constraints which are coupled (affecting each other). For example, the size of an overhang will impact the minimum orientation it can have.

This study does many things. It first provides the reader with background knowledge on T.O., on the types of existing AM constraints and on how they can be mathematically formulated. It then discusses how manufacturability can be expressed in terms of the feature's size and the feature's orientation. Finally, it presents a case study that validates the approach.

Poster 36: Manufacturing of 3D Lattice Structures by Hybrid Investment Casting

Abdoul-Aziz Bogno, Mubashir Chand Tamboli, Ahmed Jawad Qureshi, Hani Henein
University of Alberta, Canada

Abstract: Manufacturing 3D lattice structures is motivated by the desire to minimize the amount and weight of materials used in making a component for a specific application. Aluminum alloys are the most widely used materials for weight-reduction, either in a monolithic solid or in a porous/lattice structural form. However, it is very challenging to manufacture periodic lattice structures of a defined unit cell, size, and solid material volume fraction using conventional casting techniques. A combination of 3D printing and investment casting in a hybrid manufacturing process is found to yield low cost complex shape products with improved surface quality. This paper reports on the hybrid investment casting of diamond strut-based periodic lattice structures of A356. Stereolithography (SLA) 3D printing was used to produce mold pattern for casting. Various mold, and melt temperatures were investigated to determine the effects of each thermal history on the microstructure and mechanical properties of the generated lattice structures. Optical an electron microscopy were used to characterize the microstructural scale and phase fractions. Cooling rates were deduced from cell spacing measurement, and fraction porosity was estimated by stereology. Vickers hardness, tensile, and compression tests were carried out to determine the mechanical properties.

CANCELED Poster 37: Mechanical performance of Additively Manufactured Aluminium Auxetic Structures

Manpreet Singh, Arun Arjunan
University of Wolverhampton, United Kingdom

Abstract: The ability of additive manufacturing (AM) to create highly complex metallic structures at the micron-scale that can exhibit auxetic behavior is gets significant interest in recent years. The reason behind is the auxetic behavior is non-traditional and have superior mechanical and energy absorption capabilities. While unique properties of auxetic makes them superior as compared conventional materials but they are limited in availability. The research aims to design and study the mechanical performance of a new class of layered negative Poisson's ratio structures that is inherently stable. These structures exhibit average negative Poisson's ratio despite allowing both lateral expansion and compression under loading. While these structures exhibit some areas of lateral expansion, the overall behavior is comparable to re-entrant auxetic architecture. The research objectives will be achieved by exploiting the geometrical freedom provided by metal additive manufacturing. The layered designs will be informed through finite element analysis and experimental testing. Design of experiments (DoE) will be consulted to inform the influence of design parameters namely wall thickness and auxetic angle on the mechanical performance of thin and thick-walled variants. It is anticipated that the research aids in the development of lightweight auxetic structures suitable for multiple application.

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

Poster 38: Geometric Consideration of Support Structures Design for Overhang Features of Dental Implants Fabricated by Selective Laser Melting

Arman Khobzi*, Swee Leong Sing**, Wai Yee Yeong**, Steven Cockcroft*, Daan Maijer*, Farzaneh Farhang-Mehr*
**The University of British Columbia, Canada | **Nanyang Technological University, Singapore*

Abstract: Successful production of parts using selective laser melting (SLM) process, often requires additional structures that provide heat dissipation and mechanical support in the overhang features and prevent geometrical distortion caused by thermal stresses. Support structures are removed after the process is finished and add additional cost and time to the process; therefore, designs must be optimized such that they reduce waste and increase the sustainability of the process. Additionally, surface quality and deformation of the overhanging features are influenced by the geometry of the support structure. In this research, the effect of the geometrical design of support structures on surface quality and deformation of the finished parts are investigated using design of experiment (DOE) method. Based on the obtained results, several designs are suggested by the authors for a dental implant. Additionally, various designs of support structures were produced and analyzed to find the critical parameters one should consider when designing support structures. Wall thickness of hollow structures, support hatch distance, fixation points interval and surface area of each fixation point were found to be critical and improper design of each parameter may result in process termination or impose significant costs and time to the process.

