HI-AM Conference

2nd | 2019

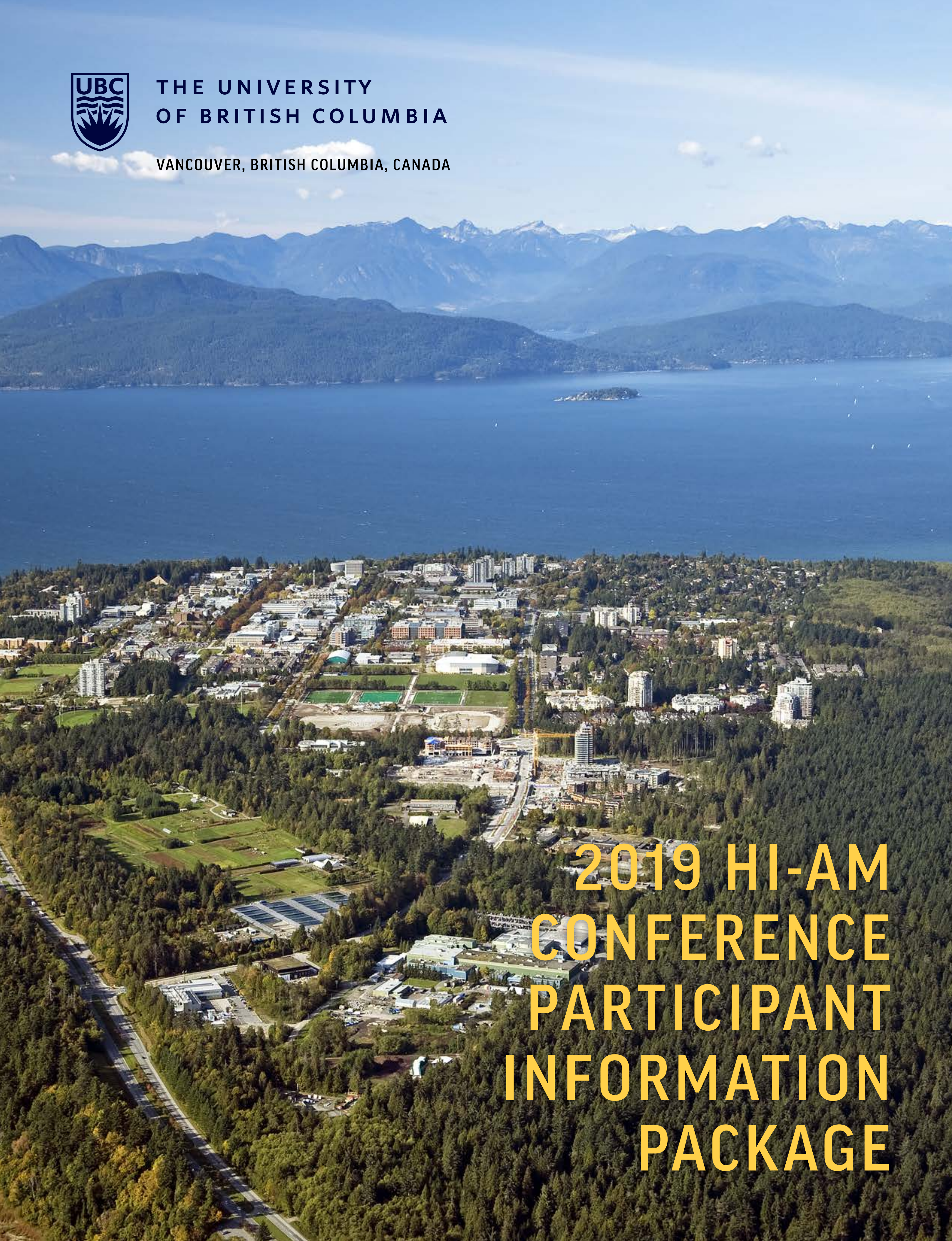
HOLISTIC INNOVATION IN ADDITIVE MANUFACTURING

PARTICIPANT INFORMATION PACKAGE

JUNE 26 & 27
VANCOUVER, BC, CANADA

conference.nserc-hi-am.ca

NSERC HI-AM | UNIVERSITY OF WATERLOO | NSERC CRSNG | INNOVATION.CA CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION



THE UNIVERSITY
OF BRITISH COLUMBIA

VANCOUVER, BRITISH COLUMBIA, CANADA

2019 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 2019 HI-AM Conference.

This year, the conference is being hosted at the University of British Columbia. We look forward to seeing the HI-AM Network members and other participants from across Canada and around the World at the beautiful UBC, Point Grey campus.

This conference provides an opportunity for HI-AM Network researchers and industrial partners to come together, share findings, explore future research directions and opportunities for collaboration. Furthermore, numerous opportunities for networking will be provided throughout the conference and during the conference dinner on Wednesday night.

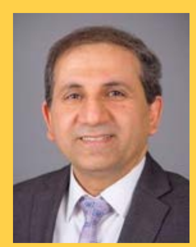
We are honored to have as our keynote speakers: Prof. David Bourell, the University of Texas at Austin, United States; Prof. Christoph Leyens, Fraunhofer IWS, Germany; Prof. Milan Brandt, RMIT, Australia; Dr. Ali Bonakdar, Siemens, Canada; and Dr. Hannes Gostner, EOS, Germany. The Conference also features 95 presentations on cutting edge research in the area of metal additive manufacturing (AM) under four research Themes: material development, advanced process modeling, process monitoring and control, and novel AM processes/products. Each of the conference's Themes will be represented in a select number of oral presentations by HI-AM Network members as well as distinguished National and International speakers. In addition, Posters will be on display during the conference, with the main viewing session scheduled for Wednesday afternoon.

On behalf of the Conference Organizing Committee, we extend our gratitude to all those who have contributed to the planning and organization of this event. In addition to our main supporter, Natural Sciences and Engineering Research Council of Canada (NSERC), we would also like to express our appreciation to co-sponsors KSB, Multi-Scale Additive Manufacturing Laboratory, EOS, TRUMPF, PULSTEC, Cimetrix, RAPIDIA, Keyence, Optomec, Stresstech, Canada Makes, Ontario Advanced Manufacturing Consortium, and America Makes.

We hope you enjoy and benefit from the 2nd HI-AM Conference.

Ralph Resnick
Chairman of the Board

Steve Cockcroft
Conference Co-chair



Ehsan Toyserkani
Network Director
Conference Co-chair

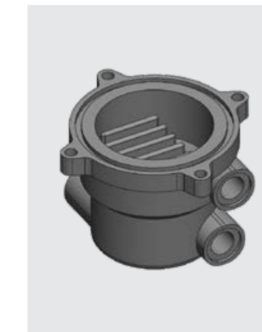
Sponsors and Exhibitors

LEAD SPONSORS

KSB

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

www.ksb.com



BEFORE
- Original oil cooler
- Designed for casting
- Several weeks to produce by casting

AFTER
- New oil cooler
- Designed for additive
- Lowest cost
- More efficient cooling
- Quality certified parts delivered in 2 weeks

MSAM

Multi-Scale Additive Manufacturing (MSAM) Laboratory is one of the largest research and development additive manufacturing facilities in Canada hosted at the University of Waterloo. 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

Sponsors and Exhibitors

PLATINUM SPONSORS

For more than 25 years, Cimetrix, a division of Javelin, has helped organizations across Canada with comprehensive additive manufacturing solutions. As a trusted partner, Cimetrix brings unmatched industry expertise. We help our customers redefine how things are made, with solutions that empower freedom of design and manufacturing flexibility.

www.cimetrixsolutions.com

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

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

www.keyence.ca

With Optomec, the promise of high-volume additive manufacturing is a reality today, transforming how companies design, build and maintain critical parts and products and enabling new manufacturing possibilities.

Optomec additive manufacturing technology provides compelling advantages over traditional manufacturing approaches by enabling customers to add materials onto existing 3D parts, providing production grade/production scale 3D printing of fully functional end-use devices, and supporting a wide range of functional materials and feature sizes.

www.optomec.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-cycle time analyzer can measure RESIDUAL-STRESS, FWHM and RETAINED-AUSTENITE by detecting the full Debye ring's profile from single incident X-ray angle. Ideal to use in lab or on-site.

www.pulstec.co.jp

The Rapidia metal 3D printing system uses a wide range of water-based metal (or ceramic) pastes. The process requires no debinding and the printed object is ready to go into the sintering furnace immediately. We save about 50% of the metal used by other bound metal systems on rafts and supports. Using the water bonding process, a complex object can be printed with minimal supports and joined simply by wetting the joint line to become a single part. This system is the most office-friendly available, as it uses no solvents and plugs into a standard single phase 220-240V 50A outlet, like your stove.

www.rapidia.com

PLATINUM SPONSORS

Stresstech provides non-destructive testing solutions for process and quality control inspection. The inspection equipment and turn-key solutions serve the automotive, aerospace and other manufacturing industries as well as universities and research institutes.

Stresstech's line of diffractometers are designed for residual stress and retained austenite measurements. This non-destructive technology can provide customers with reliable, unmatched data for quality control assessment. The Xstress product line of diffractometers is suitable for use in the field, factory, and laboratory settings.

Measurement services are available in our ISO/IEC 17025 accredited laboratories, or on-site for customer convenience.

www.stresstech.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

SILVER SPONSORS

America Makes is the United States' leading collaborative partner in AM and 3DP technology research, discovery, creation, and innovation. Structured as a public-private partnership with member organizations from industry, academia, government, non-government agencies, and workforce and economic development resources, America Makes is working together to innovate and accelerate AM and 3DP to increase the United States' global manufacturing competitiveness.

www.americamakes.us

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

www.canadamakes.ca

Ontario's Advanced Manufacturing Consortium (AMC) is a partnership between McMaster University, University of Waterloo and Western University that connects industry partners to world-class facilities and research expertise in automotive, advanced materials, additive manufacturing, robotics, wireless and more. AMC's objective is to accelerate innovation in the manufacturing sector through creation of new products, production methods and processes that will generate jobs and uphold Ontario as leading manufacturing region.

www.oamc.ca

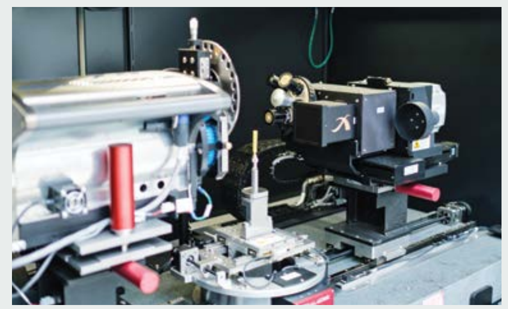
NSERC HI-AM Network

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 the crucial arena of advanced manufacturing.

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



NSERC HI-AM

ACADEMIC AND RESEARCH INSTITUTION PARTNERS

MEMBERS

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

COLLABORATORS

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

INTERNATIONAL

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

INDUSTRY AND HEALTHCARE PARTNERS

- Autodesk
- BOCO Technology Inc
- Flexcap
- Linamar
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- Mount Sinai Hospital
- GKN Driveline
- Pratt & Whitney Canada
- Promation
- Renishaw
- Rio Tinto
- Siemens
- Syncrude
- TIMET

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- Canada NRC-CNRC
- Natural Resources Canada / Ressources naturelles Canada
- InnoTech Alberta
- DRDC RDDC

NON-PROFIT PARTNERS

- Canada Makes
- CM&E Canadian Manufacturers & Exporters
- Canada Mining Innovation Council
- ReMAP
- AAPF

Venue

Venue wifi network: ubcvisitors

HI-AM 2019 is held at the stunning Point Grey campus of the University of British Columbia (UBC) in Vancouver, BC. The conference venue for HI-AM 2019 is the Great Hall of The AMS Nest which is 20 minutes away from both downtown Vancouver and Vancouver International Airport. Built in 2015, The Nest is one of the newest and most vibrant UBC buildings. This LEED Platinum Certified building has been designed with sustainability as the top priority. With multiple stores, restaurants, meeting spaces, an art gallery, and a three-story climbing wall, The AMS Nest has something to offer for everyone. It is also located within a comfortable walking distance of on-campus hotels and residences. Located in front of the major bus loop of UBC (UBC Exchange), access to the public transportation is convenient. Buses #4, #44, #14, and #N17 travel to downtown Vancouver.

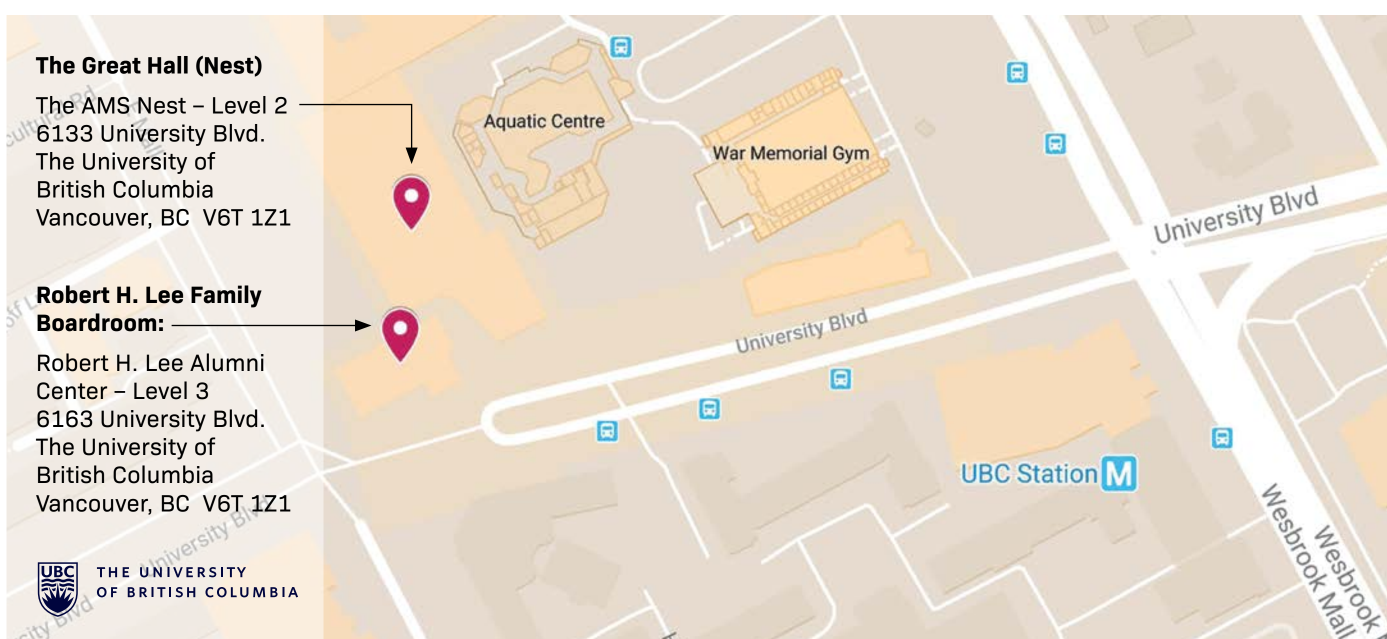
The UBC campus is surrounded by forests and offers a spectacular view of the ocean and North Shore Mountains. UBC is also home to multiple beaches, gardens, museums, art galleries, restaurants and iconic buildings. During your visit, enjoy the Museum of Anthropology, Pacific Spirit Regional Park, UBC Botanical Garden, Pacific Museum of the Earth and many more sites.

Photo credit: Alma Mater Society (AMS) of the University of British Columbia – www.nestcatering.com

HI-AM Network Meetings

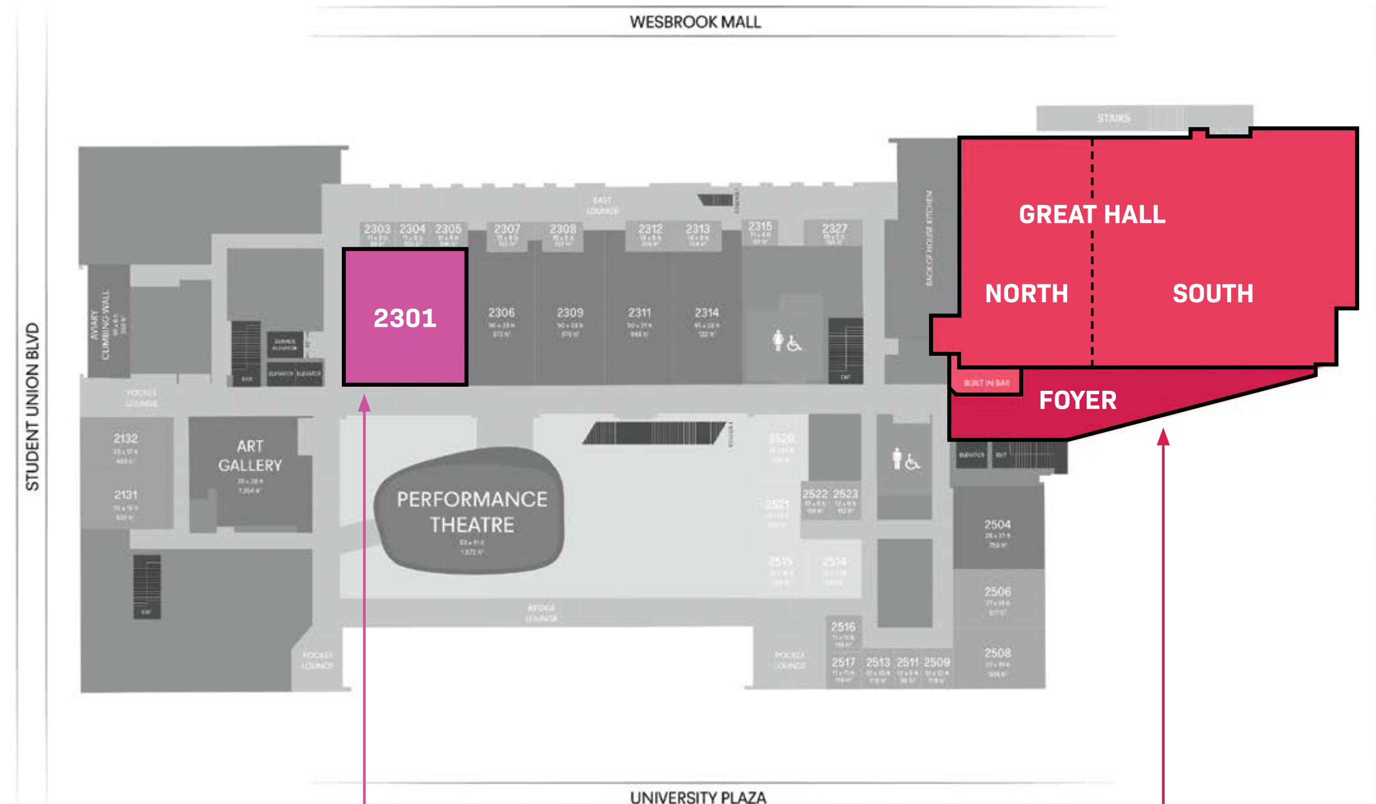
The meetings will be held in Robert H. Lee family boardroom in the UBC Alumni Center (third floor) right next to The AMS Nest building.

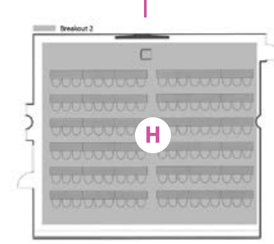
MEETING	DATE	TIME	COORDINATOR
Scientific Advisory Committee	June 26	5:40pm – 6:40pm	**Farzad Liravi** fliravi@uwaterloo.ca
TraCLight-HiptSLAM	June 27	2:10pm – 3:10pm	**Gregor Graf** g.graf@rosswag-engineering.de
Board of Directors	June 27	4:00pm – 5:00pm	**Farzad Liravi** fliravi@uwaterloo.ca



Venue Map

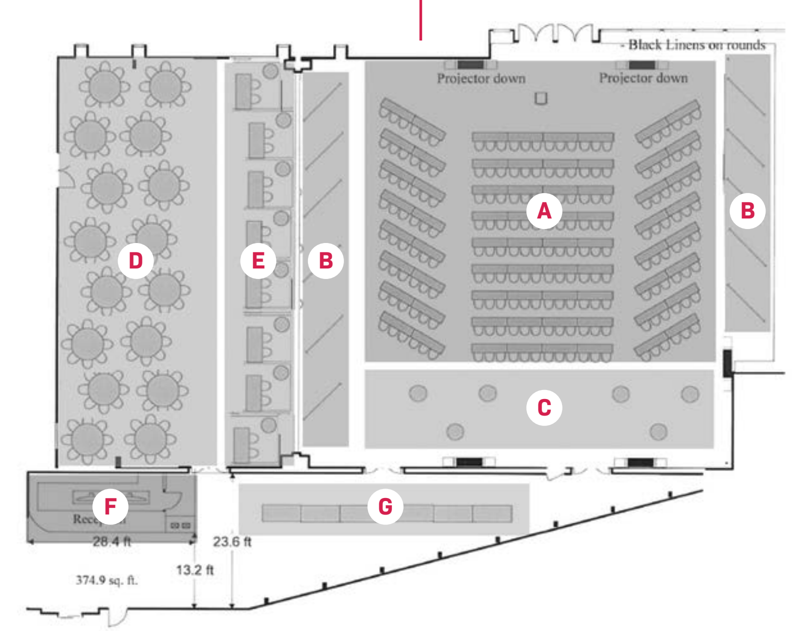
The AMS Nest – Level 2





Classroom 2301

H Breakout 2



Great Hall – South

A Plenary/Breakout 1
B Poster Display Area
C Networking Area

Great Hall – North

D Catering
E Exhibitors

Foyer

F Reception
G Buffet

Conference Dinner

The Conference dinner will be held in the Gallery & Patio of The Nest on Wednesday June 26, 6:40pm – 9:00pm. We invite you to join us in this stylish restaurant for a night of food and drink, friendly chat with AM experts from academia and industry, and a great view of UBC campus on the outside terrace.

