HI-AM Conference

4th | 2021

HOLISTIC INNOVATION IN ADDITIVE MANUFACTURING

PARTICIPANT INFORMATION PACKAGE

JUNE 1 & 2
VIRTUAL

nserc-hi-am.ca/2021

NSERC HI-AM

UNIVERSITY OF WATERLOO

NSERC CRSNG

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CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION

UNIVERSITY OF WATERLOO

DALHOUSIE UNIVERSITY

2021 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 2021 HI-AM Virtual Conference.

It is hard to believe that one year has passed from last year's virtual conference. We were hoping to organize the 2021 HI-AM conference in person in Halifax, but the continuation of the pandemic gave us no choice but to hold the event virtually once again. With the deployment of vaccinations around the globe, it seems we are at the end of the tunnel, and we may hopefully get back to some normalcy soon. If so, we are planning to arrange for a hybrid in-person and virtual conference in 2022 at McGill University in Montreal.

This second 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, and explore opportunities for future research collaborations. Furthermore, numerous opportunities for online networking will be provided throughout the conference platform.

We are honored to have five internationally recognized experts as our keynote speakers: Professor Anthony Rollett, Carnegie Mellon University, United States; Dr. Simon Hoeges, GKN Additive, Germany; Professor Michael Schmidt, Institute of Photonic Technologies-FAU, Germany; Professor Christopher Williams, Virginia Tech, United States; and Professor Michael Sealy, University of Nebraska-Lincoln, United States. The conference also features 115 presentations and posters on cutting-edge research in the area of metal additive manufacturing (AM).

In this welcome package, you will find information on how to navigate through the conference online platform (Pathable) so as to watch the presentations, make a connection with participants/exhibitors, plus many more features. We encourage you to read through this package to ensure you are fully aware of all 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, the Natural Sciences and Engineering Research Council of Canada (NSERC), we would also like to express our appreciation to our exhibitors and partners, SLM Solutions, TRUMPF, Suncor, EOS, PostProcess Technologies, Promation, Xact Metal, Javelin, KSB, Pulstec, Exergy Solutions, Multi-Scale Additive Manufacturing Laboratory (MSAM), and Leichtbau BW (TracLight).

We have implemented a number of new features in this year's gathering. Hence, we anticipate that the conference will go forward smoothly and sincerely hope that you enjoy, and benefit from, this Virtual HI-AM event.

Ralph Resnick
Chairman of the Board

Paul Bishop
Conference Co-chair

Ehsan Toyserkani
Network Director
Conference Co-chair

Exhibitors and Partners

PARTNERS

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

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

PLATINUM SPONSORS

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

EXERGY SOLUTIONS is Alberta's largest additive manufacturing company with industrial scale AM equipment including FDM, SLA, SLS and HP MJF polymer printers and a Renishaw metal printer, production scale depowdering and vapour smoothing and CNC machining. Our AM team develops solutions to AM's toughest technical and design challenges. Exergy works with a wide range of partners including universities and colleges, start-ups, SMEs, and Alberta's largest companies. Exergy's mission is to accelerate innovation for current industries and to support the growth of clean technology companies and AM is a key enabler of this mission.

www.exergysolutions.com

Exhibitors and Partners

PLATINUM SPONSORS continued

POSTPROCESS TECHNOLOGIES is the world leader in automated additive manufacturing post-printing technology. We are the first and only provider of data-driven, intelligent, end-to-end solutions for post-printing, also known as post-processing of 3D printed parts. PostProcess removes the “bottleneck” in the third step of additive manufacturing – post-printing - through a combination of patent-pending, integrated technologies including software, hardware, and chemistry. Our solutions deliver unparalleled consistency and increased throughput as well as enable greater productivity.

www.postprocess.com

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

www.promation.com

SLM SOLUTIONS GROUP AG is a publicly traded company headquartered in Lübeck, Germany. As an inventor of the selective laser melting process, our company focuses on the development and distribution of the most innovative, production-oriented metal additive manufacturing systems. Our focus is to be a leader in product performance and innovation and for you, as our customer, to benefit from that approach.

www.slm-solutions.com

SUNCOR ENERGY is a unique and sustainable energy company dedicated to vigorous growth in worldwide markets through meeting or exceeding the changing expectations of our current and future stakeholders.

www.suncor.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

GOLD SPONSORS

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

Pulstec Industrial Co., Ltd.

PULSTEC provides non-destructive X-ray diffraction(XRD) based residual stress analyzer. This small, light-weight, low-cost, low-radiation-dose, fast-cycletime analyzer can measure RESIDUAL-STRESS, FWHM and RETAINED-AUSTENITE by detecting the full Debye ring's profile from single incident X-ray angle. Mapping option is available.

www.pulstec.co.jp/en/

SILVER SPONSORS

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. They have partnered with many Canadian Industry leaders, taking their 3D design processes to the next level.

www.javelin-tech.com/3d/

KSB is a pioneer in end-to-end solutions in additive manufacturing. With our state-of-the-art technology and equipment, we offer our expertise across the entire additive manufacturing process. KSB has been developing expertise in metal additive manufacturing (AM) over the past 10 years, investing in equipment and processes to implement AM into pump and valve manufacturing. KSB has a materials engineering approach to AM, understanding how AM compares to casting and forging and allowing it to implement AM for serial product production. KSB has the first ever certificate for additive manufacturing of materials and semi-finished products for pressure equipment from TÜV SÜD. In 2018, after receiving many requests for support from others, KSB set up an AM consulting and testing service. KSB is offering all of its expertise in AM, from business case development, design for additive, alloy development, production, quality control, and testing. KSB has been contracted by equipment manufacturers, equipment end users, AM machine vendors and metal powder vendors in Europe and Canada. KSB believes that by supporting the manufacturing industry to adopt AM successfully, this technology will mature more quickly, benefiting everyone.

www.ksb.com/additive

NSERC HI-AM Network

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

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

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

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

NSERC HI-AM

Network Partners

ACADEMIC AND RESEARCH INSTITUTION PARTNERS

MEMBERS

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

COLLABORATORS

École de technologie supérieure (ÉTS) · University of Windsor

INTERNATIONAL

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

INDUSTRY PARTNERS

AP&C a GE Additive company · Autodesk · BOCO Technology Inc · equispheres · FLEXCAP
GKN · KSB · MDA · Pratt & Whitney Canada A United Technologies Company · PROMATION
Renishaw apply innovation™ · RioTinto · Siemens Energy · Syncrude · TIMET

GOVERNMENT PARTNERS

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

NON-PROFIT AND HEALTHCARE PARTNERS

CM&E Canadian Manufacturers & Exporters · Canada Mining Innovation Council · ReMAP Refined Manufacturing Acceleration Process · AAPF Accélération de l'amélioration des processus de fabrication
Mount Sinai Hospital

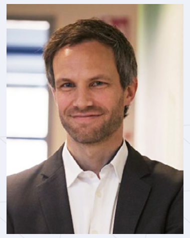
Keynote Speakers

Anthony Rollett

US Steel Professor of Metallurgical Engineering & Materials Science
Carnegie Mellon University, PA, United States

Rollett is the US Steel Professor in Metallurgical Engineering and Materials Science at Carnegie Mellon University where he has been since 1995, having previously been at the Los Alamos National Laboratory from 1979. He is recipient of multiple awards including Fellow of TMS in 2011 and International Francqui Professor for 2021-2022 (Belgium). He is known for his work on texture, 3D microstructures and micromechanical simulation. He is a co-Director of the NextManufacturing Center at CMU and is a leader in research & education in metals additive manufacturing.

Presentation Title: ICME Gaps for Qualification of Metals Additive Manufacturing of Metals



Simon Hoeges

Director Technology & Manufacturing Engineering
GKN Additive, Germany

Simon is responsible for Technology and Manufacturing Engineering at GKN Additive. He joined GKN in 2014 after positions in Medical industry and Academia all associated with Additive Manufacturing giving a track record of 15 years within the technology. At GKN he is responsible for development, validation and global implementation of new technologies, processes and materials. The technology focus within GKN Additive is with Laser Powder Bed Fusion and Binder Jetting showing strong synergies with its parent company GKN Powder Metallurgy. Simon holds a diploma in physics and a PhD in mechanical engineering from RWTH Aachen University.

Presentation Title: AM Designed Materials – Application Driven Hand in Hand Material and Process Development

Michael Schmidt

Head of Institute of Photonic Technologies
Friedrich–Alexander University Erlangen–Nürnberg, Germany

Head of Institute (Ordinarius), Lehrstuhl für Photonische Technologien, Friedrich-Alexander-Universität Erlangen-Nürnberg (since 03/2009)

Managing Director, Bayerisches Laserzentrum GmbH (blz) (since 01/2005)

Mega Grant (Presidential Grant) in Russia: Build up a laboratory on Additive Technology with KAI – Kazan University (2014 – 2018)

INO – Institute National d'Optique, Québec, Canada: Associate Researcher (2011 – now), Member of R&D Advisory Committee (2011 – now)

Laser Demonstration Center (LDC), Sankt Petersburg: Advisory Board (2009 – now)

CIRP: STC-E-Chairman (2020 – 2023); Associate Member (2014 – now)

Presentation Title: The Benefit of Using Nanoscale Additives in Laser- and Powder-based Additive Manufacturing (AM) of Metals

Christopher Williams

L. S. Randolph Professor, Mechanical Engineering
Virginia Tech, VA, United States

Dr. Christopher Williams is the L.S. Randolph Professor and the Electro-Mechanical Corporation Senior Faculty Fellow in the Department of Mechanical Engineering at Virginia Tech. He is the Director of the Design, Research, and Education for Additive Manufacturing Systems (DREAMS) Laboratory. The lab has published over 185 peer-reviewed articles on topics spanning innovations in additive manufacturing processes and materials, Design for Additive Manufacturing methodologies, and cyber-physical security for AM. He is a recipient of a National Science Foundation CAREER Award (2013). He currently serves as the Vice Chair of the Additive Manufacturing Community Advisors for SME.

Presentation Title: Leveraging the Flexibility of Binder Jetting: Printing with Fine Powders, Nanosuspensions, Metal Foams, and Foundry Sand

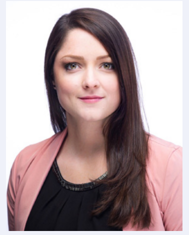
Michael Sealy

Professor, Mechanical & Materials Engineering
University of Nebraska-Lincoln, NE, United States

Dr. Michael Sealy joined the University of Nebraska-Lincoln (UNL) in Lincoln, NE, USA as an Assistant Professor in 2015. His primary research focuses on using advanced manufacturing to solve problems in health and food. More specifically, he currently investigates coupling additive manufacturing with surface treatment technology on metals and polymers to print functionality in biodegradable magnesium implants and tissue engineered constructs for cultured meat. He founded and directs the Nebraska Engineering Additive Technologies (NEAT) Lab. He has received national and international recognitions from ASME, SME, ASM, and MRS, including the prestigious NSF CAREER and SME Outstanding Young Manufacturing Engineer awards.

Presentation Title: Innovative Hybrid AM Processing Technologies and Applications

Invited Speakers

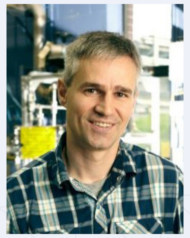


Amy Elliott

Research Staff
Oak Ridge National Laboratory, TN, United States

Dr. Amy Elliott is a full research staff at Oak Ridge National Laboratory and principle investigator for inkjet-related additive manufacturing technologies. Dr. Elliott has published over 50 papers related to additive manufacturing and has several patents and awards in the field. Dr. Elliott's research interests include densification strategies for powder preforms shaped via additive manufacturing and binder systems for binder jet additive manufacturing.

Presentation Title: Metal Additive Manufacturing at Oak Ridge National Laboratory

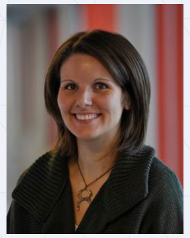


Greg Hersak

Manager, Mechanical Equipment Development
Canadian Nuclear Laboratories, ON, Canada

Greg Hersak graduated from Carleton University in 2002 as a Mechanical Engineer and joined CNL (AECL at the time) in the Mechanical Equipment Development Branch. As an Engineer in this Branch, Greg designed and developed custom mechanical tooling and equipment for the nuclear industry. Greg has been the manager of the Mechanical Equipment Development Branch since 2014. In addition to custom equipment design for nuclear applications, the Branch also operates a number of 3D printers that were selected carefully for design, prototyping and advanced applications targeted at the needs of the nuclear industry.

Presentation Title: Advanced (Additive) Manufacturing at Canadian Nuclear Laboratories

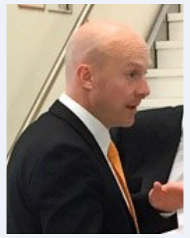


Tonya Wolfe

Manager
Centre for Innovation in Manufacturing Technology Access Centre, Red Deer College, AB, Canada

Dr. Tonya Wolfe recently joined Red Deer College as the Manager for the Centre for Innovation in Manufacturing-Technology Access Centre (CIM-TAC). The team at CIM-TAC use advanced manufacturing tools to design and validate prototypes and solve productivity challenges faced by industry. Tonya has spent two decades developing technology and expertise in metallurgy, materials design, additive manufacturing, welding, wear resistant materials, steelmaking, biomedical engineering and process modeling. She is an adjunct professor at University of Alberta in additive manufacturing, collaborating across multiple departments in the Faculty of Engineering. She leads the Alberta Additive Manufacturing Network, an industry-led organization growing additive manufacturing in Alberta.

Presentation Title: Preparing for an (Un)certain Future: Technology Adoption for Alberta Manufacturing



Ian Brooks

Technical Fellow, AMRC North,
United Kingdom

Ian has extensive experience in the manufacturing industry across different sectors. Up until recently he was a Principal Engineer for Additive Manufacturing where he led the technical delivery of a number of research and NPI projects across the aerospace, medical and industrial sectors. Now a Technical Fellow for the AMRC, he leads the generation and delivery of the AM project themes for the AMRC with key industrial stakeholders and he sits on a number of standards committees as a representative of the BSI's AM steering group.

Presentation Title: Metal AM – Cutting Through the Hype

Matthew Harding

Program Manager
Additive Manufacturing, Tronosjet Maintenance Inc, PE, Canada

Dr. Harding completed a bachelor's in mechanical engineering, followed by a PhD in materials engineering, both at Dalhousie University. His PhD research focused on the industrial production and effects of post-sinter processing steps on the mechanical properties of a commercial 7XXX series aluminum powder metallurgy alloy. Since completion of his PhD, he has been employed by Tronosjet on Prince Edward Island, establishing additive manufacturing (AM) within their Manufacturing Division. He has overseen all aspects of this move into AM, including technology/equipment selection and commissioning, support equipment acquisition, material testing, customer relations, establishing research partnerships and liaison with certification bodies.

Presentation Title: Additive Manufacturing in Aerospace: An SME Perspective

Jorge Cisneros

Application Engineer
EOS, United States

Jorge Cisneros loves to push to boundaries of what is possible to create and develop business cases for the use of additive manufacturing. Jorge Joined EOS in August of 2019 as Application Engineer in Novi, MI, USA. Jorge leverages his many years of experience in the automotive industry as a design engineer that has hands on experience in product development, with his knowledge of additive manufacturing to develop business cases for additive manufacturing improving production efficiency. Jorge received a Bachelor of Science in Mechanical Engineering from The University of Michigan, and Master's from Wayne State University in Mechanical.

Presentation Title: AM and Injection Molding: A Match Made in Automotive Heaven

Invited Speakers

Mark Kirby

Industry Training Manager
University of Waterloo, ON, Canada

After graduating Aero/Astro from MIT, Mark joined Rolls Royce's rocket programme, before moving to his Father's machine shop, Jet Blades. Mark worked his way from CAD/CAM programmer to Managing Director, making parts for Formula 1 teams and jet engines. In 2007 Mark emigrated to the Maritimes in Canada. Mark provided hands-on coaching in advanced manufacturing and taught Engineering at UNB. Mark joined Renishaw in 2013 to head their new Canadian additive manufacturing business and start up their first North American Solutions Centre. In 2020 Mark moved to the University of Waterloo to lead industry training for additive manufacturing.

Presentation Title: Deeper Learning from Productive Failure in Technology Adoption

Ulf Ackelid

Co-founder
Freemelt AB, Sweden

Dr. Ackelid received his Ph.D. degree in Applied Physics from Linkoping University in Sweden in 1995. He has been active in the field of Additive Manufacturing (AM) since 2002, focusing on Electron Beam Powder Bed Fusion (E-PBF). His main interests have been innovation and experimental development of powders, materials and processes for E-PBF. He is a frequent speaker at AM conferences and holds about 20 patents and patent applications in the AM field. In 2017, Dr. Ackelid co-founded Freemelt AB, a new Swedish company exploring the frontiers of E-PBF.

Presentation Title: ProHeat – A New Smoke-safe Preheating Method for Electron Beam Powder Bed Fusion, Opening up a Wider Range of Processable Feedstocks

Career Advice with Additive Manufacturing Professionals

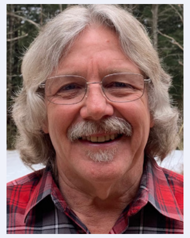
Careers in additive manufacturing can be quite diverse, with an even more diverse career path. Often times, it takes talent, perseverance, networking, planning, and a bit of luck to find your way onto an exciting profession. Join us for a candid "Career Advice with AM Professionals" where you will learn from leaders in the field and have a chance to network and ask questions. The session will be moderated by student peers and we hope it will be informative and fun.

AM CAREER PATHS IN INDUSTRY – MENTORS

Ali Bonakdar

Advanced Manufacturing Technology Lead
Siemens Energy, QC, Canada

Dr. Ali Bonakdar is working at Siemens Energy Canada, as Advanced Manufacturing Technology Lead responsible for strategic development of various advanced manufacturing processes with a particular focus on additive manufacturing. In addition to his industrial role, he is an Adjunct Professor at Concordia University, University of Waterloo and École de technologie supérieure (ÉTS); leading several industrial-academic research projects. He has more than 20 years of industrial and academic experience in different aspects of mechanical engineering, advanced manufacturing and gas turbine engines by working at the state-of-the-art labs and world-class aerospace and energy industries such as Rolls-Royce and Siemens. He completed a Ph.D. in Mechanical Engineering in the Department of Mechanical and Industrial Engineering at Concordia University and continued his studies in the Center for Intelligent Machines at McGill University as Postdoctoral Fellow. He is the author and co-author of several journal and conference papers mostly in advanced manufacturing and materials.



Ian Donaldson

Director Advanced Technology Applications, Labs and IP
GKN Sinter Metals, NH, United States

Ian Donaldson is currently the Director Advanced Technology Applications, Labs and IP for GKN Sinter Metals LLC and adjunct professor in the Mechanical Engineering Dept. at Dalhousie University. With over 41 years in the Powder Metal industry, Ian has served on numerous professional boards and committees. A GKN Engineering Fellow and APMI Fellow, he has over 85 technical publications and 45 patents. He obtained his BS in Metallurgical Engineering from the University of Michigan and a MS in Materials Engineering from Worcester Polytechnic Institute.

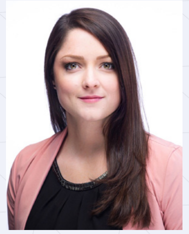
Career Advice with Additive Manufacturing Professionals

AM CAREER PATHS IN RESEARCH LABS – MENTORS

Priti Wanjara

Principal Research Officer
National Research Council, QC, Canada

Dr. Priti Wanjara is Principal Research Officer at the National Research Council of Canada (NRC). She earned her B. Eng (1993) and Ph.D. (1999) degrees from McGill University in Metallurgical and Materials Engineering. Her research has focused on manufacturing process development for metallic materials to the benefit of the scientific community and operations of industrial partners in the aerospace, defence, automotive and energy sectors. Recognized internationally as a leading material scientist, she has co-authored over 200 refereed articles and 100 NRC reports. She is Fellow of ASM International, the Canadian Institute of Mining, Metallurgy and Petroleum and the Canadian Welding Bureau.



Amy Elliott

Research Staff
Oak Ridge National Laboratory, TN, United States

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AM RESUME BUILDING STRATEGIES – MENTORS

Mark Kirby

Industry Training Manager
University of Waterloo, ON, Canada

After graduating Aero/Astro from MIT, Mark joined Rolls Royce's rocket programme, before moving to his Father's machine shop, Jet Blades. Mark worked his way from CAD/CAM programmer to Managing Director, making parts for Formula 1 teams and jet engines. In 2007 Mark emigrated to the Maritimes in Canada. Mark provided hands-on coaching in advanced manufacturing and taught Engineering at UNB. Mark joined Renishaw in 2013 to head their new Canadian additive manufacturing business and start up their first North American Solutions Centre. In 2020 Mark moved to the University of Waterloo to lead industry training for additive manufacturing.

Mihaela Vlasea

Assistant Professor
University of Waterloo, ON, Canada

Mihaela Vlasea is an Assistant Professor at the University of Waterloo, Mechanical and Mechatronics Engineering Department and the Research Co-Director of the Multi-Scale Additive Manufacturing Laboratory. Her research focuses on innovative design, process optimization and adoption of new materials for powder bed fusion and powder bed binder jetting additive manufacturing processes. The research goals are to bridge the technological gaps necessary to improve AM part quality, process repeatability and reliability.

Online Platform Guide

In light of the COVID-19 pandemic, the HI-AM 2021 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 2021 OFFERS THE FOLLOWING FEATURES:

EDUCATION
- On-demand Presentations
- Poster Sessions
- Customized Agenda
- Live Q&A

NETWORKING
- Small Private Meetings
- Discussion Forums
- Private Conversations

VIRTUAL EXHIBITION
- Virtual Tradeshows
- Live Exhibitor Presentations
- Private Conversations with Industry Representatives
- Request Product Information

General Guidelines

IMPORTANT DATES

Access to conference web app for exhibitors:
May 18, 2021

Exhibitor training #1:
May 19, 2021
11am-12pm EDT (meeting link)

Exhibitor training #2:
May 20, 2021
3pm-4pm EDT (meeting link)

Access to conference web app for all registrants:
May 25, 2021

Speaker training #1:
May 26, 2021
11am-12pm EDT (meeting link)

Speaker training #2:
May 27, 2021
3pm-4pm EDT (meeting link)

Conference day 1:
June 1, 2021

Conference day 2:
June 2, 2021

End of access to conference web app:
June 9, 2021

TRAINING & SUPPORT

The virtual 2021 HI-AM Conference is powered by Pathable, an award-winning cross-device desktop web and mobile experience platform providing digital presentation, networking, and exhibition capabilities. Detailed instructions on how to use Pathable platform is provided in this booklet (see pages 18-31). In addition, the following resources are available to speakers, exhibitors, and attendees:

Camp Pathable

To access Pathable's Training Resource Hub:

- Visit **camp.pathable.co**
- Click "Create a New Account" and enter your information
- Use the access code **pathabletraining**

Once logged in to Camp Pathable, a variety of training resources will be available to you:

1. **On-demand training:** Watch recorded training sessions from the Camp Pathable Replays Section. Please note that the HI-AM conference web app is highly customized and not all the information covered in these recordings will be applicable to our event.
2. **Live training sessions:** Live speaker and exhibitor training sessions are provided weekly by Pathable staff. Sign up for these sessions if you have any questions not answered in on-demand training videos.

Technical Support

Contact us about any technical issues you are facing or any questions you might have at **fliravi@uwaterloo.ca** prior to, during, or after the conference. We will direct your questions to Pathable support team.

Exhibitor Training

Two training sessions are scheduled for exhibitors on May 19 and 20 (see the important dates above for details). You will receive calendar invitations with meeting information in May. Please note that you only need to take part in one of these sessions. Topics such as configuration of exhibition booth, Talk Now settings, and hosting exhibitor presentations will be covered in exhibitor trainings.

Speaker Training

Two training sessions are scheduled for presenters on May 26 and 27 (see the important dates above for details). You will receive calendar invitations with meeting information in May. Please note that you only need to take part in one of these sessions.

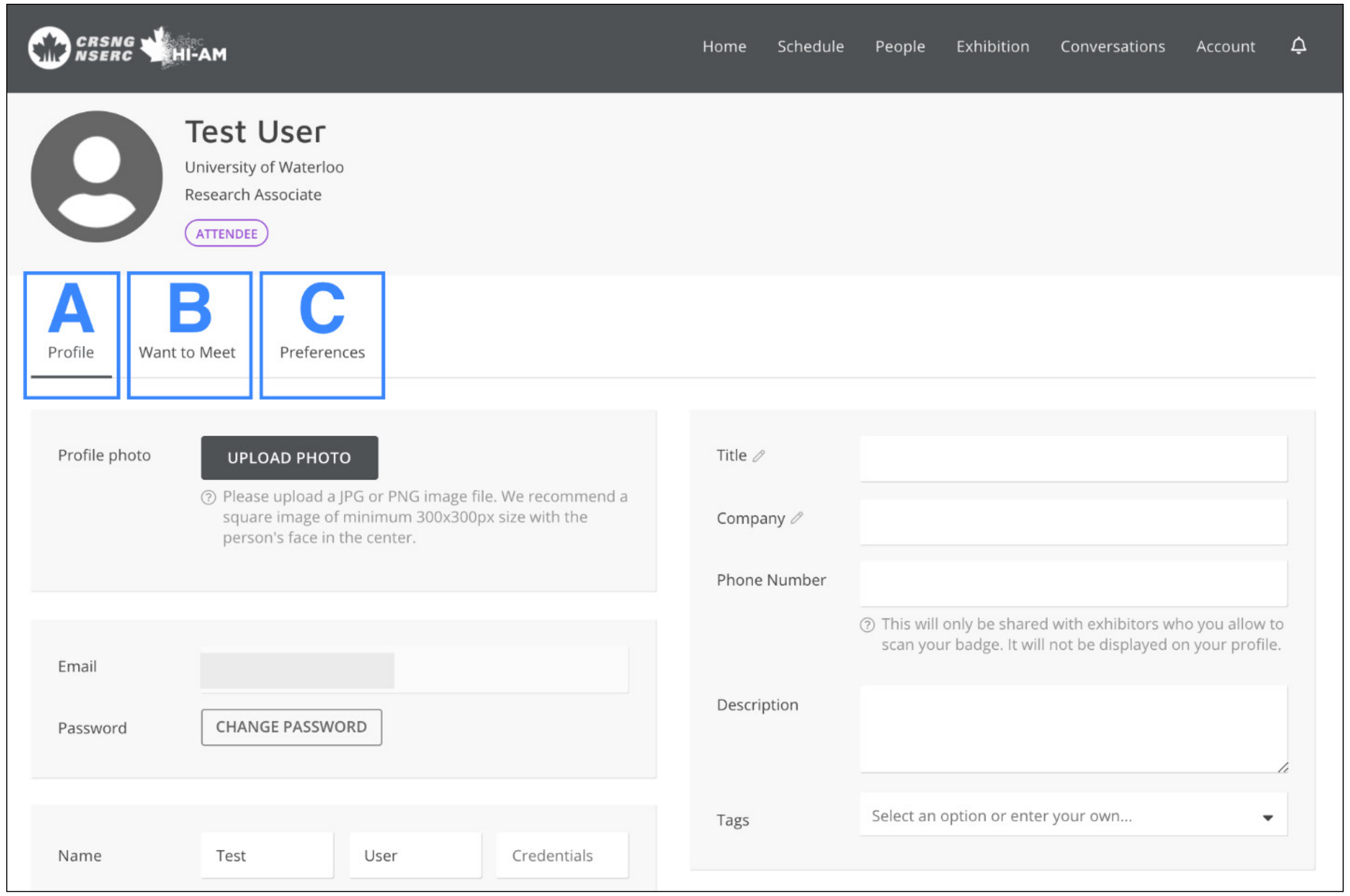
General Guidelines

LOG IN AND SET UP YOUR PROFILE

- You will receive an invitation email to access the conference app a few days before the conference.
- If you have problems 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.
- **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.

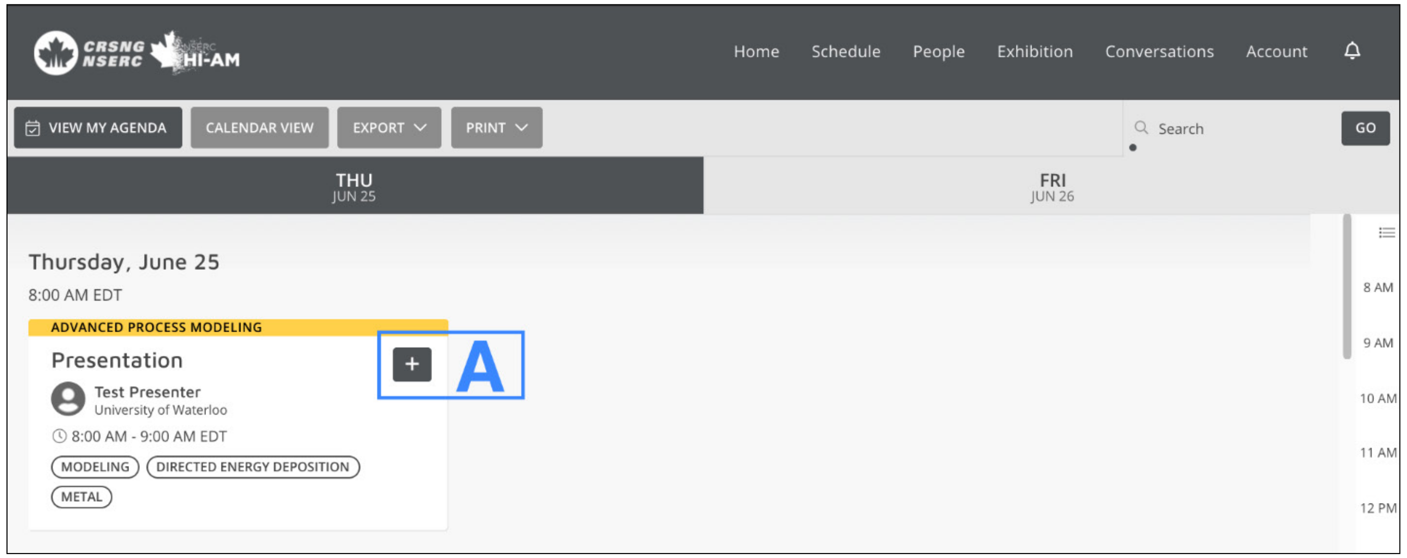


BUILD YOUR AGENDA

- 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.



