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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.

Ehsan Toyserkani
Network Director
Conference Co-chair

Steve Cockcroft
Conference Co-chair

Ralph Resnick
Chairman of the Board

Sponsors and Exhibitors

LEAD SPONSORS

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

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

PLATINUM SPONSORS

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

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.americmakes.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.amc.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.
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.

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.

<table>
<thead>
<tr>
<th>MEETING</th>
<th>DATE</th>
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<tbody>
<tr>
<td>Scientific Advisory Committee</td>
<td>June 26</td>
<td>5:40pm – 6:40pm</td>
<td>Farzad Liravi <a href="mailto:fliravi@uwaterloo.ca">fliravi@uwaterloo.ca</a></td>
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<tr>
<td>TraCLight-HiptSLAM</td>
<td>June 27</td>
<td>2:10pm – 3:10pm</td>
<td>Gregor Graf <a href="mailto:g.graf@rosswag-engineering.de">g.graf@rosswag-engineering.de</a></td>
</tr>
<tr>
<td>Board of Directors</td>
<td>June 27</td>
<td>4:00pm – 5:00pm</td>
<td>Farzad Liravi <a href="mailto:fliravi@uwaterloo.ca">fliravi@uwaterloo.ca</a></td>
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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

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 80 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

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.

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Presentation Title: Innovative Aerospace and Space Structures made by Additive Manufacturing
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 (ETS), 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:
8:00-8:30am  BREAKFAST

8:30-8:40am  CONFERENCE OPENING – Location: Great Hall South
Santa Oro, UBC President and Vice Chancellor
James Dixon, Dean of the UBC Faculty of Applied Science
Ehsan Toosyarkani, HI-AM Director

8:40-9:20am  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 Buchlin  KBB, Germany

9:40-10:00am  Presentation 2: Low Cost, Medium-Speed Stereovision for Spatter Tracking in Powder Bed Fusion
Eric MacDonald  University of Idaho, United States

10:00-10:20am  Presentation 3: Efficient Parameter Development Strategy of Tool Steel Materials for Laser Additive Manufacturing
Gregor Graf*, Manuela Leon**, Tobias Muller, Jörg Fischer-Buhner, Daniel Beckerten*, Iwen Donisi*, Frederik Zanger**, Volker Schütt**  *Rosswag GmbH, Germany | **Karlsruhe Institute of Technology, Germany

10:20-10:40am  MORNING TEA, POSTER AND EXHIBITION VIEWING

10:40-11:20am  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 Alloysed Titanium by Selective Laser Melting
Igor Nadrizhte*, Ina Nadrizhte**, Pavel Krahmalev**, Anton du Plessis**, Eric Nealaby*, Dean Koupershto*  *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 TiAlloy Fan Blades
Perti Wanjara*, Javad Gholipour*, Kosuke Watanabe**, Koji Nezaki**  *Central University of Technology, South Africa | **Karlstud University, Sweden | ***Stellenbosch University, South Africa

12:00-12:20pm  Presentation 6: Development of Metal Slurry Three-Dimensional Printing System Based on Meeless Projection Method
Cho-Pei Jiang*, Shin-Liang Chiang**  *National Taipei University of Technology, Taiwan | **National Formosa University, Taiwan

12:20-12:40pm  SESSION 3: MATERIAL DEVELOPMENT I
Chair: Paul Bishop  Location: Great Hall South

12:40-1:00pm  Presentation 7: Effect of Powder Attributes on Microstructure and Mechanical Properties of 3D-printed AlSi10Mg Alloy Using Laser Powder Bed Fusion Technique
Yahid Fahal*, Qinghong Zhang*, Mark Galletta**, Mark Queen's University, Canada

1:00-2:00pm  SESSION 4: ADVANCED PROCESS MODELING I
Chair: Dan Maijer  Location: Room 2301

1:20-1:40pm  Presentation 8: Development of Modified AB and 87 Tool Steel Powders for Additive Manufacturing by LP-AM
Denis Mutel, Carl Blais  Université Laval, Canada

1:40-2:00pm  Presentation 9: Studying the Impact of Particle Morphology on Powder Spreading and Laser Powder Bed Fusion Characteristics to Maximize the Process Productivity
Sahel Edin Birka, Morgan Lekensmann*, Christopher Alex Gor*, Vladimir Brailovski**  *ETIS Montreal, Canada | **University of Waterloo, Canada | ***Silesia, Canada

2:00-2:20pm  Presentation 10: Selective Electron Beam Melting of Al-Cu-Mg Alloy: Processability and Characterization
Mohammad Saleh Kenevisi, Feng Lin  University of Waterloo, China

2:20-2:40pm  SESSION 5: PROCESS MONITORING AND CONTROL I
Chair: Mihaela Vlase  Location: Room 2301

2:40-2:40pm  Presentation 11: In-situ Melt Pool Monitoring of Laser Powder-bed Fusion
Kakweis Tehalilawan*, Zheng Ma*, Emad Sheydaian*, Ali Ghods*, Martin Otto**, Christopher Eischer**, Ehsan Toyserkani**  *University of Waterloo, Canada | **MPI Energie, Germany

2:40-3:00pm Presentation 12: Topology Optimization of Support Structures for Laser Powder-bed Fusion Based on the Inherent Strain Method

3:00-3:20pm  Presentation 13: A Fast and Part-level Numerical Simulation of Temperature Field in Selective Laser Melting Process
Zhibo Liu, Fionia Zhao  McGill University, Canada

3:20-3:40pm  Presentation 14: Fast-to-run Predictive Model for Thermal Fields During Additive Manufacturing
Meat Uppalhyay, Daan Maijer, Steve Cockcroft  The University of British Columbia, Canada

3:40-4:00pm  Presentation 15: Selective Laser Melting of Ni-based Laser Powder-beded Components: Influence of Porous Bone Replacement Implants
Ashita El-Emin*, David Malanczan**, Meisam Asgari*, Liu Lu*, Daan Maijer  *McGill University, Canada | **University of British Columbia, Canada

4:00-4:20pm  AFTERNOON TEA, POSTER AND EXHIBITION VIEWING

4:20-5:00pm  SESSION 6: NOVEL AM PROCESSES AND PRODUCTS I
Chair: Valhid Falah  Location: Great Hall South

4:40-5:00pm  Presentation 16: In-situ Sensing and Measurement for Quality Control in Metal Additive Manufacturing: Review and Future Directions
Thomas Latimer*, Tanya Wolfe**, Hari Heniek*, Ahmad Qureshi**  *University of Alberta, Canada | **AVI, Alberta, Canada

5:00-5:20pm  Presentation 17: Cost Effective Real-Time Thermal Dynamics Modeling in Laser Materials Processing
Lucas Boido*, Arif Khajapour  University of Waterloo, Canada

Neda Mohammadian*, Pavlos Katsikas*, Kostas Kalliatis*, Mark Droukides**  *ETIS Montreal, Canada | **École Polytechnique de Montréal, Canada

5:40-6:00pm  SESSION 7: MATERIAL DEVELOPMENT II
Chair: Paul Bishop  Location: Great Hall South

6:00-6:20pm  Presentation 19: Machine Learning Aided Optimization of Conformal Cooling Channel
Zhenyang Gao, Fiona Zhao  McGill University, Canada

6:20-6:40pm  SESSION 8: ADVANCED PROCESS MODELING II
Chair: Dan Maijer  Location: Room 2301