Operated by the Nest Catering, the sustainable menu features fresh delicious food made from organic ingredients provided by local companies.

This event is only open to the **full conference registrants.** Please do not forget your badge and banquet coupons!

The AMS Nest – Level 4
6133 University Blvd.
The University of British Columbia
Vancouver, BC V6T 1Z1

Photo credit: Alma Mater Society (AMS) of the University of British Columbia – www.nestcatering.com

The AMS Nest – Level 4

Keynote Speakers at HI-AM 2019

Prof. David Bourell

Temple Foundation Professor and Director, Laboratory for Freeform Fabrication, The University of Texas at Austin, Texas, United States

Dr. David L. Bourell is the Temple Foundation Professor of Mechanical Engineering at The University of Texas at Austin. Dr. Bourell's areas of research include particulate processing with emphasis on sintering kinetics and densification, and materials issues associated with Laser Sintering (LS). Professor Bourell is a leading expert in advanced materials for Laser Sintering, having worked in this area since 1988. Dave was the lead author on the original materials patent for LS technology. Issuing in 1990, this patent has been cited by over 225 other patents, and it represents the original intellectual property for mixed and coated powders for LS, including binders. Since 1995, he has chaired the organizing committee for the Annual International Solid Freeform Fabrication Symposium – An Additive Manufacturing Conference. This meeting is a leading research conference on additive manufacturing and is the oldest, continuously running conference on AM in the world. He holds 9 primary patents dealing with materials innovations in LS dating back to 1990 and has published 250 papers in journals, conference proceedings and book chapters. He is a founding member of the ASTM F42 Technical Committee on Additive Manufacturing and currently serves on the ten-member ASTM/ISO Joint Group 51 on Terminology for AM. Dr. Bourell is a Fellow of ASM International and TMS, and he is also a lifetime member of TMS. In 2009, he received the TMS Materials Processing and Manufacturing Division Distinguished Scientist/Engineer Award. In 2017, he received the Society of Manufacturing Engineers Albert M. Sargent Progress Award for "significant accomplishments in the field of manufacturing processes".

Presentation Title: Metals for Additive Manufacturing

Prof. Christoph Leyens

Managing Director, Fraunhofer Institute of Materials and Beam Technology, Germany

Born in 1967, Dr. Christoph Leyens studied physical metallurgy and materials technology at RWTH Aachen, Germany, where he earned his diploma in 1993 and his Ph.D. in 1997. He is currently a full professor for materials science at the Technische Universität Dresden, Germany, and director of the Fraunhofer Institute of Materials and Beam Technology, Dresden.

Dr. Leyens has covered a wide range of research topics with a focus on high temperature and light weight materials, functional materials, surface technology, coatings and additive manufacturing. He has published more than 200 papers, seven books and holds eleven patents. Dr. Leyens is initiator and coordinator of the 90 Million Euro R&D project "AGENT-3D", Europe's largest single project on AM. Out of a total of 120 partners, the consortium comprises more than 100 companies, aiming at the industrial implementation of AM as an enabling technology for advanced manufacturing.

Presentation Title: Innovative Aerospace and Space Structures made by Additive Manufacturing

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Keynote Speakers at HI-AM 2019

Prof. Milan Brandt

Director, Centre for Additive Manufacturing, Advanced Manufacturing Precinct, RMIT University, Victoria, Australia

Dr. Milan Brandt is a Distinguished Professor in Advanced Manufacturing in the School of Engineering, Technical Director Advanced Manufacturing Precinct and Director RMIT Centre for Additive Manufacturing, RMIT University, Melbourne, Australia. Professor Brandt has been involved with lasers and manufacturing technologies professionally for some 34 years and is recognised nationally and internationally as the leading Australian researcher in the field. He is the recipient of a number of awards and is the author of over 200 publications, 7 book chapters and a book on laser additive manufacturing. Professor Brandt is an executive member and fellow of the Laser Institute of America, honorary fellow of WTIA and Professorial Fellow department of Medicine, Melbourne University. He is also the senior editor of the Journal of Laser Applications. In 2018 he served as the President of the Laser Institute of America for 12 months.

Presentation Title: Additive Manufacturing Landscape in Australia

Dr. Ali Bonakdar

Advanced Manufacturing Technology Lead, Siemens Canada

Dr. Ali Bonakdar is working at Siemens Canada Limited, Gas and Power Division, 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.

Presentation Title: Industrialization of Additive Manufacturing: A Journey from Fundamental Research to Production

Dr. Hannes Gostner

Director, Research and Development, EOS, Germany

Dr. Hannes Gostner is Director Research and Development at EOS, the industry's leading provider of industrial AM solutions. In this role, he is responsible for the development of machines, materials, software and processes for both Polymer and Metal Powder Bed Fusion. With ten years of experience at EOS, he is an expert in AM technology development. Dr. Gostner obtained a Masters degree in Physics and a Ph.D. in Astronomy, both at the University of Heidelberg, before he moved to the Manufacturing industry.

Presentation Title: Mastering AM Freedom

Notes:

DAY 1 – June 26, 2019 MORNING

8:00-8:30am	**BREAKFAST**
8:30-8:40am	**CONFERENCE OPENING – Location: Great Hall South** Santa Ono, *UBC President and Vice Chancellor* James Olson, *Dean of the UBC Faculty of Applied Science* Ehsan Toyserkani, *HI-AM Director*
8:40-9:20am	**KEYNOTE: Metals for Additive Manufacturing – Location: Great Hall South** David Bourell, *Temple Foundation Professor, Director of Laboratory for Freeform Fabrication, The University of Texas at Austin*
	SESSION 1: ADVANCES IN ADDITIVE MANUFACTURING I **Chair: Steve Cockcroft Location: Great Hall South**
9:20-9:40am	**Presentation 1: Business Case for Additive Manufacturing in Serial Production** Alexander Boehm *KSB, Germany*
9:40-10:00am	**Presentation 2: Low Cost, Medium-Speed Stereovision for Spatter Tracking in Powder Bed Fusion** Eric MacDonald *Youngstown State University, United States*
10:00-10:20am	**Presentation 3: Efficient Parameter Development Strategy of Tool Steel Materials for Laser Additive Manufacturing** Gregor Graf*, Manuela Leoni**, Tobias Muller, Jorg Fischer-Buhner, Daniel Beckers*, Sven Donisi*, Frederik Zanger**, Volker Schulze** **Rosswag GmbH, Germany | **Karlsruhe Institute of Technology, Germany*
10:20-10:40am	**MORNING TEA, POSTER AND EXHIBITION VIEWING**
10:40-11:20am	**KEYNOTE: Innovative Aerospace and Space Structures Made by Additive Manufacturing – Location: Great Hall South** Christoph Leyens, *Managing Director, Fraunhofer Institute of Materials and Beam Technology, Germany*
	SESSION 2: ADVANCES IN ADDITIVE MANUFACTURING II **Chair: Daan Maijer Location: Great Hall South**
11:20-11:40am	**Presentation 4: Optimisation of Process Parameters for In-situ Alloyed Titanium by Selective Laser Melting** Igor Yadroitsev*, Ina Yadroitsev*, Pavel Krakhmalev**, Anton du Plessis***, Eric Newby*, Dean Kouprianoff* **Central University of Technology, South Africa | **Karlstud University, Sweden | ***Stellenbosch University, South Africa*
11:40am-12:00pm	**Presentation 5: Novel Repair Strategy Using Additive Manufacturing to Address Severe Foreign Object Damage on Ti Alloy Fan Blades** Priti Wanjara*, Javad Gholipour*, Kosuke Watanabe**, Koji Nezaki** **National Research Council of Canada-Montreal | **IHI Corporation, Japan*
12:00-12:20pm	**Presentation 6: Development of Metal Slurry Three-Dimensional Printing System Based on Maskless Projection Method** Cho-Pei Jiang*, Shinn-Liang Chang** **National Taipei University of Technology, Taiwan | **National Formosa University, Taiwan*

DAY 1 – June 26, 2019 AFTERNOON

12:20-1:00pm	**LUNCH**	
1:00-2:00pm	**POSTER VIEWING – Location: Great Hall South | EXHIBITION VIEWING – Location: Great Hall North**	
2:00-2:40pm	**KEYNOTE: Mastering AM Freedom – Location: Great Hall South** Hannes Gostner, *Director Research and Development, EOS, Germany*	
	SESSION 3: MATERIAL DEVELOPMENT I **Chair: Paul Bishop Location: Great Hall South**	**SESSION 4: ADVANCED PROCESS MODELING I** **Chair: Damiano Pasini Location: Room 2301**
2:40-3:00pm	**Presentation 7: Effect of Powder Attributes on Microstructure and Mechanical Properties of 3D-printed Al10SiMg Alloy Using Laser Powder Bed Fusion Technique** Vahid Fallah, Qingshan Dong, Mark Gallermeault *Queen's University, Canada*	**Presentation 11: Thermo-Mechanical Numerical Modelling of Selective Laser Melting for Prediction of Residual Stress** Jean-Sebastien Cagnone, Jean-Philippe Marcotte, Marjan Molavi-Zarandi, Florin Ilinca, Kabanemi Kalonji Kabaa *National Research Council of Canada-Boucherville*
3:00-3:20pm	**Presentation 8: Development of Modified A8 and S7 Tool Steel Powders for Additive Manufacturing by LPB-AM** Denis Mutel, Carl Blais *Universite Laval, Canada*	**Presentation 12: Topology Optimization of Support Structures for Laser Powder-bed Fusion Based on the Inherent Strain Method** Zhidong Zhang*, Osezua Ibhadode*, Pouyan Rahnama*, Ali Bonakdar**, Ehsan Toyserkani* **University of Waterloo, Canada | **Siemens, Canada*
3:20-3:40pm	**Presentation 9: Studying the Impact of Particle Morphology on Powder Spreading and Laser Powder Bed Fusion Characteristics to Maximize the Process Productivity** Salah Eddin Brika*, Morgan Letenneurm*, Christopher Alex Dion**, Vladimir Brailovski* **ETS Montreal, Canada | **PyroGenesis Additive, Canada*	**Presentation 13: A Fast and Part-level Numerical Simulation of Temperature Field in Selective Laser Melting Process** Zhibo Luo, Fiona Zhao *McGill University, Canada*
3:40-4:00pm	**Presentation 10: Selective Electron Beam Melting of Al-Cu-Mg Alloy: Processability and Characterization** Mohammad Saleh Kenevisi, Feng Lin *Tsinghua University, China*	**Presentation 14: Fast-to-run Predictive Model for Thermal Fields During Additive Manufacturing** Meet Upadhyay, Daan Maijer, Steve Cockcroft *The University of British Columbia, Canada*
4:00-4:20pm	**AFTERNOON TEA, POSTER AND EXHIBITION VIEWING**	
	SESSION 5: PROCESS MONITORING AND CONTROL I **Chair: Mihaela Vlasea Location: Room 2301**	**SESSION 6: NOVEL AM PROCESSES AND PRODUCTS I** **Chair: Vahid Fallah Location: Great Hall South**
4:20-4:40pm	**Presentation 15: In-line Melt Pool Monitoring of Laser Powder-bed Fusion** Katayoon Taherkhani*, Zheng Ma*, Esmat Sheydaeian*, Ali Ghodsi*, Martin Otto**, Christopher Eischer**, Ehsan Toyserkani* **University of Waterloo, Canada | **EOS, Germany*	**Presentation 19: Machine Learning Aided Optimization of Conformal Cooling Channel** Zhenyang Gao, Fiona Zhao *McGill University, Canada*
4:40-5:00pm	**Presentation 16: Modelling and Identification of Electron Beam Deflection System** Scott Parks, Zekai Murat Kilic, Yusuf Altintas *The University of British Columbia, Canada*	**Presentation 20: Hybrid Additive Manufacturing and Casting Processes for Non Ferrous Alloys** Axelle Sabouraud, Artitra Biswas, Abdoul-Aziz Bogno, Hani Henein, Ahmed Qureshi *University of Alberta, Canada*
5:00-5:20pm	**Presentation 17: Cost Effective Real-Time Thermal Dynamics Modeling in Laser Materials Processing** Lucas Botelho, Amir Khajepour *University of Waterloo, Canada*	**Presentation 21: Mechanical and Functional Performance of Porous Bone Replacement Implants** Asma El Elmi*, David Melancon**, Meisam Asgari*, Liu Lu*, Damiano Pasini* **McGill University, Canada | **Harvard University, United States*
5:20-5:40pm	**Presentation 18: In-situ Sensing and Measurement for Quality Control in Metal Additive Manufacturing: Review and Future Directions** Thomas Lehmann*, Tonya Wolfe**, Hani Henein*, Ahmed Qureshi* **University of Alberta, Canada | **InnoTech Alberta, Canada*	**Presentation 22: Surface Finishing of Titanium and Nickel-based Laser Powder Bed-fused Components: Abrasive Flow Machining Versus Electrochemical Polishing** Neda Mohammadian*, Victor Urlea*, Clement Bouland*, Sylvain Turenne**, Vladimir Brailovski* **ETS Montreal, Canada | **Ecole Polytechnique de Montreal, Canada*
5:40-6:40pm	**POSTER VIEWING – Location: Great Hall South | EXHIBITION VIEWING – Location: Great Hall North**	
5:40-6:40pm	**SIENTIFIC ADVISORY COMMITTEE MEETING – Location: Robert H. Lee Boardroom Alumni Centre**	
6:40-9:00pm	**CONFERENCE DINNER – Location: Gallery & Patio Restaurant**	

DAY 2 – June 27, 2019 MORNING

8:00-8:30am	**BREAKFAST**	
8:30-9:10am	**KEYNOTE: Additive Manufacturing Landscape in Australia – Location: Great Hall South** Milan Brandt, *Director Centre for Additive Manufacturing, Advanced Manufacturing Precint, RMIT University, Australia*	
	SESSION 7: MATERIAL DEVELOPMENT II **Chair: Ahmed Qureshi Location: Room 2301**	**SESSION 8: ADVANCED PROCESS MODELING, MONITORING AND CONTROL** **Chair: Fiona Zhao Location: Great Hall South**
9:10-9:30am	**Presentation 23: Fabrication of Rene 41 Parts with Laser Powder Bed Fusion** Sila Atabay*, Kevin Plucknett**, Mathieu Brochu* **McGill University, Canada | **Dalhousie University, Canada*	**Presentation 27: Geometric Deviations of Laser Powder Bed Fused AlSi10Mg Components: Numerical Predictions Versus Experimental Measurements** Floriane Zongo*, Charles Simoneau**, Anatolie Timercan*, Antonie Tahan*, Vladimir Brailovski* **ETS Montreal, Canada | **SimuTech Group, Canada*
9:30-9:50am	**Presentation 24: Particle Decoration: A Method for Developing New Material for Additive Manufacturing** Ehsan Marzbanrad, Yahya Mahmoodkhani, Ehsan Toyserkani *University of Waterloo, Canada*	**Presentation 28: Melt Pool Geometry Modeling and Monitoring Via In-situ Vision System for Powder Fed Laser Fusion Process** Deniz Sera Ertay, Josh van Houtum, Mihaela Vlasea *University of Waterloo, Canada*
9:50-10:10am	**Presentation 25: Electrostatic Atomisation of Metals** Bilal Bharadia, Abdoul-Aziz Bogno, Hani Henein *University of Alberta, Canada*	**Presentation 29: Temperature Fluctuations at Boundary Points in Laser Powder Bed Fusion** Emre Ogeturk, Mary Wells *University of Waterloo, Canada*
10:10-10:30am	**Presentation 26: Implementation of the Kitagawa-Takahashi Approach for Prediction of Fatigue Limit of Inconel 625 Components Containing Intentionally-seeded Defects** Jean-Rene Poulin, Patrick Terriault, Vladimir Brailovski *ETS Montreal, Canada*	**Presentation 30: Design of a Test Artefact to Evaluate Critical Design Features for Ti-6Al-4V Parts in Electron-Beam Melting Additive Manufacturing (EBAM)** Gitanjali Shanbhag, Mihaela Vlasea *University of Waterloo, Canada*
10:30-10:50am	**MORNING TEA, POSTER AND EXHIBITION VIEWING**	
	SESSION 9: ADVANCED PROCESS MODELING II **Chair: Marjan Molavi-Zarandi Location: Great Hall South**	**SESSION 10: NOVEL AM PROCESSES AND PRODUCTS II** **Chair: Vladimir Brailovski Location: Room 2301**
10:50-11:10am	**Presentation 31: Microscale Interaction Between the Laser and Metal Powder in Powder-bed Additive Manufacturing: Conduction Mode Versus Keyhole Mode** Hongze Wang, Yu Zou *University of Toronto, Canada*	**Presentation 36: Investigating Residual Stress Characteristics for Selected Direct Energy Deposition Process Settings: P420 Steel Single Bead Deposition on Mild Steel** Jill Urbanic*, Navid Nazemi** **University of Windsor, Canada | **AMG Metal Inc., Canada*
11:10-11:30am	**Presentation 32: A Predictive System for Manufacturability Analysis of Laser Powder Bed Fusion Process** Ying Zhang, Fiona Zhao *McGill University, Canada*	**Presentation 37: Evaluation of Additive Manufacturing for Repair and Remanufacturing Purposes** Fatih Sikan*, Priti Wanjara**, Javad Gholipour**, Mathieu Brochu* **McGill University, Canada | **National Research Council of Canada-Montreal*
11:30-11:50am	**Presentation 33: Thermal Fluid Modeling for Melt Pool Generation of Ti6AL4V Powder Bed In The Electron Beam Additive Manufacturing** Eiko Nishimura, Steve Cockcroft, Daan Maijer, Farzaneh Farhang-Mehr *The University of British Columbia, Canada*	**Presentation 38: Laser Powder Bed Fusion of AlSi10Mg for Fabrication of an Aluminum Transmission Pump Housing** Lisa Brock, Hamed Asgari, Mihaela Vlasea *University of Waterloo, Canada*
11:50am-12:10pm	**Presentation 34: Normative Benchmark Design and Preliminary Geometric Quality Results for Selective Laser Melting Process** Baltej Singh, Marc Secanell, Ahmed Qureshi *University of Alberta, Canada*	**Presentation 39: Direct Laser Deposition of Ti–5Al–5V–5Mo–3Cr Alloy** Xinjin Cao*, Alexander Bois-Brochu**, Javad Gholipour* **National Research Council of Canada | **Centre de metallurgie du Quebec, Canada*
12:10-12:30pm	**Presentation 35: Numerical Analysis of Melt Pool Geometry in Laser Powder-bed Fusion of Hastelloy X** Shahriar Imani*, Adhitan Rani Kasinathan*, Zhidong Zhang*, Yahya Mahmoodkhani*, Usman Ali*, Ali Keshavarzkermani*, Ehsan Toyserkani*, Ali Bonakdar** **University of Waterloo, Canada | **Siemens, Canada*	**Presentation 40: Predicting Defects in 3D Printed Lattice Structures** Ken Nsienpba, Ehsan Toyserkani *University of Waterloo, Canada*