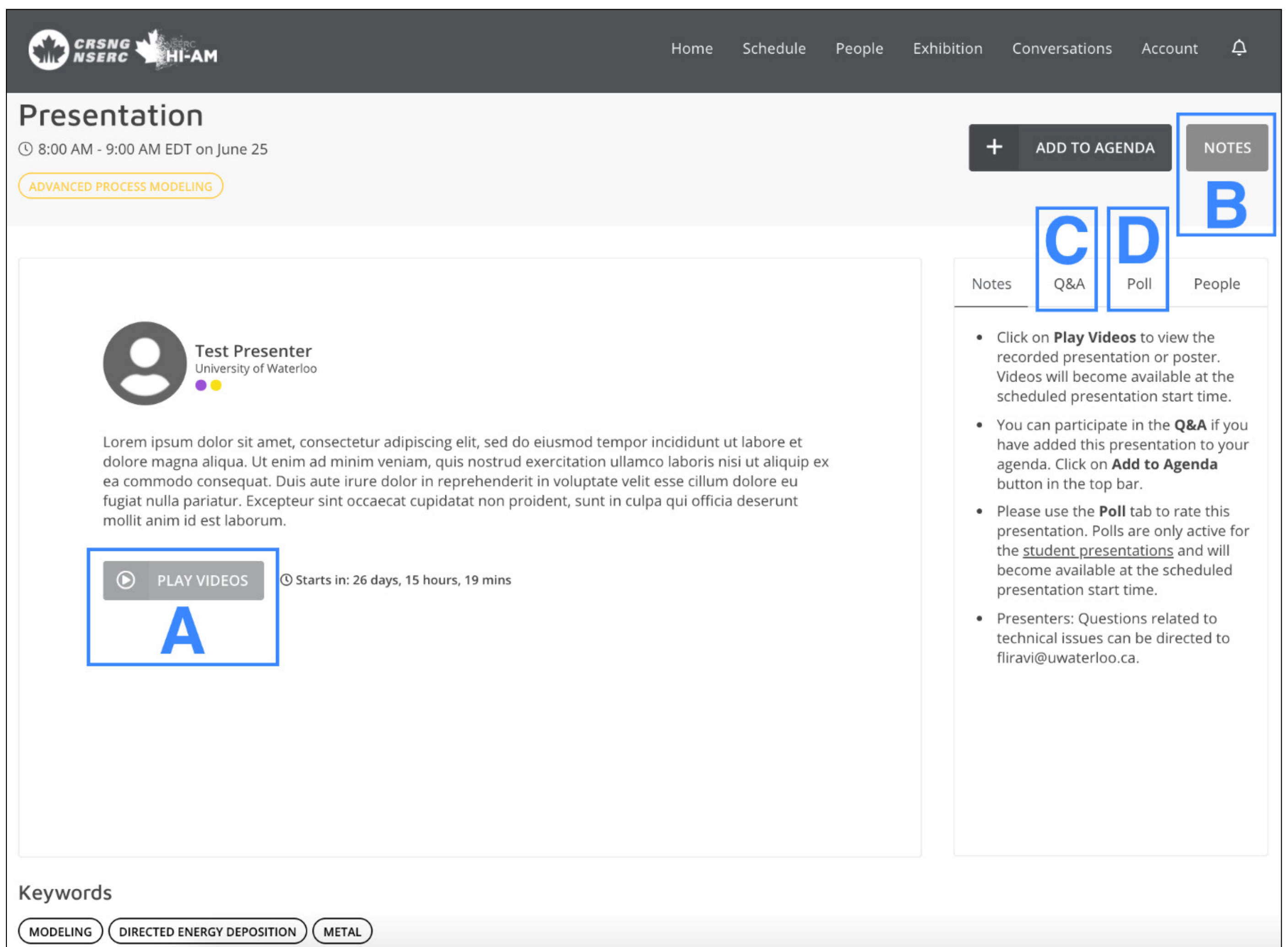
General Guidelines

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.



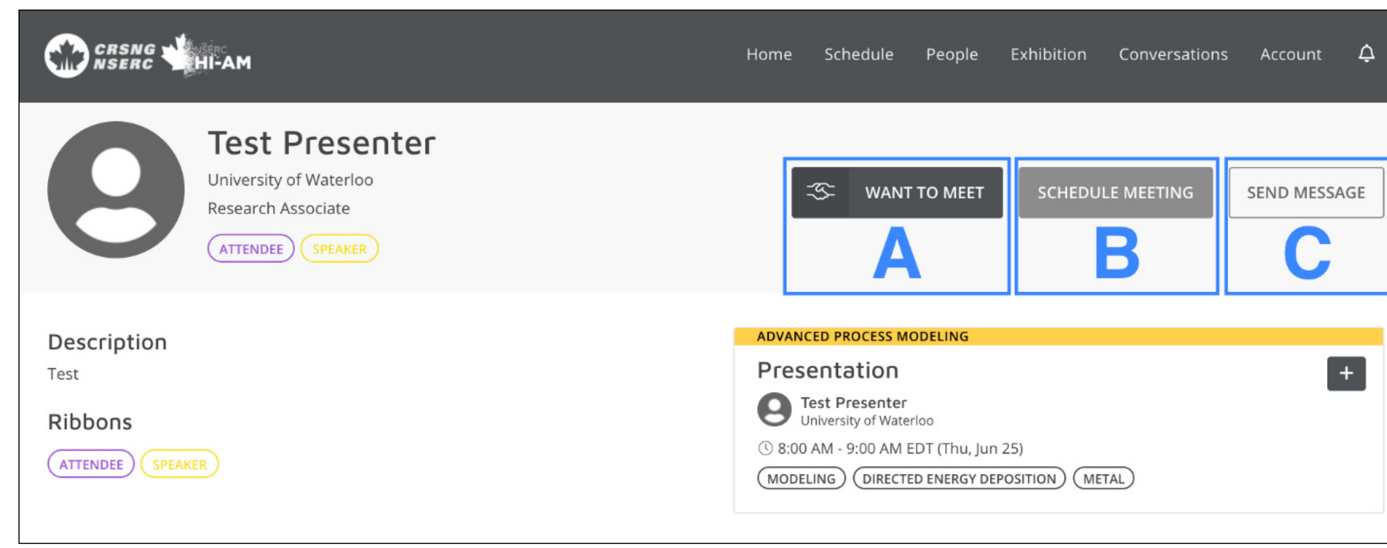
MEET PRESENTERS

- 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.



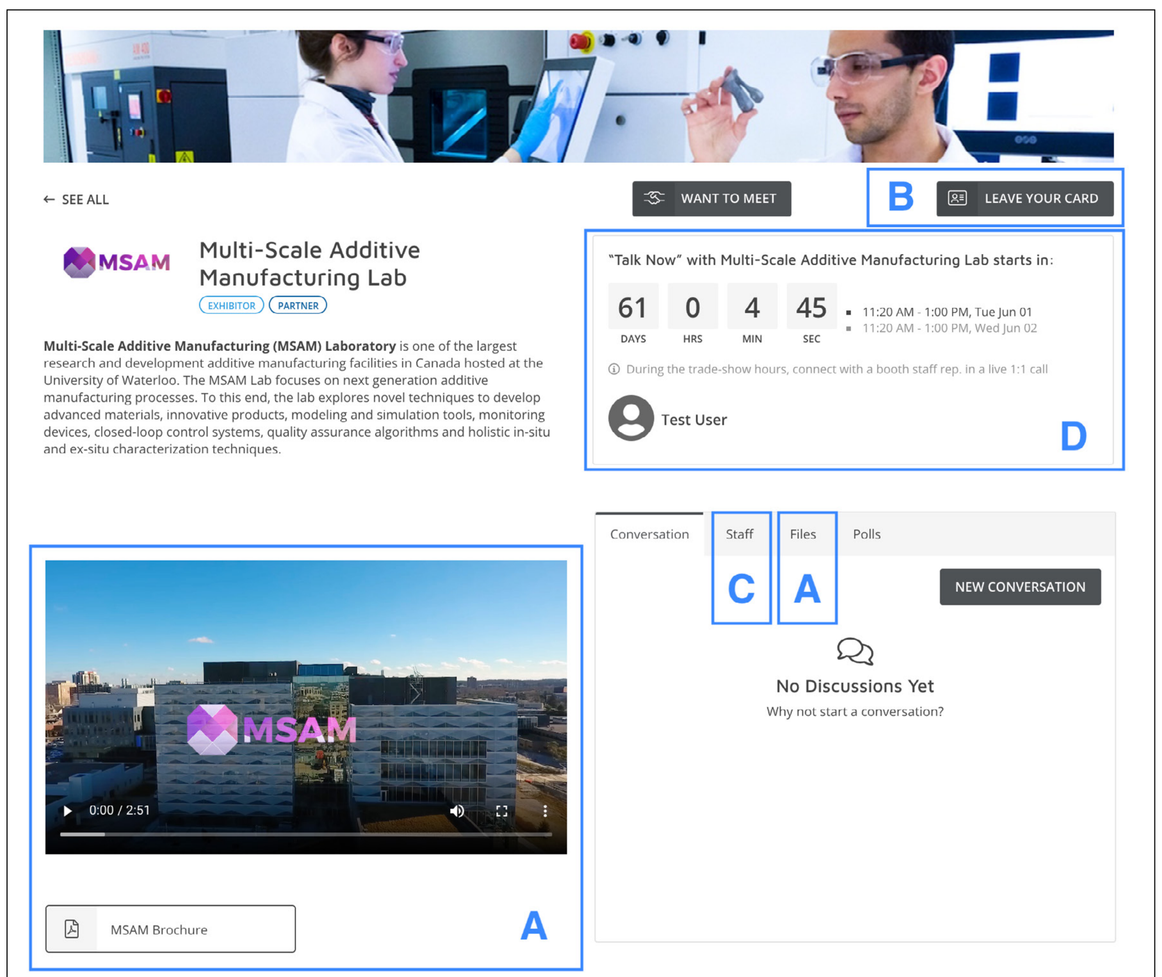
General Guidelines

ATTEND A VIRTUAL EXHIBITION

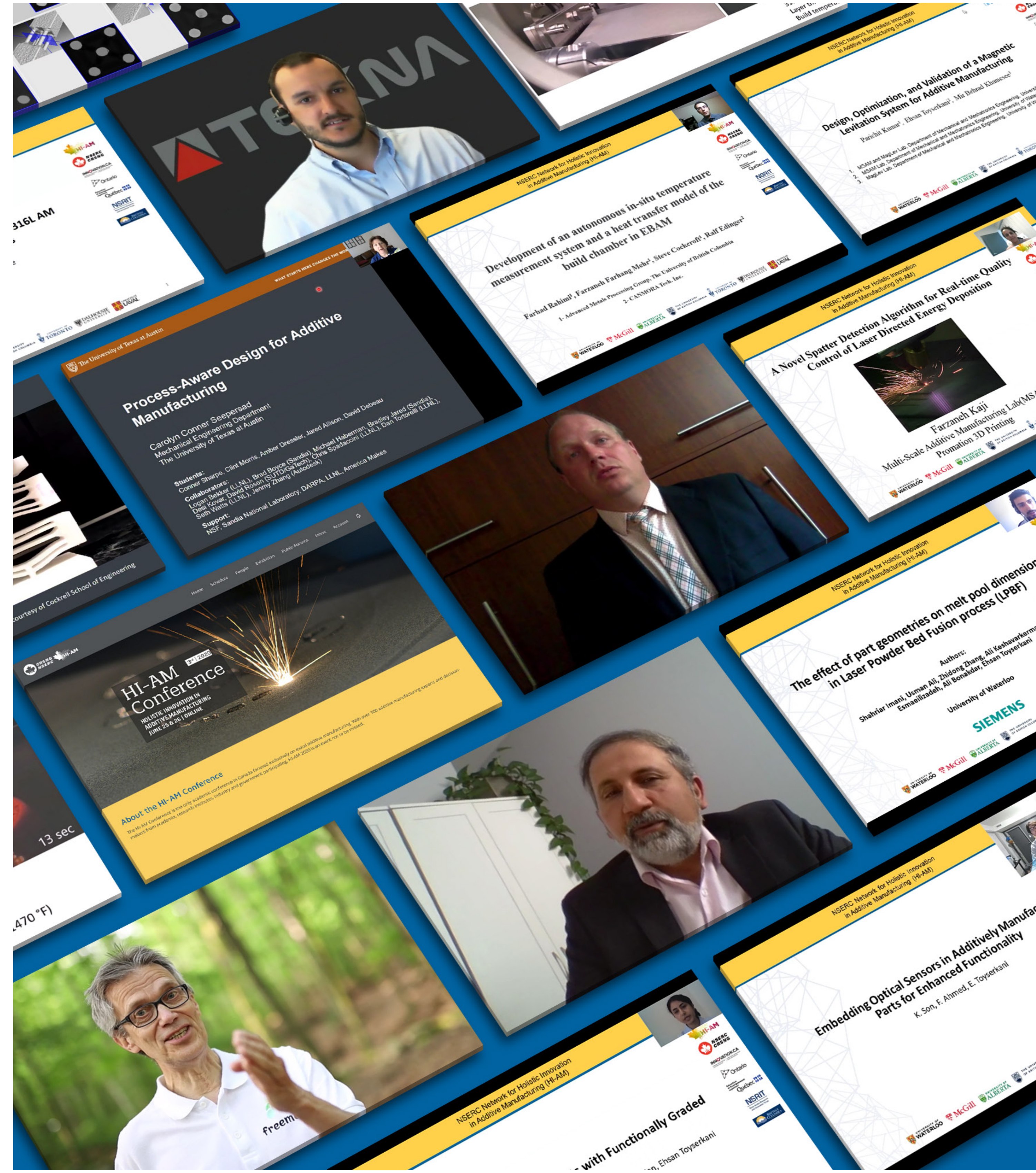
- Exhibitor organizations have their own landing page within the conference app. You can enter the exhibition area by hovering over **EXHIBITION** in the top bar and selecting **EXHIBITORS.** It is also accessible from the Exhibition section of the main page.
- View the videos and download the digital brochures from the **FILES SECTIONS (A).**
- Click on **LEAVE YOUR CARD (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 **STAFF** tab **(C)** to view the list of exhibit staff. Click on their name to view their profile (see “Meet Presenters” for details).
- You can connect with the available exhibit staff in a live 1:1 Zoom call during the Virtual Tradeshow times. Follow the instructions in Section **D** to call the exhibitors during the assigned times.

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.
2. Talk Now feature is only available for Platinum and Gold Sponsors.



2020 HI-AM Conference Presentation Samples



Guidelines for Presenters

VIRTUAL PRESENTATION AND Q&A

- 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.

  May 26, 2021 – 11am-12pm EDT
  May 27, 2021 – 3pm-4pm EDT
  View page 19 for other available training resources

- 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 2021 is very easy. 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.

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 attendees. Your presentation will remain available for viewing until June 9, 2021.

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 9, 2021.

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

TECHNICAL SUPPORT

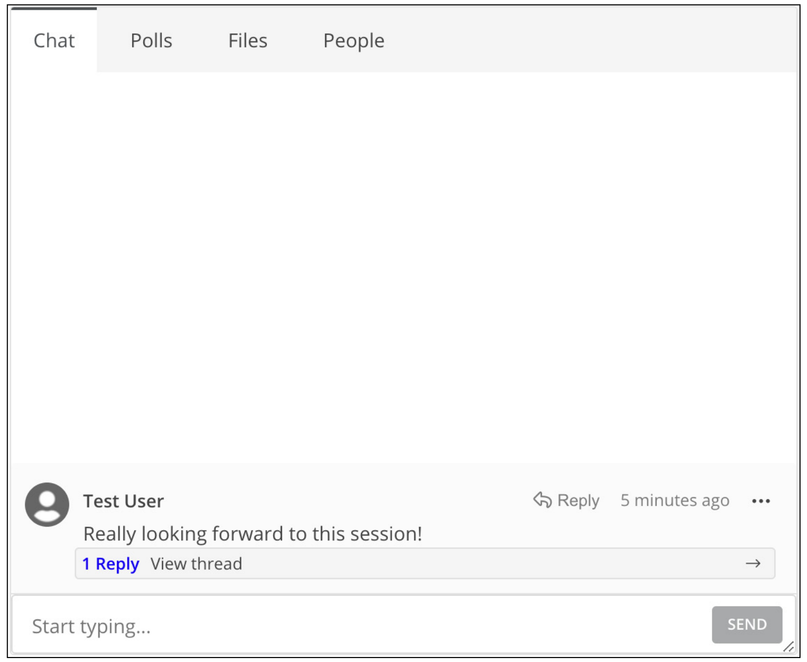
Technical support is available throughout the conference for presenters.
Contact us at **fliravi@uwaterloo.ca** if you have any technical difficulties.

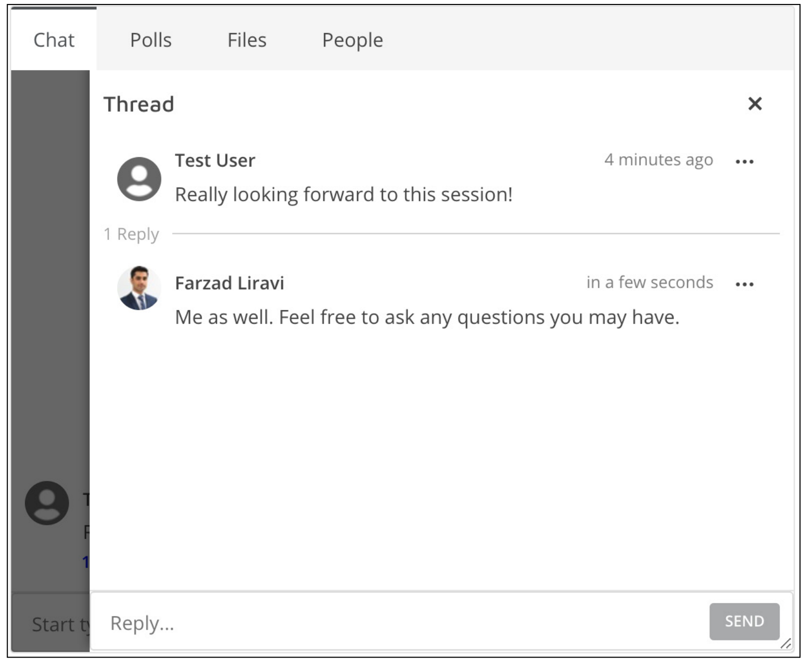
VIRTUAL PRESENTATION AND Q&A continued

Chat Widget

You can reply directly to any of the questions sent by attendees via Chat widget and start a conversation thread. The widget will show how many messages have been posted in the thread.

- To start a thread from a message, hover over the message and click the **REPLY** button. The widget will open a new pop-up window with the thread displayed.
- To view an existing thread, either click on the **REPLY** button or the number of replies shown with the message.
- 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 **ELLIPSIS** button on the upper-right corner of the message.
  - Select **DELETE** from the drop down menu.
  - Report the user to the conference staff.





Evaluation Polls

- 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.

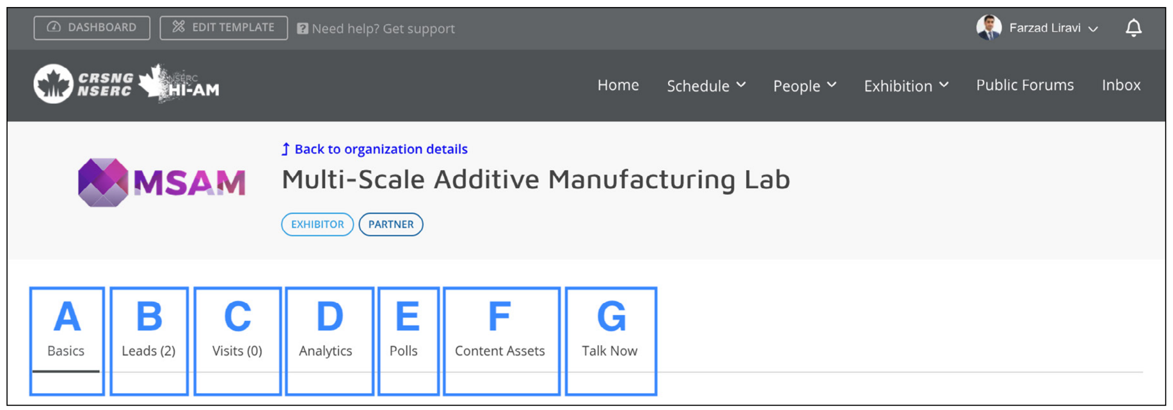
Guidelines for Exhibitors

SET UP YOUR EXHIBITION PAGE

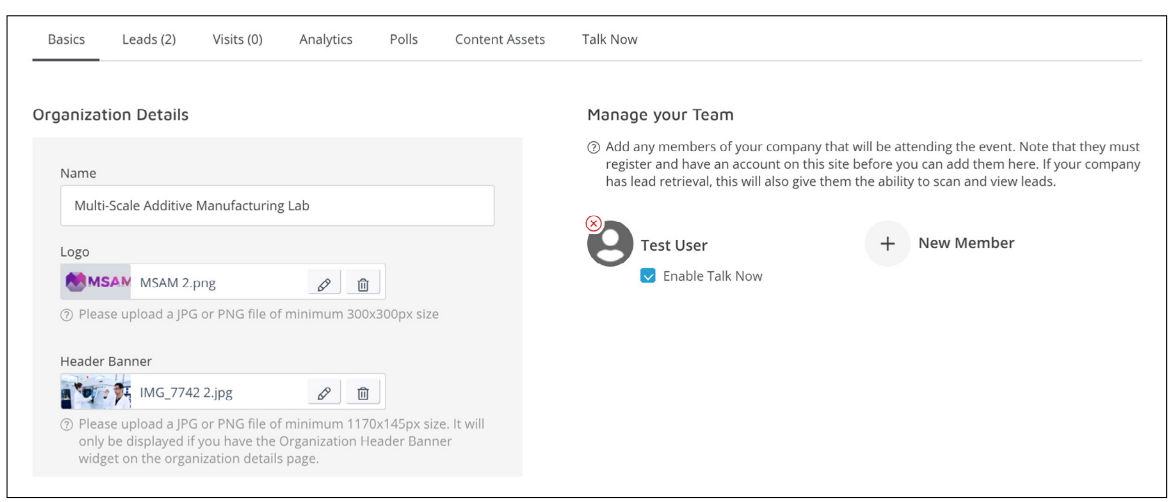
- Take part in one of the following exhibitor training sessions to learn about managing your organization page and all the features that are available to you as an exhibitor. You will receive a calendar invitation to join the training sessions.

  May 19, 2021 – 11am-12pm EDT
  May 20, 2021 – 3pm-4pm EDT
  View page 19 for other available training resources

- 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.

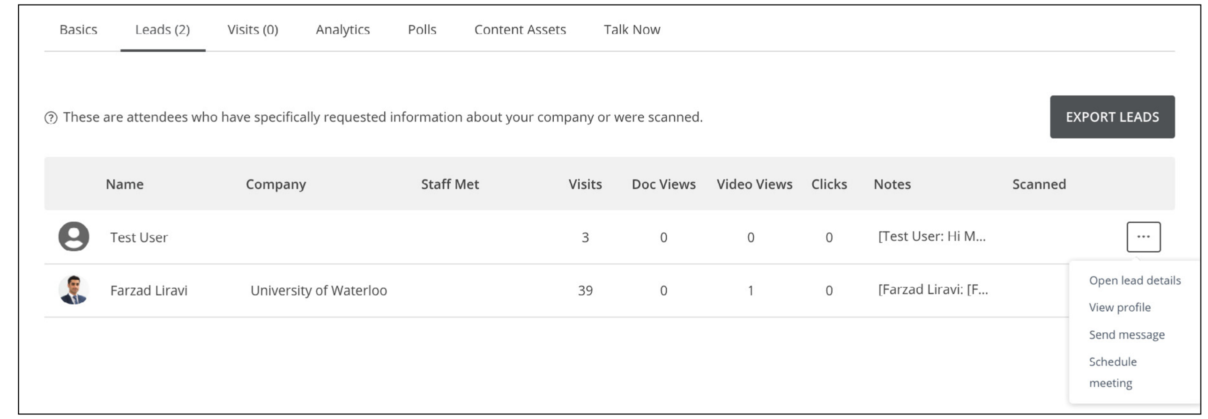


- Click the **MANAGE** button in the upper-right corner of your page. On the Manage menu, there are a number of tabs on the left:
  - **BASICS (A)** (shown below) allows you to edit the Organization's details: Name, logo, Description, and tags/keywords. On the right, the **MANAGE YOUR TEAM** area allows you to add/remove registered members to your team and grant Talk Now privilege to staff. Team members have management access.

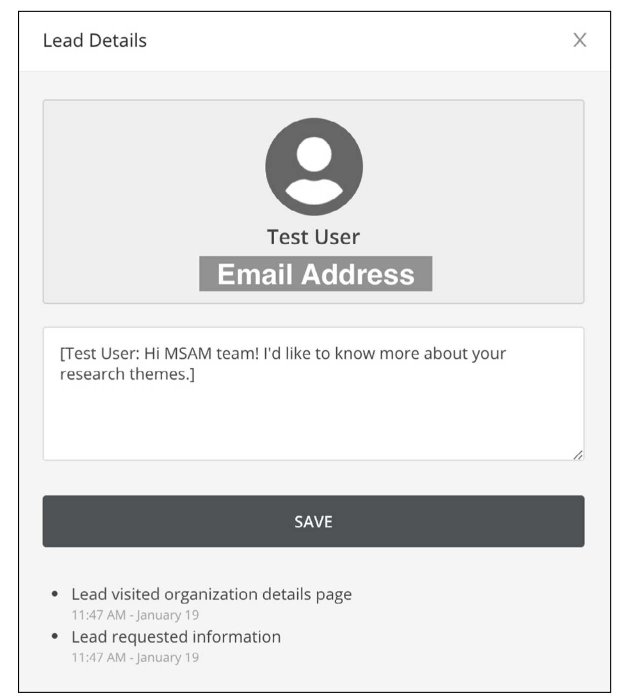


SET UP YOUR EXHIBITION PAGE continued

- **LEADS (B)** (shown below) lists information about attendees who would like more information from you. You are able to download the leads. You can also click on the ellipsis button on the right to view lead details, view sender's profile, and directly contact the sender.



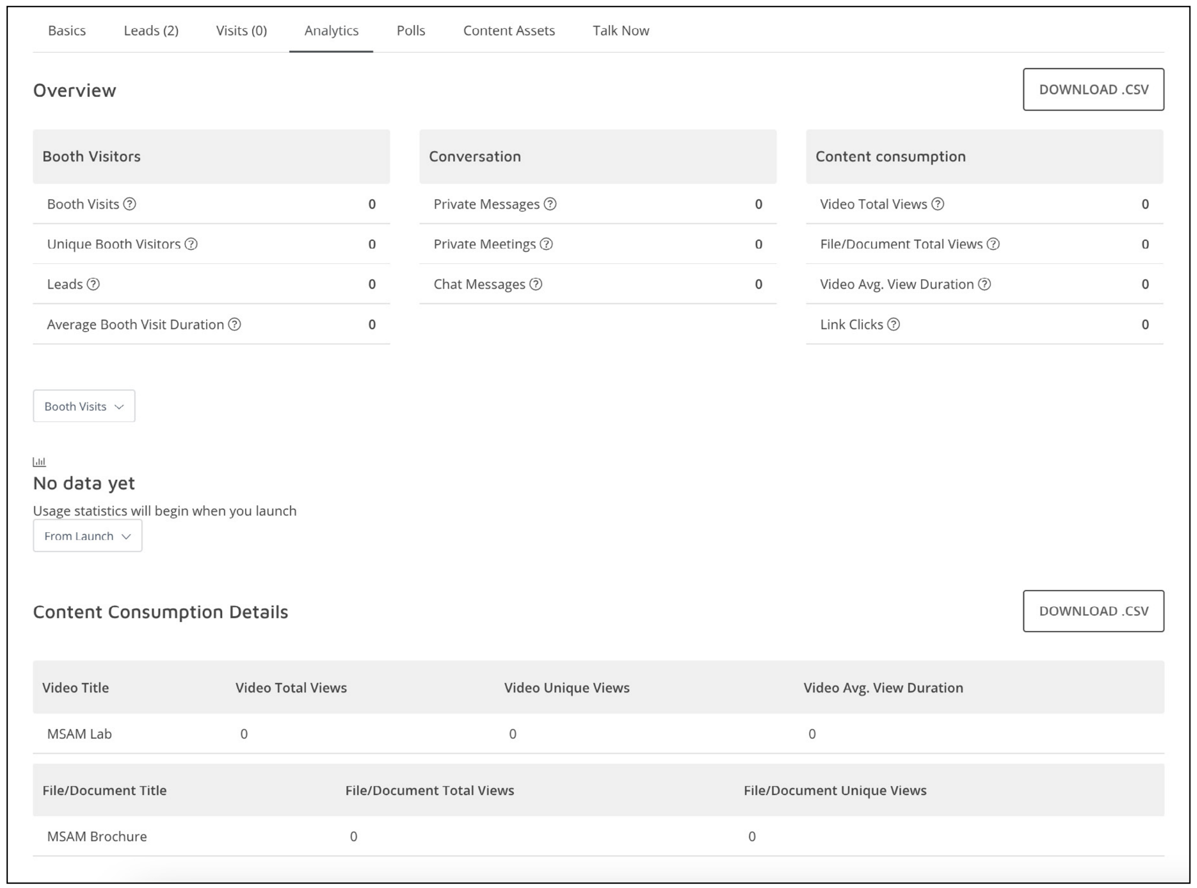
A Lead sample:



Guidelines for Exhibitors

SET UP YOUR EXHIBITION PAGE continued

- **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. You are able to download the list of visitors or contact them from this tab.
- **ANALYTICS (D)** (shown below) lists the number of Booth Visits, Conversations, and Content Consumption for the organization – please see **this article** for more detail on analytics.