6:40-6:50pm  Presentation 20: Hybrid Additive Manufacturing and Casting Processes for Non Ferrous Alloys
Awalee Sabouraud, Anita Bossis, Abdoul-Kazim Bogno, Hari Heniek, Ahmed Qureshi  University of Alberta, Canada
Session 7: Material Development II
Chair: Ahmed Qureshi
Location: Room 2301
9:10-9:30am Presentation 23: Fabrication of Rene 41 Parts with Laser Powder Bed Fusion
Sila Kalyati*, Kevin Puckrada**, Mathieu Brochu*
*McGill University, Canada | **DALhouse University, Canada
Presentation 27: Geometric Deviations of Laser Powder Bed Fused AISI310Mg Components: Numerical Predictions Versus Experimental Measurements
Florene Zong®, Charles Simonneau®, Anatoile Timcen®,
Antoine Tahari®, Vladimir Brailovski*
ET3 Montreal, Canada | **SimuTech Group, Canada
9:30-9:50am Presentation 24: Particle Decoration: A Method for Developing New Material for Additive Manufacturing
Ehsan Moosazadeh, Yahya Mahmodkhani*, 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
Dania Sara Eyaat, Josiah van Houtum, Mihalisa Vlasea
University of Waterloo, Canada
9:50-10:10am Presentation 25: Electrostatic Atomization of Metals
Bilal Bhuradia, Abdul-Alli Begi, Hanin Hanek
University of Alberta, Canada
Presentation 29: Temperature Fluctuations at Boundary Points in Laser Powder Bed Fusion
Emre Ozdogan, Mary Walls
University of Waterloo, Canada
10:10-10:30am Presentation 26: Implementation of the Kikagawa-Takahashi Approach for Prediction of Laser Power Limit of Inconel 625 Components Containing Intentionally-seeded Defects
Jean-Rene Poulin, Patrick Temault, Vladimir Brailovski*
ET3 Montreal, Canada
Presentation 30: Design of a Test Artfaptcha to Evaluate Critical Design Features for Ti-RAI-6V Parts in Electron-Beam Melting Additive Manufacturing (EBAM)
Otarijal Sharbhag, Mihalisa Vlasea
University of Waterloo, Canada
10:30-10:50am MORNING TEA, POSTER AND EXHIBITION VIEWING
Session 9: Advanced Process Modeling II
Chair: Marian Moliari-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: Microneedle Interaction Between the Laser and Metal Powder in Powder-bed Additive Manufacturing
Ehsan Mozaffari, Yahya Mahmodkhani*, Ehsan Toyserkani*
University of Waterloo, Canada
Hongxia Wang, Yu Zou
University of Waterloo, Canada
Presentation 37: Evaluation of Additive Manufacturing for Repair and Remanufacturing Purposes
Faith Sikari*, Priti Wanjara*, Jawaad Shilpouri**, Mathieu Brochu*
McGill University, Canada | **DALhouse University, 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 38: Laser Powder Bed Fusion of AISI310Mg for Fabrication of an Aluminum Transmission Pump Housing
Lisa Brock, Hamed Asgari, Mihaela Vlasea
University of Waterloo, Canada
Eike Nishimura, Steve Liddickoff, Daan Majier, Farzaneh Farhang Mehr
The University of British Columbia, Canada
Presentation 39: Direct Laser Deposition of Ti-SiAl-5V-5Mo-3Cr Alloy
Xixin Cao, Alexander Bois-Brochu**, Jawaad Shilpouri**
*National Research Council of Canada | **DALhouse University, Canada
11:50am-12:10pm Presentation 34: Normative Benchmark Design and Preliminary Geometric Quality Results for Selective Laser Melting Process
Bashir Singh, Arif Sezani, Ahmed Qureshi
University of Alberta, Canada
Presentation 35: Numerical Analysis of Melt Geometry in Laser Powder-bed Fusion of Hastelloy X
Shan Nakashima, Ehsan Toyserkani
York University, Canada
Presentation 36: Predicting Defects in 3D Printed Lattice Structures
Shahin Nekoozpa, Ehsan Toyserkani
University of Waterloo, Canada
12:10-12:30pm Presentation 37: Integrated Solution for Additive Manufacturing: Numerical Prediction and Additive Manufacturing
Ehsan Toyserkani*
University of Waterloo, Canada
Presentation 40: Predicting Defects in 3D Printed Lattice Structures
Shahin Nekoozpa, Ehsan Toyserkani
University of Waterloo, Canada
12:30-1:10pm LUNCH
Session 11: Material Development III
Chair: Hani Heimich Location: Great Hall South
Session 12: Advanced Process Modeling and Novel AM Processes
Chair: Priti Wanjara Location: Room 2301
1:10-1:50pm Presentation 41: Correlating the Columnar Grain Structure with the Anisotropic Mechanical Response of Hastelloy X Produced by Laser Powder-bed Fusion
Ali Kashkawalzarian*, Reza Esmaeilzadeh*, Shahriar Imani*,
Hamidjahed Motlagh*, Norman Zhao*, Ali Bonakdar**
*University of Waterloo, Canada | **Siemens, Canada
Presentation 45: Laser Powder Bed Processing of Aluminum Powders Containing Iron and Nickel Additions
Greg Swat*, Jon Hierathy*, Ian Donaldson**,
Mathieu Brochu**, Paul Bishop*
*McGill University, Canada | **Dalhouse University, Canada
1:50-2:10pm Presentation 42: Tool Path Related Process Planning Challenges for Direct Energy Deposition Systems
Bob Hackrick**, Ali Urbanic**
*CAMFerturing Solutions Inc., Canada | **University of Windsor, Canada
Presentation 46: Tool Path Related Process Planning Challenges for Direct Energy Deposition Systems
Bob Hackrick**, Ali Urbanic**
*CAMFerturing Solutions Inc., Canada | **University of Windsor, Canada
2:10-2:30pm Presentation 43: Application of Fast Cooling Calorimetry in AM
Shi Fur*, Piems Hudson*, Paul Bishop**, Mathieu Brochu*
*McGill University, Canada | **Dalhouse University, Canada
Presentation 47: Selective Laser Melting of Graphene-reinforced Aluminum Matrix Composites for Electrical Batteries
Masafeta Yaseki, M. A. Elbestawi
McMaster University, Canada
2:30-2:50pm Presentation 44: Selective Laser Melting of Copper, Aluminum, and Copper-Aluminum Alloy
Hao Kun Sun, Yu Zou, Giselle Adzmi
University of Toronto, Canada
Presentation 48: Influence of Operating Parameters During Plasma Transferred Arc Additive Manufacturing on Carlsbed Concentration of 70/30 Ni-WC Metal Matrix Composite Components
Sitar Raisa*, Tonny Wolfe**, Hani Heimich*, Lejla Lepadatu*
*University of Alberta, Canada | **Incotech, Alberta, Canada
2:50-3:10pm AFTERNOON TEA, POSTER AND EXHIBITION VIEWING
Presentation 45: Laser Powder Bed Processing of Aluminum Powders Containing Iron and Nickel Additions
Greg Swat*, Jon Hierathy*, Ian Donaldson**,
Mathieu Brochu**, Paul Bishop*
*McGill University, Canada | **Dalhouse University, Canada
Presentation 49: Integration of Physically-based Analytical Model and Statistically-driven Empirical Model for Multi-objective Optimization of Laser Powder-bed Fusion
Yaze Yuan, Hamed Aghaei, Mohammad Ansari,
Behrad Khamesee, Ehsan Toyserkani
University of Waterloo, Canada
Presentation 50: Progress in Applying Fused Filament Fabrication to Metal Matrix Composites (MMC)
Nancy Bhardwaj*, Hani Heimich*, Lejla Lepadatu*
*University of Alberta, Canada | **Incotech, Alberta, Canada
3:30-3:50pm Presentation 46: Laser Powder Bed Processing of Aluminum Powders Containing Iron and Nickel Additions
Greg Swat*, Jon Hierathy*, Ian Donaldson**,
Mathieu Brochu**, Paul Bishop*
*McGill University, Canada | **Dalhouse University, Canada
Presentation 51: Integration of Physically-based Analytical Model and Statistically-driven Empirical Model for Multi-objective Optimization of Laser Powder-bed Fusion
Yaze Yuan, Hamed Aghaei, Mohammad Ansari,
Behrad Khamesee, Ehsan Toyserkani
University of Waterloo, Canada
3:50-4:00pm CLOSING REMARKS AND AWARDS – Location: Great South Hall
4:00-5:00pm BOARD OF DIRECTORS MEETING – Location: Robert H. Lee Boardroom Alumna Centre
THEME 1 - MATERIAL DEVELOPMENT

Poster 1: Innovative Surface Finishing Methods for Reducing Internal and External Surface Roughness of Metal Additive Manufacturing Parts
Hannah Fasafar, Mihalas Vesse, Ehsan Toyserkani
University of Waterloo, Canada