DAY 2 – June 27, 2019 AFTERNOON

12:30-1:10pm	**LUNCH**	
1:10-1:50pm	**KEYNOTE: Industrialization of Additive Manufacturing: A Journey from Fundamental Research to Production** **Location: Great Hall South** Ali Bonakdar, *Advanced Manufacturing Technology Lead, Siemens, Canada*	
	SESSION 11: MATERIAL DEVELOPMENT III **Chair: Hani Henein Location: Great Hall South**	**SESSION 12: ADVANCED PROCESS MODELING AND NOVEL AM PROCESSES** **Chair: Priti Wanjara Location: Room 2301**
1:50-2:10pm	**Presentation 41: Correlating the Columnar Grain Structure with the Anisotropic Mechanical Response of Hastelloy X Produced by Laser Powder-bed Fusion** Ali Keshavarzkermani*, Reza Esmaeilizadeh*, Shahriar Imani*, Hamid Jahed Motlagh*, Norman Zhou*, Ali Bonakdar**, Ehsan Toyserkani* **University of Waterloo, Canada |**Siemens, Canada*	**Presentation 46: Tool Path Related Process Planning Challenges for Direct Energy Deposition Systems** Bob Hedrick*, Jill Urbanic** **CAMufacturing Solutions Inc., Canada | **University of Windsor, Canada*
2:10-2:30pm	**Presentation 42: Graphene Nanocellulose Composites for 3D Printed Electrodes** Taylor Morrison, Hani Naguib *University of Toronto, Canada*	**Presentation 47: Selective Laser Melting of Graphene-reinforced Aluminum Matrix Composites for Electrical Batteries** Mostafa Yakout, M. A. Elbestawi *McMaster University, Canada*
2:30-2:50pm	**Presentation 43: Application of Fast Cooling Calorimetry in AM** An Fu*, Pierre Hudon*, Paul Bishop**, Mathieu Brochu* **McGill University, Canada | **Dalhousie University, Canada*	**Presentation 48: Influence of Operating Parameters During Plasma Transferred Arc Additive Manufacturing on Carbide Concentration of 70wt% Ni-WC Metal Matrix Composite Components** Dylan Rose*, Tonya Wolfe**, Hani Henein*, Leijun Li* **University of Alberta, Canada | **InnoTech Alberta, Canada*
2:50-3:10pm	**AFTERNOON TEA, POSTER AND EXHIBITION VIEWING**	
3:10-3:30pm	**Presentation 44: Selective Laser Melting of Copper, Aluminum, and Copper-Aluminum Alloy** Hao Kun Sun, Yu Zou, Gisele Azimi *University of Toronto, Canada*	**Presentation 49: Integration of Physically-based Analytical Model and Statistically-driven Empirical Model for Multi-objective Optimization of Laser Powder-bed Fusion** Yuze Huang, Hamed Asgari, Mohammad Ansari, Behrad Khamesee, Ehsan Toyserkani *University of Waterloo, Canada*
3:30-3:50pm	**Presentation 45: Laser Powder Bed Processing of Aluminum Powders Containing Iron and Nickel Additions** Greg Sweet*, Jon Hierlihy*, Ian Donaldson**, Mathieu Brochu***, Paul Bishop* **Dalhousie University, Canada | **GKN, Canada | ***McGill University, Canada*	**Presentation 50: Progress in Applying Fused Filament Fabrication to Metal Matrix Composites (MMC)** Nancy Bhardwaj*, Hani Henein*, Tonya Wolfe** **University of Alberta, Canada | **InnoTech Alberta, Canada*
3:50-4:00pm	**CLOSING REMARKS AND AWARDS – Location: Great South Hall** Andrew Szeri, *UBC VP Academic and Provost*	
4:00-5:00pm	**BOARD OF DIRECTORS MEETING – Location: Robert H. Lee Boardroom Alumni Centre**	

Poster Presentation Gallery

THEME 1 - MATERIAL DEVELOPMENT

Poster 1: Innovative Surface Finishing Methods for Reducing Internal and External Surface Roughness of Metal Additive Manufacturing Parts
Haniyeh Fayazfar, Mihaela Vlasea, Ehsan Toyserkani
University of Waterloo, Canada

Poster 2: The Contribution of Moisture from Cellulosic Filters in LPBF AM
Aniruddha Das, Mathieu Brochu
McGill University, Canada

Poster 3: Laser DED Cladding of H13 Tool Steel and Elemental Equivalents
Owen Craig, Kevin Plucknett
Dalhousie University, Canada

Poster 4: A Novel Binder Jetting Process to Fabricate Functionally Graded Nanocomposites for Hygroscopic Sensing and Actuation
Xuechen Shen, Hani Naguib
University of Toronto, Canada

Poster 5: Mechanical Properties of Additively Manufactured Tessellated Metamaterial Design Configurations
Anastasia Wickeler, Hani Naguib
University of Toronto, Canada

Poster 6: Improving Surface Finish of Low-cost Irregular Powders in Laser Powder-bed Fusion
Seung Ho Jeong, Sagar Patel, Allan Rogalsky, Mihaela Vlasea, Adrian Gerlich, Mary Wells
University of Waterloo, Canada

Poster 7: Reactive Sintering for Post-processing of Binder-jet Additive Manufactured Metal Matrix Composites
Pablo Enrique, Norman Zhou, Ehsan Toyserkani
University of Waterloo, Canada

Poster 8: Characterization of Commercial Mo Powders and Their Laser Powder Bed Fusion Additive Manufacturing Behavior
Tejas Ramakrishnan, Eileen Ross Espiritu, Mathieu Brochu
McGill University, Canada

Poster 9: Elevated-temperature Tensile and Creep Properties of Laser Powder Bed-fused IN625 Components
Alena Kreitcberg*, Karine Inaekyan*, Sylvain Turenne**, Vladimir Brailovski*
**ETS Montreal, Canada | **Ecole Polytechnique de Montreal, Canada*

Poster 10: Rapid Solidification of Al-Cu Eutectic
Daniela Diaz, Abdoul-Aziz Bogno, Jonas Valloton, Hani Henein
University of Alberta, Canada

Poster 11: Effect of Rapid Solidification on Microstructure and Properties of Al-Si alloys
Daniela Diaz, Hani Henein, Abdoul-Aziz Bogno
University of Alberta, Canada

Poster 12: Processing of Ti-64 by Laser Powder Fed Additive Manufacturing
Nick Gosse*, Ian Donaldson**, Kevin Plucknett*, Paul Bishop*
**Dalhousie University, Canada | **GKN, Canada*

Poster 13: Binder Jet Printing of Low Cost Tool Steel Powders
Ryen Ley*, Ian Donaldson**, Paul Bishop*
**Dalhousie University, Canada | **GKN, Canada*

Poster 14: Rapid Solidification of Al-Si-Sc Alloy
Akankshya Sahoo*, Abdoul-Aziz Bogno*, William Hearn**, Hani Henein*
**University of Alberta, Canada | **Chalmers University of Technology, Sweden*

Poster 15: Correlating the Columnar Grain Structure with the Anisotropic Mechanical Response of Hastelloy X Produced by Laser Powder-bed Fusion
Ali Keshavarzkermani, Reza Esmaeilizadeh, Shahriar Imani, Hamid Jahed Motlagh, Norman Zhou, Ehsan Toyserkani
University of Waterloo, Canada

THEME 2 - ADVANCED PROCESS MODELING

Poster 16: Evaluation of Residual Stresses Induced in Laser Powder-bed Fusion Additive Manufacturing Process: Finite Element Simulation and Experimental Investigation
Marjan Molavi-Zarandi*, Ali Bonakdar**, Ramin Sedaghati***
**National Research Council of Canada-Boucherville | **Siemens, Canada | ***Concordia University*

Poster 17: Control of Density and Microstructure in Laser Powder Bed-fused Components Using a Combination of Melt Pool Modeling and Design of Experiment Approaches
Morgan Letenneur, Alena Kreitcberg, Vladimir Brailovski
ETS Montreal, Canada

Poster 18: Adaptive Trajectory Planning for Direct Energy Deposition Using Tri-Dexel Model
Farzaneh Kaji*,**, Vadim Kozhevnikov*,**, Ehsan Toyserkani*
**University of Waterloo, Canada | **Promation, Canada*

Poster 19: Mechanics of Additively Built Porous Biomaterials
Ahmed Moussa*, Asma El Elmi*, David Melancon**, Damiano Pasini*
**McGill University, Canada | **Harvard University, United States*

Poster 20: Topology Optimization of Structures Under Design-dependent Pressure Loads
Pouyan Rahnama, Osezua Ibhadode, Zhidong Zhang, Ehsan Toyserkani
University of Waterloo, Canada

Poster 21: Design for Additive Manufacturing: Topology Optimization of a Mechanical Assembly
Osezua Ibhadode, Pouyan Rahnama, Ehsan Toyserkani
University of Waterloo, Canada

Poster 22: Study on Fracture Mechanism of Ti-6Al-4V EBM Manufactured Under Different Loading Conditions Through a Hybrid Experimental-numerical Approach
Mohammad Shaterzadeh, Marcilio Alves
University of Sao Paulo, Brazil

Poster 23: Numerical Model of Al-33wt%Cu Eutectic Growth During Impulse Atomization
Jonas Valloton, Abdoul-Aziz Bogno, Hani Henein
University of Alberta, Canada

Poster 24: Residual Stress and Distortion in Electron Beam Additive Manufacturing of Ti-6Al-4V Build Plates
Pegah Pourabdollah, Farzaneh Farhang-Mehr, Steve Cockcroft, Daan Maijer
The University of British Columbia, Canada

Poster 25: Meso-scale Thermal, Elastic and Plastic Strain Evolution in PB-EBAM
Asmita Chakraborty, Farzaneh Farhang-Mehr, Daan Maijer, Steve Cockcroft
The University of British Columbia, Canada

Poster 26: Residual Deformation and Stress Measurement
Farhad Rahimi, Farzaneh Farhang-Mehr, Daan Maijer, Steve Cockcroft
The University of British Columbia, Canada

Poster 27: Beam/Powder/Melt Pool Interaction; Experimental Validation
Arman Khobzi, Farzaneh Farhang-Mehr, Daan Maijer, Steve Cockcroft
The University of British Columbia, Canada

Poster Presentation Gallery

THEME 3 - PROCESS MONITORING AND CONTROL

Poster 28: Literature Survey of Laser Ultrasound Imaging Techniques Applicable to Defect Detection in Metal Additive Manufactured Parts
Alexander Martinez-Marchese, Ehsan Toyserkani
University of Waterloo, Canada

Poster 29: Leveraging Keyhole Mode Melting Models in Laser Powder Bed Fusion
Sagar Patel, Mihaela Vlasea
University of Waterloo, Canada

Poster 30: Detection of Internal Defects and Surface Cracks in Additively Manufactured Conductive Parts by Eddy Current Technique
Heba Farag, Behrad Khamesee, Ehsan Toyserkani
University of Waterloo, Canada

Poster 31: Modelling of Powder Spreading to Optimize Compaction Consistency
Alexander Groen, Mihaela Vlasea, Kaan Erkorkmaz
University of Waterloo, Canada

Poster 32: Anisotropic Finite Element Modeling of an Aluminum Alloy Made by Additive Manufacturing
Henrique Ramos*, Rafael Santiago*, Marcilio Alves**, Peter Theobald***, Shwe Soe***
**Federal University of ABC, Brazil | **University of Sao Paulo, Brazil | ***University of Cardiff, UK*

Poster 33: Investigation of Binder Deposition and Infiltration Strategies for Binder Jetting
Marc Wang, Ken Nsiempba, Mihaela Vlasea
University of Waterloo, Canada

Poster 34: Current-controlled Line Energy – Porosity Relation for EBAM of Ti-6Al-4V
Frederik Lindenau*,**,***, Chadwick Sinclair**, Heinz Voggenreiter*,**,***
**University of Stutttgart I ** The University of British Columbia | ***DLR*

THEME 4 - NOVEL AM PROCESSES AND PRODUCTS

Poster 35: Design, Manufacture and Testing of Porous Materials with Ordered and Random Porosity: Application to Porous Medium Burners
Mykhailo Samoilenko, Patrice Seers, Patrick Terriault, Vladimir Brailovski
ETS Montreal, Canada

Poster 36: Patient-specific Endoprostheses for Limb Sparing in Dogs: Design, Manufacturing, in Vitro Study and Clinical Trial
Anatolie Timercan*, Bernard Seguin**, Yvan Petit*, Bertrand Lussier***, Vladimir Brailovski*
**ETS Montreal, Canada | **Colorado State University, Colorado | ***Universite de Montreal*

Poster 37: Predicting Defects in 3D Printed Lattice Structures
Ken Nsiempba, Ehsan Toyserkani
University of Waterloo, Canada

Poster 38: Magnetic Levitation and Suspension Systems for Additive Manufacturing Techniques
Parichit Kumar, Behrad Khamesee, Ehsan Toyserkani
University of Waterloo, Canada

Poster 39: An Analytical Model for Interaction of Laser Beam and Powder Stream in a Coaxial Nozzle for Directed Energy Deposition
Mohammad Ansari, Yuze Huang, Alexander Martinez-Marchese, Ehsan Toyserkani
University of Waterloo, Canada

Poster 40: Processing Conditions of 17-4 PH using Plasma Transfer Arc Additive Manufacturing
Sandy El Moghazi*, Hani Henein*, Tonya Wolfe**, Leijun Li*
**University of Alberta, Canada | **InnoTech Alberta, Canada*

Poster 41: Nanoindentation Studies of Dual-phase Ti-6Al-2Zr-1Mo-1V Alloys Made by Additive Manufacturing
Zhiying Liu, Yu Zou
University of Toronto, Canada

Poster 42: Dip Coating of Tool Steel H13 with TiC-Ni3Al Cermet Suspensions, and Their Subsequent Laser Cladding
Zhila Russell, Kevin Plucknett
Dalhousie University, Canada

Poster 43: Geometrical Accuracy of NiTi Shape Memory Parts Produced by Laser Powder Bed Fusion
Saeed Khademzadeh, Paolo Bariani, Simone Carmignato
University of Padova, Italy

Poster 44: Porous Scaffolds Based on Triply Periodic Minimal Surface (TPMS) Manufactured by Different Additive Manufacturing Methods
Xin Zhang*, Rizhi Wang*, Dawei Wang**
**The University of British Columbia, Canada | **Southern University of Science and Technology, China*

Abstracts

Keynotes

June 26 | 8:40am | Great Hall South

Metals for Additive Manufacturing

David Bourell
Temple Foundation Professor, Director of Laboratory for Freeform Fabrication, The University of Texas at Austin

Abstract: Metal Additive Manufacturing (AM) has garnered significant attention in the research community over the last ten years or so, although the first direct metal part was made using a modern AM fabricator over 25 years ago. This presentation covers the development of metal additive manufacturing and provides a snapshot of the current state of the art in terms of process development and part service properties. Lessons learned from recent research at The University of Texas at Austin will be presented on the use of elemental powder feedstock in AM in an attempt to create crack-free aluminum-based parts using difficult-to-process alloy systems (i.e., AISI 6061 Al).

June 26 | 10:40am | Great Hall South

Innovative Aerospace and Space Structures made by Additive Manufacturing

Christoph Leyens
Managing Director, Fraunhofer Institute of Materials and Beam Technology, Germany

Abstract: Additive manufacturing of metals is currently paving its way into industrial applications at high pace. While in medical applications there is already a widespread use of AM for customized solutions, the strongest innovation boost in AM is coming from aviation industry, followed by the energy sector, automotive industry, space and toolmaking industry. The focus of this keynote lecture is on aerospace and space applications that have recently attracted major attention, some of the already being in series production.

Using powder bed-based and nozzle-based (wire and powder) AM processes a large variety of customized solutions is feasible, ranging from micrometer-size parts with filigree features to the meter scale of large-size components. With regards to the processing requirements either high accuracy or high productivity can be achieved, whereas a combination is difficult. Among others, examples of industrialized solutions of micro-AM structures for aeroengine use will be given as well as a demonstrator component for space applications with a total diameter of 3 meters.

The presentation will highlight recent developments in AM related to different processes, metal alloys and part sizes/geometries. Unlike any other manufacturing technology, AM of high quality parts requires an in-depth understanding of the close relationship between the AM process, the material and the resulting component properties. As a matter of fact, customized hardware, online diagnostics and control systems are required for robust processing of AM parts. Moreover, the effects of defects on part quality must be studied in detail. Some of the results presented are derived from a 80 Mio. Euro research project on AM, initiated and coordinated by the presenting author.

June 26 | 2:00pm | Great Hall South

Mastering AM Freedom

Hannes Gostner
Director Research and Development, EOS, Germany

Abstract: Laser based Additive Manufacturing provides an immense number of degrees of freedom. So far, however, these have hardly been utilized. Current AM technology merely aims at reproducing properties that have been achieved in Casting or Forging decades ago. With the combination of process observation, modelling and data analysis, we can now start to tap into the vast potential of AM: Automated process control, targeted property manipulation, and novel material properties. It is the beginning of truly digitized manufacturing that will change the way we design and build things.

June 27 | 8:30am | Great Hall South

Additive Manufacturing Landscape in Australia

Milan Brandt
Director Centre for Additive Manufacturing, Advanced Manufacturing Precint, RMIT University, Australia

Abstract: Additive manufacture also referred to as 3D printing is now playing a major role in a range of industries globally such as the aerospace, automotive and medical because it enhances the ability to fabricate more complex and more functional component parts. It utilizes technologies both metal and polymer to mass manufacture components directly from computer generated data. The products are grown/printed layer by layer without the need for many time consuming manufacturing processes such as tooling, line set up or material change over. Fully functional parts or products are able to be produced, on an as needed basis, with many different components able to be built at the same time dramatically accelerating product's time to market and reducing the cost of production.

Manufacturing industries in Australia face a number of significant challenges, including global economic uncertainty through trade wars, increasing global competition and cost of labour. It is critical that Australia's manufacturing is positioned to address these challenges through enhanced skills and technology. Australian companies over the last five years have invested in additive technology and universities and government labs are supporting this investment through R&D activities.

The presentation will cover Australian additive manufacturing landscape and some of the local R&D activities taking place with a particular focus on research projects undertaken at the RMIT Centre for Additive Manufacturing.

June 27 | 1:10pm | Great Hall South

Industrialization of Additive Manufacturing: A Journey from Fundamental Research to Production

Ali Bonakdar
Advanced Manufacturing Technology Lead, Siemens Canada

Abstract: Challenges and opportunities regarding the additive manufacturing technology acquisition for industrial applications are presented. Production challenges are highlighted in order to address the gaps required to be filled by the establishment of strategic research programs. Then, an overview of the research activities and opportunities at Siemens is presented. Additionally, Siemens capabilities in metallic additive manufacturing are introduced for the purpose of potential collaborations with the Canadian industries, governmental entities and universities.

Oral Presentations

Session 1: Advances in Additive Manufacturing I
June 26 | 9:20am – 10:20am | Great Hall South

9:20am

Presentation 1: Business Case for Additive Manufacturing in Serial Production

Alexander Boehm
KSB, Germany

Abstract: The presentation will review how industry can adopt metal additive manufacturing into their manufacturing strategies as a complement to traditional manufacturing. The benefits of additive manufacturing are increasingly well understood in many industries. However there is so much R&D underway and to be pursued which continually improve the benefits. This presents both opportunities and challenges, since the speed of evolution of the technology make it more difficult for companies to decide when and how to proceed. This presentation will review several KSB case studies for additively produced parts, including a review of a 2-year field trial of a pump impeller. The presentation will also review why a materials science and engineering focus is important for achieving the industrial benefits expected from additive manufacturing and the importance of new testing and quality control processes for end users to accept additively produced parts into their operations.

9:40am

Presentation 2: Low Cost, Medium-Speed Stereovision for Spatter Tracking in Powder Bed Fusion

Eric MacDonald
Youngstown State University, United States

Abstract: Powder Bed Fusion Additive Manufacturing affords new design freedoms for metallic structures with complex geometries in high performance materials. The aerospace industry has identified the inherent benefits of AM not just in terms of shape creation but also with regard to producing replacement parts for an aging fleet of aircraft. However, for these parts to be deployed in flight-critical applications, the quality must be well established given the lack of flight heritage for the manufacturing process. As additive manufacturing is executed layerwise, opportunities exist to non-destructively verify the fabrication in situ with a qualify-as-you-go methodology. In this study, a pair of low cost, medium spped cameras are integrated and synchronized together to provide stereovision in order to identify the size, speed, direction and age of spatter ejected from the laser melt pool. The driving hypothesis of the effort is that the measured behavior of spatter can be reliably captured in order to determine the health of the laser process and ensure that spatter is not contaminating the build or obscuring the laser. Opportunities, future work and challenges are discussed.

10:00am

Presentation 3: Efficient Parameter Development Strategy of Tool Steel Materials for Laser Additive Manufacturing

Gregor Graf*, Manuela Leoni**, Tobias Muller, Jorg Fischer-Buhner, Daniel Beckers*, Sven Donisi*, Frederik Zanger**, Volker Schulze**
**Rosswag GmbH, Germany | **Karlsruhe Institute of Technology, Germany*

Abstract:

The requirements regarding the materials in use are steadily increasing in the AM market. As part of a GER-CAN research project (HiPTSLAM), the development of high-performance tool steels for AM is a promising topic regarding the acceptance of LBM technology for functional optimized die, forming and cutting tools. Therefore, a new, holistic development process to efficiently qualify new materials is introduced and its advantages are shown based on a case study with a well-known tool steel. In the case study, effects of defined metal powder particle size fractions are evaluated in combination with the LBM parameters on the material properties. Based on initial microstructure analysis, promising sets of parameters were used to build samples for mechanical characterization and machining investigations. During the machining tests, process characteristics like cutting forces were measured and afterwards discussed in terms of the mechanical properties. Furthermore, a small amount of metal powder with a modified chemical composition is produced via gas atomization and used to build specimens for benchmarking the previous results. By means of further investigations of the process interfaces, it will be possible to optimize the interaction of the whole AM process chain.