- **POLLS (E)** allows you to configure interactive polls for attendees.

TECHNICAL SUPPORT

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

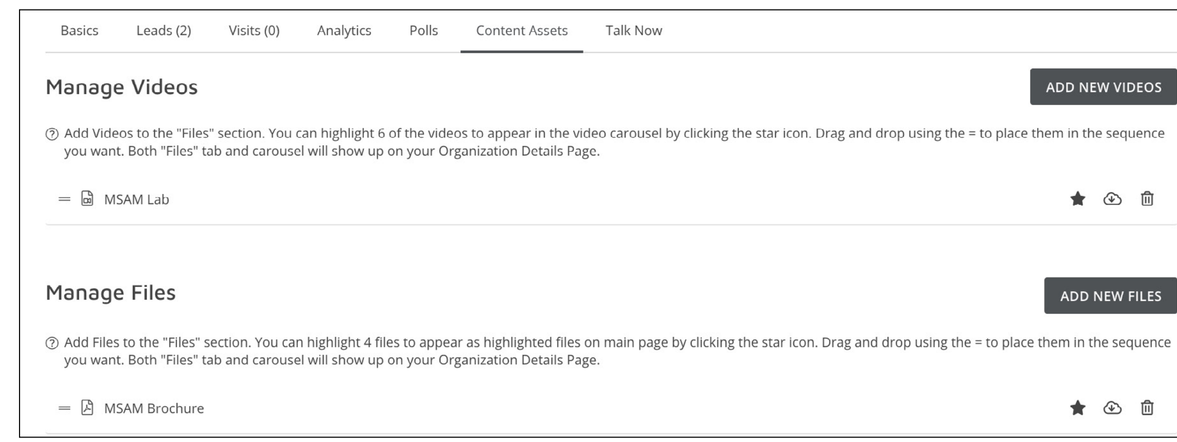
SET UP YOUR EXHIBITION PAGE continued

- **CONTENT ASSETS (F)** (shown below) allows you to add, edit, reorder your own content (handouts, one-sheets, videos, etc.) that attendees can download from or view in your organization page. You will be able to add as many files as you wish, however, you will be limited to featuring up to 6 videos and 4 files to be previewed on the Organization Page. On the attendee-facing side, the featured videos will be displayed in a carousel format, the featured files will be visible for download, and all of the content will be also displayed in the Files tab. (See section A of Attend a Virtual Exhibition on page 24.)

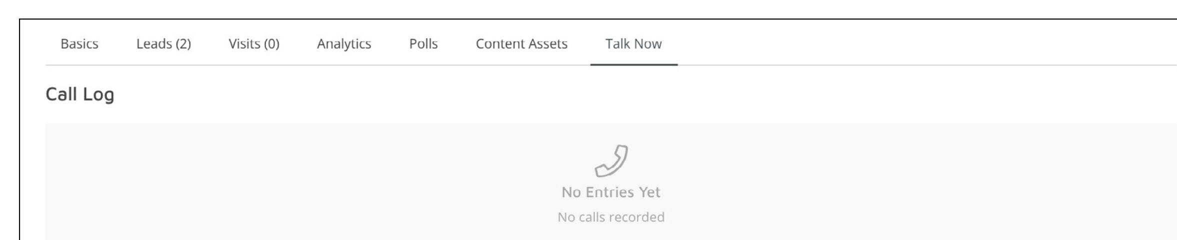
  To feature a file or video, you must select the Star icon on the right side of the page.

  NOTE: The file size should be less than 10 GB.

  NOTE: Only videos added to Content Assets/Videos section will be previewed on the Organization Page. If you add your video file to Content Assets/Add New Files section, it will only be available for download from files tab.



- **TALK NOW (G)** (shown below) allows the exhibit staff to access their Talk Now log that can be exported as a CSV file and provides the following data:
  - Caller and Responder
  - Call time, response and duration
  - Status of the call:
    - Responded
    - Declined
    - Attendee hung up
    - Timed out [card OR meeting] – indicates if caller left a card or requested an after-hours meeting when nobody picked up



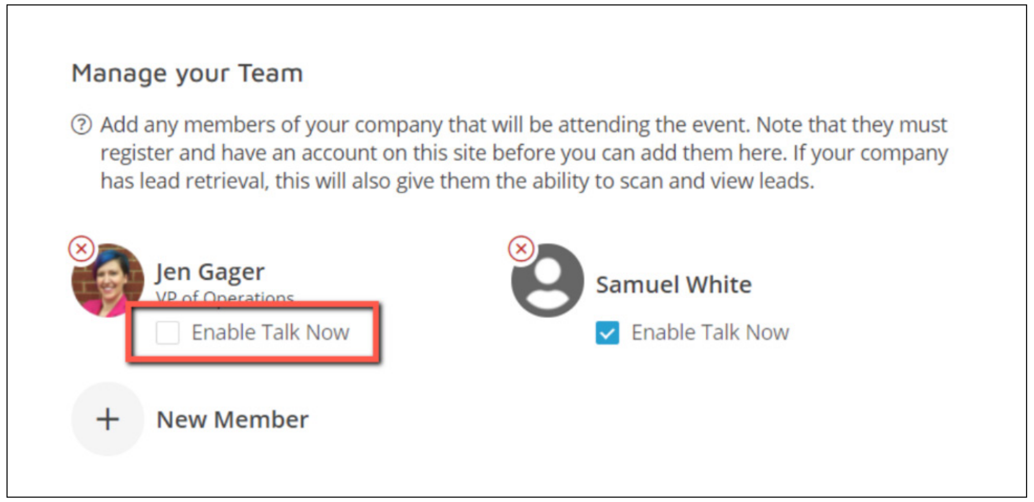
Guidelines for Exhibitors

CONFIGURE TALK NOW FOR VIRTUAL TRADESHOW

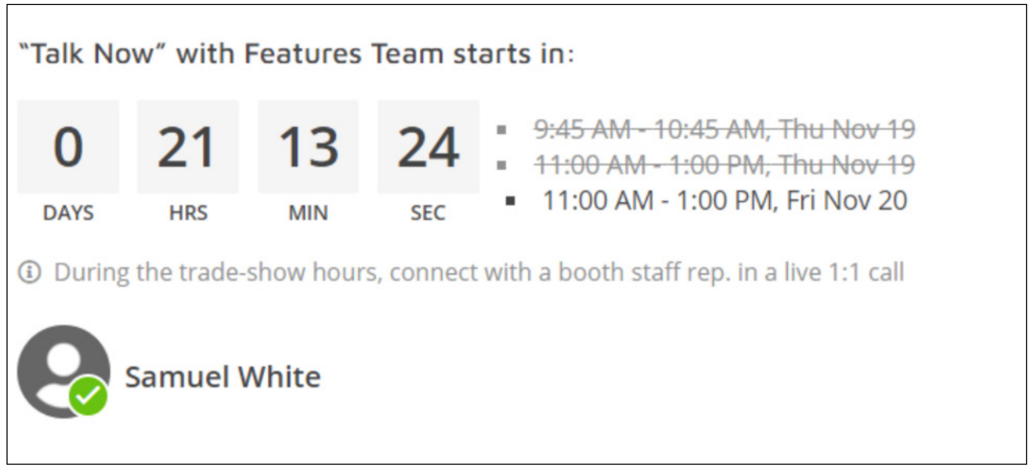
Grant Talk Now Privilege

The Virtual Tradeshow is available to Gold and Platinum Sponsors. Attendees can connect with the available exhibit staff in a live 1:1 Zoom call during the Virtual Tradeshow times. Only staff members of your organization with Talk Now enabled will be able to accept Talk Now calls. To grant Talk Now privileges to staff members:

1. Navigate to **MANAGE YOUR TEAM** under **BASICS** tab of your organization (see Set Up Your Exhibition page).
2. Select the checkbox for all staff members that should have Talk Now abilities.



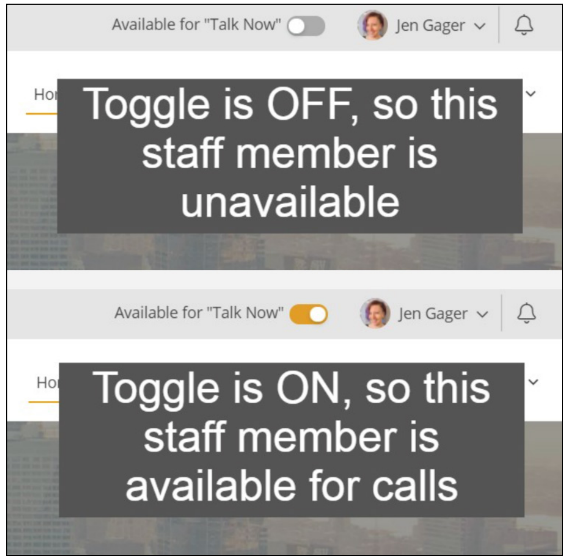
Staff members enabled for taking Talk Now calls will be listed in the Talk Now section of your Organization Page with a green check mark next to their name.



CONFIGURE TALK NOW FOR VIRTUAL TRADESHOW continued*

Availability Status

Each staff member can manage their availability status on the app header. A staff member must have Talk Now turned on to be in the call rotation during a Virtual Tradeshow session by sliding the toggle at the top of the page from off to on. Staff members will always start with Talk Now turned off and must manually turn their availability on, to indicate that they are ready to accept calls.



Call Routing

Talk Now calls are routed in a round-robin fashion among all staff members who are set to *Available*, to provide a fair distribution of calls among all organization staff members.

The next call is routed to the staff member that is ***Available*** and has the lowest amount of calls taken so far. In cases where there is more than one staff member available, the one first on the list is selected.

If the staff member does not pick up within the pick up threshold time (90 seconds), then the call is routed to the next person, applying the same 3 rules as before.

If no one picks up in the incoming pick up time (the default is 270 seconds), the caller is given the choice to either schedule a private meeting or create a written message, which will be delivered to the organization's staff members.

Taking a Call

Calls can be accepted from any page within the conference platform. The system notifies a staff member of an incoming call by displaying a popup message, with options to accept or decline, and playing a ringtone. Declining the call will send the caller to the alternative contact options (make a meeting or leave a written message), whereas accepting the call will instantly trigger the following display:

- A Zoom video call, in "theater mode"
- A sidebar with a Notes field; notes will be saved, along with the call record, as a lead in the Organization's Leads menu.

NOTE: When the staff member ends the call, they are set to Unavailable so that they may complete any notes before returning to the page they were on before accepting the call. The staff member must make themselves available again before they will receive another call.

* The instructions provided in this section are taken from the Pathable Knowledgebase: support.pathable.com

Guidelines for Exhibitors

CONFIGURE EXHIBITOR PRESENTATIONS

The Gold and Platinum Sponsors will have the opportunity to lead group meetings during the conference. **Zoom** is used to host these group meetings.

Preparation Before the Event

We recommend getting your machine set up at least several days prior to your presentation.

1. Install and set up **"Zoom Client for Meetings"** from zoom.us/download.

   NOTE: On Mac computers (see Figure A), you may need to update your security settings if you wish to share your screen during your presentation. You can do this through System Preferences > Security & Privacy > Privacy > Screen Recording. Check the option for zoom.us.

   For more information, see support.zoom.us/hc/en-us/articles/360016688031

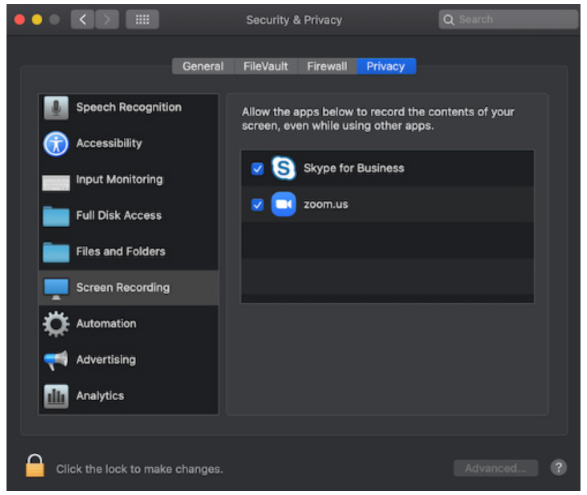
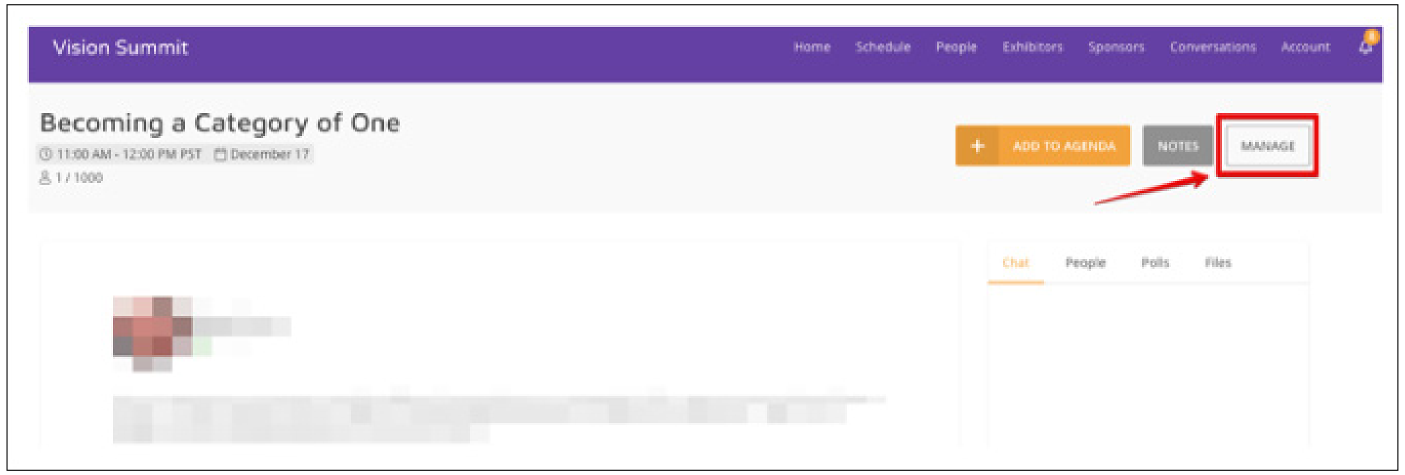


Figure A

2. Use the access link provided by the conference staff to sign in to your account on the virtual event site and complete your profile.
3. Approximately 20 minutes prior to your presentation, use the menu at the top of the page to visit the agenda, find the **EXHIBITOR PRESENTATIONS SESSION** and click on your video room.
4. Click the **MANAGE** button in the upper right.
5. Click **START** if you are the primary speaker with responsibility for "starting" the meeting.

This will launch the Zoom meeting application and enters you into the presentation area. During this time, you will be able to see and hear other presenters, and they will be able to see and hear you. However, the attendees will not be able to join the meeting until one minute before the scheduled start time.



CONFIGURE EXHIBITOR PRESENTATIONS continued*

Using Zoom Controls

The Zoom toolbar will appear once you have launched the Zoom application. It consists of the following controls:

- **MUTE:** allows you to silence yourself or participants. Use this if someone else is talking and the system's natural echo cancellation is not working. The up-arrow next to **MUTE** can be used to select your audio input (e.g., switch from your computer's microphone to a headset).
- **START VIDEO:** This allows you to turn on your webcam. The up-arrow next to **START VIDEO** will also give you access to the virtual background feature.
- **PARTICIPANTS:** Allows you to see the names of the people watching.
- **SHARE SCREEN:** Allows you to share what is displayed on your monitor with viewers. If you have dual monitors, you can select which monitor to display and which to reserve for your reference and notes.
- **BREAKOUT ROOMS:** Allows you to prepare breakout rooms within a Zoom meeting and let your attendees choose the room they'd like to visit.

NOTE: After the Exhibitor Presentations event ends, you can stay in your Zoom session for 10 minutes to save the chat, notes, and follow up information. The information exchanged through Zoom application will not be transferred to the Leads section of your Organization's page.

* The instructions provided in this section are taken from the Pathable Knowledgebase: support.pathable.com

TECHNICAL SUPPORT

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

DAY 1 – June 1, 2021

ONLINE CONFERENCE PROGRAM

MORNING

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

7:40am	**CONFERENCE OPENING**
	SESSION 1: Metal Additive Manufacturing (Keynote Presentations)
8:00am	**KEYNOTE 1: ICME Gaps for Qualification of Additive Manufacturing of Metals** Anthony Rollett *US Steel Professor of Metallurgical Engineering and Materials Science, Carnegie Mellon University, United States*
8:40am	**KEYNOTE 2: AM Designed Materials – Application Driven Hand in Hand Material and Process Development** Simon Hoeges *Director Technology & Manufacturing Engineering, GKN Additive, Germany*
9:20am	**KEYNOTE 3: The Benefit of Using Nanoscale Additives in Laser- and Powder-based Additive Manufacturing (AM) of Metals** Michael Schmidt *Head of Institute, Institute of Photonic Technologies, FAU, Erlangen, Germany*
10:00am	**KEYNOTE 4: Leveraging the Flexibility of Binder Jetting: Printing with Fine Powders, Nanosuspensions, Metal Foams, and Foundry Sand** Christopher Williams *L. S. Randolph Professor, Virginia Tech, United States*
10:40am	**KEYNOTE 5: Innovative Hybrid AM Processing Technologies and Applications** Michael Sealy *Assistant Professor, University of Nebraska-Lincoln, United States*
11:20am	**POSTER SESSION I | EXHIBITION VIEWING + VIRTUAL TRADESHOW I**

DAY 1 – June 1, 2021

NSERC HI-AM

AFTERNOON

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

1:00pm	**EXHIBITOR PRESENTATIONS I**		
	SESSION 2: Industry Experts I	**SESSION 3: Industry Experts II**	**SESSION 4: TracLight**
1:40pm	**Presentation 1: Metal Additive Manufacturing at Oak Ridge National Laboratory** Amy Elliott *Research Staff, Oak Ridge National Laboratory, United States*	**Presentation 5: Additive Manufacturing in Aerospace: An SME Perspective** Matthew Harding *Program Manager – Additive Manufacturing, Tronosjet Maintenance Inc, Canada*	**Presentation 9: HiPTSLAM; Progress in Understanding the Powder-Processing-Heat Treatment Triangulation for the Fabrication of High Performance Tools and Dies** Mathieu Brochu*, Alexandre Bois-Brochu**, Carl Blais***, Edem Dugbenoo* *Professor, *McGill University, Canada; **Centre Métallurgie Québec, Canada; ***Universté Laval, Canada*
2:00pm	**Presentation 2: Advanced (Additive) Manufacturing at Canadian Nuclear Laboratories** Greg Hersak *Manager, Mechanical Equipment Development, Canadian Nuclear Laboratories, Canada*	**Presentation 6: AM and Injection Molding: A Match Made in Automotive Heaven** Jorge Cisneros *Application Engineer, EOS, United States*	**Presentation 10: Efficiency Increase and Weight Reduction in Modern Combustion Engines provided by Metal Additive Manufacturing** Roman Lengsdorf, Jan Bueltmann *NPECA GmbH, Germany*
2:20pm	**Presentation 3: Preparing for an (Un)certain Future: Technology Adoption for Alberta Manufacturing** Tonya Wolfe *Manager – Centre for Innovation in Manufacturing Technology Access Centre, Red Deer College, Canada*	**Presentation 7: Deeper Learning from Productive Failure in Technology Adoption** Mark Kirby *Industry Training Manager, University of Waterloo*	**Presentation 11: Application of Machine Learning for Defect Detection in Laser-Powder Bed Fusion** Dalia Mahmoud *McMaster, Canada*
2:40pm	**Presentation 4: Metal AM – Cutting Through the Hype** Ian Brooks *Technical Fellow, AMRC, United Kingdom*	**Presentation 8: Proheat – A New Smoke-safe Preheating Method for Electron Beam Powder Bed Fusion, Opening up a Wider Range of Processable Feedstocks** Ulf Ackelid *Co-founder, Freemelt AB, Sweden*	**Presentation 12: How Recent Innovations in Laser Metal AM Make the Perfect Partner for Space Exploration** Eliana Fu *Industry Manager, Aerospace & Medical, TRUMPF, United States*
3:00pm	**CAREER ADVICE WITH AM PROFESSIONALS**		

DAY 1 – June 1, 2021

AFTERNOON

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

	SESSION 5: Material Development I	SESSION 6: Novel AM Processes and Products I
4:00pm	**Presentation 13: Preliminary Investigation of Al-Zr-Y Alloys for Laser Powder Bed Fusion Using Laser Remelting** Jon Hierlihy*, Ian Donaldson**, Mathieu Brochu***, Paul Bishop* **Dalhousie University, Canada; **GKN Powder Metallurgy, Canada; ***McGill University, Canada*	**Presentation 18: In-situ Automated Scan-assisted Repair by Additive Manufacturing** Rémy Samson, Hani Henein *University of Alberta, Canada*
4:20pm	**Presentation 14: Laser Powder Bed Fusion (LPBF) of Difficult to Wend Rene 77 Superalloy** Sila Atabay, Mathieu Brochu *McGill University, Canada*	**Presentation 19: Effect of Substrate Condition and Initial Residual Stresses on Electron Beam Additive Repair and Remanufacturing** Fatih Sıkan*, Priti Wanjara**, Javad Gholipour Baradari**, Mathieu Brochu* **McGill University, Canada; **National Research Council Canada, Canada*
4:40pm	**Presentation 15: Alloy Design for Laser Powder-Bed Fusion: Hypereutectic Al-Si Systems** Daniela Diaz, Abdoul-Aziz Bogno, Hani Henein *University of Alberta, Canada*	**Presentation 20: Binder Jet Printing of MXene Composite for Energy Storage and Strain Sensing** Terek Li, Hani Naguib *University of Toronto, Canada*
5:00pm	**Presentation 16: Development of Novel A8 Tool Steel Powders for AM Produced by Water Atomization** William Chaîné, Carl Blais *Université Laval, Canada*	**Presentation 21: An Optimized Method of Powder Feedstock Handling in Directed Energy Deposition** Ambrish Singh, Sajan Kapil, Manas Das *Indian Institute of Technology Guwahati, India*
5:20pm	**Presentation 17: Manufacture and Strain Rate Effects on Gyroid Lattices Structures Made by Selective Laser Melting** Henrique Ramos*,**, Rafael Santiago**, Peter Theolbald***, Shwe Soe****, Marcilio Alves*, Mohammed Al Teneiji** **University of Sao Paulo, Brazil; **Technology Innovation Institute, United Arab Emirates; ***University of Cardiff, United Kingdom; ****University of the West of England, United Kingdom*	**Presentation 22: Influence of Heat Treatment on Microstructure and Hardness of Directed Energy Deposition (DED) Processed AISI D2 Tool Steel** Samer Omar, Kevin Plucknett *Dalhousie University, Canada*

DAY 2 – June 2, 2021

MORNING

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

	SESSION 7: Advanced Process Modeling I	SESSION 8: Process Monitoring and Control I
7:40am	**Presentation 23: The Effect of Surface Morphology on Monotonic and Cyclic Stress Behavior in 250 μm SS316L Struts Fabricated by Laser Powder Bed Fusion** Abhi Ghosh, Muralidharan Kumar, Amit Kumar, Mathieu Brochu *McGill University, Canada*	**CANCELED Presentation 28: Active Learning in Additive Manufacturing** Mihaela Vlasea, Gijs van Houtum *University of Waterloo, Canada*
8:00am	**Presentation 24: A Simplified Approach to Modelling the Thermal Balance of the Build Chamber in Electron Beam Additive Manufacturing** Farhad Rahimi, Farzaneh Farhang Mehr, Steve Cockcroft, Jun Ou, Daan Maijer *The University of British Columbia, Canada*	**Presentation 29: A Comparison Between Different Eddy Current Probe Designs with respect to Different Defect Sizes** Heba Farag, Ehsan Toyserkani, Behrad Khamesee *University of Waterloo, Canada*
8:20am	**Presentation 25: Machine-learning-assisted Manufacturability Analyzer and Recommender** Ying Zhang, Yaoyao Zhaos *McGill University, Canada*	**Presentation 30: Development of a Machine Learning Defect-detection Model through the Photodiodes Signals Collected from the Melt Pool of Laser Powder-bed Fusion** Katayoon Taherkhani*, Christopher Eischer**, Martin Otto**, Ehsan Toyserkani* **University of Waterloo, Canada; **EOS GmbH Electro Optical Systems, Germany*
8:40am	**Presentation 26: The Effect of Laser Scanning Stripe Width on Melt Pool Geometries in Laser Powder-bed Fusion Additive Manufacturing Process** Shahriar Imani Shahabad*, Zhidong Zhang*, Ali Keshavarzkermani*, Reza Esmaeilizadeh*, Ali Bonakdar**, Ehsan Toyserkani* **University of Waterloo, Canada; **Siemens Canada Limited, Canada*	**Presentation 31: Real-Time Geometry Prediction in Laser Additive Manufacturing using Machine Learning** Richard van Blitterswijk, Lucas Botelho, Amir Khajepour *University of Waterloo, Canada*
9:00am	**Presentation 27: Identification of Thermal Patterns in Distortion Generation for Bead-based Metal Additive Manufacturing as an Approach for Fast Simulations** Seyedeh Elnaz Mirazimdeh*, Syamak Pazireh*, Jill Urbanic*, Bob Hedrick** **University of Windsor, Canada; **CAMufacturing Solutions, Inc., Canada*	**Presentation 32: Sensor-Based In-situ Process Control of Robotic Wire Arc Additive Manufacturing Integrated with Reinforcement Learning** Yeon Kyu Kwak, Thomas Lehmann, Mahdi Tavakoli, Ahmed Qureshi *University of Alberta, Canada*
9:20am	**NETWORKING BREAK**	

DAY 2 – June 2, 2021

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

	SESSION 9: Material Development II	SESSION 10: Novel AM Processes and Products II
9:40am	**Presentation 33: Fatigue Resistance of Laser Powder Bed Fused Ti64 Components with Intentionally-seeded Porosity** Etienne Moquin, Morgan Letenneur, Vladimir Brailovski *École de Technologie Supérieure, Canada*	**Presentation 38: Addressing Surface Roughness and Fatigue Life in Additive Manufactured Parts** Pablo Enrique, Ehsan Toyserkani, Norman Zhou *University of Waterloo, Canada*
10:00am	**Presentation 34: Microstructure Evolution during Additive Manufacturing of 2205 Duplex Stainless Steel** Nima Haghdadi*, Hansheng Chen**, Zibin Chen**, Xiaozhou Liao**, simon Ringer**, Sophie Primig* **UNSW Sydney, Australia; **The University of Sydney, Australia*	**Presentation 39: Hybrid Additive Manufacturing through Sequential Layer-by-layer Laser Directed Energy Deposition and Remelting for Improved Hastelloy-X Properties** A N Jinoop, C P Paul, K S Bindra *Raja Ramanna Centre for Advanced Technology, India*
10:20am	**Presentation 35: Estimate Solidification Parameters of Al alloys Fabricated by AM based on T0 Curve and Non-equilibrium Solidification** An Fu, Mathieu Brochu *McGill university, Canada*	**Presentation 40: Effect of Thermal Load in Wire and Arc Additive Manufacturing (WAAM) of Ti6Al4V Multilayer Walls** Emmanuel Reyes*, Arturo Gomez**, James Perez**, Ricardo Morales Estrella* **Universidad Michoacana de San Nicolas de Hidalgo (UMSNH), Mexico; **Centro de Ingenieria Y Desarrollo Industrial (CIDESI), Mexico*
10:40am	**Presentation 36: Rapid Solidification of Al-10Si-0.4Sc Alloy** Akankshya (Akki) Sahoo, Abdoul-Aziz Bogno, Hani Henein *University of Alberta, Canada*	**Presentation 41: The Role of Heterogeneous Structures on the Mechanical Properties of Additively Manufactured AlSi10Mg** Haoxiu Chen*, Yu Zou*, Sagar Patel**, Mihaela Vlasea** **University of toronto, Canada; **University of Waterloo, Canada*
11:00am	**Presentation 37: Evolution of Microstructure During Heat Treatment of Laser Powder Bed Fused Ti-5553 Alloy** Nivas Ramachandiran, Hamed Asgari, Francis Dibia, Adrian Gerlich, Ehsan Toyserkani *University of Waterloo, Canada*	**Presentation 42: Residual Stresses Piloted Optimization of Functionally Graded Parts Using PTAAM** Geoffrey Bonias, Hani Henein, Tonya Wolfe *University of Alberta, Canada*
11:20am	**POSTER SESSION II**	**EXHIBITION VIEWING + VIRTUAL TRADESHOW II**