Poster 39: Novel Limb Sparing Technique Using 3D-Printed Patient-Specific Endoprostheses for Tumor of the Proximal Humerus

Martin Tran Hoai Tri Thien*, Anatolie Timercan**, Bertrand Lussier***, Bernard Seguin^, Yvan Petit**, Vladimir Brailovski**
École Centrale Paris, France |École de technologie supérieure Montreal, Canada | ***Université de Montréal, Canada | ^Colorado State University, United States*

Abstract: Osteosarcoma afflicting the proximal humerus is one of the predominant types of bone cancer affecting large breed dogs. Whereas the successful use of 3D printed patient-specific endoprostheses for dogs afflicted by tumors of the distal radius has been recently reported, the extension of such an approach to the proximal humerus remained unexplored. The main purpose of this project is therefore to develop the concept of limb sparing of the proximal humerus using patient-specific endoprosteses, thus offering a novel procedure for this common disease.

To start, two cadaveric limb CT-scans were used to reconstruct bone models that served as scaffolding for the design of the shoulder replacement personalized endoprostheses (PE) and cutting guides (CG). The PEs were 3D printed from metallic alloy using laser powder bed fusion technology, whereas the CGs were 3D printed from plastic using fused deposition modeling technology.

Finally, the endoprostheses were implanted in the cadaveric limbs, thus allowing the design readjustments and the operating sequence validation. To support future related studies, an instrumented artificial limb has been designed, built and tested to mimic the canine gait, observe the geometry consistency with dog anatomy, and offer validation data for biomechanical modeling.

Poster 40: Topology Optimization of Imperfect Lattice Materials Built with Process-induced Defects via Powder Bed Fusion

Ahmed Moussa, David Melancon, Asma El Elmi, Damiano Pasini
McGill University, Canada

Abstract: Lattice materials built with current additive technology feature process-induced defects that impact their mechanical properties and optimum design. This work presents a methodology to integrate geometric defects in a density-based formulation for topology optimization of additively built lattice materials. The method combines imperfect unit cell models capturing their geometric defects with a homogenization scheme upscaling their effective properties, into a topology optimization formulation. The method is of general application, and it is here demonstrated through the application to two cell topologies, the Tetrahedron-based and the Octet-truss unit cells, called to satisfy specific geometric constraints. Validation is performed through the solution of two well-known benchmark problems in 3D: the fixed-beam and the L-shaped beam, assumed to consist of either defect-free or imperfect lattice materials. The impact of process-induced defects and cell orientation is demonstrated on the elastic anisotropy of the unit cell, the optimized gradients of relative density and the global compliance of the beams. The results highlight the significance of accounting for geometric defects in topology optimization of additively built lattice materials.

Poster 41: Effects of Process Parameters on Material Characteristics During Direct Energy Deposition of AISI D2 Tool Steel

Samer Omar, Kevin Plucknett
Dalhousie University, Canada

Abstract: Additive manufacturing (AM) possesses an immense potential for growth due to its high shaping flexibility and minimum material waste. Direct energy deposition (DED) is an AM technology where fully dense metal parts can be directly produced from a CAD model. During the process a metallic substrate is scanned by a laser beam to create a molten pool, while a powder delivery system is used to convey a powder stream into the molten pool. DED manufactured parts can have high strength and high toughness. However, high residual surface roughness is one of the main challenges in DED process. In this work, various process parameters were examined in order to improve the surface roughness of the deposited part. The work has involved DED of parts of AISI D2 tool steel powder deposited onto a substrate of the same composition, where different powder feed rates and laser scanning speeds were used. The effects of each individual parameter (feed rate, scan speed, etc.) will be investigated while fixing the other parameters. The surface roughness of parts will be measured using confocal laser scanning microscopy. In addition, preliminary tensile, instrumented indentation hardness and scratch tests will be reported on both the as-deposited and austenitised/quenched/tempered materials.