Session 2: Advances in Additive Manufacturing II
June 26 | 11:20am – 12:20pm | Great Hall South

11:20am

Presentation 4: Optimisation of Process Parameters for In-Situ Alloyed Titanium by Selective Laser Melting

Igor Yadroitsev*, Ina Yadroitsev*, Pavel Krakhmalev**, Anton du Plessis***, Eric Newby*, Dean Kouprianoff*
**Central University of Technology, South Africa | **Karlstud University, Sweden | ***Stellenbosch University, South Africa*

Abstract: The formation of in-situ alloyed grade 23 Ti alloy (Ti6Al4V ELI) with Cu by laser powder bed fusion for application in medical implants was investigated. Ti6Al4V (ELI) powder was mixed with pure Cu powder of similar particle size distribution (–45 μm) and processed with EOSINT M 280. Morphology and geometrical characteristics of single tracks were studied at 170 W and 340 W laser power and powder layer thickness of 50 μm. First layers were sintered at similar process parameters and powder layer thickness. Keyhole mode, balling effect and continuous tracks with penetration into the substrate were identified. Surface roughness and 3D reconstruction of single layers were analysed. Optimal process parameters were found for in-situ alloying of Ti6Al4V-3 at.%Cu to form 99.9% dense samples. Analysis of porosity was done by microCT scans. Relations between homogeneity, microstructure and process parameters were studied by scanning electron microscope and X-ray diffraction was used for phase identification.

11:40am

Presentation 5: Novel Repair Strategy using Additive Manufacturing to Address Severe Foreign Object Damage on Ti Alloy Fan Blades

Priti Wanjara*, Javad Gholipour*, Kosuke Watanabe**, Koji Nezaki**
**National Research Council of Canada-Montreal | **IHI Corporation, Japan*

Abstract: During takeoff and landing of gas turbine aero-engines at high speeds, the ingestion of birds and debris comprised of small hard particles – such as sand, pebbles, metal shards – can give rise to foreign-object impact and damage on the leading edge of rotating airfoils, especially of the fan and compressor. Depending on the severity of the impact, the ensuing damage on the blades can result in localized dents (micro to macro plastic deformation), stress-raising notches, premature crack initiation, material loss, or even immediate fracture. To prevent catastrophic failure, aero-engine programs have developed detailed inspection, maintenance and repair procedures to detect and refurbish or replace damaged blades. A commonly applied repair scheme to refurbish extensively eroded first stage titanium alloy fan blades involves preparing a repair patch – by stamping, rolling or forging – followed by welding and machining. With the advent of additive manufacturing, foreign-object damage on metallic blades can be restored more cost-effectively. In this presentation, the application of wire-fed electron beam additive manufacturing of Ti6Al4V to build up a new section on a thin airfoil shape will be discussed through examination of the build-integrity, microstructure, residual stresses, airfoil distortion, as well as static and dynamic properties.

12:00pm

Presentation 6: Development of Metal Slurry Three-Dimensional Printing System Based on Maskless Projection Method

Cho-Pei Jiang*, Shinn-Liang Chang**
**National Taipei University of Technology, Taiwan | **National Formosa University, Taiwan*

Abstract: Digital light processing (DLP) is a good projection tool as light engine for photopolymerisation three-dimensional printer (3DP). It can be used to make resin objects and ceramic parts. However, few reports can be found in making metal parts. This study aims to synthesize a metal slurry with good suspension ability and low viscosity to be used in DLP-type 3DP. The slurry consists of trimethylolpropane triacrylate (TMPTA), photo-initiator and micro-scale powder of Inconel 719 alloy. Experimental results show that viscosity of initial slurry is 5820 mPa•s and decreases to 1930 mPa•s after ball mill treatment for 48 hours with 500 RPM. The maximal curable thickness of slurry is about 25 μm. A 10 mm cubic with uniform pore size of 200 μm is obtained to prove the printing capacity. Further experiment is to optimize the sintering treatment on low distortion and high strength of sintered parts.

Session 3: Material Development I
June 26 | 2:40pm – 4:00pm | Great Hall South

2:40pm

Presentation 7: Effect of Powder Attributes on Microstructure and Mechanical Properties of 3D-Printed Al10SiMg Alloy using Laser Powder Bed Fusion Technique

Vahid Fallah, Qingshan Dong, Mark Gallermeault
Queen's University, Canada

Abstract: High-Si Al-Si alloys (e.g. 7-12 wt.% Si) are attractive choices for weight-saving metal 3D printing applications. While being light-weight, these alloys exhibit relatively high mechanical properties in the as-deposited (or the as-cast) state. This is mainly owing to a high degree of microstructural refinement that can be achieved in these alloys under high solidification cooling rates. Laser Powder Bed Fusion (LPBF) of Al10SiMg alloy has been rigorously studied in the past few years with a focus on process optimization for higher mechanical properties in the builds. However, not much attention has been given to the effect of powder attributes such as size distribution, particle morphology, uniformity of chemical composition among particles, oxide content and surface quality. Realizing the complexities of solidification and phase evolution in Al alloys in general, we choose two widely different batches of Al10SiMg powders to study the effect of powder attributes on: (1) optimum process variables, i.e. as represented by volumetric energy density, (2) qualitative and quantitative evolution of microstructural features that determine strength and ductility such as nano precipitates, eutectic lamellae and oxide particles/scales, and (3) builds' mechanical properties such as microhardness, tensile strength, ductility (percent elongation) and fracture toughness.

3:00pm

Presentation 8: Development of Modified A8 and S7 Tool Steel Powders for Additive Manufacturing by LPB-AM

Denis Mutel, Carl Blais
Universite Laval, Canada

Abstract: A8 tool steel is well known for its high toughness and intermediate wear resistance making it an excellent material for the fabrication of dies. For its part, S7 constitutes a versatile alloy particularly well suited for shock resistance for both cold and hot work. The objective of this project is to develop novel water-atomized formulations of these two alloys to improve their wear resistance and evaluate their potential for the development of high-performance parts by Laser Powder Bed additive manufacturing (LPB-AM). Thermochemical calculations were carried out to identify the effect of chemistry modifications on the type and proportion of carbides expected to form under equilibrium conditions. The results summarized in this study originate from the selection of four compositions, two for each base alloy, manufactured by water atomization. Powder chemistry, morphology and rheological properties were determined. Test coupons were printed in LPB and characterized in terms of their microstructure and tensile properties in the as-printed and heat-treated conditions.

3:20pm

Presentation 9: Studying the Impact of Particle Morphology on Powder Spreading and Laser Powder Bed Fusion Characteristics to Maximize the Process Productivity

Salah Eddin Brika*, Morgan Letenneurm*, Christopher Alex Dion**, Vladimir Brailovski*
**ETS Montreal, Canada | **PyroGenesis Additive, Canada*

Abstract: The laser powder bed fusion process (LPBF) being sensitive to variations in morphology and particle size distribution, yet the link between the powder characteristics and the process performances is still not well established, thus complicating the development, selection and quality control of LPBF feedstock. In this study, three Ti-6Al-4V powder lots, with comparable particle size distributions (d10=25, d50=39 and d90=53μm), were selected to study the impact of particle morphology on the powder bed density and the LPBF process performances. The selected powder lots were produced by two different techniques, namely the plasma and gas atomization, yielding particles with different sphericities and internal pore contents. Following the analysis of shape, size and density (computed tomography) and chemical composition (EDS) of these powder lots, their flowability characteristics have been concurrently evaluated using Hall and Gustavsson flowmeters and an FT4 Freeman powder rheometer. Studying the impact of powder characteristics on the mechanical and geometric properties of LPBF specimens built with different layer thicknesses (30 and 60 μm) and different printing parameters (build rates of 18 and 44 cm^3/h) allowed the selection of a powder lot maximizing the process productivity, while guaranteeing an appropriate combination of mechanical and geometric features of printed components.

3:40pm

Presentation 10: Selective Electron Beam Melting of Al-Cu-Mg Alloy: Processability and Characterization

Mohammad Saleh Kenevisi, Feng Lin
Tsinghua University, China

Abstract: Additive manufacturing of meal parts has been widely taken into consideration in different industries such as aerospace, automotive, and high-tech sectors in recent years where high-strength aluminum alloys are of special interest. As the materials and alloys which can be satisfactorily processed by additive manufacturing processes are limited, there is a basic need to develop high-strength aluminum alloys to satisfy the industrial requirements. To date, the most commonly used aluminium alloys for AM are eutectic or near-eutectic alloys, containing Si as the main alloying element. However, fabricating high strength aluminum parts have not yet fully investigated. In this regard, solidification cracking and porosity formation are the main problems which make these alloys very hard to be processed. Compared with the selective laser melting, electron beam selective melting (EBSM) provides high potential for fabrication of aluminum alloys as is not affected by reflectivity of metal powders, along with the advantage of oxidation inhibition in vacuum. In this study, Al2024 parts were fabricated by EBM process and the effect of processing parameters on the internal defects formation was studied. Density measurement and microstructural analysis revealed that full-dense samples with fine and equiaxed grains can be achieved by optimizing the processing parameters. In addition, microhardness results showed an almost uniform change of hardness values within the sample in both horizontal and vertical sections.

Session 4: Advanced Process Modeling I
June 26 | 2:40pm – 4:00pm | Room 2301

2:40pm

Presentation 11: Thermo-Mechanical Numerical Modelling of Selective Laser Melting for Prediction of Residual Stress

Jean-Sebastien Cagnone, Jean-Philippe Marcotte, Marjan Molavi-Zarandi, Florin Ilinca, Kabanemi Kalonji Kabaa
**National Research Council of Canada-Boucherville*

Abstract: Laser Powder Bed Fusion (LPBF) is a powder-bed fusion additive manufacturing (AM) process that can be effectively utilized to manufacture structural components with complex geometries. In LPBF, a part is created directly from the three-dimensional model by selectively melting successive powder layers using a laser beam. Nevertheless, there are still some technical barriers and challenges for the production of metallic parts. Defect-free production of metallic parts using LPBF requires a comprehensive knowledge about the effect of the main processing parameters such as laser energy input and beam speed as well as powder properties and build conditions on the printed components. Development of a numerical model to accurately predict the induced residual stresses and distortion during the LPBF process would drastically reduce the expensive experimental costs associated with the number of tests, cut-ups, as well as manufacturing iterations required for the development of additive manufactured parts. In this study, a high fidelity finite element (FE) model has been developed to numerically simulate the LPBF process in order to predict the induced residual stresses and distortions. A novel multiscale modelling approach has been developed for three dimensional (3D) layer-by-layer simulation of LPBF. First, a microscale FE model has been introduced to predict the melt pool size and temperature profiles. Subsequently, a 3D thermo-elasto-viscoplastic macroscale model has been developed to determine the induced residual stresses and distortions. An extensive experimental investigation has also been conducted to support and validate the developed FE models.

3:00pm

Presentation 12: Topology Optimization of Support Structures for Laser Powder-Bed Fusion Based on the Inherent Strain Method

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

Abstract: Laser Powder-Bed Fusion (LPBF) is one of the most important additive manufacturing techniques, in which geometrically complex parts can be made by selectively melting layers of powder. Well-defined support structures are critical in this process because they should bear not only the gravity of the overhang area but also residual stress caused by the high thermal loading. Topology optimization, a powerful technique to find high-performance structures, has been employed in the support structure design of additive manufacturing. However, there is still a gap that residual stress is not considered in the support design, especially for LPBF. Without considering the residual stress, the support may not be strong enough to clamp the part on the substrate during the LPBF process. In this work, an innovative topology optimization model has been proposed that the residual stress within the printed part is incorporated in the topology optimization mathematical equations based on the inherent strain method. The resulting support structures have been 3D printed and compared with the default support structure from the machine manufacturer, showing the strength of the proposed model.

3:20pm

Presentation 13: A Fast and Part-level Numerical Simulation of Temperature Field in Selective Laser Melting Process

Zhibo Luo, Fiona Zhao
McGill University, Canada

Abstract: In selective laser melt process an accurate prediction of the transient temperature field of a build part is essential to calculate the thermal stress evolution

and microstructure propagation among a part. Since the temperature field is controlled by many process variables, experimental method is time consuming and expensive. Numerical heat transfer model can be used to estimate the temperature field at any time points. However, traditional numerical simulation scheme is not suitable for this layer-wised fabrication process due to the extremely high computational cost. This research put forward a new and efficient simulation scheme which can adaptively refine and coarsen the mesh and solve the nonlinear system with multiple processors in a parallel way. A new mesh strategy that aims to reduce the element number while keep the solution accuracy is developed. The simulation time is 5~20 faster compared with the traditional simulation scheme depending on the scale of the part and processor number. The simulation results are compared with experiment results. It is shown that each point in the simulation experiences the same thermal cycles of the same point in the experiment. This simulation scheme can also be used to optimize the process parameters like the scan pattern, scan velocity, and layer thickness and can be easily extended to other additive manufacturing process.

3:40pm

Presentation 14: Fast-to-Run Predictive Model for Thermal Fields During Additive Manufacturing

Meet Upadhyay, Daan Maijer, Steve Cockcroft
The University of British Columbia, Canada

Abstract: AM simulations for thermal fields are computationally expensive because of the highly disparate length and time scales involved and can sometimes take days to run. Improving the speed of these simulations enables multiple virtual experiments to be run to understand the effects of various process parameters on heat buildup and can even be useful for in situ process control based on sensor measurements from the build area. The goal of this work is to reduce the computational time of such simulations while maintaining sufficient physics fidelity to yield reliable results. Our approach is to replace the FEM model with a Fast-to-run (FTR) model which exploits the cyclic nature of the process to predict the thermal fields during AM. In this approach, peak temperatures and melt pools dimensions in a substrate melted by a moving heat source are modelled. The dependence of the heat transfer patterns on the heat source location and characteristics and the initial conditions of the substrate is modelled using data from the FEM simulation. Simulation time using the FTR model has been reduced by a factor of 30 compared to the FEM simulation. The model will be able to perform multi-layer simulations in the future for macroscale predictions.

Session 5: Process Monitoring and Control I
June 26 | 4:20pm – 5:40pm | Room 2301

4:20pm

Presentation 15: In-line Melt Pool Monitoring of Laser Powder-Bed Fusion

Katayoon Taherkhani*, Zheng Ma*, Esmat Sheydaeian*, Ali Ghodsi*, Martin Otto**, Christopher Eischer**, Ehsan Toyserkani*
**University of Waterloo, Canada | **EOS, Germany*

Abstract: Additive manufacturing (AM) is changing the entire manufacturing enterprise by offering unique features for the manufacture of complex-shapes with superior mechanical properties. In the last decade, through an exponential advancement, AM has been promoted from a prototyping to a series and mass production platform. Like all conventional technique, quality assurance procedures/tools are of the utmost importance to aid manufacturers in the quality management and certification. To this end, in-line melt pool monitoring devices, installed in laser-based AM systems, provide vital real-time information about the process characteristics that implicitly or explicitly leads towards understanding the quality of printed parts. The aim of this research is to investigate the feasibility of applying in-situ monitoring for laser powder bed fusion (LPBF) to detect disturbances in the melt pool and correlate them with the physical defects created in the parts. To this end, a set of experiments is devised to examine the role of process parameters as well as intentional defects on the melt pool characteristics such as instability in the emitted light. The variations were recorded by means of deploying a commercially avalaible monitoring system installed in the EOS-M290 (EOS, Germany). The setup includes two photodiodes (on-axis and off-axis) to measure the light intensity reflected from the melt pool. After completion of the printing process, the quality of samples is investigated by a micro computational tomography (μ CT) scanning setup to identify the size and spatial distribution of the defects (pores) formed during the process. In the next step, different methods of intelligent data processing are deployed to derive correlations between the collected data from the in-line monitoring system and μ CT scanner.

4:40pm

Presentation 16: Modelling and Identification of Electron Beam Deflection System

Scott Parks, Zekai Murat Kilic, Yusuf Altintas
The University of British Columbia, Canada

Abstract: Electron beam melting (EBM) is an emerging additive manufacturing technology for producing lightweight parts made up of difficult-to-cut materials. During the EBM process, the electron beam traverses each built layer by means of an electromagnetic beam deflection system with two-aligned pairs of air-cored coils. Currently, the precision of beam deflection systems relies on frequent time-consuming calibrations. In this study, we propose a model-based prediction of the beam position during the EBM process. Our aim is to eliminate the need for calibration while increasing geometric precision. At first, each pair of coils is modelled using equivalent lumped circuit elements with an additional constant gain to predict the magnetic flux density applied on the electron beam. Then, the parameters are identified by a custom designed experiment setup. Finally, beam position on the build plate is predicted from the Lorentz force applied by the magnetic field. This predictive model will form the basis of our studies of 1) error compensation controllers to increase the precision in beam position, 2) beam trajectory optimization, and 3) merging beam position control with melt pool dynamics model that is currently developed by partners in HI-AM network.

5:00pm

Presentation 17: Cost Effective Real-Time Thermal Dynamics Modeling in Laser Materials Processing

Lucas Botelho, Amir Khajepour
University of Waterloo, Canada

Abstract: In this research, a cost effective measurement system is discussed to model the thermal dynamics of Laser Materials Processing (LMP). A critical output of LMP is the material's microstructure, which can be controlled directly by controlling a set of correlated thermal dynamics in real time. Currently, thermal dynamics of the process such as the cooling rate, melt pool temperature, and heating rate near the laser point are recorded directly in real-time by a thermal imaging system. Due to the relatively high cost of a thermal camera, a new monitoring system using a CCD camera and pyrometers is implemented to create a more cost effective solution. An adaptive discrete model will use a CCD camera to capture intensity measurements around the laser and pyrometers to record the temperature of a few points in the region of interest for real time calibration. The model will use this data to estimate the temperature distribution induced by the laser heat source. The temperature distribution can then be used to estimate other thermal dynamics such as the cooling rate, melt pool temperature, and heating rate in real time. Later, this model can be implemented with a control system to create a reliable controller for LMP.

5:20pm

Presentation 18: In-situ Sensing and Measurement for Quality Control in Metal Additive Manufacturing: Review and Future Directions

Thomas Lehmann*, Tonya Wolfe**, Hani Henein*, Ahmed Qureshi*
**University of Alberta, Canada | **InnoTech Alberta, Canada*

Abstract: Metal additive manufacturing (AM) is a novel manufacturing technology where parts are fabricated layer by layer, which allows for products to be designed and manufactured in a free-form manner. AM has therefore gained substantial interest in the manufacturing sector in the past years. Currently, the manufacturing industry's interest in AM is, however, restrained due to significant limitations in in-situ quality assurance and control. Specific areas that negatively impact the quality of an AM product are accuracy (deformation caused by shrinkage), internal porosity, and variations in microstructure and material composition, which lead to inconsistent and insufficient mechanical properties. In order to control the quality of the part in the above-mentioned areas, reliable in-situ sensing, process monitoring, and inspection is a necessary requirement. In recent years, various sensing technologies have been proposed for measuring of features such as layer geometry, melt pool temperature and geometry, solidification and cooling rate. This paper presents the state of the art in sensing and in-situ measurement technology developed to date for metal AM and identifies still existent shortcomings and need for improvement particularly in the context of generalizing and augmenting the currently available technologies.

Session 6: Novel AM Processes and Products I
June 26 | 4:20pm – 5:40pm | Great Hall South

4:20pm

Presentation 19: Machine Learning Aided Optimization of Conformal Cooling Channel

Zhenyang Gao, Fiona Zhao
McGill University, Canada

Abstract: The plastic injection molding process is commonly used to fabricate parts with various geometry. During a production cycle of an injection molding process, the cooling takes the largest portion of the cycle time. The design of conformal cooling channel is the prominent method to reduce part cooling time with reduced surface temperature variance. Nevertheless, with conventional mould manufacturing process, true conformal cooling channel is very difficult to achieve resulting in the warpage of part surface and low part quality. Additive Manufacturing (AM) technology allows designers to design very complex channels with very little manufacturing constraints. In this research, a supervised machine learning algorithm is applied to derive an accurate mathematical model to predict the part surface temperature with respect to the part geometry and different parameters of various cooling channel topologies. With this model, an optimization method is proposed to create a cooling channel that is conformal to not only the part surface, but also the distribution of part thickness. Comparing to conventional conformal cooling design, lower temperature variance is achieved using the optimization method in this work. In addition, the cooling time can be further decreased by increasing the Reynold number of the coolant because the significant reduction of temperature variance.

4:40pm

Presentation 20: Hybrid Additive Manufacturing and Casting Processes for Non Ferrous Alloys

Axelle Sabouraud, Artitra Biswas, Abdoul-Aziz Bogno, Hani Henein, Ahmed Qureshi
University of Alberta, Canada

Abstract: In recent years, 3D printing has become an excellent alternative to casting, especially for making complex shape components that are traditionally, manufactured by investment casting. However, 3D printing, despite covering a wide range of metals and alloys is very costly for complex shapes manufacturing, and the surface finish of the printed part does not always meet the quality specifications. In this work, a novel manufacturing process, termed the hybrid investment casting, is proposed. It combines the traditional investment casting with Stereolithography (SLA) 3D printing. The process consists in creating a 3D model of the part to be manufactured, by selectively curing a polymer resin layer-by-layer using an ultraviolet (UV) laser beam. The model is then used as a pattern for the investment casting of the part. The development of the process, applied to make Al-based lattice structures, will be presented. The process parameters, their control and effects on mechanical and metallurgical properties of the final casting will be discussed.