DAY 2 – June 2, 2021

NSERC HI-AM

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

	SESSION 11: Advanced Process Modeling II	SESSION 12: Process Monitoring and Control II
1:00pm	**EXHIBITOR PRESENTATIONS II**	
1:40pm	**Presentation 43: Experimental and Numerical Investigation of Block-Type Support Structure Design Parameters on Thermal Fields within Components Fabricated by Selective Laser Melting** Arman Khobzi, Steve Cockcroft, Daan Maijer, Farzaneh Farhang Mehr *The University of British Columbia, Canada*	**Presentation 48: Automated Porosity Detection in Laser Powder Bed Fused Parts using Computed Tomography and Deep Learning Algorithms** Catherine Desrosiers*, Morgan Letenneur**, Fabrice Bernier***, Francois Guibault*, Benjamin Provencher****, Farida Cheriet*, Nicolas Piché****, Vladimir Brailovski** **École Polytechnique Montréal, Canada; **École de Technologie Supérieure, Canada; ***NRC, Canada; ****Object Research System , Canada*
2:00pm	**Presentation 44: Adaptive Physics-based Model for Laser Directed Energy Deposition** Mazyar Ansari, Mobin Khamooshi, Ehsan Toyserkani *University of Waterloo, Canada*	**Presentation 49: The Use of Sintering Models in Binder-Jet Additive Manufacturing** Roman Boychuk, Mihaela Vlasea *University of Waterloo, Canada*
2:20pm	**Presentation 45: An Experimental Study to Investigate the Influence of Infill Features on the Structural Performance of Topology Optimized Metal LPBF Parts** Osezua Ibhadode, Reza Esmaeilizadeh, Ehsan Toyserkani *University of Waterloo, Canada*	**Presentation 50: A shape Compensation Approach for Enhancing the Geometric Accuracy of Additive Manufacturing Parts** Moustapha Jadayel, Farbod Khameneifar *Polytechnique Montreal, Canada*
2:40pm	**Presentation 46: Numerical Heat Transfer Modeling of the Melt Pool in Laser Powder-bed Fusion of Metastable β Titanium Alloy** Mahyar Hasanabadi, Shahriar Imani Shahabad, Ali Keshavarzkermani, Nivas Ramachandiran, Hamed Asgari Moslehabadi, Adrian Gerlich, Ehsan Toyserkani *University of Waterloo, Canada*	**Presentation 51: Process Planning for Additive Manufacturing of Geometries with Overhang Features using a Robotic LDED system** Farzaneh Kaji, Ehsan Toyserkani *University of Waterloo, Canada*
3:00pm	CANCELED **Presentation 47: Numerical Study on the Effect of Wire Arc Additive Manufacturing Process Parameters on Residual Stresses Distribution** Rasoul Moharrami, Hamed Eshaghi *University of Zanjan, Iran*	**Presentation 52: Combining In-situ Monitoring and X-ray Computed Tomography to Assess the Quality of Parts Manufactured by Laser Powder Bed Fusion and Electron Beam Melting** Philip Sperling, Patrick Fuchs *Volume Graphics GmbH, Germany*
3:20pm	**NETWORKING BREAK**	

DAY 2 – June 2, 2021

AFTERNOON

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

	SESSION 13: Material Development III	SESSION 14: Novel AM Processes and Products III
3:40pm	**Presentation 53: Binder Jet Printing AISI 5120 Chromium Steel Powder** Addison Rayner*, Randy Cooke*, Ian Donaldson**, Paul Bishop* **Dalhousie University, Canada; **GKN Sinter Metals, United States*	**Presentation 58: Workflow Development of an Additive Manufactured Novel Implant Abutment in Titanium** Les Kalman *Western University, Canada*
4:00pm	**Presentation 54: Double-laser LPBF Processing of a High-performance Maraging Tool Steel** Gregor Graf*, Manuela Neuenfeldt**, Tobias Müller***, Jörg Fischer-Bühner****, Daniel Beckers*, Sven Donisi*, Frederik Zanger**, Volker Schulze** **Rosswag GmbH, Germany; **wbk Institute of Production Science, Germany; ***Gühring KG, Germany; ****BluePower Casting Systems GmbH, Germany*	**Presentation 59: 3D Printed Shellualr Metamaterials** Hamid Akbarzadeh*, Jiahao Shi*, Armin Mirabolghasemi*, Hossein Mofatteh*, Gilles Desharnais** **McGill University, Canada; **Axis Prototypes Inc., Canada*
4:20pm	**Presentation 55: Effect of Alloy Composition and Laser Powder Bed Fusion Parameters on the Defect Formation and Mechanical Properties of Inconel 625** Michael Benoit*, Maciej Mazur**, Mark Easton**, Milan Brandt** **University of British Columbia, Canada; **RMIT University, Australia*	**Presentation 60: Powder Parameter Development Considerations in Metal Powder-Bed Fusion Printing** David Jankowski, Eli Terry, Jon Perini *Xact Metal, United States*
4:40pm	**Presentation 56: Localized Actuation Behaviour: Implementation of Functionally Graded Structure in 4D Printed Shape Memory Polymer** Yu-Chen Sun, Yimei Wan, Ryan Nam, Marco Chu, Hani Naguib *University of Toronto, Canada*	**Presentation 61: Investigation on Derivative Face-centered Cubic Lattice Structure on Mechanical Behaviour of Stainless Steel 316L Manufactured by Selective Laser Melting** Cho-Pei Jiang*, Alvian Wibisono**, Timotius Pasang*** **National Taipei University of Technology, Taiwan; **National Taipei University of Technology, Indonesia; ***Oregon Institute of Technology, United States*
5:00pm	**Presentation 57: NiCoMoTiAl High Entropy Alloying in DED/Additive Manufacturing(AM) Process : Investigation the Potential of CVM(clogged vibration method) Powder Feeding System for Rapid Alloy Scanning** SeungJun An*, SooRan Lim*, PyuckPa Choi**, BoRyung Yoo** **Insstek, Korea, Republic of Korea; **KAIST (Korea Advanced Institute of Science and Technology), Republic of Korea*	**Presentation 62: Laser Directed Energy Deposition based Additive Manufacturing of Copper-Stainless Steel Functionally Graded Structures** Sunil Yadav, Arun Rai, Christ Paul, A Jinoop, K Bindra *Raja Ramanna Centre for Advanced Technology, India*
5:20pm	**CONFERENCE CLOSING AND AWARDS**	

Poster Presentation Gallery

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

POSTER SESSION 1: Tuesday, June 01, 2021 | 11:20am – 1:00pm

THEME 1: MATERIAL DEVELOPMENT

Poster 1: Ferritic Alloy Designed for the Realization by AM of Heat Exchangers for Applications in Corrosive Alkaline Environments
Luciano Pilloni, Giuseppe Corallo, Daniele Mirabile Gattia
ENEA, Italy

Poster 2: A Facile Method of Using Inkjet Printing to Fabricate PEDOT:PSS Electrodes onto Nafion Membrane through Ionic Bonding for Origami Inspired Actuators
Andrew Jo, Hani Naguib
University of Toronto, Canada

Poster 3: Development of Novel Water-atomized Tool Steel Powders to Improve Shock Resistance of AM Parts Made of H13 Tool Steel
Denis Mutel, Carl Blais
Université Laval, Canada

Poster 4: Electrostatically Assisted Atomisation of Metals
Bilal Bharadia, Abdoul Aziz Bogno, Hani Henein
University of Alberta, Canada

Poster 5: Fatigue Behaviour of Additively Manufactured Hastelloy X
Reza Esmaeilizadeh*, Ali Keshavarzkermani*, Ali Bonakdar**, Hamid Jahed*, Ehsan Toyserkani*
**University of Waterloo, Canada; **Siemens Energy Canada, Canada*

Poster 6: A Parametric Study on the Freeform Fabrication of Near-β alloy Ti-55511 Printed by Laser Directed Energy Deposition (L-DED) Using a Statistical Design of Experiments (DOE) Approach
Addison Rayner, Greg Sweet, Paul Bishop
Dalhousie University, Canada

CANCELED **Poster 7: A Comparison of the Microstructure and Mechanical Properties of Laser Powder Bed-fused Components Made of Maraging Stainless Steel to its Wrought Analogue**
William Turnier Trottier, Vladimir Brailovski
École de Technologie Supérieure, Canada

Poster 8: Laser Powder Bed Fusion Additive Manufacturing of Molybdenum Lattice Structures
Tejas Ramakrishnan, Mathieu Brochu
McGill University, Canada

Poster 9: Understanding of the Laser Powder Bed Fusion (LPBF) Printability of an Ni3Al Alloy
Kuanhe Li, Xianglong Wang, Tejas Ramakrishnan, Mathieu Brochu
McGill University, Canada

Poster 10: Review on Mechanical Testing of Meso-and Micro-scale Test Coupons
Muralidharan Kumar, Abhi Ghosh, Mathieu Brochu
McGill University, Canada

Poster 11: New Grade of Advanced Nanocomposite Complex Ceramic Metal Reinforcements (CCMR)
Shahram Rizaneh
University of Calgary, Canada

CANCELED **Poster 12: Multiscale Mechanical Characterization of Multiphase Materials Made by Additive Manufacturing**
Yu Zou
University of Toronto, Canada

THEME 1: MATERIAL DEVELOPMENT

Poster 13: Nanoindentation Mapping of a Near-alpha Titanium Alloy Made by Additive Manufacturing
Zhiying liu*, Jiahui Zhang*, Bei He**, Yu Zou*
**University of Toronto, Canada; **Beihang University, China*

Poster 14: Development of Hybrid Shape Memory Polymers with Conductive Fillers for Advanced 4D Printing of Therapeutic Devices
Kyra McLellan, Hani Naguib
University of Toronto, Canada

Poster 15: Influence of Post-processing Conditions on the Microstructure and Fatigue Resistance of Laser Powder Bed Fused Ti-6Al-4V Components
Erika Herrera-Jimenez, Alena Kreitcberg, Etienne Moquin, Morgan Latenneur, Vladimir Brailovski
École de technologie supérieure, Canada

Poster 16: Microstructure Characterization of Directed Energy Deposition of H13 Tool Steel
Owen Craig, Kevin Plucknett
Dalhousie University – Mechanical Engineering, Canada

Poster 17: Binder Jet Printing of Low-Cost Tool Steel Powders
Ryan Ley*, Donald Bishop*, Ian Donaldson**
Dalhousie University, Canada; **GKN Powder Metallurgy, United States*

CANCELED **Poster 18: Development of High-density Materials for Lightweight Components by Hybrid Investment Casting and Atomization**
Abdoul-Aziz Bogno*, Aquinn Hazenberg*, Jonas Valloton*, Hani Henein*, Ahmed Qureshi*, Michel Rappaz**
**University of Alberta, Canada; **École polytechnique fédérale de Lausanne, Switzerland*

Poster 19: Microstructure of Rapidly Solidified 17-4PH Stainless Steel
Anne McDonald, Abdoul-Aziz Bogno, Hani Henein
University of Alberta, Canada

Poster 20: Laser Directed Energy Deposition Processing of Beta, Near-Beta and Near-Alpha Titanium Alloys
Nicholas Gosse*, Donald Bishop*, Ian Donaldson**
**Dalhousie University, Canada; **GKN Powder Metallurgy, United States*

Poster 21: Directed Energy Deposition Processing of a Dual Phase Steel
Gregory Sweet*, Mark Amegadzie*, Ian Donaldson**, Chris Schade***, Paul Bishop*
**Dalhousie University, Canada; **GKN Powder Metallurgy, United States; ***GKN Hoeganaes Innovation Center & Advanced Materials, United States*

Poster Presentation Gallery

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

POSTER SESSION 1: Tuesday, June 01, 2021 | 11:20am – 1:00pm

THEME 2: ADVANCED PROCESS MODELING

Poster 22: A Numerical Model to Predict Residual Stresses and Distortion in a Component Fabricated by DED
Pegah Pourabdollah, Farzaneh Farhang-Mehr, Steven Cockcroft, Daan Maijer
The University of British Columbia, Canada

Poster 23: Thermo-mechanical Modelling and Validation of Direct Energy Deposition Processed 4140 Steel
Shaun Cooke*, Greg Sweet**, Keivan Ahmadi*, Paul Bishop**, Rodney Herring*
**University of Victoria, Canada; **Dalhousie University, Canada*

CANCELED Poster 24: In-plane Mechanical Properties Analysis of Modified Auxetic Metamaterials via Additive Manufacturing
Niranjan Choudhry, Biranchi Panda
Indian Institute of Technology Guwahati, India

Poster 25: Mesoscale Modelling of the Evolution of Plastic, Elastic, Thermal strain in Powder Bed Electron Beam Additive Manufacturing (PB-EBAM)
Asmita Chakraborty, Farzaneh Mehr, Steve Cockcroft, Daan Maijer
University of British Columbia Vancouver, Canada

Poster 26: Heat Transfer Modeling of Multi-track Laser Scanning in Laser Powder-bed Fusion Additive Manufacturing Using Adaptive Mesh
Zhidong Zhang*, Shahriar Imani Shahabad*, Ali Bonakdar**, Ehsan Toyserkani*
**University of Waterloo, Canada; **Siemens Energy Canada Limited, Canada*

Poster 27: Nonlinear Response of Additively Built Soft Lattices
Asma El Elmi, Damiano Pasini
McGill University, Canada

Poster 28: Thermal Fluid Modelling of Melt Pool Generation in the Powder Bed Electron Beam Additive Manufacturing (PB-EBAM) of Ti6Al4V
Eiko Nishimura, Steve Cockcroft, Daan Maijer, Farzaneh Mehr
University of British Columbia, Canada

Poster 29: Effect of the Layer-wise Temperature Field on the Geometric Tolerances of Laser Powder Bed Fusion Printed Parts – A Preliminary Study
Baltej Singh Rupal, Marc Secanell, Ahmed Jawad Qureshi
University of Alberta, Canada

Poster 30: Evaluation of Heat Transfer during Rapid Solidification of Al-33wt%Cu
Jonas Valloton*, Abdoul-Aziz Bogno*, Michel Rappaz**, Hani Henein*
**University of Alberta, Canada; **Ecole Polytechnique Fédérale de Lausanne, Switzerland*

POSTER SESSION 2: Wednesday, June 02, 2021 | 11:20am – 1:00pm

THEME 3 - PROCESS MONITORING AND CONTROL

Poster 31: Ultrasound Metal Powder Stream Focusing for Producing Variable Track Widths in Directed Energy Deposition
Alexander Martinez-Marchese*, Mazyar Ansari*, Asier Marzo**, Marc Wang*, Soyazhe Khan*, Ehsan Toyserkani*
**University of Waterloo, Canada; **Public University of Navarre, Spain*

Poster 32: Correlative Microstructural Analysis of Laser Powder Bed Fusion Fabricated 17-4 PH Stainless Steel
Maxwell Moyle*, Nima Haghdadi*, Simon Ringer**, Xiaozhou Liao**, Sophie Primig*
**The University of New South Wales, Australia; **The University of Sydney, Australia; The University of New South Wales, Australia*

Poster 33: Effect of Specimen Geometry and Orientation on Tensile Properties of Ti-6Al-4V Manufactured by Electron Beam Powder Bed Fusion
Gitanjali Shanbhag*, Evan Wheat*, Shawn Moylan**, Mihaela Vlasea*
**University of Waterloo, Canada; **National Institute of Standards & Technology (NIST), United States*

Poster 34: Divergent Beams for Laser Powder Bed Fusion of a High Reflectivity Aluminum Alloy – AlSi10Mg
Sagar Patel*, Haoxiu Chen**, Yu Zou**, Mihaela Vlasea*, Kevin Slattery***, John Barnes***
**University of Waterloo, Canada; **University of Toronto, Canada; ***The Barnes Global Advisors, United States*

Poster 35: Dedicated Metal Powder Tester for Powder Bed-based AM Applications
Salah Eddine Brika, Vladimir Brailovski
École de technologie supérieure, Canada

Poster 36: A Hybrid Model to Predict the Melt Pool Temperature in Laser Metal Deposition
Alejandra Bejarano Rincón, Antonio Estrada, Juan Alvarado Orozco
Center for Engineering and Industrial Development (CIDESI), Mexico

Poster 37: A New Model for Directed Energy Deposition Layer Geometry from Mass Balance Considerations
Gentry Wood*, Nathan Jen**, Douglas Hamre*, Dakota Jones*, Ata Kamyabi*, Anju Varghese*, Patricio Mendez**
**Apollo-Clad Laser Cladding, Canada; **Apollo-Clad Laser Cladding, Canada; University of Alberta, Canada*

Poster 38: Plasma Secondary Processing for Additively Manufactured Components of SS316L
Suyog Jhavar, Srinivasachari V
Atria Institute of Technology, Bangalore, India

Poster 39: Failure Detection in 3D Printing Using Computer Vision
Xingchen Liu*, Haoliang Zhou**, Ziqi Chen*, Stephen Luu***, Yu Zou*
**University of Toronto, Canada; **Mech Solutions Ltd., Canada, ***York University, Canada*

HI-AM CONFERENCE 2021 PROGRAM SCHEDULE

Poster Presentation Gallery

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

NSERC HI-AM

POSTER SESSION 2: Wednesday, June 02, 2021 | 11:20am – 1:00pm

THEME 4 - NOVEL AM PROCESSES AND PRODUCTS

Poster 40: A Topology Optimization Strategy for a Flexible Piezoresistive Sensor
Jeffrey Sixt, Elham Davoodi, Armaghan Salehian, Ehsan Toyserkani
University of Waterloo, Canada

Poster 41: Hybrid AM Validation for Injection Mould Industry
Florence Desravines
Precision IMS, Canada

Poster 42: TPMS Structures for Transpiration Cooling
Kevin Zhang
University of Waterloo, Canada

Poster 43: An Analytical Approach in the Design of a Complex Electromagnetic Levitation System for Additive Manufacturing
Saksham Malik, Parichit Kumar, Ehsan Toyserkani, Behrad Khamesee
University of Waterloo, Canada

Poster 44: Non-retractive Toolpath Planning Using TSP Solver
Sadaival Singh, Ambrish Singh, Sajan Kapil
Indian Institute of Technology Guwahati, India

Poster 45: Additive Manufacturing of Enhanced Resolution Shrinkable Silicone-based Scaffolds
Elham Davoodi*, Hossein Montazerian**, Ehsan Toyserkani*
**University of Waterloo, Canada; **University of California-Los Angeles, United States*

Poster 46: Semantic Segmentation of Plasma Transferred Arc Additively Manufactured NiBSi-WC Optical Microscopy Images Using a Convolutional Neural Network
Dylan Rose, Hani Henein
University of Alberta, Canada

Poster 47: Novel Limb Sparing Technique Using 3D-printed Patient-specific Endoprostheses for Tumors of the Proximal Humerus
Linh-Aurore Le Bras*, Anatolie Timercan*, Bertrand Lussier**, Bernard Seguin***, Yvan Petit*, Vladimir Brailovski*
**École de technologie supérieure, Canada; **Université de Montréal, Canada; ***Colorado State University, United States*

Poster 48: Novel Origami-Inspired Mechanical Metamaterial Development Utilizing Theoretical Modelling Verified Through 3D Printed Sample Testing
Anastasia Wickeler, Hani Naguib
University of Toronto, Canada

Poster 49: A Review of Human Bone Parameters and Implications towards Titanium Lattice Design for Powder Bed Fusion Additive Manufacturing
Martine McGregor, Sagar Patel, Stewart McLachlin, Mihaela Vlasea
University of Waterloo, Canada

THEME 4 - NOVEL AM PROCESSES AND PRODUCTS

Poster 50: Design and Analysis of a Magnetic Levitation Systems for Additive Manufacturing Applications
Parichit Kumar, Saksham Malik, Ehsan Toyserkani, Behrad Khamesee
University of Waterloo, Canada

Poster 51: Process Methodology for Laser Directed Energy Deposition of Hastelloy-X Printed Circuit Heat Exchangers
C P Paul, A N Jinoop, K S Bindra
Raja Ramanna Centre for Advanced Technology, India

Poster 52: Additive Manufacturing for the Realization of Heat Exchangers: Case Study
Giuseppe Corallo, Luciano Pilloni, Daniele Mirabile Gattia
ENEA, Italy

Poster 53: Influence of Hot Isostatic Pressing on the Microstructure and Mechanical Behaviour of Laser Powder Bed Fusion built Inconel 625 Structures
Saurav Nayak*, Sanjay Mishra**, Christ Paul**, V Kumar***, Kushvinder Bindra**
**Homi Bhabha National Institute, India; **RRCAT INDORE, India; ***Vikram Sarabhai Space Centre, India*

Abstracts

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

ONLINE CONFERENCE PROGRAM

Keynotes

SESSION 1: Metal Additive Manufacturing
June 1 | 8:00am – 11:20am EDT

Keynote 1 | 8:00am

ICME Gaps for Qualification of Metals Additive Manufacturing of Metals

Anthony Rollett
US Steel Professor of Metallurgical Engineering and Materials Science,
Carnegie Mellon University, United States

Abstract: Rapid advances in 3D printing of metals have enabled widespread used in industry. Key questions remain as to how to qualify printers and certify parts, especially in terms of defect structures. Under support from the NASA-ULI program, a multi-university team is determining process windows, characterizing defect structures, microstructures & surface finish, and measuring fatigue resistance in 4-point bend fatigue. Preliminary results point to similar process windows for the same model at different locations when using a consistent source of Ti-6Al-4V powder. Microstructure and basic mechanical properties can be predicted from thermal history albeit heuristically. Transferring the methodology to an aluminum alloy in a different printer, however, required re-evaluation of melt pool sizes, which is basic to the proposed physics-based approach to qualification. The fatigue results reveal a strong dependence of life on defect content, as expected, which suggests a close connection to the process window for printing. Overall ICME needs include the need for computational tools that predict melt pool shape & size, melt pool stability, microstructure formation, including texture, diffusion, and solid state phase transformation. The ultimate aim is to predict the process window for a given material and printer.

Keynote 2 | 8:40am

AM Designed Materials – Application Driven Hand in Hand Material and Process Development

Simon Hoeges
Director Technology & Manufacturing Engineering,
GKN Additive, Germany

Abstract: Currently early adopters of AM technology are struggling to cross the chasm to wider application industrialization. The main limitations of AM being design know-how at the end users, production throughput, industrialization / automatization limitations and material variety / properties. Although Additive Manufacturing is evolving from the Advanced Manufacturing industry since several decades there is still a low number of available materials designed to utilize the full strength of the technology. Standard casting, forging or sheet metal materials are applied even though the properties could be significantly enhanced by adopting material chemistry and processing parameters to the application requirements and technology boundary conditions. It is now time to develop and validate in line with promising serial applications tailored materials and production processes. This keynote gives an overview and examples on materials developed for Laser Powder Bed Fusion and Binder Jetting technology applied to produce serial parts in the automotive and general industry.

Keynote 3 | 9:20am

The Benefit of Using Nanoscale Additives in Laser- and Powder-based Additive Manufacturing (AM) of Metals

Michael Schmidt
Head of Institute,
Institute of Photonic Technologies, FAU, Erlangen, Germany

Abstract: Recent advancements in laser- and powder-based Additive Manufacturing (AM), individual AM processes have raised interest in science and industry. Especially, powder bed fusion with laser beam (PBF-LB/M) and direct energy deposition (DED-LB/M) have revolutionized today's research and development. These technologies offer the potential to modify an existing alloy by adding specific micro or nano-scale powders to the initial host powder. By using in-situ alloying strategies both chemical composition and microstructural properties can be adjusted which enables producing materials with innovative and outstanding characteristics.

Herein we present the benefit of adding nanoscale additives to the initial host powder for two different alloys. Firstly, we investigated the influence of titanium boride (TiB_2) nanoparticles (NP) on the processability of the hot crack-sensitive aluminium alloy EN AW-2024 in PBF-LB/M in detail. The focus here is on the impact of TiB_2-NP on the process window for the generation of nearly-fully dense and crack-free specimens. The second part is devoted to the processing of NP reinforced hot-work tool steel powder (1.2343) in DED-LB/M. The aim of these investigations is to identify and to understand the effect of carbon, tungsten carbide and TiB_2-NP on residual austenite content, the crystallite size of martensite and austenite and mechanical properties.

Keynote 4 | 10:00am

Leveraging the Flexibility of Binder Jetting: Printing with Fine Powders, Nanosuspensions, Metal Foams, and Foundry Sand

Christopher Williams
L. S. Randolph Professor,
Virginia Tech, United States

Abstract: Binder Jetting is a unique Additive Manufacturing modality as it presents opportunities to print powdered materials that are not processable on other AM platforms. Its use of ink jetting technology provides a pathway to readily scalable manufacturing platform and voxel-level control over material composition. Furthermore, its material flexibility provides pathways for both direct and indirect (e.g., printed tooling) manufacturing routes. In his talk, Dr. Williams will highlight the flexibility of the binder jetting platform by demonstrating examples of processing a series of novel materials systems to realize compositions and products that could not be fabricated by any other route. Examples will include processing of (i) fine copper powders for enhanced mechanical and electrical properties, (ii) jetted nanosuspensions for altered microstructure, (iii) foaming powders to achieve hierarchical porosity, and (iv) foundry sand for fabricating large scale metal-ceramic composite lattice structures.

Keynote 5 | 10:40am

Innovative Hybrid AM Processing Technologies and Applications

Michael Sealy
Assistant Professor,
University of Nebraska-Lincoln, United States

Abstract: This presentation focuses on innovations in hybrid additive manufacturing processing technologies and discusses applications enabled by functionally grading properties. Hybrid additive manufacturing (hybrid AM) has described hybrid processes and machines as well as multi-material, multi structural, and multifunctional printing. The capabilities afforded by hybrid AM are rewriting the design rules for materials and adding a new dimension in the design for additive manufacturing paradigm. Hybrid AM processes are defined as the use of additive manufacturing (AM) with one or more secondary processes or energy sources that are fully coupled and synergistically affect part quality, functionality, and/or process performance. Secondary processes and energy sources include subtractive and transformative manufacturing technologies, such as machining, re-melting, peening, rolling, and friction stir processing. Today's talk primarily focuses on defining hybrid AM in relation to hybrid manufacturing, classifying hybrid AM processes, and defining new terminology to describe an aggregate surface integrity from interlayer processing. As interest in hybrid AM grows, new tools are needed to model, measure, and optimize hybrid design that enable new hybrid AM machines, materials, structures, and function. Hybrid AM has ushered in the next evolutionary step in additive manufacturing and has the potential to profoundly change the way goods are manufactured.

Oral Presentations

SESSION 2: Industry Experts I
June 1 | 1:40pm – 3:00pm EDT

1:40pm

Presentation 1: Metal Additive Manufacturing at Oak Ridge National Laboratory

Amy Elliott
Research Staff,
Oak Ridge National Laboratory, United States

Abstract: Metal Additive Manufacturing (AM) is seeing major growth in the types of systems that are being developed. Oak Ridge National Laboratory's (ORNL) Manufacturing Demonstration Facility (MDF) is seeks to demonstrate, characterize, and expand current capabilities in metal AM through simulation, state-of-the-art imaging and characterization, and ground-breaking systems development. This presentation will cover the various systems being researched and developed at ORNL along with the advanced characterization capabilities that enable each technology. Advances in powder bed fusion in terms of grain-size control enabled by simulation will be discussed. Quality control on binder jetting will be demonstrated in terms of closed-loop feedback on the powder bed. New hybrid systems being developed including the "MedUSA" system – a large-scale robotic welding system that also incorporates substractive manufacturing – and other hybrid systems will be discussed. Further, a vision for the future of metal AM will be presented that covers fundamental advancements as well as advancements in automation.

2:00pm

Presentation 2: Advanced (Additive) Manufacturing at Canadian Nuclear Laboratories

Greg Hersak
Manager, Mechanical Equipment Development,
Canadian Nuclear Laboratories, Canada

Abstract: Canadian Nuclear Laboratories (CNL) is Canada's premier nuclear science and technology organization; it has been a world leader in developing nuclear technology for peaceful and innovative applications through its expertise in physics, metallurgy, chemistry, biology and engineering. At CNL, additive manufacturing is being used as part of the design of unique mechanical equipment for R&D, decommissioning applications, and service to power reactors. In addition, CNL is leveraging additive manufacturing technologies for the development of advanced nuclear fuels. In this presentation, we will explore the additive technologies that CNL has invested in and briefly look at some case studies. CNL's vision for the future with additive manufacturing technologies will be explored.

2:20pm

Presentation 3: Preparing for an (Un)certain Future: Technology Adoption for Alberta Manufacturing

Tonya Wolfe
Manager – Centre for Innovation in Manufacturing Technology Access Centre,
Red Deer College, Canada

Abstract:

Canada is renowned as an energy powerhouse, with focus on environmental stewardship, innovation and community building. Alberta has prospered from energy being a major economic driver across all sectors, including manufacturing. However, the future trajectory of the energy industry is rapidly changing, and Alberta industry is required to channel its entrepreneurial spirit to drive the intelligent adoption of new manufacturing technologies. A combination of simulation and modelling as well as fast hypothesis testing is required to evolve.

The complicated and/or complex problems that the Alberta Manufacturing sector is facing will be presented. The balance between product design, process selection and control and cost is highlighted in terms of diversification of Alberta's manufacturing sector. The areas of additive manufacturing, automation, machine learning and novel materials processing will be explored in the context of the Alberta manufacturing landscape.

The importance of strengthening relationships between industry and post secondary institutions in order to accelerate technology transfer will be addressed, as well as the creation of consortia that enable local companies to collaborate to reduce risk and costs.

2:40pm

Presentation 4: Metal AM – Cutting Through the Hype

Ian Brooks
Technical Fellow,
AMRC, United Kingdom

Abstract: Metal AM is widely regarded as the new, game-changing technology in manufacturing, but after many years of research, development and marketing it is still held up by the same fundamental problem. What parts can and should be made with the different technology types in order to grow the industry? While there has been continued development in machine platforms, software toolsets and more and more specific end use applications, adoption is still slow. From a holistic perspective, Ian Brooks will discuss such key points as: Where does AM fit in my manufacturing toolbox? Is the AM industry its own worst enemy? How do we overcome the reasons 'why not' to adopt AM? Will LPBF explode or implode?

SESSION 3: Industry Experts II
June 1 | 1:40pm – 3:00pm EDT

1:40pm

Presentation 5: Additive Manufacturing in Aerospace: An SME Perspective

Matthew Harding
Program Manager – Additive Manufacturing,
Tronosjet Maintenance Inc, Canada

Abstract: Additive manufacturing continues to see increased uptake across all industrial sectors, but arguably no more than within the aerospace industry. Tronosjet established a manufacturing division in 2016, located in Charlottetown with the sole intent of moving into metallic AM, with a focus on aerospace production. Since commissioning our first Laser Powder Bed Fusion (L-PBF) system in 2019, we have begun developing a certification plan for production of a flight control bracket from a BAe 146 aircraft using L-PBF. This presentation will focus on the current state of AM within civilian aviation, including the challenges facing small organizations in trying to establish themselves in a quickly (or in some respects slowly) changing environment.