Poster 42: Cellular Structures for Application in Intervertebral Devices: Functional Requirements and Preliminary Results

Anatolie Timercan, Vadim Sheremetyev, Vladimir Brailovski
École de technologie supérieure Montreal, Canada

Abstract: Spinal health problems are increasingly common and in extreme cases require intervertebral fusion surgery. Currently used commercial intervertebral devices present complication risks such as lack of fixation, implant migration and subsidence. An emerging solution to these problems is the use of additively manufactured devices integrating lattice structures which allow the control of mechanical properties and the possibility of osseointegration. In order to evaluate the performance of various lattice configurations, the functional requirements for such devices had to be established in terms of their adequate ranges of geometric, mechanical and fluid permeability properties.

Two types of lattice structures were selected: strut-based diamond and sheet-based gyroid. Structures with an equivalent pore size of ~750μm and porosity levels of 60, 70 and 80% were designed and numerically simulated in terms of their mechanical resistance and fluid permeability. They were then manufactured from Ti-6Al-4V powder using a Trumpf TruPrint1000 laser powder bed fusion system. The resulting components were subjected to computed tomography analyses to measure the CAD/Print geometric deviations and to identify the nature, morphology and distribution of processing-induced defects. Mechanical testing of these structures allowed the measurement of their apparent mechanical properties and experimental validation of the developed numerical models.

Poster 43: Effect of Different Production Technologies on the Miscibility of Fe-Cu and Cr-Mo

Rabia Aftab, Maksim Antonov
Tallinn University of Technology, Estonia

Abstract: Immiscible metals are metals which do not mix with each other in equilibrium conditions. Our research hypothesizes that non-equilibrium processing of immiscible metals would bridge the miscibility gap of immiscible metals, producing materials with unique (material) properties.

There are innumerable immiscible metallic systems â€“ varying in their miscibility gaps. We have studied the Fe-Cu and Cr-Mo immiscible metallic systems to begin with this research. Fe-Cu and Cr-Mo metal powders, in various weight proportions, have been fused with Selective Laser Melting (SLM). SLM offers non-equilibrium processing conditions for materials. The same immiscible metal powders have been processed with other production technologies: spark plasma sintering and ball milling. The effects of the different non-equilibrium manufacturing techniques on the miscibility of the Fe-Cu and Cr-Mo systems, have been evaluated through X-Ray Diffraction (XRD). The microstructures of the samples have been obtained through Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Spectroscopy (EDS), to make phase analyses. A comparison of the XRD patterns revealed supersaturated solid solutions in the Fe-Cu and Cr-Mo systems, with some production technologies.

Poster 44: Effect of Process Parameters on Plasma Transferred Arc Additive Manufactured (PTA-AM) 17-4PH using the Taguchi Method

Sandy Ibrahim*, Jose G. Mercado Rojas*, Tonya Wolfe**, Hani Henein*, Ahmed Qureshi*
**University of Alberta, Canada | **InnoTech Alberta, Canada*

Abstract: PTA-AM is a newly developed AM process proposed for the manufacturing of large industrial parts that can be used in the resource sector. 17-4PH stainless steel is a common material used in numerous industries due to its good corrosion resistance, ease of fabrication and an UTS of about 1400 MPa at peak age hardening. The PTA-AM system has numerous process parameters such as shielding gas pressures and flowrates, current, voltage, angle of powder nozzle deposition relative to the welding direction and speed of an automated table connected to the PTA-AM system. A G-code for the automated table was developed for each desired printed AM shape. The different combinations of the above parameters can result in numerous mechanical properties and microstructures of the AM samples. A full factorial of experiments to print an optimized (minimum porosity and at least comparable hardness and UTS relative to other manufacturing processes) 17-4PH stainless AM part isnâ€™t feasible within a reasonable timeframe. Thus, a Taguchi design of experiments (DOEs) was designed to identify the most influential parameters on the final mechanical properties and microstructure. This poster will present the results from Taguchiâ€™s DOEs and their relationship to the built PTA-AM of 17-4PH stainless steel samples.

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Contact:

Farzad Liravi
fliravi@uwaterloo.ca

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