5:00pm

Presentation 21: Mechanical and Functional Performance of Porous Bone Replacement Implants

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

Abstract: Recent advances in metallic additive processes have provided an exciting opportunity for designing customized orthopaedic implants that are porous. Their realization, however, typically incorporates material heterogeneity and geometric defects that can jeopardize their functional performance. In this work, we use a combined approach of imaging tests, mechanical experiments and computational mechanics to characterize the anisotropy of the base materials as well as the statistical distribution of a set of material and geometric attributes defining the porous architecture of the implant. Our goal is to assess the potential performance drop that the selected array of defects might have on the bone ingrowth response when such a porous material makes up the body of a bone replacement implant.

5:20pm

Presentation 22: Surface Finishing of Titanium and Nickel-Based Laser Powder Bed-Fused Components: Abrasive Flow Machining Versus Electrochemical Polishing

Neda Mohammadian*, Victor Urlea*, Clement Bouland*, Sylvain Turenne**, Vladimir Brailovski*
**ETS Montreal, Canada | **Ecole Polytechnique de Montreal, Canada*

Abstract: Almost all 3-D printed metal components require surface finishing to meet performance standards. This work focuses on two techniques for surface finishing of internal passageways of 3D-printed components: Abrasive flow Machining (AFM) and Electropolishing (EP). AFM allows polishing components with intricate geometries with no surface chemistry alteration, but this process is limited to relatively large channels due to high viscosity of the media used. EP is a good candidate for polishing small and medium size tubular components, producing scratch-free surfaces. However, EP presents challenges in designing electrodes, polishing multi-phase alloys and removal of rough surface defects. In this project, comparative experimental study has been carried out on test coupons printed with build orientations ranging from 0 to 135 deg from Ti-6Al-4V and IN625 powder feedstock. The corresponding polishing allowances have been determined by measuring the material removal on differently-oriented surfaces after the AFM and EP operations. It was shown for example that to reach a uniform roughness of Ra < 6.3 um on Ti-6Al-4V components with variably-oriented surfaces, the EP allowances need to be twice as high as the corresponding AFM allowances (EP=330 v AFM=150 mm). For IN625 components however, the same result can be reached with the EP allowances four times as high as the AFM allowances (EP=240 v AFM=60 mm).

Session 7: Material Development II
June 27 | 9:10am – 10:30am | Room 2301

9:10am

Presentation 23: Fabrication of Rene 41 Parts with Laser Powder Bed Fusion

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

Abstract: Fabrication of Ni-based superalloy by laser powder bed fusion (LPBF) is drawing attention due to design flexibility, cost and time reduction it offers. Although it has been widely studied, number of alloys that can be produced by LPBF is limited due to cracking phenomenon observed in Ni-based superalloys. Fabrication of parts that meet the engineering standards requires meticulous control over process parameters and composition of the alloy. Rene 41 is a precipitation hardenable alloy that is widely used in the hot section parts of the jet aircraft engines due to its superior creep and corrosion resistance. Due to its composition, hence the γ′ content, Rene 41 is considered as a fairly weldable alloy. In this study Rene 41 parts were fabricated, and their density was assessed by optical microscopy. Size, morphology and texture of the solidification structure were investigated both in the as printed and precipitation hardened condition. Mechanical properties in both conditions is also studied by microhardness measurement and tensile testing.

9:30am

Presentation 24: Particle Decoration: A Method for Developing New Material for Additive Manufacturing

Ehsan Marzbanrad, Yahya Mahmoodkhani, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Recent developments in additive manufacturing have heightened the need for tailoring the properties of different materials to fulfill the requirements of 3D printing technologies. This material modifications might address a wide range of deficiencies or demands such as new material development, enhancing the printability, and eliminating the printing defects. Some of these problems may resolved by adding only few percent of alloying elements to the main powder, which is used for printing technologies that employ powder bed or powder fed systems. In this case, loading the additive on the surface of the particles of main powder seems to be a feasible and versatile method. This method, which may be called particle decoration, might provide a uniform distribution of the additive material. However, it has limitations. In this paper, particle decoration has been targeted from theoretical point of view. The loading capacity of the system versus the particles size and density was evaluated different model systems. Results of this research provides a guide line for particle decoration design and introduce the limitations of this method.

9:50am

Presentation 25: Electrostatic Atomisation of Metals

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

Abstract: With the increased demand for metal powders especially in the additive manufacturing industry there is a need to find new, reliable, economical and efficient methods for producing metal powders with consistent mechanical, chemical and physical properties. Due to the relatively small powder size produced by gas and water atomization, they have been widely used for providing powders for additive manufacturing. However, these powders have many limitations such as the high energy required for atomization, the size and shape distribution of powders often with satellites are produced, and the high cost of inert gas required for atomization. This has led us to explore electrostatic atomisation which, from preliminary studies has shown itself to be more efficient as compared to other techniques. Drawing from the electrohydrodynamic spraying principles and techniques, electrostatic atomisation is based on two main phenomena, the Rayleigh maximum droplet charge distribution, and the generation of Taylor cone shape when electro spraying. Using these principles preliminary calculations have shown that the electrostatic atomisation technique could be the answer to the current limitations and constraints in metal powder production.

10:10am

Presentation 26: Implementation of the Kitagawa-Takahashi Approach for Prediction of Fatigue Limit of Inconel 625 Components Containing Intentionally-Seeded Defects

Jean-Rene Poulin, Patrick Terriault, Vladimir Brailovski
ETS Montreal, Canada

Abstract: Fatigue properties of AM-built materials have been shown to be lower than those of their wrought counterparts despite similar quasi-static mechanical properties. This debit in fatigue life is generally associated with a rougher surface finish, as well as the presence of internal defects in AM components. While many post-processing techniques are available to improve the surface finish, internal defects pose many challenges for inspection and fatigue life assessment. Among the LPBF processing-induced flaws, lack of fusion defects appear to be the most detrimental for fatigue life. Hypothesizing that these defects can be treated as cracks, we propose to evaluate the fatigue resistance of Inconel 625 components using the damage tolerance approach. To this end, the threshold stress intensity factors (ΔK_{th}) for room-temperature and R=0.1 stress-ratio conditions have been combined with the fatigue limit ($\Delta\sigma_f$) data to build a Kitagawa-Takahashi diagram for Inconel 625. Next, fatigue specimens with intentionally-seeded lack of fusion defects were fabricated by varying the laser exposure parameters in their gauge section. Finally, force-controlled fatigue testing of flawed specimens (ASTM E-466) has then been performed at the predicted fatigue limit to evaluate the survival rate and assess the damage tolerance approach validity.

Session 8: Advanced Process Modeling, Monitoring, and Control
June 27 | 9:10am – 10:30am | Great Hall South

9:10am

Presentation 27: Geometric Deviations of Laser Powder Bed Fused Alsi10mg Components: Numerical Predictions Versus Experimental Measurements

Floriane Zongo*, Charles Simoneau**, Anatolie Timercan*, Antonie Tahan*, Vladimir Brailovski*
**ETS Montreal, Canada | **SimuTech Group, Canada*

Abstract: Laser Powder Bed Fusion (LPBF) is one of the most potent Additive manufacturing (AM) processes. One of the constraints for larger industrial use is a limited knowledge of its dimensional performances and geometrical behavior, and inability to predict them as function of material, process parameters, part size and geometry. The objective of this study is the improvement of the knowledge of the geometrical and dimensional tolerancing (GD&T) performance of the LPBF process and evaluation of the distortion predictive capabilities of the ANSYS Additive Print (AP) tool. To this end, strategically designed parts were manufactured on a 250 × 250 mm build plate using an EOSINT M280 printer and AlSi10Mg powder. These parts have been scanned by means of a Metris LC50 laser scan mounted on a Mitutoyo Coordinate Measuring Machine (CMM) (~7 µm accuracy at 95% level). The dimension and geometry deviations calculations have been carried out according to the ASME Y14.5 (2009) standard and resulted in the definition of the capability range of ~ 250 µm. The same STL files used to print the parts were downloaded into ANSYS Additive Print software to calculate distortions caused by the process. The fidelity of the numerical prediction is presented and discussed.

9:30am

Presentation 28: Melt Pool Geometry Modeling and Monitoring via In-Situ Vision System for Powder Fed Laser Fusion Process

Deniz Sera Ertay, Josh van Houtum, Mihaela Vlasea
**University of Waterloo, Canada*

Abstract: Powder fed laser fusion (PFLF) is a metal additive manufacturing process where modelling and monitoring the geometry of the process are necessary to improve the accuracy and repeatability. In this work, an analytical lumped-parameter thermal and geometry models are presented, which predict the complex thermal behaviour and the geometric features of the PFLF process. The melt pool is monitored by a high dynamic range (HDR) camera during the process, which has an advantage of higher pixel depth and preferred in monitoring of the welding processes. Image processing techniques are used to detect the melt pool. The process signatures extracted with the HDR camera are used for the validation of the physics-based models and for the detection of process instability. The detected process instabilities will be used in planning post-processing in the future.The geometry of the solidified deposition is monitored by the camera and a line laser in a triangulation setup. Correspondence between the real world and pixel based coordinates is determined using a calibration object and single view geometry techniques. A response surface model is synthesised mapping the relation between laser power and deposition velocity to deposition height, width and area.

9:50am

Presentation 29: Temperature Fluctuations at Boundary Points in Laser Powder Bed Fusion

Emre Ogeturk, Mary Wells
University of Waterloo, Canada

Abstract: With the increased popularity of quality additively manufactured parts, the need for accurate process measurements has increased. The focus of this paper is in the challenge of accurate temperature measurements at boundary points for laser powder bed fusion. As layers build up on the powder bed, layers beneath experience continual heat fluctuations which can result in thermal stress. Since the powder bed is constantly dropping, conventional forms of temperature measuring will not be able to produce accurate temperature readings. Therefore, in this paper a modified baseplate was constructed which allows for the placement of thermocouples right below surface level. The thermocouples measure the heat at the very lowest layer, producing data as the layers of material continue to build up. The goal of being able to reverse model a simulation that produces accurate data is also considered in the paper. Modelling an accurate simulation allows for better prediction of material reaction to thermal stress at points after melting, resulting in an ability to predict cracks and defects before the part is built.

10:10am

Presentation 30: Design of a Test Artefact to Evaluate Critical Design Features for Ti-6Al-4V Parts In Electron-Beam Melting Additive Manufacturing (EBAM)

Gitanjali Shanbhag, Mihaela Vlasea
University of Waterloo, Canada

Abstract: The present project aims at correlating the properties of the powder layer (intra- and inter- layer powder distribution and uniformity, powder compaction density, powder preferred orientation) with the powder characteristics, for Electron Beam Additive Manufacturing (EBAM) systems. A Ti-6Al-4V test artefact will be designed and manufactured on an Arcam A2X machine. The purpose of this artefact is two-fold. Firstly, it is used to characterize the above mentioned properties of the powder layer. Secondly, it is used to evaluate features such as dimensional/ geometrical accuracy,

minimum feature size, internal channels and structures suitable for biomedical applications. In terms of biomedical applications, constraints should be introduced with the help of artefacts: e.g. constrained angles of fabrication, minimum size of cell (for de-powdering purposes) etc. When not only stiffness properties are concerned, the influence of the orientation of the struts on the microstructure and texture should also be investigated.

Session 9: Advanced Process Modeling II
June 27 | 10:50am – 12:30pm | Great Hall South

10:50am

Presentation 31: Microscale Interaction Between the Laser and Metal Powder in Powder-Bed Additive Manufacturing: Conduction Mode Versus Keyhole Mode

Hongze Wang, Yu Zou
University of Toronto, Canada

Abstract: Metal additive manufacturing (AM) techniques, particularly laser powder-bed methods, have shown tremendous advantages for producing high-value, complex, and customized components. However, precisely controlling the microstructure and defects of the products in the AM process has been a long-standing issue. Here, we have developed a coupled thermal-mechanical-fluid model to reveal the microscale dynamic evolution of metal powders, particularly for Ti-6Al-4V, during laser irradiation. Using different laser powers, layer thicknesses, and hatch spacings, we have systematically compared powder evolutions in two typical processing modes – conduction mode and keyhole mode. We have revealed the heat and mass balance in these two typical printing modes for the first time. There is only one circular flow in the longitudinal section of the molten pool in the conduction model, while two circular flows present in the keyhole mode. Gravity drives the melted metal to fill the gaps between the powders and contributes to the formation of the molten pool. The simulation results demonstrate that a larger printable powder layer thickness is achieved in the keyhole mode than that in the conduction mode. The thermal distribution during the multiple-track melting in the conduction mode is more uniform than that in the keyhole mode, leading to more uniform resulting microstructure. This study presents opportunities to control the microstructure and defects at the microscale of the AM products by modulating processing parameters and switching between conduction and keyhole modes.

11:10am

Presentation 32: A Predictive System for Manufacturability Analysis of Laser Powder Bed Fusion Process

Ying Zhang, Fiona Zhao
McGill University, Canada

Abstract: Laser-based powder bed fusion (LPBF) process is a type of additive manufacturing process which is able to produce complex metal geometries. The fast development of laser-based powder bed fusion process offers new opportunities to the industries. Comparing to the conventional manufacturing process, LPBF offers more freedom on the shape complexity, material complexity, and hierarchical complexity. Even though the LPBF process has many advantages, there are still many constraints on LPBF. At the current stage, LPBF process still has a very high threshold for industrial application. It requires designers to have extensive knowledge of LPBF process to make the design manufacturable. The need for the automatic manufacturability analysis in the early design stage is essential. In this paper, a novel approach on analyzing the manufacturability of LPBF process is introduced. The machine learning model is developed to predict the manufacturability of LPBF. The unique dataset is established as the training examples. The proposed method achieves competitive accuracy on analyzing the manufacturability of LBPF.

11:30am

Presentation 33: Thermal Fluid Modeling for Melt Pool Generation of Ti6Al4V Powder Bed in the Electron Beam Additive Manufacturing

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

Abstract: The generation and behavior of melt pool during any Additive Manufacturing (AM) process affect pore formation, temperature history and grain size. These factors influence the mechanical properties of the final built parts. In the current research, a quantitative experimental and numerical analysis was conducted during a powder-bed electron beam additive manufacturing (EBAM) process, focusing on the effect of electron beam parameters, i.e. acceleration voltage, current, scan speed and scan path. For scan path evaluation, single scan path patterns, namely contouring and hatching, were investigated. Melt pool geometry (width, depth and build up height) measurements were conducted on metallography samples and compared with melt pool shape obtained from the numerical analysis. The numerical analysis includes the development of a meso-scale thermal fluid model to describe melt pool generation using Flow-3DTM which is a Finite Volume based code. The model includes solid-liquid phase change, buoyancy, temperature dependent surface tension (Marangoni effect) and recoil pressure. The results indicate that beam penetration depth affects the depth of the melt pool. Moreover, the model shows that the surface of the melt pool is influenced by geometry of powder bed, therefore, affects melt pool generation.

11:50am

Presentation 34: Normative Benchmark Design and Preliminary Geometric Quality Results for Selective Laser Melting Process

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

Abstract: Geometric benchmark test artifacts (GBTAs) are used to assess the geometric quality characterization of the metal additive manufacturing processes. However, there are certain limitations in the state-of-the-art GBTAs and the geometric quality characterization methods, such as ignoring the standardized Geometric Dimensioning and Tolerancing (GD&T) characteristics, assembley function of the part, and tri-planer quantification of the geometric capability. To tackle these issues, a feature-based methodology was developed to systematically design the GBTAs. The new methodology is based on selecting features based on the required GD&T characteristics. For example, cylindrical features will be selected to quantify cylindricity and circulity. The methodology also takes into account the directionality of features and provides a systematic method to evaluate and quantify them. The preliminary results from the study, presented in this paper, provide generic GD&T tolerance bands for the process in three orthogonal planes. The article describes the normative GBTA design process in selective laser melting (SLM) manufacturing and the corresponding GD&T results. THe overall tolerrance band for various GD&T characteristics in all three directions was 200 microns with a mean shift of 76 microns. The results show large variations in tolerance bands in each direction and GD&T characteristics. It validates the need of new normative design and the tri-planer characterization as well as needs to develop a comprehensive methodology to incorporate them in design and manufacturing process planning.

12:10pm

Presentation 35: Numerical Analysis of Melt Pool Geometry in Laser Powder-Bed Fusion of Hastelloy X

Shahriar Imani*, Adhitan Rani Kasinathan*, Zhidong Zhang*, Yahya Mahmoodkhani*, Usman Ali*, Ali Keshavarzkermani*, Ehsan Toyserkani*, Ali Bonakdar**
**University of Waterloo, Canada | **Siemens, Canada*

Abstract: Laser powder bed fusion (LPBF) is among the various additive manufacturing (AM) processes, which has dominated the mainstream metal AM manufacturing market. LPBF has the capability to manufacture complex parts which are hindered by conventional methods. In this study, melt pool dimensional features produced in the LPBF process of Hastelloy X material have been studied numerically and experimentally. For this purpose, several single tracks were produced using an EOS M290 with different process parameters. The width and depth of melt pools have been derived numerically using COMSOL Multiphysics® and validated with experimental results. The temperature dependent material properties are implemented in the numerical model. Conical-Gaussian heat source model has been adopted for predicting accurate melt pool dimensions. The effect of the laser processing parameters such as scanning velocity and laser power on the melt pool dimensions have been studied. In addition, temperature gradients and cooling rates in the melt pool surrounding area have been extracted from numerical model to be used toward the microstructure prediction.

Session 10: Novel AM Processes and Products II
June 27 | 10:50am – 12:30pm | Room 2301

10:50am

Presentation 36: Investigating Residual Stress Characteristics for Selected Direct Energy Deposition Process Settings: P420 Steel Single Bead Deposition on Mild Steel

Jill Urbanic*, Navid Nazemi**
**University of Windsor, Canada | **AMG Metal Inc., Canada*

Abstract: Laser cladding or direct energy deposition is being employed as an additive manufacturing solution for metal. Due to the aggressive thermal cycling, the non-equilibrium solidification generates internal residual stresses in the bead, dilution zone, and the heat-affected-zone, introducing potential of a failure, or a reduced fatigue life. This research is an extension of prior physical and virtual simulation analyses, where a 3D transient fully coupled thermal-metallurgical-mechanical numerical model (using SYSWELD) was built to simulate the coaxial powder injection laser cladding process for P420 stainless steel powder onto an AISI 1018 steel plate for selected process settings. Once the model was experimentally validated by Vickers microhardness measurements and X-ray diffraction (XRD) for the residual stress analysis, simulations were performed for a wide range of process settings. Five process parameters are considered such as laser power, powder flow rate etc., and are varied to explore their impact on the residual stress curves, and their maximum and minimum values along the center of a single bead. The residual stress profile to process parameter relationships will be explored and predictive models will be developed, and their results discussed.

11:10am

Presentation 37: Evaluation of Additive Manufacturing for Repair and Remanufacturing Purposes

Fatih Sikan*, Priti Wanjara**, Javad Gholipour**, Mathieu Brochu*
**McGill University, Canada | **National Research Council of Canada-Montrea*

Abstract: Reducing manufacturing and operating costs is a key factor to promote a strong and sustainable aerospace sector. Current repair procedures utilised in the aerospace industry are characterised by long maintenance periods with high machining/material costs emerging from the numerous pre-repair, repair and post-repair steps. In this context, the development of new repair strategies is of utmost importance. Compared to current repair technologies, emerging additive manufacturing (AM) technologies are bringing forward numerous advantages for the production and refurbishment of complex parts that has sparked considerable interest in this field recently. In the present work, AM repair of Ti-6Al-4V alloy was studied with various solidification-based AM platforms such as laser powder bed fusion and electron beam wire deposition, to compare the effects of the solidification environment on repair integrity. Microstructural investigation, texture analysis and selected mechanical properties have been utilised to highlight the relations. Thermal history and phase development at the bonding interface and heat affected zone (HAZ) for the different conditions evaluated will be discussed.

11:30am

Presentation 38: Laser Powder Bed Fusion of AlSi10Mg for Fabrication of an Aluminum Transmission Pump Housing

Lisa Brock, Hamed Asgari, Mihaela Vlasea
University of Waterloo, Canada

Abstract: Additive manufacturing can provide shorter lead times, faster product development cycles, and new design freedoms when compared to traditional manufacturing methods. The feasibility of using laser powder bed fusion for the fabrication of an aluminum transmission pump housing with complex geometry was investigated. Process mapping for the printing of AlSi10Mg on a modulated laser system was completed using a full factorial design of experiment with varying levels for laser power, exposure time, and point distance. Metallographic examination of the melt pool geometry and porosity was performed. Additional test artifacts for the characterization of feature resolution, surface roughness, hardness, density, tensile strength, and corrosion properties were fabricated using the process parameters corresponding with the lowest porosity and preferred microstructure. For comparison, an existing aluminum pump housing manufactured by casting was also characterized in order to determine if laser powder bed fusion can achieve the benchmark values typical for the pump housing application in terms of both geometric tolerances and engineering specifications.