Poster 2: The Contribution of Moisture from Cellulosic Filters in LPBF AM
Amir Keshavarzkermani, Reza Esmaeilizadeh, Shahriar Imani, Mechanical Response of Hastelloy X Produced by Laser Powder-bed Fusion
*University of Alberta, Canada | **Chalmers University of Technology, Sweden

Poster 3: Mechanical Properties of Additively Manufactured Tessellated Metamaterial Design Configurations
Anastasia Wokeler, Hari Nagudi
University of Toronto, Canada

Poster 4: Improving Surface Finish of Low-cost Irregular Powders in Laser Powder-bed Fusion
Seung Ho Jeong, Sagar Patel, Allan Rogalski, Mihalas Vesse, Adrian Oracz, Mary Wells
University of Waterloo, Canada

Poster 5: Reactive Sintering for Post-processing of Binder jet Additive Manufacturing Behavior
Tapas Ranadive, Pradeep Desmukh, Zhihong Zhang, Ehsan Toyserkani
University of Waterloo, Canada

THEME 2 - ADVANCED PROCESS MODELING

Poster 6: Evaluation of Residual Stresses Induced in Laser Powder-bed Fusion Additive Manufacturing Process: Finite Element Simulation and Experimental Investigation
Marjan Malavi-Zarandi*, Ali Banadaki**, Ramin Sedaghat***
*National Research Council of Canada-Boucherville | **Concordia University

Poster 7: Control of Density and Microstructure in Laser Powder Bed-fused Components Using a Combination of Melt Pool Modeling and Design of Experiment Approaches
Morgan Letournet, Aleena Kreitzberg, Vladimir Brailovsky
ETS Montreal, Canada

Poster 8: Adaptive Trajectory Planning for Direct Energy Deposition Using Tri-Doseal Model
Farzaneh Kaji*, Ehsan Toyserkani**
*ETS Montreal, Canada | **University of Waterloo, Canada

Poster 9: Mechanics of Additively Built Porous Biomaterials
Ahmad Surajuddin, Arna El Emh, David Melancon**, Damiano Passini**
*MCIU University, Canada | **Harvard University, United States

Poster 10: Topology Optimization of Structures Under Design-dependent Pressure Loads
Poyun Ralafinar, Orazua Ekwokidide, Zhihong Zhang, Ehsan Toyserkani
University of Waterloo, Canada

Poster 11: Effect of Rapid Solidification on Microstructure and Properties of Al-33wt%Cu Eutectic
Dariana D'Az, Abdool-Aziz Bogo, Ionas Valtonen, Hari Hameen
University of Alberta, Canada

Poster 12: Processing of Ti-64 by Laser Powder Bed Additive Manufacturing
Nick Loos*, Ian Donaldson**, Kevin Paulmert, Paul Bishop**
*Dalhousie University, Canada | **McGill University, Canada

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

Poster 14: Rapid Solidification of Al-Si Alloys
Arianeh Saffa, Abdool-Aziz Bogo, William Allery**, Hari Hameen
*University of Alberta, Canada | **Dalhousie University, Canada

Poster 15: Correlating the Columnar Grain Structure with the Anisotropic Mechanical Response of Hastelloy X Produced by Laser Powder-bed Fusion
Ali Hamedanikermani, Pascale Desbonnay, Shahrar Imam, Hamid Jafet Mottagh, Norman Zhou, Ehsan Toyserkani
University of Waterloo, Canada

THEME 3 - PROCESS MONITORING AND CONTROL

Poster 16: Literature Survey of Laser Ultrasonic Imaging Techniques Applicable to Defect Detection in Metal Additive Manufactured Parts
Alexandre Martinez-Marchesse, Ehsan Toyserkani
University of Waterloo, Canada

Poster 17: Leveraging Keyhole Mode Melting Models in Laser Powder Bed Fusion
Sagar Patel, Mihalas Vesse
University of Waterloo, Canada

Poster 18: Detection of Internal Defects and Surface Cracks in Additively Manufactured Conductive Parts by Eddy Current Technique
Helia Faraj, Behzad Khamse, Ehsan Toyserkani
University of Waterloo, Canada

Poster 19: Modelling of Powder Spreading to Optimize Compaction Consistencies
Alexander Goren, Mihalas Vesse, Kaan Erkorkmaz
University of Waterloo, Canada

Poster 20: Anisotropic Finite Element Modeling of an Aluminum Alloy Made by Additive Manufacturing
Henrique Ramal*, Rafael Santago*, Marcelo Alves**, Petr Theobald***, Lea Soe***
*Federal University of ABC, Brazil | **University of Sao Paulo, Brazil | ***University of Dundee, United Kingdom

Poster 21: Investigation of Binder Deposition and Infiltration Strategies for Binder Jetting
Marc Wang, Ken Nsiempba, Mihalas Vesse
University of Waterloo, Canada

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

Poster 23: Numerical Model of Al-33wt%Cu Eutectic Growth During Impulse Atomization
Jonas Wolsten, Abdool-Aziz Bogo, Hari Hameen
University of Alberta, Canada

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

Poster 25: MSI-scale Thermal, Elastic and Plastic Strain Evolution in Pb-EBBM
Aminollah Rahimi, Farzaneh Farhang-Mehr, Daan Maijer, Steve Cockroft
The University of British Columbia, Canada

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

Poster 27: Beam/Power/Melt Pool Interaction; Experimental Validation
Amir Rakhshpanah, Farzaneh Farhang-Mehr, Daan Maijer, Steve Cockroft
The University of British Columbia, Canada

THEME 4 - NOVEL AM PROCESSES AND PRODUCTS

Sande El Moghaz*, Hari Harin*, Tony Wolff**, Leijn Lej***
*University of Alberta, Canada | **LosAlto-Alberta, Canada | ***University of Melbourne

Poster 29: Strategies for Binder Jetting
Peter Theobald***, Shwe Soe***
*University of Dundee, United Kingdom | **University of British Columbia, Canada

Poster 30: Detection of Internal Defects and Surface Cracks in Additively Manufactured Conductive Parts by Eddy Current Technique
Helia Faraj, Behzad Khamse, Ehsan Toyserkani
University of Waterloo, Canada

Poster 31: Modelling of Powder Spreading to Optimize Compaction Consistencies
Alexander Groen, Mihalas Vesse, Kaan Erkorkmaz
University of Waterloo, Canada

Poster 32: Anisotropic Finite Element Modeling of an Aluminum Alloy Made by Additive Manufacturing
Henrique Ramal*, Rafael Santago*, Marcelo Alves**, Petr Theobald***, Lea Soe***
*Federal University of ABC, Brazil | **University of Sao Paulo, Brazil | ***University of Dundee, United Kingdom

Poster 33: Current-controlled Line Energy - Porosity Relation for EBAM of Ti-6AI-4V
Frederick Uckan**, Chadrack Sincila**, Heinz Voggenmüller**,***
*University of Stuttgart | **The University of British Columbia | ***UBC

Poster 34: Current-controlled Line Energy - Porosity Relation for EBAM of Ti-6AI-4V
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*University of Stuttgart | **The University of British Columbia | ***UBC

Poster 35: Current-controlled Line Energy - Porosity Relation for EBAM of Ti-6AI-4V
Frederick Uckan**, Chadrack Sincila**, Heinz Voggenmüller**,***
*University of Stuttgart | **The University of British Columbia | ***UBC

Poster 36: Current-controlled Line Energy - Porosity Relation for EBAM of Ti-6AI-4V
Frederick Uckan**, Chadrack Sincila**, Heinz Voggenmüller**,***
*University of Stuttgart | **The University of British Columbia | ***UBC

Poster 37: Nanocomposites for Hygroscopic Sensing and Actuation
Farzaneh Kaji*,**, Vadim Kozhevnikov*,**, Ehsan Toyserkani*
*McGill University, Canada | **Harvard University, Bosnia

Poster 38: Development of an Anisotropic Dielectric Material for AM Manufacturing
Farzaneh Kaji*,**, Vadim Kozhevnikov*,**, Ehsan Toyserkani*
*McGill University, Canada | **University of Waterloo, Canada