2:00pm

Presentation 6: AM and Injection Molding: A Match Made in Automotive Heaven

Jorge Cisneros
Application Engineer,
EOS, United States

Abstract: In the automotive world, additive manufacturing (AM) applications are often considered an alternative to plastic injection molding. But what about making the injection molds themselves? Metal AM is an ideal method of creating plastic injection molds, as it helps solve a variety of problems that have inconvenienced OEMs for decades. The complex geometries of injection molds -- and the intricate vent designs required for gas and material flow – often make conventional machining a poor fit or even impossible. Due to these challenges, many commercially available molds suffer from severe performance issues, becoming clogged quickly and requiring time-consuming cleaning. Using additively manufactured injection molds, GM and EOS developed clog-resistant injection molds that can be cleaned quickly using ultrasonic technology. In this presentation, Jorge Cisneros, Metals Application Engineer at EOS North America, will discuss:

1. Why traditional injection molds cost OEMs time, money, and tool lifespan
2. The issues GM was looking to address with a new injection mold solution
3. The mechanical properties needed in the solution
4. How EOS solved an age-old manufacturing problem with AM
5. Next steps for the GM and EOS injection mold project
6. How this project could influence related applications in the auto industry

2:20pm

Presentation 7: Deeper Learning from Productive Failure in Technology Adoption

Mark Kirby
Industry Training Manager,
University of Waterloo

Abstract: "Aviation in itself is not inherently dangerous. But to an even greater degree than the sea, it is terribly unforgiving of any carelessness, incapacity or neglect." Advanced technologies such as additive manufacturing, share much in common with this famous quote. Scenario training in flight simulators coupled with human factors (cockpit resource management) now feature heavily in modern pilot training. Failure can drive innovation as well as personal and organizational learning. This talk will examine how productive failure can drive deeper understanding of additive manufacturing processes as well as provide a framework for continuous improvement via development of new standards.

2:40pm

Presentation 8: Proheat – A New Smoke-safe Preheating Method for Electron Beam Powder Bed Fusion, Opening up a Wider Range of Processable Feedstocks

Ulf Ackelid
Co-founder,
Freemelt AB, Sweden

Abstract: The evolution of Electron Beam Powder Bed Fusion (E-PBF) started in the 1990's. It was discovered early that an e-beam directed towards a powder bed is prone to scatter powder particles into a powder cloud. This phenomenon is known as "smoke" and if it happens, it usually disrupts the build process. Preheating of each powder layer with a fast-scanning e-beam was later developed to prevent smoke. The preheating semi-sinters the powder and increases its electrical conductivity prior to melting. This laid the basis of the commercial E-PBF process successfully used for titanium alloys today. However, e-beam preheating is not a universal cure. Anyone who has experimented with new powders in E-PBF knows the effort of finding smoke-safe preheating parameters. This paper introduces ProHeat, a new preheating method using infrared radiation from a heating device positioned above the powder bed. The method eliminates build-up of electric charge in the powder and gives 100% smoke suppression. This opens up a wider range of powder compositions and morphologies for E-PBF, for example very fine particle size distributions and materials of poor electrical conductivity.

SESSION 4: TracLight
June 1 | 1:40pm – 3:00pm EDT

1:40pm

Presentation 9: HiPTSLAM; Progress in Understanding the Powder-Processing-Heat Treatment Triangulation for the Fabrication of High Performance Tools and Dies

Mathieu Brochu*, Alexandre Bois-Brochu**, Carl Blais***, Edem Dugbenoo*
Professor,
**McGill University, Canada; **Centre Métallurgie Québec, Canada; ***Universté Laval, Canada*

Abstract: Additive manufacturing is seeing adoption in the tools and dies industries from the added possibility of improving the thermal management and service life of the AM part through the optimisation of conformal cooling capabilities. Such optimised cooling structures can be achieved by the direct fabrication of the channels, or the development of advanced materials having improved properties and thermal conductivity. HiPTSLAM is a project that encompass these two components, with laser powder bed and direct energy deposition AM processing. This presentation will show progress made to understand the optimisation links between powder, processing, heat treatment and performance for dies and inserts made out of tools steel materials to be used in metal casting and forming applications. Mastering these competitive interactions is paramount knowing that the dies and tools materials may have peculiar AM processing behavior.

2:00pm

Presentation 10: Efficiency Increase and Weight Reduction in Modern Combustion Engines provided by Metal Additive Manufacturing

Roman Lengsdorf, Jan Bueltmann
INPECA GmbH, Germany

Abstract: The mobility of the near future is shaped by framework conditions such as environmental compatibility, cost savings and performance. This approach inspired a consortium of seven innovative companies and institutes to tackle the research project "LeiMot", funded by the German government.

The focus is directed towards the engine block of a car because of its heavy weight. However, adjustments to it are very demanding because of the complexity and the operating conditions. In addition to weight reduction, the concept presents potentials for efficiency increase like less coolant and oil pump power, friction reduction of the piston/liner group, emission reduction at cold start and increase of turbocharger turbine power with the isolation of the exhaust ports.

Using the advantages of FEM design simulation and following the rules of additive manufacturing, additional lightweight potential and efficiency increase can be obtained.

We present an operational 3D printed engine with reduced mass of the cylinder head and crankcase by 21% compared to a current series engine with innovative cooling architecture.

Five prototypes were successfully manufactured and examined with respect to mechanical and thermodynamic performance. The know-how and findings from it have great potential to flow into series engines in the near future.

2:20pm

Presentation 11: Application of Machine Learning for Defect Detection in Laser-Powder Bed Fusion

Application of Machine Learning for Defect Detection in Laser-Powder Bed Fusion

Dalia Mahmoud,
McMaster, Canada

Abstract: The poor repeatability and reproducibility of laser powder bed fusion (L-PBF) processes prevent the technology from reaching its full potential to date. Therefore, a lot of focus has been directed to the online monitoring of the L-PBF process for automatic defect detection to take preventative or corrective actions. Three main research topics related to online monitoring and control of L-PBF will be discussed. First, the effect of spatters on the surface morphology of Invar 36 parts is also using infrared pyrometer and high speed infrared thermography will be discussed. The processing conditions that cause melt pool instabilities, excessive spattering, and delamination are presented. Then the comparison of three different controllers to control the melt pool temperature in the building direction for Inconel 625 super alloy will be explained. Finally, to highlight the integration of artificial intelligence (AI) tools such as machine learning (ML) to analyze the large amount of data collected while monitoring is necessary. Three different ML algorithms applied to data collected using acoustic sensor will be explained highlighting the classification accuracy of each technique and their benefits.

2:40pm

Presentation 12: How Recent Innovations in Laser Metal AM Make the Perfect Partner for Space Exploration

Eliana Fu
Industry Manager, Aerospace & Medical,
TRUMPF, United States

Abstract: Space exploration is one of the most demanding industry sectors for metallic engineering materials whether it is in vehicle structures, propulsion or other applications such as ground systems. Additive manufacturing or 3D printing is the ideal technology for production of complex, low volume, high value parts used in space exploration and space flights. This presentation will expand upon some new developments addressing current challenges in laser powder metal additive manufacturing. Other improved techniques such as high temperature preheating, the use of different wavelengths or melt pool sensor data, have a beneficial impact on this technology. It is imperative to make the combination of right material with right processing in order achieve these lofty goals. One material system which is becoming more prevalent in propulsion for launch vehicles is copper, such as for rocket engines. Whether it be the standard CuCrZr or the GR Cop

alloys, use of a shorter wavelength optics (TruDisk with green wavelength), on highly reflective materials allows better laser energy transfer, reduced spatter and a smoother meltpool as well as finer details for structures like cooling channels. When it comes to printing articles for space, laser AM is the perfect partner for these demanding applications.

SESSION 5: Material Development I
June 1 | 4:00pm – 5:40pm EDT

4:00pm

Presentation 13: Preliminary Investigation of Al-Zr-Y Alloys for Laser Powder Bed Fusion Using Laser Remelting

Jon Hierlihy*, Ian Donaldson**, Mathieu Brochu***, Paul Bishop*
**Dalhousie University, Canada; **GKN Powder Metallurgy, Canada; ***McGill University, Canada*

Abstract: The scope of aluminum alloys commercially available for laser powder bed fusion (LPB-AM) 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-xY (x = 0.25, 0.5 and 1 wt.%) were cast and machined. Plates were then ablated with a Yb-fibre laser operated under a range of parameters (power, scan speed, etc.) in multi-track configurations. Each was then examined (optical, SEM, laser confocal) for apparent defects (cracking, porosity, etc.) to gain a precursory sense of the feasibility of this system for LPB-AM.

4:20pm

Presentation 14: Laser Powder Bed Fusion (LPBF) of Difficult to Wend Rene 77 Superalloy

Sila Atabay, Mathieu Brochu
McGill University, Canada

Abstract: Rene 77 is a precipitation hardenable Ni-based superalloy with high γ' fractions. It is designed for a service temperature between 730-900 °C. This alloy is often used in hot gas turbine engine parts, such as vanes and disks due to its excellent corrosion resistance and high temperature strength. Due to the high Al + Ti content of this alloy is susceptible to cracking it is categorized as a difficult to weld alloy. Cracking is frequently reported during the weld repair of the surface cracks formed during the casting process. Therefore, development of new fabrication techniques for this alloy would be beneficial to extend its applicatio. This study involves the successful fabrication of crack free, dense Rene 77 parts by LPBF for the first time in literature. Fabricated parts were subjected to a solutionizing and aging heat treatment to facilitate γ' precipitation. Microstructure of the samples were investigated in detail in both as-fabricated and heat- treated conditions. Mechanical properties were characterized by tensile testing at room temperature and 810°C. Post fracture microstructural analysis were also conducted to comment on the deformation behavior of the parts.

4:40pm

Presentation 15: Alloy Design for Laser Powder-Bed Fusion: Hypereutectic Al-Si Systems

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

Abstract: Laser Powder Bed-Fusion (LPBF) is mostly used on commercially available alloys originally designed to be used in cast or wrought forms. However, due to its fast heat extraction during processing, LPBF is a Rapid Solidification (RS) technique. A new wave of material design for LPBF focuses on alloys that can benefit from RS processing. The Al-Si system provides one such set of alloys, as RS positively affects Si size, morphology, and distribution, enhancing the strength and wear resistance of the alloy. In this work, four alloys based on the Al-Si system are examined: Al-40Si, Al-40Si-1.5Ce, Al-40Si-9.2Mg, and Al-40Si-2.75Fe-2.75Mn-1.5Sc. Al-40Si serves as a basis to understand the role of RS on the microstructure of an Al-Si hypereutectic alloy. Ce alloying investigates how RS impacts the diffusion-intensive modification mechanism for which Rare-Earth elements are known. Macroalloying with Mg and Fe, Mn, and Sc are used to study the potential benefit afforded to RS-induced modification when primary Si content decreases.

5:00pm

Presentation 16: Development of Novel A8 Tool Steel Powders for AM Produced by Water Atomization

William Chaîné, Carl Blais
Université Laval, Canada

Abstract: The majority of additive manufacturing processes use metal powders that are produced by gas atomization as input material. Development of metal powders for AM produced by water atomization could bring significant advantages related to cost reduction. Obviously, water atomization is not appropriate for all the alloys of interest in AM but it certainly is for tool steels. This is even more the case since recent development allows the production of regular (near spherical) particles by water atomization. This study compares the mechanical properties of AM components made of A8 tool steel powders that were water atomized with those of identical specimens manufactured with powders that were water atomized and subsequently spheroidized in an inductivley coupled plasma. An economical analysis evaluating the potential cost reductions brought about by these two approaches is presented.

5:20pm

Presentation 17: Manufacture and Strain Rate Effects on Gyroid Lattices Structures Made by Selective Laser Melting

Henrique Ramos*,**, Rafael Santiago**, Peter Theolbald***, Shwe Soe****, Marcilio Alves*, Mohammed Al Teneiji**
**University of Sao Paulo, Brazil; **Technology Innovation Institute, United Arab Emirates; ***University of Cardiff, United Kingdom; ****University of the West of England, United Kingdom*

Abstract: This work addresses the influence of manufacturing and strain rate on the gyroid lattice impact behavior. For this, AlSi10Mg made by selective laser melting samples were manufactured using three different scanning strategies (e.g. meander, stripes, and chess) and build orientation. The specimens were then mechanically characterized using digital image correlation technique (DIC) in a universal testing machine and dynamically tested using Split Hopkinson Pressure Bar (SHPB), up to 2500/s strain rate. The aluminum constitutive parameters were then extracted and used for developing an explicit FE model in Abaqus/CAE commercial software, in order to evaluate the lattice impact response. The results indicate a minor influence of the scanning strategies on the impact response, being noted, however, a substantial change on its response when loaded quasi-static to dynamic rates (i.e. up to 1000 m/s). This study highlights the promising application of gyroid lattices made by aluminum alloys for lightweight structures for absorbing impact energies.

SESSION 6: Novel AM Processes and Products I
June 1 | 4:00pm – 5:40pm EDT

4:00pm

Presentation 18: In-situ Automated Scan-assisted Repair by Additive Manufacturing

Rémy Samson, Hani Henein
University of Alberta, Canada

Abstract: Mechanical parts sustain significant wear throughout their lifetime and consequently get defects such as cracks, abrasion, erosion, or breakage. For instance, turbine blades experience high pressure and temperature fields which can cause cracks and indentation. In this case, the parts are replaced, resulting in significant time and financial costs. One possible remedy for these losses is to repair the part using additive manufacturing (AM) through directed energy deposition processes. AM offers multiple advantages such as high precision and accuracy, limited amount of material used for repair and reduction of remanufacture time. This project focuses on an in-situ, automated repair strategy by plasma transfer arc AM. A sequence of computational algorithms and a hybrid CNC machine with an integrated 3D scanner are used to repair worn parts. All the steps for repair are applied in-situ, from the scanning to the final repair process. The integrated process results in a single-setup operation, reducing the part movements between different stations, and associated setup times. The process also provides a unified digital toolchain to enable one-step metrology, subtractive manufacturing, and AM process.

4:20pm

Presentation 19: Effect of Substrate Condition and Initial Residual Stresses on Electron Beam Additive Repair and Remanufacturing

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

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

4:40pm

Presentation 20: Binder Jet Printing of MXene Composite for Energy Storage and Strain Sensing

Terek Li, Hani Naguib
University of Toronto, Canada

Abstract: Binder jet 3D printing technology is widely adopted in industrial settings to print ceramic and metallic components. However, it has only recently been proved as a viable method to print polymer composite materials. Herein, we introduce a strategy to print poly(vinyl alcohol) (PVOH) composite with optimized MXene ink. By ejecting highly conductive MXene particles onto a PVOH matrix, the resulting sample achieved semi-conducting behavior with demonstrated potential for strain sensing and energy storage. The printed component is used as a strain sensor capable of sensing strains between 11 to 250% with a linear relationship between output and strain. The component is also used as electrode material in a sandwich-structured pseudo-capacitor achieving an energy density of 7.28mJ/cm^3 and a power density of 0.56mW/cm^3. This study demonstrates that binder jet printing has the potential to directly fabricate polymer composite materials with different end applications.

5:00pm

Presentation 21: An Optimized Method of Powder Feedstock Handling in Directed Energy Deposition

Ambrish Singh, Sajan Kapil, Manas Das
Indian Institute of Technology Guwahati, India

Abstract: Powder feedstock handling in Directed Energy Deposition (DED) plays a crucial role in the process performance and economics. Conventionally, metering, conveyance, and delivery of powder into the melt pool are accomplished via pneumatic means. However, the use of inert gases for powder feedstock handling in DED has several limitations, such as deteriorated surface finish, increased porosity, and poor aspect ratio of the deposited tracks. With the objective of eliminating these drawbacks, this study proposes a novel gravity-based, non-pneumatic method of powder feedstock handling in DED. In the proposed design, for powder metering, a screw conveyor is used, and the powder delivery into the melt pool is accomplished through a continuous coaxial nozzle with a rotating impeller mounted on top. Through Discrete Element Method (DEM) simulations and experiments with initial prototypes, the design viability of the proposed system is established. Also, preliminary observations highlight the design's efficacy in powder mixing,

which can be exploited for the fabrication of material-based Functionally Graded Materials (FGMs). The results show the granular stream, as generated by the nozzle, to be conical and convergent in nature.

5:20pm

Presentation 22: Influence of Heat Treatment on Microstructure and Hardness of Directed Energy Deposition (DED) Processed AISI D2 Tool Steel

Samer Omar, Kevin Plucknett
Dalhousie University, Canada

Abstract: In this research, the influence of heat treatment on the microstructure and hardness of directed energy deposition (DED) processed AISI D2 tool steel was assessed. For DED, the AISI D2 tool steel powder was deposited onto an annealed AISI D2 substrate. The DED parts were built employing different laser scanning speeds and powder feed rates, while the other parameters were kept fixed. The DED-processed samples were subsequently subjected to a conventional D2 heat treatment scenario, double-tempering at 500°C. Microstructures of the DED samples were investigated using scanning electron microscopy. Indentation hardness was also analyzed. The results showed that the Microstructure of the DED processed samples demonstrates dendritic morphology with columnar grains. In addition, it was found the hardness of the DED-processed parts was higher than the annealed wrought samples. Hardness was further improved by the heat-treatments.

SESSION 7: Advanced Process Modeling I
June 2 | 7:40am – 9:20am EDT

7:40am

Presentation 23: The Effect of Surface Morphology on Monotonic and Cyclic Stress Behavior in 250 μm SS316L Struts Fabricated by Laser Powder Bed Fusion

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

Abstract: Understanding the surface morphology and mechanical performance relationship of micro- and meso-scale struts is crucial towards manufacturing lattice structures with superior performance using laser powder bed fusion (LPBF). Vertically built struts of 250 μm nominal diameter with >99.7% density were successfully fabricated using LPBF. The surface morphology of the fabricated struts was characterized using profilometry and computerized tomography. Primary surface-related features and defects were identified. Monotonic tensile tests and high cycle fatigue stress regime of the struts are characterized. Maximum cyclic tensile stresses ranging between 272±10 MPa and 355±10 MPa were imposed on the struts. With tomography, the fatal defect initiating the critical fatigue crack was characterized. The fatal defect was modeled using a modified $\sqrt{Area}$ parameter to estimate its stress intensity and predict fatigue strength. Crack initiation and propagation were modeled and compared with crack growth rates obtained in macroscale fatigue specimens.

8:00am

Presentation 24: A Simplified Approach to Modelling the Thermal Balance of the Build Chamber in Electron Beam Additive Manufacturing

Farhad Rahimi, Farzaneh Farhang Mehr, Steve Cockcroft, Jun Ou, Daan Maijer
The University of British Columbia, Canada

Abstract: Temperature variation in the build chamber of an Electron Beam Powder Bed Additive Manufacturing (EB-PBAM) process can directly impact the mechanical and physical properties and dimensional accuracy of the final parts. Whether single or multiple components are being fabricated, the balance between the input heat and the heat loss in the build chamber should be optimal to ensure a successful print. The trial-and-error methodology is one approach to optimize the fabrication condition. However, this approach is not feasible, considering the materials and maintenance costs in an EB-PBAM process. The other approach is to develop a numerical model that can predict the build chamber's thermal history during the process. In this research, a simplified build chamber was replicated in an electron beam melting furnace by incorporating the ARCAM Q20Plus heat shield and a simple beam scan pattern. The build chamber was instrumented with thermocouples to record the evolution of temperature during the experiment. A 3D heat transfer model was developed to predict the heat loss in the build chamber during the experiment. The good agreement between the model predictions and the temperature measurements suggested that the numerical model could predict the thermal field in the build chamber with an acceptable accuracy.

8:20am

Presentation 25: Machine-learning-assisted Manufacturability Analyzer and Recommender

Ying Zhang, Yaoyao Zhao
McGill University, Canada

Abstract: This paper presents a novel approach to predict the manufacturability for the Laser-based Powder Bed Fusion (LPBF) process with lower computational cost and better performance compared to the existing methods. Recent researches have proposed several machine learning methods to model the manufacturability analysis. One approach is to use a Voxel-based Convolutional Neural Network (CNN). The computational capability limits this approach, and only a lower resolution has been performed. However, low resolution is not enough for analyzing the LPBF manufacturing process precisely. Some detailed features may be omitted through the voxelization process. To solve this issue, a more efficient CNN is proposed in this paper. Design data is stored in a sparse matrix so that only the occupied voxels are trained by CNN operations. It integrates with the process data, which is trained by a Neural Network (NN) model to predict whether the given design is printable without the visual defects. By performing the generalized convolutions, the computational costs reduce sharply compared to voxel-based CNN, which offers the advantage of performing with high resolutions. The approach is validated in terms of accuracy and intersection of union.

ALL TIMES ARE EASTERN DAYLIGHT TIME (UTC-04)

8:40am

Presentation 26: The Effect of Laser Scanning Stripe Width on Melt Pool Geometries in Laser Powder-bed Fusion Additive Manufacturing Process

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

Abstract: Laser Powder Bed Fusion (LPBF) has been widely used in industry and academia for fabricating customized complex shapes. In this process, a thorough investigation is required to better understand the existence of the complex phenomenon during the manufacturing of the part. Numerical modeling provides this opportunity to study the effect of process parameters on temperature distribution and melt pool dimensions without conducting expensive trial and error experimental approaches. In this paper, multi-track modeling of the LPBF process is developed to investigate the effect of stripe width on melt pool geometries and transient temperature profile. The results show that the stripe width has a significant influence on the melt pool geometries, and by decreasing the scanning stripe width, the melt pool dimensions increased significantly. Besides, the developed model shows a good agreement with experimental results.

9:00am

Presentation 27: Identification of Thermal Patterns in Distortion Generation for Bead-based Metal Additive Manufacturing as an Approach for Fast Simulations

Seyedeh Elnaz Mirazimdeh*, Syamak Pazireh*, Jill Urbanic*, Bob Hedrick**
**University of Windsor, Canada;*
***CAMufacturing Solutions, Inc., Canada*

Abstract: Thermal modelling for additive manufacturing processes is challenging due to the number of layers, and the quantity of thermal cycles a component may undergo. One approach for simplifying the modeling problem is to not consider the tool path for the heat source and the modeling is carried out on a layer by layer basis. Alternatively, the tool path is taken into account in the simulations by an element birth-and-death method, but the computational costs of this strategy are very high. In the first method, the heating and cooling processes within each layer are not properly captured. In the second approach, the simulations for components with complex geometries will encounter difficulties when intricate tool paths are generated. In this research, the effect of heating and cooling for several geometric shapes has been investigated to identify heating-cooling-distortion patterns by classifying thermal processes in context with the component geometry and tool path combinations. A novel hybrid strategy utilizing voxel-based analytical methods along with neural networks are explored.

SESSION 8: Process Monitoring and Control I
June 2 | 7:40am – 9:20am EDT

7:40am

CANCELED **Presentation 28: Active Learning in Additive manufacturing**

Mihaela Vlasea, Gijs van Houtum
**University of Waterloo, Canada*

Abstract: The acquisition of large amounts of high-dimensional data is becoming prevalent in additive manufacturing, arising from in machine vision sensor integration in such processes. Although supervised machine learning has gained popularity to predict process quality from such data, annotation can be time-consuming and labor intensive. Active learning is a sub-field within machine learning concerned with maximizing classification performance using the least amount of annotated data. The focus of this study is twofold. Firstly, a novel active learning method is introduced, called adaptive weighted uncertainty sampling (AWUS). Secondly, a novel classification method is proposed for directed-energy-deposition additive manufacturing processes which predicts the image quality for feature extraction from the melt pool. The proposed AWUS query strategy is compared against 6 state-of-the-art methods on 28 open-source data-sets and 8 in-situ machine vision recordings of directed-energy-deposition processes using 4 different classifiers. Our results show that AWUS outperforms the state-of-the-art. Furthermore, the application of AWUS can reduce the amount of necessary annotations by 50% with equivalent classification performance.

8:00am

Presentation 29: A Comparison Between Different Eddy Current Probe Designs with respect to Different Defect Sizes

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

Abstract: One of the problems in additive manufacturing (AM) technology, such as laser powder bed fusion, is the formation of pores, induced during the printing process, that undermine the printed part durability. In-situ detection of defects ensures higher product quality. Eddy current technique can be used for detection of defects induced in AM processes. Two important factors determine the success of the detection procedure. Those factors are how the eddy currents are induced inside the material and how the defect signal is sensed. Comparing the eddy current probes that work in the absolute mode and the transmit/receive mode is done with respect to different defect sizes. A significant improvement in the probe sensitivity can be achieved through the use of shielding. The design includes adding noise cancellation coils and shielding to reduce noise and increase the probe's sensitivity. This presentation will shed some light on these findings.

8:20am

Presentation 30: Development of a Machine Learning Defect-detection Model through the Photodiodes Signals Collected from the Melt Pool of Laser Powder-bed Fusion

Katayoon Taherkhani*, Christopher Eischer**, Martin Otto**, Ehsan Toyserkani*
**University of Waterloo, Canada;*
***EOS GmbH Electro Optical Systems, Germany*

Abstract: This abstract presentation aims to describe a machine-learning algorithm to detect the lack of fusion porosity by analyzing the in-situ light intensity data emitted from the melt pool of laser powder bed fusion (LPBF). The self-organized map (SOM) algorithm is chosen to identify disturbances in the light intensity signal, where the signal disturbance is mapped with the positions of defects identified through a post-processing micro-computed tomography (CT) scanning. To this end, two sets of experiments were devised: one with embedded micro-voids to purposefully mimic the lack of fusion in the printed parts to assess the sensor response and develop the analysis algorithm. The second set was printed parts with randomized pores to evaluate the proposed approach. The recorded raw data was analyzed through MATLAB and LabVIEW. In the anlsyis, the segmentation method and confusion matrix were used to examine the correlation. The results demonstrated that voids larger than 100 μm are detectable through the collected photodiode signals. The proposed unsupervised learning approach can be used to develop a comprehensive model required for an intermittent control of LPBF.

8:40am

Presentation 31: Real-Time Geometry Prediction in Laser Additive Manufacturing using Machine Learning

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

Abstract: In this research, a monitoring algorithm is discussed with the capability of measuring the geometry of added material during laser additive manufacturing (LAM). LAM is highly sensitive to small disturbances in the process inputs, resulting in variation in the geometry of the produced layer (clad). Since these changes are caused by complex metallurgical phenomena it is difficult and computationally complex to derive a mathematical model of the entire process. To circumvent the challenging modelling, real-time monitoring can be implemented to measure geometry and control methods can correct for errors. The monitoring is usually accomplished by images captured by a camera, where the geometry of the clad can be calculated based on the location of the camera relative to the clad. To improve geometry monitoring, machine learning can be used as well as implementing two camera sensors, a visible and infrared sensor. Using both sensors allows for more accurate information since the clad will appear different in each wavelength due to the differing emissivity values. A convolutional neural network (CNN) can then use these images to estimate the geometry (height and width) of a single track of LAM in real-time.

9:00am

Presentation 32: Sensor-Based In-situ Process Control of Robotic Wire Arc Additive Manufacturing Integrated with Reinforcement Learning

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

Abstract: Wire and Arc Additive Manufacturing (WAAM) is a manufacturing technique capable of fabricating large scale metallic components in a layer-by-layer fashion. As an emerging technology, there still exists numerous challenges that need to be overcome to ensure the geometrical accuracy of the part produced. With an increasing number of deposited layers, geometrical errors often accumulate in height and the accumulated heat becomes significant, leading to the slumping of the beads. The quality of the part can be enhanced through in-situ real-time feedback control. However, as the WAAM process is a time-variant process that is highly non-linear and multi-dimensional, it is difficult to model the process relating the process parameters to the final quality of the produced part. To address this challenge, a sensor-based in-situ process control framework integrated with reinforcement learning AI is proposed to iteratively learn the impacts of various process parameters to finally control the output geometry of a single-bead multi-layer part. This proposed control framework is then implemented and validated on a robotic large-scale WAAM system with embedded thermal and geometrical sensors.

SESSION 9: Material Development II
June 2 | 9:40am – 11:20am EDT

9:40am

Presentation 33: Fatigue Resistance of Laser Powder Bed Fused Ti64 Components with Intentionally-seeded Porosity

Etienne Moquin, Morgan Letenneur, Vladimir Brailovski
École de Technologie Supérieure, Canada

Abstract: To study the influence of processing-induced porosity of the fatigue life of laser powder bed fused Ti-6Al-4V components, testing specimens were printed using low, optimal and high energy densities (LED, OED, HED) to intentionally seed porosity of different levels, morphologies and distributions. The OED printing resulted in specimens with less than 0.1% of porosity, while both the LED and HED printing resulted in specimens with similar values of porosity and equivalent pore diameter (~0.3% and ~44 μm), but different pore morphologies: LED-printed specimens with elongated and aligned pores (aspect ratio 0.46) and HED-printed specimens with more spherical and random pores (aspect ratio 0.57). Initial results of an ongoing force-controlled fatigue testing campaign (ASTM E-466, R=0.1) show that for a maximum stress in a cycle of 850 MPa, the number of cycles to failure of OED specimens is ~5.4·105, of HED specimens, ~2.3·105, and of LED specimens, 2.5·104. This demonstrates that while inspecting AM parts, not only the total porosity and pore size values must be considered, but also the pore morphology and distribution.

10:00am

Presentation 34: Microstructure Evolution during Additive Manufacturing of 2205 Duplex Stainless Steel

Nima Haghdadi*, Hansheng Chen**, Zibin Chen**, Xiaozhou Liao**, simon Ringer**, Sophie Primig*
**UNSW Sydney, Australia; **The University of Sydney, Australia*

Abstract: While the aerospace, defence and biomedical industries were the first to implement metal additive manufacturing (AM) technology, a recent SmarTech report1 predicts that the oil & gas sector will be the next key adopter of AM technologies. Due to its outstanding mechanical properties and corrosion resistance, duplex stainless steel is a promising material to be used in oil and gas infrastructures. AM of these steels allows complex geometries and refined designs. The current study shows laser powder bed fusion AM can be used to successfully print these steels. A detailed correlative microscopy including optical microscopy, electron back scatter diffraction, transmission electron microscopy and atom probe microscopy reveals that AM duplex stainless steels are of a metastable ferritic matrix. Ferrite grains consists of CrN and G-phase particles mostly nucleated in the interdendritic regions. Ferrite matrix also shows a high density of dislocations and low angle grain boundaries usually enriched in N and Cr.