11:50am

Presentation 39: Direct Laser Deposition of Ti–5Al–5V–5Mo–3Cr Alloy

Xinjin Cao*, Alexander Bois-Brochu**, Javad Gholipour*
**National Research Council of Canada | **Centre de metallurgie du Quebec, Canada*

Abstract: Titanium alloys have widely been used in the aerospace industry due to their high specific strength and excellent corrosion resistance. However, for some large scale aircraft, such as Airbus A380 and Boeing 787, there is a demand for even stronger Ti alloys for structural and load bearing applications. Ti–5Al–5V–5Mo–3Cr (Ti-5553) is a relatively new metastable beta-titanium alloy that exhibits excellent strength characteristics, even higher than the currently used alfa-beta titanium grades, such as the workhorse Ti–6Al–4V. Therefore, Ti-5553 alloy has been selected for aerospace applications by some main aircraft manufacturers. To this end, it is important to develop emerging laser additive manufacturing technologies for aerospace components. To date, limited work has been conducted for this alloy. The current work is aimed at investigating the direct laser deposition technique for Ti-5553 alloy by using Optomec LENS-450XL 3D printer equipped with 1 kW continuous wave fiber laser. The laser deposited specimens have been evaluated in terms of defects, microstructures, and tensile properties in as-deposited, aged, and fully heat treated (solution treated and aged) conditions.

12:10pm

Presentation 40: Predicting Defects in 3D Printed Lattice Structures

Ken Nsienpba, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Lattice structures, or cellular materials, have been studied extensively as part of design for additive manufacturing (DfAM). Their usage has been stimulated by the widespread propagation of 3D printing technologies due to the unique characteristics of the manufacturing process. With cost no longer related to complexity, geometrically intricate parts can now be designed. Despite the adoption of lattice structures, a lot of work is needed to accurately predict their manufacturability. Furthermore, simulating lattice structures can reveal itself to be computationally expensive. This paper suggests a succinct method to predict lattice structures manufacturability. The methodology is based on the idea that most ordered cellular materials are comprised of struts and nodes; therefore, quantifying the effects of strut properties (thickness and the angle with respect to the x-y plane) with respect to their dimensional accuracy allows designers to obtain a manufacturability index based on the strut properties. The effects of strut properties on lattice structures are found by modeling the printing process and the predictions are validated through experiments. Finally, the paper presents an artificial intelligence-based algorithm explaining how to take those predictions into consideration while designing lattice structures.

Session 11: Material Development III
June 27 | 1:50pm – 3:50pm | Great Hall South

1:50pm

Presentation 41: Correlating the Columnar Grain Structure with the Anisotropic Mechanical Response of Hastelloy X Produced by Laser Powder-bed Fusion

Ali Keshavarzkermani*, Reza Esmaeilizadeh*, Shahriar Imani*, Hamid Jahed Motlagh*, Norman Zhou*, Ali Bonakdar**, Ehsan Toyserkani*
**University of Waterloo, Canada | **Siemens, Canada*

Abstract: Laser powder bed fusion (LPBF) is a popular additive manufacturing (AM) technique, in which a laser heat source melts metallic powder particles within a build compartment in a layer by layer fashion. Keeping the main heat flow direction along with building direction results to have columnar grains growth during melt pool solidification. As a result, anisotropic mechanical response observed from LPBF parts is due to the particular columnar microstructure obtained after directional solidification. In this study, mechanical response of as-built material in three different perpendicular directions has been investigated. The quasi-static tensile properties of Hastelloy X found to be highly depending on the sample orientation. It has been observed that vertical samples have lower strength than the horizontal samples while horizontal samples do not show in-plane mechanical anisotropy. It worth to mention that no specific crystallographic texture has been observed due to the applied rotation in scan strategy. It is proposed that high grain aspect ratio of columnar grain structure is responsible for the observed anisotropic tensile behaviour.

2:10pm

Presentation 42: Graphene Nanocellulose Composites for 3D Printed Electrodes

Taylor Morrison, Hani Naguib
University of Toronto, Canada

Abstract: As additive manufacturing (AM) becomes increasingly ubiquitous in both research and industrial sectors, it is important to consider sustainability when introducing new AM materials and processes. Nanocellulose is a bio-based, renewable, and abundant material in Canada with unique nanostructures and viscoelastic properties that make it an excellent candidate for the 3D printing of advanced devices. In this study, we have developed graphene nanocellulose composites suitable for the direct ink writing of electrochemical energy storage devices, namely supercapacitors, with optimal structures on both the macro and mesoscale. The shear-thinning behaviour of nanocellulose permits graphene nanoplatelets (GNP) to be 3D printed in the desired electrode configuration, while simultaneously acting as a spacer to prevent GNP agglomeration and specific surface area (SSA) reduction. The result is a conductive, high SSA, porous structure with specific capacitances up to 1.7 F/cm2. Thus, we demonstrate how the control offered by additive manufacturing can be enhanced by the integration of bio-based nanomaterials, someday leading to mobile power supplies that are more physically versatile, energy dense, and sustainable than those currently available.

2:30pm

Presentation 43: Application of Fast Cooling Calorimetry in AM

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

Abstract: The focus of this research is to understand the solidification behavior of various alloys under rapid cooling conditions, as a precursor for alloy development. Various aspects are studied including the addition of minor L12 precipitating elements, such as Er, Sc, Tb, or pretitectic forming elements, such as Fe and Ni. Evaluation of the solidification conditions were carried out in a fast (hyper) cooling DSC on a series of prealloy powders. Particular emphasis to determine the undercooling was performed. Upon DSC testing, the solidified material was analyzed via XRD and SEM to investigate the influence of the change of heating and cooling rates on microstructural evolution of the Al alloys. This work will discuss the use of hyper DSC to gain new insights into solidification events of Al alloys and present key results from this new exciting methodology.

3:10pm

Presentation 44: Selective Laser Melting of Copper, Aluminum, and Copper-Aluminum Alloy

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

Abstract: Aluminum shows advantages in lightweight and excellent corrosion resistance by forming oxide layer on its surface. Copper exhibits outstanding electrical and thermal conductivity along with antibacterial performance. Meanwhile, the coper-aluminum alloy with improved corrosion resistance and mechanical properties has been widely manufactured by conventional techniques and applied in the industry. The near-net-shape selective laser melting (SLM) improves the sustainability of manufacturing by minimising the losses of materials. However, pure copper and copper-based alloy reflect laser wave length and cause poor energy absorption with moderate laser power. In this research, SLM with various scanning speed and low laser power up to 70W was applied to fabricate pure copper and aluminum, as well as the alloy with equal composition of the two components (Al 50wt% - Cu 50wt%). The morphology, porosity, phase, and chemical composition of SLM specimens will be investigated using SEM and EDS. The grain orientation of solidified metal will be revealed by EBSD. Mechanical properties will be tested by nanoindentation mapping. The process feasibility window is expected to determine. The findings acquired in this research will show the technological innovation in the SLM of non-ferrous metal.

3:30pm

Presentation 45: Laser Powder Bed Processing of Aluminum Powders Containing Iron and Nickel Additions

Greg Sweet*, Jon Hierlihy*, Ian Donaldson**, Mathieu Brochu***, Paul Bishop*
**Dalhousie University, Canada | **GKN, Canada | ***McGill University, Canada*

Abstract: The variety of aluminum alloys currently used in laser powder bed additive manufacturing (LPB-AM) is limited, yet the demand for such materials is growing. The AM community is particularly keen on aluminum alloys that offer enhanced thermal stability. Traditionally, this trait has been instilled through transition metal additions that form stable aluminides. This project seeks to devise new LPB-AM materials in this context starting with a precursory study into the effects of iron and nickel additions. Here, gas atomized Al-1Fe and Al-1Ni (wt.%) powders were processed via LPB-AM over a range of volumetric energy densities achieved through systematic adjustments to laser power, scan speed, and hatch spacing. The microstructure (OM, SEM, EDS, XRD) and physical properties (hardness, density, surface roughness) of the products were characterized. Results indicated that Al1-Fe was more responsive to processing as it densified to 99.0% of full theoretical and had a hardness of 94 HRH. Conversely, Al-1Ni only reached 97.8% theoretical density and a peak hardness of 77 HRH. Energy density values of at least 30 J mm-3 were found to achieve peak density and hardness. Surface roughness trended negatively with volumetric energy density, reaching Sa = 13.5μm for the Al-1Ni at 52.8 J mm-3.

Session 12: Advanced Process Modeling and Novel AM Processes
June 27 | 1:50pm – 3:50pm | Room 2301

1:50pm

Presentation 46: Tool Path Related Process Planning Challenges for Direct Energy Deposition Systems

Bob Hedrick*, Jill Urbanic**
**CAMufacturing Solutions Inc., Canada | **University of Windsor, Canada*

Abstract: Additive manufacturing (AM) tool paths typically leverage 2 ½ D contour and raster fill strategies. This is a standard approach for plastic, powder bed fusion, binder jetting, etc. as well as for the machine tool / robot based direct energy deposition (DED) systems. DED AM systems are the focus of this research. Even with these basic tool path build strategies, there are unique challenges with junctions, smoothly merging thick wall – thin wall blend regions within a given layer, acute corner angles, and other geometric based scenarios. Unique AM process planning tool paths and decision logic are required to address these issues. Selected solution approaches that have been developed as part of the APlus® software (AM process planning software integrated with the Mastercam CAD/CAM package) will be presented.

2:10pm

Presentation 47: Selective Laser Melting of Graphene-Reinforced Aluminum Matrix Composites for Electrical Batteries

Mostafa Yakout, M. A. Elbestawi
McMaster University, Canada

Abstract: Graphene (Gr) is a promising material for use in the production of lithium-ion batteries for electrical vehicles because it has a high tensile strength (i.e., 130.5 GPa) and a low electrical resistivity (i.e., 1´10-8 W/m) at room temperature. It is also a good reinforcement of various composites for several applications. Graphene also has a superior printability due to its high thermal conductivity. It has been reported in the literature that multi-layer Gr sheets reinforced aluminum (Al) matrix shows an increase in the material hardness and mechanical tensile strength. However, the formation of Al carbide during the manufacturing of Gr-Al composites could lead to inferior mechanical properties. Multi-layer Gr nanosheets reinforced Al matrix showed 62% enhancement in the tensile strength and 40% enhancement in the material hardness compared to pure Al. This research investigates the selective laser melting of Gr nanosheets reinforced Al composite for electrical batteries. The study is aimed at eliminating the formation of Al carbide during the selective laser melting of Gr-Al composite. Mechanical and electrical properties of Gr-Al composite produced using selective laser melting are tested and compared to those obtained for pure Al. A process window is determined for the selective laser melting of Gr-Al composite.

2:30pm

Presentation 48: Influence of Operating Parameters during Plasma Transferred Arc Additive Manufacturing on Carbide Concentration of 70wt% Ni-WC Metal Matrix Composite Components

Dylan Rose*, Tonya Wolfe**, Hani Henein*, Leijun Li*
**University of Alberta, Canada | **InnoTech Alberta, Canada*

Abstract: Additive manufacturing (AM) is garnering interest for the production of functional parts in the Canadian Energy Industry, specifically in the mining sector. These parts are designed to withstand the aggressive environments commonly found in the mining industry, with the goal to prolong the service life of wear susceptible components. In this work, Plasma Transferred Arc (PTA) is used as an AM technique, to construct NiCrBSi-WC metal matrix composite (MMC) structures. An appropriate understanding of the operating conditions during the additive manufacturing process is imperative to guarantee the requisite build geometry, and performance of the finished product. Currently, the effects of PTA-AM operating parameters towards maintaining a homogeneous carbide concentration is not well understood. In this study, a Taguchi L18 orthogonal array was used to investigate the effects of 7 operating parameters on the carbide concentration, including: current, powder feed rate, travel speed, plasma, powder and shielding gas flow rates, as well as the PTA torch assembly. The resultant build geometry, and microstructural changes, will be discussed. An operating map will be developed which will be the basis for constructing a closed loop PTA-AM system.

3:10pm

Presentation 49: Integration of Physically-based Analytical Model and Statistically-driven Empirical Model for Multi-objective Optimization of Laser Powder-bed Fusion

Yuze Huang, Hamed Asgari, Mohammad Ansari, Behrad Khamesee, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Reducing the building time while maintaining the fabrication quality is vital to broaden the industrial application of laser power-bed fusion. However, the physically-based models alone are insufficient for quality prediction (e.g., density, roughness) due to the effect of stochastic physical phenomena (e.g., stochastic powder bed, denudation, spatter) and the immature apprehension of the underlying science (e.g., laser beam dynamic penetration in the porous powder-bed). Similarly, the empirical models for real-time fabrication characteristics (e.g., melt pool depth, subsurface temperature) are also difficult to build due to the dearth of characterization tools. Therefore, this research integrates the analytical model and empirical model to simultaneously optimize the mechanical properties (density, surface roughness) and the in-situ build rate by using a genetic optimization algorithm. The analytical model was built with considering the accumulated heat, which provides time-efficient solutions for the in-situ melt pool dimension and the real-time build rate. The empirical models were built to predict the final part-scale density and the surface roughness by using response surface regression with a Box-Behnken design. Accordingly, the multi-objective optimization was achieved in a holistic manner. The optimization results also provide the steady process window for the adoption of magnetic-based techniques to further increase the melt pool stability and the fabrication quality.

3:30pm

Presentation 50: Progress in Applying Fused Filament Fabrication to Metal Matrix Composites (MMC)

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

Abstract: Fused Filament Fabrication (FFF) is gaining interest in the Additive Manufacturing of components. While it has largely grown based on the use of polymers, the feasibility to incorporate other classes of materials is an attractive option. When metals are incorporated into the polymer, FFF provides the opportunity to retain the fine structure of the rapidly solidified powder. In order to take full advantage of FFF for application in the resource sector, it is desired to mix both metallic and ceramic powders into a polymer filament. This work will describe the progress in manufacturing of various types of polymers as filaments, their printability using the FFF technique, and sintering of final parts. The mechanical properties of the printed and sintered samples will be discussed. As both low- and high-density Polyethylene (PE) were found to be most suitable, further tests were carried out to explore the optimum powder volume fraction of NiCrBSi, WC and TiC powders that can be mixed into PE. These results will also be discussed.

Poster Presentations

Location: Great Hall South

Theme 1: Material Development

Poster 1: Innovative Surface Finishing Methods for Reducing Internal and External Surface Roughness of Metal Additive Manufacturing Parts

Haniyeh Fayazfar, Mihaela Vlasea, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Although much more work is carried on optimizing the process parameters in additive manufacturing, this technology is limited in regards to its ability to produce dimensional accuracy and high quality surface finishing. The surface imperfections inherent to AM cannot be addressed by AM process optimization alone, due to the physics of the laser-powder interaction. Looking at the costs factors for post-processing of AM parts, more cost-effective methods are needed to address finishing of complex surfaces. In this research, innovative systems and processes through electrochemical-based methods through two general categories; surface treatments by material removal and surface treatments by coating of materials has been investigated. The electrochemical-based surface treatment methods are capable of accessing internal and complex surfaces, as electrolyte can easily reach intrusions and hidden surfaces. In this study, innovative experimental procedures has been deployed for surface finishing and coatings of metallic AM parts with internal channels, made of various alloys like Al10SiMg, Ti6Al4V, and Inconel super alloys. Surface characteristics of these parts such as, surface roughness and conductivity has been investigated thoroughly.

Poster 2: The Contribution of Moisture from Cellulosic Filters in LPBF AM

Aniruddha Das, Mathieu Brochu
McGill University, Canada

Abstract: The presence of moisture in LPBF system can lead to the deleterious effect of oxygen uptake in the powders and produced parts. Moisture can arise from various sources in an LPBF system, one such source is the cellulosic pleated paper filter. The moisture absorption amount for a commercial filter paper has been determined using dynamic vapor sorption (DVS) at different RH levels. Thereafter, the total moisture present in the filter cartridge during storage has been estimated and validated using drying experiments. RH measurements within an LPBF chamber revealed that a non-dry filter releases its stored moisture on interaction with dry inert gas or in vacuum during initial chamber atmosphere preparation. Inert gas recirculation commonly used for shielding during processing also facilitates moisture release and leads to a subsequent RH equilibrium within the build chamber. The quantity and kinetics of this moisture release have been determined. To avoid moisture release from the filter, drying been shown as an effective pre-conditioning. Current work is directed towards evaluation of moisture contribution in LPBF from the remaining possible identified sources.

Poster 3: Laser DED Cladding of H13 Tool Steel and Elemental Equivalents

Owen Craig, Kevin Plucknett
Dalhousie University, Canada

Abstract: Directed energy deposition (DED) offers a wide range of material flexibility and design freedom. The ultimate goal of the present work is to develop hardened DED laser-deposited layers using elemental powder feedstocks. Initial work will involve cladding a baseline tool steel H13 onto an H13 substrate. These clads will be compared against wrought material in the annealed, quenched and various tempered conditions. Tempered samples are created due to the reheating that occurs in cladding. Cross-sections of the clad will be made to examine the amount of dilution into the substrate. After cladding has been optimized for a flat substrate, the feasibility of depositing material on varying edge angles and curved surfaces will be examined. Stage two of the work will examine blended elemental feedstock sources as a direct comparison, clad onto the same H13 substrate and also a Cu-based alternative. Microstructural characterisation of the wrought and clads materials will be conducted using optical microscopy, scanning electron microscopy, X-ray diffraction, and confocal laser scanning microscopy. Mechanical evaluation will be performed using tensile, hardness, and wear testing. Thermal properties of the wrought and clad materials will also be conducted, using dilatometry, thermal diffusivity, and differential scanning calorimetry.

Poster 4: A Novel Binder Jetting Process to Fabricate Functionally Graded Nanocomposites for Hygroscopic Sensing and Actuation

Xuechen Shen, Hani Naguib
University of Toronto, Canada

Abstract: Additive manufacturing (AM) of nanocomposites is a remaining frontier for the AM industry. Binder jetting forms the basis of a unique approach to spatially control part properties through packing density of nanoparticles by varying concentration in the ink, producing a functionally graded material (FGM). However, inkjet printheads complicate the development of such nanoparticle inks; ink compositions that exhibit volatility, rehydration, surface tension, chemical stability, and abrasiveness that deviate from printhead specifications accelerate failure and accrue heavy maintenance costs. This is especially limiting for FGM printing, which necessitates variation in ink composition. We propose a system with ubiquitous compatibility for caustic and abrasive ink compositions. The system uses inexpensive, easily modifiable, and exchangeable wetted components to eject ink in a continuous jet. We find optimal operation parameters and evaluate system performance against inkjet and fused deposition modelling (FDM). The system produces line widths between 0.2–0.5 mm, indicating feature resolution capabilities are comparable to FDM. The system is used to print a Graphene-Polyvinyl Alcohol (PVOH) composite using an aqueous graphene oxide (GO) ink. The composite exhibits conductivity up to 10-4Scm-1. The hygroscopic properties of the printed composite are investigated to realize printable soft sensors and actuators.

Poster 5: Mechanical Properties of Additively Manufactured Tessellated Metamaterial Design Configurations

Anastasia Wickeler, Hani Naguib
University of Toronto, Canada

Abstract: Tessellated metamaterials are created from a repeated pattern, or repeated “unit cell”, design to form a material that derives its properties from the shape of the structure rather than from the composition of the material used to fabricate the design. Complicated structures are costly and difficult to produce using conventional manufacturing techniques. Additive manufacturing provides a simpler and more cost-effective method of creating an array of configurations of complicated tessellated metamaterial designs for mechanical testing. This research will focus on the physical testing of a variety of additively manufactured tessellated metamaterial designs to compare the effects of changing shapes and dimensions on the strength and deformation mechanisms of the structure. The tessellated designs are composed of surfaces along varying angles which are attached to one another along their edges. These angles and edge lengths can be varied to create multiples configurations of the designs. Compression and impact testing will be utilized to compare how varying parameters affect the mechanical behaviour of the metamaterials. A parameterization study will be used to optimize the behaviour and shape of the tessellated metamaterials. An FEA model will be created to further analyse the behaviour of the metamaterials and to further optimize the tessellated pattern.

Poster 6: Improving Surface Finish of Low-Cost Irregular Powders in Laser Powder-Bed Fusion

Seung Ho Jeong, Sagar Patel, Allan Rogalsky, Mihaela Vlasea, Adrian Gerlich, Mary Wells
University of Waterloo, Canada

Abstract: With post-process surface finishing being a requirement for many applications in the automotive, aerospace, and medical industries today, they can be a significant contributor to the overall cost of L-PBF part production. With a large majority of engineering component failures in practice being surface-initiated, it is crucial to optimize surface roughness and improve sub-surface porosity. To date, literatures covered significant optimization efforts to improve up-skin surface quality, but have neglected research in optimizing side-skin and down-skin surfaces. In this work, we look at the physical and geometric limitations of the L-PBF process as they pertain to multi-oriented surfaces such as side-skin and down-skin, and discuss the results of our recent experiments designed to minimize surface roughness without compromising sub-surface density using low-cost irregular powders. This leads to guidelines for build strategy and part orientation relative to the build volume designed to minimize critical location surface roughness.