Poster 39: The University of British Columbia, Canada

Poster 40: Processing Conditions of 17-4 PH using Plasma Transfer Arc Additive Manufacturing
Sandy El Moghaz*, Hari Harin*, Tony Wolff**, Leijn Lej***
*University of Alberta, Canada | **LosAlto-Alberta, Canada | ***University of Melbourne

Poster 41: Nanointervention Studies of Double-phase Ti-6AI-2Zr-3Mo Alloys Made by Additive Manufacturing
Zhihua Li, Mine, Ken T. N. University of Toronto, Canada

Poster 42: Dip Coating of Tool Steel H13 with Ti-C3AI Cermet Suspensions, and Their Subsequent Laser Cladding
Zhihua Li, Mine, Ken T. N. University of Toronto, Canada

Poster 43: Geometrical Accuracy of Niti Shape Memory Parts Produced by Laser Powder Bed Fusion
Saeed Khademzadeh, Paolo Barlini, 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*, Rithi Wang*, Dawei Wang**
*The University of British Columbia, Canada | **Southern University of Science and Technology, China
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 integrate 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 processes. 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. The presentation will review several KSB case studies for additively produced parts, including a review of a 2-year field test application – Aluminium cast housing for an electric race car – and discuss 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 manufacturers new freedoms for metallic structures and complex geometries in high performance materials. The aerospace industry has identified the inherent benefits of AM but not 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 quality-as-you-go methodology. In this study, a pair of low-cost medium-speed stereo cameras are integrated and synchronized together to provide stereovision in order to identify the size, shape and age of spatter ejected from the laser melted pool. The driving hypothesis of the effort is that the measured behavior of spatter can be reliably captured in order to inform some of the process issues and ensure that the spatter is not contaminating the build or obscuring the laser. Opportunities, future work and challenges are discussed.
Abstract: During takeoff and landing of gas turbine aero-engines at high speeds, the ingestion of bird carcasses or 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 in metallic blades. Depending on the severity of the impact, the ensuing damage on the blades can result in localized dents (micro to macro plastic deformation), stress-raisers, premature crack initiation, material loss, or even immediate fracture. To prevent catastrophic failure, active-engine, intake-trap, trap housing, and ingestion maintenance and repair procedures to detect and refurbish or replace damaged blades. A commonly applied repair scheme to refurbish these damaged parts, especially on titanium alloy airfoil blades involves preparing a repair patch – by stamping, rolling or forming 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 this 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-Wei Jiang*, Shinn-Liang Chang**
*National Taipeh University of Technology, Taiwan | **National Formosa University, Taiwan

Abstract: Digital light processing (DLP) is a good projection tool as light engine for polymerisation three-dimensional printing. This work aims to develop the commercial maskless additive manufacturing machine for aerospace and ceramic parts. However, few reports can be found in making metal parts. This study aims to synthesize a metal slurry with good wettability and low viscosity to be used in DLP-type 3DP. The slurry consists of trimethylolpropane triacylate (TMPTA) and monomer-grade talc powder of Inconel 718 alloy. Experimental results show that viscosity of initial slurry is 6802 mPa·s and decreases to 1930 mPa·s after ball milling treatment for 48 hours with 150 RPM. The maximal curable thickness of slurry is about 25 μm. A 10 mm cubic with uniform porosity is designed and printed 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 AlSi10Mg Alloy using Laser Powder Bed Fusion Technique Vahid Falagh, Qinghao Dong, Mark Gall peanuts Queen’s University, Canada

Abstract: High-Si Al-Si alloys (e.g. 7-12 wt.% Si) are attractive choice for weight-saving metal 3D printing applications. While being light-weight, these alloys exhibit high mechanical properties in the as-deposited (or the as-cast) state. This is 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 AlSi10Mg alloy has been the past few years a focus on process optimization for higher mechanical performance of AlSi alloys. However, the attention has been given to the effect of powder attributes such as size distribution, powder morphology, uniformity of chemicals, and among the wide range of properties. In this work, the powder attributes were chosen to evaluate the two different batches of AlSi10Mg powders to study the effect of powder attributes: (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 lamellar structure, and (3) build mechanical properties such as microhardness, tensile strength, ductility (percent elongation) and fracture toughness.

3:00pm
Presentation 8: Development of Modified AlSi and 3D Tool Steel Powder for Laser Powder Bed Fusion Technology Denis Mutel, Carl Blais Universite Laval, Canada

Abstract: 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, AlSi7 constitutes a versatile alloy particularly well suited for this purpose for both cold and hot work. The objective of this project is to develop novel water-aerosolized 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 (LPBF-AM). Thermomechanical calculations were carried out to identify the effect of chemistry modifications on the type and proportion of the different solidification phases and the resulting microstructure as a function 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 lamellar structure, and (3) build mechanical properties such as microhardness, tensile strength, ductility (percent elongation) and fracture toughness.

3:30pm
Presentation 9: Studying the Impact of Particle Morphology on Powder Spreading and Processing Characteristics to Maximize the Process Productivity Salah Eddin Brika*, Morgan Letteaux**, Christopher Alex Dion**, Vladimir Brailovski*
*Universite Laval, Canada | **University of Waterloo, Canada | ***University of Toronto, Canada

Abstract: The laser powder bed fusion process (LPBF) being sensitive to variations in microstructure and particle size distribution, yet the link between the powder characteristics and the process performances is still not well established, thus complicating the development and quality control of LPBF feedstock. In this study, three Ti6Al4V powder lots, with comparable particle size distributions (d10=25, d50=38 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 from different sources, 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, the Laser Powder Bed Fusion process was concurrently evaluated using Hall and Gustavsson flowmeters and an FT4 Freeman powder rheometer. Studying the impact of powder characteristics on the LPBF process, this paper will be aimed to predict the melt pool propagation and solidification of LPBF specimens built with different layer thicknesses (30 and 60 μm) and different printing parameters (build rates of 18 and 44 cm³/h) allowed the selection of a powder lot maximizing the process productivity, while guaranteeing an optimal build of the part. In conclusion, this study predicts the mechanical and geometric features of printed components.

4:00pm
*Changzhou University | **University of Waterloo, Canada | **Siemens, Canada

Abstract: Additive manufacturing of metal 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 successfully 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 additive manufacturing processes for AM are selective or near-eutectic alloys, containing Si as the main alloying element. However, using high-strength aluminum alloys for AM has 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 it is not affected by reflectivity of metal powders, along with the advantage of oxidation inhibition in vacuum. In this study, Aluminum alloy ESM was performed and the influence of processing parameters on the internal defects formation was studied. Density measurement and microstructural analysis of the produced parts were carried out with fine polishing and equipped 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 Laser Powder Bed Fusion Additive Manufacturing of Residual Stress Jean-Sebastien Cagnone, Jean-Philippe Marcotte, Marjan Molavi-Zarandi, Florin Ilinca, Kabanemi Kalonji Kabaa* *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 a powder layer. However, the inherent 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 build orientation. In this paper, a new topology optimization model has been proposed that the residual stress within the printed part is incorporated in the topology optimization. Using this proposed topology optimization model, a novel multiscale modelling approach has been developed for this three-dimensional (3D) layer-by-layer manufacturing process. A new support structure model has been introduced to predict the melt pool size and temperature profiles. Subsequently, a 3D thermo-elasto- visco-plastic numerical model has been developed to interpret the residual stresses and distortions. An extensive experimental investigation has also been conducted to support and validate the developed FE models.

3:30pm
*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 a powder layer. However, the inherent 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 build orientation. In this paper, a new topology optimization model has been proposed that the residual stress within the printed part is incorporated in the topology optimization. Using this proposed topology optimization model, a novel multiscale modelling approach has been developed for this three-dimensional (3D) layer-by-layer manufacturing process. A new support structure model has been introduced to predict the melt pool size and temperature profiles. Subsequently, a 3D thermo-elasto- visco-plastic numerical model has been developed to interpret the residual stresses and distortions. An extensive experimental investigation has also been conducted to support and validate the developed FE models.