10:20am

Presentation 35: Estimate Solidification Parameters of Al alloys Fabricated by AM based on T0 Curve and Non-equilibrium Solidification

An Fu, Mathieu Brochu
McGill university, Canada

Abstract: In rapid solidification process such as (LPBF) Laser Powder Bed Fusion, the microstructure is much influenced by solidification parameters, for example, increased growth velocity can yield high solid solubility of strengthening elements, high cooling rate promotes grain refinement and enhances solidification undercooling. Therefore, the solidification parameters play key roles in microstructural evolutions. However, there exist remarkable challenges in direct measurement of these parameters due to the manufacturing characters of LPBF. In this study, a computational method for predicting the solidification parameters of Al alloys fabricated by AM (Additive Manufacturing) is developed. This comprehensive approach involves non-equilibrium thermodynamic modelling and rapid solidification models, based on analyzing the microstructure of AM samples. With this proposed methodology, all the common-acknowledged solidification parameters including growth velocity, cooling rate and undercooling can be estimated. Moreover, this methodology can be used in multi-component Al alloys fabricated by different AM technologies.

10:40am

Presentation 36: Rapid Solidification of Al-10Si-0.4Sc Alloy

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

Abstract: Sc addition in hypereutectic level (>0.55wt%) in binary Al-Sc is found to yield good grain refinement in Al castings, due to the precipitation of primary Al3Sc during solidification, which also acts as a recrystallization inhibiter and a favorable nucleation site for strengthening phases. However, because of its low market availability and high cost, it is economically more interesting to use Sc in hypoeutectic level (<0.55wt %), while benefiting from rapid solidification induced grain refinement, solid solution and precipitation hardening. As such, Sc has a great potential for minor elemental addition to Al-alloys for Additive Manufacturing (AM), such as the widely used industrial hypoeutectic Al-Si alloys. This work investigates the effects of minor Sc addition (0.4wt %) on Al-10wt%Si over a wide range of thermal histories. Using DSC and Impulse Atomization, hypoeutectic Al-10Si-0.4Sc alloys were produced with a wide range of cooling rates (0.1-104K/s). Microstructural characterization and mechanical properties evaluation were conducted to determine the combined effects of cooling rate and Sc addition. On this basis, the solidification pathways and resulting microstructures were quantified for slow and rapid cooling, providing a critical relationship between processing/microstructure/properties that can contribute to alloy and process development in Additive Manufacturing.

11:00am

Presentation 37: Evolution of Microstructure During Heat Treatment of Laser Powder Bed Fused Ti-5553 Alloy

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

Abstract: Ti-5553 (Ti-5Al-5Mo-5V-3Cr), a newly developed β-Ti alloy is an attractive alloy for aircraft structural applications. Recent publications confirm the printability of this alloy through laser powder bed fusion, although as-fabricated tensile strength values do not match those of traditional forgings. The inferior tensile properties may be a result of rapid heating and solidification rates involved in the metal additive manufacturing processes, which may result in a compromised microstructure, accumulated residual stresses, and hence poor mechanical properties. Thus, post-fabrication heat treatments are essential to achieve the expected performance of these printed parts. In this work, the printed Ti-5553 samples were subjected to heat treatment cycles that would promote strengthening via growth of lamellar α particles. Microstructural characterization of solution treated and aged samples revealed the growth and uniform distribution of needle-like α phase across the samples. X-Ray diffraction patterns and Electron backscatter diffraction results confirmed the presence of α phase in the heat-treated samples. Comparison reveals the heat-treated samples exhibited higher hardness values, together with a 25% increase in tensile strength at the expense of ductility. The fractured surfaces exhibited localized traces of both ductile and brittle modes of failure.

SESSION 10: Novel AM Processes and Products II
June 2 | 9:40am – 11:20am EDT

9:40am

Presentation 38: Addressing Surface Roughness and Fatigue Life in Additive Manufactured Parts

Pablo Enrique, Ehsan Toyserkani, Norman Zhou
University of Waterloo, Canada

Abstract: Additive manufactured parts are finding their way into numerous high-performance industrial applications, including rocket and turboprop engines. However, the high surface roughness and presence of near-surface porosities in additive manufactured parts have serious implications for the durability of critical components. This issue necessitates the use of post-processing surface treatments. In this research, an electrospark deposited Inconel 718 coating, and hammer peening surface treatment are used to improve the surface condition of laser powder bed fusion Hastelloy X parts. The result is a greater than 100% increase in the fatigue limit stress and a greater than 50 times increase in the cycles to failure at a stress level of 350 MPa (>1E7 cycles). This significant improvement can be attributed to reducing surface roughness, and beneficial properties of the Inconel 718 coating applied during post-processing. These findings show potential for the selective surface enhancement of critical regions in additive manufactured parts.

10:00am

Presentation 39: Hybrid Additive Manufacturing through Sequential Layer-by-layer Laser Directed Energy Deposition and Remelting for Improved Hastelloy-X Properties

A N Jinoop, C P Paul, K S Bindra
Raja Ramanna Centre for Advanced Technology, India

Abstract: Laser Directed Energy Deposition (LDED) uses focused laser energy to fuse materials by melting as they are being deposited. LDED built components have a few limitations, like - surface roughness, porosity, etc. Sequential Layer-by-layer laser remelting (SLLR), a process involving laser remelting after LDED of each layer can be one of the approaches to overcome these limitations minimizing post-processing procedures. SLLR of bulk structures shows a significant reduction in surface roughness and porosity. Both lack of fusion and gas porosity is observed in the as-built sample, while only gas porosity is witnessed in samples by combining SLLR with LDED with a density of ~ 99.99% after SLLR. The average surface roughness reduced by 71.4% (Ra from 10.5 μm to 3 μm) after SLLR. The microstructure is found to be relatively finer after SLLR without preferential growth along direction as opposed to that without SLLR due to redistribution of the thermal cycle. The finer dendritic microstructures in SLLR samples led to an increase in the microhardness and yield strength along the build direction as compared to samples without SLLR. The present work paves a path for building dense components in a single step during LDED by deploying SLLR.

10:20am

Presentation 40: Effect of Thermal Load in Wire and Arc Additive Manufacturing (WAAM) of Ti6Al4V Multilayer Walls

Emmanuel Reyes*, Arturo Gomez**, James Perez**, Ricardo Morales Estrella*
**Universidad Michoacana de San Nicolas de Hidalgo (UMSNH), Mexico; **Centro de Ingenieria Y Desarrollo Industrial (CIDESI), Mexico*

Abstract: Overheating during additive manufacturing processes has a direct impact on the geometry and mechanical behavior of Ti6Al4V walls fabricated by Wire-Arc Additive Manufacturing (WAAM) process. In this work, the heat accumulation and its effect on the geometry of the layers during the cold metal transfer wire-arc additive manufacturing (CMT-WAAM) process were evaluated by the deposition of multiple layers. In addition, microstructure is related to the mechanical properties to explore the manufacturability of Ti6Al4V parts by CMT-WAAM with a low heterogeneity. Results show an important influence of the heat accumulation on the surface oxidation of the layers, the grain size and crystallography of the deposit along the wall deposition path. These variations promote non-homogeneous hardness and differences in the microstructure of the deposit. The study aims to establish tools for understanding the effects of heat and its relationship to specific mechanical properties during a CMT-WAAM process with localized gas shielding, which will benefit the application, improvement and adoption of this process. It is suitable to determine build parameters and indicators to avoid relevant heat accumulation assuring adhesion between layers and process efficiency.

10:40am

Presentation 41: The Role of Heterogeneous Structures on the Mechanical Properties of Additively Manufactured AlSi10Mg

Haoxiu Chen*, Yu Zou*, Sagar Patel**, Mihaela Vlasea**
**University of toronto, Canada;*
***University of Waterloo, Canada*

Abstract: Additive manufacturing (AM) has been widely used to produce AlSi10Mg samples, which have heterogeneous structures. AMed AlSi10Mg samples have coarse cellular dendrites along the melting pools, fine cellular dendrites inside the melting pools, and heat-affected zone with broken Si networks beneath the melting pools. The role of the heterogeneous structures on the mechanical properties of AMed AlSi10Mg is rarely studied. In heterogeneous structures, soft regions deform plastically more than hard regions, so that gradients of plastic deformation build up. Accommodation of such plastic gradients requires the storage of geometrically necessary dislocations, which contribute to work-hardening. Correspondingly there will be a gradient in the density of geometrically necessary dislocations. Dislocation density depends on the gradient dendrite size and resulting gradient plastic strains. As a result, we build up a numerical model based on the melting pool microstructure information to derive the tensile mechanical properties of additive manufactured AlSi10Mg samples.

11:00am

Presentation 42: Residual Stresses Piloted Optimization of Functionally Graded Parts Using PTAAM

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

Abstract: In Canada, the oil sands mining field involves high maintenance costs due to intensive abrasive wear of the digging tools despite the current use of relatively tough and hard coatings. Indeed, during the coating deposition process significant detrimental residual stresses may build up and diminish the abrasive wear performance. These stresses can be reduced by adopting a tailored smooth transition from the apparatus bulk material to the coating. The main goal of the present study is therefore to design an ideal additively manufactured material path and print functionally graded geometries using a plasma transferred arc. The core of the present work includes the prediction of the thermal history and the induced thermal and residual stresses complex history during the fabrication. A macroscale thermal modeling of the additive manufacturing process has been built and is completed with a subdivision modeling the powder heating inside the plasma. Temperature predictions are being compared with IR camera light emission data backed up with thermocouples. Residual stresses are predicted on Abaqus using the temperature predictions as an input. Experimental methods are being designed for partial verification of Abaqus predictions, and consequences on the wear resistance will be verified using standard abrasion wheel tests.

SESSION 11: Advanced Process Modeling II
June 2 | 1:40pm – 3:20pm

1:40pm

Presentation 43: Experimental and Numerical Investigation of Block-Type Support Structure Design Parameters on Thermal Fields within Components Fabricated by Selective Laser Melting

Arman Khobzi, Steve Cockcroft, Daan Maijer, Farzaneh Farhang Mehr
The University of British Columbia, Canada

Abstract: The successful production of overhang features in the Selective Laser Melting (SLM) requires sacrificial structures, known as support structures. These structures provide mechanical support to the overhang regions and alter thermal fields within produced components. Therefore, optimization of support structure design requires an understanding of their impact on the thermal field and mechanical constraint. In the present research, a combination of experiments and numerical modelling was used to quantify the contribution of the geometry of the support structure to the evolution of the thermal field in a cantilevered plate and in turn, to investigate the relative role of heat transfer on component deformation. The results indicated that the total contact area of teeth and the total support base area alter thermal fields within the produced components. Increasing the area for conducting heat to the base was found to reduce the peak temperature in the overhanging platform. Additionally, increasing the contact area of teeth reduces the vertical temperature gradient within the overhanging platform, while the overall support base area was found to have a negligible impact on the temperature gradient.

2:00pm

Presentation 44: Adaptive Physics-based Model for Laser Directed Energy Deposition

Mazyar Ansari, Mobin Khamooshi, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Subsequent overlapping tracks and heat accumulation happening in laser directed energy deposition (LDED) complicate the control of the deposition accuracy during the process. Real-time feedback control can be a solution, although this method has its limits in terms of robustness to harmonic and non-harmonic process disturbances. A cost-effective solution for process control and optimization is adaptive physics-based modeling which is the focus of this research. The transient temperature field is predicted based on a moving heat source. Then a unique algorithm is developed to simulate the geometry of subsequent tracks and predict the required laser power for those tracks such that they arrive at desired geometry. This model is designed for multi-track deposition only based on a time-efficient physics-based model, which is adaptive in terms of predicting the laser power as the main processing parameter. The performance of the developed model is experimentally evaluated by depositing a titanium alloy (Ti-5553) at different laser powers, scanning speed, and powder feed rates. It was found that the adaptive model is able to control the deposition accuracy under a variety of processing conditions.

2:20pm

Presentation 45: An Experimental Study to Investigate the Influence of Infill Features on the Structural Performance of Topology Optimized Metal LPBF Parts

Osezua Ibhadode, Reza Esmaeilizadeh, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Topology optimization solves the optimal material distribution problem for a structural design. To mimic porous structures such as the trabecular bone for orthopedic applications, a local volume constraint can be imposed in topology optimization to obtain infill-like structures in a design. While the resultant lattice-like features pose little to no manufacturability challenges considering Laser Powder-Bed Fusion (LPBF), the impact on their buckling load capabilities compared to optimized designs with the global volume constraint is worth investigating. In this experimental study, the buckling load capabilities of topology optimized structures under local and global volume constraints produced by LPBF are investigated while comparing their trends with numerically obtained compliance values. Five optimized samples are investigated altogether: one with a global volume constraint only and four with additional cylindrical local volume constraints using four different radii. A tensile test is first done to determine the material properties, thereafter, displacement-controlled 3-point bending tests are carried out to obtain their load-displacement responses. A reduction in the local volume threshold results in less design freedom for structural optimality thereby increasing the compliance or decreasing the structural performance.

2:40pm

Presentation 46: Numerical Heat Transfer Modeling of the Melt Pool in Laser Powder-bed Fusion of Metastable β Titanium Alloy

Mahyar Hasanabadi, Shahriar Imani Shahabad, Ali Keshavarzkermani, Nivas Ramachandiran, Hamed Asgari Moslehabadi, Adrian Gerlich, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Among metal Additive Manufacturing methods, Laser Powder-bed Fusion (LPBF) is considered a feasible fabrication method to produce products with custom-made properties. Depending on the application, specific properties may be desired for an additively manufactured part. Among the properties, the part microstructure has a considerable role in this matter. Since the exact effects of LPBF manufacturing parameters on the microstructure of the printed objects are not well understood, an accurate and validated numerical heat transfer model could be one of the most efficient ways to shed some light on the effects of process parameters on the microstructure formed. In the current study, a highly accurate heat source model has been developed to analyze the thermal domain in the melt pool zone during LPBF of a metastable β Titanium alloy (Ti-5Al-5Mo-5V-3Cr). In this regard, several thermal variables of the melt pool, like temperature gradient, cooling rate, and solidification rate, have been extracted. To validate and calibrate this moving heat source model, several Ti-5553 single tracks with different laser power and velocity were printed and their melt pool depth and width were measured experimentally.

3:00pm

CANCELED Presentation 47: Numerical Study on the Effect of Wire Arc Additive Manufacturing Process Parameters on Residual Stresses Distribution

Rasoul Moharrami, Hamed Eshaghi
University of Zanjan, Iran

Abstract: Additive Manufacturing (AM) as a main step of CAD/CAM systems were used for making a complex piece from its three-dimensional model. Wire arc additive manufacturing (WAAM) was used for manufacturing large metallic part in the form of layer by layer by welding process. The quality of parts is affected by many parameters such as geometry of the part, microstructure, residual stresses distribution, manufacturing conditions and process parameters. Residual stresses are a common serious defect in WAAM and affect the mechanical behavior of parts. In order to achieve optimal manufacturing conditions, it is necessary to understand how the stresses were developed and the parameters effects on that. In this study, the effect of some process parameters of WAAM such as electrical current, voltage, torch speed, pass arrangement and substrate thickness on residual stresses were considered. For this purpose, with ABAQUS finite element software, manufacturing of wall-like specimen was simulated. The sample was made of stainless steel 316 and the level of process parameters and number of simulation state were obtained from Taguchi design of experiment method. The results show the development of considerable, residual stresses and the significant effect of process parameters on the magnitude and distribution of these stresses.

SESSION 12: Process Monitoring and Control II
June 2 | 1:40pm – 3:20pm

1:40pm

Presentation 48: Automated Porosity Detection in Laser Powder Bed Fused Parts using Computed Tomography and Deep Learning Algorithms

Catherine Desrosiers*, Morgan Letenneur**, Fabrice Bernier***, Francois Guibault*, Benjamin Provencher****, Farida Cheriet*, Nicolas Piché****, Vladimir Brailovski**
**École Polytechnique Montréal, Canada; **École de Technologie Supérieure, Canada; ***NRC, Canada; ****Object Research System , Canada*

Abstract: The process of Laser Powder Bed Fusion (LPBF) induces a high uncertainty in the mechanical properties of 3D-printed parts, which constitutes one of the main barriers for their wider industrial adoption. To address this problem, manufacturers need to detect critical processing-induced defects in printed parts, and X-ray computed tomography (micro-CT) represents the best-suited technology for this endeavor. However, using the micro-CT for the defect detection is facing multiple challenges. One of them is to find an appropriate greyscale threshold to separate defects from material. In this work, different threshold strategies for the porosity detection in LPBF parts were compared. To this end, Ti64 samples with intentionally-seeded and controlled porosity were printed and scanned by two different operators on two different CT scan systems. Next, the porosity of these samples was analyzed using Convolutional Neural Network (CNN) deep learning algorithms, the Otsu's and the manual thresholding approaches, and then validated using Scanning electron microscopy images. It was demonstrated that only the CNN algorithm could provide satisfactory repeatability and reliability for the automated porosity detection in LPBF parts and that, regardless of the operator and the CT scan system used.

2:00pm

Presentation 49: The Use of Sintering Models in Binder-Jet Additive Manufacturing

Roman Boychuk, Mihaela Vlasea
University of Waterloo, Canada

Abstract: Sintering is a key process in the binder-jet additive manufacturing (BJAM) process in which the printed green part undergoes significant densification and strengthening. Sintering of BJAM parts is typically either solid-state, or liquid-phase, where the dominant densifying mechanisms are grain boundary diffusion, and viscous flow from liquid capillary forces respectively. As density grows from approximately 60% to over 90%, a large degree of dimensional shrinkage occurs, often nonuniformly due to anisotropy in the powder compact, and external forces such as gravity and friction. This presentation reviews the sintering process, and examines a number of sintering models as they apply to BJAM: the master sinter curve, the kinetic Monte Carlo method, and continuum mechanics approaches (Riedel-Svoboda, and Skorohod-Olevsky viscous sintering). A rudimentary continuum mechanics model is presented as a starting point for further development on a tool to predict macro-scale sintering distortions, as well as reflections on future works.

2:20pm

Presentation 50: A shape Compensation Approach for Enhancing the Geometric Accuracy of Additive Manufacturing Parts

Moustapha Jadayel, Farbod Khameneifar
Polytechnique Montreal, Canada

Abstract: Additive manufacturing (AM) enables prototyping and manufacturing complex parts with many integrated functions, but the current AM processes have shortcomings. One major flaw is the low geometric accuracy due to the machine's mechanical errors, material warping, and other thermo-mechanical deformations. To reduce the geometric deviations of a printed part, we propose a 3D compensation methodology that allows morphing the surface mesh of the nominal geometry by the inverse of the systematic deviations to generate a compensated STL file. These systematic deviations are measured by 3D scanning multiple sacrificial parts and computing an average deviation vector field on the surface mesh. We demonstrate the advantage of filtering the random geometric deviations from the measurement data used for compensation. Case studies demonstrate that printing the compensated STL file on the same machine produces a more accurate part than the one printed based on the original STL file. The results further show that the compensated part based on the average deviation vector field of multiple parts is considerably more accurate than the compensated based on only one part.

2:40pm

Presentation 51: Process Planning for Additive Manufacturing of Geometries with Overhang Features using a Robotic LDED system

Farzaneh Kaji, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Laser Directed Energy Deposition (LDED) has been widely used for component repair as well as manufacturing of 3D components. Conventional LDED relies on sequential application of 2D layers without supports; the ability to produce overhangs is limited due to the gravity, surface tension, and fluid-flow forces acting on the nonconfined melt pool. Five-axis toolpath generation has been used for LDED of parts with overhangs more than 45°, however, process planning with collision avoidance while maintaining direction normal to the previously built layers are very challenging. In this research, overhang structures with different offset angles have been studied. A novel approach using deposition alongside a containment mesh boundary using coordinated motion is introduced to manufacture parts with overhang structures in LDED. Comparison between the containment mesh boundary and partitioning method has been also studied. Process planning and manufacturing a tubular part using a medial non-uniform rational basis spline (NURBS) curve has been studied and results will be presented in the presentation.

3:00pm

Presentation 52: Combining In-situ Monitoring and X-ray Computed Tomography to Assess the Quality of Parts Manufactured by Laser Powder Bed Fusion and Electron Beam Melting

Philip Sperling, Patrick Fuchs
Volume Graphics GmbH, Germany

Abstract: In the most recent metal powder bed fusion technologies for additive manufacturing different in-situ monitoring sensors are available. These monitoring technologies generate a huge amount of data directly during the production process. In the future, this data could be used to avoid, reduce or precisely target following destructive or non-destructive testing methods or even stop the production of this build job in an early stage. In the current state of in-situ monitoring solutions the indications and process instabilities shown are very hard to interprete. Further investigations and correlations with post-process testing measures are necessary. In our paper, we show how to correlate in-situ monitoring data with computed tomography results. For this, we use two test specimen: one set of test cubes for process parameter development from a metal laser powder bed fusion system and a set of specimen from an electron beam melting system. Both metal additive manufacturing systems are using different monitoring solutions. Further, we show different approaches of analyzing the in-situ data for process instabilities and how to use modern machine learning methods to correlate process signatures with part quality metrics.

SESSION 13: Material Development III
June 2 | 3:40pm – 5:20pm EDT

3:40pm

Presentation 53: Binder Jet Printing AISI 5120 Chromium Steel Powder

Addison Rayner*, Randy Cooke*, Ian Donaldson**, Paul Bishop*
**Dalhousie University, Canada;*
***GKN Sinter Metals, United States*

Abstract: Binder jetting additive manufacturing (BJAM) is a powder bed AM process which uses a liquid binder to selectively adhere layers of powdered material into a desired geometry. The result of the BJAM process is a "green" part which is subsequently cured, de-bound, and sintered or infiltrated into a dense material. BJAM is performed at room temperature and does not require a controlled atmosphere, avoiding common problems associated with fusion-based AM processes, such as elemental segregation, oxidation, and residual stresses. In this work, the BJAM processing response of AISA 5120 chromium steel (Fe-0.2C-0.8Cr-0.8Mn-0.2Si) powder produced through water atomization was evaluated. Initially, the raw powder was fully characterized to assess its off gassing behaviour (TG-GCMS) and phase transformations as a function of temperature (DSC). Test specimen were successfully printed, cured, de-bound, and then sintered in high vacuum and forming gas atmospheres. Analysis of in-situ sintering densification and microstructure evolution was completed through dilatometry, laser confocal microscopy, and SEM/EDS. In addition, post-sinter chemical analysis (ICP, COHN analysis) revealed the influence of temperature and atmosphere on the final chemistry of the sintered product.

4:00pm

Presentation 54: Double-laser LPBF Processing of a High-performance Maraging Tool Steel

Gregor Graf*, Manuela Neuenfeldt**, Tobias Müller***, Jörg Fischer-Bühner****, Daniel Beckers*, Sven Donisi*, Frederik Zanger**, Volker Schulze**
**Rosswag GmbH, Germany; **wbk Institute of Production Science, Germany; ***Gühring KG, Germany; ****BluePower Casting Systems GmbH, 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. In a previous work, the maraging tool steel Specialis® was developed, which can be processed by LPBF processes with a density of more than 99.9 % using a suitable set of process parameters. A hardness of more than 60 HRC can be achieved by heat treatment. To exploit further optimization potential, the influence of double-laser processing strategies on the material structure and the resulting mechanical properties will be investigated. After an initial calibration procedure, the build data is modified so that both lasers can be aligned to the melting and solidification zone at the same time. Preheating or postheating as well as complementary focusing enable specific modifications of the thermal gradients and the melt pool properties compared to standard single-laser scanning strategies with corresponding property changes of the produced material structure. The results of the investigation can be used to derive cross-material optimization potential for the production of functionally graded high-performance components on LPBF systems with synchronized multi-laser technology.

4:20pm

Presentation 55: Effect of Alloy Composition and Laser Powder Bed Fusion Parameters on the Defect Formation and Mechanical Properties of Inconel 625

Michael Benoit*, Maciej Mazur**, Mark Easton**, Milan Brandt**

**University of British Columbia, Canada; **RMIT University, Australia*

Abstract: The objective of this study is to determine the effects of laser powder bed fusion parameters and alloy composition on defect formation and mechanical properties of Inconel 625 (IN625). The effect of laser power and scan speed on defect formation was evaluated for two batches of IN625 powder with different compositions. Cracks were observed in all processing conditions for the powder with higher Si and Nb content, but not in any condition for the powder with lower Si and Nb. The elimination of cracks through composition changes led to an improvement in all tensile properties, most notably an increase in elongation from 32% to 39-48%. The effect of composition on cracking was confirmed using solidification simulations for each alloy and a numerical cracking index. Large pores were observed for excessively high and low laser scan speeds, due to lack of fusion and unstable melt pools, respectively. Nevertheless, samples with relative densities exceeding 99.8% were produced through the selection of suitable process parameters. It is concluded that porosity in IN625 is sensitive to to the selection of processing parameters, while composition changes within the nominal ranges for IN625 can significantly alter the crack susceptibility of the material.

4:40pm

Presentation 56: Localized Actuation Behaviour: Implementation of Functionally Graded Structure in 4D Printed Shape Memory Polymer

Yu-Chen Sun, Yimei Wan, Ryan Nam, Marco Chu, Hani Naguib

University of Toronto, Canada

Abstract: 4D printing is known as the practice of utilizing smart and responsive materials in traditional 3D printing practices. Due to the pre-defined material properties, the 3D printed structures have the ability to be activated in response to external stimuli; thus, the "time domain" actuation can be incorporated into the designs. Currently, shape memory polymer (SMP) is one of the most common employed materials for creating 4D printed structures, as these materials can be easily printed using conventional printers. As the 4D actuation behaviours strongly depend on material properties, it is proposed that the localized motion can be achieved by implementing functionally graded structure into the design. By tailoring the microstructures and polymer chain movements with plasticizing effect, it is possible to design shape memory polymer with different activation temperature. By combining such phenomenon with the 3D printing process, a multi-material continuous structure with pre-determined shape memory effect was established. As the degree of plasticization is varying across individual layers, they can be activated with different temperatures thus localized actuation can be achieved.

5:00pm

Presentation 57: NiCoMoTiAl High Entropy Alloying in DED/ Additive Manufacturing(AM) Process : Investigation the Potential of CVM(clogged vibration method) Powder Feeding System for Rapid Alloy Scanning

SeungJun An*, SooRan Lim*, PyuckPa Choi**, BoRyung Yoo**

**Insstek, Korea, Republic of Korea; **KAIST (Korea Advanced Institute of Science and Technology), Republic of Korea*

Abstract: High Entropy Alloys (HEAs) is attracting attention as a novel material to be used in various industrial fields with its excellent physical properties that can adapt to extreme environments. Especially in aerospace and the energy industry, the requirement for alloys maintaining properties at high temperature environments is increasing, and HEAs are being studied intensively to solve its. In this study, NiCoMoTiAl HEA with γ/γ' microstructure which can secure high temperature characteristics is alloyed through DED/AM technology, and a new "Rapid Alloy Scanning" methodology using the CVM Powder Feeding System is suggested. Each of the five elements comprising the alloy is manufactured from pure metal powders, with DED/AM technology in various combinations. This allows the rapid design of the proper portion of elements. NiCoMoTiAl HEA produced via DED/AM with optimal content has been observed region and stable FCC structure through SEM/EDS/XRD analysis. After heat treatment at 1,250°C, the γ/γ' microstructure was identified, and it has been demonstrated that the alloy has superior lattice parameter and solvus temperature than previously studied alloys. The methods used in this experiment are expected to overcome the physical limitations of conventional alloy design methods and present novel methodological paradigms of FGMs, MMCs, and HEAs studies.

SESSION 14: Novel AM Processes and Products III
June 2 | 3:40pm – 5:20pm EDT

3:40pm

Presentation 58: Workflow Development of an Additive Manufactured Novel Implant Abutment in Titanium

Les Kalman

Western University, Canada

Abstract: Dental implant components, including titanium abutments and superstructures, are currently fabricated through subtractive manufacturing. This investigation explored an additive manufacturing workflow using titanium for the fabrication of a novel dental implant abutment. The novel abutment was designed, patented, digitally refined and printed in dental grade titanium Ti64 (titanium 6-aluminum 4-vanadium) using Selective Laser Melting (SLM) technology. Numerous iterations of the abutment were designed, printed and evaluated to determine the final optimized design for additive manufacturing. Post-processing involved heat treatment, bead blasting, fixation with a custom stabilization jig and manually creating threads using a die. The coupling of the abutment with the implant body was suitable, as assessed under magnification and through radiologic assessment. Physical testing of the abutment has been completed. Data indicates that the component can withstand the recommended torque and strength required for provisionalization. The additive manufacturing pathway, utilizing Ti64 and SLM, for abutment fabrication presents an accurate, efficient, cost-effective, and customizable workflow.

4:00pm

Presentation 59: 3D Printed Shellualr Metamaterials

Hamid Akbarzadeh*, Jiahao Shi*, Armin Mirabolghasemi*, Hossein Mofatteh*, Gilles Desharnais**

**McGill University, Canada; **Axis Prototypes Inc., Canada*

Abstract: Shellular materials with triply periodic minimal surfaces (TMPS) demonstrate high surface-to-volume ratio, pore connectivity, and variable thermal conductivity with potential applications in biomedicine, photovoltaic, and electrochromic devices. However, further exploration of shellular surface by perforation is never discussed, which might provide a promising method to obtain unprecedented mechanical properties. In this study, we explore theoretically and experimentally the topology-property relationship of shellualr materials with periodic perforated metasurfaces. The Schwarz Primitive (P) is selected as an underlying shellular material while conformal-mapped holes with alternative aspect ratios and sizes are generated on the constitutive shell surface. The digital light processing (DLP) technology is used to 3D print the perforated metamaterials. The numerical and experimental compression tests affirm a significant enhancement in the reusability of energy absorbers manifested by this new class of mechanical metamaterials compared to the conventional shellulars. This study paves the way towards the development of high-performance and resilient 3D printed shell-like metamaterials.