Poster 7: Reactive Sintering for Post-Processing of Binder-Jet Additive Manufactured Metal Matrix Composites

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

Abstract: Metal matrix composites (MMCs) have many beneficial properties for use in aerospace applications, including higher strength, fracture toughness, and wear resistance. These applications typically include structural components with less strict tolerances and certification, such as the ventral fins and fuel access door covers on F-16 aircraft, helicopter rotor blade sleeves, and certain components on the space shuttle orbiter and Hubble space telescope. However, the use of MMCs is limited due to challenges associated with proper dispersion of the reinforcing phase and difficulties machining a material with both highly abrasive reinforcing particles and a ductile metal matrix. The use of binder-jet additive manufacturing to create near net-shape parts reduces the quantity of machining required, eliminating one of the largest cost-related barriers to widespread implementation of MMCs. Improved homogeneity can also be obtained, by using a novel in-situ reactive sintering process. Formation of a carbide reinforcing phase using alloying elements from the metal particles and carbon from the decomposed binder is found to create a well dispersed metal matrix composite. Wear properties and formation kinetics of the reinforcing phase are presented to demonstrate the ability for controlled MMC design.

Poster 8: Characterization of Commercial Mo Powders and Their Laser Powder Bed Fusion Additive Manufacturing Behavior

Tejas Ramakrishnan, Eileen Ross Espiritu, Mathieu Brochu
McGill University, Canada

Abstract: Laser powder bed fusion additive manufacturing (LPBF-AM) is an emerging material fabrication technology that enables the creation of complex parts and geometries in parts with much ease, and often beyond the limitations of conventional manufacturing processes. Today, multiple systems including steels, titanium, aluminum and nickel alloys have been extensively studied for processing through LPBF-AM. Molybdenum and other refractory alloys are being considered as candidate for applications in turbine blades for higher efficiency aircraft jet engines and as replacement for zircaloy in nuclear reactor components due to their higher melting point, thermal conductivities, high temperature strength and resistance. Material processing limitations hinders their adoption in the listed applications. The new manufacturing reality opened by LPBF can potentially overcome these hurdles. With the intend of developing protocols for LPBF of Mo-based alloys, the initial focus was placed on understanding the behavior of pure Mo. Several characterization tools were utilized to understand the powder behavior and optimize the recoating step. Fabrication of test samples was carried out as a second step, with the aim of understanding how high-quality components can be obtained. Microstructural characteristics of the printed Mo parts, including grain size and texture will be discussed.

Poster 9: Elevated-Temperature Tensile and Creep Properties of Laser Powder Bed-Fused In625 Components

Alena Kreitcberg*, Karine Inaekyan*, Sylvain Turenne**, Vladimir Brailovski*
**ETS Montreal, Canada | **Ecole Polytechnique de Montreal, Canada*

Abstract: This study provides a valuable insight to the tensile and creep properties of laser powder bed fused (LPBF) IN625 alloy components. To obtain these data, IN625 tensile specimens were fabricated with two build orientations: vertical and horizontal. All the specimens were then subjected to stress relief annealing (SR), and some of the SR specimens to additional solution annealing (ST). The tensile testing has been carried out in the 25-870°C (68-1600°F) temperature range. The creep testing has been conducted in the 538-760°C (1000-1400°F) temperature range, for the 0.5-0.9 yield stress conditions. At room temperature, vertical SR specimens exhibited slightly higher elongation than their horizontal counterparts (38 vs 30%). ST effectively improved homogeneity and ductility of the LPBF alloy, the latter became comparable to that of the wrought alloy of the same composition (~60%). At 538°C (1000°F), the mechanical resistance (YS=310 MPa, UTS=730 MPa), elongation to failure (~60%) and creep behavior of the ST-treated LPBF IN625 alloy were similar to those of the wrought alloy: no rupture was observed during 48 hours at a maximum load of 0.9YS with an accumulated creep strain of ~1%.

Poster 10: Rapid Solidification of Al-Cu Eutectic

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

Abstract: Rapid solidification of Al-Cu droplets of eutectic composition was carried out using Impulse Atomization in an argon atmosphere, to study the solidification microstructures forming at different cooling rates and undercoolings. Two distinct morphologies were observed within the investigated Al-33wt%Cu droplets: (i) A regular lamellar morphology and (ii) an undulated morphology. The volume fraction of each type of morphology was measured as a function of the droplet size and the nucleation undercooling was deduced using the hypercooling limit equation. Primary nucleation site was found to be affected by the alloy impurities which promote nucleation on the droplet surface. The scale of the microstructures was determined through measurements of eutectic spacing across and along the growth direction. Growth velocity and growth undercooling were deduced using Jackson and Hunt eutectic growth theory. Finally, mechanical properties were estimated through micro-hardness measurements, revealing exceptional properties.

Poster 11: Effect of Rapid Solidification on Microstructure and Properties of Al-Si Alloys

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

Abstract: Al-Si alloys are the most commonly used Al alloys for commercial applications. This stems from the great tribological properties the hard Si brings about, as well as the castability of the alloy which is characterized by a high fluidity length. However, use of Al-Si is typically limited to low Si additions due to the poor mechanical properties associated with Si-rich phases. Two approaches are commonly applied for improving these mechanical properties: addition of tertiary elements, and rapid solidification. Many additive manufacturing methods produce rapidly solidified components, making the use of Al-Si alloys for these processes promising. To date, the effect of rapid solidification on mechanical properties has not been systematically quantified for hypereutectic alloys. This work intends to correlate changes in Si morphology and the resulting properties to the solidification thermal history. Ultimately, a microstructure-processing-properties map will be built for the design of Additive Manufacturing processes so that manufacturing of components with target properties can be achieved.

Poster 12: Processing of Ti-64 by Laser Powder Fed Additive Manufacturing

Nick Gosse*, Ian Donaldson**, Kevin Plucknett*, Paul Bishop*
**Dalhousie University, Canada | **GKN, Canada*

Abstract: The long-term objective of this research is to design, develop and process novel titanium alloys for use in laser powder fed additive manufacturing (LPF-AM). The developed alloys must offer advantages in terms of processing behaviour, achievable dimensional accuracy, and post-processed physical/mechanical properties over commonly available titanium alloys. Early research aims to establish a baseline for comparison using a commercially available Ti-64 powder against which future developments can be compared. A commercial lot of Ancor Ti-64 powder was characterized and distributed to LPF-AM vendors, along with a dimensioned drawing of the desired geometry. The dimensions of each build were measured using a 3D coordinate measurement machine and compared to the specified configuration. Hardness of each sample was tested using Rockwell C, and the densities were measured according to MPIF Standard 42. Optical metallography, scanning electron microscope, differential scanning calorimetry, and x-ray diffraction were utilized to characterize the microstructures, porosity and phases present. Tensile properties were quantified in vertical and horizontal build directions in accordance with ASTM E8M while repreentative fracture surfaces were examined with a scanning electron microscope.

Poster 13: Binder Jet Printing of Low Cost Tool Steel Powders

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

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. Accordingly, water atomization is viewed as a viable contender for the production of cost-effective powders for AM technologies. The objective of this research was to investigate this concept, initially, in the context of binder jet printing. As such, a water atomized D2 tool steel powder was secured from the industrial partner targeting a nominally spherical shape and reduced D50 to aid spreadability and post-build 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 liquid phase sintered under various conditions in a thermal dilatometer to identify densification behaviour and the temperatures at which key metallurgical transitions occur.

Poster 14: Rapid Solidification of Al-Si-Sc Alloy

Akankshya Sahoo*, Abdoul-Aziz Bogno*, William Hearn**, Hani Henein*
**University of Alberta, Canada | **Chalmers University of Technology, Sweden*

Abstract: Scandium addition in Al-alloys has been found to promote excellent precipitation hardening, microstructure refinement and morphology modification. Recent research has also explored the evolution of microstructure at various stages of additive manufacturing (AM) and found rapid solidification (RS) also greatly affects the morphology/properties of hypoeutectic Al-Si alloys. However, the combined effect of both RS and Scandium addition on the conditions leading to these morphologies in Al-Si alloys is not understood in a quantitative and reproducible way. Using DSC and a novel containerless solidification technique (Impulse Atomization), hypoeutectic Al-10Si alloy with 0 wt% and 0.4 wt% Sc addition was produced with a wide range of cooling rates (0.1-104K/s). Here microstructural and phase characterization was conducted using OM, SEM, EPMA and DSC to determine the influence of cooling rate and Scandium addition. On this basis, the solidification pathways and formed microstructures were quantified for slow and rapid cooling rate, providing a critical relationship between processing/microstructure/properties that can help with the use and development of AM processes.

Poster 15: Correlating the Columnar Grain Structure with the Anisotropic Mechanical Response of Hastelloy X Produced by Laser Powder-Bed Fusion

Ali Keshavarzkermani, Reza Esmaeilizadeh, Shahriar Imani, Hamid Jahed Motlagh, Norman Zhou, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Laser powder bed fusion (LPBF) is a popular additive manufacturing (AM) technique, in which a laser heat source melts metallic powder particles within a build compartment in a layer by layer fashion. Keeping the main heat flow direction along with building direction results to have columnar grains growth during melt pool solidification. As a result, anisotropic mechanical response observed from LPBF parts is due to the particular columnar microstructure obtained after directional solidification. In this study, mechanical response of as-built material in three different perpendicular directions has been investigated. The quasi-static tensile properties of Hastelloy X found to be highly depending on the sample orientation. It has been observed that vertical samples have lower strength than the horizontal samples while horizontal samples do not show in-plane mechanical anisotropy. It worth to mention that no specific crystallographic texture has been observed due to the applied rotation in scan strategy. It is proposed that high grain aspect ratio of columnar grain structure is responsible for the observed anisotropic tensile behaviour.

Theme 2: Advanced Process Modeling

Poster 16: Evaluation of Residual Stresses induced in Laser Powder-Bed Fusion Additive Manufacturing Process: Finite Element Simulation and Experimental Investigation

Marjan Molavi-Zarandi*, Ali Bonakdar**, Ramin Sedaghati***
**National Research Council of Canada-Boucherville | **Siemens, Canada | ***Concordia Universit*

Abstract: Additive manufacturing (AM) technology cuts across a large number of industries and applications, and that is part of what makes its potential so compelling. Aerospace, automotive and medical products will drive AM into the future. Laser Powder Bed Fusion (LPBF) is an AM process that can be effectively utilized to manufacture structural components with complex geometries. In LPBF, a part is created directly from the three-dimensional model by selectively melting successive powder layers using a laser beam. Nevertheless, there are still some technical barriers and challenges for the production of metallic parts. Optimal production of metallic parts using LPBF requires a comprehensive understanding of the effect of main processing parameters such as laser energy input, powder bed properties and builds conditions. One of the main issues is the identification of ideal process parameters to build a component with minimal induced residual and thermal stresses which are the main cause of distortion. Development of a numerical model to accurately predict the induced residual stresses and distortion during the LPBF process would allow to effectively investigate the influence of processing parameters on the quality of the parts. In this work a high fidelity finite element (FE) model has been developed to numerically simulate the LPBF process in order to predict the induced residual stresses and distortions. An extensive experimental investigation has also been conducted with a particular attention to the effects of laser energy input and scan speed on the surface and in-depth residual stresses for Inconel 625 parts produced by LPBF. The assessment of the effect of process parameters on the residual stress values was performed using X-ray diffraction (XRD).

Poster 17: Control of Density and Microstructure in Laser Powder Bed-Fused Components Using a Combination of Melt Pool Modeling and Design of Experiment Approaches

Morgan Letenneur, Alena Kreitcberg, Vladimir Brailovski
ETS Montreal, Canada

Abstract: To facilitate the introduction of new AM metallic materials while avoiding the trial-and-error approach, simplified melt pool modeling is combined with design of experiment to develop a novel density and microstructure prediction tool, which can be adapted to any given powder feedstock and laser powder bed fusion (LPBF) system. To this end, calibration coupons are built using IN625, Ti64, AlSiMg, Fe and FC0208 powders and an EOS M280 LPBF system. These coupons are then manufactured using the predetermined ranges of laser power, scanning speed, hatching space, and layer thickness, and their density and microstructure are analyzed using conventional material characterization techniques. Next, a simplified melt pool model is used to calculate the melt pool dimensions, the cooling speed and the temperature gradient for the selected sets of printing parameters. The both sets of data are then combined to predict the density of next printed parts and provide insights into their microstructure (grain size and aspect ratio), risk of hot cracking, distortion and accuracy. This approach has been successfully validated using data found in the literature, thus demonstrating its potential efficiency for the laser powder bed metal fusion process optimization.

Poster 18: Adaptive Trajectory Planning for Direct Energy Deposition Using Tri-Dexel Model

Farzaneh Kaji*,**, Vadim Kozhevnikov*,**, Ehsan Toyserkani*
**University of Waterloo, Canada | **Promation, Canada*

Abstract: Direct Energy Deposition (DED) has been widely used for component repair and manufacturing of 3D parts. One of the challenges of DED is low efficiency of the process. Current CAD/CAM solutions for DED generate toolpaths based on the geometry of the parts regardless of heat distribution in the process. Ignoring such important aspect of this manufacturing process leads to inevitable situations in which different regions of the part with different thermal conductivity are manufactured with the same process parameters. In this research, a physics-based algorithm for adaptive toolpath generation based on tri-dexel model is presented. At first, STL model is converted into tri-dexel model. Then based on marching cube algorithms, CAD model is divided to cubes(voxels). Based on the number of neighborhood cubes of each cell in the model, a heat zone code is assigned to the cell. Current research considers only three different heat zones (heat-safe, heat-sensitive and critical). For each heat zone, separate toolpath is generated, and it is intersected with the tri-dexel model to find the adaptive trajectory. This algorithm could significantly improve the efficiency of the process and it is faster than current FEA simulation and modelling techniques.

Poster 19: Mechanics of Additively Built Porous Biomaterials

Ahmed Moussa*, Asma El Elmi*, David Melancon**, Damiano Pasini*
**McGill University, Canada | **Harvard University, United States*

Abstract: Porous biomaterials can be additively manufactured with microarchitecture tailored to satisfy the mechano-biological requirements imposed by bone replacement implants. During the manufacturing process, however, geometric mismatches generally emerge between the nominal and the as-built microarchitecture, a factor that leads the mechanical properties deviate from their nominal values. In this work a statistical representation of geometric defects is adopted to generate predictive models that parallel the behaviour of as-manufactured biomaterials. A multiscale homogenization scheme is used to capture the effective properties of the as-built porous biomaterial. The results emphasize the importance of factoring in geometric defects during the analysis to attain a realistic representation of the as-built biomaterial performance.

Poster 20: Topology Optimization of Structures under Design-Dependent Pressure Loads

Pouyan Rahnama, Osezua Ibhadode, Zhidong Zhang, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Topology optimization is a powerful tool for designers to predict the preliminary structure of any component under different loads cases. These structures may consist of simple geometries or possess very complex features. Additive manufacturing provides the ability to manufacture parts with geometries that have high complexities which makes topology optimization an attractive tool in design for additive manufacturing (DFAM). In this paper, comparisons between different methods for topology optimization are presented. A topology optimization model is developed and an algorithm is studied for structures under pressure loads with and without restricted geometrical boundaries. In this approach, Solid Isotropic Material with Penalization (SIMP) and Rational Approximation of Material Properties (RAMP) which are density based topology optimization methods are compared while an example is investigated and validated by literature. Also, topology optimization is performed for the same geometry using commercially available software, Hyperworks, based on SIMP and level set methods to compare the result with the proposed approach. Finally, a CAD file is designed based on the optimized geometry and further analysis are performed.

Poster 21: Design for Additive Manufacturing: Topology Optimization of a Mechanical Assembly

Osezua Ibhadode, Pouyan Rahnama, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Additive manufacturing (AM) has evolved from a prototyping technology to one that creates fully functional parts with low running costs, time savings and little or no tooling required. This has been made possible, greatly, by construction of design frameworks for additive manufacturing (DfAM). A focal aspect of DfAM is topology optimization which is a mathematical approach to solving a structural design problem. Topology optimization typically obtains the optimum material distribution within a design space based on single or multi objectives and subject to a set of constraints. In topology optimization algorithms, manufacturing constraints can be considered to ensure that the formation of optimum part topologies follow some established design rules and guidelines for a unique manufacturing technology. Laser Powder Bed Fusion (LPBF) which is adopted in this study produces metal parts by selectively melting a powder bed successively in layers guided by CAD data from a computing unit. In this research, LPBF constraints considered are overhangs, self-supporting features, void filling and minimum feature thickness because they form critical constraints that determine successful prints. An arbor press assembly is presented as case study to show how topology optimization can be a powerful tool in DfAM for developing efficient and manufacturable parts.

Poster 22: Study on Fracture Mechanism of Ti-6Al-4V EBM Manufactured Under Different Loading Conditions Through a Hybrid Experimental-Numerical Approach

Mohammad Shaterzadeh, Marcilio Alves
University of Sao Paulo, Brazil

Abstract: Additive Manufacturing (AM) has been used widely for prototype manufacturing and recently for mass production due to growing demand for advanced manufacturing process. In this study, fracture mechanisms of the Ti-6Al-4V fabricated by Electron Beam Melting (EBM) is investigated. Through a hybrid experimental-numerical scheme, Ductile Fracture (DF) of AM parts subjected to different loading conditions are explored. The porosity effect on mechanical behavior and fracture mechanism is studied herein through as-built and Hot Isostatic Pressing (HIP) specimens. The HIP process eliminates part porosity completely and improve mechanical properties of it. The experimental test program is carried out on uniaxial and biaxial tensile machines. Specimens are designed to cover a considerable range of loading condition and stress triaxiality. Effect of anisotropy and printing direction on mechanical proprieties are analyzed through tension tests of specimens fabricated on 0°, 45° and 90° angles. A numerical model for AM part is coded into finite element method (FEM) by ABAQUS. A good innovative experimental program besides precise DF criterion can simplify the AM components application and make a step forward on AM part optimization.

Poster 23: Numerical Model of Al-33wt%Cu Eutectic Growth During Impulse Atomization

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

Abstract: Rapid solidification of Al-Cu droplets of eutectic composition was carried out using Impulse Atomization in an argon atmosphere. Two distinct morphologies were observed within the investigated Al-33wt%Cu droplets microstructures: an irregular undulated eutectic assumed to form during recalescence, followed by a regular lamellar eutectic post-recalescence. The volume fraction of each morphology was measured as a function of droplet size and nucleation undercooling was deduced using the hypercooling limit. A model of the eutectic solidification was then developed and coupled to our thermal model of a falling droplet through a stagnant gas. The solidification model assumes that the kinetics of both the undulated and regular regions follows the λ2v = 88 μm3/s relationship experimentally established for α-Al–¬Al2Cu eutectic. Modelling results show that the solid fraction forming during recalescence matches the experimental undulated eutectic fraction, confirming the hypercooling limit assumption for nucleation undercooling. Furthermore, the heat balance of the droplet with the surrounding gas confirms the adiabatic nature of the solidification.

Poster 24: Residual Stress and Distortion in Electron Beam Additive Manufacturing of Ti-6Al-4V Build Plates

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

Abstract: In Electron Beam Additive Manufacturing (EBAM) processes, the prediction of distortion and residual stresses plays a significant role in enhancing dimensional accuracy and preventing delamination, fatigue failure, and buckling of metallic parts. Due to the fact that many parameters can influence the process, experimental methods for residual stresses and distortion measurements are expensive and time consuming. Hence, numerical methods can be beneficial for the estimation of residual stresses and distortion. In this research, a three-dimensional, transient, fully coupled thermo-mechanical FEM model is developed to predict temperature field, residual stress distribution, and distortion in EBAM of Ti-6AL-4V build plates. The predicted results are validated using independent experimental results.

Poster 25: Meso-Scale Thermal, Elastic and Plastic Strain Evolution in PB-EBAM

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

Abstract: Powder-Bed Electron Beam Additive Manufactured (PB-EBAM) parts can suffer from deformation and residual stresses. The former leading to a loss of dimensional control and the later leading to degradation in mechanical performance in certain applications. The deformation and residual stress development is linked to the transfer of load at the interface between a freshly consolidated zone of material and previous consolidated adjacent layers (both below the previous build layer and adjacent). The total load transferred, is dependent on the evolution in the: 1) the thermal strain; 2) the plastic strain; and 3) the elastic strain. Using information generated from sub projects 2.1.2, 2.1.4 (a) and (c), a model will be developed to explore and predict the strain evolution at the meso-scale associated solidification of the melt zone. The results of a literature review will be presented that has a focus on methods used to account for strain accumulation in in PB-EBAM and LPB. Excerpts from the following papers will be included.