3:40pm
Presentation 13: A Fast and Partial-Level Numerical Simulation of Temperature Field in Selective Laser Melting Process Zhibo Luo, Fionia Zhao, Mingzeng Mei* *National Research Council of Canada—Montreal

Abstract: In selective laser melt process an accurate prediction of the transient melt 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, accurate and reliable in-situ measurement and monitoring system and µ CT scanner. The simulation results are compared with experiment results. It is shown that melt pool characteristics such as the length and time scales involved and can sometimes take computationally expensive because of the highly disparate numerical simulation scheme is not suitable for this layer-by-layer approach, peak temperatures and melt pools dimensions in a region of interest for real time calibration. The model will use this data to estimate the thermal fields during AM. In this paper, 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 lattices, presented a new challenge, the control and effects on mechanical and metallurgical properties of the final casting will be discussed.

**Abstract:**

Metal additive manufacturing (AM) is a novel manufacturing process in which parts are fabricated layer by layer, which allows for products to be designed and manufactured in a free-form manner. AM has therefore gained a considerable interest and importance in the past years. Currently, the manufacturing industry’s interest in AM is driven by various reasons, ranging from cost savings and 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 microstructure propagation among a part. Since the temperature field is controlled by many process variables, accurate and reliable in-situ measurement and monitoring system and µ CT scanner. The simulation results are compared with experiment results. It is shown that melt pool characteristics such as the length and time scales involved and can sometimes take computationally expensive because of the highly disparate numerical simulation scheme is not suitable for this layer-by-layer approach, peak temperatures and melt pools dimensions in a region of interest for real time calibration. The model will use this data to estimate the thermal fields during AM. In this paper, 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 lattices, presented a new challenge, the control and effects on mechanical and metallurgical properties of the final casting will be discussed.

**5:20pm**

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

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

**Abstract:**

Modeling in Laser Materials Processing 5:00pm

Zhenyang Gao, Fiona Zhao  
University of Waterloo, Canada

**Abstract:**

Conformal Cooling Channel

Presentation 19: Machine Learning Aided Optimization of Conformal Cooling Channel

Zhenyong Qu*, Jian Ma**

**Abstract:**

The plastic injection molding process is commonly used to fabricate parts with various geometries. During a production cycle, certain parameters like the temperature of defects can negatively impact the quality of a part. Additive Manufacturing (AM) technology allows designers to design very complex channels with very little manufacturing support. Machine learning algorithms are used to derive an accurate material/process model to predict the defects severity with respect to the part geometry and different parameters of various cooling channel topologies. With this model, an optimal cooling channel design is derived for a specific part that is conformal to not only the part surface, but also the distribution of defects. Efficient and cost-effective conformal cooling design, lower temperature variance is achieved using the optimization method in this work. In addition, this study illustrates the correlation between the cooling channel parameters and sand casting defects. Nevertheless, with conventional mould manufacturing process, true conformal cooling channel is very difficult to achieve due to the melting and solidification of metal material with respect to the part geometry and different parameters of various cooling channel topologies. With this model, an optimal cooling channel design is derived for a specific part that is conformal to not only the part surface, but also the distribution of defects. Efficient and cost-effective conformal cooling design, lower temperature variance is achieved using the optimization method in this work. In addition, this study illustrates the correlation between the cooling channel parameters and sand casting defects.
Presentation 22: Surface Finishing of Titanium and Nickel-Based Ultra-Fused Bed-Fused Components: Abrasive Flow Machining Versus Electrochemical Polishing
Neda Mohammadzadeh*, Victor Urieu*, Clement Bouland*, Sylvain Turineau*  
*ETS Montreal, Canada  **Ecole Polytechnique de Montreal, Canada

Abstract: Almost all 3-D printed metal components require surface finishing to meet the end-use requirements. This work focuses on two techniques for surface finishing of internal passageways of 3-D printed components: Abrasive Flow Machining (AFM) and Electrochemical Finishing (EF). AFM allows polishing components with intricate geometries with no sacrificial material. The primary limitation of this process is limited to relatively large channels due to high viscosity of the media used. EF is a good candidate for polishing small and medium size tubular and flat components with complex shapes. However, EF presents challenges in designing electrodes, polishing multi-phase alloys and removal of rough surface defects. In this project, a 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 differentially-oriented surfaces after the AFM and EF operations. It was shown for example that to reach a uniform roughness of Ra = 6.3 μm on Ti-6Al-4V components with variable-oriented surfaces, the EF allowances need to be twice as high as the corresponding AFM allowances (EP=330 μm vs AFM=150 μm). For IN625 components however, the same result can be reached with the EF allowances four times as high as the AFM allowances (EP=240 μm vs AFM=60 μm).

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*  
*University of Waterloo, Canada  **University of Waterloo, 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, the y’ 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 precipitates were also investigated. Chemical properties in both 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 Marbanradan, Yahya Mahmoudizadi, Ehsan Toyskari  
University of Waterloo, Canada

Abstract: Recent developments in additive manufacturing (AM) have gained the need for tailoring the properties of different materials to fulfill the requirements of 3D printing technologies. This material modification may be achieved through wide range of deficiencies or demands such as new material development, enhancing the printability, and eliminating the printing defects. Some of the current data to date produces a tool adding only few percent of alloying elements to the main powder, which is used for printing technologies that employ powder bed fusion (PBF) process are effective in the additive on the surface of the particles of main powder seem 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 particle size and density was evaluated and the 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
Bhuli Babhara, Abdul-Aziz Bogno, Hani Henein  
University of York, Canada

Abstract: With the increased demand for metal powders especially in the additive manufacturing industry there is a need to find a new, reliable 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 powder mixture 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 not consistent with the performance of the equipment used or high cost of 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 the atomisation of metal droplets from a conductive nozzle by a high voltage electric field. The process allows for the management of the powder size and shape by adjusting the input parameters. Electrostatic atomisation provides an alternative process 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 particle size and density was evaluated and the results of this research provides a guide line for particle decoration design and introduce the limitations of this method.
minimum feature size, internal channels and structures suitable for biomedical applications. In terms of biomedical applications, constraints should be introduced with the help of pre-defined ranges of fabrication, minimum feature size of cell (for de-powdering purposes) etc. When not only stiffness features are concerned, the influence of microstructure and texture should also be investigated.

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

10:50am Presentation 31: Microscale Interaction Between the Laser and Metal Particle in Laser 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 advancements for producing high-value, complex, and customized components. Precise 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 the laser-powder interaction. We have identified different laser powers, layer thicknesses, and hatch spacings, we have systematically compared powders in two typical processing modes: conduction mode and keyhole mode. We have revealed the heat and mass balance in these two modes and demonstrated that it is only one circular flow in the longitudinal section of the molten pool in the conduction mode, while two circular flows present in the keyhole mode. In addition, the keyhole mode drives the melted metal to fill the gaps between the powders and contributes to the formation of the molten pool. Experimental results demonstrate that a large printable powder layer thickness is achieved in the keyhole mode than that in the conduction mode. The thermal distribution during the multi-track melting in the conduction mode is more uniform than that in the keyhole mode, leading to more uniform resulting microstructure. This study presents new insights into the interaction between the laser and metal particle in the AM process.

11:00am Presentation 32: A Predictive System for Manufacturability Analysis of Laser Powder Bed Fusion Process Ying Zhang, Fiona Zhao University of Toronto, Canada

Abstract: Laser-based additive manufacturing (LBF) process is one of the most promising AM technologies due to its ability to produce complex metal geometries. The fast development of LBF has opened new opportunities for the industries. Compared to the conventional manufacturing process, LBF offers more freedom on the shape complexity, material complexity, and hierarchical complexity. However, there are several limitations in the LBF process, one of the most prominent limitations is the complex geometric characterization methods, which make the design process more challenging. To overcome these issues, a feature-based methodology was developed to systematically design the BGTAs. The new methodology is based on selecting features based on the required GD&T characteristics, and the current geometric complexity is characterized. This allows the designers to use the proposed method to get the design requirements and to 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 BGTA design in selective laser melting (SLM) manufacturing and the corresponding GD&T results. The overall tolerance bands for the fabricated parts are defined, which were 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.