4:20pm

Presentation 60: Powder Development Considerations in Metal Powder-Bed Fusion Printing

David Jankowski, Eli Terry, Jon Perini

Xact Metal, United States

Abstract: The recent introduction of affordable metal powder-bed fusion printers has increased access to this key AM technology for prototyping, tooling, and training. In addition to the new scanning technology, printing parameters must be developed to optimize the printer performance. This presentation will review the process to develop printing

4:40pm

Presentation 61: Investigation on Derivative Face-centered Cubic Lattice Structure on Mechanical Behaviour of Stainless Steel 316L Manufactured by Selective Laser Melting

Cho-Pei Jiang*, Alvian Wibisono**, Timotius Pasang***

**National Taipei University of Technology, Taiwan; **National Taipei University of Technology, Indonesia; ***Oregon Institute of Technology, United States*

Abstract: Selective laser melting (SLM) can print a predefined porous structure leading to a great potential application for metallic scaffold implant. The aim of this study is to investigate the mechanical properties of SLM printed stainless steel 316L scaffold with various mesoporous face-centered cubic (FCC) based lattice structures and to compare the physical properties with natural bone. This study proposed the derivations of FCC based lattice structure including FCC, FCC-Z, S-FCC, S-FCC-Z and FCC-XYZ. Each derivation prints 6 pieces of specimen. The dimension of design specimen is 5x5x5 mm and single lattice size is 1 mm with a strut thickness of 1 mm. The printed specimens underwent a compression test and density measurement. Results show that the FCC-XYZ has the highest density of 3.1257 gr/cm3 and S-FCC has the lowest density of 1.8457 gr/cm3. Comparint with bone density, S-FCC is comparable with trabecular bone and S-FCC-Z is similar to cortical bone. The highest and lowest yield compression strength are FCC-XYZ (91 MPa) and S-FCC (27.5 MPa), respectively. Consequently, a hybrid lattice structure made of S-FCC for trabecular bone and FCC-XYZ for cortical bone was printed to mimicking the mechanical properties of nature bone.

5:00pm

Presentation 62: Laser Directed Energy Deposition based Additive Manufacturing of Copper-Stainless Steel Functionally Graded Structures

Sunil Yadav, Arun Rai, Christ Paul, A Jinoop, K Bindra

Raja Ramanna Centre for Advanced Technology, India

Abstract: The requirements of advanced engineering systems motivated the deployment of components with functionally graded materials (FGM) that finds wide application in engineering sector. Laser Directed Energy Deposition (LDED) based additive manufacturing is one of the techniques suitable for building near-net-shaped FGM components. Among the different material combinations, Cu-SS FGM is an enduring research topic. However, large difference in thermal conductivity, thermal expansion coefficient and melting temperature makes the fabrication of Cu-SS FGM challenging. Thus, a systematic investigation is carried out for fabricating Cu-SS 304L FGM by varying process parameters, compositional grading (20% and 50% grading) and inter-layer delay. Process parameters for depositing bulk FGM is identified by depositing bulk structures of individual composition (CuxSS100-x, X varies as 20,40,50,60,80). Further, bulk structures of individual composition and FGM are subjected to X-ray diffraction, optical microscopy and mechanical characterization. FGM deposited with 50% composition grading is defect free, whereas micro-cracks are observed in Cu20SS80 zone of Cu-SS FGM with 20% composition grading. It is also observed that the micro-cracks can be reduced significantly by providing inter-layer delay. The present investigation paves the way for establishing LDED as one of the techniques for fabricating Cu-SS FGM.

Poster Presentations

POSTER SESSION 1
June 1 | 11:20pm – 1:00pm EDT

Theme 1: Material Development

Poster 1: Ferritic Alloy Designed for the Realization by AM of Heat Exchangers for Applications in Corrosive Alkaline Environments

Luciano Pilloni, Giuseppe Corallo, Daniele Mirabile Gattia
ENEA, Italy

Abstract: The application of additive manufacturing technologies in energy sector is very promising as efficiency improvements in processes could be potentially achieved. The realization of complex geometries, the reduction of waste material and of assembly phases are some of the innovative aspects of these technologies. In ENEA, the design of refrigeration systems based on absorption machines has been successfully achieved in the past and some prototypes, based on ammonia-water cycle, have been realized. Heat exchangers are critical components in these machines as they are subjected to corrosive environment. Compact heat exchangers can be produced by brazing or by diffusion bonding which require long heat treatments. Moreover some materials or compounds as nickel and copper, used for brazing, are largely affected by corrosion. Additive manufacturing technologies could be used to realize compact heat exchangers with improved internal geometry and without components assembly. With the aim of realizing, by additive manufacturing, compact heat exchangers resistant to corrosive alkaline environment, a new alloy has been designed. The alloy, a ferritic type, has been produced by gas atomization in order to realize compact heat exchangers by additive manufacturing technologies. The alloy design and microstructural characterization is reported in this work.

Poster 2: A Facile Method of Using Inkjet Printing to Fabricate PEDOT:PSS Electrodes onto Nafion Membrane through Ionic Bonding for Origami Inspired Actuators

Andrew Jo, Hani Naguib
University of Toronto, Canada

Abstract: Under stimulation, origami inspired actuators can transform their planar shapes into complex structures through a series of folds. These actuators sometimes require intricate electrode shapes and so 3D printing can be used to reduce these fabrication costs. Furthermore, 3D printing PEDOT:PSS and Nafion based actuators can be used for bioapplications as they are both biocompatible, but is prone to delamination under in wet conditions. This study shows a novel fabrication technique which uses the Inkjet printer to apply a thin coating of PEDOT:PSS on the Nafion membrane under the presence of isopropyl alcohol. After printing, the PEDOT:PSS is ionically bound to the Nafion membrane even under wet environments. The shape of the PEDOT:PSS electrodes can be controlled through the computer and the thin coating of these electrodes allows for a transparent device. This facile approach of printing PEDOT:PSS electrodes onto Nafion substrates is a cost-effective method in developing transparent origami-inspired actuators that can be used in bioapplications.

Poster 3: Development of Novel Water-atomized Tool Steel Powders to Improve Shock Resistance of AM Parts Made of H13 Tool Steel

Denis Mutel, Carl Blais
Université Laval, Canada

Abstract: The development of tool steels for additive manufacturing (AM) is particularly interesting for the fabrication of dies and/or tooling. Currently, H13 is by far the most popular tool steel utilized in AM due to its excellent combination of toughness, fatigue resistance and weldability. Nevertheless, its resistance to shock loading remains a limiting factor for its utilization in more varied applications. The objective of the research summarized here is to develop a new formulation of tool steels that builds on the characteristics of H13 while presenting improved shock resistance. Novel tool steels were produced by water atomization and utilized to fabricate tensile specimens with the AM methods of directed energy deposition (DED) and laser powder bed fusion (LPBF). Test specimens were characterized in terms of microstructure and mechanical properties. Their performances are compared to those of identical specimens fabricated using a commercial H13 powder.

Poster 4: Electrostatically Assisted 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 a new metal powder atomization technique building on continuous liquid jet disintegration using mechanical disturbances, an electrostatic force is added to break the liquid jet into fine droplets. Drawing from the first principles of liquid jet break up in the Rayleigh regime, and depending on the different thermo-physical properties of the liquid a simple theoretical formulation has been established correlating the droplet size to the flow rate and required mechanical disturbance frequency. Several experiments have been conducted and the results show a consistent agreement with the mentioned formulation. The application of an electrostatic field resulted in narrowing the size distribution around smaller droplets with minimal agglomeration. This study shows promise of an efficient technique for powder production, and a good alternative to the existing production techniques of powder feedstock for additive manufacturing.

Poster 5: Fatigue Behaviour of Additively Manufactured Hastelloy X

Reza Esmaeilizadeh*, Ali Keshavarzkermani*, Ali Bonakdar**, Hamid Jahed*, Ehsan Toyserkani*
**University of Waterloo, Canada;*
***Siemens Energy Canada, Canada*

Abstract: Laser powder-bed fusion (LPBF) offers new possibilities by allowing for the fabrication of more complex geometries. However, the fatigue life prediction through available models is still in infancy. LPBF-HX shows primary hardening under cyclic loading, followed by softening at high strain amplitudes in fully reversed strain-controlled fatigue tests. As the later softening masks the primary hardening, the half-life cyclic stress-strain (CSS) curve coincides with the monotonic stress-strain curve. Various strain- and energy-based fatigue models were examined using the experimental strain-life data, and were utilized to predict the fatigue life under different loading conditions with mean stresses. The Jahed-Varvani (JV) and Smith-Watson-Topper (SWT) models showed good results.

Poster 6: A Parametric Study on the Freeform Fabrication of Near-β alloy Ti-55511 Printed by Laser Directed Energy Deposition (L-DED) Using a Statistical Design of Experiments (DOE) Approach

Addison Rayner, Greg Sweet, Paul Bishop
Dalhousie University, Canada

Abstract: Laser directed energy deposition (L-DED) is an additive manufacturing technique that can print complex net shape parts from a wide range of metal alloys. L-DED of titanium alloys has the potential to reduce the lead time and buy-to-fly ratio of titanium aerospace components compared to wrought-based processes. In the present work, the freeform fabrication of near-β alloy Ti-55511 was evaluated using a design of experiments (DOE) based approach to optimize deposition parameters. A two-stage approach was employed to rapidly infer parameters that optimized the density of deposits. First, the melt pool capture efficiency and effective deposition rates were measured for single tracks produced at various laser power, powder feed rate and traverse rates. Subsequently, solid cube with different X-Y and Z-overlaps were built in a secondary DOE using the optimal build parameters. As-printed density and microstructures (SEM/EDS, laser confocal microscopy) were used to select the ideal conditions. Tensile specimens were fabricated using optimal parameters and tested to compare with wrought values. Parametric models were found to be statistically significant and their corresponding optimized parameter sets were successful in depositing specimen with near-theoretical densities (> 99.8%).

CANCELED Poster 7: A Comparison of the Microstructure and Mechanical Properties of Laser Powder Bed-fused Components Made of Maraging Stainless Steel to its Wrought Analogue

William Turnier Trottier, Vladimir Brailovski
École de Technologie Supérieure, Canada

Abstract: The democratisation of additive manufacturing technologies, such as laser powder bed fusion (LPBF), offers to the designers a wide range of new possibilities. The capacity of printing parts with very complex geometries gives the chance to the tooling designers to optimize their products for bespoke applications. For example, optimized placement of cooling channels in injection molds (conformal cooling) help to uniformize the temperature and shorten the time of cooling of molded parts, while decreasing the risk of part distortions. However, materials for these types of molds must provide an adequate combination of hardness, thermal conductivity and corrosion resistance. Powders, such as Stainless Steel CX (EOS GmbH, Germany), could provide an answer to such a demand of the tooling industry. The focus of this project is to compare the evolution of mechanical properties of specimens produced by laser powder bed fusion of SS CX powders thru the different steps of heat treatment, including solution treatment and aging, 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 treatment and aging, and targets a final hardness of 50±1 HRC as specified by EOS GmbH.

Poster 8: Laser Powder Bed Fusion Additive Manufacturing of Molybdenum Lattice Structures

Tejas Ramakrishnan, Mathieu Brochu
McGill University, Canada

Abstract: Laser powder bed fusion additive manufacturing (LPBF-AM) is a manufacturing technology that enables the fabrication of complex parts with ease, beyond the limitations of conventional manufacturing techniques. Steel, aluminum, titanium, nickel alloys and refractory metals are some material systems that have been extensively studied for processing through LPBF-AM. Lattice structures have been produced and studied for many of these alloy systems. Molybdenum (Mo) is a high temperature material candidate for various applications due to its higher melting point, thermal conductivity, high temperature strength and resistance. There have been studies on LPBF-AM of Mo and other refractory metals, but only limited work is available on lattice structures of Mo or any refractory metals. In this study, we report the fabrication and characterization of Mo lattice structures. Microstructure characterization using various techniques will be used to discuss the grain size, morphology, and texture as a function of strut size and lattice type.

Poster 9: Understanding of the Laser Powder Bed Fusion (LPBF) Printability of an Ni3Al Alloy

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

Abstract: Ni3Al-based intermetallic alloys systems have unique properties related to the significant covalent bonding volume fraction. However, the intrinsic brittleness made them unfriendly to the AM process, such as Laser powder bed fusion (LPBF). The goal of this project is to investigate the feasibility of LPBF of an Ni3Al based alloy, by understanding the solidification process and cracking mechanism. The characterization of the samples has been done with optical microscopy, scanning electron microscopy, X-ray diffraction, and Vickers indentation microhardness test.

Poster 10: Review on Mechanical Testing of Meso-and Micro-scale Test Coupons

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

Abstract: Laser powder bed fusion (LPBF) allows the fabrication of parts with complex geometries that are otherwise difficult to achieve by conventional manufacturing processes. A recent push towards the miniaturization of components has increases pressure to fabricate parts with higher geometrical and dimensional control. To date, studies have shown that complex mesoscale LPBF parts possess significant surface irregularities, near-surface defects, and geometric deviations. In that context, the adoption of complex and thin-walled sections is restrained by the lack of standard testing protocols that can reliably measure mechanical properties and characterize the failure response of such small-scale components. In this poster, reported as-built surface morphologies on cylindrical struts and thin-walled parts with thicknesses smaller than 1mm will be presented. Factors linking surface-associated defects with localized

mechanical responses and failure modes in mesoscale and micro-scale parts subjected to quasi-static and dynamic loading regimes are discussed.

Poster 11: New Grade of Advanced Nanocomposite Complex Ceramic Metal Reinforcements (CCMR)

Shahram Rizaneh
University of Calgary, Canada

Abstract: In this paper, a new grade of Complex Ceramic Metal Reinforcement (CCMR) "Shahram.Rizaneh Reinforcement" by means of powder technology and subsequent heat treatment was designed and manufactured for the first time in the world. Because of its innate properties of this new grade of reinforcement, it could improve mechanical and physical properties of composites significantly compared to common ones used in industries when it was added to aluminum matrix via hot deformation process. Moreover, due to the CCMR nature, results were demonstrated that by using such advanced nanocomposite reinforcements in aluminum matrix, we could have ductile fracture in our materials in the tensile test; still, with the same reinforcements components in recent composite materials, specimens were failed in brittle state. By means of Additive Manufacturing (AM) processes, researchers tried to improve materials properties by using various kinds of reinforcements, but the CCMRs were not used still. In this paper, it was tried to illustrate the potentials and implementations of this new grade of reinforcements in different matrices such as polymer, metal and ceramic ones by using the Additive Manufacturing (AM) processes.

CANCELED Poster 12: Multiscale Mechanical Characterization of Multiphase Materials Made by Additive Manufacturing

Yu Zou
University of Toronto, Canada

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

Poster 13: Nanoindentation Mapping of a Near-alpha Titanium Alloy Made by Additive Manufacturing

Zhiying liu*, Jiahui Zhang*, Bei He**, Yu Zou*
**University of Toronto, Canada; **Beihang University, China*

Abstract: Titanium alloys are among the most used materials for metal additive manufacturing, but their complex microstructures and related mechanical properties have not been fully understood yet. High-speed nanoindentation is an emerging mechanical characterization tool for understanding the link between microstructure, elasticity, and plasticity in multiphase materials. Here, we employ the high-speed nanoindentation method to obtain spatial property (hardness, H, and elastic modulus, E) maps of Ti-6Al-2Zr-Mo-V samples produced by laser melting deposition. We observe good correlations between the mechanical properties (H and E contrasts) and microstructure (α and β phases) at the sub-micrometer length scale for as-deposited and as-annealed samples. The statistical analysis of 30,000 indention tests indicates that both the H and E values of the α and β phases are increased due to the element redistribution (Al diffuses from β to α; Mo and V diffuse from α to β) during annealing. Such a phenomenon cannot be easily observed using conventional indentation methods. Our study demonstrates that the high-speed nanoindentation is a powerful tool to characterize local elastic and plastic properties of materials in a high-throughput fashion, providing a new opportunity to study the mechanical behavior of multiphase materials across length scales.

Poster 14: Development of Hybrid Shape Memory Polymers with Conductive Fillers for Advanced 4D Printing of Therapeutic Devices

Kyra McLellan, Hani Naguib
University of Toronto, Canada

Abstract: 4D printing utilizes advanced Additive Manufacturing techniques and smart Shape Memory Materials (SMM) which allows for the design and fabrication of dynamic structures which can change their shape and function with time. These SMM can be 'programmed' to a temporary position which it will hold until activated, often by heat, where it will actuate back to its permanent position. The development of new SMMs with tunable properties is required for applications of this technology in areas such as biomedical devices and wearable electronics. Specifically for the design of custom therapeutics such as prosthetics/exoskeletons, and braces, utilizing 3D printing techniques can drastically reduce the cost and time of fabrication of these wearables. In this work, MXene a 2D metal-carbide filler is used to create electrically conductive networks in Shape Memory Composites and improve the mechanical properties. This conductive network allows for the use of Joule heating to selectively activate the shape memory behaviour. This study investigates the fabricated composites shape memory behaviour, rheological and mechanical properties, and the electrical Joule heating potential. The composite will be developed for 3D printing applications and demonstrate the potential for printing custom wearable rehabilitative devices.

Poster 15: Influence of Post-processing Conditions on the Microstructure and Fatigue Resistance of Laser Powder Bed Fused Ti-6Al-4V Components

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

Abstract: The microstructure, static and fatigue mechanical properties of laser powder bed fused (LPBF) Ti-6Al-4V components subjected to two different post-processing treatments are compared. The first treatment consists in a two-step heat treatment procedure that included stress relief and low-temperature annealing, while the second one is a combination of hot isostatic pressing (HIP) with beta solution-and-overaged (BSTAO) treatment. It was demonstrated that the two-step heat treatment leads to the decomposition of α' martensite inherited from the LPBF process and the formation of ($\alpha+\beta$) lamellar microstructure (average width of α lamellae ~3 µm). The HIP-BSTAO treatment leads to the formation of a relatively coarse (~15 µm) α-grain structure with fine (<1 µm in size) dispersed β phase particles. Preliminary results of the stress-controlled fatigue testing (ASTM E466-07, R=01) leads to an endurance limit of ~650 MPa after the two-step heat treatment and to that of ~550 MPa, after the HIP-BSTAO sequence (both on the base of 107 cycles). These results demonstrate that an adequate thermal treatment of LPBF Ti-6Al-4V components could be a valuable and less expensive alternative to the established HIP-BSTAO treatment procedure when fatigue life is the main concern.

Poster 16: Microstructure Characterization of Directed Energy Deposition of H13 Tool Steel

Owen Craig, Kevin Plucknett
Dalhousie University – Mechanical Engineering, Canada

Abstract: This research focused on the characterization of as-printed and heat-treated DED H13 samples when the scanning speed and powder feed rates are varied with the remaining system parameters fixed. Rectangular samples were printed using gas-atomized powder onto a wrought annealed H13 substrate. The samples were sectioned along the build direction which were examined using optical microscopy (OM), scanning electron microscopy (SEM), X-ray diffraction (XRD), and energy dispersive X-ray analysis (EDS). Typical of the DED process, the deposited material undergoes rapid solidification, producing a highly refined cellular dendritic microstructure. The lower layers consist of tempered martensite and fine carbides due to the tempering effect caused by multi-layered building. The top layers consist of fine lath martensite and retained austenite due less thermal cycling.

Poster 17: Binder Jet Printing of Low-Cost Tool Steel Powders

Ryan Ley*, Donald Bishop*, Ian Donaldson**
**Dalhousie University, Canada;*
***GKN Powder Metallurgy, United States*

Abstract: Water atomization is utilized extensively in the high-volume production of iron and steel powders that are destined for use in press-and-sinter powder metallurgy (PM) technology. This particular variant of atomization maintains a low operating cost and typically produces particles that are relatively coarse (D50 ~120 µm) and irregular in shape. While these traits are desirable for PM, they are not necessarily ideal for AM. However, with appropriate adjustment of the atomization parameters, a nearly spherical powder with a reduced D50 can be achieved. The objective of this research was to investigate cost-effective, water atomized powders 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 in detail 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. It was determined that the optimal sintering conditions for maximizing density while still maintaining part geometry was in the range of 1220°C - 1260°C with a hold time of 30 minutes.

CANCELED Poster 18: Development of High-density Materials for Lightweight Components by Hybrid Investment Casting and Atomization

Abdoul-Aziz Bogno*, Aquinn Hazenberg*, Jonas Valloton*, Hani Henein*, Ahmed Qureshi*, Michel Rappaz**
**University of Alberta, Canada;*
***École polytechnique fédérale de Lausanne, Switzerland*

Abstract: Manufacturing of 3D lattice structures by hybrid investment casting (HIC), is proven to be a cost-effective manufacturing technique. In the framework of the development and use of high-density materials in lightweight components production, diamond strut-based periodic lattice structures of Al-Cu alloys of near eutectic compositions with and without added Mg, and Si were generated by HIC, in this work. In parallel, powders of the same composition were produced by impulse atomization, to obtain samples over a wide range of thermal histories. The effect of Mg, and Si on the solidification-developed, as well as heat treated microstructures were analyzed with respect to the mechanical properties of the investigated samples. Addition of these elements are found to yield spheroidized eutectic phases and superior mechanical properties.

Poster 19: Microstructure of Rapidly Solidified 17-4PH Stainless Steel

Anne McDonald, Abdoul-Aziz Bogno, Hani Henein
University of Alberta, Canada

Abstract: 17-4 precipitation hardened stainless steel is widely used in many industrial applications throughout the aerospace, chemical and mining industries. As additive manufacturing becomes a more viable and common option for industrial use, the rapid solidification behaviour of many traditional alloys becomes an important consideration, even for well understood materials. In an effort to expand the understanding of the solidification behaviour of 17-4 PH, rapidly solidified samples were formed under different cooling rates. These rapidly solidified microstructures are characterized in this work and compared to the structures formed in as-built samples created using a Plasma Transferred Arc Additive Manufacturing system.

Poster 20: Laser Directed Energy Deposition Processing of Beta, Near-Beta and Near-Alpha Titanium Alloys

Nicholas Gosse*, Donald Bishop*, Ian Donaldson**
**Dalhousie University, Canada;*
***GKN Powder Metallurgy, United States*

Abstract: This research explores the processability of several commercially viable titanium alloys (Beta 21s, Ti-6242, Ti-5553) using laser directed energy deposition (DED). These systems represent a near-alpha (Ti-6242), beta (Beta 21-s) and near-beta (Ti-5553) alloys, and each offer advantageous properties compared to the industry standard AM titanium alloy Ti-6Al-4V. Each alloy was subjected to a series of experiments designed to highlight the most impactful process parameters, and the optimal range of values for each. The primary dependent variable for all experiments was density (MPIF Standard 42 and optical micrography). Phase I experiments strategically varied laser power and scan speed, while in Phase II, narrowed ranges for these parameters coupled with the inclusion of hatch spacing and layer thickness were considered. Although the attenuation of maximum density was the principal driver, dimensional

accuracy, and microstructural assessments were completed as well. Based on the results of these experiments, the process parameters offering a desirable balance of density, build time and dimensional accuracy were then utilized to produce rectangular test bars. These were heat treated according to common industrial protocols for the given alloy, and then machined/tensile tested in accordance with ASTM E8-M to obtain tensile properties. All obtained values were then compared to wrought.

Poster 21: Directed Energy Deposition Processing of a Dual Phase Steel

Gregory Sweet*, Mark Amegadzie*, Ian Donaldson**, Chris Schade***, Paul Bishop*
**Dalhousie University, Canada; **GKN Powder Metallurgy, United States; ***GKN Hoeganaes Innovation Center & Advanced Materials, United States*

Abstract: The objective of this research was to study the feasibility of utilizing laser directed energy deposition as a means to fabricate components from a dual-phase steel powder produced through water atomization. A statistical design of experiments approach was used to parametrically model the effects of laser power, traverse rate, hatch spacing, z-step size and powder feed rate on the density, tensile properties, microstructure, and impurity content (O-H-N) of the deposited products produced from each powder. Using optimized parameters, specimen with densities of up to 7.867 g/cm3 were obtained while maintaining an effectively equiaxed microstructure. Inter-critical heat treatments were investigated through thermodynamic modelling coupled with hands-on experiments. These efforts demonstrated that a wide range of microstructures were attainable including that of the requisite dual phase assembly (ferrite + martensite) which was found to coincide with elevated tensile properties. The prototyping capability of this material and system were then demonstrated though the fabrication of large format tubular specimen coupled with quasi-static axial compression tests.

Theme 2: Advanced Process Modeling

Poster 22: A Numerical Model to Predict Residual Stresses and Distortion in a Component Fabricated by DED

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

Abstract: The development of residual stresses in a component during Additive Manufacturing (AM) processes poses significant challenges to the adoption of this process in the commercial sector. The residual stresses and the associated distortion can reduce the mechanical performance and geometrical accuracy of the AM-fabricated parts. It is critical to have a fundamental understanding of the formation of residual stresses in AM processes to develop strategies to reduce their occurrence. In this work, a lagrangian macro-scale thermo-mechanical model was developed to predict the thermo-mechanical behaviour of a component during a Directed Energy Deposition (DED) process. The predicted results were compared to the in-situ temperature and displacement data obtained from a literature-based study. The comparison showed a good agreement between predicted and measured results. In this model, the deposited material's initial temperature was adjusted to align the predicted distortion history with the in-situ displacement data. The deposition temperature of the material essentially captures the thermal and in-elastic strain associated with the solidification of the deposited material at the meso-scale. To address this limitation, a meso-scale model is under development which is intended to capture the thermal and inelastic-strain evolution using a more fundamental-based approach.

Poster 23: Thermo-mechanical Modelling and Validation of Direct Energy Deposition Processed 4140 Steel

Shaun Cooke*, Greg Sweet**, Keivan Ahmadi*, Paul Bishop**, Rodney Herring*
**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. Pre-processing programs were developed in Python and C++ to interpret and discretize G-code commands, activate elements to simulate deposition and, determine the volume fractions of the microstructural constituents throughout the build. A thermal, mechanical and metallurgical finite element analysis of the process was conducted to model the residual stresses and grain morphology of as-built 4140 steel. Thermocouples and cameras were used to validate the temperature field while x-ray diffraction (XRD) analysis was used to map the resulting residual stresses. Further development of this model can allow machine process parameters to be tuned to achieve optimal residual stresses and microstructures in the build.

CANCELED Poster 24: In-plane Mechanical Properties Analysis of Modified Auxetic Metamaterials via Additive Manufacturing

Niranjan Choudhry, Biranchi Panda
Indian Institute of Technology Guwahati, India

Abstract: Design of auxetic metamaterials to achieve extreme properties has been an active research area in the past decades and depending on choice of materials, design parameters and manufacturing methods, the final properties can be manipulated for various applications. In this paper, we introduced a modified re-entrant structure with improved mechanical properties and this improvement mechanism is explained using simulated deformation study. Quasi-static compression experiments are conducted to verify the numerical results, which further confirms accuracy of our developed FEA model. In order to find optimum design parameters, parametric investigation is carried out by intelligently varying geometrical parameters of the modified re-entrant structure. The interaction effects of the geometrical parameters on the structure performance is also characterized in this work using additive manufactured structures. The outcomes of this study first confirms the ability of 3D printing process to mimic the complex auxetic design, despite some noticeable surface roughness defects. Secondly, it is found that the energy absorption properties can be tuned by geometry of the structures without influencing 'material' and 'manufacturing process parameters'.

Poster 25: Mesoscale Modelling of the Evolution of Plastic, Elastic, Thermal strain in Powder Bed Electron Beam Additive Manufacturing (PB-EBAM)

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

Abstract: The application of a rapidly moving heat source in metal AM processes results in recurrent rapid heating and cooling cycles at the meso and micro scales. Consequently, large thermal stresses can develop in the component that often exceeds the material's yield point. An additional source of in-situ thermal stresses may also be the thermal expansion mismatch between the build-plate and the component. Both of these sources can result in the formation of residual stresses in the final part. Understanding the evolution of thermal stresses and in-elastic strain during the melt pool solidification in EBAM continues to be a challenge. A coupled temperature displacement model is developed to investigate the in-situ stress and in-elastic strain accumulation around the melt pool at the mesoscale.

References:

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Poster 26: Heat Transfer Modeling of Multi-track Laser Scanning in Laser Powder-bed Fusion Additive Manufacturing Using Adaptive Mesh

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

Abstract: Laser powder-bed fusion (LPBF) additive manufacturing (AM) is one of the most important additive manufacturing techniques, where complex parts can be made by selectively melting layers of powder. LPBF's numerical modeling has become an effective tool to provide insightful information to allow a better understanding of the process, such as reducing defects and optimizing process parameters. However, the highly demanding time of the numerical modeling is still challenging; therefore, accelerating techniques are necessary to deliver accurate results faster. The adaptive mesh technique is among the accelerating methods, enabling the simulating of the real laser scanning within an acceptable time range. In this work, on top of the previously developed single-track simulation model of LPBF, a multi-track model, incorporating the adaptive mesh technique, has been developed, which can be run on high-performance clusters to further reduce the computing time. Different volumetric heat sources are employed to predict the physical quantities in LPBF, such as melt pool geometry, cooling rate, and temperature gradient. Then, the numerical results are validated by the experimental data. Moreover, recommendations on choosing a heat source model in the LPBF process simulation are given and explained.

Poster 27: Nonlinear Response of Additively Built Soft Lattices

Asma El Elmi, Damiano Pasini
McGill University, Canada

Abstract: Additive manufacturing of soft polymers enables the realization of materials capable of undergoing large deformations. Here we present a class of architected materials made of a hyperelastic solid that exploit defects to elicit local instabilities and induce large strains. A methodology is presented to analyze the mechanical behavior of a two-dimensional biholar sheet comprising an arrangement of small and large pores. The results contribute to uncovering principles that help us understand how geometric and material non-linearity can result in the emergence of complex – yet exploitable – behavior in soft systems. Our study provides a simple, yet powerful, strategy to achieve exotic properties by controlling the architecture of soft lattice metamaterials.