Poster 26: Residual Deformation and Stress Measurement

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

Abstract: Powder-Bed Electron Beam Additive Manufactured (PB-EBAM) parts can suffer from deformation and residual stresses. The former leading to a loss of dimensional control and the later leading to degradation in mechanical performance in certain applications. The deformation and residual stress development are linked to the layered buildup of material and presence of large thermal stresses during fabrication. It is essential that we understand how these stresses form and develop strategies to reduce or eliminate them. A key part of this, is the need to make quantitative measurements. It is not clear how this can be done in-situ owing to the high temperatures present in the process and the vacuum environment. Thus, the studies presented in the literature focus on ex-situ measurements of part deformation and residual stresses once the component is removed from the build chamber and cooled to room temperature. The results of a literature review will be presented that has a focus on measurement methods applied to characterize part deformation and residual stresses in PB-EBAM and LPB. Excerpts from the following papers will be included.

Poster 27: Beam/Powder/Melt Pool Interaction; Experimental Validation

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

Abstract: This project is focused on understanding the heat transport processes at the boundary between the meso and macroscale in the Powder-Bed Electron Beam Additive Manufacturing (PB-EBAM) process. Work is underway to understand the heat transport processes at the meso/micro scale within the liquid pool during melt consolidation of the powder, using a computational-fluid-dynamics simulation under the auspices of project 2.1.2. This program (2.1.1) is complementary and will focus on characterizing the flow of heat from the melt pool into the surrounding material, including consolidated (bulk) material and unconsolidated powder. Bulk substrate will be instrumented with an array of thermocouples to acquire data during melt consolidation of a powder layer from single and multiple passes with the electron beam. This data will be fed into an inverse analysis code, developed at UBC, to determine the volumetric heat source equivalent heat input to the to a millimeter scale domain, assuming a specified distribution relationship based on the beam parameters (beam current, beam focussing current and beam accelerating voltage). The results of a literature review will be presented that has a focus on thermocouple based-measurement methods applied to PB-EBAM and LPB. A brief review of the inverse heat conduction methodology will also be presented. Excerpts from the following papers will be included.

Theme 3: Process Monitoring and Control

Poster 28: Literature Survey of Laser Ultrasound Imaging Techniques Applicable to Defect Detection in Metal Additive Manufactured Parts

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

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

The review will span the following subjects: types and modelling of defect formation mechanisms in LPB and LPF AM, in-situ monitoring and final part inspection using other technologies (X-ray CT, pyrometry, thermal imaging and others), ultrasound imaging for non-destructive testing, laser ultrasound imaging and laser ultrasound imaging applied to AM process monitoring and inspection.

The survey will focus on:

- A mapping between machine settings and the types of defects obtained
- The advantages and disadvantages of each of the previously used defect monitoring and inspection methods
- An overview of ultrasound imaging techniques for non-destructive testing such as near-field acoustic tomography, synthetic aperture holographic imaging and synthetic aperture focusing techniques and their use in laser ultrasound
- The advantages and disadvantages of reported laser ultrasound imaging techniques and how they can be used effectively for LPB and LPF AM processes monitoring as well as final part inspection. For example how sound attenuation will change due to the size and geometry of the metal grains made in the LPB and LPF AM processes

Further work testing the above ultrasound imaging methods will be performed using a LUKS-1550-TWM laser ultrasonic system from Optech Ventures LLC. on manufactured samples.

Poster 29: Leveraging Keyhole Mode Melting Models in Laser Powder Bed Fusion

Sagar Patel, Mihaela Vlasea
University of Waterloo, Canada

Abstract: Successful laser powder bed fusion parts are obtained by the fusion of powder particles in 'conduction mode' or 'keyhole mode'. In 'keyhole mode' melting, energy from the laser evaporates the material surface forming a cavity of the shape of a keyhole which helps in almost complete absorption of the laser energy into the powder bed as compared to 'conduction mode' melting where majority of the laser energy is reflected away from the powder bed. Other than efficient energy absorption, stable 'keyhole mode' melting also helps in achieving a finer grain structure leading to higher hardness and ductility compared to 'conduction mode' melting. In this work, we propose an analytical model to predict the onset of 'keyhole mode' melting in powder bed fusion and its application to printing fully dense parts for a range of materials, powder bed fusion systems, and processing parameters. Additionally, an analytical model is proposed to incorporate the various energy-absorption mechanisms which help determine melt pool morphology in 'keyhole mode' laser powder bed fusion.

Poster 30: Detection of Internal Defects and Surface Cracks in Additively Manufactured Conductive Parts by Eddy Current Technique

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

Abstract: Laser Additive Manufacturing (LAM) involves many process parameters such as laser power, hatch spacing, scan speed, layer thickness and powder morphology. All of these parameters affect the quality of LAM-produced parts if not chosen properly. One of the main challenges that LAM encountered is porosities and cracks created within the layers of LAM-made parts. In this study, different eddy-current based probe designs are investigated to assess the feasibility of the detection of defects with different sizes and at different depths in parts made by conductive materials using LAM. According to the literature, different types of potential probes work as absolute, Transmit/ receive and differential mode. Also, the probe that is designed to work based on the differential mode includes two different sensing coil designs such as the circular and D-shaped. A comparison regarding the sensitivity to the smallest defect size is made for all suggested modes and designs. The parameters used in each model are kept constant to ensure the accuracy of the results. An experimental setup that involves all of the different probe designs/modes will be proposed.

Poster 31: Modelling of Powder Spreading to Optimize Compaction Consistency

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

Abstract: A crucial milestone for the progress of powder bed additive manufacturing is the closed loop control of the powder bed quality because it directly affects the quality of parts obtained. Current powder spreading methods including raking and rolling make no use feedback so process parameters are determined from expensive trial and error experiments. A better understanding of the process is required to create controllers that can effectively regulate the powder bed quality.

Therefore, current efforts in modelling are focussed on particle level dynamics simulations so that complex bulk powder behaviour can be related to simpler process inputs. The discrete element method is a promising simulation algorithm because the fundamental dynamics of the powder are captured by calculating the forces on each individual particle. Following the formation of a suitable simulation, different process parameters can be tested such as vibrating rollers, different spreader shapes, and vibrating build beds.

Once the dynamics of these spreading methods are better understood then suitable sensing methods can be developed to achieve closed loop feedback. Improvements to the spreading process are required to tackle current issues of low and inconsistent compaction density found in current powder beds.

Poster 32: Anisotropic Finite Element Modeling of an Aluminum Alloy Made by Additive Manufacturing

Henrique Ramos*, Rafael Santiago*, Marcilio Alves**, Peter Theobald***, Shwe Soe***
**Federal University of ABC, Brazil | **University of Sao Paulo, Brazil | ***University of Cardiff, UK*

Abstract: In this study, the constitutive parameters of an aluminum alloy, made by additive manufacturing (AM), to support the application on finite element modeling (FEM). The specimens were printed in three different directions by using selective laser melting technique (SLM) and three different manufacture scanning strategies, Meander, Stripes and, Chess. The material was characterized using the digital image correlation technique (DIC), providing the measure of a full-field strain level, where this analysis of the recorded images gave the true strains at the on the specimen surface. The AM aluminum material alloy was modeled using the Johnson-Cook (JC) constitutive law, which considers plasticity, damage, and material failure. The FEM commercial software Abaqus/CAE was used to evaluate these parameters. The FEM models were able to represent the overall response of the scanning strategy and the directions on the aluminum alloy. It was observed in the experimental test that the aluminum alloy material has anisotropic behavior and show predicted failure in the XZ direction, due to a relative layer fusion during the scanning process.

Poster 33: Investigation of Binder Deposition and Infiltration Strategies for Binder Jetting

Marc Wang, Ken Nsiempba, Mihaela Vlasea
University of Waterloo, Canada

Abstract: Additive manufacturing (AM) is revolutionizing nearly every sector of our economy. This growth is attributed to the design capabilities imparted by AM processes, such as the reduction of manufacturing cost for high value and low-volume products. Powder Bed Binder Jetting (PBBJ), historically termed 3D Printing (3DP), is an AM process where the fabricated product is generated by adhering powder material together with a binder in a particular geometry. The resulting part, also called "the green part", can be sintered to fuse the particles together. Among the AM process available for metals, it is the lowest in terms of cost for generating parts. Unfortunately, it is also the one where achieving high density and good surface quality is the most difficult without heavy post-processing. The aim of this research is to investigate different binder deposition and infiltration strategies in order to minimize binder use and mitigate layer-by-layer powder interactions which result in the mentioned drawbacks. To achieve these goals, software will be developed to generate these binder and infiltration patterns. The goal of this project is to investigate different binder deposition patterns and infiltration strategies into organized powder substrates. The resulting parts produced using these different strategies will be evaluated using the following Key Performance Indicator (KPI): green part density and particle intra- and inter-layer distribution. Pattern recognition technique will be used in order to find correlation between the strategies used and KPI.

Poster 34: Current-controlled Line Energy – Porosity Relation for EBAM of Ti-6Al-4V

Frederik Lindenau*,**,***, Chadwick Sinclair**, Heinz Voggenreiter*,**,***
**University of Stutttgart I ** The University of British Columbia | ***DLR*

Porosity control is one of the major constraints holding back metal additive manufacturing to reach its full potential. Overall material density and distribution of voids are quality measures influencing fatigue and corrosion properties. Line energy has already been directly related to porosity with a variance over beam speed. An independent open data EBAM facility was used to precisely quantify line energy values for a varying beam current at otherwise fixed parameters. This was related to metallographic evaluation of porosity. It was shown that an adequate line energy leads to a reduction even in residual gas porosity. In a comprehensive approach these findings were put up against related quality measures such as melt edge overhang, dimensional accuracy, surface roughness and evaporation loss of alloying elements. The result is a line energy – porosity relation with decision making capability qualified for various application objectives.

Theme 4: Novel AM Processes and Products

Poster 35: Design, Manufacture and Testing of Porous Materials with Ordered and Random Porosity: Application to Porous Medium Burners

Mykhailo Samoilenko, Patrice Seers, Patrick Terriault, Vladimir Brailovski
ETS Montreal, Canada

Abstract: Digital replicas of three SiSiC ceramic foams (10, 30, and 60 pores per inch, PPI) were obtained by means of X-ray computed tomography. Equivalent pore diameters were determined using a combination of the 3D Watershed analysis (VG Studio Max software) and an analytical tetrakaidecahedron model. Upon investigation, it was found that pore diameters provided by the manufacturer were underestimated. Next, diamond lattice structures equivalent to ceramic foams in terms of their porosity and permeability were designed and some of them 3D-printed from metallic CoCr alloy. A two-section porous medium burner test bench was then used to measure the temperature, pollutant emissions and pressure drop for six different arrangements of the foam and lattice structures made of either ceramic or metal materials. In all the setups, pollutant emissions were low and at the detection limit of the equipment. The application of CoCr alloy in the upstream section ensured higher flame stability and structural strength. The diamond lattice provided both the better control of porosity and higher structural stiffness in comparison with foam. Application of 3D-printed ordered porous materials with metallic alloys in the upstream section, and ceramic materials in the downstream section is recommended for further research of lean combustion regimes.

Poster 36: Patient-specific endoprostheses for limb sparing in dogs: design, manufacturing, in vitro study and clinical trial

Anatolie Timercan*, Bernard Seguin**, Yvan Petit*, Bertrand Lussier***, Vladimir Brailovski*
**ETS Montreal, Canada | **Colorado State University, Colorado | ***Universite de Montreal*

Abstract: The predominant type of canine bone cancer is osteosarcoma, generally forming at the appendicular skeleton. To preserve their dog's mobility, some oweners are inclined to select as treatment limb sparing surgery instead of amputation. Limb sparing consists in removing the affected portion of bone and replacing it with a metallic plate fixed with screws. In this case, the patient is fit to the implant, instead of the other way round, which results in suboptimal implant fit and function and numerous postoperative complications.

Additive manufacturing of personalized endoprostheses (PE) and cutting guides (CG) is proposed to overcome the limitations of conventional limb sparing. Patient's CT-scan data is used to reconstruct bone models that serve as scaffolding for the PE and CG design. PEs are manufactured from titanium using laser powder bed fusion, while CGs are manufactured from plastic using fused deposition modeling. As part of a clinical trial, five fogs were successfully instrumented with PEs. The average delay between reception of the patient data and shipping of the PE/CG kits was 75 hours. Surgery duration was reduced by 25-50%. To support this trial, a numerical model of an instrumented limb was developed and validated by biomechanical testing on cadaveric specimens.

Poster 37: Novel Strut Based Homogenization Method to Predict 3D Printed Lattice Structure Accuracy

Ken Nsiempba, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Lattice structures, or cellular materials, have been studied extensively as part of design for additive manufacturing (DfAM). Their usage has been stimulated by the widespread propagation of 3D printing technologies due to the unique characteristics of the manufacturing process. With cost no longer related to complexity, geometrically intricate parts can now be designed. Despite the adoption of lattice structures, a lot of work is needed to accurately predict their manufacturability. Furthermore, simulating lattice structures can reveal itself to be computationally expensive. This paper suggests a succinct method to predict lattice structures manufacturability. The methodology is based on the idea that most ordered cellular materials are comprised of struts and nodes; therefore, quantifying the effects of strut properties (thickness and the angle with respect to the x-y plane) with respect to their dimensional accuracy allows designers to obtain a manufacturability index based on the strut properties. The effects of strut properties on lattice structures are found by modeling the printing process and the predictions are validated through experiments. Finally, the paper presents an artificial intelligence-based algorithm explaining how to take those predictions into consideration while designing lattice structures.

Poster 38: Magnetic Levitation and Suspension Systems for Additive Manufacturing Techniques

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

Abstract: Magnetic levitation techniques and their applications have garnered strong research interests within the academic and industrial spheres. The research in the field has resulted in the development of a new avenue to provide a stable supporting structure to enhance the processes of Additive Manufacturing. Conventional Additive Manufacturing techniques rely on the use of a supporting platform to implement the fabrication process. The dependence on the supporting platform limits the fabrication in only one plane. The goal of this paper is to depict the viability of Magnetic Levitation and Suspension techniques in the domain of Additive Manufacturing. The implementation of these techniques results in the availability of multiple planes for the manufacturing processes. The concept of using magnetic levitation in additive manufacturing will be presented in this paper. The system utilizes a control system with feedback loops to regulate the positional precision and accuracy of the system.

Poster 39: An Analytical Model for Interaction of Laser Beam and Powder Stream in a Coaxial Nozzle for Directed Energy Deposition

Mohammad Ansari, Yuze Huang, Alexander Martinez-Marchese, Ehsan Toyserkani
University of Waterloo, Canada

Abstract: Laser directed energy deposition (LDED) is an established technology for metal additive manufacturing. As LDED offers high deposition rates, high material flexibility, and the possibility to deposit material on existing components, the demand for applying this technology to 3D structures has been increased in recent years. However, the use of LDED for manufacturing of 3D structures needs a sufficient knowledge of LDED process especially that of laser beam and powder stream interaction. In LDED, interaction between the laser beam and powder stream from a coaxial nozzle alters the temperature of powder and substrate. In this paper, the first process step for LDED as additive manufacturing technology, which is single-track deposition, is described. The experiments are conducted using metastable beta titanium alloy (Ti5553). A setup with a coaxial powder-fed nozzle is deployed and the process is carried out under a controlled atmosphere in a closed chamber. The influence of carrier gas flow and laser power on the dimensions of single-tracks is analyzed. These factors significantly affect the deposition quality and are also important input parameters for process optimization. The analytical model in this paper presents a method to calculate laser power and particle velocity to acquire single-tracks with an acceptable quality. The results showed that the quality of the single-tracks have a high dependency on carrier gas flow and laser power.

Poster 40: Processing Conditions of 17-4 PH using Plasma Transfer Arc Additive Manufacturing

Sandy El Moghazi*, Hani Hanein*, Tonya Wolfe**, Leijun Li*
**University of Alberta, Canada | **InnoTech Alberta, Canada*

Abstract: Additive manufacturing (AM) of steels involves the layer by layer deposition of powders or wire feedstock which are consolidated using a heating source. AM enables the production of complex and time-consuming parts in a time efficient manner. The following project focuses on producing AM parts using plasma transfer arc (PTA-AM) using 17-4 precipitation hardened (PH) stainless steel powders for oil sands applications. 17-4PH was chosen, because of its relative high strength and high corrosion resistance and for its current wide usage as a precipitation hardened steel in the oil and gas industry. There is very little literature review on 17-4PH in PTA as an AM part, making this topic an important point of focus for further understanding the properties of 17-4PH in this field. This presentation will address a review of 17-4PH steel along with results from welded samples, their mechanical properties and the current challenges of trying to resolve the issues faced when fabricating them.

Poster 41: Nanoindentation Studies of Dual-Phase Ti-6Al-2Zr-1Mo-1V Alloys Made by Additive Manufacturing

Zhiying Liu, Yu Zou
University of Toronto, Canada

Abstract: This study focuses on using nanoindentation technique to study mechanical properties of titanium alloys made by directly laser melting deposition (LMD). During varied heat treatment process in titanium alloy fabricated by LMD, both the equilibrium transformation $\beta \rightarrow \alpha$ and nonequilibrium $\alpha^{\prime\prime} \rightarrow \alpha+\beta$ process could exist and determine the complex of the multiphases microstructure. Nanomechanical testing of different phases give insights to the variety of strength and ductility, showing the prominently work hardening effect in heterogenous microstructure. Here, we present the mechanical difference between α and β phase of LMD-fabricated Ti-6Al-2Zr-1Mo-1V alloy, indicating that the hardness of α phase in respective as-deposited and as-annealed samples are higher than β phases, respectively. The difference of hardness and mechanical contrast can be explained by the solution-strengthening due to element partitioning and grain size strengthening due to finer microstructure. These results offer the guideline to predict the macroscale mechanical properties of LMD-produced titanium alloys.

Poster 42: Dip Coating of Tool Steel H13 with TiC-Ni3Al Cermet Suspensions, and Their Subsequent Laser Cladding

Zhila Russell, Kevin Plucknett
Dalhousie University, Canada

Abstract: The deposition of a thin, uniform film of a solidifying suspension, with TiC-based cermet solid particles, is proposed via dip coating. Coatings will be applied onto various steel substrates, for subsequent consolidation by a variant of conventional laser directed energy deposition cladding. The properties of the coating and substrate interface such as adhesion is a crucial factor of such coatings. The systematic theory for evaluation of feasibility and stability of TiC-Ni3Al based thin films, with various solid particle volumes, is studied on steel substrates for the application of laser cladding. A costum-made coating system has been designed for dip coating of steel coupons. The parameters of suspension formulation such as temperature, pH, H2O/-OR molar ratios, solvents, suspension ageing, kinetics of hydrolysis and condensation, drying processes, cracks formation, and crystalline transitions during the laser sintering post-treatment are presented as analytical variables for the overall understanding of the film formation theory of the coatings and further design/control of coating compositions and properties. A major part of characterisation is done by carrying out rheological studies on the coating suspensions, while the microstructure of the green body of the coating is analysed using scanning electron microscopy (SEM).

Poster 43: Geometrical Accuracy of NiTi Shape Memory Parts Produced by Laser Powder Bed Fusion

Saeed Khademzadeh, Paolo Bariani, Simone Carmignato
University of Padova, Italy

Abstract: Nickel-Titanium shape memory alloys (Nitinol) are promising for biomedical applications such as stents and bone substitutions. Conventional production routes like subtractive manufacturing are quite challenging for manufacturing of porous NiTi. In this research, selective laser melting (SLM) as a powder bed fusion technique was used to manufacture dense and porous NiTi parts. Two levels of SLM process parameters were proposed for production of singles phase austenitic Nitinol (B2-NiTi). The proposed sets of process parameters are in the same energy density range, composed of high laser parameters (HP: high laser power adjusted to high scanning speed) and low laser parameters

(LP: low laser power adjusted to low scanning speed). Using a combination of HP and LP parameters for boarder and internal regions of parts, novel porous architectures containing micro features were built up by arraying regular unit cells. Investigation of final products using micro-computed tomography (μCT) showed fairly acceptable compatibility between produced parts and predesigned models.

Poster 44: Porous Scaffolds Based on Triply Periodic Minimal Surface (Tpms) Manufactured by Different Additive Manufacturing Methods

Xin Zhang*, Rizhi Wang*, Dawei Wang**
**The University of British Columbia, Canada | **Southern University of Science and Technology*

Abstract: Additive manufacturing (AM) of porous bone scaffolds is an optimal solution to prevent stress shielding and enhance implant integration. The printing quality in terms of precisely matching the computer aided design (CAD) is still a challenging, it varies with different printing techniques. The present study compares three different AM techniques: stereolithography (SLA), fused deposition modeling (FDM) and metal 3D printing for their printing precision with the same designs. Two porous structures of 75% porosity (network diamond and Fischer Koch S) based on triply periodic minimal surfaces (TPMS) were fabricated. The real pore size, beam size and porosity were measured, and the printing quality of different AM techniques were compared. Compression test was used to study mechanical behavior of porous structures and SEM was used for monitoring failure mechanism and surface qualities. This work focuses on the main manufacturing issues on 3D printing and explores how printing quality of different techniques influence the porous scaffold's fabrication. A novel structure Fischer Koch S is also introduced in this application and compared with classic diamond structure.

Notes:

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Contact:

Farzad Liravi
(519) 888-4567 Ext. 36765
fliravi@uwaterloo.ca

Phone Numbers:

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