11:30am Presentation 33: Thermal Fluid Modelling for Melt Pool Process of TIGA618 Powder Bed in the Electron Beam Additive Manufacturing Eko Nishimura, Steve D’Crockfort, Daan Maier, Farzaneh Farhang-Mehr 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, two 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. In addition, height (depth and build up height) or volume based code. The model includes solid-liquid phase change, buoyancy, temperature dependency (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.

11:30am Presentation 34: Normative Benchmark Design and Prediction of 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 several limitations in the GBTAs and the geometric quality characterization methods, such as ignoring the standardized Geometric Dimensioning and Tolerancing (GD&T) characteristics, and the present geometric complexity is characterized by the standard deviation of the variation of the geometric tolerance. A new methodology is based on selecting features based on the required GD&T characteristics, and the current geometric complexity is characterized. This allows the designers to use the proposed method to get the design requirements and to 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 BGTA design in selective laser melting (SLM) manufacturing and the corresponding GD&T results. The overall tolerance bands for the fabricated parts were defined, which were 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.


*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 is widely used for parts that are produced using conventional techniques at very high cost. It requires designers to have a compromise in terms of both geometric tolerances and engineering specifications. In this context, the focus of our study is on 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 the Tri-Air-Ar-X and Ti-6Al-4V alloy was studied with various solidification-based additive manufacturing processes. Experimental results have been utilised to highlight the trends. 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 36: Investigating Residual Stress Characteristics for Selected Direct Energy Deposition Setups: P420 Steel Single Bead Deposition on Mild Steel Jill Urbanc*, 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 cycle, the non-equilibrium solidification process in laser cladding, residual stress is generated during the melting and solidification environment on repair integrity. Microstructural investigations of laser cladding and repair parts have been utilised to highlight the trends. Thermal history and phase development at the bonding interface and heat-affected zone (HAZ) for the different conditions evaluated will be discussed.


*McGill University, Canada | **National Research Council of Canada

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 repair processes. This is especially the case in this industry, where a 3D transient fully coupled thermal-metallurgical-potential of a failure, or a reduced fatigue life. This research is being 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. In addition, height (depth and build up height) measurements were performed on a metallographic sample and compared with experimental results. The temperature dependent material properties are implemented in the numerical model. Correl-Gausian heat source model has been adopted for predicting accurate melt pool dimensions. The effect of the laser parameters on the melt pool was investigated. In addition, temperature gradients and cooling rates in the melt pool were calculated. 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.

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

10:50am Presentation 38: Laser Powder Bed Fusion of AISI1045 for Fabrication of an Aluminum Transmission Pump Housing Lisa Brock, Hamed Asgari, Mihaela Vlasea University of Waterloo, Canada

Abstract: Additive manufacturing can provide several short term advantages, 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 a transmission pump housing with complex geometry was investigated. Process mapping for the printing of an AISI1045 on a modulated laser system was completed with the design of experiments having varying values for laser power, exposure time, and point distance. Metrolographic examination of the melt pool was completed on the metal using scanning electron microscopy. 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 to the lowest porosity and preferred microstructure. For comparing the existing aluminum pump housing manufactured by casting was also characterized in order to determine if laser powder bed fusion can achieve the same or better properties for the pump housing application in terms of both geometric tolerances and engineering specifications.
Session 11: Material Development III
June 27 | 1:50pm - 3:50pm | Great Hall South
1:50pm Presentation 39: Direct Laser Deposition of Ti-5Al-5V-3Mo-3Cr Alloy
Xin Jin Cao*, Alexander Bois-Brochu**, Jawad Gilhlouin* *National Research Council of Canada | **Centre de métallurgie du Québec, Canada
Abstract: Titanium alloys have widely been used in the aerospace industry due to their high specific strength and excellent corrosion resistance. However, aerospace components have 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-3Mo-3Cr (Ti-5553) is a relatively new metastable beta-titanium alloy that exhibits excellent strength properties, higher than the currently used alpha-beta titanium grades, such as Ti-6Al-4V. It's high strength-to-weight ratio can be attributed to its high mechanical strength while maintaining a high level of ductility. The current work is aimed at investigating the direct laser deposition technique for Ti-5553 alloy using Optomec LENS-450AL 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 Keshenpa, Ehsan Toysenkeri 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 a limiting factor, geometrically intricate parts can now be designed. Despite the adoption of lattice structures, an accurate and reliable method to predict their manufacturability is needed. Furthermore, simulating lattice structures can be an expensive process. 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 authors have demonstrated that the formability of lattice structures are found by modeling the printing process and the predictions are validated through experiments. Finally, the authors presented an artificial intelligence-based algorithm explaining how to take those predictions into consideration while designing lattice structures.

Session 12: Advanced Process Modeling and Novel AM Processes
June 27 | 1:50pm - 3:50pm | Room 201
1:50pm Presentation 41: 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 2D contour and raster fill strategies. This is a standard approach for 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 regions within a given layer. In this presentation, two conceptual approaches to overcome the buildability challenges with direct energy deposition systems will be presented.
2:10pm Presentation 42: Selective Laser Melting of Copper, Aluminum, and Copper-Aluminum Alloy
Hao Kun Sun, Yu Zou, Gisele Azimi University of Toronto, Canada
Abstract: Copper 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 copper-alloy aluminum alloy with improved corrosion resistance and mechanical properties has been widely manufactured by casting, forging, and powder metallurgy. Moreover, 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 the formation of Al carbide. This work will discuss the use of hybrid DSC to gain new insights into solidification events of Al alloys. The findings acquired in this research will show the technological innovation in the SLM of non-ferrous metal.
3:30pm Presentation 43: Selective Laser Melting of Copper Alloys and Aluminum Matrix Composites for Electrical Batteries
Mostafa Yakout, M. A. E. Ebitawei University of Waterloo, Canada
Abstract: Graphite (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., 120.5 GPa) and a low electrical resistivity (i.e., 4.4 32-8 W/m) at room temperature. It also is a good reinforcement of various composites for several applications. Graphite 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 show an increase in the material hardness and mechanical tensile strength. However, the formation of Al carbide during the manufacturing of Gr-Al composites decreases the mechanical properties. This work has been instilled through transition metal additions that form stable aluminides. This project seeks to devise new LPBF optimized alloy compositions in the material that material is growing. The AM community is particularly keen on aluminium alloys that can be used in a future industry. A recent project that started with this approach and looks into the impacts of iron and nickel additions. Here, gas atomized Al-1Fe and Al-1Ni (wt.%) powders were processed via LPBF over a wide range of volumetric energy densities (VED) and post-processing treatments. Thinning of the specimen and comparison of the products were characterized. Results indicated that Al-1Fe was more responsive to processing as it densified 89.9% of full theoretical and had a hardness of 194 HRB. Conversely, Al-1Ni only reached 97.8% theoretical density and a peak hardness of 77 HRB. Energy density values of at least 20 J mm-3 were required to achieve full density and was performed without the formation of Al carbide. Upon DSC testing, the solidified material was analyzed via XRD and SEM to investigate the influence of the change of hardening alloying element on the microstructural evolutions of the Al alloys. This work will discuss the use of high VED to gain new insights into solidification events of Al alloys and present key results from this new exciting methodology.

Session 13: Challenges for Direct Energy Deposition Systems
June 28 | 1:50pm - 3:50pm | Room 201
1:50pm Presentation 44: 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 2D contour and raster fill strategies. This is a standard approach for 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 regions within a given layer. In this presentation, two conceptual approaches to overcome the buildability challenges with direct energy deposition systems will be presented.
Abstract: The presence of moisture in LPBF system can lead to the deleterious effect on oxygen uptake in the powders and produced parts. Moisture can arise from various sources, typically one such source is the cellulose pleated paper filter. The moisture absorption amount for a commercial filter paper has been determined using dynamic vacuum sorption and RH levels. Thereafter, the total moisture present in the filter cartridge during storage has been evaluated by using gravimetric RH measurements within an LPBF chamber revealed that a non-dry filter releases its stored moisture on interaction with dry air. This phenomenon can cause system failure during the fabrication process, necessitating replacement. Inert gas recirculation commonly used for LPBF systems is also facilitated to improve moisture release; it can be seen as an effective pre-conditioning. Current work is directed towards evaluation of moisture collection in LPBF from the remaining possible identified sources.