Poster 28: Thermal Fluid Modelling of Melt Pool Generation in the Powder Bed Electron Beam Additive Manufacturing (PB-EBAM) of Ti6Al4V

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

Abstract: In this study, a series of quantitative experimental and numerical analyses were performed during the powder-bed electron beam additive manufacturing (PB-EBAM) process. These analyses were performed under single pass conditions with combinations of different electron beam operating parameters; acceleration voltage, beam scan speed and beam current. Ti6Al4V powder was melted on a CPTi substrate using a single track beam pass to determine the melt pool geometry and the melt pool's penetration into the substrate. The experimental results were analyzed and compared to the predictions of a thermal-fluid model developed in Flow3DTM software. The model includes the following phenomena: free surface, normal beam power distribution, conductive and advective heat transfer, recoil pressure due to evaporation, buoyancy forces and Marangoni forces. The numerical analysis predictions were in reasonable agreement with the experimental results.

Poster 29: Effect of the Layer-wise Temperature Field on the Geometric Tolerances of Laser Powder Bed Fusion Printed Parts – A Preliminary Study

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

Abstract: Dimensional and geometric properties of laser powder bed fusion (LPBF) manufactured parts depend largely on process parameters, such as laser power and scan speed and on interim process variables, such as temperature and stress field. High temperatures are needed in LPBF to sinter the metal powder, and it is hypothesized that the layer-wise temperature field plays a significant role in the quality of the manufactured part. Various studies in the literature have linked the effect of temperature to part deviations using

thermo-mechanical finite element simulations. This work aims at analyzing numerical simulation results including interim process variables to estimate standardized geometric dimensioning and tolerancing (GD&T) characteristics. To do so, numerical thermo-mechanical simulations of a newly designed benchmark artifact are conducted to predict the layer-wise temperature and deformations fields, and the latter is used to estimate overall and layer-wise GD&T characteristics. Simulations with different process input settings are used and then datasets are extracted for layer-wise temperature field, deviations, and GD&T characteristics. The data is then analyzed and compared to establish a correlation between layer-wise temperature field and GD&T characteristics. The correlation results presented provide a starting point for GD&T optimization.

Poster 30: Evaluation of Heat Transfer during Rapid Solidification of Al-33wt%Cu

Jonas Valloton*, Abdoul-Aziz Bogno*, Michel Rappaz**, Hani Henein*
University of Alberta, Canada;
***Ecole Polytechnique Fédérale de Lausanne, Switzerland*

Abstract: Impulse Atomization (IA) is a technique yielding droplets with high undercooling and cooling rates. It provides a reliable thermal history making quantitative analysis reliable. IA solidified droplets can be used as a model of rapid solidification in AM to benchmark heat transfer calculations. Modeling of solidification of molten metal droplets during atomization requires an understanding of the thermal transport between a droplet and the surrounding gas. Of particular import is the heat transfer coefficient. The most common approach to quantify it is to use semi-empirical equations in which the Nusselt number is averaged over the droplet surface. The Ranz-Marshall and Whitaker correlations are most commonly used, even though the range of validity in which they were derived is often exceeded. Uncertainties also remain regarding the temperature at which the thermophysical properties of gas should be evaluated, i.e. at the gas free stream temperature or at the film temperature. This paper presents experimental results of eutectic Al-33wt%Cu rapidly solidified using IA. A model of the eutectic growth is developed and coupled to a transient heat flow model of IA. The modelling results are then validated with experimental measurements of the lamellar spacing to determine which correlation is appropriate.

POSTER SESSION 2
June 2 | 11:20pm – 1:00pm EDT

Theme 3: Process Monitoring and Control

Poster 31: Ultrasound Metal Powder Stream Focusing for Producing Variable Track Widths in Directed Energy Deposition

Alexander Martinez-Marchese*, Mazyar Ansari*, Asier Marzo**, Marc Wang*, Soyazhe Khan*, Ehsan Toyserkani*
University of Waterloo, Canada;
***Public University of Navarre, Spain*

Abstract: Directed energy deposition (DED) is a method for building or repairing components. One issue with the powder-based DED process is that it is optimized for a certain track width, which determines the minimum feature size (resolution) of the component. This is mostly determined by the nozzle geometry and gas flow, which produces a powder stream with a given geometry. Attempting to change the track width significantly without changing the nozzle produces a lower catchment efficiency, the fraction of all particles that reach the melt pool, and uneven heat transfer between the laser and the powder, which will affect the final material properties. One way to affect the powder stream to allow for variable track widths is to use an ultrasound phased array (UPA). In this method, a small volume of high-intensity ultrasound with the needed period averaged sound intensity profile is produced. This profile can be tailored to affect the powder stream. Two-track sizes will be printed in AlSi10Mg and Ti64. The effect of the UPA sound field on the catchment efficiency and material properties will be discussed.

Poster 32: Correlative Microstructural Analysis of Laser Powder Bed Fusion Fabricated 17-4 PH Stainless Steel

Maxwell Moyle*, Nima Haghdadi*, Simon Ringer**, Xiaozhou Liao**, Sophie Primig*
The University of New South Wales, Australia
***The University of Sydney, Australia; The University of New South Wales, Australia*

Abstract: We investigate 17-4 precipitate hardening stainless steel, a high-strength multi-purpose alloy with applications in the aerospace and petrochemical industries. Samples were fabricated by laser powder bed fusion using a variety of scanning patterns and differing laser powers. We utilise scanning electron microscopy, electron backscattered diffraction, neutron scattering analysis, electron probe microanalysis, and atom probe tomography to characterize the microstructure across different length scales. Results show clear variation in sample texture, residual stress, phase fraction and distribution, and compositional variation as a function of the processing parameters. The main phase of the as-printed microstructure is δ-ferrite with a low volume fraction of austenite, which is mainly observed at melt pool boundaries. The total fraction of austenite increases as the time between adjacent passes of the laser decreases. In the as-printed state, samples are shown to be highly stressed, suggesting heat treatments must be applied before any practical implementation in engineering applications. Higher laser power leads to an increase in ferrite grain size and intensity of texture along the build direction due to the enhanced effect of epitaxial growth.

Poster 33: Effect of Specimen Geometry and Orientation on Tensile Properties of Ti-6Al-4V Manufactured by Electron Beam Powder Bed Fusion

Gitanjali Shanbhag*, Evan Wheat*, Shawn Moylan**, Mihaela Vlasea*
*University of Waterloo, Canada; **National Institute of Standards & Technology (NIST), United States*

Abstract: Tensile testing is often proposed as the preferred methodology to qualify builds and materials produced through additive manufacturing. While there is already work demonstrating the difference in measured properties between tensile specimens produced in different build orientations, this does not extend to different specimen geometries. In addition, the body of knowledge in this domain is typically made up of studies that utilize custom combinations of specimen geometries, part finishing, and post-processing, making it challenging to compare results. To study the impact of geometry of tensile specimens on tensile testing results, a selection of standard specimen types provided in ASTM E8/E8M was prepared in Ti-6Al-4V using an electron beam powder-bed fusion additive manufacturing machine. These specimens were characterized to observe any porosity defects, dimensional deviations, and surface topography that could impact performance. It was found that changes in specimen geometry, specimen size, build orientation, and the internal porous defects; have significant effects on the tensile properties of the specimens. This poster presents the results of the tensile testing and evaluations of any systematic correlations of mechanical performance with respect to the various specimen geometries and specimen properties.

Poster 34: Divergent Beams for Laser Powder Bed Fusion of a High Reflectivity Aluminum Alloy – AlSi10Mg

Sagar Patel*, Haoxiu Chen**, Yu Zou**, Mihaela Vlasea*, Kevin Slattery***, John Barnes***
University of Waterloo, Canada;
***University of Toronto, Canada;*
****The Barnes Global Advisors, United States*

Laser powder bed fusion (LPBF) of low reflectivity materials such as titanium, ferrous, and nickel-based alloys has been extensively studied and is well understood, but there is a vacancy in the understanding of high reflectivity materials such as aluminium (Al) alloys. Al is commonly alloyed with highly volatile elements which are very easily vaporized with the small spot sizes of the beams common in most LPBF systems, leading to multiple issues such as porosity and cracks in the final printed part. While the effects of laser power and scan speeds are extensively studied for Al alloys, the importance of the beam spot diameter is often ignored. Manufacturing maps are used to develop a better understanding of the effects of laser power, scan speed, and beam spot radius on the printability of AlSi10Mg. Additionally, a combination of manufacturing maps, beam bath planning, and material characterization equipment (X-ray computer tomography and metallography) are proposed to accelerate process parameter development for new alloys in LPBF. The application of this method has helped with process parameters leading to greater than 99.98% density with close to no subsurface defects in AlSi10Mg.

Poster 35: Dedicated Metal Powder Tester for Powder Bed-based AM Applications

Salah Eddine Brika, Vladimir Brailovski
École de technologie supérieure, 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. The different standards and methods available for powder characterization test the powder under conditions that differ from the ones involved during the LPBF recoating process. Hence the need for a novel powder characterization method adequate for powder bed-based AM applications. Therefore, a custom testing bench reproducing the main components involved in the LPBF powder spreading procedure is developed in order to evaluate the powder bed density, surface uniformity and spreading forces as functions of the particle size and shape distributions, layer thickness, recoating speed and type of the recoater blade. A comparative study case is presented to demonstrate the capabilities of the equipment and its relevance for research and development purposes as well as for powder quality control.

Poster 36: A Hybrid Model to Predict the Melt Pool Temperature in Laser Metal Deposition

Alejandra Bejarano Rincón, Antonio Estrada, Juan Alvarado Orozco
Center for Engineering and Industrial Development (CIDESI), Mexico

Abstract: Laser metal deposition (LMD) mathematical models allow reducing the number of experiments to achieve the optimal conditions of the process. Many researchers have been working on models that describe the dynamics of the LMD process; however, this is highly nonlinear and the accurate models are complex. In this work, we proposed a model to predict the temperature of the melt pool in the LMD process, by using the power laser as an input. This model combines the physics of the process (i.e., mass and energy balance equations) with the experimental data obtained by using a dual-color pyrometer. The data were obtained for IN718 powder on substrates of IN718. The unmodeled dynamics were estimated by the nonlinear autoregressive with exogenous terms (ARX) and Hammerstein Wiener models. A random input signal was used and a linear energy density range for a zone of good deposition was established. The root-mean-squared error (RMSE), and the coefficient of determination (R^2) are reported. The best prediction is obtained by a mix of the physic equations and the Hammerstein Wiener model. The proposed model will ease the efficient design of robust controllers for this system.

Poster 37: A New Model for Directed Energy Deposition Layer Geometry from Mass Balance Considerations

Gentry Wood*, Nathan Jen**, Douglas Hamre*, Dakota Jones*, Ata Kamyabi*, Anju Varghese*, Patricio Mendez**
**Apollo-Clad Laser Cladding, Canada; **Apollo-Clad Laser Cladding, Canada; University of Alberta, Canada*

Abstract: An exact analytical solution for predicting direct energy deposition (DED) layer characteristics (height, roughness, etc.) from single bead dimensions and bead overlap has been established for the first time. An approach for selecting layer overlap to achieve targeted feature thickness for both unground and post-print grinding requirements is discussed. This model has been developed and experimentally verified for DED-LB but is equally applicable to other DED technologies such as Wire-Arc Additive Manufacturing. Practical examples of these models being deployed industrially for large-scale additive manufacturing and laser clad repair at Apollo-Clad Laser Cladding facility are presented.

Poster 38: Plasma Secondary Processing for Additively Manufactured Components of SS316L

Suyog Jhavar, Srinivasachari V
Atria Institute of Technology, Bangalore, India

Abstract: Surface finish and residual stresses are two major intricacies for most of the in-situ additively manufactured components. Secondary processing of these components is suggested in most of the cases. This research aims to investigate secondary processing of additively manufactured component of SS316L using high energy plasma beam.

Various parameters of plasma beam interaction with the additively manufactured components were studied. Important parameters such as plasma power, travel speed and stand-off distance were optimized to achieve the desired surface finish, grain size and micro hardness of the components. Beam interaction for lines and planer surface have been performed. The results validated that the surface roughness of AM processed component improved from the initial surface roughness of 23.852 μm to 5.456 μm. There is subsequently a significant improvement in the grain size followed by an improvement in the micro-hardness value of the top surface. The study therefore confirms the suitability of high energy plasma beam for secondary processing of additively manufactured components.

Poster 39: Failure Detection in 3D Printing Using Computer Vision

Xingchen Liu*, Haoliang Zhou**, Ziqi Chen*, Stephen Luu***, Yu Zou*
**University of Toronto, Canada; **Mech Solutions Ltd., Canada; ***York University, Canada*

Abstract: Fused deposition modelling is a widespread technology used in various applications. Due to an insufficient level of accuracy, the filament may not be sticky on the printing bed or previous layer, causing a high failure rate and hindering the wide application of additive manufacturing. To this end, this paper proposes to develop an innovative computer vision model to monitor and detect this malfunction during the printing process. The purpose of this model is to halt the process immediately when a failure occurs, avoiding further printing error and reducing the material waste. In this model's development, several hundred images are initially captured and labelled with the bounding boxes. And then the image data is pre-processed and augmented to improve the model accuracy. Next, the model is trained to acquire the optimized loss function. Finally, the developed model has been validated, and the accuracy result proves the model has a good prediction. In this manner, time-consuming human supervision can be replaced by this artificial intelligence program, which dramatically reduces the workforce while improving the efficiency of 3D printing. The developed model can thus be effectively adopted for printers using metal 316L and polymer filaments.

Theme 4: Novel AM Processes and Products

Poster 40: A Topology Optimization Strategy for a Flexible Piezoresistive Sensor

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

Abstract: Recent interest in wearable technologies and flexible robotics has led to significant efforts in developing sensors for these applications. This includes flexible piezoresistive sensors, which have been shown to exhibit wide strain-sensing ranges, durability, and vibration sensing capabilities. Additive manufacturing (AM) has also been successfully utilized in manufacturing these sensors. However, AM design flexibility has not yet been fully leveraged to formally optimize flexible piezoresistive sensor designs. Here we present the multi-objective topology optimization of a flexible, piezoresistive sensor for dynamic strain measurements. The sensor is made of silicone rubber and graphene nanoplatelets using fused deposition modeling. Sensor sensitivity and the first natural frequency are maximized by modifying manufacturing parameters and sensor geometry using a decomposition optimization strategy. The optimal sensor is then fabricated and characterized under vibration base excitation. Manufacturability and advantages of the topology optimization strategy are also considered and discussed.

Poster 41: Hybrid AM Validation for Injection Mould Industry

Florence Desravines
Precision IMS, Canada

Abstract: Precision IMS is specialized in injection mould, tooling and complex part production. Our customers entrust us their most complex projects. For over 20 years, we have continually innovated in our production processes to remain on the cutting edge of technology. That is why we have decided to launch our additive manufacturing workshop. We decided to invest in a hybrid SLM technology. For our process validation we choose a part that represent some of the major characteristics we are interested in with this technology and that could be problematic for the process (channels, variable thickness, lattices structures, spindle synchronization, variable angles, etc.). We wanted our validation part to be representative of some of the challenges an additive manufacturing machine could encounter while being used for mould production. One of the main challenges we encountered while validating our equipment was the precision. For our first validation part, tolerance interval was of around 200 microns. While producing a mould, tolerance intervals are standards to 10 microns. After working and tweaking the process for several month we managed to divide the interval by 4. We are proposing to present the different research direction we explored while working on this challenge and conclusion after this work.

Poster 42: TPMS Structures for Transpiration Cooling

Kevin Zhang
University of Waterloo, Canada

Abstract: Transpiration cooling is an emerging technology for thermal protection against hot gas flows in hypersonic flight, rocket engine liners, and gas turbines. The process uses a coolant flow through a porous medium, which reduces heat loads through two mechanisms: convective heat transfer within the material, and film cooling on the surface. To date, materials for transpiration cooling have been restricted to porous ceramic composites and sintered metal foams. These are stochastic materials: only their bulk porosity and structure can be controlled. Advances in additive manufacturing have enabled the manufacturing of "architected" lattices, which have deterministic mesostructures. One such family of these lattices are triply-periodic minimal surfaces (TPMS), which are continuous, repeating 3D geometries defined by mathematical equations. Additively-manufactured TPMS structures are already being studied for biomedical applications. It is proposed that they could offer several advantages for transpiration cooling as well: high surface area-to-volume ratio, pore inter-connectivity, and mechanical strength. In this present work, a brief review of the mechanical, thermal, and fluid flow performance of TPMS structures is assessed via literature review and compared to current materials and structures used in transpiration cooling. In addition, an initial simulation of fluid flow behaviour in a TPMS structure is presented.

Poster 43: An Analytical Approach in the Design of a Complex Electromagnetic Levitation System for Additive Manufacturing

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

Abstract: The application of electromagnetic levitation in an additive manufacturing process, enables the fabrication of complex shapes with an added level of ease in ideal scenarios. This paper identifies strategies to compute inductance in a custom electromagnetic levitation setup, through an analytical approach. Inductance plays a significant role in electromagnetic system analyses as it adds to the net impedance in the system, with an amplified effect at higher frequencies. This system operates within a range of 60Hz – 1000 Hz leading to very high impedance values, potentially reduced by optimizing the system for the least inductance. Theoretical formulas are used to compute inductance for a multi-coil multi-core system and compared with data from ANSYS Maxwell. The computation is further inspected through magnetic superposition to create an equivalent single-coil single-core system. ANSYS Maxwell is used for computing the RMS magnetic field over a vertical polyline, coaxial with the system coils. This is important since a greater value of the magnetic field is equivalent to greater levitation forces. Coil dimensions are optimized for the maximum magnetic field and the least inductance.

Poster 44: Non-retractive Toolpath Planning Using TSP Solver

Sadaival Singh, Ambrish Singh, Sajan Kapil
Indian Institute of Technology Guwahati, India

Abstract: Toolpath planning affects the properties of the product in Additive Manufacturing (AM). The present study utilizes the computational problem of Travelling Salesman Problem (TSP) to minimize the retractions of toolpath, which would have led to uneven deposition and an increase in build time. TSP is applied by converting the area within the boundary of a slice of the model into an array of points, and feeding these points as cities to a TSP Solver. The study explores the use of rectangular and circular grids as different arrangement of points for the digitization of boundary. The grid is generated to fill the area completely without voids and maintain a constant stepover throughout the geometry for effective overlap. Various parameters of these grids can be modified to make the toolpath parallel to a particular direction thereby reducing the number of turns. Using the property of favoring different directions in different segments of the boundary leads to the development of retraction free hybrid toolpaths. Many Required properties of the final toolpath can be translated to the characteristics of the grid generated during the digitization process. The proposed toolpath finds its application in several AM processes such as, FDM, WAAM, PBF, etc.

Poster 45: Additive Manufacturing of Enhanced Resolution Shrinkable Silicone-based Scaffolds

Elham Davoodi*, Hossein Montazerian**, Ehsan Toyserkani*
**University of Waterloo, Canada;*
***University of California-Los Angeles, United States*

Abstract: Additively manufactured silicone-based scaffolds have shown great potential for healthcare and tissue engineering applications due to their unique properties such as bioinertness and high flexibility. However, additive manufacturing (AM) of high-resolution architected silicone scaffolds is challenging due to the viscose nature of the silicone ink and the layer-by-layer curing process. This study addresses these limitations by introducing a sacrificial AM technique to fabricate architected macro-porous silicone scaffolds using an accessible, low-cost fused deposition modeling (FDM) system. Then, the sacrificial templates are removed using specific solvents after the silicone prepolymer is cast and cured. The silicone prepolymer is modified with additives to enable on-demand physical shrinkage through solvent treatment process. The silicone scaffolds are fabricated on a larger scale defined by the FDM system and isotopically shrank to the desired size. In this manner, the silicone scaffolds experience a volumetric shrinkage of up to ~70%, and the macro-pores in the range of 500-600 μm are obtained. Full strain recovery under compressive loadings with extreme strains (85% of initial scaffold length) confirmed that the silicone scaffolds can maintain acceptable mechanical properties after the treatment process. The macro-porous scaffolds are infilled with cell-laden gelatin methacryloyl (GelMA), and cell viability of ~90% is observed.

Poster 46: Semantic Segmentation of Plasma Transferred Arc Additively Manufactured NiBSi-WC Optical Microscopy Images Using a Convolutional Neural Network

Dylan Rose, Hani Henein
University of Alberta, Canada

Abstract: NiBSi-WC metal matrix composites (MMCs) are commonly used as an overlay material to improve the service life of components that are subject to aggressive wear environments. Plasma transferred arc-additive manufacturing (PTA-AM) offers the ability to customize the composition of the depositing material, allowing for the construction of parts out of the combination of NiBSi and WC, theoretically enhancing the service life. The wear resistance of these materials is warranted to the inherent properties of the reinforcement particles, and their distribution within the metal matrix. However, the analysis of optical images to determine the weight fraction, size, and mean free path of the WC particles requires a combination of image processing and hand labelling, resulting in a time consuming and tedious task. State of the art in convolutional neural networks (CNNs) can completely automate this process, allowing for the carbide characteristics from optical microscopy images to be generated automatically. In this work, the semantic segmentation of NiBSi-WC images using a CNN architecture will be discussed. Furthermore, these advanced processing techniques can begin relating the operating parameters of the PTA-AM system to the performance of NiBSi-WC deposits in abrasive wear conditions.

Poster 47: Novel Limb Sparing Technique Using 3D-printed Patient-specific Endoprostheses for Tumors of the Proximal Humerus

Linh-Aurore Le Bras*, Anatolie Timercan*, Bertrand Lussier**, Bernard Seguin***, Yvan Petit*, Vladimir Brailovski*
**École de technologie supérieure, Canada; **Université de*

*Montréal, Canada; ***Colorado State University, United States*

Abstract: Osteosarcoma is the most common bone tumour in dogs. The most affected anatomic site is the proximal humerus. To date, the standard of care is amputation. However, close to 40% of owners report a change in their dog's behaviour after amputation and it is contraindicated in certain dogs. The successful use of personalized endoprostheses has been reported for dogs afflicted by distal radius tumors. However, such an approach to the proximal humerus remained unexplored. The purpose of this project is to develop a concept of limb and joint sparing of the proximal humerus using patient-specific endoprostheses. To ensure adequate mobility, optimal 3D-printed endoprosthesis design and implantation feasibility, the minimum number of muscles that is necessary to be attached to the endoprosthesis is determined via a quasi-static study of the shoulder biomechanics. A better understanding of the muscles' contributions is necessary to: a) assist the veterinary surgeons in the selection of muscles to be preserved during surgery and b) allow the engineers to integrate in the prosthesis design a set of strategically located textured zones, thus improving the potential of a durable muscles-prosthesis attachment via the tissue ingrowth.

Poster 48: Novel Origami-Inspired Mechanical Metamaterial Development Utilizing Theoretical Modelling Verified Through 3D Printed Sample Testing

Anastasia Wickeler, Hani Naguib
University of Toronto, Canada

Abstract: New materials developed through the inspiration of origami patterns are an exciting and vibrant field of study for creating novel mechanical metamaterials. There are many aspects of an origami design that must be examined when seeking to understand new patterns. In this study, a triangular-based origami tessellated design is first parameterized; the flat fold pattern parameters include changing the triangle side length, varying the center angle of the isosceles triangle in the fold pattern, and varying the location of the folded peak in the triangle. The fold patterns are then theoretically modelled to determine how the fold angle of the tessellated origami sheet influences the overall shape of the structure. To compare how the theoretical folding of the pattern is related to structural, mechanical origami-inspired, materials, the various configurations of origami-inspired materials were 3D printed and compression tested. Digital image correlation was used to measure how the 3D printed origami structures deformed under the compression load, and this test data was compared to the theoretical data. This study demonstrates how 3D printing multiple configurations of a complex geometry is an important tool for effective material development.

Poster 49: A Review of Human Bone Parameters and Implications towards Titanium Lattice Design for Powder Bed Fusion Additive Manufacturing

Martine McGregor, Sagar Patel, Stewart McLachlin, Mihaela Vlasea
University of Waterloo, Canada

Abstract: Additive manufacturing (AM) of titanium (Ti) alloy lattices has been proposed for bone implants and augmentation devices. Ti alloys have favourable biocompatibility, corrosion resistance and fatigue strength for bone applications, yet the optimal parameters for Ti alloy lattice designs corresponding to the natural microarchitecture of human trabecular and cortical bone are not well understood. A comprehensive review was conducted to compare the natural latticing measured in human bone to Ti alloy lattice structures for bone replacement and repair. Ti alloy lattice porosity has varied from 15% to 96.2% with most studies reporting a porosity between 50-70%. Cortical bone is roughly 5-15% porous; Ti alloy lattices with 50-70% porosity are optimal for achieving comparable stiffness, compressive strength, and yield strength. Trabecular bone has a reported porosity range from 70-90%, with trabecular thickness varying from 120-200 μm. Existing powder bed fusion technologies have produced a strut/wall thicknesses ranging from 200-1669 μm using Ti alloys. This suggests limited overlap between current AM Ti alloy lattice structures and trabecular bone microgeometry. As a result, replicating human trabecular bone with Ti alloy latticing is prohibitively challenging. This review further clarified design recommendations for AM of Ti alloy lattices to the natural parameters of bone microarchitecture.

Poster 50: Design and Analysis of a Magnetic Levitation Systems for Additive Manufacturing Applications

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

Abstract: The feasibility of magnetic levitation applications has been successfully shown for additive manufacturing operations. Through optimization, an ideal levitator setup has been designed. The system, however, is still susceptible to impedance issues. Impedance is defined as the opposition to the current flow offered by a circuit. The primary difference between impedance and resistance is that the impedance also accounts for the effect of the capacitance and inductance of the system. This phenomenon is especially encountered in high-frequency applications. Since the system operates within a range of 60-1000 Hz, the overall impedance of the system is quite high. Strategies to overcome this impedance are studied. Due to the highly inductive nature of the circuit presented, the use of a capacitor to counteract the effect of inductance are emphasized in this study. The results of the addition of a capacitor in parallel to the levitator circuit are described. ANSYS Maxwell and PartSim (a SPICE simulator engine) are used to conduct this analysis.

Poster 51: Process Methodology for Laser Directed Energy Deposition of Hastelloy-X Printed Circuit Heat Exchangers

C P Paul, A N Jinoop, K S Bindra
Raja Ramanna Centre for Advanced Technology, India

Abstract: Laser Directed Energy Deposition (LDED) is attractive for developing near-net-shaped engineering components captivating advantages of shape design and material design freedom. Printed Circuit Heat Exchanger (PCHE) is one of the typical applications of Hastelloy-X in the power sector. The LDED of PCHE involves the fabrication of thin walls and overhang geometries with a pre-defined strategy to achieve desired channel shape. A comprehensive study was initiated to make overhang geometry by understanding the effect of process parameters such as percentage overlap (x-shift) and a fraction of layer height (z-increment) on the angle and uniformity of deposition. It is observed that for all other process parameters kept constant, the maximum x-shift that can be deployed for fabricating overhang walls without failure is 15%. Channels built at different combination of process parameters show that the process parameter selection, channel size and overlap percentage between layers influences the quality of channels. Further, prototype PCHE of size 200 mm × 200 mm × 170 mm is built using a combination of thin walls and overhang structures. The channels are found to be open from both ends. The study paves a way towards the deployment of LDED for building PCHEs of different geometries.

Poster 52: Additive Manufacturing for the Realization of Heat Exchangers: Case Study

Giuseppe Corallo, Luciano Pillloni, Daniele Mirabile Gattia
ENEA, Italy

Abstract: Heat exchangers are largely used in the industrial and domestic sectors. Compact heat exchangers as, plate type, are realized by assembling many plates, with an optimized shape, in a stack and using rubber or silicon gaskets to avoid leakages. For high pressure and temperature applications heat exchangers are realized by brazing or diffusion bonding which require long heat treatments. In ENEA, in the past, it has been patented an heat exchanger obtained by stacking perforated plates for application in absorption machines based on water-ammonia cycle. In this work it is reported the realization of this heat exchanger in a single component by AM processes. The heat exchanger has been realized in polymeric material by SLA in order to test it on a test bench, determining pressure drops and global heat exchange coefficient, and to compare with others, realized with a different internal geometry. A thermofluidodynamic study has also been performed. The possibility of realizing the heat exchanger with an optimized geometry in metal alloy by AM in a powder bed system will be discussed. The work is financed in the framework of Program Agreement with the Italian Ministry of Economic Development: project "Advanced Materials for Energy".

Poster 53: Influence of Hot Isostatic Pressing on the Microstructure and Mechanical Behaviour of Laser Powder Bed Fusion built Inconel 625 Structures

Saurav Nayak*, Sanjay Mishra**, Christ Paul**, V Kumar***, Kushvinder Bindra**
**Homi Bhabha National Institute, India; **RRCAT INDORE, India; ***Vikram Sarabhai Space Centre, India*

Abstract: Laser Powder Bed Fusion (LPBF) is the most commonly used Laser Additive Manufacturing (LAM) process to build complex-shaped engineering components due to the excellent shape design freedom. However, LPBF suffers from inherent processing defects such as internal cracking, porosity, non-homogenous microstructure, etc. that can be solved by using suitable post-processing techniques. In the present work, the effect of Hot isostatic pressing (HIPing) on the porosity, microstructure and mechanical properties of LPBF built Inconel 625 (IN625) structures built with an unconventional higher layer thickness (100 μm) is studied. It is observed that the LPBF-built IN625 revealed significantly reduction of porosity both in size and numbers after HIPing treatment. Homogenous microstructure is obtained after HIP and elemental mapping of both the samples revealed carbides and elemental segregations. A reduction in the strength is observed after HIPing with reduced anisotropy. This study provides an insight to the effect of HIPing on LPBF built components to develop ~100% dense, defect-free and isotropic engineering components.

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