Poster 3: Laser DED Cladding of H13 Tool Steel and Elemental Equivalents
Dwen Craig, Kevin Plucknett
University of Toronto, 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 hard DED laser-based DED cladding strategies for heat-resistant materials through DED. Initial work will involve cladding a baseline tool steel H13 onto an Inconel 718 substrate. Challenges will involve describing the strength of the clad material in the as-deposited state, as well as post-processing of the clad material. Experimental testing 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 Sorption
Xuechen Shen, Hani Naguib
University of Toronto, Canada
Abstract: Additive manufacturing (AM) of nanocomposites is a relatively new field in the AM industry. Binder jetting forms the basis of a unique approach to spatially control part properties through packing density of nanoparticles by varying the combination of jetting parameters. In this study, the feasibility of depositing metal onto varying edge lengths can be varied to create multiple configurations of complicated tessellated metamaterials. A FEA model will be created to further analyse the behaviour of the metamaterial and find the optimal printed structure.

Poster 6: Internal Surface Roughness of Multi-Layer Powder Bed Fusion
Seung Ho Jeong, Sagar Patel, Allan Rogalsky, Mihaela Vlasea, Adnan Senfich, Mary Wells
University of Waterloo, Canada
Abstract: Print a Graphene-Polyvinyl Alcohol (PVOH) composite using fused deposition modelling (FDM). The system produces a soft, easily manipulable, and exchangeable wetted components for caustic applications. We propose a system with ubiquitous compatibility for caustic and abrasive ink compositions. The system uses inexpensive, easily modifiable, and exchangeable wetted components to solidify a continuous line of ink. The system parameters and evaluate system performance against inkjet and fused deposition modelling (FDM). The system produces line width of 0.01mm, indicates feature resolution capabilities are comparable to FDM. The system is used to print a Graphene-Polyvinyl Alcohol (PVOH) composite on an aqueous graphene oxide (GO) ink. The composite exhibits conductivity up to 10-45cm-1. The hygroscopic properties of the ink demonstrate the need to be investigated to realize printable soft sensors and actuators.

Poster 5: Mechanical Properties of Additively Manufactured Tessellated Metamaterial Design Configurations
Anastasia Wickerl, Hani Naguib
University of Toronto, Canada
Abstract: Tessellated metamaterials are created from a repeated pattern, or so-called “unit cell”, design to fabricate 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 then fabricated through drawing properties are controlled through DED. Tesselated metamaterial designs to compare the effects of changing edge designs for mechanical testing. This research will focus on the use of 3D printing to fabricateadditively manufactured tool steel H13 substrates. In the initial phase of the work, the feasibility of depositing material on varying edge lengths can be varied to create multiple configurations of complicated tessellated metamaterials. A FEA model will be created to further analyse the behaviour of the metamaterial and find the optimal printed structure.
Microstructural characteristics of the printed Mo parts, characterization tools were utilized to understand the powder hindering their adoption in the listed applications. The new for zircaloy in nuclear reactor components due to their higher systems including steels, titanium, aluminum and nickel (LPBF-AM) is an emerging material fabrication technology for material properties were estimated through micro-hardness Dhani Diaz, Abdul-Aziz Boggan, Jonas Vallotton, Hani Henein University of Alberta, Canada

Abstract: Rapid solidification of Al-Cu eutectics 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-35wt%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 elements were found to pin the solid/liquid interface promoting nucleation on the droplet surface. The scale of the microstructures was determined from the dendritic arms, the 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 12: Processing of Ti-64 by Laser Powder Fed Additive Manufacturing

Nik Gooss*, Ian Donaldson**, Paul Bishop*
*Dalhousie University, Canada | **GKN, Canada

Abstract: Water atomization is utilized extensively in the field of powder metallurgy, and many studies have been performed using various methods to study the properties of the as-atomized 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 components of high-stress applications. In this study, atomization parameters, a nearly spherical powder with a relatively smooth surface, produced by water atomization is viewed as a viable contender for the production of cost-effective powders for AM technologies. The objective of this study is 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 for this project. This powder was characterized in detail using light using X-ray scattering, optical microscopy, SEM, and DSC. Preliminary builds were then printed, de-bound, and liquid phase sintered under standard conditions. The resulting material had a very high density and very low porosity and was shown to be a viable candidate for producing high-quality and complex parts with minimal post-processing.

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 field of powder metallurgy, and many studies have been performed using various methods to study the properties of the as-atomized 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 components of high-stress applications. In this study, atomization parameters, a nearly spherical powder with a relatively smooth surface, produced by water atomization is viewed as a viable contender for the production of cost-effective powders for AM technologies. The objective of this study is 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 for this project. This powder was characterized in detail using light using X-ray scattering, optical microscopy, SEM, and DSC. Preliminary builds were then printed, de-bound, and liquid phase sintered under standard conditions. The resulting material had a very high density and very low porosity and was shown to be a viable candidate for producing high-quality and complex parts with minimal post-processing.

Poster 14: Rapid Solidification of Al-Cu Si Alloy

Aakashnya Sahore*, Abdul-Aziz Boggan*, William Heam**, Ian Donaldson***
*University of Alberta, Canada | **Chalmers University of Technology, Sweden

Abstract: Scandium addition in Al-Si alloy has been found to promote nucleation and improve the microstructure of the solidified microstructure of the solidified microstructure. 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 hypereutectic Al-Si alloys. However, the combined effect of both RS and Scaddition has not yet been studied. To address these problems in Al-Si alloys is not understood in a quantitative and reproducible way. Using DSC and a novel continuous dilatometer device (P49 Thermal Analysis), hypereutectic (Al-10Si) alloy with 0.4 wt% and 0.4 wt% Si addition was produced at two different cooling rates (104-6°C/s). Here microstructural and phase characterization was conducted using OM, SEM, EPMA and DSC to determine the influence of cooling rate on the microstructure. These results show that the solidification pathways and formed microstructures were quantified for slow and rapid cooling rate, providing a critical relationship between cooling rate/properties that can help with the use and development of AM processes.
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 stress and deformation caused by distortion. Development of a numerical model to accurately predict the induced residual stress 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 FE model (FE) model has been developed to numerically simulate the LPBF process in order to predict the induced residual stresses and distortions. An extensive experimental program was 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 built 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 Modelling and Design of Experiment Approaches

Fazaneh Kaji*,**, Vadim Kozhevnikov*,**, Ehsan Toyserkani*
Deposition Using Tri-Dexel Model
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 processing system. For this, end, calibration coupons are built using In625, Ti64, AlSi10Mg, Fe and FC30208 powders and an EDS M280 LPBF system. These conditions were then used to simulate melt pool and microstructure generation based on the tri-dexel model. 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 voxel cell, hatching space, and layer thickness, 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 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 hatching space, 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 the effects of laser parameters (power, scan speed 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 laser powder bed metal fusion process optimization.

Poster 18: Adaptive Trajectory Planning for Direct EnergyDeposition Using Tri-Dexel Model
Farzaneh Kaji**, Vadim Kozhevnikov**, Ehsan Toyserkani*
University of Waterloo, 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/DFM solutions for the build path design are based on the geometry of the parts regardless of heat distribution in the process. Ignoring such important aspect of this manufacturing process results in build paths 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 the 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 voxel cell, hatching space, and layer thickness, 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 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 hatching space, 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 the effects of laser parameters (power, scan speed 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 laser powder bed metal fusion process optimization.

Poster 21: Design for Additive Manufacturing: Topology Optimization of a Mechanical Assembly
Deseza Dhahode, Pouyan Rahnama, Ehsan Toyserkani
Waterloo University, 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. This has been made possible, greatly, by the design of construction frameworks for additive manufacturing (DMF). A focal aspect of DMF is topology optimization which is a powerful tool that can be used to solve multi-objective and subject to a set of constraints in order to minimize the mass and cost of the part. Topology optimization algorithms, manufacturing constraints can be used to optimize an AM part topology follows 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 features. The topology optimization algorithm then form critical constraints that determine successful prints. An arm press assembly is presented as case study to show how topology optimization can be a powerful tool in DMF for developing efficient and manufacturable parts.

Poster 22: Study on Fracture Mechanism of Ti-6Al-4V EBMB Manufactured Under Different Loading Conditions Through a Hybrid Experimental-Numerical Approach
Mohammad Shaterzadeh, Marcelio Alves
University of Sao Paulo, Brazil
Abstract: Additive Manufacturing (AM) has been used widely for prototype manufacturing and recently for mass production due to the rapid advancement in manufacturing processes. In this study, fracture mechanisms of the Ti-6Al-4V fabricated by Electron Beam Melting (EBM) is investigated. Through a set in this research, LPBF constraints considered are overhangs, self-supporting features, void filling and minimum features. The topology optimization algorithm then form critical constraints that determine successful prints. An arm press assembly is presented as case study to show how topology optimization can be a powerful tool in DMF for developing efficient and manufacturable parts.

Poster 23: Numerical Model of Al-33wt%Cu Eutectic Growth During Impulse Atomization
Jonas Valloton, Abdoul-Aziz Bogno, Hani Henein
The University of British Columbia, Canada
Abstract: During Impulse Atomization 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 recrystallization, followed by a more eutectic post-recrystallization. The volume fraction of each morphology was measured as a function of droplet size and nucleation underrun of the regular eutectic lamellae. The proposed model of the eutectic solidification was then developed and coupled to our thermal model of a falling droplet through a stagnation. A numerical simulation model assumes that the kinetics of both the undulated and regular regions follows the experimental findings of the liquidus, confirming the hypo- eutectic 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 Majer
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 ensuring both manufacturing accuracy and preventing delamination, fatigue failure, and buckling of metallic parts. Due to the fact that many parameters can influence the distortion of EBAM parts, the prediction of residual stress and distortion measurements are expensive and time consuming. Hence, numerical methods can be beneficial for the prediction of residual stresses and distortion. In this research, a three-dimensional, transient, fully coupled thermo- mechanical FE 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: Mesoscale Temperature, Elastic and Plastic Strain Evolution in PB-EBAM
Asmita Chakraborty, Farzaneh Farhang-Mehr, Daan Majer, Steve Cockcroft
The University of British Columbia, Canada
Abstract: Powder-Bed Electron Beam Additive Manufacturing (PBB-EBAM) parts can suffer from deformation and residual stress and distortions are expensive and time consuming. Hence, numerical methods can be beneficial for the prediction of residual stresses and distortion. In this research, a three-dimensional, transient, fully coupled thermo- mechanical FE 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 26: Residual stress and distortion in electron beam additive manufacturing of Ti-6Al-4V build plates
Pegah Pour Abdollah, Farzaneh Farhang-Mehr
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 ensuring both manufacturing accuracy and preventing delamination, fatigue failure, and buckling of metallic parts. Due to the fact that many parameters can influence the distortion of EBAM parts, the prediction of residual stress and distortion measurements are expensive and time consuming. Hence, numerical methods can be beneficial for the prediction of residual stresses and distortion. In this research, a three-dimensional, transient, fully coupled thermo- mechanical FE 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 27: Evolution in PB-EBAM
Steve Cockcroft
The University of British Columbia, Canada
Abstract: Additive Manufacturing and (AM) is a powerful tool that can be used to solve multi-objective and subject to a set of constraints in order to minimize the mass and cost of the part. Topology optimization algorithms, manufacturing constraints can be used to optimize an AM part topology follows 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 features. The topology optimization algorithm then form critical constraints that determine successful prints. An arm press assembly is presented as case study to show how topology optimization can be a powerful tool in DMF for developing efficient and manufacturable parts.
Abstract: This project is focused on understanding the heat
transport processes associated with heat generation and
accumulation within the Powder-Bed Electron Beam Additive
Manufacturing (PB-EBAM) process. Work is underway to
characterize the physics and mechanisms which help determine
melt pool morphology in additively manufactured components
made in the LPB and LPF AM processes. Further work testing the
above ultrasound imaging methods will be performed in a
LIG-X/S550-TW laser thermal system from Optech Ventures LLC,
on-manufactured samples.

Poster 32: Anisotropic Finite Element Modeling of an
Additive Manufacturing (AM) process where the fabricated product is generated by adhering powder
together with a binder in a particular geometry. The resulting parts produced using these
different strategies will be evaluated using the following
mechanisms which help determine melt pool morphology in
'keyhole mode' laser powder bed fusion.

Abstract: The review will span the following subjects: types
and modelling of defect formation in LPB and LPF AM,
and forward/ inverse analysis.

Abstract: Following the formation of a suitable simulation, different
strategies for binder jetting will be proposed.

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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 together into material choices with metallurgical edge overlap, dimensional accuracy, surface roughness and evaporation loss of alloying elements. The result is a line energy – processing time relationship 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 Terriaux, Vladimir Brailovski  
ETS Montreal, Canada  
Abstract: Digital replicates 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 and the Mar℉ technique (Watershed/REGION) analysis (Watershed).  

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

Ken Nakayama, 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 dimensions and strut to node distance with respect to a theoretical 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 algorithm explaining how to take those predictions into consideration while designing lattice structures.

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

Parvish Kumar, Behrad Khamese, Ehsan Toyserkani  
University of Waterloo, Canada  
Abstract: Magnetic levitation techniques and their applications have garnered strong research interests within the academic community. The research in the field has resulted in the development of a new avenue to provide a stable supporting structure to enhance the process of Additive Manufacturing (AM). The integration of these techniques rely on the use of a supporting platform to implement the fabrication process. The dependence on the supporting structure is removed with the implementation of these techniques due to their two-dimensional behavior. 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 is proposed 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-Menchaca, Ehsan Toyserkani  
University of Waterloo, Canada  
Abstract: Laser directed energy deposition (LDED) is an established technology for metal additive manufacturing. As LDED process parameters such as power and powder flow rates of different phases give insights to the variety of strength and ductility, showing the prominently work hardening effects of a certain level. Yet, the mechanical difference between a β and β phase of LMD-fabricated Ti-6Al-2Zr-1Mo-1V alloy, indicating that the hardness of the former material field as-deposited and annealed samples are higher than β phases, respectively. The difference of hardness and mechanical contrast can be explained by the dislocation and grain strengthening due to faster microstructure. These results offer the guideline to predict the macro-mechanical properties of LMD-produced titanium alloys.

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

Zhila Russell, Kevin Plucknett  
University of Waterloo, Canada  
Abstract: 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 variety of conventional laser directed energy deposition cladding. The properties of the coating and substrate interface such as adhesion and microstructure are of interest. The systematic theory for evaluation of feasibility and stability of TiC-NiTiAl based thin films, with various solid particle volumes, is studied on steel substrates for the coating application. A cost-effective coating system has been designed for dip coating of steel coupons. The parameters of suspension formulation such as temperature, pH, H2O2-GR molar ratios, solvents, suspension ageing, kinetics of hydrolysis and condensation, drying processes, cracks formation, and crystalline transitions during the laser sintering process treatment are presented as analytical variables for the overall understanding of the experimental methods of the coating 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 microscope (SEM).

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

Saeds Khademzadeh, Paolo Ibarian, 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) is used to manufacture dense and porous NiTi parts. Two levels of SLM process parameters were proposed for production of single and multiple walls. Nanomechanical test results 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.
Abstract: Additive manufacturing (AM) of porous bone scaffolds is an optimal solution to prevent stress shielding. The feasibility of using additive manufacturing (AM) to facilitate porous bone scaffolds was introduced in this application and compared with classic scaffold’s fabrication. A novel structure Fischer Koch S is still a challenging, it varies with different printing techniques. Using a diamond structure.

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

Minimal Surface (Tpms) Manufactured by Different Additive Manufacturing Methods

Xin Zhang*, Rizhi Wang*, Dawei Wang**

Manufacturing Methods

Abstract: Investigation of final products using micro-computed tomography (μCT) showed fairly acceptable compatibility between produced parts and predesigned models.

Micro features were built up by arraying regular unit cells. Real 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 regions of parts, novel porous architectures containing micro and macro structures.

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